NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 18, 2016
Proposed starting date: June 1st, 2016
Expected duration: September 15th, 2016

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermodification.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Neil Brackin, President Tel: (701) 235-5500
nbrackin@weathermod.com
Local Organization: Weather Modification, Inc. Tel. (403) 335-8359
Olds-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Mr. Daniel Gilbert, Chief Meteorologist
B.S., 13 years' experience
WMA Certified Weather Modification Operator #78
Office Tel: (403) 335-8359
(see Part 5 for details of qualifications and experience)

Vice President - Meteorology Mr. Bruce Boe
Project Manager/Meteorology, 42 years' experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermodification.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe Weather Management Society and US$5 million by Weather Modification, Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996. The contractor (operator) for this entire period has been WMI.

b. Elsewhere:
- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 50 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Alberta, Burkina Faso, California, Idaho, Mexico, UAE, India, Indonesia, Mali, Nevada, North Dakota, Saudi Arabia, Senegal, and Wyoming within the last 10 years.

4. References:
1. Dr. Terry Krauss
   Krauss Weather Services
   79 Irving Crescent
   Red Deer, AB T4R 3S3 Tel. 403-318-0400
2. Mr. Darin Langerud, Director
   State of North Dakota Atmospheric Resource Board
   900 E. Boulevard Ave.
   Bismarck, ND 58505 Tel. 701-328-2788
3. Dr. Ronald E. Rinehart
   4408 Greystone Drive
   St. Joseph, MO 64505 Tel. 816-233-1394
4. Dr. Paul L. Smith
   South Dakota School of Mines & Technology
   501 E. St. Joseph Street
   Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
todd.klapak@intact.net
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel. 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Springbank airport tel. 403-247-0001
- Red Deer industrial airport tel. 403-886-7857

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Daniel Gilbert, Chief Meteorologist
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359,
e-mail: dgilbert@weathermodifcation.com
home page: http://www.weathermodification.com/

Qualifications of field officer in charge (Gilbert):

Education
Bachelor of Science, Meteorology and Environmental Studies (double major) May 2004, Iowa State University, Ames, IA
Associate of Arts, Liberal Arts, May 2000, Iowa Central Community College, Fort Dodge, IA

Weather Modification Experience
Chief Meteorologist, Weather Modification, Inc. (Wyoming and Alberta) - November 2009 to present
Forecaster, radar operator, rawinsondes, direction of seeding aircraft. Case declarations, wintertime (Wyoming) research program.
Meteorologist, RHS Consulting (Fresno, CA) – November 2008-February 2009
Directed airborne and ground based cloud seeding operations over portions of the central and southern Sierra Nevada Mountains. Set up and performed routine maintenance of ground based ice nucleus generators. Provided daily forecasts for clients and project personnel.
Meteorologist, Independent Contractor, (Boise, ID) – October 2007 to April 2008
Provided meteorological services to support Idaho Power Company's winter cloud seeding project in West Central Idaho, directed airborne and ground seeding operations, directed rawinsonde releases, provided short-term operational forecasts and nowcasts for pilots, communicated with aircraft via two-way radio
Field Meteorologist, North Dakota Cloud Modification Project, (Stanley or Bowman, ND) – Summers, 2003-2009
Operated 5 cm weather radar equipped with TITAN software package, launched and directed seeding aircraft using two-way radio and GPS tracking, performed data recording and documentation of cloud seeding operations, prepared silver iodide seeding solution, assisted with radar calibrations, prepared forecasts and briefed pilots daily, supervised intern meteorologists, presented case studies for ground school, operated cloud condensation nuclei counter for joint research with South Dakota School of Mines
Forecaster, Atmospherics Incorporated, (Fresno, CA) - October 2006 - May 2007
Field Meteorologist, Atmospherics, Inc. (Modesto, CA) - November 2005 - April 2006
Field Meteorologist, Atmospherics, Inc. (Paso Robles, CA) - December 2004 - February 2005
Provided daily forecasts for seeding operations and/or clients, operated 5cm weather radar, directed winter cloud seeding operations over the Sierra Nevada utilizing both glaciogenic and hygroscopic seeding agents, traced radar overlays, performed data recording of operations, wrote monthly and annual reports

Memberships and Honors

- Meteorologist Distinguished Service Award, 2013, Weather Modification Association
- Member, Weather Modification Association (certified operator #78)
- Member, American Meteorological Society
- Iowa Central Community College Honor Society, inducted April 27, 2000
- Wilbur E Brewer Professionalism Award, 2007 North Dakota Cloud Modification Project

Field Address:	Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no.	403-335-8359
Field personnel:	full time = 3 part time = 14

Daily records of activities: Custodian = Ms. Erin Fischer
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Hailstorms in the City of Calgary caused >$500 Million in 2010 and again in 2012. In addition, hailstorms have caused >$100 Million damage to crops annually since 2007 and the damage to crops was >$400 Million in 2012. Hailstorms have now become a billion dollar problem to the economy of Alberta. The 20 largest insurance companies and their affiliates have banded together to conduct hail suppression operations in the "hail alley" of central Alberta to combat urban hail damage in the Calgary to Red Deer area. The current program has conducted cloud-seeding operations in central Alberta each summer since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. The insurance industry has been encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the first 10 years of the project indicated a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer,

Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.
Approximate total cost: approx. $3.1 million per year.

Funds to be expended in Canada: est. $600,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5°C temperature level, and are considered to be a potential hail threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI-solution burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave

unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5°C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude. Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5°C and -10°C. The pencil flares fall approximately 1.5 km (approximately 10°C) during their 35-40 second burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5°C and - 10°C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g. 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Wing-tip seeding solution burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gram of pyrotechnic, active at -10°C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gram flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one Advanced Radar Corporation C-band Doppler weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Three Beechcraft C90 King-Air prop-jet aircraft (two in Springbank and one in Red Deer).
- Two Cessna 340 aircraft (one in Springbank and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (ejectable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- A solution of acetone, silver iodide, sodium perchlorate, paradichlorobenzene, and ammonium iodide will also be burned for continuous seeding at cloud base. The products of combustion yield silver iodide (AgI) ice nuclei, carbon dioxide (CO_2), and water (H_2O).

Activation tests performed at Colorado State University indicate greater than 10^{14} ice crystals per gram of seeding agent burned, active at -10°C.

Total flight hours and quantities to be dispersed: We estimate the project may use 5000 twenty-gram flares and 500 one hundred-fifty gram flares, plus approximately 150 gallons of the seeding solution (2% AgI by volume) will be burned. The number of operational days, flights, and amount of seeding material dispensed over the past fifteen years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in

precipitation (above background levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far, far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Three C90 King Air prop-jet aircraft, two in Springbank (N904DK and N518TS) and one based in Red Deer (N522JP).
- Two Cessna 340 aircraft, one in Springbank (N457DM) and one in Red Deer (N37356).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be deployed for the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

TEMPERATURE INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from the U.S. National Center for Atmospheric Research (NCAR).

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract.

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:
~~Todd Klapak~~ KEN DE DECKER, BOARD MEMBER.
~~President~~, Alberta Severe Weather Management Society
~~(403) 231-1357, Todd.Klapak@intact.net~~
403-231-1300 KEN.DEDECKER@INTACT.NET.

Signature: Date: May 18, 2016

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer:
Bruce A. Boe
Vice President of Meteorology
(701) 235-5500

Signature: Date: May 18, 2016

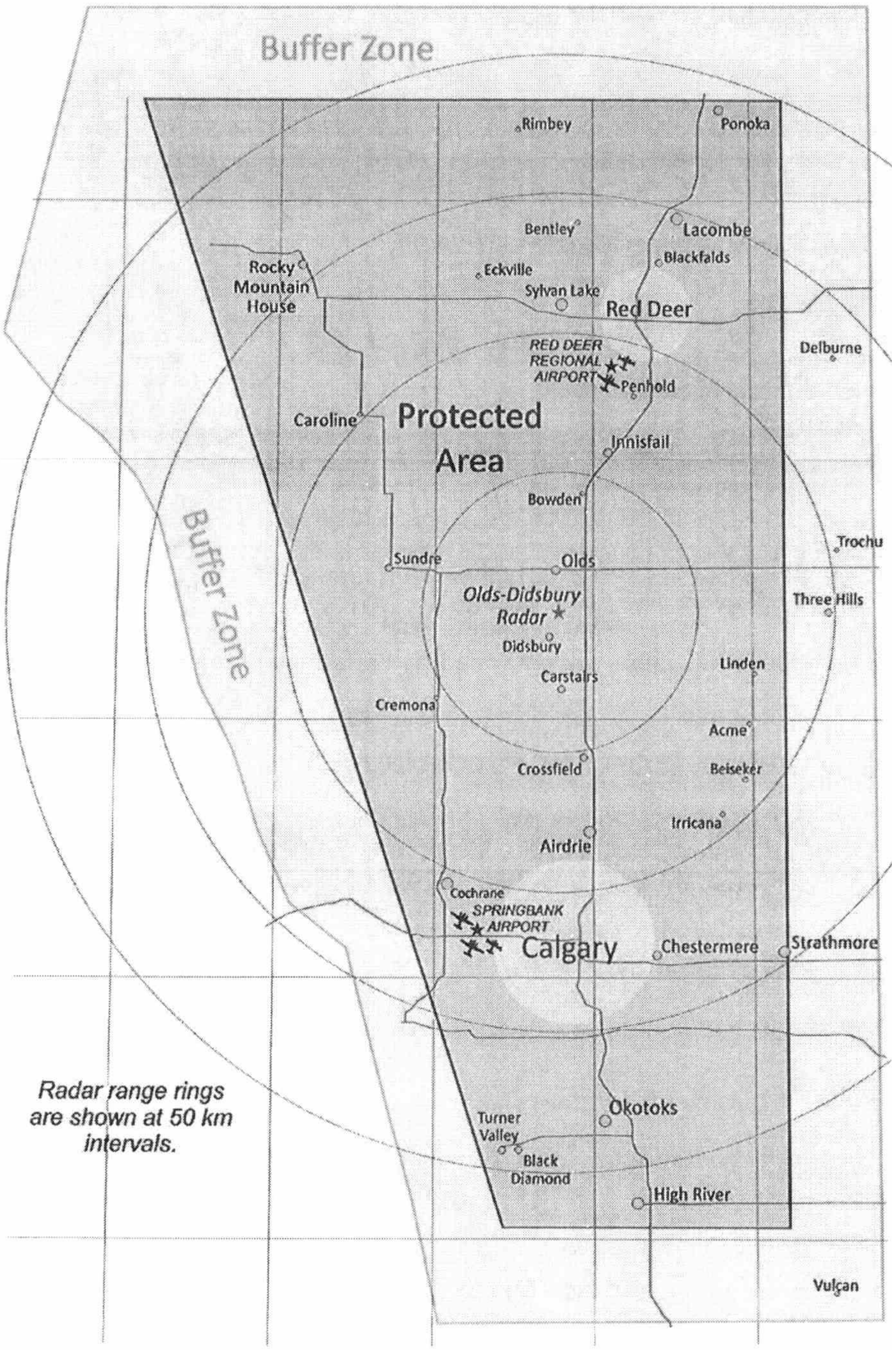

Figure 1: Map of south-central Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2015.

Seeding Activity by Season												
Season	Storm Days With Seeding	Aircraft Missions (Seeding & Patrol)	Total Flight Time (hours)	Number of Storms Seeded	Total Seeding Agent (kg)	Seeding Agent Per Day (kg)	Seeding Agent Per Hour (kg)	Seeding Agent Per Storm (kg)	Ejectable Flares	Burn-in-place Flares	Seeding Solutions (gallons)	Season Activity Rank
2015	25	117	233.3	79	349.2	14.6	1.37	4.42	8127	1138	262.9	6
Mean	30.9	103.4	212.8	91.8	214.6	6.9	1.02	2.4	5179.6	666.2	162.6	
2014	32	128	259.5	101	382.5	12.0	1.47	3.79	10782	1020	228.6	3
2013	26	103	229.6	70	233.3	9.0	1.02	3.33	6311	636	131.7	10
2012	37	143	300.1	116	314.6	8.5	1.16	2.70	7717	914	260.3	2
2011	48	158	383.0	134	400.1	8.3	1.13	3.00	10779	1020	350.2	1
2010	42	115	271.8	118	263.8	6.3	1.10	2.20	5837	851	227.5	7
2009	20	38	109.3	30	48.4	2.4	0.84	1.60	451	237	56.5	20
2008	26	112	194.7	56	122.9	4.7	1.00	2.20	1648	548	113.5	15
2007	19	76	115.3	41	99.7	5.2	0.90	2.40	1622	413	77	19
2006	28	92	190.2	65	214	7.6	1.10	3.30	4929	703	145.4	12
2005	27	80	157.9	70	159.1	5.9	1.00	2.30	3770	515	94.2	16
2004	29	105	227.5	90	270.9	9.3	1.20	3.00	6513	877	132.7	8
2003	26	92	163.6	79	173.4	6.7	1.10	2.20	4465	518	92.6	14
2002	27	92	157.4	54	124.2	4.6	0.80	2.30	3108	377	80.3	18
2001	36	109	208.3	98	195	5.4	0.90	2.00	5225	533	140.8	9
2000	33	130	265.2	136	343.8	10.4	1.30	2.50	9653	940	141.3	4
1999	39	118	251.3	162	212.7	5.5	0.80	1.30	4439	690	297.5	5
1998	31	96	189.9	153	111.1	3.6	0.60	0.70	2023	496	193.8	11
1997*	38	92	188.1	108	110.8	2.9	0.60	1.00	2376	356	144.3	13
1996*	29	71	159.1	75	163.3	5.6	1.00	2.20	3817	542	80.5	17

**The 1996 and 1997 seasons began on June 15, not June 1, which has been the norm ever since.*

Environnement et Changement climatique Canada
Environment and Climate Change Canada

AOÛT AUG 2 1 2017

MIN-219531

MEMORANDUM TO MINISTER

SUMMARY AND ANALYSIS OF THE DRAFT U.S. CLIMATE SCIENCE SPECIAL REPORT

(For Information)

PURPOSE

To provide a more detailed analysis of the fifth order draft of the U.S. climate science special report, including comparisons with Canadian science, where available and appropriate.

SUMMARY

- The draft U.S. Global Change Research Program climate science special report was profiled in the New York Times on August 7, 2017 (see attached article), but has not yet been released by the U.S. government.

- The findings reported in the report reiterate the major conclusions of the Intergovernmental Panel on Climate Change (IPCC) in its last assessment (that warming of the climate system is unequivocal, human activity is the main cause, and the choices made in the coming decades about reducing emissions will strongly influence future climate-related risks).

- Warming is evident across the U.S., but there are significant regional variations, as in Canada. Alaska is amongst the regions experiencing the largest increases in temperature, consistent with amplified warming in the Canadian Arctic.

- Each chapter in the report assesses the state of the science of a particular aspect of the changing climate. For example, the report notes that the average annual temperature over the contiguous U.S. is projected to rise, with increases of about 1.4°C relative to the recent past projected for the next few decades.

- It also reports on extreme events within the U.S., including heat waves, cold snaps, wet seasons, individual storms, and droughts, and concludes that most of the events studied reveal a human influence.

- The report is focused on the U.S., but it includes findings that are relevant to Canada, particularly for the Arctic.

- Two media requests regarding this report were received on August 8, 2017. Responses are being led by Communications.

CONTEXT AND CURRENT STATUS

The U.S. Global Change Research Program climate science special report is an authoritative assessment of the science of climate change, with a focus on the United States. It will serve as the foundation for efforts to assess climate-related risks and inform decision making on

Canada

responses. This report has been developed as part of the U.S. Global Change Research Program's sustained National Climate Assessment process, which is undertaken every four years.

Scientists from 13 different U.S. federal agencies contributed to the report. The report underwent multiple reviews, including an open public review and review by the U.S. National Academy of Sciences. The report discusses climate trends and future changes at several scales: global, nationwide for the United States, and for 10 specific U.S. regions. It does not include an assessment of the scientific literature on climate change mitigation and adaptation measures, economic valuation, or societal responses, nor does it include policy recommendations.

The findings in this report are based on a large body of scientific peer-reviewed research, as well as a number of other publicly available sources, including well-established and carefully evaluated observational and modelling datasets.

An overview of the main scientific findings of the report is provided in Annex I (attached).

CONSIDERATIONS

The findings reported in the report reiterate the major conclusions of the IPCC in its last assessment (that warming of the climate system is unequivocal, human activity is the main cause, and the choices made in the coming decades about reducing emissions will strongly influence future climate-related risks). There are no major surprises in terms of the findings presented, and the Department's climate scientists confirm this. Given that Canada and the U.S. share common geographic regions, similar changes can be expected for parts of Canada.

Canada does not have a mandated national climate assessment process like the one in the U.S., but the Government of Canada does routinely assess the state of knowledge of climate change, associated impacts, and adaptation responses for Canada, with Natural Resources Canada leading this effort. The next national assessment for Canada is underway, with a series of reports to be released over the next few years, culminating in 2021.

The first report in this series will be Canada's changing climate report, led by the Department. Like the U.S. climate science special report, it will provide the science foundation for other products of the Canadian national assessment. While this initiative is led by the federal government, with the involvement of Fisheries and Oceans Canada and Natural Resources Canada, non-governmental experts will also be engaged in development and review of Canada's changing climate report. Its completion is anticipated for late 2018.

Steph Lucas

Stephen Lucas Deputy Minister c.c. Martine Dubuc	Martine Dubuc Associate Deputy Minister c.c. Stephen Lucas

Attachments (3):

- *Scientists fear Trump will dismiss blunt climate report. New York Times (August 7, 2017, with corrections of August 9 and 15, 2017)*
- *Annex I – Supplemental Information*
- *Strategy on Short-lived Climate Pollutants – 2017 (Environment and Climate Change Canada)*

BACKGROUND

The U.S. Global Change Research Act (1990) established the National Climate Assessment, to be undertaken every four years. Over time, the U.S. Global Change Research Program has moved toward a sustained National Climate Assessment process, to maintain momentum, strengthen and evolve assessment capacity, facilitate continued engagement of scientists and stakeholders, and be positioned to assess new information as it emerges.

The U.S. Global Change Research Program aims to develop products that are informed by and tailored to user needs so that the end products are relevant and support decision making. A sustained assessment process also links directly to the needs of decision makers on an ongoing basis by providing access to climate data, information, and services. In this way, it is envisioned that the U.S. National Climate Assessment will be a dynamic resource that can bring climate information into mainstream decision making.

The Fourth National Climate Assessment cycle is currently underway, to be completed in 2018. The climate science special report will be the first product of this current cycle (public release is awaiting final clearance of the completed report). The report is an authoritative assessment of the science of climate change, with a focus on current and future changes in the United States, to serve as the foundation for efforts to assess climate-related risks and inform decision making on responses. It is expected to provide the scientific foundation for other components of the National Climate Assessment, mainly the forthcoming national issues and regional issues assessment reports, due in 2018.

Overview of process

The National Oceanic and Atmospheric Administration (NOAA) is the lead agency responsible for preparing the climate science special report, and authors included scientists from U.S. federal agencies, national laboratories, universities, and the private sector. The findings in this report are based on a large body of scientific peer-reviewed research, as well as a number of other publicly available sources, including well-established and carefully evaluated observational and modelling datasets. The report underwent multiple reviews, including an open public review and review by the National Academy of Sciences.

The process of developing the U.S. National Climate Assessment reports is similar to, and modelled on, the process used by the Intergovernmental Panel on Climate Change (IPCC) to deliver global assessments of climate change science, impacts, and responses. Key similarities include the adoption of IPCC terminology for assessing the likelihood of a change occurring, use of the same emission scenarios and future climate projections from the coordinated global climate modelling experiments, and the adoption of a rigorous review process with both expert and government review phases.

The U.S. National Climate Assessment relies on IPCC assessments and provides useful updates of the science in some areas, but it does not attempt to reassess the vast body of literature assessed by the IPCC. An added value for a domestic audience is provided by focusing on the United States and by providing detailed regional analyses that are beyond the scope of the IPCC. Many countries, including Canada, have national assessment processes to serve domestic needs.

The New York Times https://nyti.ms/2vdswoz

CLIMATE

Scientists Fear Trump Will Dismiss Blunt Climate Report

By LISA FRIEDMAN AUG. 7, 2017

WASHINGTON — The average temperature in the United States has risen rapidly and drastically since 1980, and recent decades have been the warmest of the past 1,500 years, according to a sweeping federal climate change report awaiting approval by the Trump administration.

The draft report by scientists from 13 federal agencies concludes that Americans are feeling the effects of climate change right now. It directly contradicts claims by President Trump and members of his cabinet who say that the human contribution to climate change is uncertain, and that the ability to predict the effects is limited.

"Evidence for a changing climate abounds, from the top of the atmosphere to the depths of the oceans," a draft of the report states. It was uploaded to a nonprofit internet digital library in January but received little attention until it was published by The New York Times.

The authors note that thousands of studies, conducted by tens of thousands of scientists, have documented climate changes on land and in the air. "Many lines of evidence demonstrate that human activities, especially emissions of greenhouse (heat-trapping) gases, are primarily responsible for recent observed climate change," they wrote.

The report was completed this year and is a special science section of the National Climate Assessment, which is congressionally mandated every four years. The National Academy of Sciences has signed off on the draft report, and the authors are awaiting permission from the Trump administration to release it.

One scientist who worked on the report, Katharine Hayhoe, a professor of political science at Texas Tech University, called the conclusions among "the most comprehensive climate science reports" to be published. Another scientist involved in the process, who spoke to The New York Times on the condition of anonymity, said he and others were concerned that it would be suppressed.

The White House and the Environmental Protection Agency did not immediately return calls or respond to emails requesting comment on Monday night.

The report concludes that even if humans immediately stopped emitting greenhouse gases into the atmosphere, the world would still feel at least an additional 0.50 degrees Fahrenheit (0.30 degrees Celsius) of warming over this century compared with today. The projected actual rise, scientists say, will be as much as 2 degrees Celsius.

A small difference in global temperatures can make a big difference in the climate: The difference between a rise in global temperatures of 1.5 degrees Celsius and one of 2 degrees Celsius, for example, could mean longer heat waves, more intense rainstorms and the faster disintegration of coral reefs.

Among the more significant of the study's findings is that it is possible to attribute some extreme weather to climate change. The field known as "attribution science" has advanced rapidly in response to increasing risks from climate change.

The E.P.A. is one of 13 agencies that must approve the report by Aug. 18. The agency's administrator, Scott Pruitt, has said he does not believe that carbon dioxide is a primary contributor to global warming.

"It's a fraught situation," said Michael Oppenheimer, a professor of geoscience and international affairs at Princeton University who was not involved in the study. "This is the first case in which an analysis of climate change of this scope has come up in the Trump administration, and scientists will be watching very carefully to see how they handle it."

Scientists say they fear that the Trump administration could change or suppress the report. But those who challenge scientific data on human-caused climate change say they are equally worried that the draft report, as well as the larger National Climate Assessment, will be publicly released.

The National Climate Assessment "seems to be on autopilot" because of a lack of political direction, said Myron Ebell, a senior fellow at the Competitive Enterprise Institute.

The report says significant advances have been made linking human influence to individual extreme weather events since the last National Climate Assessment was produced in 2014. Still, it notes, crucial uncertainties remain.

It cites the European heat wave of 2003 and the record heat in Australia in 2013 as specific episodes where "relatively strong evidence" showed that a man-made factor contributed to the extreme weather.

In the United States, the authors write, the heat wave that broiled Texas in 2011 was more complicated. That year was Texas' driest on record, and one study cited in the report said local weather variability and La Niña were the primary causes, with a "relatively small" warming contribution. Another study had concluded that climate change made extreme events 20 times more likely in Texas.

Based on those and other conflicting studies, the federal draft concludes that there was a medium likelihood that climate change played a role in the Texas heat wave. But it avoids assessing other individual weather events for their link to climate change. Generally, the report described linking recent major droughts in the United States to human activity as "complicated," saying that while many droughts have been long and severe, they have not been unprecedented in the earth's hydrologic natural variation.

Worldwide, the draft report finds it "extremely likely" that more than half of the global mean temperature increase since 1951 can be linked to human influence.

In the United States, the report concludes with "very high" confidence that the number and severity of cool nights have decreased since the 1960s, while the frequency and severity of warm days have increased. Extreme cold waves, it says, are less common since the 1980s, while extreme heat waves are more common.

The study examines every corner of the United States and finds that all of it was touched by climate change. The average annual temperature in the United States will continue to rise, the authors write, making recent record-setting years "relatively common" in the near future. It projects increases of 5.0 to 7.5 degrees Fahrenheit (2.8 to 4.8 degrees Celsius) by the late century, depending on the level of future emissions.

It says the average annual rainfall across the country has increased by about 4 percent since the beginning of the 20th century. Parts of the West, Southwest and Southeast are drying up, while the Southern Plains and the Midwest are getting wetter.

With a medium degree of confidence, the authors linked the contribution of human-caused warming to rising temperatures over the Western and Northern United States. It found no direct link in the Southeast.

Additionally, the government scientists wrote that surface, air and ground temperatures in Alaska and the Arctic are rising at a frighteningly fast rate — twice as fast as the global average.

"It is very likely that the accelerated rate of Arctic warming will have a significant consequence for the United States due to accelerating land and sea ice melting that is driving changes in the ocean including sea level rise threatening our coastal communities," the report says.

Human activity, the report goes on to say, is a primary culprit.

The study does not make policy recommendations, but it notes that stabilizing the global mean temperature increase to 2 degrees Celsius — what scientists have referred to as the guardrail beyond which changes become catastrophic — will require significant reductions in global levels of carbon dioxide.

Nearly 200 nations agreed as part of the Paris accords to limit or cut fossil fuel emissions. If countries make good on those promises, the federal report says, that will be a key step toward keeping global warming at manageable levels.

Mr. Trump announced this year that the United States would withdraw from the Paris agreement, saying the deal was bad for America.

Correction: August 9, 2017

An article on Tuesday about a sweeping federal climate change report referred incorrectly to the availability of the report. While it was not widely publicized, the report was uploaded by the nonprofit Internet Archive in January; it was not first made public by The New York Times.

Correction: August 15, 2017

An article last Tuesday about a sweeping federal climate change report misstated the professional credentials of Katharine Hayhoe, who contributed to the report. She is a professor at Texas Tech University, not a government scientist.
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A version of this article appears in print on August 8, 2017, on Page A1 of the New York edition with the headline: Climate Report Full of Warnings Awaits President.

ANNEX I

SUPPLEMENTAL INFORMATION

Overview of the main scientific findings

Key global findings
The U.S. climate science special report reiterates previous findings about human influence on global mean surface temperature from the most recent scientific assessment by the Intergovernmental Panel on Climate Change. It states, "…it is extremely likely that human activities, especially emissions of greenhouse gases, are the dominant cause of the observed warming since the mid-20th century." The report establishes that the short-term slowdown in the rate of increase in global mean surface temperature over the early 21st century has ended. This "hiatus" in global warming was given some attention in the 2013 assessment by IPCC Working Group 1, but at that time the causes of the slowdown were not yet clear. The climate science special report updates the rise in global average temperature (an increase of 1.0°C over the period 1901–2016), noting the record warmth in 2014, 2015, and 2016. Further record-breaking warmth is expected with continued emissions of greenhouse gases causing additional climate warming.

Key regional findings
As in Canada, warming is evident across the U.S. but with significant regional variations. Alaska is amongst the regions experiencing the largest increases in temperature, consistent with amplified warming in the Canadian Arctic. Pan-Arctic temperatures have increased over the past 50 years at a rate more than twice as fast as the global average.

Heavy precipitation events over most of the U.S. have increased in both intensity and frequency since 1901, and the frequency and intensity of heavy precipitation events are projected to continue to increase over the 21st century.

The incidence of large forest fires in the western U.S. and Alaska has increased since the early 1980s and is projected to increase further in those regions as the climate warms, with profound changes to certain ecosystems. This is consistent with Canadian analyses that suggest fire activity may increase in Canadian regions due to climate change.

The report also assesses the latest developments in extreme event attribution, in other words, the quantification of the influence of anthropogenic (i.e., human caused) climate change on an individual extreme weather event. It reports on events within the U.S., including heat waves, cold snaps, wet seasons, individual storms, and droughts, and concludes that most of the events studied reveal a human influence.

Changes in the Arctic
Sea ice cover in the Arctic continues to decline, and the transition from old multi-year ice to young seasonal ice stated in the report is also consistent with reductions observed in Canadian marine waters. Further, the report notes that the extent of spring snow cover has been on the decline, with a trend toward earlier snowmelt in the western U.S. This is consistent with reductions in spring snow cover over the boreal and Arctic regions of Canada. Projected impacts of changes in seasonal snow cover and land ice on the availability of water in the western U.S. can likewise be anticipated over regions of Canada, including the western Cordillera.

The strong warming in the Arctic is causing the permafrost to thaw and become more discontinuous in extent. It is known that when frozen, waterlogged soils, rich in deposits of undecomposed plant material, begin to thaw, the plant material will decompose and release methane and carbon dioxide. This positive feedback can have an amplifying effect on global warming. In keeping with other large assessments, such as those led by the Arctic Council, the report concludes that there is large uncertainty about the magnitude of this feedback.

Sea level rise and ocean acidification
The global mean sea level has risen by about 16–21 cm since 1900, with about 7 cm of that amount occurring since 1993. Human-caused climate change has made a substantial contribution to this rise. Future global sea level rise poses hazards for coastal communities. As in Canada, exposure to future sea level rise will vary by region, depending on global sea level rise and local vertical land motion and other factors.

To inform adaptation planning, the report considered a wide range of future global sea level rise scenarios. This included an extreme scenario with rapid loss of ice from the Antarctic ice sheet producing global sea level rise in excess of 8 feet (>2.4 m) by 2100; however, the probability of such an outcome cannot be assessed. This finding is significantly higher than in the IPCC Fifth Assessment Report.

Under a high emissions scenario, oxygen levels in the ocean are projected to decrease by as much as 3.5% by 2100 relative to pre-industrial values, and global ocean surface acidity is projected to increase by 100% to 150%. High-latitude marine ecosystems tend to have less buffering capacity against increasing acidity than systems at lower latitudes.

Mitigation
The report also provides some perspectives on mitigation, and these are consistent with other reports. While global carbon emissions have slowed since 2014, stabilization of emissions is only the first step. Significant and sustained reductions in the rate of carbon dioxide emissions, with net emissions becoming zero or negative later this century, are needed to meet the long-term temperature goal of the Paris Agreement (keep the increase in global average surface temperature to well below 2°C above pre-industrial levels).

Total emissions of carbon dioxide are the main determinant of future warming, but the rate of warming in the near term can be influenced by emissions of substances with a large global warming potential and shorter lifetime, such as methane and black carbon. Mitigation of these substances can contribute cooling benefits in the near term while also providing benefits for air quality.

The Department recently released the Strategy on Short-lived Climate Pollutants (2017) (attached), recognizing that taking action on these substances can help reduce the rate of warming in the near term and help achieve the temperature targets in the Paris Agreement.

The report notes that unanticipated and difficult or impossible-to-manage changes in the climate system are possible throughout the next century as critical thresholds are crossed and/or multiple climate-related extreme events occur simultaneously. The risk of such occurrences is greater under high emissions scenarios. The report addresses the possibility that interest in geo-engineering may grow and concludes that assessments of the technical feasibilities, costs, risks, co-benefits, and governance challenges of geo-engineering approaches are needed before judgements about the benefits and risks of such approaches can be made with confidence.

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Canada

STRATEGY ON SHORT-LIVED CLIMATE POLLUTANTS – 2017

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Photos: © Getty Images

Aussi disponible en français
Stratégie de lutte contre les polluants climatiques de courte durée de vie, 2017.

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CONTEXT

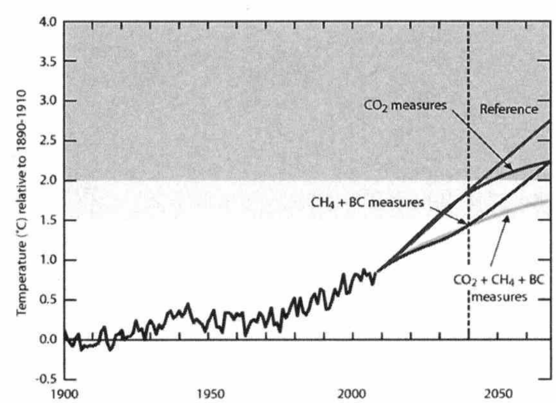
Canadians are experiencing the effects of climate change across the country, particularly in the climate-sensitive North. At the same time, exposure to air pollution is negatively affecting the health of Canadians and degrading the environment. Canada is taking action on climate change through the Pan-Canadian Framework on Clean Growth and Climate Change (the Pan-Canadian Framework). This Framework is Canada's plan to grow the economy while reducing emissions and building resilience to adapt to a changing climate. It was developed in partnership with provinces and territories, and in close consultation with Indigenous Peoples. Canada is also committed to advancing measures that lead to cleaner air and healthier communities, in partnership with provinces and territories.

Short-lived climate pollutants (SLCPs) are potent greenhouse gases (GHGs) and air pollutants. They have relatively short atmospheric lifetimes compared to longer-lived GHGs such as carbon dioxide (CO_2), and have a warming impact on climate. As such, reducing SLCPs can help achieve our climate and air quality objectives. SLCPs include methane and hydrofluorocarbons (HFCs), black carbon, which is a component of fine particulate matter ($PM_{2.5}$), and ground-level ozone.

Recent studies indicate that global action on carbon dioxide and SLCPs together is needed to keep average global temperatures to no more than 1.5 to 2°C above pre-industrial levels this century, and to meet the temperature goals in the Paris Agreement. Reducing SLCP emissions can also result in significant air quality benefits. Implementation of black carbon, methane and ozone measures has the potential to reduce global warming in 2050 by approximately 0.5°C and by approximately 0.7°C in the Arctic by 2040, prevent more than two million premature deaths worldwide each year, and avoid global crop losses of more than 30 million tonnes annually by 2030[1].

Air quality benefits would be felt mainly within the countries where measures are implemented. Consequently, SLCP mitigation has garnered significant attention in Canada and internationally.

IMPLEMENTATION OF GLOBAL MEASURES TO MITIGATE SLCPs AS A COMPLEMENT TO CO_2 MITIGATION COULD SLOW THE RATE OF NEAR-TERM GLOBAL WARMING, AND HELP TO KEEP AVERAGE GLOBAL TEMPERATURES FROM RISING BY MORE THAN 2°C ABOVE PRE-INDUSTRIAL LEVELS THIS CENTURY.



Source: UNEP Integrated Assessment of Black Carbon and Tropospheric Ozone, Summary for Policy Makers.

[1] UNEP/WMO. 2011. "Integrated Assessment of Black Carbon and Tropospheric Ozone". Available at: http://www.unep.org/dewa/Portals/67/pdf/BlackCarbon_report.pdf

There is a key opportunity to slow the rate of near term warming by reducing emissions of SLCPs, while at the same time advancing national priorities related to air quality and health. The expected benefits of SLCP mitigation are particularly relevant for Canada as an Arctic nation. Our Arctic warmed by 2.2°C between 1948 and 2013 resulting in significant impacts to local populations and sensitive northern ecosystems. Black carbon is of particular significance in the Arctic due to its additional warming effect when deposited onto snow or ice. Therefore, black carbon emissions emitted near or within Arctic nations have a particularly significant impact on Arctic climate.

All levels of government in Canada have implemented policies and measures that address emissions of SLCPs. In the case of black carbon, reductions have occurred largely as a co-benefit of other measures. While progress has been made, knowledge and mitigation gaps remain. The Pan-Canadian Framework advances SLCP mitigation objectives through a wide variety of new actions across all sectors of the economy, including specific actions focused on methane and HFCs, as well as actions to foster innovation that will help catalyze the transition to a clean growth economy (see summary box on page 13). As Canada works to implement the Pan-Canadian Framework, advance its Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, and develop its next steps to address air quality, there is a key opportunity to better coordinate and expand efforts on SLCPs, and to communicate Canada's priorities and progress in these areas.

This Strategy outlines a holistic Environment and Climate Change Canada (ECCC) approach to addressing SLCPs through five pillars for action: 1) enhancing domestic mitigation efforts; 2) science and communications; 3) engaging in international fora; 4) improving coordination of ECCC and government-wide activities; and 5) collaborating with provincial and territorial governments and other possible partners.

Implementation of this Strategy will: generate reductions from all key SLCP emissions sources; ensure that the Department's work on SLCPs and that of other government departments is mutually reinforcing; leverage policy levers across all levels of governments in Canada to better coordinate mitigation efforts; and continue our work internationally in leadership roles. Implementation of this Strategy will be coordinated with, and complementary to, implementation of the Pan-Canadian Framework.

IMPACTS, EMISSIONS, AND CURRENT MEASURES

BLACK CARBON

Black carbon is a component of $PM_{2.5}$ generated by the incomplete combustion of fossil fuels and biomass. Black carbon emissions are estimated to be the third largest contributor to current warming, after CO_2 and methane. Black carbon influences climate in multiple ways: by directly heating surrounding air when suspended in the atmosphere; by reducing the reflectivity of the earth's surface when deposited, an effect particularly strong over snow and ice; and through additional indirect effects related to interaction with clouds. Black carbon is estimated to be 3,200 (range of 270-6,200) times more potent a warming agent than CO_2 over a 20-year period[2,3]. Reducing uncertainties related to quantifying the overall warming effects of black carbon represents an active area of scientific research internationally.

Short-term and long-term exposure to $PM_{2.5}$, of which black carbon is a component, is also associated with a broad range of human health impacts, including respiratory and cardiovascular effects as well as premature death. In its 2012 assessment of the health effects of black carbon, the World Health Organization (WHO) noted that black carbon is a "carrier" of other pollutants, delivering them deep into the respiratory system, and further that a reduction in exposure to $PM_{2.5}$ containing black carbon should lead to a reduction in the health effects associated with $PM_{2.5}$[4].

In line with commitments under the Arctic Council, ECCC has published an annual black carbon emissions inventory since 2015. The initial inventory was for the 2013 data year. The black carbon inventory is also submitted annually to the United Nations Economic Commission for Europe (UNECE) and posted on ECCC's website.

It is estimated that 41 kilotonnes (kt) of black carbon were emitted in Canada in 2014. Recognizing the uncertainties related to global warming potentials (GWP) for black carbon and that these should be used with caution, application of the GWP_{20} values above would imply that Canada's 2014 emissions of black carbon are approximately equivalent to 131 megatonnes (Mt) of CO_2 emissions over a 20-year period. On- and off-road diesel vehicles and engines are estimated to be the largest source of black carbon emissions in Canada, accounting for over 40% of Canada's total black carbon emissions in 2014. Residential wood-burning follows as the second largest source, accounting for about one quarter of emissions. Emissions from stationary diesel engines are also regionally significant in the North, where they are commonly used for electricity generation in remote communities and at off-grid mine sites. Marine shipping may also constitute an increasingly significant source in the Arctic, due to projected increases in shipping activity in the region. See figure 1 below for a more detailed breakdown of Canada's black carbon emissions.

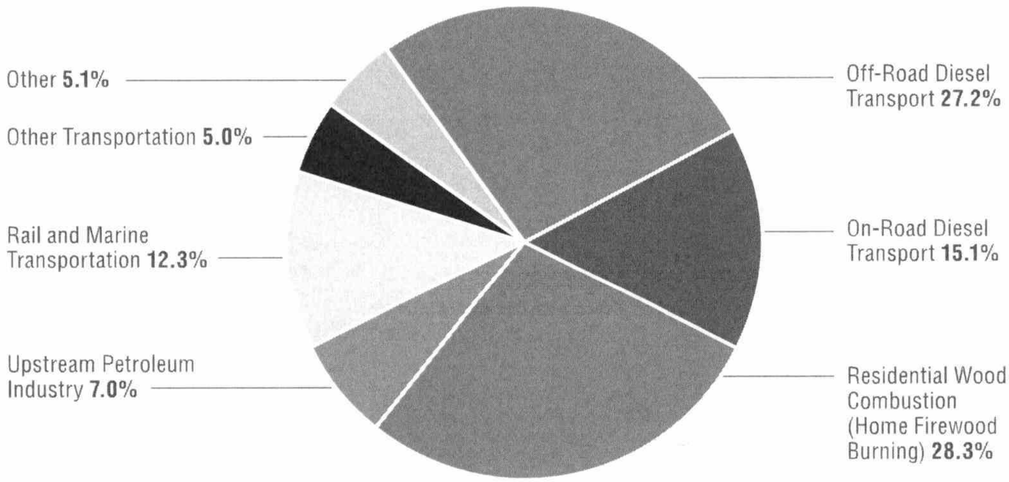
2 GWP_{20} from Bond et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment.

3 The use of the GWP_{20} in this section is to help communicate the potential contribution of black carbon mitigation to reducing near-term warming. Given the very different ways black carbon and CO_2 influence climate and their vastly different lifetimes in the atmosphere, there is not yet scientific consensus on a metric to quantify black carbon relative to CO_2. Further science work to reduce uncertainties and develop more appropriate metrics is needed.

4 World Health Organization, 2012. "Health effects of black carbon". Available at: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2012/health-effects-of-black-carbon-2012.

FIGURE 1: BLACK CARBON EMISSIONS BY SOURCE (2014)

(Source: Black Carbon Inventory 2017)



A number of federal measures already in place are expected to reduce emissions of black carbon as a co-benefit of other measures including stringent transportation sector air pollutant regulations for new on- and off-road vehicles and engines, ambient air quality standards for $PM_{2.5}$, and GHG regulations for coal-fired electricity generation (expected to generate co-benefit reductions in black carbon as coal power plants are phased-out). The North American Emission Control Area (ECA) for ships requires that ships sailing within 200 nautical miles of the United States (U.S.) and Canadian coasts (Arctic waters not included) burn a fuel with sulphur content no greater than 0.1%. Throughout Canada and the U.S., the ECA is expected to lead to a 74% reduction in $PM_{2.5}$ emissions below levels by 2020. Federal programs such as Natural Resources Canada's SmartWay Transport Partnership also support black carbon emission reductions.

Examples of provincial, territorial or municipal measures expected to result in reduced emissions of black carbon include transportation programs and policies (e.g. motor vehicle inspections, scrappage programs), emission standards for new wood-burning appliances, and wood stove change-out programs in some provinces and territories. For example, British Columbia recently updated its wood-burning regulations, and Ontario included $4 million in funding for a wood stove change-out program in its recently released Five Year Climate Action Plan. The City of Montreal has put in place stringent standards for wood-burning stoves and fireplaces. Provinces such as Alberta, British Columbia and Saskatchewan have implemented measures to reduce flaring from oil and gas operations.

RECENT FEDERAL ACTIONS AND COMMITMENTS ON BLACK CARBON

- Canada's endorsement of the World Bank's Zero Routine Flaring by 2030 initiative in April 2016 will support reductions in black carbon emissions resulting from routine flaring at oil production facilities.
- New federal investments that support clean technologies in place of those that rely on fossil fuels will reduce emissions of black carbon over the longer term. Examples include:
  - Budget 2017 provided $220 M over four years to help reduce reliance on diesel and other fossil fuels for electricity generation and heating in Northern, remote and Indigenous communities.
  - The Pan-Canadian Framework includes a number of actions that will help reduce black carbon emissions by reducing fossil fuel consumption. These include actions to improve energy efficiency and reduce emissions in the transportation sector, and to reduce reliance on diesel in northern and remote communities. See summary table on page 13 for more details.
- Canada has committed to develop national actions to reduce black carbon emissions in the Leaders' Statement on a North American Climate, Clean Energy, and Environment Partnership in July 2016.
- In May 2017, Canada, alongside other Arctic States, adopted the Expert Group on Black Carbon and Methane summary report which recommends that Arctic States further collectively reduce their black carbon emissions by at least 25 – 33 percent below 2013 levels by 2025.
- Transport Canada published draft emissions regulations for the rail sector in June 2016, including exhaust emission standards for particulate matter.
- ECCC initiated regulatory development for new stationary diesel (compression-ignition) engines in November 2016.

Black carbon gaps

Based on an assessment of current measures related to black carbon emissions, key mitigation gaps for black carbon include existing on- and off-road mobile diesel sources, stationary diesel engines and wood-burning appliances.

In the case of **on- and off- road mobile diesel** sources, current federal regulatory measures focus on fuels as well as new vehicles and engines. These have and will continue to result in black carbon emission reductions as fleets turn over. However, due to the long lifetimes of diesel vehicles, turnover of the in-use fleet is slow, and fleets are still dominated by engines pre-dating the most recent emissions standards. Although some provinces and territories have implemented measures focusing on existing vehicles, on- and off- road diesel vehicles and engines continue to be Canada's largest source of black carbon emissions.

Though emissions from **stationary diesel engines** are not estimated to be a large source of black carbon emissions nationally, they are a source of particular concern in many Northern remote and Indigenous communities, where engines operate 24 hours a day for off-grid electricity generation, often in close proximity to homes and schools, impacting local air quality. These emissions also generate local warming impacts, including through the deposition of black carbon on snow and ice, which accelerates melting. There are currently no federal regulations and few provincial and territorial measures targeting emissions from stationary engines.

Regulatory measures to address **wood-burning appliances** are limited at both federal and provincial/territorial levels. Some provinces regulate the sale of new wood-burning appliances, while some municipalities have by-laws relating to residential wood combustion, including emission standards, bans on certain types of appliances, or restrictions on the use of wood-burning appliances during smog days. Measures to address emissions from existing sources are limited to wood stove change-out programs or rebates for certain new appliances in some provinces and territories.

A number of non-regulatory initiatives related to wood burning have taken place through the Canadian Council of Ministers of the Environment (CCME). These include development of a guidance document for Canadian jurisdictions on open-air burning (2016); review of municipal, provincial, territorial and federal policies for open-air burning in selected Canadian and international jurisdictions (2016); a Code of Practice for Residential Wood Burning Appliances (2012); and a review of municipal, provincial and federal policies for wood burning appliances in selected Canadian and U.S. jurisdictions (2012).

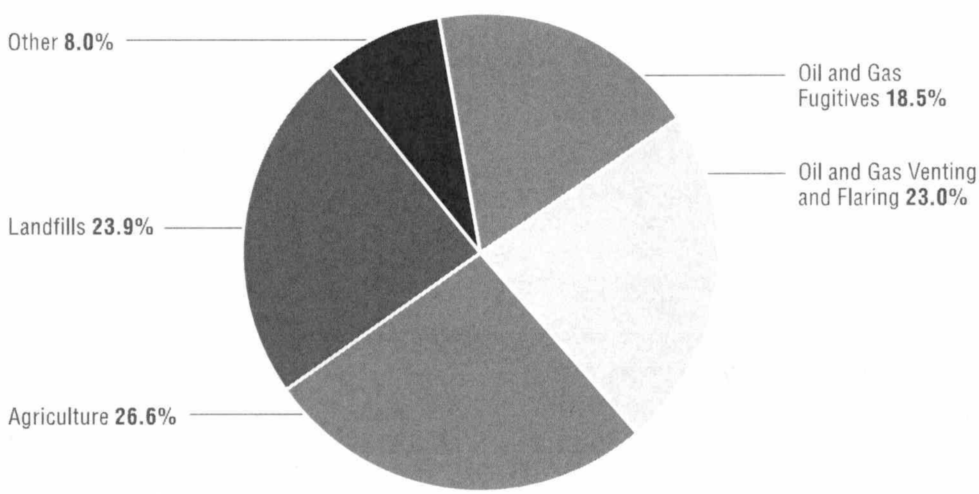
METHANE

Methane is a potent GHG. Methane is estimated to be 86 times more potent a warming agent than CO_2 over a 20-year period, and 34 times more potent than CO_2 over a 100-year period[5]. In addition to its significant climate impacts, methane contributes to the formation of ground-level ozone.

4,300 kt of methane were emitted in Canada in 2014, accounting for 108 Mt CO_2e, or 15%, of Canada's total GHG emissions[6] (using the most recent GWP for methane, this is equivalent to 361.2 Mt of CO_2 emissions over a 20-year period). The oil and gas sector accounted for 44% of Canada's methane emissions in 2014, largely from oil and natural gas fugitive sources, including venting and flaring (42% of national total). 91% of these emissions are produced in Alberta and Saskatchewan. The remainder of Canada's methane emissions is largely from agriculture and solid waste disposal (e.g. landfills). See figure 2 below for a more detailed breakdown of Canada's methane emissions.

FIGURE 2: METHANE EMISSIONS BY SOURCE (2014)

Source: National Inventory Report 1990-2014 - Part 3)



[5] Table 8.7 In Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 659–740, doi:10.1017/ CBO9781107415324.018. The GWP20 and GWP100 values given here account for climate-carbon feedbacks, which increases the GWP values relative to values without these feedbacks.

[6] National Inventory Report 1990-2014 – Part 3. Canada's reported GHG emissions for methane are based on a 100-year GWP of 25, per the IPCC's 4th assessment report and UNFCCC reporting guidelines.

Federal measures already in place addressing methane include funding for solid waste projects under selected federal infrastructure programs.

At the provincial and territorial level, British Columbia, Alberta and Saskatchewan have implemented measures to reduce venting and fugitive emissions from oil and gas operations. Alberta recently announced a new goal to cut methane emissions by 45% from oil and gas operations by 2025. Alberta is also proposing the development of specific requirements for new facilities as well as a voluntary initiative aimed at reducing venting and fugitive emissions from existing facilities. In British Columbia's Climate Leadership Plan released in 2016, the province set a target to reduce methane emissions from oil and gas extraction and processing infrastructure built before January 1, 2015, by 45 percent by 2025. British Columbia will also be offering incentives to reduce emissions from applications built between 2015 and 2018 with a Clean Infrastructure Royalty credit program, as well as a new offset protocol. The province also plans to establish standards for the development of projects after 2018-2020, including mandatory leak detection and repair.

Several provinces have landfill gas capture regulations or incentives. Different approaches have been taken in terms of scope and requirements.

RECENT FEDERAL ACTIONS AND COMMITMENTS ON METHANE

- In the Pan-Canadian Framework, Canada committed to work with provinces and territories to reduce methane emissions from the oil and gas sector by 40-45% below 2012 levels by 2025.
- To achieve this goal, Canada will implement federal methane regulations for the oil and gas sector, which will address Canada's largest source of methane emissions and provide clear and consistent requirements across the country. Canada published proposed regulations in May 2017.
- In the Leaders' Statement on a North American Climate, Clean Energy, and Environment Partnership, Canada also committed to developing and implementing a national methane strategy, taking action to reduce emissions from landfills, and implementing voluntary measures to reduce and recover food waste.

Methane gaps

Forthcoming federal, provincial and territorial measures under development to address oil and gas sources will address the largest mitigation gap for this SLCP. The key remaining mitigation gaps for methane are for **municipal solid waste landfills** and agriculture sources (enteric fermentation in particular). Recommendations on mitigation measures for the agriculture sector are not included in this Strategy however could be pursued in collaboration with Agriculture and Agri-Food Canada, taking into consideration efforts under the Pan-Canadian Framework on Clean Growth and Climate Change.

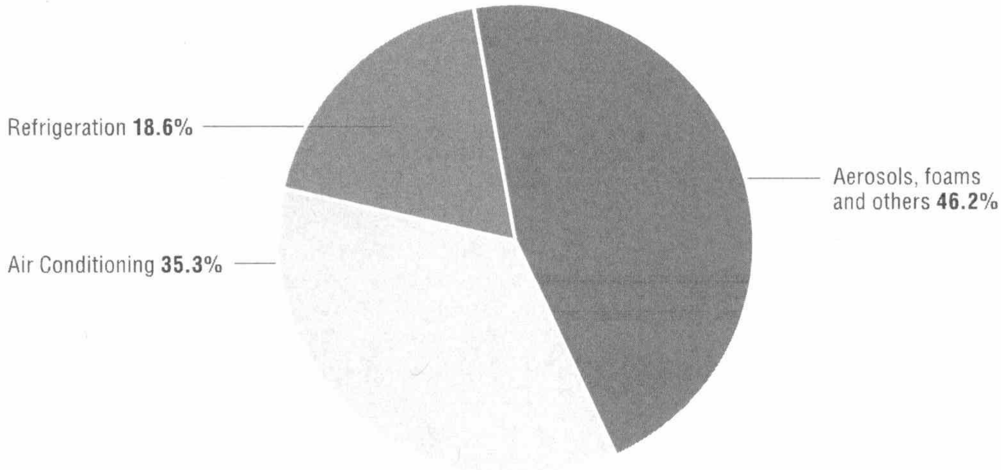
HYDROFLUOROCARBONS (HFCs)

HFCs are potent GHGs. The potency of HFCs varies by species and ranges from <1 to 10,800 times that of CO_2 over a 20-year period, and <1 to 12,400 that of CO_2 over a 100-year period[7]. Although HFC emissions are not currently a significant contributor to total GHG emissions in Canada, they are projected to more than triple between 2013 and 2030 unless additional policy measures are introduced. Most HFC emissions come from aerosols and foams, air-conditioning and refrigeration, where their use has rapidly increased in place of ozone-depleting substances. See figure 3 below for a more detailed breakdown of Canada's HFC emissions.

[7] Appendix 8: A In Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 659–740, doi:10.1017/ CBO9781107415324.018.

FIGURE 3: HFC EMISSIONS BY SOURCE (2014)

(Source: National Inventory Report 1990-2014)



A suite of existing federal and provincial and territorial regulations control ozone-depleting substances and HFCs once they are in use in refrigeration, air-conditioning and fire-extinguishing systems.

RECENT FEDERAL ACTIONS AND COMMITMENTS ON HFCs

- A federal permitting and reporting system for the import, export and manufacture of HFCs was established in spring 2016.
- A notice published in May 2016 requires the preparation and implementation of pollution prevention plans for the sound management of end-of-life halocarbon refrigerants. The notice, which includes HFCs, will contribute to preventing emissions of HFCs at end-of-life.
- Federal regulations were proposed in November 2016 to phase down the consumption of HFCs and to prohibit the import and manufacture of products containing or designed to contain HFCs. Regulations will avert future HFC releases to the environment and allow Canada to ratify and comply with the Kigali Amendment to phase-down HFCs under the Montreal Protocol.
- Canada committed to update public procurement processes to transition away from high-GWP HFCs whenever feasible in the U.S.-Canada Joint Statement on Climate, Energy and Arctic Leadership.

HFC gaps

There are no measures in place to limit growth of the use of HFCs however new federal measures proposed in 2016 would help control the consumption of HFCs, thereby reducing their use and avoiding future emissions.

OZONE

Ozone is a product of precursors including nitrogen oxides (NO_x), volatile organic compounds (VOCs) and carbon monoxide (CO), which transform into ozone in the atmosphere. Ground-level ozone is a powerful GHG, a significant contributor to current warming, and a key component of smog. It has deleterious effects on human health, damages plants and affects agricultural production. In Canada, the transportation and oil and gas sectors are key sources of ozone precursors. Residential wood combustion is also a significant source of CO emissions.

Measures to address ozone precursors are part of air quality actions, driven primarily by human health concerns. Transportation measures are the most mature, including several significant air pollution measures that address ozone precursors and that as a co-benefit, reduce black carbon. Other federal measures include consumer and commercial sector VOC regulations and new, more stringent Canadian ambient air quality standards (CAAQS) for ozone. The continued implementation of Canada's Air Quality Management System (AQMS) framework provides the basis for future mitigation efforts and air quality improvements. As part of this effort, Base Level Industrial Emission Requirements (BLIERs) instruments were finalized and others proposed in spring 2016. This represents an important step forward in addressing emissions of ozone precursors from industrial sources. Provincial measures to reduce ambient concentrations and prevent the exceedance of the CAAQS for ozone and fine particulate matter would also contribute to future emission reductions.

RECENT FEDERAL ACTIONS AND COMMITMENTS ON OZONE

- Multi-sector Air Pollutants Regulations (MSAPR) finalized in June 2016 will reduce emissions of ozone precursors from industrial boilers and heaters, the cement sector, and natural gas-fired stationary engines.
- Non-regulatory instruments for the aluminium and the iron, steel and ilmenite sectors were finalized in May 2016.
- Draft instruments for 7 other sectors published in May 2016 will also help to address ozone precursors.

Ozone gaps

A gap analysis for ozone has not been undertaken.

A HOLISTIC APPROACH TO ADDRESSING SLCPs

This SLCP Strategy complements the Department's foundational work on climate change and clean air. It will coordinate and enhance work under these programs by focusing on five pillars for action, which are all key for achieving desired outcomes: 1) enhancing domestic mitigation; 2) Enhancing science and communications to broaden understanding; 3) systematically engaging in international fora; 4) improving coordination of ECCC activities; and 5) collaborating with provincial and territorial governments and other possible partners.

Enhancing domestic mitigation

Increased awareness of SLCPs from a policy perspective has only occurred in the last few years. All levels of government have implemented measures that reduce emissions of SLCPs – sometimes targeted, such as in the case of methane and HFCs, or from what would later be understood as a co-benefit of $PM_{2.5}$ actions, in the case of black carbon. However, these measures were not in the context of an integrated approach to climate and air policy.

Enhanced domestic mitigation of SLCPs will provide a cost-effective way to contribute to Canada's international commitments to help limit global warming this century to well below 2°C above pre-industrial temperatures, while striving towards 1.5°C. It will also generate near-term air quality and health benefits. Black carbon measures implemented in or near the North have the potential to realize local Arctic benefits.

Enhanced measures could continue to be undertaken through approaches that address GHGs and air quality. However now that the short-term climate effects and health impacts of SLCP emissions are better understood, there is scope to do so more effectively than has been the case to date, by explicitly considering and quantifying the multiple benefits of SLCP mitigation when making mitigation decisions.

Enhancing science and communications to broaden understanding

ECCC's science work relating to SLCPs includes emissions characterization, atmospheric monitoring, processes studies and modelling. Monitoring provides measurements for determining long-term atmospheric trends, and for setting a baseline against which the success of mitigation efforts can be assessed and climate and air quality models evaluated. Monitoring also allows the relative importance of various sources of pollutants to be assessed by sector and jurisdiction, and assess how their relative contributions to total emissions evolve over time. Processes research and modelling allows improved representation of atmospheric and terrestrial processes in air quality and climate prediction systems in order to quantify the influence of SLCPs on climate and air quality. See Annex II for additional detail on ECCC's current science work relating to SLCPs.

Scientific challenges differ with each pollutant. Enhancing scientific work to increase understanding of the interactions between SLCPs and other pollutants as well as of their climate and air quality impacts will support the quantification of the multiple benefits that can be derived from action on SLCPs.

Though SLCPs are increasingly part of the dialogue on climate change, the importance of SLCP mitigation and the multiple benefits it can achieve is still not always understood by decision-makers. Targeted efforts will be undertaken to communicate how SLCPs contribute to climate change and air pollution and why it is important to include SLCP mitigation as a fundamental component of strategies to mitigate climate change, in parallel with near-term action on CO_2. These efforts will aim to increase understanding of SLCPs more broadly, within policy communities and by the general public.

Systematically engaging in international fora

Canada's recent international engagement on SLCPs reflects the emerging understanding that the best opportunity to slow the rate of near-term warming globally, and in sensitive regions such as the Arctic, is by cutting emissions of SLCPs – both at home, and internationally. Effective action is needed on many fronts, including outside the United Nations Framework Convention on Climate Change (UNFCCC), if commitments to avoid global temperature increase are to be achieved.

Canada's international climate finance and SLCP funding contributions aim to reduce GHG and SLCP emissions internationally, with a focus on developing countries.

ECCC is actively engaged in numerous international fora that seek to advance mitigation and scientific understanding of SLCPs globally (see Annex II for details). A more systematic approach to this engagement will leverage our existing North American partnerships, deepen our multilateral engagement, and seek to showcase our national and subnational activities.

Improving coordination of ECCC and Government of Canada activities

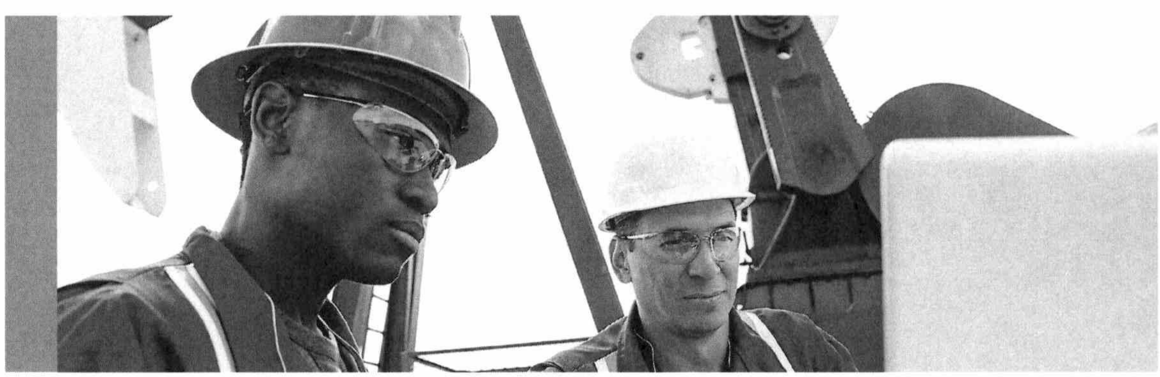
Canada's domestic mitigation, science and international work on SLCPs are increasingly linked. For example, both the Climate and Clean Air Coalition (CCAC) and the Arctic Council are calling for countries to step up domestic actions. Improved coordination of the Department's work on SLCPs will help to better integrate ECCC's science, policy and regulatory activities, and its domestic, North American, and international actions. Effective governance will also facilitate the prioritization and coordination of ECCC activities and engagement (domestically and internationally) within anticipated resourcing, and ensure that they are mutually reinforcing.

Other Government of Canada departments (OGDs) have the mandate to address SLCP sources such as the marine, rail, aviation and agricultural sectors. Improved coordination with OGDs will enhance the overall effectiveness of Canada's action on SLCPs.

Collaborating with provincial and territorial governments and other partners

Provinces and territories hold many SLCP policy levers and are important actors in SLCP mitigation. Increased collaboration with provincial and territorial partners on SLCPs is needed to coordinate action in order to drive emission reductions across key sources. ECCC could seek to advance coordinated action in priority areas that fall under joint jurisdiction, such as the transportation sector, building on the momentum of the Pan-Canadian Framework on Clean Growth and Climate Change to further advance action on SLCPs. Collaboration among governments is also needed to improve the consistency of emission inventories across jurisdictions, through alignment of reporting requirements or establishing data sharing agreements while minimizing duplication of efforts.

Canadian capabilities on SLCP mitigation extend beyond governments. This Strategy will leverage the knowledge, capacity and engagement of a broad suite of actors in Canada, including cities, municipalities, private sector, academia, government agencies such as the National Research Council, non-government organizations (NGOs), and Indigenous communities.



ACTIONS TO SUPPORT EACH PILLAR

The sections below outline a suite of actions through which ECCC could implement a holistic approach to SLCPs based on the five pillars.

It is recognized that a phased approach will be required for implementation, and that measures addressing the same pollutant from the same source, or that further scientific understanding, could be layered over time. Near-term actions ECCC will take are highlighted. Complementary actions that ECCC could advance in the future are also identified. A graphic of current and potential actions to address SLCP emissions is provided in Annex I.

Enhancing domestic mitigation action

The actions outlined below take into consideration issues related to shared jurisdiction, and sector-specific barriers to reducing emissions. Additional detail on each of the actions described is provided in Annex II.

A summary of how the Pan-Canadian Framework contributes to domestic SLCP mitigation is also provided in the box below.

OVERARCHING

Inclusion of SLCP mitigation objectives in departmental priorities, requiring consideration of SLCPs in decision-making on air quality and GHG actions, and inclusion of benefits of SLCP mitigation in cost benefit analyses of air pollutant and GHG mitigation measures could help to institutionalize the consideration of SLCP benefits in mitigation approaches.

ADVANCING SLCP MITIGATION UNDER THE PAN-CANADIAN FRAMEWORK

In December 2016, First Ministers adopted the Pan-Canadian Framework on Clean Growth and Climate Change, the country's first-ever pan-Canadian climate plan. The Pan-Canadian Framework aims to grow the economy while reducing emissions and building resilience to the impacts of climate change. It was developed in collaboration with provinces and territories, and in consultation with Indigenous Peoples.

The Pan-Canadian Framework has four main pillars: pricing carbon pollution; complementary measures to further reduce emissions across the economy; measures to adapt to the impacts of climate change and build resilience; and actions to accelerate innovation, support clean technology, and create jobs.

Many of the actions under the Pan-Canadian Framework will help reduce emissions of short-lived climate pollutants across multiple sectors of the economy.

Electricity

- Measures to help reduce reliance on diesel in northern, remote and Indigenous communities

Built environment

- Improving the efficiency of appliances and equipment
- Improving building codes and energy efficiency of housing, which will reduce the energy required to heat buildings

Transportation

- Continuing to improve fuel efficiency of new light-duty and heavy-duty vehicles
- Improving the efficiency of existing heavy-duty vehicles by requiring retrofits
- Increasing the number of zero-emission vehicles on the road
- Developing a clean fuel standard, which can help move away from fuels that contribute to black carbon, such as diesel

Industry

- Reducing methane emissions from the oil and gas sector
- Phasing down the use of HFCs
- Investing in new industrial technologies

Forestry, agriculture and waste

- Generating bioenergy and bioproducts, such as generating renewable fuel from waste

Innovation

- Support new approaches to early-stage technology development to advance research in areas that have the potential to substantially reduce GHG emissions and other pollutants

BLACK CARBON

Black carbon mitigation gaps will be addressed through air pollution measures or programs targeting and/or prioritizing those $PM_{2.5}$ sources known to result in significant black carbon emissions, or that have significant regional impacts, such as in the Arctic, or in densely populated areas. Actions taken to address black carbon gaps will support Canada's commitment to pursue significant national actions to reduce black carbon emissions in North America.

Diesel emissions, which are very high in black carbon, are of particular concern from a human health perspective. In 2012, the World Health Organization (WHO) classified diesel exhaust as carcinogenic to humans. This conclusion is supported by Health Canada's Diesel Exhaust Health Risk Assessment (2016), which links exposure to diesel exhaust from mobile sources alone to 700 premature deaths in Canada annually. Health Canada's risk assessment also found that diesel emissions are associated with significant numbers of acute respiratory symptom days, restricted activity days, asthma symptom days, hospital admissions, emergency room visits, child acute bronchitis episodes and adult chronic bronchitis cases across Canada.[8]

A combination of regulatory and program approaches, addressing both new and existing sources, could be an effective way to reduce emissions from wood-burning appliances and stationary diesel engines.

Jurisdictional considerations are an important factor in assessing how best to address mitigation gaps for **on- and off- road diesel vehicles and engines**. Once a vehicle is sold at the retail level, provincial and territorial governments have jurisdiction over its environmental performance within their respective boundaries, and along with municipalities have the most policy levers to support action on existing fleets. The Government of Canada could explore opportunities with provinces and territories to further reduce emissions from these sources.

[8] Health Canada, 2016. "Human Health Risk Assessment for Diesel Exhaust – Summary". Available at: https://www.canada.ca/en/health-canada/services/publications/healthy-living/human-health-risk-assessment-diesel-exhaust-summary.html

Stationary diesel engines are used in many applications throughout Canada. They are a source of particular concern in many Northern communities, where engines operate 24 hours a day for off-grid electricity generation, often in close proximity to homes and schools, impacting local air quality. Federal regulations to implement performance standards for new stationary diesel engines, similar to U.S. standards in place since 2006, are being advanced through funding received under Budget 2016. Support for retrofits and replacements in collaboration with provincial and territorial partners would help to reduce emissions from existing units. This would support commitments under the Pan-Canadian Framework to work with Indigenous Peoples and northern and remote communities in reducing their reliance on diesel by improving the energy efficiency of diesel generating units, supporting the demonstration and installation of hybrid or renewable energy systems, and connecting communities to electricity grids.

There are approximately 3.6 million **wood-burning appliances** in Canada. A large fraction of emissions come from older appliances. Federal measures for new residential and commercial/institutional wood-burning appliances would ensure consistent national standards across Canada and ensure new appliances are efficient. Minor amendments to the *Canadian Environmental Protection Act, 1999* (CEPA) would be needed to allow regulation of manufacturers and importers (rather than individual households or businesses). A key challenge is slow rates of turnover due to decades-long lifetimes; replacing an inefficient wood-burning appliance with a modern one can reduce $PM_{2.5}$ emissions by up to 70% on a per unit basis, with co-benefits for methane and CO_2. In addition to health benefits associated with reduced $PM_{2.5}$ and therefore black carbon emissions, reducing emissions from wood-burning appliances could also generate other co-benefits related to human health. For example, they could also help to reduce emissions of VOCs and other toxics such as polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, and help to reduce wintertime smog.

Enhanced domestic actions could also be targeted to supporting Government of Canada and ECCC objectives to **promote the use of clean technologies**. For example, the Government of Canada operates a number of facilities in the Arctic that rely on diesel fuel for electricity generation, including ECCC's Eureka weather station. Investments in solar or other renewable sources, based on the results of a feasibility study, would reduce fuel-use and lower emissions from diesel combustion and demonstrate the application of renewable technologies in the Arctic. In the Pan-Canadian Framework, the Government of Canada committed to reduce its own GHG emissions to 40 percent below 2005 levels by 2030 or earlier, and also set a goal of using 100 percent clean power by 2025.

There may also be potential to reduce emissions from **marine** sources in partnership with Transport Canada and continued collaboration with members of the International Maritime Organization (IMO). Canada will continue to work with Arctic partners to determine how best to address the risks posed by black carbon emissions from Arctic shipping.

NEW NEAR-TERM ECCC ACTIONS ON BLACK CARBON

- Proposed regulations for new stationary diesel engines will be published in the *Canada Gazette, Part I* for a public comment period. The target date for publication is 2018.The emission standards will contribute to air quality, health and climate benefits.

METHANE

Announced measures to address methane from oil and gas sources at the federal level, in Alberta and in British Columbia will reduce Canada's largest source of methane emissions, with co-benefits reductions of some ozone precursors, and contribute to Canada's GHG emissions reduction targets.

A landfill gas (LFG) recovery initiative could further reduce methane from **municipal solid waste landfills**. Measures identified in consultation with provinces and territories, requiring or incenting the capture of landfill gas are being advanced through new funding received under Budget 2016. There are opportunities to accelerate the capture and utilisation rate of landfill gas and support the implementation of technologies and infrastructure to divert and manage organic waste as a long-term solution.

Furthermore, there is a growing body of evidence that identifies **waste prevention, reuse and recycling** as the largest source of untapped potential for GHG reductions in the waste sector. Measures to reduce GHGs could focus on food waste reduction, organics diversion, and recycling and material reuse. These would complement actions to reduce emissions from landfills. Food waste is a major part of the organic materials that emit methane from landfills. Under United Nations Sustainable Development goals, and in the recent NALS joint action plan, Canada committed to work towards reducing food waste by 50%. ECCC will collaborate with Agriculture and Agri-Food Canada (AAFC) as they develop a national food policy.The current national waste diversion rate is about 25% of the waste generated, largely due to provincially regulated recycling programs, and provincial and municipal organics diversion regulations and initiatives. Leading countries from the Organization for Economic Co-operation and Development (OECD) divert up to 50-60% of their waste. Additional measures to be identified in collaboration with provinces and territories, and with input from stakeholders, could increase resource utilization and recycling, and move Canada toward a circular economy.

The national methane strategy committed to in the Leaders' Statement on a North American Climate, Clean Energy, and Environment Partnership may include additional measures beyond those considered in this Strategy.

NEW NEAR-TERM ECCC ACTIONS ON METHANE

- The federal government will work with provinces and territories to achieve the objective of reducing methane emissions from the oil and gas sector, including offshore activities, by 40-45 percent below 2012 levels by 2025, including through equivalency agreements.
- ECCC will develop measures to address methane from landfills in consultation with provinces and territories.
- Consultations on strategies to reduce avoidable food waste, increase organics diversion, and increase recycling and reuse will begin in 2017.

HYDROFLUOROCARBONS (HFCs)

Building on new federal measures finalized in spring 2016, **comprehensive regulatory measures** proposed in late 2016 would control the consumption of HFCs through a phase-down of the manufacture, import and export of HFCs and prohibit the manufacture and import of HFC-containing products and equipment in certain sectors. These measures could be complemented by pursuing work with OGDs to ensure energy efficiency programs and regulations are well coordinated, and by engaging and collaborating with other actors to communicate the importance of technology development and implementation related to HFCs.

Additional actions could be taken to **encourage the replacement of HFC systems and products** with more climate-friendly alternatives, where feasible. For example, the Government of Canada will be "leading by example" by implementing an HFC procurement program to promote the use of climate-friendly low-global warming potential alternatives whenever feasible, and to gradually transition to equipment that uses more sustainable alternatives to high-global warming potential HFCs.

NEW NEAR-TERM ECCC ACTIONS ON HFCs

- ECCC will work to develop final regulations for the proposed HFC regulatory measures that were published in 2016. These measures will allow Canada to comply with its Montreal Protocol HFC obligations and ratify the Kigali amendment.
- The federal commitment to update public procurement processes to transition away from high-GWP HFCs whenever feasible will further reduce HFC emissions.

OZONE

The publication of the CAAQS for fine particulate matter and ozone should help to drive down ambient concentrations of these two pollutants. Under the AQMS, provinces and territories are expected to develop air quality management action plans for regions (air zones) within their jurisdiction where concentrations of these pollutants are approaching or exceeding the CAAQS. Action plans would look at all sources of these pollutants and management actions could include regulatory and non-regulatory instruments including those under the AQMS and MSAPR.

At the federal level, work will proceed to finalize draft instruments for seven industrial sectors posted in May 2016. Proposed regulations for petroleum and refinery gases, which are VOCs, from the downstream oil and gas sector as part of the Chemicals Management Plan, will also help to address ozone precursors.

There may be scope to set more ambitious ambient air quality standards for $PM_{2.5}$ and ozone, as some aspects of current standards are not as stringent as levels proposed by the World Health Organization (WHO). In addition, consideration could be given to developing additional emissions standards for industrial sectors where emissions and impacts on local air quality can be very significant (e.g. petroleum refining, coal-fired power plants).

NEW NEAR-TERM ECCC ACTIONS ON OZONE

- ECCC will finalize proposed instruments for the aluminum, steel, potash, pulp and paper, iron ore pellets, and base metals smelting sectors and for cross-sectoral turbines.
- ECCC is leading development of more stringent ambient air quality standards and is working to bring forward additional emissions standards for key pollutants and sectors.
- ECCC will seek approval from federal, provincial and territorial Ministers of the Environment for new Canadian ambient air quality standards for NO_2, and lead the review of PM and ozone standards.
- Proposed federal regulations to reduce petroleum and refinery gases will be published in the *Canada Gazette, Part I*, in 2017.

SUMMARY OF APPROACHES

TABLE 1: SUMMARY OF POTENTIAL MEASURES

SOURCES	POTENTIAL MEASURES					
	REGULATIONS	OTHER CONTROL MEASURES	INCENTIVES AND PROGRAMS	TECHNOLOGY DEMONSTRATION AND SUPPORT	JURISDICTION	TIMELINES
BLACK CARBON						
Existing diesel vehicles and engines			✓		Provincial/ territorial and municipal	Medium-longer term
New diesel vehicles and engines	✓				Federal	In place
Existing stationary diesel engines			✓	✓	Federal and/or provincial/ territorial	Medium-longer term
New stationary diesel engines	✓				Federal	Near term
Existing wood-burning appliances		✓	✓		Provincial/ territorial and municipal	Medium-longer term
New wood-burning appliances	✓	✓			Federal and provincial/ territorial	Medium-longer term
METHANE						
Existing oil and gas operations	✓				Federal and provincial/ territorial	Near term
New oil and gas operations	✓				Federal and provincial/ territorial	Near term
Existing solid waste landfills	✓[1]	✓[1]	✓[1]		Federal and provincial/ territorial	Near to medium term
New solid waste landfills	✓[1]	✓[1]	✓[1]		Federal and provincial/ territorial	Near to medium term
HFCs						
Existing and new systems	✓	✓	✓	✓	Federal and provincial/ territorial	Near term: regulations and other control measures Medium term: incentives and programs, technology demonstration and support

SOURCES	POTENTIAL MEASURES					
	REGULATIONS	OTHER CONTROL MEASURES	INCENTIVES AND PROGRAMS	TECHNOLOGY DEMONSTRATION AND SUPPORT	JURISDICTION	TIMELINES
OZONE						
Canadian ambient air quality standards					Federal	Near term: NOx Medium term: more stringent $PM_{2.5}$/ozone
Existing industrial sources	✓	✓			Federal and provincial/ territorial	Near term: MSAPR and 7 sectors for which instruments proposed in 2016
New industrial sources	✓	✓			Federal and provincial/ territorial	Near term: MSAPR and 7 sectors for which instruments proposed in 2016

[1] To be determined in consultation with provinces and territories.

Enhancing science and communications to broaden understanding

ECCC's Climate Change and Clean Air science programs provide the foundation to support the effective incorporation of SLCPs into the plan to combat climate change and reduce GHG emissions, as well as support the setting of air quality standards. ECCC is the only agency in Canada making long-term, continuous observations of GHGs and black carbon. ECCC also engages in international research communities to ensure that the climate prediction and SLCP science on which decisions are based remain leading edge and consistent with current scientific understanding.

Implementation of the following actions is critical to addressing SLCP knowledge gaps and improving ECCC's quantification of emissions of SLCPs and supporting the assessment of trends, with a focus on black carbon and methane. It would also provide science-based evidence to support decisions related to climate change mitigation and air quality, and improve dissemination of that knowledge to policy communities and the general public.

Refinement of ECCC's Climate and Air Quality Models

Atmospheric methane and black carbon levels are influenced by both human activities and natural terrestrial systems (e.g. wetlands, wildfires, permafrost releases). The proposed approach is to improve the representation of methane and black carbon in ECCC's earth system-based climate model and regional scale air quality model in order to differentiate contributions related to human activities from contributions related to changes in natural systems. Doing so would then allow analyses to determine the potential impact and efficacy of different mitigation scenarios.

Reconciling estimates of methane and VOC emissions from oil and gas operations

The oil and gas sector is the largest source of both methane and VOC emissions in Canada. Additional scientific work is needed to improve approaches for estimating fugitive emissions of methane and VOC emissions from oil and gas operations. This would begin with a study to reconcile emissions estimates generated by top-down (based on ambient atmospheric observations, including from field campaign intensive studies and satellite) and bottom-up (detailed equipment count and emissions measurements at the equipment or facility level) quantification approaches. Study findings would be used to improve quantification of fugitive emissions from the sector as a whole. This would improve knowledge of emissions from the oil and gas sector, supporting the development of emissions reduction scenarios in air quality and climate prediction systems, and increasing confidence in sector emissions reported in national emissions inventories. It would also result in improved understanding of climate and air quality impacts of SLCPs from oil and gas operations in Canadian, North American and global contexts. This work would facilitate more realistic simulations of emissions changes and of the specific climate and air quality response to those changes, improving understanding of the range of emissions consistent with meeting global targets, and of the climate change and air quality benefits from actions on SLCPs.

Further refining the black carbon inventory to support the development of priority mitigation measures

The quantification of black carbon emissions can be improved for some regions in Canada (such as the North) and for poorly understood emission sources such as biomass burning, flaring and diesel combustion in stationary and mobile equipment. Priorities identified for improvements in the black carbon emission inventory are based on priorities for domestic action. Historical trends in black carbon emissions will be developed as additional years are added to future inventory editions. These will allow the impact of measures to date to be assessed. Consideration could also be given to possible amendments to National Pollutant Release Inventory (NPRI) reporting requirements to support black carbon inventory refinements.

Communicating SLCP science and the importance of SLCP mitigation

ECCC is assessing climate change science content on the Department's website as part of the web renewal process. Refreshing content on SLCPs will be included in this exercise. The Department will also consider other opportunities to communicate: SLCP science, as feasible within existing capacity; the importance of SLCP mitigation; and Canada's related actions; and bring these forward for consideration as appropriate.

NEW NEAR-TERM ACTIONS

- ECCC will enhance methane and black carbon representation in the Department's earth system-based climate model and air quality models. Climate and air quality model data, scientific reports, and targeted analysis for the regulatory community will be available in 2018-2019.
- ECCC will improve the quantification of black carbon and ozone precursors emitted by residential biomass burning, via direct measurement studies.
- ECCC will update web content on SLCPs.
- ECCC will propose complementary communications products to emphasize the need to act to policy communities and the general public, and communicate Canada's actions to address SLCPs on domestic and international fronts.

Systematically engaging in international fora

ECCC could **build on bilateral and continental partnerships** and relationships to further SLCP objectives through continental actions. For example, Canada and the U.S. have been collaborating on air quality through the Canada-U.S. Air Quality Agreement (AQA), signed in 1991 with the purpose of addressing the transboundary movement of air pollutants that cause acid rain. In 2000, an annex to address ground-level ozone was added. Over the past two years, Canada and the U.S. have been informally exploring possible options for updating and strengthening the Agreement. ECCC officials successfully worked with counterparts in the U.S. and Mexico to include SLCP commitments in the North American Clean Energy and Environmental Partnership called for in the Minister's mandate letter. Opportunities to advance SLCP objectives under the Commission for Environmental Cooperation (CEC) could also be explored.

ECCC could **deepen its multilateral engagement** on SLCPs through new actions to support SLCP objectives in a number of existing fora in which it participates. There is a key opportunity to bring international attention to SLCPs and high-profile visibility to Canada's current and planned SLCP mitigation actions under the **UNFCCC process**, by highlighting efforts to address SLCPs in the revised **Nationally Determined Contribution submission (NDC submission)** to be submitted by Canada following completion of the Pan-Canadian Framework on Clean Growth and Climate Change, as well as in related communications materials. This could be as simple as including narrative to highlight that: Canada recognizes the importance of reducing SLCPs in concert with action on CO_2 in attaining temperature goals; measures on methane and HFCs in the NDC contribute to SLCP reductions; and that Canada is also working to reduce emissions of black carbon. In addition, ECCC could advocate for more SLCP-related projects to be supported through climate finance contributions that aim to mobilize private sector investments at multilateral development banks.

In addition, as part of Canada's $2.65 billion pledge in international climate financing to help developing countries transition to low-carbon and resilient economies, Canada committed $35M to reduce SLCP emissions. This investment includes, amongst other things, a $10M contribution to the CCAC Trust Fund and $14 million to support NDC implementation in Mexico and Chile through the deployment of clean technologies to reduce methane emissions (1) in the Mexican oil and gas sector and (2) in the Chilean waste management sector.

Canada's engagement on SLCPs under the **Arctic Council's** Expert Group on Black Carbon and Methane provides an opportunity to influence benchmarking activities on SLCPs and re-invigorate or leverage partnerships with non-Arctic States participating in the group towards broader climate and clean air-related goals. Canada will work to implement recommendations from the Expert Group on Black Carbon and Methane Summary of Progress and Recommendations to contribute to the achievement of the collective goal on black carbon. Canada will also continue to engage constructively in discussions within the Expert Group, including to revisit the collective goal on black carbon during future Arctic Council chairmanships. Canada could also undertake new activities through other Arctic Council working groups. For example, Canada could propose project-based work under the Arctic Council's Arctic Contaminants Action Programme's (ACAP) Short-lived Climate Pollutants Expert Group (SLCP EG), focusing on activities that can reduce emissions of black carbon that are transported to and deposited in the Arctic.

A Canadian project could explore and address data gaps for key sources or focus on achieving real reductions in black carbon emissions in the Canadian Arctic region by working with industry and other stakeholders. The project could be a desktop study or data review, or implement concrete and cost-effective measures to reduce emissions. ECCC could also explore work with the territories to develop and submit a case study on black carbon reduction activities or best practices to ACAP's Black Carbon Case Studies Platform, a web-based interactive map that houses case studies from across Arctic States to help the general public find information on black carbon activities in the Arctic. Canada will continue to engage with the expert science community on SLCPs through representation on the AMAP expert group on black carbon, methane and ozone. Additional opportunities such as reducing the use or carriage of heavy fuel oil in the Arctic could also be explored under the Arctic Council and other multilateral fora such as the IMO.

Canada's **endorsement of the World Bank Zero Routine Flaring by 2030 initiative** is expected to contribute to reduced emissions of black carbon, CO_2 and other pollutants produced by routine flaring from oil production operations. This initiative requires that participating governments provide a legal, regulatory, investment, and operating environment that provides oil companies the confidence and incentive to invest in flare elimination solutions. The federal government has committed to work with provincial and territorial governments to implement consistent requirements across the country. Canada will encourage federal, provincial and territorial oil and gas regulators to continue efforts towards eliminating routine flaring, recognizing that flaring for certain specific circumstances, such as safety or emergency reasons, may still need to occur. Specifically, Canada will encourage federal, provincial and territorial oil and gas regulators in efforts to ensure gas conservation regulatory requirements are robust and achieve no routine flaring. The use of Best Available Technology Economically Achievable (BATEA) is encouraged to eliminate flaring. A number of regulators have already taken such action, such as: existing and proposed legislation and policies for solution gas flaring management in Alberta and British Columbia, as well as efforts under the Frontier and Offshore Regulatory Renewal Initiative between the Canada-Newfoundland and Labrador Offshore Petroleum Board, the Canada-Nova Scotia Offshore Petroleum Board and the National Energy Board.

ECCC has **increased** its **engagement in the CCAC** by serving as co-chair of the CCAC Working Group, the operational decision-making body of the Coalition, for the 2016-2018 period. In addition, CCAC funding provided by Canada, as well as other CCAC Partners, will help to reduce SLCP emissions from key industrial sectors in developing countries, contributing to Canada's international objectives on climate change and in reducing the rate of near-term warming. It also strengthens Canada's profile in efforts to reduce SLCPs. Canada could also nominate experts to the CCAC's new Solutions Centre and expert roster. Furthermore, the Assistant Deputy Minister of the Environmental Protection Branch (ECCC) is co-chairing the Global Methane Initiative for the 2016-2018 period. Participation in these fora demonstrates Canada's commitment to advancing supplementary and complementary efforts to the UNFCCC.

HFCs are the fastest growing GHGs in developing countries due to rapid growth of the refrigeration and air conditioning sector in these countries and their use as replacements for ozone-depleting substances being phased out under the **Montreal Protocol**. Studies have shown that global HFC emissions could constitute up to 10% of total CO_2e emissions by 2050. The most widely used HFCs have lifetimes ranging from 10-30 years. Immediate action to phase down HFCs can therefore make a significant impact in achieving relatively near-term climate mitigation. International engagement to promote the global phase-down of HFCs through an amendment to the Montreal Protocol has represented a critical component of ECCC's approach to mitigating this SLCP. Canada co-sponsored a North American Proposal to phase down HFCs under the Montreal Protocol in 2009, and undertook unrelenting efforts over the past seven years to promote such a phase-down through to the adoption of the Kigali amendment on October 15, 2016. ECCC will **pursue its leadership role under the Montreal Protocol** by encouraging Parties to ratify the Kigali Amendment as soon as possible and by working with Parties towards the implementation of the amendment.

Ratification of the amended Gothenburg Protocol to the Convention on Long-range Transboundary Air Pollution would demonstrate Canada's commitment to addressing SLCPs and air pollutants in an international treaty. Canada's commitments are indicative in nature and would be automatically incorporated into the treaty upon ratification. Moreover, once this treaty comes into force for Canada, it would replace three earlier treaties to which Canada is a party and under which we have reporting and reduction obligations.

Engagement in all these fora could seek to **showcase national and subnational activities**, and Canadian SLCP mitigation technologies. For example, national reports on black carbon and methane submitted to the Arctic Council provide an ongoing opportunity to share progress on Canada's scientific and mitigation activities, best practices or lessons learned, at international, national, and subnational levels. Several Canadian companies and end users have developed and implemented innovative technologies to transition from current HFC technologies. ECCC could demonstrate its support for clean technologies by hosting a side event at an upcoming Montreal Protocol Meeting to showcase emerging Canadian climate-friendly alternatives to current HFC technologies. Canada could also work to raise the profile of, and advocate for, action to reduce SLCPs in international fora such as the Organisation for Economic Co-operation and Development (OECD), the United Nations Environment Assembly (UNEA), the G7/G20, as well as non-traditional environmental fora such as the International Maritime Organization (IMO), as appropriate.

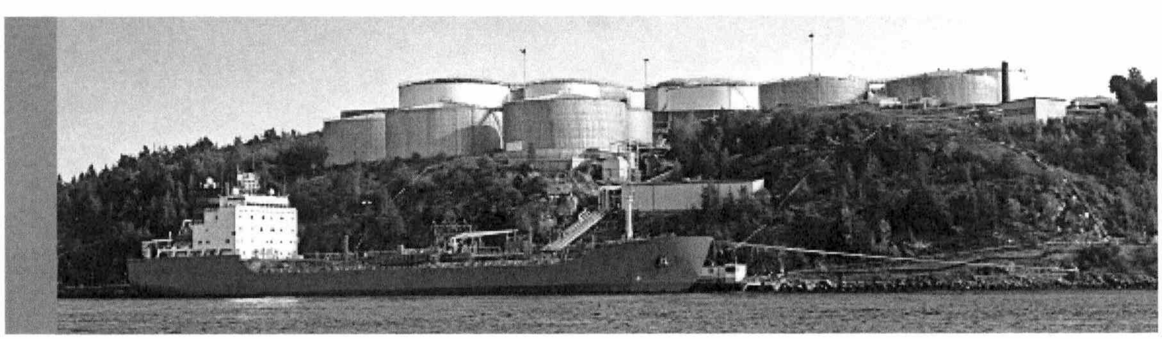
NEW NEAR-TERM ACTIONS

- ECCC will develop high-level language regarding the importance of SLCP mitigation to include in the narrative for Canada's **NDC submission**.
- ECCC will work to implement several recommendations from the Expert Group on Black Carbon and Methane Summary of Progress and Recommendations to contribute to the achievement of the **collective goal on black carbon under the Arctic Council**.
- ECCC will support efforts to explore opportunities to reduce the use or carriage of heavy fuel oil in the Arctic under multilateral fora such as the IMO or the Arctic Council.
- ECCC will encourage Parties to ratify the Kigali Amendment to the Montreal Protocol as soon as possible, and will work with Parties towards the implementation of the amendment.
- ECCC will work with provincial/territorial governments to implement consistent requirements for the World Bank Zero Routine Flaring by 2030 initiative across the country.
- Canada will continue to strategically engage in the CCAC, focusing on its role as a catalyst for SLCP emission reductions internationally.
- ECCC will work to ratify the Gothenburg Protocol.

Improving coordination of ECCC and Government of Canada activities

The breadth of actions that could be taken on SLCPs suggests that it would be useful to formalize governance of ECCC's SLCP actions in order to enable prioritization and coordination of activities across ECCC's Environmental Protection, Science and Technology, International Affairs, and Strategic Policy Branches.

An **ECCC-wide SLCP integration committee** will be convened to support the implementation of this Strategy, prioritize and coordinate work plans across ECCC, develop resource allocation options, and track progress to ensure that priorities identified for SLCPs are advanced under agreed upon timelines. Members of the committee will represent and serve as SLCP contact points for their programs. The committee will report to the Assistant Deputy Minister of the Environmental Protection Branch.



In the near term, such coordination will assist in ensuring timely, consistent, and streamlined input and consultation across the Department on SLCP activities. Over the longer term, it will ensure the Department's science, policy and international dimensions are working toward coherent and unified strategic goals, aligned with the Ministerial mandate and the Pan-Canadian Framework.

Collaboration with other government departments will be important in developing a well-rounded federal response to SLCPs. For example, Transport Canada (TC) has the mandate to address emissions from marine, rail and aviation, and Agriculture and Agri-Food Canada has the mandate to address methane emissions from the agricultural sector.

A number of other departments are also actively engaged in activities, have implemented programs relevant to SLCPs, or are planning on doing so, including: Natural Resources Canada's (NRCan) Program of Energy Research and Development (PERD), SmartWay Transport Partnership, FleetSmart and its R2000 Housing Standards; and Infrastructure Canada programs, such as the Green Infrastructure Fund and the Public Transit Infrastructure Fund. Health Canada (HC) has undertaken studies to quantify health impacts related to exposure of diesel exhaust, and analysis of the potential air quality and health benefits of a widespread program to retrofit diesel engines.

Other government departments could be formally engaged through the ECCC SLCP Integration Committee. Creation of a federal working group could also be considered.

NEW NEAR-TERM ACTIONS

- ECCC will launch an SLCP integration committee to improve coordination of ECCC and Government of Canada SLCP activities, including to track the implementation of this Strategy and to identify new priorities.
- ECCC will engage other federal departments regarding opportunities to reduce emissions of SLCPs for key sources falling under their mandates.

Collaborating with provincial and territorial governments and other possible partners

ECCC could seek to advance **SLCP mitigation through collaboration with provincial and territorial partners**, by focusing on priority areas that fall under joint jurisdiction, including:

- Black carbon: in-use on- and off-road diesel vehicles and engines, stationary diesel engines, and wood-burning appliances;
- Methane: venting and fugitives from oil and gas operations, landfill gas reduction and capture;
- Ozone: Continuing to work with provinces and territories under the AQMS to address air pollutants, including ozone precursors such as NOx and VOCs;
- HFCs: Preventing emissions of HFCs through a suite of federal/provincial/territorial controls, including public procurement of equipment with alternatives to high-GWP HFCs; and
- Collaboration on improving the consistency of emission inventories across jurisdictions, through alignment of reporting requirements or establishing data sharing agreements while minimizing duplication of efforts.

The federal government has been working with the provinces and territories on methane, including through the process to develop the Pan-Canadian Framework. The need to consider black carbon as a co-benefit was also included and recognized by the specific mitigation opportunities working group. There is also potential to mobilize existing mechanisms within the CCME for longer term collaboration on priority areas.

Of note are the: Mobile Source Working Group (MSWG) where sharing information on how to reduce emissions from in-use fleets, including high emitting on-road vehicles, is one of the primary objectives (revising this group's mandate to include action could be considered); the Air Management Committee, under which ECCC collaborated with provincial and territorial partners to develop a code of practice for wood-burning appliances and a guidance document for open-air burning; the National Action Plan for the Environmental Control of Ozone-depleting Substances and their Halocarbon Alternatives, which includes HFCs; and the Waste Management Task Group. Collaboration will also continue under the AQMS framework more broadly through the Air Management Committee which oversees the implementation of the AQMS.

Municipalities hold a number of policy levers on SLCPs, including related to waste, transit and wood burning. ECCC could **explore possible partnerships with municipalities**. There may also be opportunities to showcase the strengths of cities internationally and draw municipalities into collaboration with federal, provincial and territorial governments as key partners in addressing SLCPs.

ECCC could also **explore possible partnerships with other actors**. Further analysis could be undertaken to better understand how engagement with arms-length institutions and others outside government could support policy objectives, and where engagement efforts could best be focused. Analysis could include consideration of engagement with: funding institutions such as Sustainable Development Technology Canada; the Federation of Canadian Municipalities (FCM); academia, for example on SLCP science; Indigenous communities; NGOs; and the private sector.

NEW NEAR-TERM ACTIONS

- ECCC will continue to collaborate with provincial and territorial partners to advance SLCP mitigation priorities. Discussions could build on existing collaboration on in-use diesel transportation fleets and wood-burning appliances under the Canadian Council of Ministers of the Environment. Further collaboration on accelerating the turnover of existing wood-burning appliances and in-use stationary engines could be proposed.

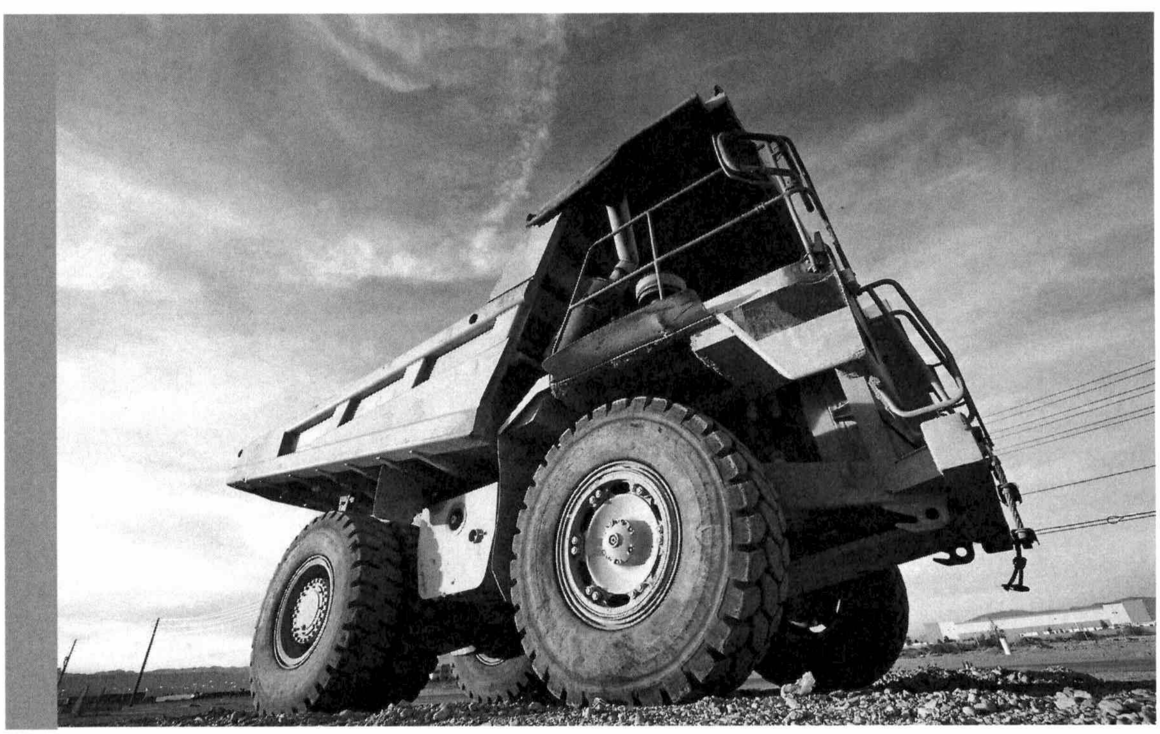
CONCLUSION

ECCC is committed to reducing emissions of carbon dioxide and other long-lived GHGs as well as SLCPs as part of its comprehensive approach to climate change mitigation. Reducing emissions of SLCPs supports Canada's commitments under the Paris Agreement, and domestic priorities for cleaner air and healthier communities. Comprehensively addressing SLCPs requires new, coordinated actions at home and abroad.

Ideally, all of the actions identified in this Strategy would be undertaken in the near future. However, many of the actions to enhance domestic action and increase scientific understanding require additional resources. Some would also require collaboration with key partners outside ECCC to deliver. Engaging other federal departments and provincial and territorial partners will be a key next step. A phased approach will be taken to advance remaining actions, taking into consideration jurisdictional authorities.

Implementation of new near-term actions will represent an important step forward in addressing SLCP mitigation and knowledge gaps. It will also help to ensure that the Department's work on SLCPs, as well as that of other departments and levels of government are mutually reinforcing. Implementation will be coordinated with, and complementary to, implementation of the Pan-Canadian Framework.

Sustained efforts will be required to advance the implementation of a holistic approach to SLCPs, and to generate the SLCP emissions reductions required domestically and internationally to achieve climate mitigation and air quality goals.



ANNEX I – SUMMARY OF SLCP ACTIONS

Strategy on Short-Lived Climate Pollutants

A holistic approach to address SCLPs that includes mitigation, science, communications, international and federal/provincial/territorial engagement dimensions

Pillar 1: Enhancing domestic mitigation

Pillar 1 : Near Term

1. **Black carbon**
   - ✓ Initiate development of federal regulations for **new stationary diesel engines**
   - ✓ **Reduce reliance on diesel** for electricity and heat in Northern, remote and Indigenous communities
   - Initiate development of federal measures for **new wood-burning appliances**
2. **Methane**
   - ✓ Advance federal regulations for **oil and gas** operations
   - ✓ Initiate actions for **landfills**
3. **Ozone**
   - ✓ Finalize **MSAPR** and non-regulatory **BLIERs** already developed
   - Approve **CAAQS for SO_2 and NO_2**
4. **HFCs**
   - ✓ Finalize **permitting and reporting system** and **Pollution Prevention Notice** and advance **regulatory measures**

Pillar 1: Medium-Longer Term

1. **Black carbon**
   - Consider options for reducing emissions from **in-use vehicles and engines (including stationary engines)**
   - Consider options for reducing emissions from **in-use wood-burning appliances**
   - Reduce reliance on **diesel generation at Government of Canada Arctic facilities**
2. **Methane**
   - **National methane strategy**
   - **Initiative on food waste reduction**
   - **Strategy for Recycling and a Circular Economy**
   - **Landfill Gas Recovery Initiative** including economic incentives and an outreach program
3. **Ozone**
   - **More stringent CAAQS** for PM2.5 and ozone
   - Consider **emission standards** for ozone precursors for industrial sectors

Pillar 2: Enhancing science and communications to broaden understanding

Pillar 2 : Near Term

1. Enhance **methane and black carbon** representation in ECCC's **earth system-based climate model and air quality models**
2. Further refine the **black carbon inventory** to support the development of priority mitigation measures
3. Update **web content** on SLCPs
4. Propose **communications products** to emphasize need to act and to communicate Canada's actions

Pillar 2 : Medium-Longer Term

1. Reconcile bottom-up and top-down **estimates of fugitive methane** and **VOC** emissions from **oil and gas** operations
2. Ongoing refinements to the **black carbon inventory** to support the development of priority mitigation measures

Pillar 3: Systematically engaging in international fora

Pillar 3 : Near Term

- ✓ Continue to take active role to promote an **HFC amendment** to the **Montreal Protocol**
- ✓ **Collaborate** with US on **methane from oil and gas**
- ✓ Co-chair the **Global Methane Initiative** and the **CCAC Working Group** for 2016-2018
- ✓ Integrate **SLCPs** into a **North American agreement** on energy and the environment
- ✓ **Agree** to a **quantitative collective goal on black carbon** under the Arctic Council

1. Highlight **SLCPs** in Canada's **NDC submission**
2. Consider adding $PM_{2.5}$ in the process of **refreshing the Canada-US Air Quality Agreement**
3. Initiate work to implement consistent national requirements for the **World Bank Zero Routine Flaring by 2030** initiative
4. Use a portion of ECCC's **Climate Finance envelope** to mobilize private sector investments through facilities within **multilateral development banks**
5. Advocate for support for SLCP-related projects at multilateral development banks that mobilize private sector investments
6. Contribute an additional $10M contribution to the CCAC Trust Fund over 5 years.
7. Support NDC implementation in Mexico and Chile through technology deployment in the oil and gas and waste sectors.
8. **Ratify** the amended **Gothenburg Protocol** to the Convention on Long-range Transboundary Air Pollution

Pillar 4: Improving coordination of ECCC and Government of Canada activities

Pillar 4 : Near Term

1. Establish an **ECCC SLCP integration committee**
   - Develop 5-year work plan
   - Refine and elaborate analysis of trade-offs
   - Work to include SLCP mitigation objectives in Departmental priorities
2. **Collaborate with OGDs** through ECCC SLCP Integration Committee to enhance the overall effectiveness of the Government of Canada's action on SLCPs

Pillar 3 : Medium-Longer Term

1. Advance **SLCP** objectives under the **CEC**
2. Host a **side event at a Montreal Protocol meeting** to profile innovative Canadian technologies that could assist in the transition from current **HFC technologies**
3. Consider extending **North American Emissions Control Area to the Arctic**
4. Lead a **project** or **case study** under the **Arctic Council** to help address data gaps or reduce emissions in Canada's North

Pillar 5: Collaborating with provinces/territories and other possible partners

Pillar 5 : Near Term

1. Collaborate with provinces/territories on SLCP mitigation priorities including through the **CCME** (e.g. diesel vehicles and engines, stationary diesel engines, wood-burning appliances, oil and gas operations, landfills, HFC refrigerants)

Pillar 5 : Medium-Longer Term

1. Explore **partnerships with municipalities** (e.g. waste, transit, wood-burning)
2. Explore **partnerships with other actors** (private sector, academia, government agencies, NGOs, Indigenous communities)

NOTES

- Near-term: 2017-2018
- Medium-longer term: series of actions that could be taken over time to drive deeper reductions

ANNEX II – CURRENT STATUS OF ECCC SCIENCE AND INTERNATIONAL ENGAGEMENT ON SLCPs

Science

The ongoing ECCC science program delivers targeted science and science advice, throughout the policy chain from the identification of policy needs and air pollutant issues, to the development and implementation of regulatory actions, to the evaluation of their efficacy in reducing atmospheric levels of pollution. This program also supports the quantification of co-benefits that can be derived from specific action on air pollutants and SLCPs (specifically for black carbon) on climate change mitigation.

Science on SLCPs is composed of: 1) identification of emission sources and quantification of emission rates; 2) measurement of ambient levels of SLCPs; 3) study of the atmospheric processes with respect to different SLCPs; 4) development and application of climate and air quality models to assess the impact of changes in SLCP emissions on ambient levels of SLCPs and radiative forcing; and 5) characterization of SLCP emissions from mobile sources.

Identification of SLCP emission sources

Monitoring allows the relative importance of various sources for different pollutants to be assessed, as well as tracking how their relative contributions to total emissions evolve over time.

Emissions of all SLCPs (or their precursors) are quantified annually at the national level and for different sectors. National and provincial/territorial emissions of methane and HFCs are included in Canada's National Inventory of GHG Sources and Sinks (NIR). Ozone precursors are included in Canada's Air Pollutant Emissions Inventory annual report (APEI). Canada's first Black Carbon Inventory was released in 2015 for the 2013 year, and is published annually as part of Arctic Council commitments. All reports are submitted to the UN (UNFCCC or UNECE), and are also available via the Open Government data portal. The NIR and APEI follow international reporting formats, making them comparable to reports of other countries that use the same reporting formats.

Current scientific work on monitoring emissions includes the development and improvement of black carbon and methane emission estimates and emission factors, as well as targeted projects focused on characterization of transportation and oil and gas emissions. Challenges include quantifying regional and fugitive sources, refining emission rates by technologies and operating conditions, and quantifying emissions from sources with skewed emission distributions.

Monitoring of ambient levels of SLCPs

ECCC operates the long-term measurement networks for atmospheric levels of SLCPs (including methane, black carbon and ozone) to determine long-term trends and the atmospheric response to changes in emissions over time. As these pollutants also undergo long range transport, the monitoring program also contributes to understanding the influence of regional to global sources on air quality and climate. These measurements take place at sentinel sites across Canada, and form the basis for the development of baselines against which to assess atmospheric change and to verify the efficacy of mitigation policies. ECCC's long-term measurements (as well as those of other nations, and combined with satellite observations) are also applied to characterize emissions of SLCPs at a regional-scale, providing a top-down approach (i.e.: observations based) to improving emissions estimates.

The work also includes analysis of the data to understand the impacts of domestic and international sources on the long-term trends. ECCC also undertakes ongoing black carbon method inter-comparison work with international partners to better integrate results across programs, and between atmospheric and emission source methodologies. ECCC is also working to better understand the contribution of local emission sources (including increased ship traffic) to air pollution in northern communities.

Atmospheric processes research and development and application of air quality and climate models

The processes studies effort focuses on improving our scientific understanding of atmospheric and terrestrial processes affecting SLCPs, and the resulting impact on air quality and climate. This scientific knowledge will subsequently inform model development and parameterization of these processes in ECCC's models, improving our ability to estimate the climate response to these pollutants individually and as a group, and thereby our ability to predict Canadian and global climate change to inform domestic and international mitigation plans. This work also contributes to improved air quality projections to quantify short-term air quality benefits derived from reductions in emissions of SLCPs, informing the development of policy.

Processes research and modelling enables the development of impact assessments of the various sources/types of pollutants. Current work includes: studying the atmospheric transport pathways and chemical transformations related to SLCPs to improve air quality and climate predictions; quantifying the magnitudes of aggregate regional and area sources; daily air quality forecasts and air quality scenario analyses, which can discern the relative contribution of biomass burning versus anthropogenic emissions to black carbon levels; and Canadian Earth System Model (CanESM) simulations to evaluate the climate effects of SLCP emissions from particular sectors and regions globally. Challenges include regional-scale climate influence on air quality and weather and precipitation, as well as the impact of SLCPs on human health and ecosystems.

Characterization of SLCP mobile source emissions

Efforts to characterize black carbon emissions from mobile sources focus on improving understanding of vehicle/engine operational conditions and fuel characteristics that impact quantity and formation of black carbon. This work will subsequently inform mitigation decisions related to the reduction of black carbon emissions from on- and non-road mobile source sectors, including marine vessels.

Continental and international engagement

Canada is currently engaged actively in a number of international fora addressing SLCPs. This existing engagement provides a starting point for considering ways in which Canada's international action on SLCPs can be better integrated with domestic science and mitigation priorities.

Arctic Council

The Arctic Council was one of the first fora to recognize the importance of taking action to address SLCPs. Its early work focused on scientific contributions, confirming the substantially disproportionate impact that SLCPs have on the Arctic and concluding that reductions would lead to near-term climate, health and economic benefits in the Arctic, while also contributing to the global effort to limit the increase in the global average temperature.

ECCC scientists actively participate in the Arctic Council Arctic Monitoring and Assessment Program's (AMAP) Expert Group on Short-Lived Climate Forcers. This will enhance targeted science and monitoring regarding Arctic climate responses to SLCPs and builds on ECCC contributions to the 2015 assessments through the participation of climate scientists in the ongoing analysis of observations and application of climate models under AMAP.

Canada's current policy engagement on SLCPs under the Arctic Council builds on the work of the Task Force on Short-lived Climate Forcers (TF SLCF) under Denmark's 2009-2011 and Sweden's 2011-2013 Chairmanships. This Task Force produced two sets of recommendations that have informed the Arctic Council's subsequent SLCP work.

Addressing SLCPs affecting the Arctic was a key priority for Canada's 2013-2015 Chairmanship, during which the Canadian co-chaired Task Force for Action on Black Carbon and Methane (TFBCM) was established. The TFBCM's deliverable for 2013-2015 was *Enhanced Black Carbon and Methane Reductions: An Arctic Council Framework for Action*, adopted by

Arctic Ministers at the April 2015 Ministerial. The *Framework* commits Arctic States and participating Observer States to enhanced, ambitious national (and collective) action plans or mitigation strategies, as well as to improve science and inventories, and to exercise leadership by working with Arctic Council Observer States and others to reduce emissions produced beyond the borders of Arctic States. It also includes commitments to submit biennial national reports on emissions and action, and to submit black carbon inventories to the United National Economic Commission for Europe's (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP). As part of Canada's commitment to addressing SLCPs under the Arctic Council, the federal government submitted its first Black Carbon Inventory to the UNECE in February 2015 and its first *National Black Carbon and Methane Report* to the Arctic Council in December 2015.

An Expert Group was created under the Framework to support the implementation of the Framework, including by reviewing and synthesizing national reports, and delivering a summary of progress and recommendations to Arctic Council Ministers. ECCC represents Canada in the Expert Group on Black Carbon and Methane (EGBCM) and is working with Arctic partners to deliver on these commitments. The EGBCM recently published its first Summary of Progress and Recommendations, which was adopted during the Tenth Ministerial Meeting of the Arctic Council in May 2017. The report is the first Pan-Arctic report on collective progress to reduce black carbon and methane emissions by the Arctic States and several Observer States. The report recommends that Arctic States collectively reduce their black carbon emissions by at least 25 – 33 percent below 2013 levels by 2025. The report also makes 12 recommendations for enhanced policy action focused on four sectors where large near-term gains are possible: diesel-powered mobile sources; methane leakage, venting and flaring in the oil and gas sector; residential biomass combustion; and solid waste disposal.

Other key elements of the Arctic Council Framework include continued monitoring, research and scientific reporting; increasing awareness; and, the carrying out of project and sector-based activities. These are activities ECCC is already actively engaged in, or in some cases leading, in other international fora, including the UNECE, UNFCCC, CCAC and the WMO. Canada's engagement in the Arctic Council's work on SLCPs could work to enhance the Arctic perspective on climate and air quality discussions in other international fora, and leverage existing expertise and opportunities found in these other fora while avoiding duplicative efforts.

The Arctic Council's Arctic Contaminants Action Program's (ACAP) Short-lived Climate Pollutants Expert Group (SLCP EG) is carrying out ongoing project-based science and mitigation work, including the Black Carbon Case Studies Platform, which showcases work undertaken by Arctic States to improve black carbon science and enhance mitigation. Efforts are underway to achieve a pan-Arctic scope for the Black Carbon Case Studies Platform.

Climate and Clean Air Coalition

Canada is a founding member of the Climate and Clean Air Coalition (CCAC) and work under this forum has been a Canadian priority since 2012.

Canada recently announced funding of $25M for SLCP mitigation action with key partner countries, including for projects that aim to reduce black carbon emissions to benefit the Arctic. This includes $10M for the CCAC Trust Fund to support programs and initiatives in developing countries, bringing Canada's total contribution to the CCAC Trust Fund to $23M. ECCC will work to ensure that these funds align with, and build on domestic and international policy imperatives, science and technical expertise, and Canadian products and services which can help foster reductions in SLCPs.

Through a series of sector-based initiatives, the CCAC seeks to promote near-term reductions of SLCPs worldwide (including across developed and developing contexts). Canada co-leads the implementation of initiatives on black carbon from heavy-duty diesel vehicles and engines, the promotion of HFC alternative technologies and SLCP mitigation from agriculture and municipal solid waste. Canada is also a Partner in the CCAC's Oil and Gas Initiative—chairing the Technology Demonstration Component and acting as lead Partner of the Methane Partnership—which focuses on venting and flaring in the oil and gas sector in Africa, Latin America and Asia.

Canada is the co-chair of the CCAC Working Group for 2016-2018. The Working Group is the operational decision making body of the Coalition which meets twice a year, as well as for short preparatory meetings in advance of the High Level Assembly of Ministers and Heads of non-state Partner organizations. The Working Group makes decisions on such things as approving new partners, approving new initiatives, funding for new projects, and formulating recommendations to the High Level Assembly. Canada is also a member of the CCAC Steering Committee and Chair of the Communications Working Group.

Global Methane Initiative

The Global Methane Initiative (GMI) is a voluntary international partnership which addresses fugitive emissions of methane through the development, deployment and diffusion of clean technologies. Since 2004, it has mobilized a network of over 1,300 public and private sector organizations, and leveraged nearly $480 million in investment from private companies and financial institutions. The GMI is active in the five key methane-emitting sectors, which include oil and gas, coal mining, municipal waste, wastewater and agriculture. Its primary activities include building national and regional capacity for technical and policy approaches to methane mitigation, sector-specific assessments of project opportunities, developing and disseminating best practices, and supporting development of methane action plans.

Canada has been an active member of the GMI since 2005. Canada has funded a variety of projects over the years and participated actively in the Steering Committee and subcommittees. Canada is also co-chairing the Global Methane Initiative for the period 2016-2018, and for which new terms of reference were announced in March 2016. As part of this role, Canada is responsible for providing strategic leadership to the Steering Committee and hosting at least one annual meeting.

As both Co-Chair of the CCAC Working Group and the GMI Steering Committee, Canada is well positioned to support the increasing collaboration between the CCAC and the GMI, and create synergy between their complementary mandates.

Gothenburg Protocol

The Gothenburg Protocol to the UNECE's LRTAP Convention was established in 1999 to address acid rain, smog, ozone and the degradation of water bodies. Initially focusing on sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia and volatile organic compounds (VOCs), the Protocol was amended in 2012 to include new commitments for 2020 as well as black carbon as a component of fine particulate matter ($PM_{2.5}$). Parties are encouraged to prioritize $PM_{2.5}$ measures that will also significantly reduce emissions of black carbon. The LRTAP Convention also developed the initial guidance documents for black carbon emissions inventories.

Current work under the Gothenburg Protocol includes ongoing discussions and negotiations on improving the procedures by which Parties may adjust their emissions reduction targets, and the preparation of the 2016 LRTAP Assessment Report, which assesses the Convention's impacts throughout the UNECE region and will inform subsequent policy discussions under the Convention.

Canada is a signatory to the Gothenburg Protocol, and has ratified other Protocols under the Convention that will be subsumed under the amended Gothenburg Protocol when it comes into force (requires ratification by two thirds of Parties to the original Protocol). The Protocol contains flexibilities to facilitate ratification. Canadian commitments, for example, are to be indicative and automatically incorporated. At present, Canada is working to ratify the Gothenburg Protocol.

Canada and the U.S. regularly work closely within the LRTAP Convention to express North American interests. The U.S. ratified the amended Gothenburg Protocol in January 2017. Sweden was the first to ratify the amended Protocol in November 2015. There is a current initiative by Parties and the LRTAP Convention to accelerate ratification of the amended protocol (both in the Eastern European Caucasus and Central European (EECCA) region and in North America.

Canada-U.S. Air Quality Agreement

The Canada-United States Air Quality Agreement seeks to control and reduce transboundary air pollution between Canada and the US, originally addressing emissions of SO_2 and nitrogen dioxide (NO_2) that cause acid rain. In 2000, the Agreement was amended by adding the Ozone Annex to address emissions of pollutants that lead to the formation of ground-level ozone, namely NO_x and VOCs. The Agreement has led to significant decreases in air pollutant emissions responsible for acid rain and smog on both sides of the border.

Both countries met their respective commitments under the Agreement a number of years ago. Over the past two years, the two countries have been exploring the possibility of updating and strengthening the Agreement, including renewing the commitments and possibly integrating $PM_{2.5}$ into the Agreement.

Commission for Environmental Cooperation

The Commission for Environmental Cooperation (CEC) is a Canada-U.S.-Mexico tri-lateral forum to facilitate environmental protection in an increasingly integrated North America and may achieve a heightened profile following COP21.

In its 2015-2020 Strategic Plan for Climate Change Mitigation, the CEC has prioritized enhancing national efforts to address SLCPs as part of broader approaches to climate change. The Strategic Plan also supports emerging areas of scientific research on SLCPs as well as a focus on indigenous dimensions, enhancing information-sharing, capacity-building and communication among Canada, the U.S. and Mexico.

Recent work on SLCPs under the CEC has focused on documenting and comparing emission estimation methodologies for black carbon and co-pollutants, as well as on climate change modeling and assessment, waste diversion and transportation sector emissions reductions.

Montreal Protocol

The Montreal Protocol is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances that are responsible for ozone depletion. The Montreal Protocol has achieved unparalleled success in eliminating these substances worldwide over the past 30 years.

HFCs were developed as replacements for ozone-depleting substances being phased out under the Montreal Protocol. Canada, along with Mexico and the U.S., began promoting the phase-down of HFCs under the Montreal Protocol in 2009. In October 2016, Parties to the Montreal Protocol adopted the Kigali amendment to phase down the consumption and production of HFCs.

Implementation of the Kigali amendment could avoid up to 0.5 degrees Celsius of warming by the end of the century, thus making a significant contribution to the objectives of the Paris Agreement. HFC emissions will continue to be reported and accounted for under the United Nations Framework Convention on Climate Change (UNFCCC).

International Maritime Organization (IMO)

The IMO is the UN agency responsible for setting global standards applicable to international shipping, including environmental standards. Transport Canada leads Canada's delegation at the IMO and is supported by ECCC through the provision of expert technical and policy advice relating to air pollutant and GHG emissions from ships. ECCC is contributing emissions testing expertise to a multi-year IMO work plan, to assess the impacts on the Arctic of black carbon emissions from ships. Other SLCPs being studied by ECCC and under discussion at the IMO include fugitive VOCs from tankers.

ECCC – NOAA collaboration in aerosols and GHG monitoring over North America

The two institutions have a long (multi-decadal) history of coordinated research and monitoring for GHGs and aerosols (including black carbon) which will continue to provide observations and insights regarding source influences, necessary to assess the efficacy of mitigation actions and to support ongoing development and evaluation of climate and air quality models.

Active participation in the international black carbon method development and intercomparison studies for North America and Europe

ECCC's Science and Technology Branch participates in several international fora including the World Meteorological Organization's Global Atmosphere Watch Program, ECCC-NOAA bilateral collaborations, and individual research collaborations, which support the advancement of developing and testing of observational methods and calibration protocols for the monitoring of atmospheric concentrations.

ANNEX III – ENHANCED DOMESTIC MITIGATION

This Annex provides additional detail on potential near and medium-longer term actions described in the main body of the Strategy.

BLACK CARBON

Collaborate with provincial and territorial partners to reduce emissions from in-use diesel fleets

Despite emissions reductions that have resulted from stringent federal regulations since 2004 to address air pollutants from newly manufactured on- and off-road diesel vehicles and engines, and regulatory and program measures focused on existing vehicles in some provinces, the sector continues to be Canada's largest source of black carbon emissions. Turnover of the in-use fleet – still dominated by engines pre-dating the most recent emissions standards – is slow.

Once a vehicle is sold at the retail level, provincial/territorial governments have jurisdiction over its environmental performance within their respective boundaries, and along with municipalities have the most policy levers to support action on existing fleets. The Government of Canada could explore opportunities with provinces and territories to further reduce emissions from these sources.

The U.S. EPA estimates that retrofitting on-road vehicles with diesel particulate filters is one of the most cost-effective ways to reduce diesel emissions. Estimated costs range from US$8,000-$20,000 depending on vehicle type, with the potential to reduce black carbon emissions by up to 99%[9]. It has also estimated that for every dollar invested in reducing diesel exhaust, a community may achieve an estimated $13 in public health benefits. For every dollar the EPA invests in its Clean Diesel Program, as many as $3 is invested by other government agencies, private organizations, industry and non-profit organizations.

In 2012, the World Health Organization (WHO) classified diesel exhaust as carcinogenic to humans[10]. This conclusion was supported by Health Canada's Diesel Exhaust Health Risk Assessment, released in March 2016, which links exposure to diesel exhaust to 700 premature deaths, as well as to annual morbidity outcomes, and notes that mitigation strategies that target diesel engines would significantly reduce health risks to Canadians. Health Canada also completed an analysis of the potential air quality and health benefits of a widespread program to retrofit diesel engines, and released a final report in 2016.

Implement a multi-pronged approach to reduce emissions from wood-burning appliances

Residential wood combustion is the second most significant source of black carbon in Canada, accounting for 28% of estimated emissions in 2014. It is also one of the largest sources of particulate matter, VOCs and other toxics such as polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, and a key contributor to wintertime smog. There are approximately 3.6 million wood-burning appliances in Canada[11]. A large fraction of emissions come from older appliances. Emissions from this source are also of significance in Canada's North, where use of wood burning appliances is increasing due to biomass strategies that promote the use of wood for space heating as a means of reducing reliance on imported fossil fuels.

Some provinces regulate the sale of new wood-burning appliances, while some municipalities have by-laws relating to residential wood combustion, including bans on certain types of appliances. However, regulations largely require conformity with U.S. EPA (1988) standards or Canadian Standards Association (CSA B415) codes, which have become dated (the EPA released strengtened

[9] US EPA Report to Congress on Black Carbon (2012).

[10] WHO -IARC press release, IARC: Diesel engine exhaust carcinogenic, 12 June 2012.

[11] Environment Canada (2005). Impact of Residential Wood Stove Replacement on Air Emissions in Canada.

wood combustion standards in 2015). Non-certified appliances are still sold in Canada, and there is potential for future growth in sales of imported, lower cost, non-certified models. Measures to address emissions from existing sources are limited to wood stove change-out programs or rebates for certain new appliances in some provinces and territories.

A mix of initiatives targeting both new and existing wood-burning appliances could be effective in reducing emissions from this source. Federal regulations could ensure consistent national standards in Canada. Minor amendments would be needed to CEPA 1999 in order to allow regulating manufacturers and importers (rather than individual households). However, regulatory development could be done concurrently with CEPA amendments. Replacing an inefficient wood-burning appliance with a modern one can reduce $PM_{2.5}$ emissions by up to 70% on a per unit basis[12], with co-benefits for methane and CO_2[13].

Implement measures to reduce emissions from stationary diesel engines

Stationary diesel engines are used in many applications throughout Canada. Many of Canada's northern communities rely on stationary diesel engines for electricity generation, including all communities in Nunavut, and many remote communities in the Northwest Territories, Quebec, Newfoundland and Labrador, Ontario, British Columbia, and Manitoba. Diesel engine exhaust has been classified as carcinogenic by the World Health Organization (WHO). The prevalent use of diesel engines in these communities is a concern for local air quality, where engines operate 24 hours a day, often in close proximity to homes and schools.

There are no federal regulations and few provincial measures targeting $PM_{2.5}$ emissions from stationary engines. Budget 2016 provided funding to begin development of federal regulations that will implement performance standards for new stationary engines (as is done in the U.S.). Retrofits and replacements to reduce emissions from existing sources could also be considered.

[12] Arctic Council (2014). Reduction of Black Carbon Emissions from Residential Wood Combustion in the Arctic Black Carbon Inventory, Abatement Instruments and Measures.

[13] US Environmental Protection Agency, Report to Congress on Black Carbon (2012) p. 210.

The federal *Sulphur in Diesel Fuel Regulations* presently limit sulphur in diesel fuel to 15 ppm and 1000 ppm for use in small and large stationary diesel engines, respectively. It is possible that the limit will need to be lowered for large stationary engines to enable tighter emission standards for these engines.

Reduce emissions from flaring during oil and gas production

Endorsement of the World Bank Zero Routine Flaring by 2030 initiative will help to reduce black carbon emissions resulting from routine flaring during oil production operations. This initiative requires that participating governments provide a legal, regulatory, investment, and operating environment that provides oil companies the confidence and incentive for investing in flare elimination solutions. The federal government will work with provincial/territorial governments to implement consistent requirements across the country. Canada will encourage federal, provincial and territorial oil and gas regulators to continue efforts towards eliminating routine flaring, recognizing flaring for certain specific circumstances, such as safety or emergency reasons, may still need to occur. Specifically, Canada will encourage federal, provincial and territorial oil and gas regulators in efforts to ensure gas conservation regulatory requirements are robust and achieve no routine flaring. The use of Best Available Technology Economically Achievable (BATEA) is encouraged to eliminate flaring. A number of regulators have already taken such action, such as: existing and proposed legislation and policies for solution gas flaring management in Alberta and British Columbia, as well as efforts under the Frontier and Offshore Regulatory Renewal Initiative between the Canada-Newfoundland and Labrador Offshore Petroleum Board, the Canada-Nova Scotia Offshore Petroleum Board and the National Energy Board. This measure will reduce routine flaring during oil production and related emissions of black carbon, CO_2 and other pollutants.

Reduce emissions from marine sources

The marine sector accounts for 6.9% of black carbon emissions. Though not a large contributor nationally, recent analysis by ECCC found that, in 2010, ships sailing in the Canadian Arctic contributed up to 10% of local black carbon emissions, and that emissions may increase to as much as 40% locally by 2030 as levels of Arctic shipping traffic increase. The North American Emission Control Area (ECA) implemented domestically under the *Canada Shipping Act* requires that ships sailing within 200 nautical miles of the Canadian shoreline burn a fuel with a sulphur content no greater than 0.1%. Throughout Canada and the United States, the ECA is expected to lead to a 74% reduction in $PM_{2.5}$ emissions below levels in 2020 absent the ECA. The ECA does not extend into Canada's Arctic.

With expertise and support from ECCC, Transport Canada (TC) regulates emissions from the marine sector and ECCC has been working with TC to reduce marine emissions. In collaboration with TC, ECCC plans to continue to advance its multi-year work plan to assess the potential impacts of current and future-forecasted shipping emissions on Arctic air quality, human health and ecosystems. ECCC will also continue to provide expert technical and policy contributions to an international study on marine emissions of black carbon.

Reduce emissions from Government of Canada facilities in the Arctic

The Government of Canada operates a number of facilities in the Arctic that rely on diesel fuel for electricity generation, including the Eureka weather station and Canadian Forces Station Alert on Ellesmere Island, as well as number of other facilities operated by Parks Canada, Fisheries and Oceans Canada and Natural Resources Canada. Diesel generation at these facilities is expensive and a source of black carbon and other emissions.

Some of these facilities are located in northern regions where solar power is feasible due to high amounts of sunlight in the spring and summer months and low levels of annual precipitation and cloud cover. For example, Eureka, Nunavut, with an average of over 2,000 hours of sunshine per year, has an annual solar photovoltaic (PV) potential similar to Victoria, B.C. or St. John's, NL. During the month of May, Eureka, NU has higher solar PV potential than any major city in Canada[14].

Investment in solar power to supplement diesel generation at the Eureka weather station and other Government of Canada facilities in the North would reduce fuel-use and lower emissions from diesel combustion. It would also offer the potential for long term cost savings, while demonstrating technical feasibility and national leadership for the advancement of renewable energy technologies for off-grid and remote applications across Canada.

METHANE

Implement regulations to reduce methane from oil and gas operations

The oil and gas sector accounted for 44% of Canada's methane emissions in 2014, largely from venting and fugitive sources, which accounted for 42% of the national total. Alberta and Saskatchewan produce more than 90% of Canada's oil and gas methane emissions.

In the Pan-Canadian Framework, Canada committed to work with provinces and territories to reduce methane emissions from the oil and gas sector by 40-45 percent below 2012 levels by 2025. In 2016, Canada undertook over 150 hours of consultations with partners and stakeholders, including provinces, on the development of the proposed regulatory approach. In May 2017, Canada announced proposed regulations to reduce methane emissions from Canada's oil and gas sector, which will also reduce air pollutants (volatile organic compounds) as a co-benefit.

British Columbia, Alberta and Saskatchewan have also implemented measures to reduce venting and fugitive emissions from oil and gas operations. Alberta recently announced a new goal to cut methane emissions from oil and gas by 45% by 2025, and also is proposing the development of specific requirements for new facilities as well as a voluntary initiative aimed at reducing venting and fugitive emissions from existing facilities. In their recently released Climate Leadership Plan, British Columbia set a target to reduce methane emissions from oil and gas extraction and processing infrastructure built before January 1, 2015, by 45 percent by 2025. British Columbia will also be offering incentives to reduce emissions from applications built between 2015 and 2018 with a Clean Infrastructure Royalty credit program, as well as a new offset protocol, and plans to establish standards for the development of projects after 2018-2020 onwards, including mandatory leak detection and repair. All these measures would help to address this mitigation gap, while generating co-benefits for VOCs, which contribute to ground-level ozone and of which many are toxic to humans. Methane and VOCs are released by many of the same sources in the oil and gas sector.

Implement a landfill gas recovery initiative

The waste sector accounts for approximately 26% of national methane emissions, most of which come from solid waste landfills (approximately 24% of national total). There are no federal measures addressing waste, other than eligibility of solid waste projects for funding under some federal infrastructure programs. Though some provincial governments have regulations that require the capture of landfill gases from their largest landfills and others have programs to incent landfill gas recovery, these measures vary significantly in scope, stringency and results.

Methane from municipal waste landfills could be addressed through a landfill gas (LFG) recovery initiative that would involve complementary federal and provincial measures. A number of options were discussed under the Mitigation Working Group, under the Pan-Canadian Framework development process. Budget 2016 also provided funding to begin development of federal regulations or other control measures identified in consultation with provinces and territories to reduce methane from landfills.

[14] Natural Resources Canada, Photovoltaic Potential, http://pv.rncan.gc.ca

Actions would aim to increase the 2012 capture rate for LFG from roughly 36% to 51%, in line with the U.S. capture rate (57%), and achieve a reduction of up to 5.5[15] MT CO_2e per year. A focus on utilization of landfill gas could yield approximately 4.4 Mt CO_2e in reductions, with net annual revenues. Further analysis is needed to assess black carbon emissions from landfill gas flaring and to determine best practices to mitigate these emissions and consultations with provinces/ territories and other stakeholders to determine the appropriate mix of provincial and federal measures and incentives to deliver reductions.

HYDROFLUOROCARBONS (HFCs)

Implement regulatory measures to control HFC consumption

HFCs are increasingly being used as substitutes to ozone-depleting substances in the refrigeration and air-conditioning sectors, as foam blowing agents and, to a lesser extent, in aerosol products and fire-extinguishing equipment. A suite of federal and provincial/territorial regulations control ozone-depleting substances and HFCs once they are in use in refrigeration, air-conditioning and fire-extinguishing systems. However, there are no measures that limit the use of HFCs in these sectors. In Canada, total HFC emissions are projected to more than triple between 2013 and 2030 in the absence of further action.

Federal measures finalized in spring 2016 establish a **permitting and reporting system** for the import, export and manufacture of HFCs. In addition, a notice requiring the preparation and implementation of **pollution prevention plans** for the sound management of end-of-life halocarbon refrigerants, which include HFCs, will contribute to preventing emissions of HFCs at end-of-life.

Comprehensive regulatory measures proposed in 2016 would avoid emissions of HFCs through a phase-down of the manufacture, import and export of HFCs, allowing Canada to comply with its Montreal Protocol HFC obligations and to ratify the Kigali amendment. The regulation will also include a prohibition on the manufacture and import of specific products and equipment using HFCs, such as those used in refrigeration, air conditioning, foams and aerosols. These measures could be complemented by pursuing work with other government departments to ensure energy efficiency programs and regulations are well coordinated, and by engaging and collaborating with other actors to communicate the importance of technology development and implementation related to HFCs.

Encourage transitions to climate-friendly alternatives

Additional actions could be taken to encourage the replacement of HFC systems and products with more climate-friendly alternatives, where feasible.

In the U.S.-Canada Joint Statement on Climate, Energy and Arctic Leadership, the Government of Canada committed to "leading by example" by updating public procurement processes to transition away from high global warming potential HFCs, whenever feasible, through government purchase of more sustainable and greener equipment and products. This could include promoting the procurement of refrigeration, air-conditioning and fire-extinguishing systems, as well as of manufactured items such as foam products in office furniture and construction insulation, that are HFC-free or climate-friendly. This initiative also aligns with Canada's commitments under the CCAC to promote public procurement of climate-friendly low-global warming potential alternatives whenever feasible, and to gradually transition to equipment that uses more sustainable alternatives to high-global warming potential HFCs. ECCC could act as a center of expertise for this initiative.

Implementation of these initiatives would also encourage development of alternative technologies.

[15] With revised Global Warming potential value of 25 from 21 (IPCC 4th Assessment Report), the estimated amount of additional methane emission reduction is 6.5 Mt eCO_2

OZONE

Finalize implementation of proposed instruments for industrial sectors

In the near term, as part of the continued implementation of the Air Quality Management System (AQMS), ECCC will finalize proposed instruments published in May 2016 for the aluminum, steel, iron ore pellets, potash, pulp and paper, and base metals smelters sectors and for cross-sectoral turbines. Under the Air Management Committee, ECCC will continue to collaborate with provinces and territories to develop a new CAAQS for NO_2.

Building on this, there may be scope to set more ambitious ambient air quality standards for $PM_{2.5}$ and ozone, as some aspects of current standards are not as stringent as levels proposed by the World Health Organization (WHO). In addition, ECCC is working to bring forward additional emissions standards for key pollutants and industrial sectors where emissions and impacts on local air quality can be very significant (e.g. petroleum refining, coal-fired power plants).

ALBERTA HAIL SUPPRESSION PROJECT 2011
DAILY SUMMARY REPORTS
WEEK No.1

Date	Weather	Activities Summary
June 01, Wednesday	A deep upper level trough was positioned over the Pacific Northwest. Southwesterly upper level jet energy was concentrated over southern AB. Several potent shortwave troughs passed through the project area, and the atmosphere was moderately unstable. The region saw low freezing levels along with excellent speed shear. Weak echoes began to form over Banff and Canmore during the early morning hours. Then, during the afternoon hours, stronger cells developed W of Sundre and moved from W to E across the project area. In the evening, another band of moderate convection moved over Rocky MH. Max titan cell= 11.0 km top, 62 max dBz, 64.0 max VIL Tmax YC = 16.6C and 3.4mm of rain. Tmax QF = 17.0C and no data. Tmax Radar = 16.3C and 31.5mm of rain.	No aircraft operations, awaiting clearance to fly from Transport Canada. Work continued on the radar. Adjustments were made to the radar display and TITAN programming.
June 02, Thursday	The trough over the Pacific Northwest moved E which helped push a few shortwaves through central AB. The atmosphere was moderately unstable with weak shear. Positive vorticity advection was the main trigger mechanism. Cumulus clouds started forming over the mountains in the morning. Slightly better convection began to form in the early afternoon but remained outside of the project area. Then around 00z, a few cells began to make their way off the foothills and into the project area. A cluster of convection formed over the Calgary metropolitan area during the early evening hours. The strongest storms of the day formed NW of Sundre and north of Rocky MH. Moderately strong convection was observed through the late evening hours. Max titan cell= 9.1 km top, 60 max dBz, 41.4 max VIL Tmax YC = 17.0C and no rain. Tmax QF = 19.0C and no rain. Tmax Radar = 17.6C and a trace of rain.	The radar software parameters and settings were adjusted and updated. HS3 and HS4 preformed a ferry flight from YYC to YQF and each aircraft tested the seeding equipment. All equipment functioned properly. HS1 patrolled north of Calgary. They fired 1BIP and 2 EJ to test the seeding equipment which functioned properly. HS2 flew a patrol flight northwest of Calgary. Pilots encountered data logger problems, and landed at the Olds-Didsbury airport to troubleshoot. The aircraft then performed a ferry flight from the Olds-Didsbury airport to YYC. HS1 was launched to a growing cell over northern YYC at 0042Z (06/03). The flight was airborne at 0107Z and began patrolling over northern YYC. At 0129Z HS1 report embedded conditions with no liquid water while patrolling N of Cochrane. HS1 eventually found liquid water NW of Sundre and started seeding at 0144Z. The flight only seeded for a short period of time before returning to patrol. HS1 then RTB at 0211Z. HS2 performed a patrol flight over northern YYC. The aircraft was launched at 0047Z (06/03). Pilots reported only minimal inflow and growth over YYC, so the aircraft just patrolled the area. The flight RTB at 0147Z. <u>Flight Summary</u>

		HS3: 2000-2037Z; 1 BIP, 3 EJ, ferry flight. HS4: 2001-2047Z; 1 BIP, 1 EJ, ferry flight. HS1: 2112-2230Z; 1 BIP, 2 EJ, patrol Airdrie. HS2: 2142-2230Z; no seeding, patrol Cochrane. HS2: 0005 (06/03)-0044Z (06/03); 1 BIP, 2 EJ, ferry flight. HS1: 0050 (06/03)-0230Z (06/03); 2 EJ; patrolled N of Cochrane and NW of Sundre, Storm #1 NW of Sundre. HS2: 0053 (06/03)-0200 (06/03); no seeding; patrolled near Airdrie.
June 03, Friday	A cold front moved south through the area, slowing down and stalling as the day went on. The atmosphere was slightly unstable with low freezing levels. The sounding was marginal for hail. Weak thunderstorms began after 19z, forming off the foothills and moving into the project area. The storms had high reflectivity and VIL during their maturing stage, but quickly weakened and became embedded. Another round of strong thunderstorms began around 0030Z (06/04) as frontal passage occurred over the region. These storms also pulsed down after a short period of time. As cool temperatures set in, stratiform rain developed overnight. Max titan cell= 9.9 km top, 58 max dBz, 41.1 max VIL Tmax YC = 17.8C and 1.0 mm of rain. Tmax QF = 14.2C and 1.4 mm of rain. Tmax Radar = 14.6C and 0.7 mm or rain.	HS2 was launched at 1846Z to patrol cells near YYC, and also to test Airlink. At 1907Z, HS2 was airborne, and reported bases around 8.0kft, rain, and poorly defined bases. At 1934Z, HS2 began seeding over southern YYC after encountering marginal inflow. At 1955Z, HS2 began seeding the northern end of the storm. As the storm began to weaken, HS2 was directed to a cluster of storms to the NW at 2008Z. Bases were 7.0kft and more defined on this storm. HS2 continued to seed the storm until 2045Z, when they had to move further NW as directed by ATC. HS2 then attempted to find inflow along the line headed for Calgary, but the line dissipated so at 2124Z HS2 RTB. At 2247Z, HS1 launched for Olds for Airlink testing. They were airborne at 2308Z, and RTB to YYC after Airlink continued to encounter problems. At 0012Z, HS1 and HS2 were launched SW of Calgary. HS1 was directed to top at 15kft, HS2 to 7.5kft. HS1 was airborne at 0031Z (06/04) and W for the cell NW of Okotoks. Bases were observed at 5.5kft. HS2 was airborne at 0032Z for the same cell. Due to the low bases and proximity to the foothills, HS2 RTB at 0049Z. The cells quickly dissipated well below hail criteria, and HS1 RTB at 0111Z. <u>Flight Summary</u> HS2: 1855-2145Z; 116 min acetone generator time; #1 over YYC and #2 NW of YYC. HS1: 2253-2339Z; no seeding, Airlink testing. HS2: 0016 (06/04)-0105Z (06/04); no seeding; patrol NW of Okotoks. HS1: 0018 (06/04)-0126Z (06/04); no seeding; patrol NW of Okotoks.
June 04, Saturday	A cold front was positioned over southern Alberta. The area was experiencing weak cold advection aloft. The atmosphere was slightly unstable for most of the day. Southern Alberta saw clearing early in the day. No upper level triggers were present but a quasistationary warm front was draped over the northeastern part of the region overnight. Mist and light rain showers fell in the morning. The stratiform cloud cover thinned out during the afternoon.	No aircraft operations.

	Cumulus clouds were observed during the late afternoon hours. Weak convection was present over the YQF area during the evening. The strongest cells of the day moved through near Lacombe around 10z. Small hail was reported near Lacombe. Max titan cell= 8.4 km top, 64 max dBz, 43.2 max VIL Tmax YC = 17.0C and 1.0 mm of rain. Tmax QF = 14.9C and 1.0 mm of rain Tmax Radar = 16.5C and 0.5 mm of rain.	

ALBERTA HAIL SUPPRESSION PROJECT 2011
DAILY SUMMARY REPORTS
WEEK No. 2

Date	Weather	Activities Summary
June 05, Sunday	The upper level jet was located in Saskatchewan and no upper or midlevel triggers were present. Soundings indicated that atmospheric instability was moderate with good speed shear. A weak stationary front was located over southern Alberta. Morning fog indicated high amount of low level moisture. Cloud cover was diminishing during the afternoon allowing for increased surface heating. The surface boundary moved from N to S during the afternoon creating marginal hail storms from Sundre to Calgary along the foothills. The most intense cell developed over Cochrane and moved through Airdrie. Convection became weak and embedded after midnight. Light to moderate rain continued through the morning with low echo tops. Max cell top: 7.5km, 62 max dBz, 27.9 max VIL Tmax YC = 20.2C and 0.2mm of rain. Tmax QF = 18.0C and a trace of rain. Tmax Radar = 19.0C and 2.4mm of rain.	HS3 was launched at 1830Z to NW of Panoka. At 1903Z, the aircraft was airborne. HS3 began top seeding storm #1 NW of Panoka at 1916Z. By 1923Z, pilots reported weak growth with no seedable targets; seeding was stopped and the aircraft patrolled the area. At 1931Z, HS3 was repositioned to growth upwind of Red Deer. They began seeding storm #2 NW of Red Deer at 1939Z with pockets of moderate liquid water and embedded cumulus towers. At 2007Z, the aircraft was repositioned northwest of Calgary for new growth which was determined to be low-topped and not seedable. HS3 was directed to RTB at 2043Z and landed at YQF at 2103Z. HS4 was launched at 1858Z for development NW of Red Deer. The aircraft was airborne at 1913Z and headed toward the Sylvan Lake area. HS4 began seeding storm #2 at 1931Z NW of Red Deer for cells approaching Lacombe. HS4 base seeded with acetone generators and BIP flares. Pilots reported abundant inflow at base. At 2009Z, the storm began to weaken; seeding continued with generators only. The storm continued to weaken as it moved east of the cities, and seeding was halted at 2028Z. HS4 patrolled for a brief time and was then directed to RTB at 2043Z. HS4 landed at YQF at 2055Z. HS1 was launched at 0029Z (06/06) for new cells developing NW of Cochrane. The aircraft was airborne at 0059Z (06/06) and began top seeding storm #3 at 0127(06/06). HS1 repositioned to southwest of Calgary at 0135Z (06/06) and patrolled that area reporting only weak vertical development. This growth was not seeded. HS1 then shifted back to the NW and resumed seeding on two connecting cells (storm #3) NW of Cochrane at 0159Z (06/06). They continued to seed this same storm until HS3 moved in to take their place. HS1 stopped seeding and RTB at 0256Z (06/06). The aircraft landed at 0311Z (06/06). HS4 was launched at 0121Z (06/06) for their second flight of the day. They were airborne at 0132Z (06/06) and headed south toward the cells near Cochrane. HS4 began base seeding storm #3 with burners and BIPs at 0202Z (06/06). They ran racetrack seeding patterns at cloud base NW of Calgary along with HS2. HS4 stopped using BIP flares and seeded with generators only at 0235Z (06/06) as the storm

		became more linear and weaker over NW Calgary. At 0318Z (06/06) HS4 repositioned to new growth west of Caroline as the cells near Calgary were no longer a hail threat. HS4 began seeding storm #6 W of Caroline at 0342Z (06/06). Seeding continued until the cells were no longer a hail threat. Seeding ended at 0413Z (06/06) and HS4 was directed to RTB. The plane landed at 0428Z (06/06). HS2 was launched at 0139Z (06/06) for cells near Calgary. They were airborne at 0151Z (06/06) and began searching for inflow on weak echoes developing over SW Calgary. HS2 began base seeding storm #4 west of Calgary at 0205Z (06/06). Not much inflow was reported in this area, and the cells to the SW of YYC were determined to be nonthreatening. HS2 was shifted north to the two connecting cells NW of YYC. Seeding began on storm #3 at 0222Z (06/06). Pilots flew racetracks in the same area with HS4 at cloud base. They continued seeding the cells as they moved through N YYC into Airdrie. The storm then weakened below hail criteria so HS2 stopped seeding and was directed to RTB at 0350Z (06/06). The plane landed at 0357Z (06/06). HS3 was launched at 0137Z (06/06) for a new cell forming near Sundre. They were airborne at 0206Z (06/06). They were instructed by ATC to deviate from the most direct flight path due to skydiving activity near Innisfail. They reached the developing storm near Sundre and began top seeding storm #5 at 0222Z (06/06). The storm then weakened to below hail criteria. At 0235Z (06/06), they stopped seeding and began patrol NW of Olds. At 0241Z (06/06) they were redirected to the activity NW of Calgary and began seeding storm #7 NW of Cochrane. Shortly after that, HS1 RTB and HS3 took their place seeding storm #3 NW of Calgary at 0246Z (06/06). After several hours of seeding, the Calgary storm weakened, and HS3 was directed to stop seeding and RTB at 0451Z (06/06). They landed at 0508Z (06/06). <u>Flight Summary</u> HS3: 1846-2107Z; 90 EJ, #1 NW of Ponoka, #2 NW of Red Deer, patrol W of Didsbury. HS4: 1905-2059Z; 4 BIP, 114 min acetone generator time; #2 NW of Red Deer. HS1: 0050 (06/06)-0314Z (06/06); 198 EJ, 3 BIP; patrol W of Didsbury, storm #3 NW of Cochrane. HS4: 0126 (06/06)-0431Z (06/06); 5 BIP, 262 min acetone generator time; #3 N of Cochrane, #6 W of Caroline. HS2: 0143 (06/06)-0400Z (06/06); 206 min acetone generator time; #4 SW of YYC, #3 N of Cochrane. HS3: 0200 (06/06)-0515Z (06/06); 233 EJ, 15

		BIP; #5 NW of Olds, Patrol NW of Olds, #3 N of Cochrane, #7 NW of Cochrane.
June 06, Monday	A deep low pressure system, previously lingering off the coast of California, was forecast to move quickly to the NE ejecting multiple shortwave troughs through the project area. The model sounding indicated high amounts of upper level moisture, with sufficient speed shear for organized convection. The surface was moist due to overnight rain showers. Afternoon highs were expected to reach the convective temperature. Isolated rain showers occurred during the morning. Intense cells developed over the far NW quadrant of the project area during the afternoon. The cells moved southward parallel to the foothills remaining outside the project boundary. The most intense cell occurred in the buffer zone west of Sundre. Only weak convection and dissipating thunderstorms moved through the project area. There were no hail threats inside the project boundaries. Weak showers moved through during the overnight hours. Max cell top: 7.6km, 56 max dBz, 20.2 max VIL Tmax YC = 14.2C and 12.4mm of rain. Tmax QF = 15.4C and 0.4mm of rain. Tmax Radar = 13.7C and a trace of rain.	HS3 was launched at 2134Z for intense hailstorms approaching the NW corner of the project area. They were airborne at 2154Z. At 2212Z, HS3 began patrolling NW of RMH. The cells then shifted to a more southerly track parallel to the foothills, remaining outside the project area. It was determined that the cells would not enter the project area. HS3 was directed to RTB at 0004Z (06/07). They landed at YQF at 0022Z (06/07). <u>Flight Summary</u> HS3: 2144 (06/06)-0026Z (06/07); no seeding; patrol NW of RMH.
June 07, Tuesday	The upper level jet was located along the back side of a closed upper low over Vancouver. A cold front was moving southward through AB but it was progged to became stationary during the evening hours. Atmospheric instability was moderate with weak speed shear favoring short-lived cells. The vertical wind profile indicated that the wind directions switched from easterly to westerly at around 500mb, which inhibited storm growth above this level. The region had weak moisture convergence at the surface. Low topped pop-up convection occurred during the morning and afternoon. Cells were generally less than 7km tall and not significant hail threats. Cell motion was from SE to NW due to the position of a surface low pressure system that developed to the south. Light stratus rain occurred during the overnight hours. Max cell top: 8.4km, 61 max dBz, 38.8 max VIL Tmax YC = 15.5C and 1.6mm of rain. Tmax QF = 16.0C and 7.2mm of rain. Tmax Radar = 16.9C and 4.6mm of rain.	HS1, HS3, and HS4 all performed brief maintenance flights to test Airlink tracking after modifications to the data logger software. HS4 also tested the wing tip generators. Airlink tracking problems were resolved with all three planes, and aircraft tracks were displayed on the TITAN computer. <u>Flight Summary</u> HS1: 2128-2205; no seeding; maintenance flight to test Airlink system. HS3: 2336 (06/07)-0012 (06/08); no seeding; maintenance flight to test Airlink system. HS4: 2337 (06/07)-0007 (06/08); no seeding; maintenance flight to test Airlink system.
June 08, Wednesday	A closed upper level low continued to slowly shift to the southeast over southern British Columbia. The atmosphere was slightly unstable with poor speed and directional shear. Vorticity advection was minimal, but a surface trough over the area was progged to initiate convection. Light stratiform rain occurred in the morning. Low topped, unorganized pop-up convection occurred during the afternoon and evening hours. There were no significant hail threats in the project area. Widespread light stratus rain and virga moved through during the night.	HS2 performed a maintenance flight in the morning hours to test Airlink tracking after modifications to the GPS and the data logger software. The test was successful, and tracks were displayed on the TITAN computer. <u>Flight Summary</u> HS2: 1645-1723; no seeding; maintenance flight for Airlink testing.

	Max cell top: 6.9km, 61 max dBz, 25.0 max VIL Tmax YC = 15.6C and 2.8mm of rain. Tmax QF = 17.2C and 1.8mm of rain. Tmax Radar = 15.2C and 3.4mm of rain.	
June 09, Thursday	The strongest upper level jet energy was south of AB. A deep closed low was located over Idaho during the morning hours which quickly weakened into an open wave trough as it moved eastward across Montana. Weak, upper level ridging then built over AB during the daytime hours. A surface trough formed along the lee side of the Rockies. The atmosphere was slightly unstable but capped with weak wind shear. The low level cap held strong throughout the forecast period, and surface dew points remained lower than expected. Skies were mostly clear for the entire period. There were no TITAN cells or significant radar echoes. Tmax YC = 18.3C and no rain. Tmax QF = 21.4C and no rain. Tmax Radar = 18.9C and no rain.	No aircraft operations.
June 10, Friday	The upper level jet remained south and west of AB. The upper level ridge moved east over Saskatchewan and a trough pushed into the area during the afternoon and evening. At the surface, a low formed over central AB during the late afternoon and evening hours. The atmosphere was unstable with CAPE values near 1100J/kg, and the wind shear was weak. During the early afternoon, rain showers occurred west of the project area. During the midafternoon, storms developed west of Calgary and Rocky Mountain House, moving down from the foothills. The storms were slowly moving to the northeast, and were marginal hail threats through the evening. The storms weakened significantly around midnight. During the overnight hours, there were widespread convective showers. Max cell top: 10.6km, 62.5 max dBz, 46.4 max VIL Tmax YC = 22.7C and no rain. Tmax QF = 24.2C and no rain. Tmax Radar = 23.1C and 0.5mm of rain.	HS4 performed a maintenance flight to check aircraft tracking with the backup TITAN computer. The test was successful. Aircraft tracks were displayed on the backup TITAN system. HS2 was launched at 2142Z to development SW of Calgary. At 2200Z HS2 was airborne. At 2216Z, HS2 found 500-1000 fpm inflow on storm #1 and began seeding with generators and BIP flares. At 2259Z, HS2 reported weaker inflow and continued seeding with burners only. At 0044Z (06/11) the storm was no longer a hail threat and HS2 RTB. They landed at YYC at 0057Z (06/11). HS1 was launched at 2142Z for development SW of Calgary. At 2221Z, HS1 was airborne. At 2233Z, HS1 began top seeding storm #1 west of Cochrane with EJs and BIPs. At 0014Z (06/11), HS1 was directed to stop seeding and patrol the weakening storm #1. HS1 reported additional growth on the storm at 0053Z (06/11), and resumed seeding for a short period of time. At 0200Z (06/11), the storm weakened and HS1 RTB to YYC. They landed at 0205Z (06/11). HS3 was launched at 2229Z for development SW of RMH. At 2250Z, they were airborne. At 2312Z, HS3 began top seeding with EJs on storm #2 S of RMH. This cell quickly diminished. At 2323Z, they stopped seeding and began to patrol the area. At 2332Z, there were no seedable targets left and HS3 was directed to RTB. They landed at YQF at 2348Z.

		HS4 was launched at 0026Z (06/11) for development SW of Caroline. At 0045Z (06/11) HS4 was airborne. At 0058Z (06/11), HS4 started base seeding storm #3 with acetone generators SW of Caroline. HS4 found good inflow and a shelf cloud for the next few hours as the storm moved through Caroline and into Eckville. At 0329Z (06/11), as the storm left Eckville, they stopped seeding and RTB. They landed at YQF at 0342Z (06/11). After landing at YQF, HS3 was immediately launched again at 0042Z (06/11) on storm #3 S of RMH, moving NNE. At 0100Z (06/11) HS3 was airborne, and at 0110Z began top seeding storm #3 S of Caroline with EJs and BIP flares. HS3 reported a steep radar gradient and intensifying lightning as they continued to seed the storm. As the storm left the project area, HS3 stopped seeding and RTB at 0318Z (06/11). They landed in YQF at 0336Z (06/11). HS1 was launched SW of Cochrane at 0317Z (06/11) after a cell showed up on radar. By the time they were airborne, the cell had diminished and they were instructed to patrol without seeding. At 0400Z (06/11), they RTB after radar and pilot observations showed the storm was not a hail threat. They landed in YYC at 0413 (06/11). <u>Flight Summary</u> HS4: 1654-1725Z; no seeding. Mx flight S of Red Deer to test Airlink tracking. HS2: 2147 (06/10)-0102Z (06/11); 3 BIP, 300 min acetone generator time; storm #1 SW Cochrane. HS1: 2210 (06/10)-0210Z (06/11); 119 EJ, 3 BIP; storm #1 SW Cochrane. HS3: 2240-2353Z; 18 EJ; patrol W of Caroline, storm #2 S of RMH. HS 4: 0035 (06/11)-0345Z (06/11); 1 BIP, 300min acetone generator time; Storm #3 SW of Caroline. HS3: 0052 (06/11)-0339Z (06/11); 295 EJ, 14 BIP; Storm #3 SW Caroline. HS1: 0325 (06/11)-0418Z (06/11); No seeding; patrol W of Cochrane.
June 11, Saturday	An upper level trough remained over British Columbia. Several vorticity lobes slowly passed over the project area during the day. Low pressure remained over the area during the morning and afternoon hours. This surface low was progged to move off to the southeast overnight. Rain showers were visible on radar all day. During the early afternoon, strong storms exploded in the eastern buffer and moved to the northeast away from the project boundaries. Stratus and widespread convective showers lingered over the project area throughout the period. Max cell top: 12.1km, 63.5 max dBz, 87.3 max VIL	No aircraft operations.

	Tmax YC = 12.0C and 7.2mm of rain. Tmax QF = 15.1C and 6.0mm of rain. Tmax Radar = 13.1C and 3.6mm of rain.	

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Date	Weather	Activities Summary
June 12, Sunday	An upper level trough was centered over Alberta for most of the day. The trough axis shifted towards eastern AB overnight. A shortwave trough moved from W to E across the project area during the early afternoon hours. Vorticity advection was minimal along the trough. A surface low pressure system was positioned along the AB and Saskatchewan border. Towering cumulus was observed in the late morning, and radar echoes began popping up around briefing time. Storms lasted all day, initiating mainly along a shortwave trough moving through the area. Storm motion was toward the ENE throughout the day. West of the shortwave, there was minimal activity until the early evening when a storm initiated over the mountains and moved E towards Sundre. As the storm moved into the project area, it became organized and began to move right, spawning additional cells in its outflow boundary. The atmosphere stabilized in the late evening. All convective activity ceased and there was no precipitation overnight. Max titan cell top=9.9km, 67 max dBz, 83.4 max VIL Tmax YC = 18.4C and 0.2mm of rain. Tmax QF = 18.2C and 0.4mm of rain. Tmax Radar = 18.0C and 1.6mm of rain.	HS4 was launched at 1750Z to a cell S of Sundre. They were airborne at 1803Z and began base seeding storm #1 at 1824Z. This storm quickly dissipated. HS4 stopped seeding at 1830Z and was redirected to a cell near Southern Calgary. HS4 began seeding storm #2 with generators at 1854Z. At 1921Z, storm #2 was dissipating so HS4 repositioned to the north and began seeding storm #3 W of Cremona. Storm #3 then diminished on TITAN, and HS4 repositioned to storm #5 W of Airdrie and began seeding at 2011Z. In response to strengthening inflow and radar signature, HS4 began using flares at 2023Z. Storm #5 began to weaken significantly after this, and as it ceased to be a hail threat, HS4 stopped seeding and RTB at 2106Z. They landed at 2136Z. HS3 was launched at 1933Z for a cell W of Didsbury. HS3 was airborne at 1959Z. Storms intensified W of Caroline and Eckville, and HS3 was directed to the area. At 2017Z, HS3 began seeding storm #4 W of Caroline with EJs. They descended to shed ice at 2109Z, and resumed seeding at 2141Z. At 2156Z, HS3 had stop seeding due to conflict with skydiving operations. Seeding resumed at 2205Z. HS3 had to stop seeding for parachute traffic again at 2220Z, and decided to descend to shed ice. At 2245Z, HS3 was able to begin climbing again. They seeded storm #6 with BIPs during the climb. The Red Deer cell quickly weakened below hail criteria, and HS3 RTB at 2258Z. They landed at 2308Z. HS2 launched as a top seeder at 2023Z for storm #5 W of Airdrie. At 2041Z, HS2 was airborne. HS2 ignited burners at 2049Z on storm #5 and used BIPs during the climb to cloud top as well. This cell near Airdrie quickly diminished. At 2113Z, HS2 stopped seeding and began patrolling S of Cochrane. At 2200Z, HS2 descended to cloud base, and repositioned to the E side of the line of thunderstorms W of Innisfail. At 2233Z, HS2 began base seeding storm #6 between Innisfail and Red Deer with generators and BIPs. As the cell moved beyond Innisfail, HS2 stopped seeding storm #6 at 2309Z. They were then directed to patrol NW of Sundre. When radar and pilot observations indicated no seedable activity in the Sundre area, HS2 RTB at 2345Z. They landed at 0003Z (06/13).

		HS1 launched for top seeding at 0003Z (06/13) on the cell NW of Sundre which HS2 had patrolled earlier. At 0021Z (06/13), HS1 was airborne. They began top seeding storm #7 W of Sundre at 0049Z (06/13). Pilots reported a difficult time finding good feeder clouds. HS1 moved further to the west. They found good growth along the south side of the storm and continued seeding. At 0254Z (06/13), HS1 reported fewer feeder clouds, and TITAN also showed the storm diminishing. By 0336Z (06/13), the storm was below hail criteria, and HS1 RTB. They landed at 0350Z (06/13). Up to 22mm hail was reported W of Sundre. HS4 was launched for base seeding at 0045Z (06/13) for the hailstorm NW of Sundre to work with HS1. HS4 was airborne at 0109Z (06/13) and advised by the radar of severe overhang on the eastern and southern areas of this cell. They commenced seeding with acetone generators and BIPs at 0115Z (06/13). HS4 found very good inflow, which continued for the next 2 hours. HS4 RTB at 0336Z (06/13) when TITAN and pilot observations showed the cell diminishing below hail criteria. They landed at 0354Z (06/13). FLIGHT SUMMARY HS4: 1754-2141Z; 304 min acetone generator time, 10 BIP; patrol SW of Calgary, #2 Calgary, #3 Cremona, #5 Airdrie. HS3: 1947-2311Z; 143 EJ, 15 BIP; #4 Caroline to Eckville, #6 Red Deer. HS2: 2034Z (06/12)-0005Z (06/13); 112 min acetone generator time, 4 BIP; #5 Airdrie, patrol SW Calgary, #6 Innisfail, patrol NW of Sundre, patrol W of Caroline. HS1: 0015Z (06/13)-0355Z (6/13); 213 EJ, 8 BIP; #7 Sundre HS4: 0100Z (06/13)-0354Z (6/13); 258 min acetone generators, 5 BIP; #7 Didsbury
June 13, Monday	The upper level jet was well to the southwest. Midlevel charts indicated a shortwave trough approaching from the west with a few small vorticity maxima expected to move through during the day. Upper levels were relatively warm in the morning, but gradually cooling throughout the day. There was abundant low level instability below 7.5km, but only minimal instability above 7.5km. Widespread low topped thundershowers were forecast to occur throughout the afternoon with a few isolated cells expected to reach up to 30kft. Stratus rain was expected overnight. Convective rain showers began in the early afternoon over the entire project area as vorticity advection occurred. The cells inside the project area were mainly pulse type storms with low tops, heavy rain, and no hail. In the early evening, two bowing cells initiated over the mountains and moved into the project area. One of these was visually observed from the Olds radar. The storm had a shelf cloud on the east side for a brief time. These	No aircraft operations.

	cells quickly diminished below hail criteria. Max titan cell top=8.4km, 62.5 max dBz, 37.8 max VIL Tmax YC = 18.6C and 2.6mm of rain. Tmax QF = 21.4C and 6.6mm of rain. Tmax Radar = 20.0C and 0.6mm of rain.	
June 14, Tuesday	The upper level jet remained south of the project area. A developing low pressure system was approaching the west coast, progged to develop into a deep closed low during the forecast period. A weak N/S oriented lobe of midlevel vorticity was progged to push through from the W during the afternoon and evening. At the surface, a low pressure trough was centered over NW Saskatchewan. The atmosphere was slightly unstable below 25kft with weak wind shear. Weak convection was forecast during the afternoon/evening with no hail expected. Thick cloud layers, stratus rain, and low ceilings were forecast for the overnight hours. Beginning in the early afternoon, vorticity advection over the area set off a line of rain showers. Lightning was observed in some of the storms, and some reached hail threat criteria. Storms grew slowly and glaciated rapidly. No long-lived multicellular storms were observed. In the early evening, a shortwave feature visible on radar moved in from the north and triggered storms in the northern part of the project area. These storms would develop dark rain shafts and good shelf clouds, but dissipate after the initial push due to lack of wind shear. Around sunset, all storms diminished becoming light convective rain showers and stratiform rain. Max titan cell top=8.4km, 63 max dBz, 32.3 max VIL Tmax YC = 18.9C and no rain. Tmax QF = 19.6C and a trace of rain. Tmax Radar = 19.0C and 4.4mm of rain.	HS1 was launched on growth W of Didsbury at 2016Z, and was airborne at 2035Z. They patrolled W of Didsbury reporting glaciated clouds and no feeders. They were then directed to patrol cells W of Acme at 2053Z and reported similar conditions. HS1 then RTB to YYC 2109Z. They landed at 2131Z. HS4 was launched at 0143Z (06/15) for a cell W of Innisfail, and became airborne at 0158Z (06/15). As they approached the storm, HS4 reported a shelf cloud and heavy rain on storm #1 and lit acetone generators at 0207Z (06/15). HS4 soon found inflow up to 800fpm and began lighting BIPs as well. HS4 worked a long line from Innisfail to Bowden until the storm was past these two towns. At 0249Z (06/15), HS4 stopped seeding and was redirected to a cell NW of Penhold for patrol. Finding no good bases and poor inflow on the cell, HS4 RTB at 0307Z (06/15). They landed at 0319Z (06/15). <u>Flight Summary</u> HS1: 2025Z-2131Z; patrol W Didsbury, patrol W Acme. HS4: 0148Z (6/15) – 0322Z (06/15); 6 BIP, 104 min acetone generator time; Storm #1 W Innisfail, patrol N Caroline.
June 15, Wednesday	A deep low pressure system was centered over the region. The upper jet core remained to the south of Alberta. Multiple intense pockets of vorticity were progged to wrap around the upper low and push through the project area from the N during the evening and overnight hours. Afternoon and evening instability was weak, and the shear profile was not favorable for long-lived convection. Upper level winds were from the NNE due to the position of the upper level circulation. Surface winds were westerly due to the position of a surface low over Saskatchewan. Weak thundershowers were forecast during the afternoon and evening with tops expected to remain below 25kft. Stable conditions were expected after midnight with widespread stratus rain and low ceilings through morning. Light rain showers occurred over the southern half of the project area during the afternoon. Clouds were predominantly fair weather cumulus, and everything remained below hail criteria. In the early evening, a line of strong cells initiated north of Calgary moving south. These cells quickly diminished in strength, and passed	HS1 was launched at 0056Z (06/16) on cells north of Calgary. They were airborne at 0110Z (06/16) and directed to the north side of the cells. They reported embedded conditions throughout the flight, but they were able to find adequate liquid water and began seeding with BIPs at 0138Z (06/16), making East-West passes. By 0206Z (06/16), both radar and pilot reports indicated the cells were diminishing in intensity. At 0214Z (06/16), HS1 stopped seeding and began patrol. HS1 RTB at 0227Z (06/16) as the cell continued to die out. They landed at 0236Z (06/16). <u>Flight Summary</u> HS1: 0102Z (06/16)-0240Z (06/16); 6 BIP; #1 NE of YYC.

	through Calgary as rain showers. Overnight, some rain showers occurred. Max titan cell top=8.4km, 62.5 max dBz, 34.4 max VIL Tmax YC = 14.9C and 5.8mm of rain. Tmax QF = 16.6C and 3.0mm of rain. Tmax Radar = 16.0C and 12.0mm of rain.	
June 16, Thursday	A deep low pressure system remained in place over the region, centered just east of the project area over far eastern AB. Ample amounts of vorticity advection were expected throughout the day and overnight hours as lobes of vorticity wrapped around the north side of the low and pushed through the project area. A surface low was also centered just to the east of the project area. Forecast soundings indicated weak to moderate instability during the afternoon and evening with a weak wind shear profile. The atmosphere was expected to stabilize overnight. Afternoon and evening thundershowers were expected with small hail possible. Rain showers were also expected to occur throughout the forecast period. Convective rain showers fell over the project area for most of the day. Convective development was strongest during the afternoon hours over the northern part of the project area, near Sylvan Lake and Red Deer. The evening and overnight hours saw continued rain showers, especially over the Sundre region. Max titan cell top=9.1km, 61 max dBz, 38.4 max VIL Tmax YC = 11.5C and 19.6mm of rain. Tmax QF = 13.6C and 24.2mm of rain. Tmax Radar = 11.5C and 12.5mm of rain.	HS3 was launched to the north of YQF at 1907Z. The flight became airborne at 1925Z and quickly found growth near the YQF airport and over the YQF area. HS3 started seeding storm #1, over YQF, at 1934Z. The crew reported minimal growth over YQF at 1940Z, so the flight was redirected towards new and stronger growth south of the Lacombe area. The aircraft started seeding storm #2, northeast of Sylvan Lake, at 2000Z. HS3 continued to seed this storm until it was south of Sylvan Lake. The aircraft then stopped seeding at 2031Z and RTB as the activity diminished. They landed at 2043Z. <u>Flight Summary</u> HS3: 1920-2047Z; 114 EJ, 9 BIP; #1 over YQF, #2 NE of Sylvan Lake.
June 17, Friday	The deep low pressure system over the region was shifting slightly to the east over SK during the period. A small amount of midlevel vorticity was expected to move through the region. A surface trough was draped over the northeastern portion of the project area during the early afternoon. The atmosphere was slightly unstable. The wind shear profile was very weak and cell motion was expected to be from the northeast at less than 5 knots. Weak popup single cells were expected during the afternoon. Cells were expected to develop and dissipate rapidly with tops less than 28kft. Clearing was expected during the evening and overnight hours. A line of nearly stationary popup convection formed over the eastern buffer during the morning hours. This line moved southwestward into the project area. Another line of thunderstorms extending from Ponoka to Stettler moved into the northeastern part of the project area. These storms were the strongest of the day but were short lived due to the weak shear profile. The rest of the day saw weak pop-up convection but not significant hail threats. Max titan cell top=9.1km, 61 max dBz, 34.2 max VIL Tmax YC = 15.6C and 1.4mm of rain. Tmax QF = 16.4C and 2.8mm of rain. Tmax Radar = 15.5C and a trace of rain.	HS3 was launched at 2214Z northeast of YQF for a marginal hail threat developing in the northern buffer zone. The flight was airborne at 2231Z. The crew found good liquid water at 2243Z and began top seeding. Seeding stopped at 2249Z once the pilots determined the new growth was only reaching 20kft. The flight RTB at 2259Z and landed at 2307Z. HS4 flew a night currency flight over the YQF area. <u>Flight Summary</u> HS3: 2224-2310Z; 18 EJ, 1 BIP; #1 NE of YQF. HS4: 0445 (06/18)-0548Z (06/18); no seeding, currency flight over YQF.

June 18, Saturday	The deep low pressure system over the region shifted back toward the west. It was centered over the AB/SK border. At the surface, a trough of low pressure was located east of the project area near the SK border. The atmosphere was stable throughout the forecast period. Heavy stratiform rain was expected throughout the day and overnight hours along with gusty northwesterly surface winds and low ceilings. Stratiform rain showers fell over the region for most of the day. A few short lived convective cells formed in the buffer zone northeast of Red Deer during the early evening. There were no hail threats. Max titan cell top=6.9km, 59 max dBz, 17.7 max VIL Tmax YC = 13.6C and 10mm of rain. Tmax QF = 12.2C and 15mm of rain. Tmax Radar = 12.0C and 11mm of rain.	No aircraft operations.

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WEEK No.4

Date	Weather	Activities Summary
June 19, Sunday	The stacked low remained the main weather feature on the map, located over the Alberta-Saskatchewan border. PVA supplied by the low was forecast to keep cloud cover thick, limiting severe convection as surface temperatures remained low. Some convection was expected in the early evening. The low level cloud cover started to become broken during the early afternoon which allowed surface heating to occur. The southern half of the project area received more insolation which allowed for slightly stronger convection to develop. The most organized cells formed during the late afternoon and early evening hours. These storms mainly occurred along the western project area boundary. The northern half also saw lots of convection, but cell tops rarely grew above 6km. Max cell top: 9.9km, 63 max dBz, 37.5 max VIL. Tmax YC = 18C and 1.4mm of rain. Tmax QF = 17C and 7.4mm of rain. Tmax Radar = 16C and 0.6mm of rain.	HS2 was launched at 2226Z because of cell development NW of Cochrane. At 2243Z, HS2 became airborne. Seeding began on storm #1 over northwestern Calgary at 2254Z. Then at 2310Z the pilot reported that the storm was beginning to weaken. HS2 stopped seeding storm #1 over Calgary at 2335Z. The flight was redirected to NW of Airdrie and patrolled for a short time before being RTB at 2349Z. HS2 was launched for a second base seeding flight at 0016Z (06/20) to an intensifying cell NW of Turner Valley and Black Diamond. The flight became airborne at 0030Z (06/20). The aircraft was forced to maneuver around a weak cluster of cells to the south of Calgary before intercepting the main cell. Once the crew arrived, they quickly found inflow and started seeding storm #2 NW of the towns of Turner Valley and Black Diamond at 0045Z (06/20). HS2 continued seeding the storm until it started to enter the southern buffer zone. HS2 stopped seeding at 0145Z (06/20) and was redirected to new growth near the Calgary airport. The flight ended up patrolling northern Calgary until 0230Z (06/20) when HS2 RTB. <u>Flight Summary</u> HS2: 2239Z (06/19)-0007Z (06/20); 2 BIP, 82 min acetone generator time; #1 NW YYC, patrol NW of Airdrie. HS2: 0025Z (06/20)-0301Z (06/20); 8 BIP, 120 min acetone generator time; #2 NW of Turner Valley and Black Diamond, patrol northern Calgary.
June 20, Monday	The low pressure system moved to the east and weakened. There were no upper level triggers. Clearing in the morning indicated a very warm day was likely. High temperatures were forecast to be well above convective temperature, providing the primary trigger for the day. Although instability was good, shear was poor, so storms were expected to be "pop-up" and short lived. Convection developed over the mountains during the late morning hours and began to move over the foothills around noon. Several moderately strong cells then moved off the foothills during the early afternoon hours. The most intense storms formed near the Cochrane area. One of these storms (#2) moved eastward through northern Calgary and Airdrie. Once this storm moved to northeastern Calgary, another strong cell developed near Cochrane and slowly moved to the south-southeast. The project area to the north of Calgary saw several multicellular storms which produced moderate to heavy	HS1 was launched at 1822Z to growing cells southwest of Calgary. By the time the flight became airborne at 1843Z, the cells were diminishing SW of Calgary, so the aircraft was redirected towards a developing cell NW of Calgary. HS1 started seeding this storm (#1) at 1904Z. Next the crew reported strong multicellular growth over the Springbank area and started seeding this storm (#2) at 1925Z. HS1 continued to find decent growth and followed the storm eastward across the project area. At 2154Z, HS1 stopped seeding and RTB. HS2 was launched to a growing cell NW of Okotoks at 1910Z. The aircraft became airborne at 1924Z. HS2 started seeding storm #3 NW of Okotoks at 1946Z. HS2 continued to seed the storm until it was over Okotoks. The

	rain showers across this region during the later afternoon and evening. Overnight, the area saw weak scattered rain showers. Max cell top: 10.6km, 65.5 max dBz, 69.4 max VIL. Tmax YC = 18C and 2.8mm of rain. Tmax QF = 19C and no rain. Tmax Radar = 19C and 10.5mm of rain.	aircraft was then redirected to growing convection over northwestern Calgary. HS2 started seeding storm #2 over northwestern Calgary at 2010Z. The aircraft then remained along the southern end of the cell as it moved eastward towards northern Strathmore. At 2141Z, HS2 repositioned to new cells W of Calgary. Then at 2202Z the aircraft began seeding storm #4. At 2254Z HS2 stopped seeding and RTB. HS3 was launched at 2104Z to replace HS1 who was getting low on fuel and chemical, but once HS3 became airborne at 2124Z, the aircraft was redirected to new development W of Calgary (Storm #4). HS3 started seeding at 2153Z. The aircraft continued to seed the storm until it ran out of flares. HS3 stopped seeding and RTB at 2330Z. HS4 was launched at 2143Z to the same storm (#4) that HS3 was working W of Calgary. The flight became airborne at 2200Z and headed toward Springbank. At 2230Z, HS4 started seeding Storm #4 W of Calgary. The flight continued to seed the storm as it moved south-southeastward through the towns of Turner Valley, Black Diamond, and High River. HS4 stopped seeding at 0117Z (06/21) and RTB. HS1 was launched for a second flight at 2256Z to take over seeding for HS3 on a cell SW of Calgary. HS1 was airborne at 2312Z. The aircraft climbed to cloud top and headed down south along the SE side of the main cell. The flight started seeding Storm #4 at 2331Z, making east-west passes along the southern end of the storm. Then at 0025Z (06/21), HS1 was not finding any growth on Storm #4 W of Okotoks so the flight was redirected to convection W of Didsbury. The aircraft briefly seeded these cells (Storm #5). HS1 stopped seeding at 0057Z (06/21) and then patrolled NW of Calgary. The aircraft RTB at 0132Z (06/21). <u>Flight Summary</u> HS1: 1836-2214Z; 230 EJ, 6 BIP; #1 NW of YYC, #2 over Springbank. HS2: 1918-2305Z; 21 BIP, 340 min acetone generator time; #3 W of Okotoks, #2 NW YYC, #4 YYC. HS3: 2114Z (06/20)-0002Z (06/21); 298 EJ, 11 BIP; #4 W of YYC. HS4: 2150Z (06/20)-0209Z (06/21); 17 BIP, 320 min acetone generator time; #4 W of YYC. HS1: 2305Z (06/20)-0148Z (06/21); 39 EJ, 6 BIP; #4 W of YYC, #5 W of Didsbury, patrol NW of YYC.
June 21, Tuesday	Mostly clear skies with some morning towering cumulus indicated an active day. There was some mid-level	HS4 was launched at 1846Z to a cluster of cells to the W of Rocky MH. As the flight became

	ridging during the day, and soundings indicated slight capping until early evening. High forecast surface dewpoints and temperatures, as well as excellent speed shear made for an unstable hail-type sounding. Storms were expected to initiate along the mountains due to orographic lift in the late afternoon, and would be concentrated in the northern part of the project area where the ridging was weaker. Convection first started to form over the mountains W of Rocky MH during the late morning hours. This line of cells eventually moved eastward during the afternoon. The further this line moved to the east, the more intense the cells became. One major storm moved southeastward away from the line through Sylvan and part of Red Deer. Around 00z another strong storm developed NW of Rocky MH and made its way southeastward through Rocky MH. Once this very intense storm began to diminish, another series of cells popped up W of Sundre and eventually made its way through Red Deer. Max cell top: 11.4km, 69.5 max dBz, 119.6 max VIL. Tmax YC = 22C and no rain. Tmax QF = 22C and 0.4mm of rain. Tmax Radar = 22C and a trace of rain.	airborne at 1904Z, the convection near Rocky MH diminished, so the flight was redirected towards new growth to the south of Red Deer. The aircraft began seeding at 1918Z and briefly seeded Storm #1. HS4 then patrolled the Red Deer area. At 2040Z, HS4 was redirected to convection S of Lacombe. The flight did not find any active growth near Lacombe, so the flight was then redirected to a new storm (#2) SW of Sylvan. The aircraft started seeding this storm at 2056Z. HS4 continued to seed this storm until a stronger line of convection developed NW of Sylvan. The crew started seeding storm #3 at 2135Z. The flight continued to seed this storm as it passed over Sylvan and part of Red Deer. At 2316Z HS4 stopped seeding and RTB. HS3 was launched at 2102Z to a strengthening line of cells stretching from Rimbey to NW of Sylvan. The flight became airborne at 2121Z. The aircraft started seeding at 2132Z upon arrival along the southern portion of the line of convection. The flight continued to seed this storm as it passed over Sylvan and part of Red Deer. At 2317 HS3 reported that the storm was beginning to come down in intensity. Then at 2320Z the aircraft stopped seeding and patrolled the Red Deer area. HS3 RTB at 2335Z. HS1 was launched at 0028Z (06/22) to a rapidly growing cell NW of Rocky MH. The flight became airborne at 0049Z. By the time the aircraft arrived to seed the storm (#4) at 0120Z (06/22), the intense storm was already over the Rocky MH region. HS1 continued to seed the storm as it moved towards Innisfail. The aircraft stopped seeding the cell at 0208Z (06/22) and was redirected to a new storm (#5) W of Sundre. The flight started seeding this storm at 0301Z (06/22). This storm eventually began to diminish, so HS1 started seeding storm #6 SW of Sylvan at 0423Z (06/22). This convection eventually became fairly embedded, so the aircraft was forced to reposition itself on the southeastern side of the storm. HS1 stopped seeding at 0514Z (06/22) and RTB. HS4 was launched for a second flight at 0135Z (06/22). The flight became airborne at 0145Z (06/22) and started seeding storm #4 at 0156Z (06/22) NW of Innisfail. HS4 stopped seeding at 0214Z (06/22) and was redirected to new cells S of Rocky MH. HS4 found no new growth while patrolling between Caroline and Rocky MH, so the flight RTB at 0223Z (06/22). HS2 performed a patrol flight W of Sundre and over the Cochrane area. The aircraft was launched at 0301Z (06/22) and became airborne at 0320Z (06/22). HS2 found no inflow

		along storm #5, so it was redirected to patrol the Cochrane area for a short time before being RTB at 0416Z (06/22). HS4 was launched for its third flight of the day at 0455Z (06/22) due to embedded convection to the W and S of Red Deer. The flight became airborne at 0511Z (06/22) and started seeding storm #6 W of Red Deer at 0516Z (06/22). Then at 0516Z (06/22) the aircraft found a good pocket of 500fpm inflow. HS4 eventually stopped seeding at 0547Z (06/22). HS4 decided to land at the Olds-Didsbury airport for a short time to wait out the storms passing over the Red Deer airport. Once the convection had passed the airport in Red Deer, HS4 took off at 0656Z (06/22) from the Olds-Didsbury airport and landed at the Red Deer airport at 0715Z (06/22). <u>Flight Summary</u> HS4: 1855-2327Z; 16 BIP, 292 min acetone generator time; #1 S of YQF, #2 SW of Sylvan, and #3 NW of Sylvan. HS3: 2113-2346Z; 229 EJ, 13 BIP; #3 NW of Sylvan. HS1: 0035Z (06/22)-0549Z (06/22); 172 EJ, 18 BIP; #4 NW of Innisfail, #5 W of Sundre, and #6 SW of Sylvan. HS4: 0138Z (06/22)-0248Z (06/22); 36 min acetone generator time; #4 NW of Innisfail. HS2: 0316Z (06/22)-0431Z (06/22); no seeding; patrol W of Sundre and over Cochrane. HS4: 0503Z (06/22)-0605Z (06/22); 1 BIP, 62 min acetone generator time; #6 W of YQF; landed at Olds-Didsbury airport due to storms over the Red Deer airport. HS4: 0650Z (06/22)-0718Z (06/22); no seeding; flew a ferry flight from Olds-Didsbury airport to Red Deer once the storms had moved to the east of the airport.
June 22, Wednesday	A 500mb ridge provided clear skies during the morning, allowing temperatures and dewpoints to increase rapidly. The sounding for the day was impressive, showing an unstable atmosphere with good speed shear. There were numerous triggers during the day but the ridge was expected to delay convection until later in the day. Troughing was progged to begin by the evening hours, coupled with an area of moderate PVA. Winds had a strong easterly component which was thought would aid in storm initiation. The project area was mostly clear throughout the forecast period. A few towering cumulus were observed over the foothills and north of Rocky MH. Some of the towering cumulus developed into virga and very weak radar echoes. There was nothing remotely seedable all day. The atmosphere was indeed moderately unstable, but it remained capped due to upper level ridging. Tmax YC = 23C and no rain. Tmax QF = 24C and 1.6mm of rain.	No aircraft operations.

	Tmax Radar = 23C and no rain.	
June 23, Thursday	A low pressure system was developing east of the Rockies, with a cold front expected to make its way through the area, followed by the trough axis. High temperatures and dewpoints made for an unstable atmosphere, while speed and directional shear were conducive to severe storms. The first wave of convection was forecast to occur before 3pm as the cold front moved through the project area, with another event beginning after 6 pm as the trough axis moved through. The overnight forecast was for clear skies as temperatures dropped, stabilizing the atmosphere. Rapidly growing embedded thunderstorms formed just south of Springbank within an hour after the noon briefing. A long line of intense hail storms developed along a cold front from YYC to Rocky MH with cells moving northward along the front. There were multiple significant hail threats along this line with the most significant cells over Airdrie, Eckville, and Rimbey. All aircraft were utilized for seeding this line of storms. By late afternoon, the cold front had moved to the NE of the project area, but the upper level trough axis was approaching west of Banff. Another line of intense convection was observed on radar approaching far to the west. As the first wave moved out, all aircraft were directed to RTB and prepare for another round of seeding to begin shortly. The second wave of hailstorms then developed from Rocky MH toward YYC and moved toward the northeast along a mesoscale frontal boundary that was visible on radar. This second wave of hailstorms was somewhat weaker than the first with lower echo tops and less intense radar reflectivity. Three aircraft were utilized for this second wave. All cells dissipated before sunset. The project area was cold, clear and stable overnight. Max cell top: 12.9km, 65.5 max dBz, 60.7 max VIL. Tmax YC = 25C and .2mm of rain. Tmax QF = 25C and a trace of rain. Tmax Radar = 23C and .22mm of rain.	HS2 was launched at 1834Z for new cells developing southwest of YYC. They were airborne at 1853Z and began base seeding storm #1 SW of YYC at 1905Z. They continued to work a developing hailstorm over YYC as it moved northward toward Airdrie. The best inflow and new growth was on the N to NE side of the cells. At 2025Z, HS2 was redirected to another area of growth approaching Innisfail. They began seeding storm #2 SW of Innisfail at 2032Z. They continued to work this line of cells toward the north along with HS3 at cloud base. At 2127Z, the Innisfail cells diminished and HS2 started working the northern end of the line near Sylvan as HS3 pulled off in order to ascend to cloud top. HS2 was eventually replaced by HS4 N of Sylvan. HS2 stopped seeding at 2146Z and RTB to YYC to prepare for another wave of activity. They landed in YYC at 2228Z. HS1 was launched at 1847Z for top seeding over SW YYC. They were airborne at 1910Z and began seeding storm #1 at 1915Z dragging BIPs through their climb to cloud top. Pilots reported excellent liquid water and updrafts over the YYC and Airdrie area. At 2020Z, HS1 had descended to shed airframe icing. At 2022Z, HS1 began seeding storm #2 near Innisfail. They continued to work the same storm as it moved northward toward Eckville. At 2140Z, HS1 was out of flares and was replaced at cloud top by HS3 near Bentley. HS1 RTB at that time and landed in YYC at 2210Z to prepare for another wave of activity approaching from the west. HS3 was launched at 1925Z toward a line of development southeast of Rocky MH. They were airborne at 1947Z and reported excellent seedable bases extending from Rocky MH toward Airdrie. HS3 was directed to turn south and begin base seeding with BIPs. They began seeding storm #2 at 2009Z working from just NW of Olds to just S of Didsbury. HS3 continued base seeding the line as it pushed toward the north near Sylvan. At 2132Z, HS3 was directed to stop base seeding, ascend for top seeding and replace HS1 near Eckville. They began top seeding storm #2 at 2140Z. At 2217Z, the storm began to weaken and HS3 RTB to YQF to prepare for another wave of activity coming from the west. They landed at 2228Z. HS4 was launched at 2124Z for base seeding near Sylvan. They were airborne at 2141Z and began base seeding storm #2 at 2143Z. They worked the north end of the line from Eckville to Rimbey until the storm moved out of the project

		area to the north. At 2239Z, HS4 stopped seeding storm #2 and repositioned to the south intending to patrol near Cochrane as another wave moved in. They reached the Cochrane area at 2321Z and were then directed to land in YYC to top off their fuel and generators. They landed in YYC at 2332Z. HS3 was launched again at 0000Z (06/24) for development near Caroline moving toward Rocky MH. They were airborne at 0022Z (06/24) and began patrol S of Rocky MH at 0035Z (06/24). They then began top seeding storm #4 S of Caroline at 0126Z (06/24). At 0148Z (06/24), HS3 stopped seeding storm #4 and repositioned to the east near Carstairs. They began top seeding storm #3 at 0200Z (06/24). They descended to shed ice at 0208Z. After climbing back to cloud top, the storm was dissipating and seeding was halted. HS3 was directed to RTB at 0250Z (06/24). As HS3 was arriving near YQF, they reported new growth directly over the airport. They were instructed to cancel their RTB and began top seeding storm #5 over YQF at 0258Z (06/24). The cell quickly pulsed up and down and dissipated between Sylvan and Red Deer. HS3 RTB to YQF at 0325 (06/24) and landed at 0331Z (06/24). At 0011Z (06/24) HS4 was directed to relaunch out of YYC as soon as they were finished refueling and filling the generators. At 0103Z (06/24) the aircraft was ready and airborne with full fuel and chemical. They headed northeast of Cochrane and began base seeding storm #3 near Carstairs at 0121Z (06/24). At 0132Z (06/24), HS4 reported excellent inflow and a large shelf cloud connecting two cells. HS4 was then pushed out to the east of the storm by a mesoscale frontal boundary while the storm dissipated over the radar. At 0244Z (06/24), there were no hail threats and HS4 was directed to stop seeding and RTB. As they were heading home at 0303Z (06/24) they briefly patrolled a dissipating cell over the YQF airport. No inflow was found. They landed in YQF at 0325Z (06/24). HS2 was launched again at 0141Z (06/24) for hailstorms from Carstairs to Olds. HS2 was airborne out of YYC at 0158Z (06/24) and began patrolling at cloud base near Carstairs in the same area with HS4. The storm was already dissipating by the time they reached the area, and no inflow was found. HS2 was directed to RTB at 0236Z (06/24). No seeding occurred on this flight. They landed in YYC at 0255Z (06/24). <u>Flight Summary</u> HS2: 1844-2230Z; 11 BIP, 320 min acetone

		generator time; #1 SW of YYC, #2 SW of Innisfail. HS1: 1858-2216Z; 275 EJ, 20 BIP; #1 Calgary, #2 Innisfail to Sylvan. HS3: 1938-2232Z; 70 EJ, 21 BIP; #2 Didsbury to Sylvan. HS4: 2130-2336Z; 108 min acetone generator time; #2 SW Lacombe, patrol Cochrane. HS3: 0016Z (06/24)-0336Z (06/24); 188 EJ, 12 BIP; #4 S of Caroline, #3 Carstairs, #5 over YQF. HS4: 0050Z (06/24)-0332Z (06/24); 8 BIP, 166 min acetone generator time; #3 Carstairs, patrol YQF. HS2: 0149Z (06/24)-0300Z (06/24); no seeding, patrol Carstairs.
June 24, Friday	An upper level low was situated over the area with multiple pockets of vorticity rotating around it. The low provided good speed shear in the sounding, and moisture from the previous day's rain over the northern half of the project area provided good instability. Dewpoints were quite low in Calgary, limiting the chance of convective activity. The main trigger was a shortwave progged to move through the project area during the afternoon. Widespread weak thundershowers developed from west to east across the project area beginning just before the noon briefing. Cells were mostly embedded, low-topped, and nonthreatening. A few afternoon cells developed into significant hail threats between Bowden and Caroline, but they were not seeded as they did not pose a threat to any project cities. These hailstorms were nearly stationary. Pea size (5-10mm) hail was reported over far southeast YQF associated with a short-lived cell that developed directly over the city. By late evening, convection ended and widespread stratus rain developed over most of the region along with gusty surface winds. The western part of the project area cleared out overnight while light stratus rain lingered over the far northeast portion of the project area until morning. No convection occurred overnight. Max titan cell top=9.9km, 65 max dBz, 73.9 max VIL Tmax YC = 17C and a trace of rain. Tmax QF = 20C and 7.8mm of rain. Tmax Radar = 22C and 1.8mm of rain.	HS1 was launched at 1832Z for new weak development southwest of YYC. They were airborne at 1847Z and began patrolling from Cochrane to Okotoks. Pilots reported nothing seedable with only shallow convection. There were no hail threats, and HS1 was directed to RTB at 1915Z. They landed back in YYC at 1929Z. No seeding occurred. HS4 was launched at 0155Z (06/25) for possible development southwest of YQF. They were airborne at 0208Z (06/25), but had to land immediately due to problems with the acetone generators. They landed at 0215Z (06/25). HS4 fixed the generator problem quickly and took off again immediately. They were airborne again at 0221Z (06/25). They patrolled west of Sylvan for a brief time, but nothing seedable was found. All activity was diminishing and HS4 RTB at 0243Z (06/25). No seeding occurred. HS4 landed in YQF at 0250Z (06/25). <u>Flight Summary</u> HS1: 1840-1934Z; no seeding; patrol Calgary. HS4: 0202Z (06/25)-0218Z (06/25); no seeding; maintenance flight due to acetone generator failure. HS4: 0218Z (06/25)-0254Z (06/25); no seeding; patrol Sylvan.
June 25, Saturday	The upper level jet was located along the southern AB/SK border. Additionally, an upper level closed low was over the central AB/SK border. A shortwave trough swung counter-clockwise around the low. Weak vorticity advection occurred along the shortwave. The atmosphere was moderately unstable with weak speed shear. Weak thundershowers moved through the region during the afternoon and early evening. In the late afternoon, one isolated cell developed a 7.6km top east of Bowden. Another small area of threatening cells developed upwind of Red Deer in the late afternoon which seemed to be growing larger and taller, but the cells diminished before reaching any cities. There were no significant hail storms. The project area was stable overnight.	HS4 was launched at 2329Z for weak cells developing in the buffer zone northwest of YQF. They were airborne at 2350Z and patrolled for a short time near Sylvan Lake. The cells in the area were completely dissipating at that time and nothing seedable was observed. HS4 RTB at 0002Z (06/26). They landed in YQF at 0009Z (06/26). <u>Flight Summary</u> HS4: 2343Z (06/25)-0012Z (06/26); no seeding; patrol Sylvan.

	Max titan cell top=7.6km, 58 max dBz, 17.8 max VIL Tmax YC = 18.8C and no rain. Tmax QF = 17.6C and 2.8mm of rain. Tmax Radar = 16.0C and 10.0mm of rain.	

ALBERTA HAIL SUPPRESSION PROJECT 2011
DAILY SUMMARY REPORTS
WEEK No.5

Date	Weather	Activities Summary
June 26, Sunday	The previous day's closed upper level low weakened into a trough as it moved eastward across SK. Weak ridging began to replace the trough during the early evening hours. Vorticity advection was minimal over the area. At the surface, a cold front pushed southward over northern AB and became stationary over the Edmonton area. The only trigger mechanism was surface heating, and the sounding showed weak speed shear. Rapidly developing cells occurred over the northern half of the project area from early afternoon through early evening. Cells grew to threatening heights with 9 to 10 km tops. These hailstorms were short lived. They generally dissipated within 45 minutes of formation. Cells moved quickly from N to S. All activity cleared out well before dusk, and the project area was clear overnight. Max cell top: 10.6km, 64.5 max dBz, 79.5 max VIL Tmax YC = 18.9C and 5.2mm of rain. Tmax QF = 19.9C and 1.8mm of rain. Tmax Radar = 18.4C and 3.2mm of rain.	HS3 was launched at 1950Z for rapidly developing, short lived hail storms in the NE quadrant of the project area. The aircraft was airborne at 2014Z and began top seeding storm #1 N of YQF at 2027Z. At 2117Z, HS3 repositioned to N of Sylvan and began seeding storm #2 at 2126Z. At 2146Z, HS3 repositioned to near Rocky MH and began seeding storm #3 at 2158Z. At 2210Z, HS3 repositioned to N of Olds and began seeding storm #4 at 2221Z. At 2301Z, HS3 reported they were out of flares. They were replaced by HS1 at cloud top and RTB at that time. The aircraft landed in YQF at 2312Z. HS1 was launched at 2245Z for top seeding as the replacement for HS3. They were airborne at 2304Z and headed toward the eastern project boundary. They began seeding storm #5 N of Strathmore at 2319Z. At 2347Z, they stopped seeding storm #5 and repositioned to N of Olds for patrol. They then repositioned N of Three Hills and began seeding storm #6 at 0020Z (06/27). By 0025Z (06/27), convective activity began to diminish and HS1 was directed to RTB. On the way home, they reported some new development over YYC and patrolled for a brief time. Nothing significant developed in that area, and they landed in YYC at 0117Z (06/27). HS4 was launched at 2343Z for cells near Innisfail. They were airborne at 2359Z and began patrolling 0009Z (06/27) N of Olds with only weak inflow at cloud base. At 0022Z (06/27) HS4 repositioned to near Rocky MH. Nothing seedable was observed near Rocky MH, and all convective activity started to diminish. HS4 was directed to RTB at 0106Z (06/27) without doing any seeding. They landed in YQF at 0129Z (06/27). <u>Flight Summary</u> HS3: 2000Z-2315Z; 294 EJ, 18 BIP; #1 N of YQF, #2 Sylvan, #3 N of Rocky MH, #4 Olds. HS1: 2255Z (06/26)-0120Z (06/27); 39 EJ; #5 Strathmore, #6 Three Hills, patrol YYC. HS4: 2350Z (06/26)-0134Z (06/27); no seeding; patrol Olds, patrol Rocky MH.
June 27, Monday	Jet energy was located west and south of AB. At the mid-levels, a deep low formed off the coast of BC and began creeping towards California. A weak shortwave trough passed through the project area during the late afternoon and early evening hours, and weak vorticity was	HS4 flew a PR Flight from YQF to Olds for a radar tour. They departed YQF at 1722Z and landed in Olds at 1738Z. After the tour, they returned to YQF. They departed Olds at 2135Z and landed in YQF at 2153Z.

	associated with the shortwave. The atmosphere was capped with weak speed shear. Although the atmosphere was unstable, a strong midlevel cap developed at 10kft inhibiting any deep convection. There were a few shallow towering cumulus clouds in the afternoon, but no rain. A few weak radar echoes passed close to the N border overnight, but there were no TITAN cells detected on radar. Tmax YC = 22.5C and no rain. Tmax QF = 23.5C and no rain. Tmax Radar = 22.9C and no rain.	<u>Flight Summary</u> HS4: 1712Z-1741Z; no seeding; PR flight to Olds. HS4: 2129Z-2158Z; no seeding; PR return flight from Olds to YQF.
June 28, Tuesday	An upper level trough was positioned over BC which aided in sending several lobes of vorticity over central AB. The atmosphere was potentially very unstable but was capped for most of the day. Thunderstorms were expected to be longer lived due to the decent speed and directional shear. High clouds persisted throughout the day with a few modest cumulus clouds over the foothills producing rain showers and virga. In the early evening, a cell moved through the southern half of the project area. The cell eventually grew large enough to produce lightning after leaving the project area. No aircraft operations were conducted. Max cell top: 7.6km, 51.5 max dBz, 7.0 max VIL Tmax YC = 25.8C and no rain. Tmax QF = 23.8C and no rain. Tmax Radar = 25.2C and no rain.	No aircraft operations.
June 29, Wednesday	A small upper level jet streak was positioned over the Jasper National Park area. An upper level trough remained over BC for most of the day before moving northeastward through AB overnight. A shortwave trough moved across the area during the late afternoon and early evening hours. At the surface, a low formed just north of Red Deer with a trough extending southward along the lee side of the Rockies. The main triggers were surface heating and the shortwave trough. CAPE values were near 1200J/kg. During the afternoon, strong thunderstorms were observed to the north of the project area, but no significant radar echoes occurred inside the buffer zone borders. As evening set in, a line of weak echoes formed W of Red Deer. These did not grow to thunderstorm strength, and dissipated as night fell. Overnight, there were weak rain showers over the project area as a front moved through. Max cell top: 7.6km, 55.5 max dBz, 12.7 max VIL Tmax YC = 25.9C and no rain. Tmax QF = 26.7C and no rain. Tmax Radar = 24C and no rain.	HS4 was launched at 0104Z (6/30) for weak echoes W of Red Deer. Ground observations showed slowly growing clouds with crisp tops and wide bases. HS4 was airborne at 0122Z (06/30), and they were directed to patrol the southern edge of the line. They found marginal inflow and poor bases, and as radar failed to detect any intensification, HS4 RTB at 0142Z (06/30). They landed in Red Deer at 0148Z (06/30). <u>Flight Summary</u> HS4: 0112Z (06/30)-0153Z (6/30); no seeding; Patrol W of Red Deer.
June 30, Thursday	The upper level jet was over the Vancouver area during the afternoon hours and began to nudge its way into west central AB overnight. A shortwave trough moved over the	HS2 was launched at 1849Z for a cell over Calgary. They were airborne at 1904Z and reported a dissipating cell with poor bases and

	project area overnight. A surface trough was positioned over southern AB for most of the day. The atmosphere was slightly unstable with weak convective inhibition over the northeast part of the project area. Weak echoes from cumulus clouds were apparent on radar in the late morning. Shortly after briefing, a line over Calgary began to intensify, with more cells farther to the northwest threatening the southern and central section of the project area. Cells were a marginal hail threat to a few towns, and were patrolled and seeded for some time. During the early evening, a few significant cells formed quickly over the foothills moving to the central part of the project area before dissipating into rain showers for the overnight period. Max cell top: 9.9km, 63.5 max dBz, 51.2 max VIL Tmax YC = 20C and no rain. Tmax QF = 19C and 5mm of rain. Tmax Radar = 18C and 2.4mm of rain.	marginal inflow. They were then directed to patrol a weak echo W of Okotoks, which they observed to be a cumulus cloud with very little growth and no precipitation. As conditions near Calgary and Okotoks continued to weaken, HS2 was directed to a growing cell W of Carstairs at 2007Z. They reported a heavy rain shaft, lightning, and small pockets of 500fpm inflow on the SE side of the cell. They began seeding with acetone burners at 2025Z in response to more constant 500fpm inflow. At 2101Z, HS2 began using BIPs when radar showed intensification and pilots reported inflow increasing. At 2115Z, HS2 reported the cell was weakening and stopped using BIPs. As the cell continued to weaken and moved to the E of Carstairs, HS2 RTB YYC and landed at 2220Z. At 0255Z (07/01), HS4 launched for a significant cell W of Didsbury. This storm had intense lightning and was exhibiting right-turning tendencies. HS4 was airborne at 0311Z (07/01) and reported disorganized, low bases with light rain. Radar confirmed that the cell had dissipated significantly. The cell was patrolled until HS4 RTB at 0350Z (07/01). HS4 landed at 0409Z (07/01). <u>Flight Summary</u> HS2: 1900Z-2225Z; 3 BIP, 190 min acetone generator time; patrol E of Calgary, patrol W of Okotoks, patrol W of Carstairs, storm #1 W of Carstairs. HS4: 0302Z (07/01)-0414Z (07/01); no seeding; patrol W of Didsbury.
July 1, Friday	The upper level jet was pushing into southern Alberta while a ridge was beginning to develop over the area. Strong warm air advection was occurring at midlevels. Low levels were relatively dry. There were no significant surface features or forcing mechanisms and the atmosphere was stable above 16kft. Only a very shallow layer of instability was present from 10kft to around 16kft. A few isolated convective echoes were expected with mainly just virga and/or sprinkles of rain. Widespread fair weather cumulus was expected in the afternoon. Stable conditions were expected overnight. Small convective rain showers and virga were observed on radar during the late morning through afternoon, and a layer of fair weather cumulus was present throughout the day. Clouds cleared during the evening and overnight. There were no TITAN cells. Tmax YC = 19.6C and no rain. Tmax QF = 18.2C and no rain. Tmax Radar = 17.5C and no rain.	No aircraft operations.
July 2, Saturday	The upper level jet was positioned just north of the project area over northern AB. An upper level ridge remained in place with warming and subsidence aloft. Surface dew	No aircraft operations.

	points were rising to around 8 to 10C during the day, but the thermodynamic profile was mainly stable due to the warm temperatures aloft. A Chinook arch cloud was present along the range during the morning which indicated stable conditions. A very thin layer of unstable air was present just below 16kft, but only enough to provide some afternoon fair weather cumulus. No convective precipitation was forecast. Stable, clear conditions were expected overnight. Cirrus and chinook clouds were visible during the late morning. A few isolated fair weather cumulus clouds were observed during the afternoon, but skies remained mostly clear throughout the day and overnight. There were no radar echoes through the period. Tmax YC = 23.7C and no rain. Tmax QF = 24C and no rain. Tmax Radar = 24C and no rain.	

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Date	Weather	Activities Summary
July 3, Sunday	A southwesterly upper jet was positioned over southern Alberta. A cold front and a shortwave trough were progged to push through the project area during the early afternoon hours. Low level moisture was present with surface dew points near 12C. Midlevels were cooling gradually. The atmosphere was unstable with nearly 1000 J/Kg CAPE and a Lifted Index of -5. The project area was under the left exit quadrant of the upper jet. There was decent speed shear, but poor directional shear. Severe hailstorms were expected to begin shortly after the noon briefing, lasting through the evening hours. Stable conditions were forecast for the overnight hours. In the early afternoon, convection began to initiate along the cold front as it crested the Rockies. The storms along the front were weak at first, but became more severe as the front moved through the project area. Seeding conditions were very embedded and difficult to work during this wave of convection. After frontal passage, the project area was void of storms except for the northern area, where storms began to initiate along a trough during the evening. These storms displayed strong right moving characteristics and tracked through some densely populated areas, including Red Deer. The overnight period was uneventful. Hail up to 25mm was reported in NW Red Deer. Max cell top: 12.1km, 66.5 max dBz, 88.6 max VIL Tmax YC = 26.4C and no rain. Tmax QF = 24.4C and 3mm of rain. Tmax Radar = 24.0C and no rain.	HS2 flew from Calgary to Spring Bank for refueling due to problems with the Calgary fuel truck. They were airborne at 1709Z and landed at 1718Z. They refueled successfully and were ready for operations shortly after landing. HS2 was launched from Springbank to patrol some developing storms SW of Sundre at 1740Z. They were airborne at 1758Z and reported a weak code 2 rain shaft, while radar showed some shallow embedded convection during the same period. HS2 patrolled the cells until 1849Z when they RTB YYC after no intensification of the cells was noted. They landed at 1858Z. HS1 was launched for top seeding at 1913Z in response to quickly developing cells over N Calgary and Airdrie. They were airborne at 1935Z and began using BIPs at 1947Z as they climbed to top seeding altitude and were redirected to a cell developing directly over Calgary. When they reached altitude, they found embedded conditions and began using EJs. They continued to experience low visibility and embedded conditions, and radar indicated the storm beginning to dissipate as it moved W of Calgary. At 2036Z, HS1 was redirected to Cochrane as the Calgary cell continued to dissipate. It was immediately obvious that this cell was a low topped cumulus of no threat, so HS1 RTB at 2045Z. They landed at 2100Z. HS2 was launched again to base at 1918Z to the cells over Airdrie and N Calgary. They were airborne at 1936Z and were redirected to the cells growing directly over Calgary. HS2 lit burners at 1950Z, with BIPs following shortly at 1955Z. They initially found good inflow, but by 1959 were finding only outflow, so they were directed to the E end of the cell to protect Strathmore using only acetone generators. They continued to find only outflow with visibility becoming poor. As the storm continued to weaken, they were directed to patrol SW of Calgary at 2026Z. As the cells appeared to pose no threat, HS2 RTB to Spring Bank for fuel at 2121Z. They landed in Spring Bank at 2135Z. HS3 was launched for top seeding at 1921Z on development W of Red Deer. They were airborne at 1941Z and reported a good convective base with embedded conditions at top. They had difficulty finding many feeders, but feeders had good liquid water and they

		seeded with BIPs and EJs. At 2025, HS3 stopped seeding as the main cell had passed Red Deer, and the convection to the W proved to be weak rain showers. Pilot and radar observations continued to show no threat of severe convection for Red Deer, so at 2049Z HS3 RTB Red Deer. They landed at 2055Z. HS4 was launched to cloud base for convection W of Red Deer at 1923Z. They were airborne at 1936Z. They were told to ignite burners at 1942Z, and to use BIPs beginning at 1955Z. It soon became apparent that the cells W of Red Deer posed little threat. HS4 was redirected over Sylvan Lake and told to stop using BIPs at 2003Z. They were unable to find any seedable bases, and reported poor visibility. They were directed to patrol further W over the RMH VOR on some weak cells identified on radar. They reported light rain and glaciated tops, so HS4 RTB to Red Deer at 2102Z. They landed at 2127Z. HS2 was launched again at 2210Z to patrol severe cells N of RMH. They were airborne at 2224Z, and were directed to climb to cloud top at 2307Z due to difficulty with radio communication. They began to seed lightly with EJs at 2336Z as the storm was intense and would eventually enter some target cities. They reported a lack of performance from their aircraft due to ice buildup. At 0042Z (07/04), HS3 arrived to replace HS2 at cloud top, and HS2 descended to base where they began seeding with BIPs and acetone generators at 0054Z (07/04). They continued to find excellent inflow for the duration of the storm. After the storm moved E of Red Deer, HS2 RTB to YQF at 0140Z (07/04). They landed at 0148Z (07/04). HS3 was launched again at 0012Z (07/04) to the storm N of RMH. They were airborne at 0029Z (07/04) and directed to top where they would replace HS2. They arrived and began seeding with BIPs and EJs at 0042Z (07/04), reporting excellent liquid water and very strong updrafts. They descended to shed ice at 0118Z (07/04), ascending again at 0126Z (07/04), lighting BIPs during the climb. As the storm moved E of Red Deer, they repositioned for a cell W of Innisfail which had formed along the storms outflow boundary. They seeded using only EJs beginning at 0148Z (07/04). At 0221Z (07/04), as the storm moved E of Innisfail, they were directed to stop seeding and patrol W of Olds on a towering cumulus spotted from the radar. They found the cell to be no threat. They RTB to Calgary at 0227Z (07/04). They landed at 0244Z (07/04). HS4 was launched at 0015Z (07/04) to a storm

		NW of Lacombe. They were airborne at 0036Z (07/04) and began seeding with acetone generators at 0048Z (07/04). As this storm posed little threat to Lacombe, and the storm W of Red Deer was very severe, they were directed to move to the Red Deer storm at 0101Z (07/04) leaving their acetone generators on and lighting BIPs when they arrived at the storm. They found excellent inflow and a good base, sharing the space with HS2 until the storm was E of Red Deer. At 0139Z (07/04), they repositioned to W of Innisfail, continuing to seed with generators and BIPs beginning at 0150Z (07/04). They reported intensifying and then diminishing conditions. They stopped seeding at 0224Z (07/04) as the inflow became marginal. They then RTB to YQF at 0227Z (07/04), landing at 0251Z (07/04). HS1 was launched at 0133Z (07/04) to patrol a towering cumulus W of Olds which was spotted by meteorologists and appeared to indicate storm initiation along a gust front. They reported mechanical problems and remained on the ground in Calgary. HS3 flew a reposition flight from Calgary to Red Deer after the threat of storms had passed. They were airborne at 0436Z (07/04) and landed at 0500Z (07/04). <u>Flight Summary</u> HS2: 1702Z-1720Z; no seeding; YYC to Spring Bank for fuel. HS2: 1752Z-1901Z; patrol SW Sundre, patrol SW Didsbury; no seeding; launched from Spring Bank, landed at YYC. HS3: 1935Z-2100Z; 68 EJ, 2 BIP; storm #2 Red Deer. HS1: 1925Z-2105Z; 72 EJ, 3 BIP; storm #1 Calgary to Strathmore. HS4: 1928Z-2131Z; 2 BIP, 84 min generator time; #2 Red Deer, patrol Sylvan, patrol RMH. HS2: 1928Z-2137Z; 1 BIP, 70 min acetone generator time; storm #1 Calgary to Strathmore, patrol SW of Calgary. Takeoff from Calgary, land in Spring Bank. HS3: 0024Z (07/04)-0248Z (07/04); 271 EJ, 2 BIP; storm #3 Red Deer, storm #5 W Innisfail, patrol W Olds; Landed at YYC. HS4: 0028Z (07/04)-0255Z (07/04); 12 BIP, 190 min generator time. Storm #4 Lacombe, storm #3 W Red Deer, patrol NW Innisfail. HS2: 2218Z (07/03)-0150Z (07/04); 72 EJ, 9

		BIP, 110 min generator time; patrol NW Red Deer, top seed #3 NW Red Deer, base seed #3 NW Red Deer. Takeoff Spring Bank, land Red Deer. HS3: 0426Z (07/04)-0505Z (07/04): Reposition from YYC to YQF.
July 4, Monday	A weak upper jet was positioned over central Alberta. The upper level flow was nearly zonal with no significant vorticity pushing through the region. The atmosphere was warming aloft. Southeasterly surface winds were channeling moisture into the region. Morning dew points were low and forecast to reach modest levels during the day. Weak thunderstorms were forecast during the afternoon with low tops below 25kft. The atmosphere was expected to stabilize after 8z. Afternoon dew points rose higher than expected which allowed for deep convection. Towering cumulus clouds began to slowly form over the foothills during the late afternoon hours. Most of these growing cumulus clouds were short-lived and did not become large enough to show up on radar. Around 00z, stronger growth was observed north of Sundre. This convection eventually turned into a strong TITAN cell that marched southeastward across the project area. Another strong cell formed W of this large storm and tracked southeastward through Carstairs. Overnight, the atmosphere was stable. Max cell top: 9.1km, 63 max dBz, 43.9 max VIL Tmax YC = 21.8C and no rain. Tmax QF = 20.0C and no rain. Tmax Radar = 21.0C and 8mm of rain.	HS2 flew a reposition flight from Red Deer to Calgary. The flight became airborne at 1855Z and landed at 1925Z. HS3 was launched at 0107Z (07/05) to a rapidly growing cell W of Olds. The flight became airborne at 0128Z (07/05) and found growth along the southern edge of the storm. At 0142Z (07/05) HS3 started seeding storm #1 NW of Didsbury. Then at 0147Z (07/05) the aircraft reported excellent growth. HS3 continued to seed the storm as it moved over the town of Didsbury. At 0248Z (07/05), the aircraft stopped seeding storm #1 and was repositioned toward new growth S of Sundre. HS3 started seeding storm #2 W of Didsbury at 0253Z (07/05). The aircraft fired its last EJ at 0317Z (07/05), so the aircraft dropped to base and started seeding the same storm with BIPs. At 0408Z HS3 (07/05) stopped seeding and RTB to Calgary. The aircraft landed in YYC at 0420Z (07/05). HS4 was launched to storm #1 NW of Didsbury at 0122Z (07/05). The flight became airborne at 0147Z (07/05). At 0207Z (07/05) the pilots quickly found 500fpm inflow and started seeding storm #1 NW of Didsbury. HS4 continued to seed this convection until it began to leave the project area near the town of Acme. The aircraft was then redirected to another storm (#2) NW of Carstairs. They started seeding this storm at 0402Z (07/05) and stopped seeding the storm, at 0443Z (07/05) once it was past Carstairs. The aircraft RTB at the same time, landing in YQF at 0457Z (07/05). HS2 was launched to top seed storm #2 NW of Carstairs at 0324Z (07/05). The aircraft became airborne at 0335Z (07/05). HS2 eventually found growing turrets along the southern edge of the storm and started seeding storm #2 at 0402Z (07/05). The aircraft stopped seeding the storm after it had passed over the town of Carstairs at 0445Z and RTB. The aircraft landed in Calgary at 0455Z (07/05). HS3 flew a reposition flight from Calgary to Red Deer. The flight became airborne at 0614Z (07/05) and landed at 0640Z (07/05). <u>Flight Summary</u> HS2: 1850Z-1928Z; no seeding; reposition

		flight from YQF to YYC. HS3: 0119Z (07/05)-0429Z (07/05); 300 EJ, 18 BIP; #1 NW of Didsbury, patrol NW of Olds, and #2 W of Didsbury. HS4: 0137Z (07/05)-0502Z (07/05); 308 min generator time, 17 BIP; #1 W of Didsbury and #2 Carstairs. HS2: 0330Z (07/05)-0500Z (07/05); 63 EJ; #2 Carstairs. HS3: 0606Z (07/05)-0642Z (07/05); no seeding; reposition flight from YYC to YQF.
July 5, Tuesday	The upper level jet core stretched across northern Alberta. A broad ridge was building over the region, and midlevels were warming. A significant temperature inversion was expected to develop around 15kft as the day progressed. Some weak instability was present in a shallow layer below the stable layer. The midlevel cap was expected to inhibit any low level cumulus from developing into thunderstorms. Only fair weather cumulus was expected to develop during the afternoon. Stable conditions were expected overnight. Fair weather cumulus clouds formed along the western and eastern borders of the project area during the afternoon hours. Otherwise, skies remained mostly clear and there were no radar echoes. Tmax YC = 24.3C and no rain. Tmax QF = 24.5C and no rain. Tmax Radar = 23.0C and no rain.	HS2 flew a PR Flight from YYC to Olds for a radar tour. They departed YYC at 1708Z and landed in Olds at 1723Z. After the tour, they returned to YYC. They departed Olds at 2118Z and landed in YYC at 2138Z. <u>Flight Summary</u> HS2: 1700Z-1725Z; no seeding; PR flight to Olds. HS2: 2115Z-2140Z; no seeding; PR return flight from Olds to YYC.
July 6, Wednesday	A broad ridge was positioned over Alberta. Low levels were very moist with dew points up above 12C. A warm front was draped across N Alberta and a cold front stretched from Jasper to Seattle. The atmosphere was unstable with CAPE values near 1300 J/Kg and lifted index of -4. The wind shear was weak and not sufficient for organized updrafts. There was a low level cap, but afternoon high temperatures were expected to reach convective temperature, and there was weak upslope flow. Otherwise, there were no other triggers for afternoon convection. Afternoon and evening hailstorms were forecast with a possibility for activity continuing into the overnight hours. A weak cold front was expected to approach the area late in the forecast period. Towering cumulus clouds were observed along the western project area border during the late afternoon hours. All thunderstorm activity was concentrated just north of the project area. There were no TITAN cells inside the project area. Tmax YC = 26C and no rain. Tmax QF = 26C and no rain. Tmax Radar = 25C and no rain.	No aircraft operations.
July 7, Thursday	Early morning fog and then clear skies later in the morning evidenced a very unstable and eventful day. An approaching 500mb trough was expected to initiate lee cyclogenesis during the afternoon with a series of fronts expected to be the main triggers throughout the day. Strong upslope flow was also expected to contribute to	HS3 was launched at 1933Z to a developing storm SW of Sundre. The flight became airborne at 2002Z. HS3 started low dose seeding storm #1 at 2020Z. Then at 2102Z the aircraft was redirected to storm #2 SW of Rocky MH. The flight seeded this convection

	storm initiation. The atmosphere was very unstable with good speed shear and was capped during the early afternoon, displaying a classic loaded gun type situation with a curved hodograph. Very severe convection was forecast to start in the midafternoon with supercells possible. Towering cumulus began to form over the foothills during the early afternoon hours. The southern cumulus clouds had trouble busting through the cap. On the other hand, the northern convection quickly broke through the cap and explosive cellular growth soon followed. This storm (#1) was originally back-building over the foothills and near stationary SW of Sundre, but the storm eventually became a supercell and began to move east towards Innisfail and Red Deer. The supercell dropped tennis ball sized hail near Sundre and eventually moved through Bowden, Penhold, Innisfail, and Red Deer before dissipating near the town of Lacombe. Golf ball sized hail was reported in western Red Deer while eastern Red Deer received only heavy rain. Additionally, 2.5 to 5 cm hail was reported in Penhold. This strong storm system also produced several tornadoes between Sundre and Innisfail. One tornado destroyed some rural property near Innisfail. Other storms formed over the project area during this same time period but were minimal in comparison to the supercell. Overnight, a cold front moved from W to E across central AB which triggered several weak convective TITAN cells over the region. These cells produced rain showers. Max cell top: 15.1km, 67.5 max dBz, 117.4 max VIL Tmax YC = 27C and no rain. Tmax QF = 23C and 14.2mm rain. Tmax Radar = 25C and a trace of rain.	for a short time, seeding began at 2142Z. At 2152Z, HS3 was redirected to an intensifying supercell near Sundre. The flight started seeding storm #1 again at 2216Z. Then at 2258Z the aircraft dropped to base and continued to seed storm #1. HS3 base seeded along with HS4. At 2349Z the aircraft RTB and landed at 0009Z (07/08). HS1 was launched at 1942Z to patrol the area W and SW of Calgary. The flight became airborne at 1959Z and RTB at 2214Z. The aircraft landed at 2230Z. HS4 was launched at 2211Z to an intense storm (#1) over Sundre. The aircraft became airborne at 2223Z. Then at 2238Z HS4 started base seeding storm #1 W of Didsbury. HS4 base seeded along with HS3. Once HS3 RTB, the aircraft then base seeded with HS2. The crew reported they were finding 900fpm inflow along the S side of the cell at 0051Z (07/08). At 0133Z (07/08), HS4 stopped seeding and RTB to YYC. The aircraft landed at 0156Z (07/08). HS2 was launched at 2231Z to top seed Storm #1 W of Olds. The aircraft became airborne at 2259Z. The flight's airborne time was delayed due to royalty flying into the Calgary airport. At 2330Z HS2 began top seeding Storm #1 with ejectables flares only. The aircraft began to pick up a lot of airframe ice by 2344Z. Then at 2350Z, the crew reported that they could not maintain altitude with their aircraft due to ice buildup, so HS2 was dropped to base. The aircraft then started seeding with BIPs and generators. Next, the crew reported at 0122Z (07/08) that the inflow was increasing. HS2 then continued to seed as the supercell moved northeastward across the project area. At 0308Z (07/08) the crew reported that the left generator was empty. The aircraft RTB at 0314Z (07/08) after running out of chemical and landed at 0345Z (07/08). HS1 was launched at 2347Z to a supercell W of Olds; this was HS1's second flight of the day. The flight became airborne at 0002Z (07/08) and started seeding Storm #1 at 0019Z (07/08). At 0034Z (07/08), HS1 got out of position and was redirected to the S. Unfortunately, the aircraft started to become boxed in with growing turrets, so the crew was forced to continue to the NW side of the Supercell. The aircraft then had to fly around another cell to the W before they were able to come back around to the S side of the supercell again. At 0248Z (07/08), HS1 descended to base and started seeding. The flight then stopped seeding storm #1 at 0314Z (07/08) and RTB. HS1 landed at 0425Z (07/08).

		HS3 was launched for a second flight at 0114Z (07/08); the crew returned to the same supercell (Storm #1) which was now SW of Innisfail. The aircraft became airborne at 0130Z (07/08) and flew around the eastern side of the storm in order to start base seeding. The flight started seeding at 0145Z (07/08). Then at 0157Z (07/08) the crew reported a tornado. The aircraft stopped base seeding and began to climb up to top in order to replace HS1, at 0235Z (07/08). The supercell (storm #1) diminished around 0359Z (07/08), so the aircraft was redirected to new growth SW of Rocky MH. HS3 started seeding Storm #3, SW of Rocky MH, at 0421Z (07/08). The flight stopped seeding the storm at 0438Z (07/08) and started patrolling the same area. They RTB at 0454Z (07/08) and landed at 0514Z (07/08). HS4 flew an overnight reposition flight from Calgary to Red Deer. The aircraft was airborne at 0856Z and landed at 0926Z (07/08). <u>Flight Summary</u> HS3: 1952Z (07/07)-0013Z (07/08); 298 EJ, 16 BIP; #1 SW of Sundre, #2 SW of RMH. HS1: 1952Z-2237Z; no seeding; patrol W and SW of Calgary. HS4: 2214Z (07/07)-0202Z (07/08); 335 min generator time, 24 BIP; #1 W of Didsbury to YQF. HS2: 2241Z (07/07)-0349Z (07/08); 381 min generator time, 20 BIP, 35 EJ; #1 W of Olds to YQF. HS1: 2354Z (07/07)-0429Z (07/08); 269 EJ, 16 BIP; #1 W of Olds to YQF. HS3: 0125Z (07/08)-0516Z (07/08); 125 EJ, 13 BIP; #1 Innisfail to YQF and #3 SW of Rocky MH. HS4: 0845Z (07/08)-0931Z (07/08); no seeding; reposition flight from YYC to YQF.
July 8, Friday	Low pressure was located over central Alberta, and a 500mb trough axis was just breaching the Rockies. A dry continental air mass was encroaching into the area with dewpoints and temperatures expected to drop throughout the day. Showers were possible in the early afternoon, but the atmosphere was stabilizing throughout the day. No severe convection was expected. Rain showers began to push into the region during the afternoon. Weak, short-lived convection sprung up along the leading edge of these stratiform rain showers. By the evening hours, most of the project area was experiencing light to moderate rain showers. The stratiform rain showers lasted through the rest of the forecast period. Max cell top: 6.1km, 53 max dBz, 16.4 max VIL Tmax YC = 20C and 0.2mm rain. Tmax QF = 20C and 6.4mm rain. Tmax Radar = 21C and a trace of rain.	No aircraft operations.

July 9, Saturday	A closed low was located over central Alberta with wrap around clouds and vorticity obvious on satellite imagery. The wrap around moisture gave a chance of showers and possibly a weak thunderstorm in the northern buffer zone. The southern half of the project area was expected to remain free of precipitation. The atmosphere was marginally unstable with poor shear indicating the threat for severe convection was nil. Deep convection remained far to the northeast of the project area during the day. Bands of light stratus rain pushed through the area during the afternoon and evening. A few convective clouds were embedded in the stratus rain during the afternoon, but no lightning was detected. Isolated light showers moved through the project area during the overnight hours. Max cell top: 5.4km, 51 max dBz, 5.1 max VIL Tmax YC = 20C and 0.2mm of rain. Tmax QF = 20C and 6.4mm of rain. Tmax Radar = 21C and a trace of rain.	No aircraft operations.

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WEEK No. 7

Date	Weather	Activities Summary
July 10, Sunday	One trough was located to the north over Edmonton and another over central British Columbia. Combined with upslope flow, these were expected to be the main triggers for the day. Wind shear was poor with very little instability in the forecast sounding as well. Rain showers were expected for the later afternoon with no threat of severe convection. The focus was on the northern half of the project area where rain the previous few days provided the boundary layer with more moisture than in the southern sections of the project area. A line of weak convection moved off the hills along the western project boundary at 00Z and pushed east through the entire project area throughout the evening. A few cells developed into marginal hail threats over the Calgary area, and some seeding took place during the early evening between Calgary and High River. Convection became weak during the late evening and eventually transitioned to widespread stratiform rain which lingered over the area through morning. Max cell top: 9.9km, 63.5max dBz, 53.8max VIL Tmax YC = 21C and 7mm of rain. Tmax QF = 19C and a trace of rain. Tmax Radar = 19C and 7.4mm of rain.	HS2 was launched at 0140Z (07/11) for a line of convection developing along the foothills west of Cochrane. They were airborne at 0152Z (07/11). HS2 began base seeding storm #1 over Calgary at 0204Z (07/11) with acetone generators. At 0221Z (07/11) HS2 repositioned to another cell nearing southern Calgary. They began seeding #2 near Okotoks at 0232Z (07/11). At 0239Z (07/11) they moved back to cell #1 and continued seeding. At 0313Z (07/11) they shifted back to cell #2 near Okotoks again and continued seeding with only marginal inflow. At 0332Z (07/11) HS2 repositioned to near High River for patrol. They then reported a burner problem and briefly landed in High River to fix the burner. They were airborne and seeding again with both generators on storm #3 High River at 0350Z (07/11). At 0424Z (07/11) they stopped seeding and RTB to YYC. They landed at 0445Z (07/11). HS1 was launched at 0310Z (07/11) for top seeding near High River. They were airborne at 0326Z (07/11) and began seeding storm #3 near High River at 0343Z (07/11). All activity then began to diminish below hail criteria as it cleared the High River area. HS1 stopped seeding and RTB to YYC at 0434Z (07/11). They landed at 0448Z (07/11). <u>Flight Summary</u> HS2: 0148Z (07/11)-0449Z (07/11); 8 BIP, 176min acetone generator time; #1 YYC, #2 Okotoks, #3 High River. HS1: 0319Z (07/11)-0453Z (07/11); 72 EJ; #3 High River.
July 11, Monday	The day began with cool temperatures and thick cloud cover over the project area. Surface moisture was high, but cloud cover was expected to keep temperatures somewhat low. There was good shear in the sounding and modest instability in the southern half of the project area. While there were a few factors inhibiting convection for the day, such as mid-level warming and the presence of high pressure, these were not anticipated to completely prevent convection. Convection was anticipated to arise mainly over the foothills beginning in the mid-afternoon as a surface trough approached and convective temperatures were breached. Good upslope flow during the day was to aid in convective initiation. Stratiform rain was present during the morning hours. Thunderstorms began developing south of Calgary in the late morning and intensified to above hail criteria during the noon briefing. Widespread thunderstorms moved	HS3 flew a PR flight from Red Deer to Olds for a radar tour. They took off at 1727Z and landed in Olds at 1740Z. HS1 was launched at 1807Z for hailstorms south of Calgary moving toward the north. They were airborne at 1824Z and began top seeding storm #1 south of Calgary at 1839Z with good feeders and liquid water. They seeded the cell until it moved well clear of Calgary. They stopped seeding and RTB at 1952Z. HS1 landed in YYC at 2004Z. HS2 was launched at 1755Z for developing hailstorms south of Calgary. They were airborne at 1820Z and began base seeding storm #1 south of Calgary at 1826Z with one acetone burner and BIPs. They had trouble

	through the entire project area throughout the afternoon and all evening. Most cells remained just below hail criteria, but there were also multiple hail storms that were seeded. Thunderstorms finally transitioned to rain showers around 08Z. Stratus rain lingered through the rest of the night. Max cell top: 12.9km, 69.5max dBz, 132.4max VIL Tmax YC = 19C and 10.4mm of rain. Tmax QF = 20C and 0.6mm of rain. Tmax Radar = 20C and 0.6mm of rain.	with the right burner and could not get it ignited. At 1933Z inflow began to diminish. At 1950Z, HS2 reported no inflow left and RTB to YYC. They landed at 2005Z. HS3 was launched at 1937Z from Olds-Didsbury airport (at radar for tour) toward cells near Carstairs. They were airborne at 1947Z and began patrol near Carstairs finding nothing worth seeding. They then continued south to a storm over Okotoks headed toward Strathmore. They began top seeding storm #2 at 2030Z. At 2038Z, they stopped seeding #2 and patrolled near Cochrane. At 2104Z, they moved back toward the cell approaching Strathmore and resumed seeding at 2124Z. At 2127Z, they stopped seeding #2 and patrolled the cell as it was starting to track south of Strathmore. They then repositioned to near Red Deer. At 2214Z HS3 began seeding #4 over YQF. This cell remained weak, and they stopped seeding at 2223Z to patrol Rocky MH. At 2306Z, they moved southward and then began seeding #6 near Cremona at 2319Z. At 2347Z, HS3 was low on fuel and RTB. They landed in Olds-Didsbury at 2357Z to drop off a field meteorologist who was on board observing the flight. HS3 then took off from Olds-Didsbury immediately to return to YQF. They were airborne at 0001Z (07/12) and landed in YQF at 0012Z (07/12). HS4 was launched at 2027Z to the Lacombe area. They were airborne at 2045Z and began base seeding storm #3 near Lacombe at 2051Z with burners and BIPs in good inflow. At 2146Z, the cell cleared the Lacombe area. HS4 stopped seeding #3 and RTB. They landed in YQF at 2151Z. HS1 was launched again at 2121Z for new development west of Calgary. They were airborne at 2133Z and began top seeding storm #5 near Cochrane at 2214Z. They continued to seed at a very low rate in developing cumulus towers near Cochrane until 0006Z (07/12) when they were directed to stop seeding and just patrol west of Calgary. At 0130Z (07/12) they began top seeding #7 west of Okotoks. At 0222Z (07/12) HS1 was getting low on fuel and RTB. They landed in YYC at 0237Z (07/12). HS2 was launched again at 2236Z to southwest of Springbank. They were airborne at 2258Z. Due to low cloud bases, HS2 was forced to stay east of the foothills and patrol, awaiting any significant activity moving off the hills. At 2329Z, HS2 began base seeding storm #5 southwest of Calgary with burners only. At 0006Z (07/12) they lost all inflow and were directed to stop seeding and patrol the area. At 0019Z (07/12) activity was diminishing

		and HS2 RTB to YYC. They landed at 0029Z (07/12). HS2 was launched for a third flight at 0121Z (07/12). They were airborne at 0146Z (07/12) and headed for a cell approaching Okotoks. They began base seeding storm #7 near Okotoks at 0202Z (07/12) with burners and BIPs along the east side of a large shelf cloud. At 0337Z (07/12), HS2 stopped seeding when the cell became weaker and inflow dropped off. They continued to patrol the area near Okotoks. At 0359Z (07/12), the cell dissipated and HS2 RTB to YYC. They landed at 0414Z (07/12). HS3 was launched again at 0224Z (07/12) for an intense cell near Okotoks. They were airborne at 0243Z (07/12). At 0317Z (07/12), they began top seeding storm #7 near Okotoks finding lots of liquid water and graupel for a short time. At 0337Z (07/12), they stopped seeding and reported very minimal growth. They continued to patrol the area for a short time as the cell continued to weaken. At 0349Z (07/12) they started heading back north. At 0406Z (07/12) they started seeding storm #8 near Sundre, but only made a couple passes on the storm before repositioning to near Eckville at 0412Z (07/12). They began seeding storm #9 near Eckville at 0422Z (07/12). At 0427Z (07/12), HS3 pulled off that cell and repositioned to near Rocky MH. At 0435Z (07/12) they began seeding #10 near Rocky MH. They RTB at 0442Z (07/12) as all activity across the area was diminishing. They landed in YQF at 0454Z (07/12). HS4 was launched at 0348Z (07/12). They were airborne at 0359Z (07/12) and headed toward cells near Eckville. They began base seeding storm #9 near Eckville at 0406Z (07/12) with burners and BIPs. The storm moved out of the project area and HS4 RTB at 0524Z (07/12). They landed in YQF at 0533Z (07/12). <u>Flight Summary</u> HS3: 1716Z-1741Z; no seeding; PR flight from YQF to Olds-Didsbury. HS2: 1815Z-2010Z; 11 BIP, 92 min acetone generators; #1 Calgary. HS1: 1811Z-2009Z; 9 BIP, 232 EJ; #1 Calgary. HS3: 1942Z-2359Z; 1 BIP, 197 EJ; #1 Calgary, patrol S Didsbury, #2 Okotoks, patrol Cochrane, #2 SW Strathmore, #4 Red Deer, patrol RMH, #6 SW Cremona; Landed at Olds-Didsbury. HS4: 2035Z-2154Z; 2 BIP, 106 min generator time; #3 Lacombe. HS1: 2125Z (07/11)-0241Z (07/12); 177 EJ; patrol W Calgary, #5 Cochrane to Calgary, #7

		Okotoks. HS2: 2250Z (07/11)-0033Z (07/12); 80 min acetone generators; #5 Cochrane to Calgary. HS3: 0000Z (07/12)-0015Z (07/12); no seeding; reposition flight from Olds to Red Deer. HS2: 0135Z (07/12)-0416Z (07/12); 13 BIP, 188 min acetone generators. #7 Okotoks. HS3: 0236Z (07/12)-0501(07/12); 152 EJ; #7 Okotoks, #8 Sundre, #9 Eckville, #10 RMH. HS4: 0353Z (07/12)-0537Z (07/12); 5 BIP, 164 min acetone generators; #9 Eckville.
July 12, Tuesday	A trough was expected to move into the area, finally becoming a factor after having lingered over BC for several days. There were multiple triggers, with upslope flow and troughing the main aids to convection. Beginning in the early evening, the area would also be under warm air advection from the surface through the low levels. Convection was expected to begin as early as the early afternoon, continuing throughout the day. The model sounding was best in the early evening, displaying good wind shear and ample instability. Elevated instability lingered overnight, but strong triggers were lacking, indicating a quiet night after significant capping had occurred. Stratiform rain was moving through during the early morning hours. All rain cleared out after dawn, and the project area saw some partial clearing. Weak convection developed along the foothills during the afternoon, but it dissipated before it could reach any project cities. After 04Z in the evening, hailstorms southwest of Calgary moved far enough to the east to be a threat, and aircraft seeded several cells that moved through Calgary. Around 07Z, all convection moved east of Calgary and weakened into rain showers. The project area was clear for a few hours overnight, but another wave of rain was moving into the foothills at the end of the forecast period. Max cell top: 12.1km, 68.5 max dBz, 83.6 max VIL Marble size hail was reported over southeast Calgary. Tmax YC = 20.7C and 2.4mm of rain. Tmax QF = 18.0C and 2.4mm of rain. Tmax Radar = 18.6C and 1.5mm of rain.	HS1 was launched at 0329Z (07/13) for cells west and south of Calgary. They were airborne at 0352Z (07/13) and began top seeding storm #1 southwest of Calgary at 0404Z (07/13). HS1 worked in embedded seeding conditions, and picked up very heavy airframe icing throughout the flight. At 0447Z (07/13) they descended to shed ice. They resumed seeding at 0455Z (07/13) as they dragged BIPs through the climb back to altitude where they resumed seeding with ejectables. At 0500Z (07/13) HS1 reported explosive growth over Calgary with over 2,500 fpm updrafts and very frequent lightning. They descended to shed ice again at 0520Z (07/13). At 0539Z (07/13) HS1 stopped seeding storm #1. They repositioned to southwest of Calgary and began seeding storm #2 at 0552Z (07/13). As the cell approached Calgary, they were replaced by HS3 and RTB at 0640Z (07/13). They landed at 0649Z (07/13). HS2 was launched at 0433Z (07/13) for hailstorms to the southwest of Calgary. They were airborne at 0450Z (07/13) and began seeding storm #1 at 0453Z (07/13) with burners and BIPs. They seeded the storm over Calgary as long as possible, but lowering cloud bases became a safety concern and they were forced to RTB at 0528Z (07/13). They landed at 0545Z (07/13). HS3 was launched at 0555Z (07/13) toward the storms over Calgary as backup for HS1. They were airborne at 0620Z (07/13). They began seeding storm #2 over Calgary at 0650Z (07/13). They only seeded for a brief time before the storm was determined to be raining out. They stopped seeding at 0656Z (07/13). At 0705Z (07/13) HS3 reported nothing seedable in the area and RTB to YQF. They landed at 0737Z (07/13). <u>Flight Summary</u> HS1: 0340Z (07/13)-0655Z (07/13); 204 EJ, 16 BIP; #1 Calgary, #2 SW Calgary. HS2: 0440Z (07/13)-0551Z (07/13); 3 BIP, 60min acetone generator time; #1 Calgary. HS3: 0606Z (07/13)-0740Z (07/13); 15 EJ; #2 Calgary.
July 13,	At the surface, a low moved through central AB which	HS1 was launched at 2352Z for a rapidly

Wednesday	contained a warm front as well as a cold front. The warm and cold front influenced project area weather during the morning and early afternoon hours. A closed mid-level low was located over southern BC. Jet energy was mainly over southeastern BC. During the evening, a shortwave trough moved across the project area. The sounding showed a moderately unstable profile with wind shear favoring organized storms. A frontal band of rain moved through during the morning and early afternoon with some weak embedded convection that was not a hail threat. More significant convection moved in from the south around 00Z. Cells moved quickly from the south. As these cells moved in, more convection began to form over the project area with some tall cells that moved through Calgary. Once all the activity was through the Calgary area, the aircraft focused on a larger but weaker line of convection that moved from W to E through the northern half of the project area. The line dissipated over Red Deer. The project radar was mainly clear overnight. Max cell top: 13.6km, 67 max dBz, 81.2 max VIL Tmax YC = 22.5C and 10.0mm of rain. Tmax QF = 21.4C and 11.2mm of rain. Tmax Radar = 20.7C and 3.2mm of rain.	moving cell moving northward toward High River. They were airborne at 0020Z (07/14) and observed hard growth SW of Calgary. They continued down to the cell near Okotoks and began seeding storm #1 at 0042Z (07/14). At 0058Z (07/14), HS1 repositioned to SW of Calgary and began seeding storm #2. They seeded heavily as the cell was a significant hail threat for downtown Calgary. They were replaced at cloud top by HS3 and RTB at 0218Z (07/14). They landed in YYC at 0241Z (07/14). HS2 was launched at 0030Z (07/14) for developing hailstorms over southwest Calgary. They were airborne at 0046Z (07/14) and began base seeding storm #2 over Calgary at 0057Z (07/14) with burners and BIPs. At 0146Z (07/14) HS2 reported a funnel cloud over SW Calgary near Signal Hill. The funnel was immediately reported to Environment Canada. At 0245Z, HS2 stopped seeding storm #2 and climbed to cloud top near Didsbury. They began top seeding storm #4 at 0311Z (07/14) southwest of Red Deer. They continued to top seed until they were replaced at top by HS3 and RTB at 0342Z (07/14). They landed at 0407Z (07/14). HS3 was launched at 0053Z (07/14) for cells approaching Rocky MH. They were airborne at 0108Z (07/14). HS3 began seeding storm #3 near Rocky MH at 0126Z (07/14). At 0144Z (07/14) they descended to shed ice and stopped seeding #3. They climbed back to cloud top and began seeding storm #2 over Calgary at 0218Z (07/14) with ample seedable targets reported. At 0245Z (07/14), they repositioned toward Sylvan Lake. HS3 began seeding a long line of convection #4 west of Sylvan at 0301Z (07/14), mainly dragging BIP flares in embedded conditions. At 0340Z (07/14) HS3 moved down to the south end of the line and replaced HS2. At 0424Z (07/14) HS3 descended to shed ice. They then patrolled the area near YQF for a brief time and then RTB to YQF at 0440Z (07/14). They landed at 0453Z (07/14) once the storm was past the airport. HS4 was launched at 0238Z (07/14) to the area northwest of Olds. They were airborne at 0248Z (07/14) and began base seeding storm #4 at 0306Z (07/14) with burners and BIPs in good inflow along a shelf cloud. At 0342Z (07/14) they reported trouble with the right burner blowing a circuit breaker. At 0432Z (07/14) the storm began to rain out and there were no good areas for base seeding. They stopped seeding and RTB at that time. HS4 landed at Olds-Didsbury to wait for the storm to clear the YQF airport before returning home.

		They landed at 0435Z (07/14). HS4 then flew a reposition flight from Olds-Didsbury to YQF. They were airborne at 0619Z (07/14) and landed in YQF at 0635Z (07/14). Flight Summary HS1: 0005Z (07/14)-0245Z (07/14); 305 EJ, 13 BIP; #1 Okotoks, #2 Calgary. HS2: 0043Z (07/14)-0412Z (07/14); 62 EJ, 20 BIP, 240min acetone generators; #2 Calgary, #4 SW of Red Deer. HS3: 0100Z (07/14)-0500Z (07/14); 227 EJ, 6 BIP; #3 SW of Rocky MH, #2 Calgary, #4 W of Sylvan. HS4: 0246Z (07/14)-0437Z (07/14); 7 BIP, 112min acetone generator time; #4 SW of YQF; landed at Olds-Didsbury. HS4: 0615Z (07/14)-0640Z (07/14); no seeding; reposition flight from Olds-Didsbury to YQF.
July 14, Thursday	The left exit region of a southerly jet was over the region during the afternoon and evening hours. A closed low over BC weakened into an upper level trough as it entered AB during the evening hours. Vorticity advection was expected to be strongest during the evening. The previous day's surface low was now along the AB/SK border. Dew points were higher along the northern part of the project area, so atmospheric instability was highest over this region. Weak cells developed over Calgary in the afternoon, but they did not develop into hailstorms. A patrol flight was launched over Calgary as the cells were propagating upwind toward town. The northern half of the project area saw more significant afternoon convection from Sunde to Red Deer. Several hailstorms pushed through the northern project area through the early evening, but they diminished to convective rain showers and dissipated as they reached the Red Deer area. A few weak showers lingered through midnight. The project area was mainly clear overnight except for a small rain shower over the northern buffer zone. Max cell top: 12.1km, 65.5 max dBz, 67.4 max VIL Tmax YC = 21.0C and 0.8mm of rain. Tmax QF = 21.9C and 4.2mm of rain. Tmax Radar = 21.2C and no rain.	HS2 was launched at 2151Z for back building weak convection over Calgary. They were airborne at 2213Z and began patrol over Calgary. Nothing seedable was observed over the area. At 2249Z, they repositioned to near Sundre and began base seeding storm #1 with burners only. At 2257Z, they found excellent inflow and began using BIP flares for a brief time before the cell diminished and all inflow was lost. They stopped seeding #1 at 2304Z and headed back toward the Cochrane and Airdrie area for more patrolling. At 2352Z, they headed north toward Olds and began seeding #2 SW of Innisfail at 2359Z with burners and BIPs. At 0039Z (07/15) HS2 stopped using BIPs as the cell was less of a hail threat. Shortly after that, all inflow dropped off and HS2 RTB at 0041Z (07/15). They landed in YYC at 0103Z (07/15). HS4 was launched for top seeding at 2255Z and began top seeding storm #2 W of Olds at 2342Z. They worked the area at cloud top until HS3 relieved them. At 0029Z (07/15) they descended and began base seeding with burners at 0031Z (07/15) in the same area with HS2. The storm began to diminish by 0043Z (07/15) and HS4 stopped seeding and just patrolled, searching for new pockets of inflow. No additional growth was found and HS4 RTB to YQF at 0109Z (07/15). They landed in YQF at 0133Z (07/15). HS3 was launched at 2344Z for a cell north of Olds that was headed toward Red Deer. They were airborne at 0009Z (07/15). HS3 replaced HS4 on the south end of the cell at cloud top. They began top seeding storm #2 at 0036Z (07/15) and continued working that same storm until it weakened below hail criteria. They stopped seeding at 0109Z (07/15) and patrolled briefly. At 0119Z (07/15) they RTB. They

		landed at 0138Z (07/15). <u>Flight Summary</u> HS2: 2202Z (07/14)-0106Z (07/15); 8 BIP, 110min acetone generators; #1 Sundre, #2 SW of Innisfail. HS4: 2308Z (07/14)-0138Z (07/15); 106 EJ, 24min acetone generators; #2 SW of Innisfail, patrol Red Deer. HS3: 2357Z (07/14)-0142Z (07/15); 130 EJ, 2 BIP; #2 SW of Innisfail.
July 15, Friday	Jet energy was nonexistent over AB. A mid-level, open wave low was located along the northern AB/SK border which aided in sending a lobe of vorticity through the project area during the early afternoon hours. Warm air advection was present at the mid-levels which helped to inhibit tall convection from occurring. At the surface, a lee trough developed over the region. Dewpoints were again much higher over the northern project area than the southern portion. The project area was partly cloudy throughout the day with stable mountain wave clouds in the afternoon. There were several very weak convective echoes near Caroline and in the northern buffer during the late afternoon, but they were just virga/light sprinkles. No lightning strikes were detected, and there were no TITAN cells. The area remained clear overnight. Tmax YC = 22.2C and no rain. Tmax QF = 22.7C and no rain. Tmax Radar = 23.1C and no rain.	No aircraft operations.
July 16, Saturday	The jet stream was positioned over southern SK and MB. Weak mid-level ridging occurred over AB for most of the day, but weak lobes of vorticity still passed over the region during the evening and overnight. Surface low pressure was centered over central BC, and a stationary front was draped across northern AB. Low level moisture advection was expected out of the SE overnight. The atmosphere was capped for most of the daytime hours. The daytime hours were mainly clear, with only a few cirrus clouds and some cumulus over the mountains and more extensive cloud coverage over Calgary. During the evening, a surface trough moved through the PA from the southwest to the northeast triggering a few storms near High River and over Calgary. These storms formed quickly, but were very short lived. During the overnight period, stabilization occurred such that the trough developed only light rain showers/virga. Max cell top: 9.9km, 59.5 max dBz, 31.7 max VIL Tmax YC = 23.5C and 0.2mm of rain. Tmax QF = 23.8C and no rain. Tmax Radar = 22.6C and no rain.	HS1 was launched on development near Calgary at 0527Z (07/17). They were airborne at 0548Z (07/17) and began climbing to top seed. The cell quickly grew into a 9.9km topped storm, but then began to steadily diminish in intensity from radar scan to scan. As HS1 reached top seeding altitude, the cell had diminished into a light rain showers on radar, and pilots reported no weather over Calgary. Due to the cessation of any threat whatsoever, and the lack of any weather behind the trough, HS1 RTB YYC at 0604Z (07/17). They landed at 0623Z (07/17). <u>Flight Summary</u> HS1: 0540Z (07/17)-0626Z (07/17); no seeding; patrol Calgary.

ALBERTA HAIL SUPPRESSION PROJECT 2011
DAILY SUMMARY REPORTS
WEEK No.8

Date	Weather	Activities Summary
July 17, Sunday	The upper level ridge that was over AB the previous day began to move eastward. A closed low was centered off Vancouver Island and was expected to slowly dig southward. In the evening, a shortwave trough slid through central AB providing weak vorticity advection. A surface low was expected to form over the Red Deer area during the afternoon hours. The atmosphere was moderately unstable with good speed and directional shear. Atmospheric instability was also expected during the overnight hours as low level moisture poured into the region from the southeast. Skies were clear all day, with no echoes detected on radar. A few weak rain showers then appeared on radar during the evening. Overnight, cells moving into the project area from the South exploded into severe convection over the project area. Storms continued to initiate quickly over the entire area through the early morning hours, until they cleared shortly after sunrise. Rare late night/early morning seeding occurred. Max cell top: 15.9km, 69.5 max dBz, 157.5 max VIL Tmax YC = 27.0C and 0.2mm of rain. Tmax QF = 26.6C and no rain. Tmax Radar = 26.7C and no rain.	HS1 was launched at 0903Z (07/18) for cells SW of Strathmore. They were airborne at 0921Z (07/18) and began top seeding storm #1 at 0945Z (07/18). They stopped seeding and began patrol near Sundre at 1003Z (07/18). As development was observed W of Red Deer, they were repositioned to the area and began seeding storm #2 for Lacombe at 1053Z (07/18). They stayed on this storm as it tracked through Blackfalds and Lacombe, then began seeding storm #3 S of Red Deer at 1123Z (07/18). They reported weak development and seeded at a low rate until 1143Z (07/18), when they stopped seeding and began patrolling. As no new development was occurring, they RTB YYC at 1151Z (07/18), landing at 1220Z (07/18). HS2 was launched at 0903Z (07/18) for development SW of Strathmore. They were airborne at 0919Z (07/18), and began seeding storm #1 with burners at 0940Z once they reached the storm. They found a shelf cloud on the N end of their pass, and worked this area until 1003Z (07/18) when they were instructed to stop seeding. They then reposition to the W and began patrolling. No new targets were observed. HS1 RTB at 1022Z (07/18) and landed at 1028Z (07/18). HS4 was launched at 1107Z (07/18) for the development S of Red Deer, and became airborne at 1129Z (07/18). They were unable to find seedable bases near Red Deer, so at 1135Z (07/18) they were directed towards Eckville. They continued to find only dissipating cells and no seedable bases. At 1211Z (07/18) they RTB to Red Deer. They landed at 1223Z (07/18). <u>Flight Summary</u> HS1: 0910Z (07/18)-1226Z (07/18); 108 EJ, 2 BIP; #1 Strathmore, #2 Lacombe, #3 S. Red Deer. HS2: 0911Z (07/18)-1031Z (07/18); 46 minutes generator time; #1 Strathmore. HS4: 1118Z (07/18)-1227Z (07/18); no seeding; patrol S. Red Deer, patrol W Ponoka.
July 18, Monday	The left exit region of a jet streak was over the area during the afternoon and evening hours. A closed, mid-level low was now over northern California and aided in sending vorticity lobes towards AB. In the evening, a	HS2 was launched at 2102Z for weak echoes SW of Calgary. With the very unstable conditions that day, cells were expected to grow rapidly. HS2 was airborne at 2122Z and

	shortwave trough slid across the project area. A weak cold front also pushed into the area from the north. Copious amounts of low level moisture were expected with dewpoints in the high teens. The atmosphere was extremely unstable with CAPE values over 1800 J/kg. There was also decent wind shear which supported long lived severe thunderstorms. Dew points reached above 20C over the region. The day started out with a few tall cumulus and some echoes indicating rain on the radar. During the afternoon, storms began to form and became severe over the course of a couple hours. Storms continued into the evening, when cooling and significant capping shut off convection for the overnight period. Max cell top: 16.6km, 68 max dBz, 160.1 max VIL Tmax YC = 28.6C and no rain. Tmax QF = 27.7C and 0.8mm of rain. Tmax Radar = 26.8C and 6.5mm of rain.	reported no threat from the clouds in the area, which were being sheared apart. They were directed to patrol W of Calgary. At 2230Z, development appeared on radar near Sundre, and they were directed to patrol this area. This cell developed into a marginal hail threat, and HS2 seeded storm #2 with generators from 2245Z to 2258Z, stopping when it had weakened and was past Sundre. They then moved S to patrol near Spring Bank. They RTB YYC and landed at 2321Z. HS3 was launched at 2140Z for development SW of RMH. They were airborne at 2209Z, and were directed to seed as soon as they reached the cell. At 2230Z, they began seeding storm #1 reporting light to moderate water and moderate updraft. They seeded until the cell was through RMH at 2255Z, and then moved to storm #3 S of RMH. They reported good updraft, but quickly lost feeders as the cell glaciated. In anticipation of more severe convection beginning in the next few hours, HS3 RTB YQF at 2314Z, landing at 2327Z. HS4 was launched at 2340Z for a severe cell N of Sundre. They were airborne at 0000Z (07/19), and began seeding storm #4 with burners and BIPs at 0023Z (07/19). They seeded in good inflow along a shelf on the SE side of the storm until 0114Z (07/19) when a change in shape of the cell pushed them onto the W side of the storm. They stopped using BIPs. They were able to reposition to the SE side of the cell again at 0125Z (07/19), and resumed using BIPs again at 0131Z (07/19). As the storm moved past Red Deer, HS4 RTB 0157Z (07/19), and landed at 0204Z (07/19). Throughout this mission, HS4 reported a malfunction in their right burner. HS1 was launched at 0003Z (07/19) for development W of Airdrie. They were airborne at 0030Z (07/19) and began seeding on the S end of the cell at 0102Z (07/19). They reported explosive growth and mammatus clouds. They seeded storm #6 until 0126Z (07/19). They were instructed to seed at a reduced rate at 0203Z (07/19) as the cell approached Irricana. After conferring with the ASWMS project manager, HS1 stopped seeding and RTB to YYC at 0214Z (07/19). The storm was only seeded with one base seeding aircraft as it moved through Irricana. HS1 landed at 0225Z (07/19). HS3 was launched at 0009Z (07/19) for a cell W of Olds. They were airborne at 0029Z (07/19) and began seeding storm #5 at 0042Z (07/19). As radar showed this cell weakening, and a cell to the N creeping towards Sylvan Lake, they were redirected to storm #4 and

		began seeding at 0055Z, working above HS4. They reported explosive growth on this cell. HS3 RTB to YQF at 0157Z (07/19). They landed at 0205Z (07/19). HS2 was launched at 0029Z (07/19) for development W of Airdrie. They were airborne at 0048Z (07/19) and reported a shelf on storm #6, lighting burners at 0052Z (07/19). At 0103Z (07/19), they found abundant inflow and began using BIPs. They continued to find very good inflow as it moved through Airdrie. They ceased BIPs at 0147Z (07/19) when the cell moved into an unpopulated area. At 0230Z (07/19), with the cell E of any targets, HS2 turned off burners at 0214Z (07/19) and RTB YYC at 0230Z (07/19). They landed at 0250Z (07/19). Flight Summary HS2: 2118Z-2324Z; 26 minutes generator time; patrol SW Calgary, #2 Sundre. HS3: 2156Z-2332Z; 97 EJ; #1 SW RMH, #3 S RMH. HS4: 2348Z- 0209Z (07/19); 93 minutes generator time, 9 BIP; #4 SW Sylvan. HS1: 0020Z (07/19)-0229Z (07/19); 126 EJ, 5 BIP; #6 Airdrie. HS3: 0021Z (07/19)-0209Z (07/19); 228 EJ; #5 Olds, #4 SW Sylvan HS2: 0041Z (07/19)-0254Z (07/19); 12 BIP, 190 minutes generator time; #6 Airdrie.
July 19, Tuesday	The upper level jet core was directly over the project area. It was progged to exit the region toward the east during the evening and overnight hours while an upper level trough moved southeastward into AB from northern BC. The southern half of the project area was under a favorable jet quadrant providing shear vorticity. Midlevel vorticity was progged to move through the area during the afternoon, mostly impacting the southern project areas. The atmosphere was highly unstable throughout the afternoon, and expected to stabilize after 03Z. Southeasterly surface winds were progged to shift to westerly by early evening as well. Severe hail storms were forecast to occur through the early evening and then stable conditions were expected in the evening and overnight hours. Convection began in the early afternoon with a few weak rain showers. Over the course of a few hours, more cells began to initiate over the entire project area, most of them severe. Convection ended in the early evening and the project area was quiet overnight. Very heavy rain occurred in Red Deer with urban flash flooding. Very heavy rain also occurred in Calgary, but no significant flooding occurred. One inch hail was reported SSW of Strathmore near Carseland. Max cell top: 15.1km, 70.5max dBz, 210.8max VIL Tmax YC = 24.0C and 39.6mm of rain. Tmax QF = 21.7C and 31.8mm of rain.	HS3 was launched at 1800Z for development SW of RMH. They were airborne at 1828Z. They were directed to patrol a weak echo near Sundre at 1855Z. They patrolled areas of growth from Sundre to Cochrane. HS3 then moved down to SW of Calgary for a significant system tracking directly toward the metropolitan area. They started seeding storm #1 at 2043Z. They repositioned to High River at 2124Z, seeding until 2201Z, when they stopped seeding and RTB YYC as the cells moved away from major population centers. They landed in YYC at 2217Z. HS1 was launched at 2025Z for development near Calgary. They were airborne at 2047Z. HS1 began seeding storm #1 at 2131Z. After the cell moved through Cochrane, HS1 moved N to seed storm #3. They worked that line until 2254Z when they RTB to YYC as the cell moved NE of Red Deer. They landed at 2321Z. HS4 was launched at 2029Z for development S of RMH. They were airborne at 2043Z, and reported embedded conditions. They began seeding storm #2 with burners at 2114Z with good inflow. At 2124Z, the cell appeared to be merging with a line to the SE. HS4 moved to the E side of the cell heading towards Red

	Tmax Radar = 22.0C and 12.5mm of rain.	Deer. They began seeding storm #3 at 2141Z. At 2228Z, HS4 reported their right burner was inoperative. By 2243Z, they were finding continuous substantial inflow, and began lighting BIPs. At 2300Z, they were told to RTB. They attempted to get around the N side of the line in order to circumnavigate it and land in Red Deer. They were unable to find a break in the line, however, and landed at Edmonton City Center. They landed at 0002Z (07/20). HS2 was launched at 2045Z to development S of High River. They were airborne at 2105Z and began seeding storm #1 at 2128Z. At 2146Z, they were directed far to the N to assist HS4 in base seeding storm #3. They lit burners again at 2216Z, and seeded until 2254Z, when they were directed to storm #4 SW of Olds. They resumed seeding at 2317Z, and moved to storm #5 W of Cochrane at 2350Z, as storm #4 was to the NE of Olds. Their left burner ran out of chemical at 2356Z, and they began using BIPs at 0011Z (07/20). They RTB YYC at 0027Z (07/20). They landed at 0040Z (07/20). HS3 was launched for a cell SW of Cochrane. They were airborne at 2331Z and began seeding storm #5 at 2351Z. As this cell moved past any target areas, they repositioned to the SW of Calgary, and began seeding storm #6 at 0032Z (07/20). They found very vigorous activity, and had to descend for ice at 0057Z (07/20). They resumed seeding at 0106Z (07/20). They quickly accumulated ice, and began descending at 0141Z (07/20). HS3 RTB YQF at 0144Z (07/20), landing at 0221Z (07/20). <u>Flight Summary</u> HS3: 1818Z-2224Z; 293 EJ; patrol RMH, #1 SW YYC. Landed at YYC. HS1: 2034Z-2327Z; 253 EJ, 16 BIP; #1 Cochrane, #3 W of Olds. HS4: 2035Z (07/19)-0006Z (07/20); 161min acetone generator time, 12 BIP; #2 Caroline, #3 Olds to Red Deer; Landed at YXD in Edmonton. HS2: 2100Z (07/19)-0043Z (07/20); 221min acetone generator time, 17 BIP; #1 SW YYC, #3 Red Deer, #4 SW Olds, #5 Cochrane. HS3: 2317Z (07/19)-0229Z (07/20); 294 EJ, 3 BIP; #5 Cochrane, #6 SW Calgary. HS4: 0308Z (07/20)-0412Z (07/20); No seeding; reposition from Edmonton City Center to YQF.
July 20, Wednesday	As the upper jet was shifting east of Alberta, a digging trough was closing off into a deep low pressure system.	HS3 was launched for base seeding at 1958Z on development W of Red Deer. Despite the

	Vorticity advection was expected to deal a glancing blow to the northern parts of the project area where surface moisture was higher. The northern part of the project area was the most unstable while drier downslope winds made for less instability in YYC. The atmosphere was slightly unstable below 26kft. Weak convection with small hail was forecast to occur in the afternoon with the bulk of convection to the north of the area. Stable conditions were expected overnight. In the early afternoon, a line of thunderstorms moved through the N half of the project area. Most of the cells were weak, producing light to moderate rain with a few a bits of pea sized hail. There were reports of quarter sized hail in a cell west of Red Deer. After this first line of convection, the project area had a few convective rain showers, but there were no severe echoes. Radar echoes diminished into the evening and the area was clear overnight. Max cell top: 10.6km, 63.5max dBz, 67.9max VIL Tmax YC = 21.0C and 1.8mm of rain. Tmax QF = 19.3C and 0.2mm of rain. Tmax Radar = 18.7C and 0.5mm of rain.	benign appearance of these storms, there had been reports of quarter sized hail from them. They were airborne at 2017Z and immediately began seeding storm #1 with BIPs. They reported good lightning, a green tint, and moderate inflow. After the storm had passed through Red Deer, HS3 RTB YQF 2044Z. They landed at 2053Z. <u>Flight Summary</u> HS3: 2012Z-2057Z; 7 BIP; #1 Red Deer.
July 21, Thursday	A deep low pressure system was approaching the project area. The atmosphere was only slightly unstable. Surface dew points were somewhat high, but the moisture was confined to a very shallow surface layer. Overall, the low levels were not particularly moist. A surface low was located over the project area with an occlusion progged to pass through during the day. Behind the occlusion, low levels were expected to dry out. The upper level circulation and associated vorticity advection were progged to affect the area in the evening and overnight hours, but the atmosphere was expected to stabilize overnight. Weak afternoon convection was forecast with stratus and low ceilings overnight. The day began with a few fair weather cumulus and no echoes on the radar. A few larger clouds were seen throughout the afternoon, but no significant echoes were observed beyond a few rain showers. During the early evening, a more significant line of convection occurred in the N half of the project area, but as this diminished, the overnight period proved clear. Max cell top: 9.1km, 62.5 max dBz, 40.9 max VIL Tmax YC = 22.5C and no rain. Tmax QF = 22.9C and a trace of rain. Tmax Radar = 22C and a trace of rain.	HS1 flew a public relations flight to the Olds-Didsbury operations center. They took off at 1721Z and landed in Olds at 1738Z. After the tour, they returned to Calgary. They took off from Olds at 2120Z and landed back in YYC at 2140Z. HS4 was launched at 0316Z (07/22) on weak development W of Red Deer. They were airborne at 0332Z (07/22) and began seeding storm #1 with acetone generators at 0346Z (07/22). By 0407Z (07/22), the cell had weakened on radar, and HS4 was reporting a poor base and weak inflow. As the cell was not a hail threat, HS4 RTB YQF at 0421Z (07/22), landing at 0427Z (07/22). <u>Flight Summary</u> HS1: 1703Z-1740Z; no seeding; PR flight from YYC to Olds. HS1: 2115Z-2144Z; no seeding; PR flight from Olds to YYC. HS4: 0325Z (07/22) - 0432Z (07/22); 42 min generator time; #1 Red Deer.
July 22, Friday	A deep low pressure system was slowly moving through central AB during the period. Ample vorticity was expected over the project area. All surface features had moved east of the project area by forecast time, and only upper level triggers were present for the rest of the day. The 500mb vorticity center was progged to reach the project area around 00Z. Low levels were relatively dry with some weak downslope winds. Surface temperatures	No aircraft operations.

	were unseasonably cool, and dense cloud was expected to inhibit afternoon insolation. Some weak thundershowers were present in the morning, but no significant strong convection was expected during the day. Widespread stratus rain was forecast through the evening with embedded weak thunderstorms likely. No major hail threats were forecast. Stable conditions were expected overnight. The project area experienced weak thunderstorms with light to heavy rain showers. The early afternoon hours saw slightly stronger thunderstorms near High River and Okotoks. During the evening hours, the convection began to move eastward out of the region. Max cell top: 9.9km, 62.5 max dBz, 33.0 max VIL Tmax YC = 13.3C and 13.4mm of rain. Tmax QF = 13.7C and 5mm of rain. Tmax Radar = 12.0C and 1.5mm of rain.	
July 23, Saturday	A deep low pressure system was moving out of the area early in the period with upper level ridging expected to begin in the afternoon. Midlevels were warming significantly, and low levels were cool and fairly dry. The atmosphere was only very slightly unstable. A shallow layer of instability was present below 18kft during the afternoon. The atmosphere was expected to be completely stable overnight. Afternoon fair weather cumulus was all that was expected with cloud tops below 18kft. During the afternoon hours, a band of very weak low topped convection moved through the northern part of the project area from Sylvan to YQF. This convection was short lived and only produced light to moderate rain showers and a couple strikes of lightning. There were no hail threats. Altocumulus and cirrus were observed in the evening and overnight. Max cell top: 6.9km, 58 max dBz, 12 max VIL Tmax YC = 21.0C and no rain. Tmax QF = 19.4C and 4.8mm of rain. Tmax Radar = 19.0C and no rain.	No aircraft operations.

ALBERTA HAIL SUPPRESSION PROJECT 2011

DAILY SUMMARY REPORTS
WEEK No.9

Date	Weather	Activities Summary
July 24, Sunday	The upper level jet was south of the project area, stretched along the US/Canada border. A broad ridge was well established over the region. Low levels were relatively dry, and midlevels were warm. The atmosphere was stable. No significant weather was forecast. Mostly clear skies were forecast to persist throughout the period. Cumulus, altocumulus, and cirrus clouds were observed. The region was also stable overnight. No radar echoes. Tmax YC = 23C and no rain. Tmax QF = 23C and no rain. Tmax Radar = 23C and no rain.	No aircraft operations.
July 25, Monday	The forecast period began with high pressure over the project area. A strong midlevel trough was located over British Columbia, expected to move through the project area and be the main trigger for later in the day. Excellent instability and shear made the day look very active. Storms were expected in the evening and overnight periods. The first convection of the day formed W of Rocky MH. Late in the afternoon, this convection eventually made its way off the foothills. The strongest of these cells developed SW of Rocky MH and slowly tracked towards the town. Then around 00z, a long line of thunderstorms formed along the mountains and moved eastward across the region. The strongest cell along the line was near the Sundre area. The convection dissipated as it reached the center of the project area. Max cell top: 12.1km, 65.0 max dBz, 72.9 max VIL Tmax YC = 25C and no rain. Tmax QF = 26C and no rain. Tmax Radar = 25C and 1.6mm of rain.	HS3 was launched at 2108Z to a rapidly intensifying cell SW of Rocky MH. The flight became airborne at 2139Z and flew toward the cell. While flying to the cell, the crew reported that the storm had a dark flat base. At 2159Z HS3 started seeding storm #1 SW of Rocky MH. Then at 2215Z, the pilots reported decent overhang along the southern edge of the cell. The aircraft continued to seed the storm until it dissipated to the E of Rocky MH at 2327Z. The crew then patrolled the Rocky MH area until they RTB at 0040Z (07/26). The flight landed in Red Deer at 0056Z (07/26). HS2 was launched at 0103Z (07/26) to top seed a cluster of cells SW of Calgary. The flight became airborne at 0126Z (07/26). The aircraft found a small amount of new growth along the SW side of the cluster of convection. Once the flight found the weak growth, they started top seeding storm #2 near Okotoks at 0143Z (07/26). Then at 0205Z (07/26) the aircraft was finding no new growth, so they stopped seeding and started patrolling the same area. HS2 was eventually redirected to new convection near the Cochrane area at 0245Z (07/26). The aircraft then patrolled an area N of Cochrane until 0316Z (07/26), when the flight RTB. They landed in Calgary at 0332Z (07/26). HS4 was launched at 0133Z (07/26) to a line of convection extending from Rocky MH to Cremona. They were airborne at 0151Z (07/26) and flew toward the most intense cell just W of Sundre. HS4 started seeding the Sundre storm (#3) at 0209Z (07/26). They continued to seed the storm as it moved across the project area. By 0311Z (07/26), the storm had almost completely dissipated, so HS4 stopped seeding storm #3 and RTB. The

		aircraft landed in Red Deer at 0335Z (07/26). Flight Summary HS3: 2122Z (07/25)-0100Z (07/26); 155 EJ; #1 Rocky MH, patrol Rocky MH. HS2: 0117Z (07/26)-0336Z (07/26); 12 EJ; #2 Okotoks and patrol Cochrane. HS4: 0141Z (07/26)-0339Z (07/26); 124 min generator time; #3 Sundre and patrol W of Sylvan.
July 26, Tuesday	A low pressure system was located just east of the project area. A surface trough was located over British Columbia, progged to move through in the early evening. There was good wind shear, but weak instability indicated that severe storms were not likely. The area saw widespread weak thunderstorms during the morning hours. In the mid-afternoon, a stronger line of convection developed along the mountains and foothills. The first cells along this line originally formed south of Sundre and moved eastward towards Carstairs before dissipating. As the line moved eastward, stronger cells continued to develop along the southern end of the line. The tallest and most intense of these cells formed W of Cochrane and moved southeastward towards Okotoks. During this same time, another line of convection formed north of Rocky MH and moved southeastward across the northern half of the project area. Scattered, convective rain showers then persisted through the overnight hours. Max cell top: 12.1km, 64.0 max dBz, 73.6 max VIL Tmax YC = 17C and 13.0mm of rain. Tmax QF = 19C and 27.2mm of rain. Tmax Radar = 18C and 12.6mm of rain.	HS1 was launched at 2157Z to patrol actively growing convection W of Carstairs and Crossfield. The aircraft became airborne at 2216Z. The crew eventually found growth along the northeast side of storm #1 and started seeding at 2242Z. HS1 next reported that the storm was dissipating. At 2253Z, they stopped seeding and repositioned toward new actively growing cells W of Calgary. They found moderate growth W of Cochrane and started seeding storm #2 at 2301Z. The aircraft continued to seed the storm until it was passed the Okotoks area. At 0019Z (07/27), HS1 stopped seeding storm #2 and started patrolling High River. Then at 0113Z (07/27) the flight was redirected to growing convection NW of Olds. Once the aircraft arrived at the storm they patrolled an elongated line of convection until it began to dissipate. HS1 RTB at 0205Z (07/27) and landed in Calgary at 0225Z (07/27). Flight Summary HS1: 2210Z (07/26)-0230Z (07/27); 104 EJ, 8 BIP; #1 W of Carstairs, #2 W of Calgary, patrol High River, and patrol Olds.
July 27, Wednesday	Some weak vorticity, observed on the 500mb map, along with mid-level divergence was expected to be the main focus for thunderstorms. While temperatures were cool, parameters indicated moderate instability. Storms were expected to initiate in the mid to late afternoon across the entire project area with skies clearing overnight as temperatures cooled. The morning hours mainly saw widespread rain showers but a few convective cells did begin to form over the foothills during the late morning. Throughout the early afternoon, the convection began to push off the foothills near the Calgary area. One of these storms (#1) became severe W of Cochrane but ended up tracking south-southeastward along the project area border before dissipating near Turner Valley. Loonie sized hail was reported SW of Calgary from storm #1. Then around 21Z, a moderately strong cell (#2) formed directly over southern Calgary and tracked southeastward. The northern half of the region mainly saw convective rain showers that were heavy at times. At around 2230Z another cell formed W of Calgary and tracked southeastward towards the town of Okotoks. Once this particular storm (#3) started to approach Okotoks, it was apparent that more cells were being triggered to the W of this storm. This line of convection eventually tracked	HS2 was launched at 1918Z to patrol a developing storm W of Cochrane. The flight became airborne at 1931Z. They found inflow and started seeding storm #1 W of Calgary. At 2050Z, HS2 reported the cell was beginning to become less intense. They stopped seeding storm #1 at 2102Z and repositioned to a cell directly over southern Calgary. HS2 started seeding this storm (#2) at 2108Z. The aircraft seeded this storm until it moved southeast of Calgary. HS2 stopped seeding at 2133Z and was directed to patrol the Olds area. The crew patrolled Olds for a short period of time before being redirected to strong development NW of Calgary. The aircraft starting seeding storm #3 NW of Cochrane at 2222Z. HS2 stopped seeding at 0007Z (07/28) and RTB. The aircraft landed at 0017Z (07/28). HS1 was launched to storm #3 W of Calgary at 2305Z. The aircraft became airborne at 2319Z and was found good growth along the south side the cell. The crew began seeding W of Calgary at 2334Z. Then at 0008Z (07/28), HS1 reported only weak to moderate updrafts. At 0019Z (07/28), no feeders were being found, so

	southward forming the strongest cell of the day over the southern buffer zone. Max cell top: 13.6km, 67.0 max dBz, 132.7 max VIL Tmax YC = 17C and 8.8mm of rain. Tmax QF = 19C and 4.4mm of rain. Tmax Radar = 19C and a trace of rain.	HS1 stopped seeding and started patrolling. The aircraft continued to patrol the line of convection until it was no longer a threat to the towns of Okotoks, Turner Valley, and Black Diamond. At 0108Z (07/28), HS1 stopped patrolling and RTB. The aircraft landed at 0124Z (07/28). Flight Summary HS2: 1925Z (07/27)-0020Z (07/28); 13 BIP, 473 min generator time; #1 NW of Turner Valley, #2 southern Calgary, patrol Olds, and #3 NW of Cochrane. HS1: 2310Z (07/27)-0127Z (07/28); 75 EJ; #3 W of Calgary, patrol Okotoks.
July 28, Thursday	West winds and a weak ridge over the area assured the day started out clear, allowing temperatures to rebound quickly. Surface dew points were expected to be high. The ridge was progged to persist throughout the day, but a weak surface trough was expected to be enough to fire off a few weak thunderstorms after peak heating. Thunderstorms were expected in the early evening. A few very weak convective showers developed in the northern half of the project area during the late afternoon. There was one strike of lightning. More widespread convective rain showers occurred overnight. There were no hail threats and no seed flights. Max cell top: 5.4km, 46.0 max dBz, 3.8 max VIL Tmax YC = 22C and no rain. Tmax QF = 22C and no rain. Tmax Radar = 21C and no rain.	HS3 performed a maintenance flight. They were airborne at 1929Z and landed back in YQF at 1945Z. Flight Summary HS3: 1922Z-1950Z; no seeding; maintenance flight.
July 29, Friday	A strong vort max moving through central Alberta was the main focus for convection, expected to initiate storms in the early evening. Speed shear was excellent, and instability parameters were conducive to moderate sized hail. After the vort max moved through, ridging was expected to occur, and clear skies were expected overnight. Severe hailstorms developed in the early afternoon. The storms were long lived and moved through the entire project area. The most severe cells moved through Rocky MH to Red Deer and Airdrie to Strathmore. The atmosphere stabilized by early evening, and the project area was stable overnight. 32mm hail and high wind was reported in Red Deer with lots of shredded trees and vegetation. Loonie to golf ball size hail was reported in Airdrie. Max cell top: 12.9km, 69.0 max dBz, 172.4 max VIL Tmax YC = 21C and no rain. Tmax QF = 20C and a trace of rain. Tmax Radar = 20C and no rain.	HS3 was launched at 1924Z for developing hailstorms near Rocky MH. They were airborne at 1940Z and began top seeding storm #1 west of Rocky MH at 2003Z. At 2028Z, the storm moved through Rocky MH, and HS3 stopped seeding. They descended to shed ice and then climbed back to top. They began seeding storm #2 NW of Sylvan at 2042Z. They continued seeding the storm until it cleared the Red Deer area. They stopped seeding #2 at 2145Z and descended again to shed ice. At 2151Z, they began seeding storm #5 near Innisfail. They stopped seeding #5 at 2217Z and RTB to YQF as the cell passed Innisfail and they were getting low on fuel. They landed at 2226Z. HS1 was launched at 2033Z for intensifying clusters of cells approaching Airdrie. They were airborne at 2048Z and began top seeding storm #3 Airdrie at 2055Z. At 2139Z, they stopped seeding #3 as the cell moved east of Airdrie. They then moved a few kilometers to the west and began seeding #4 west of Airdrie at 2143Z. They continued working the cell as it passed through the northern Calgary/Airdrie area all the way through Strathmore. They stopped seeding #4 at 2306Z and RTB to YYC.

		They landed at 2318Z. HS4 was launched at 2038Z for an organized hailstorm near Rocky MH heading toward Sylvan and Red Deer. They were airborne at 2054Z and began base seeding storm #2 near Sylvan at 2103Z with excellent inflow. They continued working the storm until it cleared the Red Deer area. They stopped seeding storm #2 at 2145Z and repositioned to a cell approaching Innisfail. They began seeding storm #5 Innisfail at 2151Z. They stopped seeding #5 at 2215Z and repositioned to near Sundre for patrol. At 2308Z, HS4 reported increasing inflow and began seeding storm #6 west of Innisfail. They stopped seeding #6 at 2316Z and patrolled for a few minutes before RTB at 2320Z. They landed in YQF at 2334Z. HS2 was launched at 2116Z for cells near Airdrie. They were airborne at 2139Z and began base seeding storm #4 Airdrie at 2146Z with burners and BIPs. They stayed with the storm as it moved all the way through Strathmore. They stopped seeding #4 at 2306Z and RTB to YYC. They landed at 2322Z. Flight Summary HS3: 1935Z-2231Z; 13 BIP, 146 EJ; #1 Rocky MH, #2 Sylvan, #5 Innisfail. HS1: 2042Z-2325Z; 11 BIP, 265 EJ; #3 Airdrie, #4 Airdrie to Strathmore. HS4: 2048Z-2339Z; 12 BIP, 160min acetone generator time; #2 Sylvan, #5 Innisfail, #6 Innisfail, patrol Sundre. HS2: 2130Z-2325Z; 18 BIP, 160min acetone generator time; #4 Airdrie to Strathmore.
July 30, Saturday	A strong 500mb ridge was located over Alberta and British Columbia, with clear skies over the project area. The ridge was expected to slowly move off during the overnight period, providing no threat of convection during the forecast period. Skies were completely clear all day and all night. There were no radar echoes. Tmax YC = 25.5C and no rain. Tmax QF = 24.4C and no rain. Tmax Radar = 24.7C and no rain.	No aircraft operations.

ALBERTA HAIL SUPPRESSION PROJECT 2011
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Date	Weather	Activities Summary
July 31, Sunday	Two upper level jet streaks were positioned over AB. The right rear quadrant of the northern jet streak passed over the project area during the evening hours. At the mid-levels, a trough was in place over BC and northwestern AB. A weak shortwave trough was expected to move through the region during the evening hours. At the surface, a low was forming near Red Deer and moving eastward. The atmosphere was moderately unstable with decent speed shear. The project area remained partly cloudy through most of the morning and afternoon. Towering cumulus began to develop in the late afternoon, but they were sheared apart over the project area for the most part. More intense organized cells developed near Rocky MH in the early evening which developed into significant hail threats over the far northern part of the project area. The cells moved from Rocky MH through the Lacombe and Panoka area dropping toonie size hail west of Panoka. Activity diminished around dusk. Weak convective showers lingered over the area through the night. Max cell top: 12.1km, 71.5 max dBz, 159.6 max VIL Tmax YC = 29.4C and no rain. Tmax QF = 23.2C and 0.6mm of rain. Tmax Radar = 26.0C and no rain.	HS4 was launched at 0207Z (08/01) for a severe cell developing near Rocky MH. They were airborne at 0220Z (08/01). They began base seeding at 0240Z (08/01) on storm #1 near Rocky MH. They continued working that cell until it was through town. They stopped seeding #1 at 0309Z (08/01) and repositioned to the northeast for a storm heading toward Lacombe and Panoka. They began seeding that storm as it was north of Sylvan Lake at 0319Z (08/01). The storm moved clear of Panoka and they RTB at 0415Z (08/01). They landed in YQF at 0426Z (08/01). HS3 was launched at 0225Z (08/01) to the same area as HS4 near Rocky MH. They were airborne at 0244Z (08/01). They began seeding storm #1 west of Rocky MH at 0302Z (08/01). As the storm cleared Rocky, they stopped seeding #1 at 0317Z (08/01) to reposition to the northeast. They began seeding #2 west of Lacombe at 0322Z (08/01). They top seeded until they were forced to descend to shed ice. The cell was nearly through Panoka at that time so they stopped seeding and RTB at 0404Z (08/01). They landed in YQF at 0410Z (08/01). Flight Summary HS4: 0212Z (08/01)-0430Z (08/01); 9 BIP, 196min acetone generator time; #1 Rocky MH, #2 Panoka. HS3: 0236Z (08/01)-0415Z (08/01); 86 EJ, 10 BIP; #1 Rocky MH, #2 Panoka.
August 1, Monday	The upper level jet was south and east of AB. Weak mid-level ridging was expected to begin influencing the area during the evening hours. Vorticity advection was expected during the afternoon but the atmosphere was capped. At the surface, high pressure was over northern AB, and a cold front was over southern AB. The cold front was progged to shift southeastward throughout the day. The atmosphere was expected to be stable in the evening and overnight. A few weak thundershowers were still lingering over the project area in the very early morning hours. By dawn, all showers had ended. The project area had a few towering cumulus and widespread fair weather cumulus throughout the afternoon. Skies cleared out in the late afternoon and remained clear overnight. There were no hail threats. Max cell top: 6.1km, 47.5 max dBz, 7.5 max VIL Tmax YC = 21.5C and no rain. Tmax QF = 22.0C and 0.6mm of rain. Tmax Radar = 23.3C and no rain.	No aircraft operations.

August 2, Tuesday	The upper level jet continued to be south and east of the province. At the mid-levels, the ridge began to flatten over AB during the morning and early afternoon. The late evening saw a shortwave trough with strong vorticity move across the region. Low level moisture was also expected to increase in the evening. The region was slightly unstable with moderate speed shear, but the atmosphere experienced convective inhibition for most of the daytime hours. The day began mostly clear with a few clouds over the foothills. During the afternoon, a few towering cumulus formed on the foothills, while east of the range clear skies prevailed. Marginal hail storms developed just before midnight over the far northern project area. They moved through Lacombe. All activity ended around 8Z in the morning. Max cell top: 11.4km, 67 max dBz, 69.7 max VIL Tmax YC = 23.6C and no rain. Tmax QF = 22.6C and no rain. Tmax Radar = 22.9C and no rain.	HS4 was launched at 0543Z (08/03) for marginal hail storms west of Sylvan. They were airborne at 0600Z (08/03). They began seeding storm #1 southwest of Lacombe with acetone generators at 0606Z (08/03). At 0635Z (08/03) they stopped seeding storm #1 and began patrol near Red Deer. They RTB at 0708Z (08/03) and landed in YQF at 0717Z (08/03). HS3 was launched at 0549Z (08/03) for cells west of Sylvan. They were airborne at 0608Z (08/03) and began dragging BIPs for storm #1 west of Lacombe at 0617Z (08/03). They stopped seeding at 0636Z (08/03) and started patrol SW of Sylvan. No more seedable clouds were found. They RTB at 0709Z (08/03) and landed in YQF at 0720Z (08/03). Flight Summary HS4: 0552Z (08/03)-0721Z (08/03); 60min acetone generator time; #1 Lacombe. HS3: 0601Z (08/03)-0725Z (08/03); 5 BIP; #1 Sylvan.
August 3, Wednesday	An upper level ridge was over northern BC. A shortwave trough was expected to slide down the backside of the ridge through central AB during the afternoon and evening hours. At the surface, a lee trough was progged to form over the area during the afternoon and evening hours. Another low was also centered near the Vancouver area which aided in sending weak vorticity towards the Calgary area. The atmosphere was slightly unstable with weak convective inhibition. During the afternoon, a few rain showers initiated along the foothills, moving into the project area with little threat. As the afternoon progressed, a few of these storms became more severe, some tracking through the Calgary metropolitan area. By midnight, storms had died down as the atmosphere became sufficiently capped. Quarter sized hail reported just SW of Calgary. Max cell top: 11.4km, 67 max dBz, 88.3 max VIL Tmax YC = 22.0C and 17.2mm of rain. Tmax QF = 21.8C and 3.2mm of rain. Tmax Radar = 20.2C and 0.6mm of rain.	HS4 was launched at 2234Z for a cell near Sundre, tracking for Olds and Didsbury. They were airborne at 2246Z. At 2307Z, HS4 began seeding storm #1 with burners. They continued until the storm moved E of Didsbury at 2346Z. They were then directed to patrol a cell near Sundre, and then repositioned W of Airdrie. They began seeding storm #2 at 0058Z (08/04). At 0151Z (08/04), as it became clear this storm would head through Calgary, HS4 was directed to burn BIPs end to end. They continued until the storm moved past Calgary, stopping BIPs at 0240Z (08/04). At 0315Z (08/04) they reported that the generators were running empty, and HS4 RTB at 0319Z (08/04). They landed at 0353Z (08/04). HS1 was launched at 0114Z (08/04) for a storm NW of Calgary. They were airborne at 0127Z (08/04) and began top seeding storm #2 at 0142Z (08/04). They continued until 0232Z (08/04), when they began reporting glaciated conditions. They were then repositioned to storm #3, also tracking through Calgary. At 0317Z (08/04), as the storm left Calgary and there was no other troubling convection in the area, HS1 RTB. They landed at 0331Z (08/04). HS2 was launched at 0155Z (08/04) for storm #2. They were unable to takeoff immediately due to the proximity of the storm to the airport. They became airborne at 0227Z (08/04) and began base seeding storm #3 at 0232Z (08/04) with both acetone generators and BIPs. They experienced good inflow, but by 0251Z (08/04) reported the bases deteriorating slightly. They were told to stop using BIPs at 0300Z (08/04) as the storm became weaker both on radar and

		from pilot reports. As the storm moved out of Calgary, HS2 RTB YYC at 0328Z (08/04), landing at 0340Z (08/04). HS3 was launched at 0217Z (08/04) for storm #2. They were airborne at 0240Z (08/04) and were directed along the east side of the storm to avoid conflicts with ATC. They began seeding with BIPs at 0306Z (08/04), reporting only isolated seedable clouds. It became apparent the storm would not pose a threat to any target cities, and HS3 RTB at 0328Z (08/04), landing at 0411Z (08/04). <u>Flight Summary</u> HS4: 2240Z-0357Z (08/04); 18 BIP, 351 minutes acetone generators; #1 Didsbury, patrol NW Sundre, patrol Airdrie, #2 NW Calgary. HS1: 0122Z (08/04)-0334Z (08/04); 284 EJ, 15 BIP; #2 Calgary. HS2: 0200Z (08/04)-0345Z (08/04); 8 BIP, 112 minutes acetone generator time; #3 NW Calgary, #2 Strathmore. HS3: 0232Z (08/04)-0415Z (08/04); 3 BIP; #2 Strathmore.
August 4, Thursday	The jet was located over SK and MB. Northern BC and AB experienced ridging while southern BC and AB had zonal flow. A shortwave trough was expected to slide through central AB during the early evening hours. The area saw SE moisture advection and 850mb theta-e ridging for most of the day. The Calgary sounding showed directional shear with the wind veering with height. Additionally, the sounding showed a moderately unstable atmosphere with decent speed shear. Fair weather cumulus and a few towering cumulus occurred throughout the day. The area saw clearing during the late afternoon. During the evening, a few hail storms occurred in the northern part of the project area. They moved ESE through the northern buffer zone through Blackfalds and clipped the north end of Red Deer. Max cell top: 12.9km, 68 max dBz, 98.3 max VIL Tmax YC = 23.1C and a trace of rain. Tmax QF = 23.3C and 0.2mm of rain. Tmax Radar = 22.6C and no rain.	HS4 flew a PR flight from Red Deer to Olds-Didsbury airport. They took off at 1708Z and landed at 1725Z. For their return flight to Red Deer, they took off at 2126Z and landed at 2144Z. HS3 was launched to cloud top at 0455Z (08/05) for development W of Lacombe. They were airborne at 0506Z (08/05) and reported large mammatus clouds and frequent cloud to ground lightning. At 0522Z (08/05), they reported their right engine ice deflector door was malfunctioning. They were unable to rectify the problem. They performed a few top seeding runs before they had to descend to warmer temperatures. They began top seeding storm #1 at 0527Z (08/05), reporting moderate updrafts and good liquid water. They descended at 0542Z (08/05) and began base seeding with BIPs at 0549Z (08/05). They continued seeding until the storm moved past Red Deer. They RTB to YQF at 0731Z (08/05), landing at 0743Z (08/05). HS4 was launched to base at 0519Z (08/05) for development W of Lacombe. They were airborne at 0543Z (08/05) and reported a right burner malfunction. They began seeding storm #1 with their working burner at 0555Z (08/05), beginning BIPs at 0653Z (08/05) in response to increased inflow and intensification on radar. They continued seeding until the storm moved past Red Deer. They RTB YQF at 0731Z (08/05), landing at 0739Z (08/05). <u>Flight Summary</u>

		HS4: 1658Z-1729Z; no seeding; PR flight YQF to Olds. HS4: 2120Z-2148Z; no seeding; PR flight Olds to YQF. HS3: 0500Z (08/05)-0747Z (08/05); 20 BIP, 81 EJ; #1 Lacombe. HS4: 0534Z (08/05)-0744Z (08/05); 6 BIP, 97 minutes acetone generators; #1 Red Deer.
August 5, Friday	The main synoptic feature was a closed, upper level low over northern BC. Several lobes of weak to moderate vorticity were expected to pass over the project area from the SW to NE during the day. At the surface, a cold front was over central BC which was progged to begin pushing through AB during the late-night hours. The surface wind was expected to remain southeasterly for most of the day. 850mb theta-e ridging continued over the region, and the sounding data showed a moderately unstable atmosphere. The wind shear profile hinted at the possibility for long lived thunderstorms. During the late morning, skies were generally clear except for some strong storms in the southern buffer zone. Storms formed in the foothills during the early afternoon, and some of them moved into the project area. One severe storm moved down off the foothills and directly impacted Calgary. All aircraft were involved with seeding this Calgary storm. Overnight, there were a few rain showers and weak thunderstorms across the project area as the cold front passed through. There was one report of golf ball sized hail in northwest Calgary, and several reports of rivers of pea sized hail flowing in the streets. Nickel to quarter size hail was reported to the north of downtown. Flash flooding in the city was reported by the news media. An elderly man died in Calgary when he was washed under his vehicle in flood waters. Several people were stranded on the roofs of vehicles on flooded streets. Max cell top: 15.1km, 67 max dBz, 142.2 max VIL Tmax YC = 24.8C and 15.4mm of rain. Tmax QF = 24.5C and 0.4mm of rain. Tmax Radar = 24.0C and no rain.	HS2 flew to the Red Deer airport for scheduled maintenance. They were airborne at 1615Z and landed at 1653Z. HS1 was launched for development W of Okotoks at 1727Z, becoming airborne at 1745Z. They began patrol near Okotoks. HS1 found good growth on the NE side of the cell, but the storm began to change shape such that no cities were being threatened. It also began to weaken significantly as it moved off the foothills. HS1 RTB YYC at 1812Z, landing at 1833Z. HS2 was launched for development NW of Cochrane at 1957Z, becoming airborne at 2013Z. They reported a poorly defined base. They were told to patrol. At 2143Z, as the storm appeared to be holding its intensity and began moving towards Carstairs and Crossfield, HS2 began seeding storm #1 with burners. At 2234Z, as the storm strengthened and began to track more for Airdrie and northern Calgary, HS2 began using BIPs. A cell to the south of storm #1 showed explosive growth, and HS2 moved to storm #2 at 2312Z. This storm began to move south directly through Calgary, and was seeded heavily by HS2 until 0008Z (08/06), when they had to RTB for fuel. Because the storm was over the Calgary airport, they RTB YQF, landing at 0038Z (08/06). HS1 was launched to top at 2207Z for storm #1 W of Airdrie. They were airborne at 2225Z, and began seeding the south end of the storm at 2241Z. As storm #2 formed south of storm #1, they repositioned to it at 2318Z. At 0014Z (08/06), HS1 exhausted their EJs, and descended to 14kft to use BIPs at the -5C level. They continued until 0037Z (08/06) when they ran out of BIPs, at which point they RTB YYC. They landed at 0051Z (08/06). HS4 was launched at 2322Z to replace HS2 on storm #2. They were airborne at 2339Z and began seeding with generators and BIPs at 0011Z (08/06). They were initially restricted to E of the storm due to conflicts with ATC, but soon began a favorable track and reported moderate inflow. Throughout the flight, HS4 reported the storm weakening, with radar imagery confirming this. At 0058Z (08/06), due to reports of holes in the base and poor inflow,

		they stopped using BIPs and moved their track farther to the west in search of better inflow. No more inflow was found, only downdraft so they stopped seeding and began patrol at 0115Z (08/06). The storm continued to weaken on radar, and HS4 RTB YQF at 0123Z (08/06). They landed at 0155Z (08/06). HS3 was launched at 2346Z to replace HS1 on storm #2. They were airborne at 2357Z and began seeding storm #2 at 0025Z (08/06). They found good water and strong updrafts initially, but found more and more glaciated as the cell moved through Calgary. By 0101Z (08/06), they were finding nearly no liquid water, and stopped seeding at 0106Z (08/06). They RTB YQF 0113Z (08/06) as the storm ceased to be a hail threat. HS3 landed at 0145Z (08/06). HS2 flew a reposition flight from YQF to YYC. They became airborne at 0147Z (08/06) and landed at 0229Z (08/06). <u>Flight Summary</u> HS2: 1610Z-1657Z; no seeding; maintenance flight. HS1: 1739Z-1837Z; no seeding; patrol W Okotoks. HS2: 2003Z (08/05)-0040Z (08/06); 22 BIP, 286 minutes acetone generator time; #1 Airdrie, #2 Calgary; takeoff YQF, land YQF. HS1: 2215Z (08/05)-0057Z (08/06); 293 EJ, 23 BIP; #2 Calgary. HS4: 2330Z (08/05)-0158Z (08/06); 5 BIP, 126 minutes acetone generator time; #2 Calgary. HS3: 2351Z (08/05)-0148Z (08/06); 147 EJ; #2 Calgary. HS2: 0143Z (08/06)-0232Z (08/06); no seeding; reposition from YQF to YYC.
August 6, Saturday	There were no significant upper jet streaks over the area, but a closed upper low was moving through the northern project area in the afternoon and evening hours. The atmosphere was only moderately unstable. Wind shear was weak. A cold front had pushed through to the east by forecast time and would not be a factor for the day. Small hail was expected during the afternoon and early evening as the upper low moved through the area. Stratiform showers were expected overnight after the atmosphere stabilized in the evening. Clear skies prevailed during the morning, becoming cloudy during the early afternoon. A few showers occurred over the foothills. In the late afternoon, the upper low moving through the northern project area set off severe thunderstorms in the northern half of the PA. The most intense cells were east of Rocky MH. A moderately strong cell went through Penhold. Overnight, cold air set in, the atmosphere stabilized, and a few rain showers occurred. Barry Robinson reported lots of pea to marble sized hail	HS4 was launched for development near RMH at 0017Z (08/07). They were airborne at 0035Z (08/07), and started seeding storm #1 at 0052Z (08/07) with both burners. As the cell intensified on radar, they began using BIPs at 0101Z (08/07). They were directed to shift their track to the NE at 0129Z (08/07) as this was threatening Sylvan Lake. HS4 continued seeding the storm, moving d own to the S end of the cell at 0241Z (08/07). When the storm was past Red Deer at 0250Z (08/07), they discontinued seeding and repositioned to storm #3 by Sundre. They began seeding again at 0303Z (08/07) using only their left burner, as their right burner would not restart. The storm dissipated, and they RTB YYC. They landed at 0341Z (08/07). HS3 was launched at 0102Z for development W of RMH. They were airborne at 0111 (08/07), and began seeding storm #1 at 0125Z (08/07) with both EJs and BIPs. After one

	in Penhold. Nickel size hail occurred 2 km south of Didsbury. Max cell top: 11.4km, 69.5 max dBz, 156.6 max VIL Tmax YC = 21.8C and no rain. Tmax QF = 20.7C and 29mm of rain. Tmax Radar = 20.0C and 2mm of rain.	pass, they were directed to storm #2 W of Didsbury, which they began seeding at 0140Z (08/07). As this tracked south of Didsbury, HS3 moved back to storm #1, which was now threatening Sylvan Lake. They began seeding again at 0200Z (08/07). They found exceptional liquid water in this cell, and at 0214Z (08/07) descended to melt ice. They began climbing again at 0224Z (08/07), using BIPs through the climb. By this time, they were having trouble finding feeders on the SW side of the storm, so were directed to the E side where they were more successful. HS3 continued seeding this cell until it had moved past Red Deer, and were told to RTB YQF at 0255Z (08/07). Due to rain at the airport, they had to hold before landing, and finally touched down at 0314Z (08/07). HS2 was launched to storm #1 at 0129Z (08/07). They were airborne at 0145Z (08/07), and began seeding with burners at 0204Z (08/07). They began BIPs at 0208Z (08/07). They continued until 0241Z (08/07), when HS4 replaced them and they moved down to storm #2 W of Linden. They resumed seeding at 0250Z (08/07) with generators, stopping when the storm moved past Linden. They then repositioned to the Olds area at 0321Z (08/07). When a gust front pushed them far out from the storm, they RTB YYC at 0328Z (08/07). They landed at 0349Z (08/07). HS1 was launched at 0308Z (08/07) for the storm W of Olds. They were airborne at 0321Z (08/07). They were unable to find any updraft or suitable seeding area due to the dissipating nature of the storm. As this cell did not appear to be a hail threat, HS1 RTB YYC at 0352Z (08/07), landing at 0406Z (08/07). HS4 repositioned from YYC back to YQF after all activity diminished in the late night hours. They took off at 0713Z (08/07) and landed at 0751Z (08/07). <u>Flight Summary</u> HS4: 0028Z (08/07)-0345Z (08/07); 15 BIP, 256 minutes acetone generators; #1 RMH, #3 Sundre. HS3: 0103Z (08/07)-0320Z (08/07); 189 EJ, 17 BIP; #1 RMH, #2 Didsbury, #1 Red Deer. HS2: 0136Z (08/07)-0352Z (08/07); 5 BIP, 138 minutes acetone generators; #1 Sylvan Lake, #2 Linden, patrol Olds. HS1: 0314Z (08/07)-0410Z (08/07); no seeding; patrol W Olds. HS4: 0704Z (08/07)-0756Z (08/07); no seeding; reposition YYC to YQF.

ALBERTA HAIL SUPPRESSION PROJECT 2011

DAILY SUMMARY REPORTS
WEEK No.11

Date	Weather	Activities Summary
August 7, Sunday	An upper low was located over the Alberta-Saskatchewan border. The low was moving off to the east, and a ridge was building over the project area. Low levels were drying, midlevels were warming, and the sounding was nearly stable. A very shallow unstable layer was evident below 15kft. Weak convective showers were forecast to occur over the northern project area and foothills. Gusty winds were expected in the afternoon. Skies were expected to clear in the late afternoon, and stable conditions were forecast overnight. The day started out clear with fair weather cumulus over the area during the afternoon. As night fell, clearing occurred. A weak rain shower producing mainly virga passed through the northern part of the project area overnight. Max cell top: 5.4 km, 49.5 max dBz, 5.0 max VIL Tmax YC = 20.0C and no rain. Tmax QF = 19.0C and 3.4mm of rain. Tmax Radar = 18.0C and no rain.	No aircraft operations.
August 8, Monday	There was no significant upper jet over the region. A weak ridge was established over the project area. High pressure was in place, while surface dew points were high. The atmosphere was moderately unstable. A lee trough was expected to develop during the afternoon, and upslope winds were forecast to initiate thunderstorms along the foothills. The wind shear was unfavorable for sustained updrafts and long lived convection. The ridge was expected to inhibit thunderstorms over the plains, and convection was forecast to be confined to the foothills. Stable conditions were expected overnight. Uneventful weather occurred during the morning and afternoon as only some fair weather cumulus was present. In the late afternoon, some cells initiated over the foothills and moved to the south, dissipating as they moved into the project area. Overnight, skies were mostly clear. Max cell top: 6.1 km, 47.5 max dBz, 5.6 max VIL Tmax YC = 21.9C and no rain. Tmax QF = 22.6C and no rain. Tmax Radar = 2300C and no rain.	No aircraft operations.
August 9, Tuesday	No upper jet features were evident over the region. The upper ridge was flattening, and the upper level flow was weak from the northwest. Moderate instability was present, especially over the northern project area. Upslope flow was expected to trigger pulse-type thunderstorms during the day. Storms were expected to move off the mountains in the late afternoon. The wind	HS4 was launched at 2020Z to growing convection NW of Rocky MH. The aircraft became airborne at 2039Z. At 2058Z, the crew reported that they were only finding weak sporadic inflow, so they patrolled the Rocky MH area. Then at 2144Z the flight was redirected to new convection NW of Airdrie. The aircraft

	shear profile was weak, and long lived severe storms were not expected. Small hail was forecast to occur during the afternoon and evening. Weak instability was expected overnight with elevated weak thundershowers continuing through morning. Convection began forming along the mountains and foothills during the late morning hours. This convection grew in the afternoon and began pushing off the foothills in the mid-afternoon. The strongest storm (#2) of the day formed NW of Cochrane and initially tracked south-southeastward along the foothills. Once the storm neared the Cochrane area, it began to move off the foothills and passed through northern Calgary before dissipating. The late evening and overnight hours saw strong embedded storms across the northern part of the project area. Most of these storms were of the pulse variety and mainly consisted of heavy rain. Max cell top: 11.4 km, 64 max dBz, 102.3 max VIL Tmax YC = 24.3C and 4.2mm of rain. Tmax QF = 25.2C and no rain. Tmax Radar = 24.9C and 1mm of rain.	patrolled this area for a short time before being redirected to stronger convection NW of Sylvan at 2250Z. HS4 started seeding the Sylvan storm (#1) at 2317Z with one generator due to failure of the right generator. HS4 briefly seeded storm #1 until the flight was redirected at 2327Z to a much stronger storm NW of Calgary. The aircraft began seeding the Calgary storm (#2) at 2352Z. The aircraft seeded with BIPs only as the left burner would not reignite. HS4 continued to seed Storm #2 until HS2 replaced them. HS4 stopped seeding and RTB at 0021Z (08/10). The aircraft landed in YQF at 0049Z (08/10). HS1 was launched at 2313Z to strong development NW of Cochrane. The flight became airborne at 2335Z. HS1 started seeding storm #2 from Cochrane to Calgary at 2350Z. At 0059Z (08/10), the aircraft stopped seeding and started patrolling after the crew said they were finding minimal feeder clouds. HS1 stopped patrolling and RTB at 0153Z (08/10). The flight landed in YYC at 0210Z (08/10). HS2 was launched at 2345Z to replace HS4 at cloud base for storm #2 near Cochrane. The flight became airborne at 0016Z (08/10). The aircraft quickly found inflow and started seeding the Calgary storm (#2) at 0027Z (08/10). At 0044Z (08/10), the crew reported that the storm's base was breaking up and inflow diminishing. HS2 stopped seeding and started patrolling at 0105Z (08/10). HS2 then patrolled the southern Calgary area until 0222Z (08/10) when they RTB. The aircraft landed in YYC at 0233Z (08/10). HS4 was launched for a brief patrol flight to the SW of Red Deer at 0630Z (08/10). The flight became airborne at 0646Z (08/10). Nothing seedable was found and they RTB at 0714Z (08/10). They landed back in YQF at 0723Z (08/10). <u>Flight Summary</u> HS4: 2028Z (08/09)-0052Z (08/10); 9 min acetone generator time, 6 BIP; patrol Rocky MH, patrol Airdrie, #1 Sylvan, and #2 Calgary. HS1: 2320Z (08/09)-0215Z (08/10); 174 EJ, 3 BIP; #2 Calgary and patrol Calgary. HS2: 0010Z (08/10)-0237Z (08/10); 74 minutes acetone generator time, 3 BIP; #2 Calgary and patrol Calgary. HS4: 0637Z (08/10)-0727Z (08/10); no seeding; patrol Red Deer.
August 10, Wednesday	There was no significant upper level jet over the area. An upper level trough was progged to begin moving into the area during evening hours. Midlevels of the atmosphere were cooling while low level moisture was increasing.	HS2 flew a maintenance flight from Calgary to Red Deer. The aircraft was airborne at 1513Z and landed at 1541Z.

	Moderate instability was expected throughout the forecast period. Wind shear was weak and unfavorable for severe storm development. Afternoon and evening pulse-type hail storms were forecast. Weak nocturnal convection was also expected through morning. Convection began to form along the foothills around noon. The afternoon saw a line of TITAN cells developing along the foothills. As the line began to move off the foothills onto the project area, many of these cells diminished and became embedded rain. One storm W of Airdrie was able to make its way into the project area. This storm (#1) eventually strengthened and moved through Airdrie and northern Calgary during the late afternoon hours dropping nickel and quarter size hail. The rest of the project area saw weak to moderate thunderstorm activity. Max cell top: 12.4 km, 68 max dBz, 118.8 max VIL Tmax YC = 22.6C and 4.2mm of rain. Tmax QF = 25.5C and 10.2mm of rain. Tmax Radar = 22.0C and no rain.	HS2 then flew a public relations flight from Red Deer to the Olds-Didsbury airport. The aircraft was airborne at 1715Z and landed at 1729Z. HS2 was launched from the Olds-Didsbury airport at 2116Z in order to patrol an area N of Cochrane. The flight became airborne at 2125Z. HS2 started seeding storm #1 W of Airdrie at 2205Z. The aircraft followed the storm as it moved through Airdrie and northern Calgary. At 2303Z, HS2 was restricted by air traffic control to the south-southwest side of the storm. HS2 stopped seeding at 2354Z and briefly patrolled the area before being RTB at 2357Z. The aircraft landed in Calgary at 0006Z (08/11). HS1 was launched at 2219Z to storm #1 W of Airdrie. The aircraft became airborne at 2239Z. The crew quickly found seedable conditions over northern Calgary and started seeding storm #1 at 2248Z. At 2306Z the crew reported they were finding 1000fpm updrafts. Once the storm diminished, HS1 stopped seeding at 2354Z and started patrolling eastern Calgary. At 0009Z (08/11) the flight RTB to Calgary. The aircraft landed at 0015Z (08/11). HS4 was launched for a patrol flight near the Lacombe area at 0024Z (08/11). The flight became airborne at 0036Z (08/11). No hailstorms developed over the area. HS4 RTB at 0119Z (08/11) and landed in YQF at 0129Z (08/11). <u>Flight Summary</u> HS2: 1506-1545Z; no seeding; maintenance flight Calgary to Red Deer. HS2: 1709-1731Z; no seeding; PR flight Red Deer to Olds-Didsbury airport. HS2: 2122Z (08/10)-0011Z (08/11); 200 min acetone generator time, 11 BIP; #1 Airdrie/Calgary and patrol Calgary. HS1: 2227Z (08/10)-0020Z (08/11); 168 EJ, 10 BIP; #1 Airdrie/Calgary and patrol Calgary. HS4: 0030Z (08/11)-0132Z (08/11); no seeding; patrol Lacombe.
August 11, Thursday	The upper level jet remained well south of the project area. An upper low was located along the Montana border southeast of the project area. A low level circulation was present to the east of Calgary moving out of the area in the morning. Weak ridging was expected to begin in the afternoon. A thick cirrus cloud layer was expected to persist throughout the day which would inhibit insolation. A lee trough was expected to develop in the afternoon, and upslope flow was progged to initiate storms along the foothills. The atmosphere was moderately unstable with a weak wind shear profile. Early morning weak thunderstorms had already occurred by forecast time. Thundershowers were expected during the afternoon and evening. Stable, clear conditions were	HS1 was launched to new growth near the Cochrane area at 2233Z. The flight became airborne at 2259Z and was initially vectored by air traffic control to the SW of Calgary. Then at 2325Z the aircraft started seeding storm #1 over southern Calgary. HS1 then stopped seeding at 2339Z and RTB at 2341Z. The flight landed in Calgary at 2357Z. <u>Flight Summary</u> HS1: 2252Z (08/11)-0002Z (08/12); 40 EJ; #1 southern Calgary to Okotoks.

	forecast to begin around midnight. A line of embedded convection formed over the foothills during the afternoon hours. This line extended from Sundre down to High River and eventually moved into the project area during the late afternoon. The strongest storm (#1) formed just south of Cochrane and moved southeastward through Calgary and Okotoks dropping pea size hail. The rest of the project area saw weaker thunderstorms. The region then experienced clearing during the late evening and overnight. Max cell top: 11.4 km, 65.0 max dBz, 67.1 max VIL Tmax YC = 19.0C and 2.0mm of rain. Tmax QF = 20.0C and 2.4mm of rain. Tmax Radar = 20.0C and no rain.	
August 12, Friday	An upper level ridge had developed with its axis over central Alberta. The atmosphere was moderately unstable. Due to the significant ridging and lack of strong triggers, no severe convection was expected. A weak easterly wind and good instability made rain showers a possibility for later in the afternoon. The region saw mainly clear skies with occasional fair weather cumulus. Thunderstorms formed over the foothills south of Calgary but dissipated before reaching the project area boundary. Stronger thunderstorms were seen west of Edmonton and south of High River. Tmax YC = 22C and no rain. Tmax QF = 23C and no rain. Tmax Radar = 23C and no rain.	No aircraft operations.
August 13, Saturday	An upper level ridge axis was located over the Alberta-Saskatchewan border, and a weak trough was located over central Alberta. The upper jet had protruded into the project area, but there were no jet streaks. Due to the ridge, no severe convection was expected, despite the moderate instability and good shear on the sounding. Rain showers in the eastern buffer were forecast due to the proximity of the trough. Towering cumulus clouds were seen along the northern foothills during the afternoon hours. These clouds dissipated as they approached the project area. The northern buffer zone saw convective rain showers during the late afternoon and early evening. Clear skies then occurred in the late evening and overnight hours. Max cell top: 5.4km, 53.5 max dBz, 11.2 max VIL Tmax YC = 26C and no rain. Tmax QF = 26C and no rain. Tmax Radar = 26C and no rain.	No aircraft operations.

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Date	Weather	Activities Summary
August 14, Sunday	The upper level trough was moving in during the forecast period, and small midlevel shortwaves were present. Moisture was in very good supply, and combined with speed shear and mid-level cooling made for an impressive sounding. A dry cold front extending SE through the center of the project area was obvious on the surface observations. Severe thunderstorms were expected beginning in the mid-afternoon focused on the northern half of the project area. Convection developed in the afternoon along the foothills between Sundre and Rocky MH. Around 00Z, some of these cells became strong enough to move into the project area. Storm #1 moved through Rocky MH at roughly 01Z before dissipating. The foothills near Rocky MH continued to see strong convection during the rest of the evening. Weaker convective storms moved through the project area overnight. Max cell top: 10.6km, 59.0 max dBz, 30.6 max VIL Tmax YC = 27C and no rain. Tmax QF = 22C and no rain. Tmax Radar = 23C and 1.2mm rain.	HS4 was launched at 2319Z to a cluster of convective cells W and SW of Rocky MH. The flight became airborne at 2334Z. The aircraft began patrolling the still developing storm (#1) SW of Rocky MH at 2356Z. HS4 started seeding storm (#1) at 0025Z (08/15) once it was apparent on radar that the storm was moving off the foothills towards Rocky MH. At 0134Z (08/15) HS4 stopped seeding and started patrolling the Rocky MH area. The aircraft stopped patrolling and RTB at 0150Z (08/15). HS4 landed in YQF at 0206Z (08/15). <u>Flight Summary</u> HS4: 2326Z (08/14)-0210Z (08/15); 140 min acetone generator time, 3 BIP; #1 Rocky MH and patrol Rocky MH.
August 15, Monday	The upper level trough axis was located W of the BC/AB border, with an associated jet streak producing stratus rain and a thick cloud shield over the Rockies. This band of showers was expected to be the main feature for the day, with some weak thunderstorms possible in NE areas of the project area, where temperatures could possibly increase enough to support convection. Due to exceptionally cool temperatures, no convection was expected in the evening or overnight. It was rainy and cloudy during the early afternoon with clearing occurring by late afternoon. During the early evening, some storms occurred over the foothills moving off into the central and southern project area. Marginal hail storms moved from Sundre through the Airdrie/Calgary area. Some weaker cells moved over the radar and Didsbury area. Weak showers lingered over the northern project area through the late evening, and then the area was clear overnight. In Sundre, pea sized hail to a depth of 1 inch was reported. Ice pellets smaller than 4mm were observed at the radar. Max cell top: 9.9km, 67.5 max dBz, 78.2 max VIL Tmax YC = 14C and no rain. Tmax QF = 14C and 9.8mm rain. Tmax Radar = 15C and 9.3mm rain.	HS3 was launched at 0020Z (08/16) for cells near Sundre. They were airborne at 0040Z (08/16). HS3 began seeding storm #1 near Sundre at 0050Z (08/16) dragging BIPs through their climb to cloud top. They seeded the cell very briefly making only one seeding pass before being redirected to new growth on the west side of Calgary. They stopped seeding #1 at 0055Z (08/16) as they headed toward Calgary. They began top seeding storm #2 over Calgary at 0110Z (08/16) with BIPs and EJs. At 0144Z (08/16) HS3 stopped seeding over Calgary and moved back to storm #1 and began seeding it again at 0158Z (08/16) as it was approaching Airdrie. At 0210Z (08/16) there were no hail threats left to seed so HS3 stopped seeding and RTB to YQF. They landed at 0229Z (08/16). HS1 was launched at 0105Z (08/16) for base seeding over the Calgary area to work the same area with HS3. HS1 was airborne at 0127Z (08/16) and began base seeding storm #1 near Airdrie with BIPs at 0154Z (08/16). They only seeded for a brief time before the storm moved east and was no longer a hail threat. They stopped seeding at 0211Z (08/16) and patrolled for a few minutes before RTB at 0225Z (08/16). They landed back in YYC at 0232Z (08/16).

		Flight Summary HS3: 0031Z (08/16)-0234Z (08/16); 157 EJ, 6 BIP; #1 Sundre and Airdrie, #2 Calgary. HS1: 0117Z (08/16)-0235Z (08/16); 5 BIP; #1 Airdrie.
August 16, Tuesday	With the trough axis west of the project area, the mid and high levels were in zonal flow. With no mid or low level triggers, cool temperatures, and low dewpoints, no convection or precipitation was expected throughout the period. The project area was mostly clear throughout the period. Chinook arch clouds formed late in the day. There were no TITAN cells or precipitation observed. Tmax YC = 21C and no rain. Tmax QF = 21C and no rain. Tmax Radar = 22C and no rain.	No aircraft operations.
August 17, Wednesday	An upper level trough was progged to move through the project area during the afternoon and evening, with associated vorticity in the N half of the PA during the early evening hours. The sounding showed some instability during this period with good speed shear. A few weak thunderstorms were thus anticipated in the evening, becoming embedded as night fell. After the passage of this feature, northwest flow was expected to dominate, and no convection was expected overnight or tomorrow. Mountain wave and Chinook arch clouds overspread the project area in the morning and afternoon hours. During the late afternoon, an isolated convective cell developed near Rocky MH which moved ESE through the Red Deer area dropping pea sized hail. The cell was seeded from Sylvan to Red Deer. A large band of rain showers then moved through from northwest to southeast during the evening and overnight hours. There were some weak low-topped embedded convective cells overnight, but no hail threats. HS3, Jody Fischer, Terry Krauss, and all meteorology staff were present for an afternoon radar tour presented to insurance industry representatives. Max cell top: 8.4km, 64.5 max dBz, 35.2 max VIL Tmax YC = 22.9C and no rain. Tmax QF = 22.3C and 1.6mm of rain. Tmax Radar = 22.1C and 5.8mm of rain.	HS4 was launched at 2350Z for a weak cell near Sylvan approaching the Red Deer area. They were airborne at 0004Z (08/18) and began seeding storm #1 near Sylvan at 0011Z (08/18) with burners only. They then reported some pockets of strong inflow 0027Z (08/18) and burned two BIP flares. As the cell moved east of Red Deer, HS4 stopped seeding and RTB at 0049Z (08/18). They landed at 0054Z (08/18). Flight Summary HS3: 1709Z-1735Z; no seeding; PR flight YQF to radar. HS3: 2120Z-2143Z; no seeding; PR flight from radar back to YQF. HS4: 2356Z (08/17)-0057Z (08/18); 2 BIP, 72min acetone generator time; #1 Sylvan to Red Deer.
August 18, Thursday	The upper level jet flow was mainly over southern AB, but jet PVA was possible over Calgary. Mid-level flow was northwesterly with one shortwave trough moving through the southern part of the project area during the late afternoon and early evening hours. Moderate vorticity advection was expected with the shortwave late in the day. The sounding showed a slightly unstable atmosphere with moderate speed shear. Weak convection occurred throughout the early and midafternoon without lightning. By late afternoon, activity intensified. Cells near Calgary developed into hail threats and moved directly through Calgary from northwest to southeast. Two storms were seeded as they moved	HS1 was launched at 0029Z (08/19) for marginal hail storms approaching northwestern Calgary. They were airborne at 0048Z (08/19) and began top seeding storm #1 with EJs and BIPs over northern Calgary at 0056Z (08/19). They continued seeding that cell until it was beginning to move out of the southeast Calgary area and repositioned to another cell near Cochrane at 0141Z (08/19). They began seeding storm #2 over northwestern Calgary at 0144Z (08/19). Once the second cell moved out of Calgary, HS1 RTB to YYC at 0242Z (08/19). They landed at 0254Z (08/19).

	through the Calgary area dropping hail up to 27mm. All activity diminished by around 04Z and the atmosphere was stable overnight with just a few isolated weak showers through morning. 27mm hail was reported 1km east of Cochrane. Marble size hail was observed at YYC. Max cell top: 9.9km, 64 max dBz, 54.5 max VIL Tmax YC = 15.9C and 6.0mm of rain. Tmax QF = 17.4C and 3.2mm of rain. Tmax Radar = 15.2C and 0.6mm of rain.	HS2 was launched toward a cell near Cochrane at 0047Z (08/19). They were airborne at 0117Z (08/19) and began seeding storm #2 over northwestern Calgary at 0123Z (08/19). They continued base seeding the cell with burners and BIPs until it moved out of the Calgary area to the southeast. They RTB at 0244Z (08/19) and landed in YYC at 0256Z (08/19). <u>Flight Summary</u> HS1: 0038Z (08/19)-0258Z (08/19); 275 EJ, 14 BIP; #1 Calgary, #2 Calgary. HS2: 0102Z (08/19)-0259Z (08/19); 15 BIP, 162min acetone generator time; #2 Calgary.
August 19, Friday	Jet energy was mainly to the NE of the region. A shortwave trough moved through the project area during the late morning and early afternoon hours. Mid-level ridging then occurred through the rest of the forecast period, but a weak lobe of vorticity passed over the region in the evening. The atmosphere was warming near 500mb which inhibited convective growth above 20kft. Weak thundershowers occurred in the morning and early afternoon over the far northeast and eastern project area. There were no hail threats. All activity moved well east of the area by late afternoon and the region remained mostly clear through the night with some cirrus moving in from the northwest. Max cell top: 6.9km, 60 max dBz, 21.0 max VIL Tmax YC = 18.0C and no rain. Tmax QF = 18.6C and no rain. Tmax Radar = 17.4C and no rain.	No aircraft operations.
August 20, Saturday	A broad upper level ridge was in place over the region. No vorticity advection was expected, and a surface trough developed in the lee of the Rockies. The atmosphere was capped with strong convective inhibition in the low levels and subsidence aloft. An isolated very small echo was observed over the far southeastern buffer zone near Vulcan around dawn. Other than that, the project area remained echo free and clear for the entire day and overnight. There were no TITAN cells. 29.5 max dBz Tmax YC = 23.1C and no rain. Tmax QF = 24.1C and no rain. Tmax Radar = 24.3C and no rain.	No aircraft operations.

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Date	Weather	Activities Summary
August 21, Sunday	The upper level jet continued to be NW of central AB. At the mid-levels, the ridge axis was now along the AB/SK border. A disturbance was expected to push through the region during the evening with weak vorticity advection, and a surface trough remained in the lee of the Rockies. This trough was to gradually move eastward during the day. The project area was mostly clear and warm throughout the day. During the late overnight hours, there was one small convective rain shower in the buffer zone near Rocky MH with no lightning. There were no TITAN cells. 40.0 max dBz, 2.8 max VIL Tmax YC = 29.7C and no rain. Tmax QF = 29.9C and no rain. Tmax Radar = 30.1C and no rain.	No aircraft operations.
August 22, Monday	The jet stream was over central AB for most of the day, so the region was experiencing slight jet PVA. The mid-levels were still seeing weak ridging during the afternoon hours. Zonal flow was expected by evening. Vorticity advection was possible throughout the forecast period. At the surface, a cold front was expected to push through during the late evening hours. The project area was partly cloudy with a few very small convective and stratiform echoes in the morning and overnight. There was little more than a sprinkle from these cells. There was no lightning, and there were no TITAN cells. 35 max dBz Tmax YC = 27.6C and no rain. Tmax QF = 26.8C and no rain. Tmax Radar = 23.7C and no rain.	No aircraft operations.
August 23, Tuesday	The right entrance region of an upper level jet streak was over the northern part of the project area. Mid-level ridging was expected during the afternoon hours and a stationary front existed over southern AB. The atmosphere was only slightly unstable with moderate speed shear. The project area remained echo-free and partly cloudy throughout the day. Overnight, a very small convective echo was observed in the southeast buffer zone for a few radar scans. This was the only significant echo detected on radar throughout the entire forecast period. No TITAN cells. 41.5 max dBz. Tmax YC = 22.6C and no rain. Tmax QF = 22.0C and no rain. Tmax Radar = 22.0C and no rain.	HS4 flew a PR flight from YQF to Olds-Didsbury for a radar tour. They took off from YQF at 1700Z and landed in Old-Didsbury at 1719Z. After the tour, they departed at 2141Z and landed back in YQF at 2156Z. <u>Flight Summary</u> HS4: 1648Z-1723Z; no seeding; PR flight from YQF to radar HS4: 2135Z-2200Z; no seeding; PR return flight from radar to YQF.

August 24, Wednesday	The upper level jet was positioned over far northern Alberta. Some very weak instability was expected in the late afternoon and early evening hours, but it was not expected to create deep convective clouds. A cold front was progged to pass through the project area in the late evening without creating precipitation. A potent lobe of vorticity was progged to pass just to the north of the project area overnight. Sunny weather occurred during the morning and afternoon hours. The evening and overnight hours saw weak, scattered radar echoes near Lacombe and east of Red Deer. No TITAN cells. 19 max dBz Tmax YC = 28.9C and no rain. Tmax QF = 29.2C and no rain. Tmax Radar = 29.0C and no rain.	No aircraft operations.
August 25, Thursday	A weak upper level jet streak was nosing into far northwestern Alberta. Midlevel charts indicated ridging and warming over the northern project area. Modest instability was expected over the far southern project area during the afternoon and evening. Ridging and unfavorable upper level dynamics were expected to suppress any convection over the project area. Storms were expected to be confined to the foothills west of Calgary and areas to the southwest. Thunderstorms developed along the foothills southwest of Calgary in the afternoon. One large storm barely clipped southwestern buffer zone. This storm was not a threat to the project area. In the evening and overnight, scattered rain showers fell along the eastern buffer. Max cell top: 13.6km, 64.5max dBz, 106.7max VIL Tmax YC = 22.5C and no rain. Tmax QF = 21.5C and no rain. Tmax Radar = 22.0C and no rain.	HS3 flew a public relations flight from Red Deer to the radar. The aircraft was airborne at 1736Z and landed at 1747Z. HS3 then flew a public relations flight back to Red Deer. The flight was airborne at 2137Z and landed at 2150Z. <u>Flight Summary</u> HS3: 1729-1749Z; no seeding; PR flight YQF to radar. HS3: 2134-2155Z; no seeding; PR return flight from radar back to YQF.
August 26, Friday	The upper level jet core had shifted east into Saskatchewan, and a broad flat ridge was developing over the region. A weak shortwave trough was progged to move through northern Montana in the evening. The atmosphere was moderately unstable in the far south while the northern project area was stable. The atmosphere was capped in the low levels. For the second day in a row, convection was progged to remain along the foothills west and south of Calgary. The thunderstorm activity once again occurred over the foothills south of Calgary and the southern buffer zone. The thunderstorms dissipated before entering the project area. Weak echoes were also seen north of the project area in the evening. Overnight, scattered convective rain showers fell over the region. Max cell top: 9.1km, 50.5max dBz, 13.2max VIL Tmax YC = 23.7C and no rain. Tmax QF = 23.9C and no rain.	No aircraft operations.

	Tmax Radar = 23.0C and no rain.	
August 27, Saturday	An upper level jet streak was pushing into western Alberta. Midlevel ridging and warming was expected to begin in the afternoon. The atmosphere was slightly unstable in the morning, but it was expected to stabilize in the afternoon through overnight hours. Weak convective showers were likely in the morning with clearing expected late in the day and overnight. The early morning hours saw weak convective rain showers. Mid-level cumulus clouds were then seen in the late morning and afternoon. Cirrus clouds were also observed during the same time period. There were no TITAN cells. 41 max dBz Tmax YC = 27.2C and no rain. Tmax QF = 26.3C and no rain. Tmax Radar = 27.0C and no rain.	No aircraft operations.

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Date	Weather	Activities Summary
August 28, Sunday	A broad upper level ridge was established over the region. Midlevels were warming and low levels were drying. The atmosphere was stable. A cold front was moving through British Columbia, well west of the project area. The region saw mostly clear skies. There were no radar echoes. Tmax YC = 24.5.0C and no rain. Tmax QF = 24.5C and no rain. Tmax Radar = 24.5C and no rain.	No aircraft operations.
August 29, Monday	The atmosphere was unstable due to high surface dew points and cooling aloft. A surface low was progged to form just east of the project area during the afternoon. Winds were southeasterly in the morning, expected to become northwesterly in the afternoon. A cold front was progged to reach the northern project area by evening and possibly stall over the area. Speed shear was favorable for hailstorms, but winds were backing with height. There was a layer of dry stable air in the low levels above the moist surface layer. A moderately strong cold front moved from north to south through the project area during the late afternoon hours. This front triggered convection east of Bowden. The evening hours saw another cold front slowly push through the region. This time, convection first formed south of Sundre and moved east-northeastward through Olds. These cells only produced light to moderate rain showers and no hail. Overnight, scattered rain showers fell over parts of the project area. Max cell top: 8.4km, 58.5 max dBz, 17.2 max VIL Tmax YC = 30.4C and no rain. Tmax QF = 27.2C and no rain. Tmax Radar = 30.4C and 1.6mm of rain.	HS4 flew a maintenance flight. The aircraft was airborne at 2045Z and landed at 2104Z. <u>Flight Summary</u> HS4: 2035Z-2109Z; no seeding; Maintenance flight.
August 30, Tuesday	No upper level jet energy was expected over the region. The main trigger was vorticity advection from a mid-level trough approaching from BC. The previous day's cold front was now draped along the AB and Montana border. The morning sounding indicated max cloud tops would be around 7.5km, so small hail was a remote possibility. Bands of stratus rain pushed through the region all day. A few weak embedded thundershowers were observed in the morning and early afternoon, but there were no significant hail threats. The stratus rain continued throughout the night as well. Max cell top: 8.4km, 60.5 max dBz, 19.9 max VIL Tmax YC = 14.2C and 4.4mm of rain. Tmax QF = 14.2C and 15.0mm of rain.	No aircraft operations.

	Tmax Radar = 10.8C and 15.2mm of rain.	
August 31, Wednesday	The upper level jet flowed over southern AB, but jet energy was mainly W and E of the area. At the mid-levels, a trough axis extended from northern AB down through the state of Washington. Several lobes of vorticity were expected to move over the region, and a stationary front was draped across AB, SK, and MB. The sounding indicated a stable atmosphere above 4km. Widespread stratus rain was observed throughout the entire period with low ceilings. Rain finally began moving out of the project area to the SE around 11Z in the morning. Max cell top: 4.6km, 55.0 max dBz, 5.4 max VIL Tmax YC = 9.3C and 22.4mm of rain. Tmax QF = 10.6C and 3.0mm of rain. Tmax Radar = 8.5C and 5.0mm of rain.	No aircraft operations.
September 1, Thursday	No upper level jet influence was expected. An upper level closed low was over northern BC during the daytime hours. Overnight, this low began to push into northern and central AB. A cold front also passed through the project area during the late evening and overnight hours. There was vorticity advection behind the cold front, and the atmosphere was slightly unstable with weak speed shear. A few isolated convective echoes were observed during the morning and afternoon, but nothing with significant precipitation. Widespread heavy stratiform rain overspread the project area around 06Z and lingered throughout the night. Terry Krauss, Jody Fischer, and HS4 were present at the radar for an afternoon tour presented to insurance representatives. Max cell top: 5.4km, 58.0 max dBz, 10.8 max VIL Tmax YC = 18.2C and 0.2mm of rain. Tmax QF = 18.7C and no rain. Tmax Radar = 18.4C and 4.0mm of rain.	HS4 flew to the radar for a tour. They took off from YQF at 1713Z and landed at Olds-Didsbury at 1729Z. After the tour, they took off from the radar at 2137Z and landed back at YQF at 2156Z. HS2 performed a brief maintenance flight. They were airborne at 1907Z and landed back at YYC at 1911Z. <u>Flight Summary</u> HS4: 1701Z-1732Z; no seeding; PR flight from YQF to radar. HS4: 2132Z-2200Z; no seeding; PR return flight to YQF. HS2: 1855Z-1914Z; no seeding; Maintenance flight.
September 2, Friday	The jet core was over BC, expected to slide eastward through AB overnight. A mid-level trough was over southern AB. Nevertheless, the main trigger for thunderstorms was a shortwave trough which pushing through the project area during the afternoon hours. The surface wind flow was west-northwesterly and did not favor orographic lift. Storm motion data suggested that the convection would move towards the south-southeast. Heavy rain moved out in the early morning hours. Thunderstorms moved through the southern half of the project area during the afternoon with some marginal hail threats developing from Springbank to High River. The project area cleared out in the evening and remained clear overnight. There were no hail reports. Max cell top: 10.6km, 62.5 max dBz, 47.5 max VIL Tmax YC = 14.6C and 3.6mm of rain. Tmax QF = 13.6C and 5.8mm of rain. Tmax Radar = 12.0C and 0.2mm of rain.	HS2 was launched at 1952Z for marginal hail threats developing over Springbank. They were airborne at 2007Z. They began seeding storm #1 northwest of Okotoks at 2025Z with acetone generators only. They stopped seeding storm #1 at 2048Z and began patrol near Cochrane. They RTB at 2121Z and landed back in YYC at 2135Z. <u>Flight Summary</u> HS2: 2000Z-2140Z; 46min acetone generators; #1 Okotoks, patrol Cochrane.

September 3, Saturday	The upper level jet was north and east of the area. Additionally, upper level ridging was occurring over AB for most of the day. 500mb temperatures were warming across the project area which inhibited deep convection. Surface high pressure was dominant across the region. Shallow fair weather cumulus was present in the early afternoon, and then the project area was mostly clear for the remainder of the period. Tmax YC = 17.0C and no rain. Tmax QF = 17.9C and no rain. Tmax Radar = 17.1C and no rain.	No aircraft operations.

ALBERTA HAIL SUPPRESSION PROJECT 2011

DAILY SUMMARY REPORTS
WEEK No.15

Date	Weather	Activities Summary
September 4, Sunday	Upper level jet energy remained north of AB. The upper level ridge was now over SK and MB, so AB mainly saw zonal mid-level flow. Weak vorticity advection was expected during the evening and overnight hours. At the surface a lee trough developed along foothills during the day and slowly moved eastward. The project area saw strong convective inhibition. The project area saw clear skies all day and overnight. There were no radar echoes. Tmax YC = 24.9C and no rain. Tmax QF = 25.2C and no rain. Tmax Radar = 25.0C and no rain.	No aircraft operations
September 5, Monday	An upper level ridge remained over the region. Low levels were dry, and the atmosphere was stable. A stationary front was draped across northern Alberta. Clear skies were expected throughout the forecast period. Mostly clear skies were observed across the project area. No echoes were seen on radar. Tmax YC = 26.5C and no rain. Tmax QF = 26.5C and no rain. Tmax Radar = 27.0C and no rain.	No aircraft operations.
September 6, Tuesday	An upper level ridge was amplifying over the region. Low levels remained dry, and the atmosphere was stable. At the surface, high pressure was building over the region. Clear skies were forecast to occur throughout the period. A few patches of upper level cirrus clouds were seen over the project area throughout the day. The radar showed no radar echoes. Tmax YC = 26.1C and no rain. Tmax QF = 27.3C and no rain. Tmax Radar = 27.0C and no rain.	No aircraft operations.
September 7, Wednesday	The upper level jet was positioned north of the project area. A broad high amplitude ridge remained over the region. The atmosphere was stable. Low levels were dry. Clear skies were forecast to occur throughout the period. The project area saw sunny and dry weather. The radar was clear overnight as well. Tmax YC = 27.2C and no rain. Tmax QF = 27.8C and no rain. Tmax Radar = 27.0C and no rain.	No aircraft operations.
September	The upper jet was well north of the area and a broad	No aircraft operations.

8, Thursday	ridge remained over the western half of Canada. A small amount of midlevel instability was present during the afternoon, but low levels were dry and stable. Convective inhibition was expected to prevail and clear skies were forecast for the period. Mostly sunny skies were observed. A few cirrus clouds passed overhead and isolated altocumulus clouds formed over the foothills in the midafternoon. The region was clear overnight. No radar echoes. Tmax YC = 27.9C and no rain. Tmax QF = 28.4C and no rain. Tmax Radar = 29.0C and no rain.	
September 9, Friday	An upper ridge remained in place with the upper jet well north of the project area. Weak elevated instability was present, but low levels were stable and dry. Mainly clear skies were expected throughout the period with reduced visibility over southern AB due to smoke. Isolated cumulus and altocumulus clouds were seen over the foothills during the day while cirrus passed overhead. The radar showed no radar echoes for the entire period. Tmax YC = 27.1C and no rain. Tmax QF = 29.8C and no rain. Tmax Radar = 29.5C and no rain.	No aircraft operations.
September 10, Saturday	The upper level ridge over the region was flattening and northwesterly flow was developing over the region. The jet was gradually sagging southward into northern AB. Midlevels were slightly unstable, but stable low levels were expected to inhibit convection. Mostly clear skies were forecast throughout the period. Smoke was present over southern AB which was expected to keep visibility below 4 miles. Skies were free of cloud throughout the period. Smoke lingered over the region and reduced visibility. The mountains were not visible from the radar at times. No radar echoes. Tmax YC = 24.2C and no rain. Tmax QF = 24.6C and no rain. Tmax Radar = 23.2C and no rain.	No aircraft operations.

ALBERTA HAIL SUPPRESSION PROJECT 2011
DAILY SUMMARY REPORTS
WEEK No.16

Date	Weather	Activities Summary
September 11, Sunday	The upper level jet continued to sag to the south for most of the day. A mid-level shortwave trough moved through central AB during the day. This shortwave was expected to stay just north of the project area. A surface low formed south of Edmonton and tracked southeastward towards southern SK. There was a cold front associated with the low which pushed through the project area during the morning and early afternoon hours. The atmosphere was slightly unstable with decent speed shear. Cloud cover was increasing throughout the morning. By late afternoon, waves of stratiform rain and a few weak convective cells moved across the northern part of the project area. There were no hail threats, no lightning strikes, and no TITAN cells. The precipitation ended by 6Z. 39.0 max dBz Tmax YC = 23.6C and no rain. Tmax QF = 21.3C and no rain. Tmax Radar = 20.0C and no rain.	No aircraft operations.
September 12, Monday	Upper level jet energy was mainly to the north of the area. Vorticity advection was also north of the region. A surface cold front was expected to slide from north to south through the project area during the late evening hours. The modified sounding showed a layer of weak instability between 8 and 11kft. The project area was cold and cloudy throughout the period. In the early evening, a small line of weak convection developed over the southeastern part of the project area. There were no lightning strikes and no hail threats. No TITAN cells. 36.5 max dBz Tmax YC = 12.3C and no rain. Tmax QF = 14.2C and no rain. Tmax Radar = 13.1C and no rain.	No aircraft operations.
September 13, Tuesday	The mid-levels saw ridging over BC and AB. A lobe of weak vorticity was expected to slide through the project area from NW to SE during the afternoon hours. A cold front pushed through the region during the morning hours which triggered weak convection. The main surface feature was a broad high pressure system over AB and SK. A layer of instability existed between 6 and 9kft. The project area was cloudy and cold throughout the daytime and evening hours. Waves of stratus rain moved through all day and overnight. Late in the period, a few weak convective showers developed with a few strikes of lightning observed. Max cell top: 6.1km, 49.5 max dBz, 5.6 max VIL	No aircraft operations.

	Tmax YC = 11.4C and no rain. Tmax QF = 11.0C and no rain. Tmax Radar = 12.0C and no rain.	
September 14, Wednesday	A mid-level trough passed over the region during the morning hours, and moderately strong vorticity advection was associated with the trough. The rest of the day saw upper level ridging. At the surface, a low formed over the Rockies as a large, dominant high pressure system, over the prairies, moved southeastward into the U.S. The Calgary sounding showed a mostly stable atmosphere during peak heating hours. Weak thundershowers were observed near Sundre and west of Calgary very early in the period. During the daytime hours, the project area was mostly clear while a few hailstorms lingered over the foothills. None of the storms moved into the project area. Convective activity diminished in the early evening and the project area cleared out overnight. Max cell top: 6.1km, 50.5 max dBz, 8.5 max VIL Tmax YC = 17.1C and a trace of rain. Tmax QF = 18.3C and no rain. Tmax Radar = 17.3C and no rain.	HS4 performed a maintenance flight. They took off from YQF at 1852Z and landed at YQF at 1915Z. <u>Flight Summary</u> HS4: 1830Z-1920Z; no seeding; Mx flight.
September 15, Thursday	An upper level jet streak passed over central AB during the overnight hours. Additionally, a mid-level trough was also expected to slide through during the late evening and overnight hours. The southwest flow caused several lobes of vorticity to move through during the late afternoon, evening, and overnight hours. At the surface, a low pressure system moved over the area. Convective inhibition was present between 5 and 12kft. A wave of virga moved through the northern project area around dawn. The project area had low overcast in the morning and afternoon hours. More virga and light stratus rain was present over the southern project area in the afternoon and evening. A few weak convective cells were observed. Max cell top: 7.6km, 47.5 max dBz, 8.5 max VIL Tmax YC = 22.7C and no rain. Tmax QF = 22.5C and no rain. Tmax Radar = 23.2C and 0.3mm of rain.	No aircraft operations.

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: Monday, April 20, 1998

Proposed starting date: June 1st, 1998

Expected duration: September 15, 1998 and continuing in 1999 and 2000

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which is the same as in 1996 and 1997).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry, private and public property, agriculture.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI) http://www.wmi.cban.com/

Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
WXMOD@worldnet.att.net
Local Organization: Weather Modification Canada Ltd.
P. O. Box 2717
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, General Manager
Ph.D. Atmospheric Science, 23 years experience
Tel: (403) 342-5685 and Fax: (403) 342-5685
(see Part 5 for details of qualifications and experience)

Primary activities of organization (see enclosed brochure):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: $50 million CDN by the Alberta Severe Weather Management Society c/o Wawanesa Mutual Insurance Co. and US$5 million by Weather Modification Inc.

List of similar weather modification activities previously undertaken:

a. Canada

- With the Alberta Research Council, Jim Renick and Terry Krauss were actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984 .

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years. For the summer of 1998, WMI is operating 9 aircraft in North Dakota.
- WMI has conducted operational cloud seeding in Oklahoma the last 3 years. During the summer of 1998, WMI is operating 3 aircraft in Oklahoma for Rain Enhancement and Hail Suppression
- WMI has conducted operational cloud seeding in Greece, Texas, Nevada, Turkey, United Arab Emirates within the last 5 years. For the summer of 1998, WMI is operating 5 aircraft in Texas, and 2 aircraft in Greece.
- With the Bethlehem Precipitation Research Project, South Africa, T. Krauss was director of the project over the period Sept. 1984 to April. 1986.
- With INTERA Technologies Ltd. of Calgary, AB, T. Krauss was actively involved in the Greek National Hail Suppression Project over the period March 1987 to June 1992.

4. References:

1. Mr. Jim Renick
   11 Warwick Drive,
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Bruce Boe, Director
   State of North Dakota Atmospheric Resource Board
   P.O. Box 1833
   Bismarck, ND 58502 Tel. 701-224-2788
3. Mr. George W. Bomar, Director
   Texas Natural Resource Conservation Commission
   Austin, TX 78711 Tel. 512-239-0381
4. Mr. Michael E. Mathis, Chief, Planning and Management Division
   Oklahoma Water Resources Board
   3800 N. Classen Blvd.
   Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 will be providing aircraft maintenance services to WMI.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)
#600, 708 - 11th Ave. S.W.
Calgary, AB T2R 0E4

Chief officer: Mr. Don McKay, President Tel. 403-269-9900
Mr. Rick Rogers, Past President Tel. 403-260-9261

Director of ASWMS: Mr. Jim Renick, M.Sc.
11 Warwick Drive
Red Deer, AB T4N 6L4 Tel. 403-347-1545

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of assembling funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-3616 and 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-291-4426 c/o ESSO AVITAT
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (cellular)
e-mail: krausst@agt.net
home page: http://www.wmi.cban.com/

Qualifications of field officer in charge:

- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- American Meteorological Society Member of Technical Committee on Weather Modification
- Certified Manager of the Weather Modification Association

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
c/o Olds-Didsbury Airport Commission
4911-51 ave., Olds, AB T4H 1R5

Field Telephone no. 403-335-3616 and 403-335-8359
Field personnel: full time = 1
part time = 11

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8
All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- storm radar echo data report and maps
- radar calibration report
- operations summary report
- daily operations log report
- chemical inventory report
- equipment status report
- aircraft flight report and flight track maps
- flight hour log report
- aircraft no-flight report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of more than $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers

and brokers, have donated about $7 million to conduct a hail suppression project over a 5 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized.

Secondary effects anticipated: Reductions in crop damage due to hail will also be realized. Seeding may also provide an increase in precipitation.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 21 to highway no. 36 may also benefit from the seeded storms.

Approximate total cost: approx. $1.4 million per year for 5 years.

Funds to be expended in Canada: est. $800,000 per year.

General period of operation: June 1st - Sept. 15th annually from 1998-2000 inclusive.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, extensive aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of 35 dBZ at heights above the -5 C temperature level. When large hail is forecast, seeding will commence when radar reflectivities reach 25 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used previously in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms which evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

All convective cells (defined by radar) with maximum reflectivity >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project areas, will be seeded. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of towering cumulus clouds or when radar cells exceed 18 kft height over the higher terrain along the western border.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors which determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -8 C and -12 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Strictly speaking, if the radar reflectivity criteria are met, seeding of all cells could be continued. However, seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts >10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

For cloud base seeding, a seeding rate of 1 or 2 end-burner flares (150 g each) is used, dependent on cloud updraft velocity. For an updraft >500 ft/min, 2 flares per seeding run are typically used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding at low concentrations if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if downdrafts only are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $4x10^{13}$ nuclei per g of AgI at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with a greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 30ft tower mounted plus radome.
- one Cheyenne II prop-jet aircraft located at Calgary airport
- two C-340 aircraft, one in Calgary and one in Red Deer.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable)pyrotechnic flares are 20 gm AgI formulation of the type and/or similar to those of Weather Modification Group of Okotoks, Alberta.
- Cloud base (end-burning) flares are 150 gm AgI formulation of the type and/or similar to those of

Weather Modification Group of Okotoks, Alberta.

- A mixture of Acetone, Silver iodide and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate >10^{13} ice crystals per gram of pyrotechnic at -10°C.

Total quantities to be dispersed: estimate of 3000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). Quantities dispensed in 1996 were 3817 ejectable flares (76.3 kg AgI), 542 end burn flares (81.3 kg AgI), and approx. 80 gals. of acetone mix (5.5 kg AgI). The amount of silver-iodide dispensed during the 1997 field season consisted of 2376 ejectable or cloud-top flares (47.5 kg AgI), 356 end-burning or cloud-base flares (53.4 kg AgI), and 144 gallons of AgI-acetone solution (9.9 kg AgI).

Total flight hours: 300 hours (est.) Total cloud seeding flight hrs. in 1996 was 160 hrs. During the summer of 1997, a total of 92 operational flights took place on 43 storm days. Clouds were seeded during 76 flights on 38 days. There were 16 patrol flights. The total flight hours during 1997 were 188.

No harmful effects from these materials is expected. This is based on years of studies to detect silver in precipitation (above background contamination levels) following cloud seeding (both in the USA and Canada). The amount of silver distributed by the cloud seeding is small compared to the output from industry and falls within the USA EPA guide lines (even within the cloud seeding plume).

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- one Cheyenne II aircraft
- two C-340 aircraft

Ministry of Transport operating authority granted File number 5260-1 (AARXC).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the rainfall display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be specially equipped with a special cloud physics data acquisition . A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals measurements from the following instruments: Rosemount total temperature, reverse flow temperature, EGG dew point, JW-hot wire liquid water probe, ice particle counter (Turner-Radke laser type), static and differential pressure transducers for airspeed and altitude, GPS latitude and longitude, and heading.

Vertical velocity can be calculated in post-analysis. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm which is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

The Special-Seeder could be the first aircraft launched on patrol and can be used to record an environmental sounding during initial ascent to seeding altitude, and provide a measurement of the convective cloud base temperature and altitude. A representative environmental sounding is an extremely important piece of information to help forecast and assess the potential and severity of convective weather. Special-Seeder missions can be flown to collect data from penetrations of the first convective clouds of the day. The data from these special instruments can be used to determine the suitability of individual clouds in a system for seeding, and also to monitor changes in the cloud microstructure that are expected as a result of seeding.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, And Nowcasting) was used for the 1997 season and proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Jim Renick, M. Sc. Title: Project Director

Signature: [signature] Date: 24 Apr. 1998

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Canada Ltd.

Full name of certifying officer: Terry W. Krauss, Ph.D. Title: Project Manager

Signature: T.W. Krauss Date: April 22, 1998

WEATHER MODIFICATION, INC.
P.O. Box 146 • Fargo, North Dakota 58107-0146 • Phone: (701) 235-5500 • Fax: (701) 235-9717

P.O. Box 27177 ● Red Deer, Alberta, Canada T4N 6X8 ● Phone (403) 342-5685 ● Fax (403) 342-5685
e-mail: krausst@agt.net WMI Home Page at http://www.wmi.cban.com/

May 10, 1999

Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario M3H 5T4

Attention: Mr. Jack Power, Weather Modification Information Officer

Dear Mr. Power:

Subject: Notice of Intent to Conduct Cloud Seeding - Alberta Hail Suppression Project 1999.

Please find enclosed our notice of intent to engage in weather modification activities pursuant to the Weather Modification Information Act of Canada.

Weather Modification Inc., (WMI) is entering the fourth year of a five year contract with the Alberta Severe Weather Management Society to conduct cloud seeding to mitigate hail damage to property in the Calgary - Red Deer region of Alberta. The cloud seeding operations will be conducted from June 1st to September 15th, 1999. All other operational aspects of the program are the same as conducted in 1996, 1997, and 1998. A full description of our activities is included in our Annual Final Reports for 1996, 97, and 98 which have already been sent to you.

If you require any further information about our project, please do not hesitate to contact me.

Sincerely,

TW Krauss

Terry W. Krauss, Ph.D.
Project Manager

copy: Mr. Jim Renick, ASWMS

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: Monday, May 10, 1999

Proposed starting date: June 1st, 1999

Expected duration: September 15, 1999 and continuing in 2000

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which is the same as in 1996,1997, and 1998).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry, private and public property, agriculture.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.wmi.cban.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
WXMOD@worldnet.att.net
Local Organization: Weather Modification Canada Ltd.
P. O. Box 2717
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, General Manager
Ph.D. Atmospheric Science, 23 years experience
Tel: (403) 342-5685 and Fax: (403) 342-5685
(see Part 5 for details of qualifications and experience)

Primary activities of organization (see enclosed brochure):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: $50 million CDN by the Alberta Severe Weather Management Society c/o Wawanesa Mutual Insurance Co. and US$5 million by Weather Modification Inc.

List of similar weather modification activities previously undertaken:

a. Canada

- With the Alberta Research Council, Jim Renick and Terry Krauss were actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984 .

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years. For the summer of 1999, WMI is operating 9 aircraft in North Dakota.
- During the southern summer (Dec. 1998 to April 1999), WMI provided hail suppression to Mendoza, Argentina using 3 Cheyenne II aircraft and a Lear Jet.
- WMI has conducted operational cloud seeding in Oklahoma the last 3 years. During the summer of 1999, WMI is operating 3 aircraft in Oklahoma for Rain Enhancement and Hail Suppression
- WMI has conducted operational cloud seeding in Greece, Texas, Nevada, Turkey, United Arab Emirates within the last 5 years. For the summer of 1999, WMI is operating 4 aircraft in Texas, and 2 aircraft in Greece.
- With the Bethlehem Precipitation Research Project, South Africa, T. Krauss was director of the project over the period Sept. 1984 to April. 1986.
- With INTERA Technologies Ltd. of Calgary, AB, T. Krauss was actively involved in the Greek National Hail Suppression Project over the period March 1987 to June 1992.

4. References:
   1. Mr. Jim Renick
11 Warwick Drive,
Red Deer, AB T4N 6L4 Tel. 403-347-1545
   2. Mr. Bruce Boe, Director
State of North Dakota Atmospheric Resource Board
P.O. Box 1833
Bismarck, ND 58502 Tel. 701-224-2788
   3. Mr. George W. Bomar, Director
Texas Natural Resource Conservation Commission
Austin, TX 78711 Tel. 512-239-0381
   4. Mr. Michael E. Mathis, Chief, Planning and Management Division
Oklahoma Water Resources Board
3800 N. Classen Blvd.
Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Mr. Gary Hillman, Penhold, Alberta (403) 886-4137 will be providing aircraft maintenance services to WMI.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)
#600, 708 - 11th Ave. S W.
Calgary, AB T2R 0E4

Chief officer: Mr. Don McKay, President Tel. 403-269-9900
Mr. Rick Rogers, Past President Tel. 403-260-9261

Director of ASWMS: Mr. Jim Renick, M.Sc.
11 Warwick Drive
Red Deer, AB T4N 6L4 Tel. 403-347-1545

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of assembling funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-3616 and 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-291-4426 c/o ESSO AVITAT
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (cellular)
e-mail: krausst@agt.net
home page: http://www.wmi.cban.com/

Qualifications of field officer in charge:

- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- American Meteorological Society Member of Technical Committee on Weather Modification
- Certified Manager of the Weather Modification Association

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
c/o Olds-Didsbury Airport Commission
4911-51 ave., Olds, AB T4H 1R5

Field Telephone no. 403-335-3616 and 403-335-8359
Field personnel: full time = 5
part time = 7

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8
All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- storm radar echo data report and maps
- radar calibration report
- operations summary report
- daily operations log report
- chemical inventory report
- equipment status report
- aircraft flight report and flight track maps
- flight hour log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of more than $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers

and brokers, have donated about $7 million to conduct a hail suppression project over a 5 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 3 years, the insurance industry is very encouraged by the results so far.

Secondary effects anticipated: Reductions in crop damage due to hail will also be realized. Seeding may also provide an increase in precipitation. The crop hail insurance data for the last three years indicates a drop in the loss-to-risk values on the order of 35% to 48% below the long term average.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 21 to highway no. 36 may also benefit from the seeded storms.

Approximate total cost: approx. $1.4 million per year for 5 years.

Funds to be expended in Canada: est. $800,000 per year. 96?

General period of operation: June 1st - Sept. 15th annually from 1999-2000 inclusive.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, extensive aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of 35 dBZ at heights above the -5 C temperature level, and pose a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach 25 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used previously in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms which evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

All convective cells (defined by radar) with maximum reflectivity >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project areas, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of towering cumulus clouds or when radar cells exceed 18 kft height over the higher terrain along the western border.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors which determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms. √

Cloud top seeding is conducted between typically between -8 C and -12 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a

seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Strictly speaking, if the radar reflectivity criteria are met, seeding of all cells could be continued. However, seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts >10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 end-burner flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if downdrafts only are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $4x10^{13}$ nuclei per g of AgI at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with a greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 30ft tower mounted plus radome.
- one Cheyenne II prop-jet aircraft located at Calgary airport
- two C-340 aircraft, one in Calgary and one in Red Deer.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable)pyrotechnic flares are 20 gm AgI formulation of the type and/or similar to those of CHEMOD, Macedonia or WMG, Alberta.

- Cloud base (end-burning) flares are 150 gm AgI formulation of the type and/or similar to those of CHEMOD, Macedonia or WMG, Alberta.
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate >10^{13} ice crystals per gram of pyrotechnic at -10°C.

Total quantities to be dispersed: estimate of 3000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). Quantities dispensed in 1996 were 3817 ejectable flares (76.3 kg AgI), 542 end burn flares (81.3 kg AgI), and approx. 80 gals. of acetone mix (5.5 kg AgI). The amount of silver-iodide dispensed during the 1997 field season consisted of 2376 ejectable or cloud-top flares (47.5 kg AgI), 356 end-burning or cloud-base flares (53.4 kg AgI), and 144 gallons of AgI-acetone solution (9.9 kg AgI). The amount of silver-iodide dispensed during the 1998 field season consisted of 2023 ejectable or cloud-top flares (40.5 kg AgI), 496 end-burning or cloud-base flares (57.3 kg AgI), and 190 gallons of AgI-acetone solution (13.3 kg AgI). No harmful effects from these materials is expected. This is based on years of studies to detect silver in precipitation (above background contamination levels) following cloud seeding (both in the USA and Canada). The amount of silver distributed by the cloud seeding is small compared to the output from industry and falls within the USA EPA guide lines (even within the cloud seeding plume).

Total flight hours: 300 hours (est.) Total cloud seeding flight hrs. in 1996 was 160 hrs. The total flight hours during 1997 was 188. During the summer of 1998, a total of 96 operational flights took place on 36 storm days. Clouds were seeded during 78 flights on 30 days. There were 17 patrol flights. The total flight hours during 1998 was 189.9.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- one Cheyenne II aircraft
- two C-340 aircraft

Ministry of Transport operating authority granted File number 5258-10262 (AARXH).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

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SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be specially equipped with a special cloud physics data acquisition . A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals measurements from the following instruments: Rosemount total temperature, reverse flow temperature, EGG dew point, JW-hot wire liquid water probe, ice particle counter (Turner-Radke laser type), static and differential pressure transducers for airspeed and altitude, GPS latitude and longitude, and heading. Vertical velocity can be calculated in post-analysis. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm which is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

The Special-Seeder could be the first aircraft launched on patrol and can be used to record an environmental sounding during initial ascent to seeding altitude, and provide a measurement of the convective cloud base temperature and altitude. A representative environmental sounding is an extremely important piece of information to help forecast and assess the potential and severity of convective weather. Special-Seeder missions can be flown to collect data from penetrations of the first convective clouds of the day. The data from these special instruments can be used to determine the suitability of individual clouds in a system for seeding, and also to monitor changes in the cloud microstructure that are expected as a result of seeding.

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PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Jim Renick, M. Sc. Title: Project Director

Signature: [signature] Date: May 11/99

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Canada Ltd.

Full name of certifying officer: Terry W. Krauss, Ph.D. Title: Project Manager

Signature: TW Krauss Date: May 10/1999

EDMONTON
16
2
Hail-suppression project area
ALBERTA
"Hail Alley"
Red Deer
Red Deer River
ROCKY MOUNTAINS
Olds
Olds-Didsbury Airport
1
Prevailing direction of storms
Banff
95
Calgary
Bow River
1
BRITISH COLUMBIA
2
3
Lethbridge
Cranbrook
3
0 50 100 km
CANADA
U.S.A.

002914

WEATHER MODIFICATION, INC.

P.O. Box 27177 ● Red Deer, Alberta, Canada T4N 6X8 ● Phone (403) 342-5685 ● Fax (403) 342-5685
e-mail: krausst@agt.net WMI Home Page at http://www.wmi.cban.com/

May 10, 2000

Weather Modification Information Officer
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario

Fax: (416) 739 4211

Attention: Mr. Jack Power

Dear Mr. Power:

Subject: Alberta Hail Suppression Project - 2000: Notice of Intent to Conduct Cloud Seeding.

Please find attached our notice of intent to engage in weather modification activities pursuant to the Weather Modification Information Act of Canada.

Weather Modification Inc., (WMI) is entering the fifth year of a five year contract with the Alberta Severe Weather Management Society to conduct cloud seeding to mitigate hail damage to property in the Calgary to Red Deer region of Alberta. The cloud seeding operations will be conducted from June 1st to September 15th, 2000. All other operational aspects of the program are the same as conducted since 1996.

I am faxing this notification to you now, without the signature of Mr. Jim Renick, Director of the Alberta Severe Weather Management Society. Mr. Renick is out of town until May 17 and is unable to sign the form at this time. The original signed copy will be sent to you via courier after May 17. A full description of our activities during 1999 is included in our Annual Final Report 1999 which will be sent to you with the original hard copy of this notification. Please do not hesitate to contact me if you require further information.

Sincerely,

TW Krauss

Terry W. Krauss, Ph. D.
Project Manager

N.B. Original sent by FedEx on May 25/00.
JK.

002915

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: Wednesday, May 10, 2000

Proposed starting date: June 1st, 2000

Expected duration: September 15, 2000.

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.wmi.cban.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
WXMOD@worldnet.att.net
Local Organization: Weather Modification Canada Ltd.
P. O. Box 2717
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, General Manager
Ph.D. Atmospheric Science, 25 years experience
Tel: (403) 342-5685 and Fax: (403) 342-5685
(see Part 5 for details of qualifications and experience)

Primary activities of organization (see enclosed brochure):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: $50 million CDN by the Alberta Severe Weather Management Society c/o Wawanesa Mutual Insurance Co. and US$5 million by Weather Modification Inc.

List of similar weather modification activities previously undertaken:

a. Canada

- With the Alberta Research Council, Jim Renick and Terry Krauss were actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984 .

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years. For the summer of 2000, WMI is operating 9 aircraft in North Dakota.
- WMI has a new 5 year contract during the southern summer, to conduct hail suppression in Mendoza, Argentina using 4 Cheyenne II aircraft and a Lear Jet.
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- With the Bethlehem Precipitation Research Project, South Africa, T. Krauss was director of the project over the period Sept. 1984 to April. 1986.
- With INTERA Technologies Ltd. of Calgary, AB, T. Krauss was involved as a scientist and manager for the Greek National Hail Suppression Project over the period March 1987 to June 1992.

4. References:

1. Mr. Jim Renick
   11 Warwick Drive,
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Bruce Boe, Director
   State of North Dakota Atmospheric Resource Board
   P.O. Box 1833
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3. Mr. George W. Bomar, Director
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4. Mr. Michael E. Mathis, Chief, Planning and Management Division
   Oklahoma Water Resources Board
   3800 N. Classen Blvd.
   Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 will be providing aircraft maintenance services to WMI.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)
#600, 708 - 11th Ave. S.W.
Calgary, AB T2R 0E4

Chief officer: Mr. Dave Johnson, President Tel. 403-269-7961
Mr. Rick Rogers, Past President Tel. 403-260-9261
Mr. Don McKay, Past President Tel. 403-269-9900

Director of ASWMS: Mr. Jim Renick, M.Sc.
11 Warwick Drive
Red Deer, AB T4N 6L4 Tel. 403-347-1545

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of assembling funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-3616 and 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-291-4426 c/o ESSO AVITAT
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (cellular)
e-mail: krausst@agt.net
home page: http://www.weathermod.com/

Qualifications of field officer in charge:

- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- Certified Manager of the Weather Modification Association
- Past Member American Meteorological Society Technical Advisory Committee on Weather Modification.

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
c/o Olds-Didsbury Airport Commission
4911-51 ave., Olds, AB T4H 1R5

Field Telephone no. 403-335-3616 and 403-335-8359
Field personnel: full time = 5
part time = 10

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8
All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- storm radar echo data report and maps
- radar calibration report
- operations summary report
- daily operations log report
- chemical inventory report
- equipment status report
- aircraft flight report and flight track maps
- flight hour log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of more than $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers

and brokers, have donated about $7 million to conduct a hail suppression project over a 5 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 4 years, the insurance industry is very encouraged by the results so far.

Secondary effects anticipated: Reductions in crop damage due to hail will also be realized. Seeding may also provide an increase in precipitation. The crop hail insurance data for the last four years indicates a drop in the loss-to-risk values on the order of 45% below the long term average.

Geographic area affected (see attached report): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 21 to highway no. 36 may also benefit from the seeded storms.

Approximate total cost: approx. $1.4 million per year for 5 years.

Funds to be expended in Canada: est. $800,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, extensive aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of 35 dBZ at heights above the -5 C temperature level, and pose a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach 25 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used previously in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than $-20^{\circ}C$ and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms which evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

All convective cells (defined by radar) with maximum reflectivity >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project areas, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of towering cumulus clouds or when radar cells exceed 18 kft height over the higher terrain along the western border.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors which determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -8 C and -12 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a

seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Strictly speaking, if the radar reflectivity criteria are met, seeding of all cells could be continued. However, seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts >10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 end-burner flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if downdrafts only are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $2x10^{14}$ nuclei per g of AgI at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with a greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 30ft tower mounted plus radome.
- Two Cheyenne II prop-jet aircraft located at Calgary and Red Deer airports
- One C-340 aircraft in Calgary.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable)pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (end-burning) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of pyrotechnic at $-10^{\circ}C$.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past four years is summarized in the following table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guide lines (even within the cloud seeding plume).

	1999	*1998*	*1997**	*1996**
Storm Days	45	36	43	30
Aircraft Missions	118	96	92	71
Total Flight Time (hrs)	251.3	189.9	188.1	159.1
Number of Storms Seeded	162	153	108	75 (approx.)
Cloud Seeding Flares Used:				
- cloud top (ejectable)	4439	2023	2376	3817
- cloud base (burn-in-place)	690	496	356	542
- acetone	262 gal	170 gal	127 gal	71 gal
Total Seeding Material	212.7 kg	111.1 kg	110.8 kg	163.3 kg

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Two Cheyenne II aircraft
- One C-340 aircraft

Ministry of Transport operating authority granted File number 5258-10262 (AARXH).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the rainfall display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be specially equipped with a special cloud physics data acquisition . A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals measurements from the following instruments: Rosemount total temperature, reverse flow temperature, EGG dew point, JW-hot wire liquid water probe, ice particle counter (Turner-Radke laser type), static and differential pressure transducers for airspeed and altitude, GPS latitude and longitude, and heading. Vertical velocity can be calculated in post-analysis. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm which is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

The Special-Seeder could be the first aircraft launched on patrol and can be used to record an environmental sounding during initial ascent to seeding altitude, and provide a measurement of the convective cloud base temperature and altitude. A representative environmental sounding is an extremely important piece of information to help forecast and assess the potential and severity of convective weather. Special-Seeder missions can be flown to collect data from penetrations of the first convective clouds of the day. The data from these special instruments can be used to determine the suitability of individual clouds in a system for seeding, and also to monitor changes in the cloud microstructure that are expected as a result of seeding.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, And Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

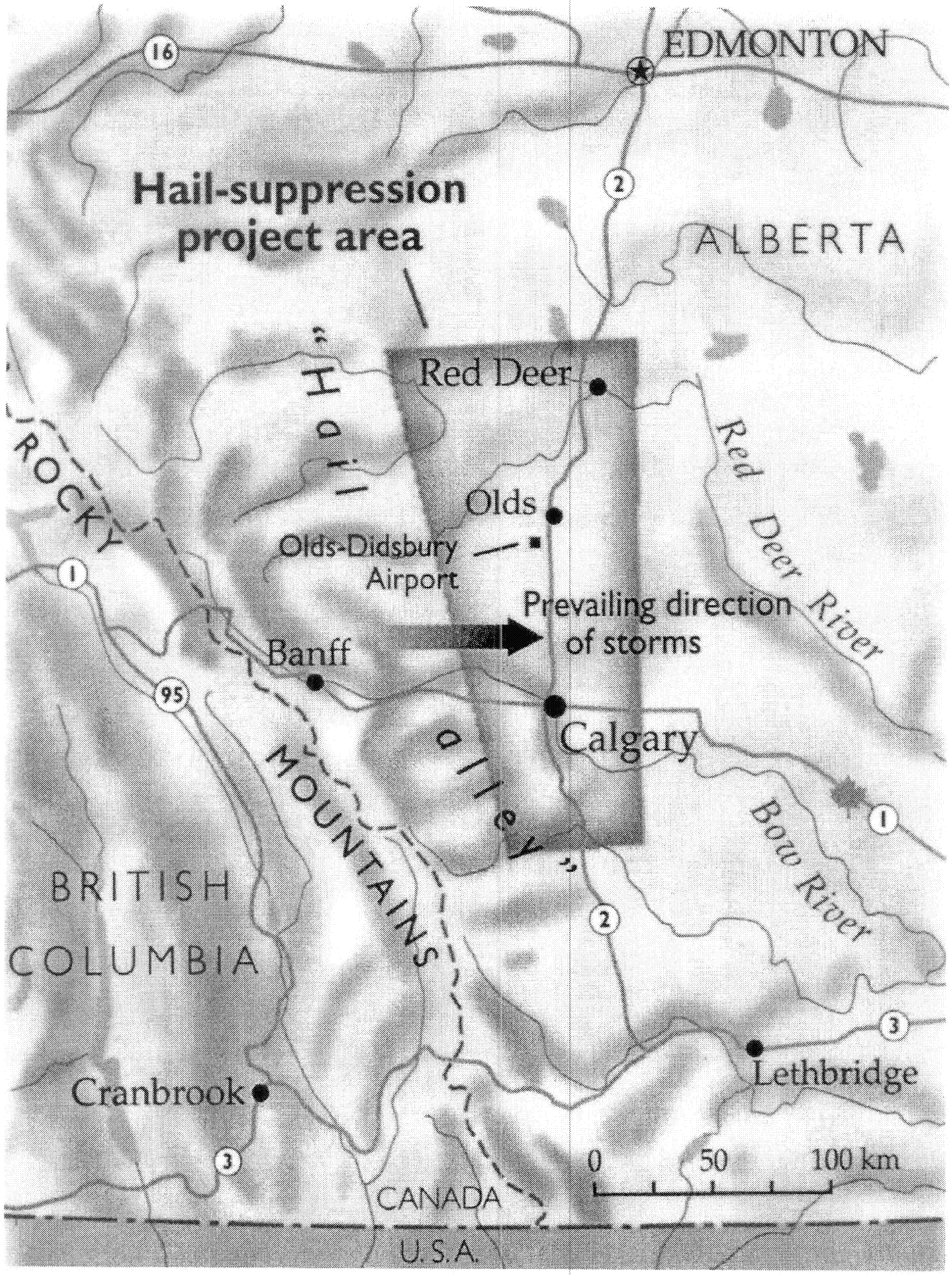

Figure 1: Map of southern Alberta showing the project area covered by the Hail Suppression activities.

WEATHER MODIFICATION INC.

3802 20th St. N.
Fargo, ND 58102

Phone
(701) 235-5500

Fax
(701) 235-9717

www.weathermod.com

info@weathermod.com

May 7, 2001

Weather Modification Information Officer
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario

Fax: (416) 739 4211

Attention: Mr. Jack Power

Dear Mr. Power:

Subject: ***Alberta Hail Suppression Project - 2001: Notice of Intent to Conduct Cloud Seeding.***

Please find attached our notice of intent to engage in weather modification activities pursuant to the Weather Modification Information Act of Canada.

Weather Modification Inc., (WMI) is entering the first year of a new five year contract with the Alberta Severe Weather Management Society to conduct cloud seeding to mitigate hail damage to property in the Calgary to Red Deer region of Alberta. The cloud seeding operations will be conducted from June 1st to September 15th, 2001. All other operational aspects of the program are the same as those previously conducted during the first five year program (1996-2000).

I am faxing this notification to you now. The original signed copy will be sent to you via courier along with a copy of our 2000 Field Program Final Report. Please do not hesitate to contact me if you require any further information.

Sincerely,

[signature]

Terry W. Krauss, Ph. D., Project Manager
Weather Modification Inc., Canada
P.O. Box 27177
Red Deer, Alberta, T4N 6X8

krausst@agt.net

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PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
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WXMOD@worldnet.att.net
Local Organization: Weather Modification Canada Ltd.
P. O. Box 2717
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, General Manager
Ph.D. Atmospheric Science, 26 years experience
Tel: (403) 342-5685 and Fax: (403) 342-5685
(see Part 5 for details of qualifications and experience)

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Director of ASWMS: Mr. Jim Renick, M.Sc.
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Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of assembling funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

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tel. & fax. 403-342-5685 and 403-318-0400 (cellular)
e-mail: krausst@agt.net
home page: http://www.weathermod.com/

Qualifications of field officer in charge:

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- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
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Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
c/o Olds-Didsbury Airport Commission
4911-51 ave., Olds, AB T4H 1R5

Field Telephone no. 403-335-3616 and 403-335-8359
Field personnel: full time = 5
part time = 10

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8
All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- storm radar echo data report and maps
- radar calibration report
- operations summary report
- daily operations log report
- chemical inventory report
- equipment status report
- aircraft flight report and flight track maps
- flight hour log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of more than $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers

and brokers, have donated about $15 million to conduct a hail suppression project over a 10 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 5 years, the insurance industry is very encouraged by the results so far.

Secondary effects anticipated: Reductions in crop damage due to hail will also be realized. Seeding may also provide an increase in precipitation. The crop hail insurance data for the last five years indicates a drop in the loss-to-risk values on the order of 16% below the long term average. The net surplus for the hail insurance program over the five year seeding period has been >$35 million.

Geographic area affected (see attached report): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 21 to highway no. 36 may also benefit from the seeded storms.

Approximate total cost: approx. $1.7 million per year for 5 years.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, extensive aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used previously in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms which evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

All convective cells (defined by radar) with maximum reflectivity >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project areas, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of towering cumulus clouds or when radar cells exceed 18 kft height over the higher terrain along the western border.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors which determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -8 C and -12 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a

seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts >10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 end-burner flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if downdrafts only are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $2x10^{14}$ nuclei per g of AgI at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with a greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Two Cheyenne II prop-jet aircraft located at Calgary and Red Deer airports
- One C-340 aircraft in Calgary.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable)pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (end-burning) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of pyrotechnic at $-10^{\circ}C$.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past four years is summarized in the following table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guide lines (even within the cloud seeding plume).

Table 1: Operational statistics for the past five years of the Alberta Hail Suppression Project.

	2000	*1999*	*1998*	*1997**	*1996**
Storm Days	46 (13 patrol)	45 (6 patrol)	36 (5 patrol)	43 (5 patrol)	30 (1 patrol)
Aircraft Missions	130	118	96	92	71
Total Flight Time	265.2 hrs	251.3 hrs	189.9 hrs	188.1 hrs	159.1 hrs
Number of Storms Seeded	136	162	153	108	75 (approx.)
cloud top flares (ejectable)	9653	4439	2023	2376	3817
cloud base flares (burn-in-place)	940	690	496	356	542
acetone	56.5 hrs	119.0 hrs	77.5 hrs	57.7 hrs	32.2 hrs
Total Seeding Material	343.8 kg	212.7 kg	111.1 kg	110.8 kg	163.3 kg

*1997, 1998 seasons were June 15th to Sept. 15th.
"patrol" = days with only patrol or test flights and no seeding.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Two Cheyenne II aircraft
- One C-340 aircraft

Ministry of Transport operating authority granted File number 5258-10262 (AARXH).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the rainfall display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals measurements from the following instruments: The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm which is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, And Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Jim Renick, M. Sc. Title: Project Director

Signature: [signature] Date: May 7, 2001

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Inc., Canada

Full name of certifying officer: Terry W. Krauss, Ph.D. Title: Project Manager

Signature: T W Krauss Date: May 7, 2001

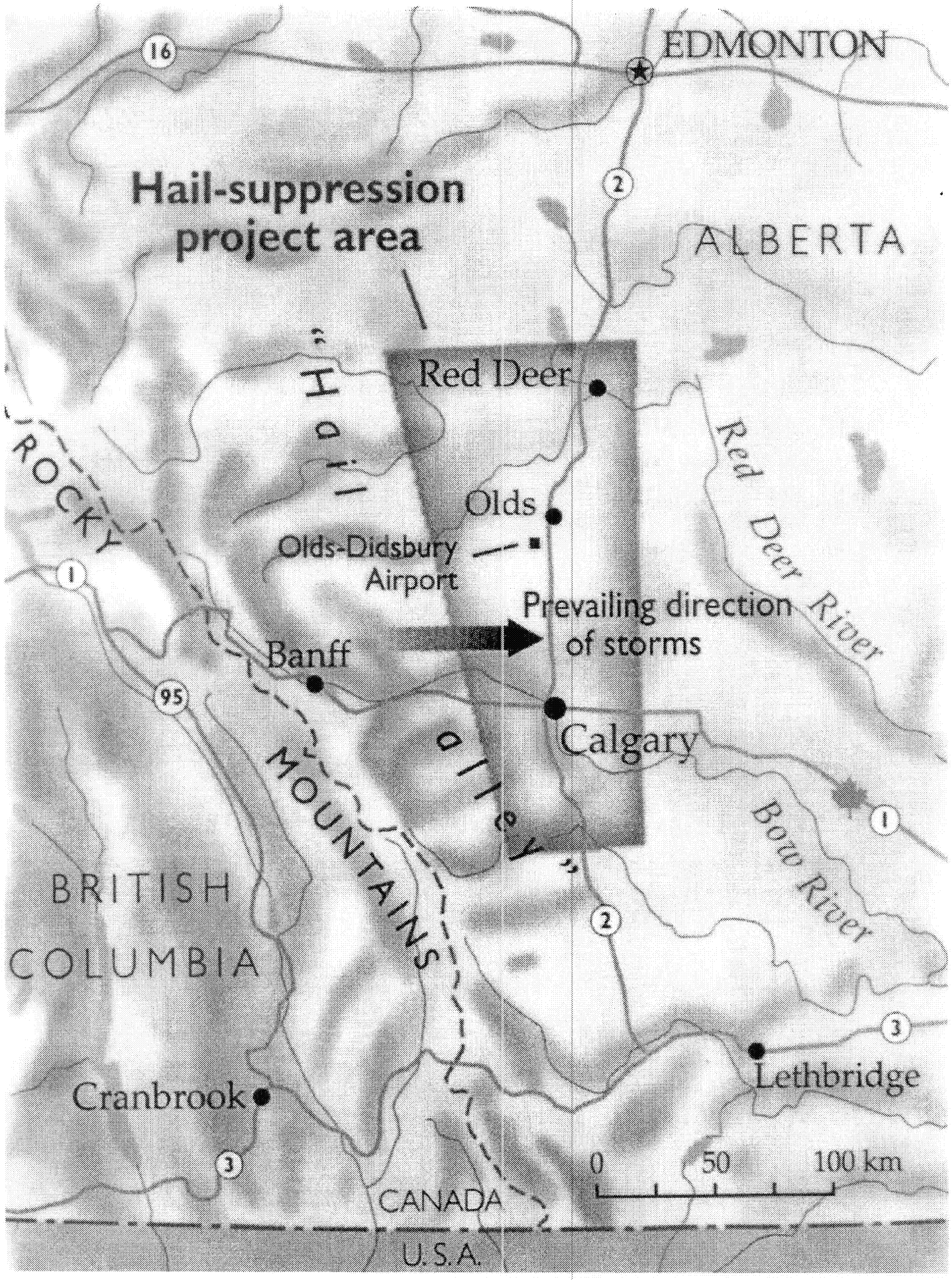

Figure 1: Map of southern Alberta showing the project area covered by the Hail Suppression activities.

WEATHER MODIFICATION INC.

3802 20th St. N.
Fargo, ND 58102

Phone
(701) 235-5500

Fax
(701) 235-9717

www.weathermod.com

info@weathermod.com

May 13, 2002

Weather Modification Information Officer
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario, M3H 5T4 Fax: (416) 739 4211

Attention: Mr. Jack Power

Dear Mr. Power:

Subject: ***Alberta Hail Suppression Project - 2002: Notice of Intent to Conduct Cloud Seeding.***

Please find attached our notice of intent to engage in weather modification activities during the summer of 2002, pursuant to the Weather Modification Information Act of Canada.

Weather Modification Inc., (WMI) is entering the second year of a renewed five year contract with the Alberta Severe Weather Management Society to conduct cloud seeding to mitigate hail damage to property in the Calgary to Red Deer region of Alberta. The cloud seeding operations will be conducted from June 1st to September 15th, 2002. All other operational aspects of the program are the same as those previously conducted during 1996-2001.

I am faxing this notification to you now. The original signed copy will be sent to you via courier along with a copy of our 2001 Field Program Final Report. Please do not hesitate to contact me if you require any further information.

Sincerely,

T W Krauss

Terry W. Krauss, Ph. D., Project Manager krausst@agt.net
Weather Modification Inc., Canada
P.O. Box 27177
Red Deer, Alberta, T4N 6X8 phone/fax: 403-342-5685

13may02ECnotice_ltr.doc

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: Monday, May 13, 2002

Proposed starting date: June 1st, 2002

Expected duration: September 15th, 2002.

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermod.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
WXMOD@worldnet.att.net
Local Organization: Weather Modification Canada Ltd.
P. O. Box 27177
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, General Manager
Ph.D. Atmospheric Science, 28 years experience
Tel: (403) 342-5685 and Fax: (403) 342-5685 Cell: (403) 318-0400
(see Part 5 for details of qualifications and experience)

Primary activities of organization (see enclosed brochure):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CDN$50 million by the Alberta Severe Weather Management Society c/o Wawanesa Mutual Insurance Co. and US$5 million by Weather Modification Inc.

List of similar weather modification activities previously undertaken:

a. Canada

- With the Alberta Research Council, Jim Renick and Terry Krauss were actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984 .

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years.
- WMI has conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2002.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Greece, Texas, California, Mexico, UAE, and Thailand within the last 5 years. For the summer of 2002, WMI is operating 2 aircraft in Texas, and 2 aircraft in Greece.
- With the Bethlehem Precipitation Research Project, South Africa, T. Krauss was director of the project over the period Sept. 1984 to April. 1986.
- With INTERA Technologies Ltd. of Calgary, AB, T. Krauss was involved as a scientist and manager for the Greek National Hail Suppression Project over the period March 1987 to June 1992.

4. References:

1. Mr. Jim Renick
   11 Warwick Drive,
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Darren Langerud, Director
   State of North Dakota Atmospheric Resource Board
   P.O. Box 1833
   Bismarck, ND 58502 Tel. 701-224-2788
3. Mr. George W. Bomar, Director
   Texas Natural Resource Conservation Commission
   Austin, TX 78711 Tel. 512-239-0381
4. Mr. Michael E. Mathis, Chief, Planning and Management Division
   Oklahoma Water Resources Board
   3800 N. Classen Blvd.
   Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 and Doug Boston, Calgary, AB (403) 250-3172 will be providing aircraft maintenance services to WMI.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)
#600, 708 - 11th Ave. S.W.
Calgary, AB T2R 0E4

Chief officers:
Mr. Robin Seacombe, President Tel. 403-233-6910
Mr. Rick Rogers, Past President Tel. 403-260-9261
Ms. Catherine Tagg, Secretary-Treasurer Tel. 403-260-9261

Director of ASWMS: Mr. Jim Renick, M.Sc.
11 Warwick Drive
Red Deer, AB T4N 6L4 Tel. 403-347-1545

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of assembling funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-3616 and 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-291-4426 or 403-250-8070
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (cellular)
e-mail: krausst@agt.net
home page: http://www.weathermod.com/

Qualifications of field officer in charge:

- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- Certified Manager of the Weather Modification Association
- American Meteorological Society Past Member of Technical Advisory Committee on Weather Modification.

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
c/o Olds-Didsbury Airport Commission
4911-51 ave., Olds, AB T4H 1R5

Field Telephone no. 403-335-3616 and 403-335-8359
Field personnel: full time = 5
part time = 10

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8
All records are maintained June 1st -Sept. 15th annually.

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and brokers, have donated about $15 million to conduct a hail suppression project over a 10 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 6 years, the insurance industry is very encouraged by the results so far.

Secondary effects anticipated: Reductions in crop damage due to hail will also be realized. Seeding may also provide an increase in precipitation. The crop hail insurance data for the last five years indicates a drop in the loss-to-risk values on the order of 17% below the long term average. The net benefit for the hail insurance program over the five year seeding period has been estimated to be approximately $100 million.

Geographic area affected (see attached report): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year for 5 years.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

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The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than $-20^{\circ}C$ and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

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CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of towering cumulus clouds or when radar cells exceed 18 kft height over the higher terrain along the western border.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors which determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -8 C and -12 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts >10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 end-burner flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if downdrafts only are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $2x10^{14}$ nuclei per g of AgI at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with a greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Two Cheyenne II prop-jet aircraft located at Calgary and Red Deer airports
- One C-340 aircraft in Calgary.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable)pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (end-burning) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of pyrotechnic at $-10^{\circ}C$.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past four years is summarized in the following table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guide lines (even within the cloud seeding plume).

Table 1: Operational statistics for the past six years.

	2001	2000	1999	1998	1997*	1996*
STORM DAYS	43 (7 patrol)	46 (13patrol)	45 (6 patrol)	36 (5 patrol)	43 (5 patrol)	30 (1 patrol)
MISSIONS	109	130	118	96	92	71
FLIGHT TIME	208.3 HRS	265.2 HRS	251.3 HRS	189.9 HRS	188.1 HRS	159.1 HRS
STORMS SEEDED	98	136	162	153	108	75 (approx.)
FLARES : Top	5271	9653	4439	2023	2376	3817
Base	533	940	690	496	356	542
Acetone	56.3 HRS	56.5 HRS	119.0 HRS	77.5 HRS	57.7 HRS	32.2 HRS
TOTAL MASS	195.0 Kg	343.8 Kg	212.7 Kg	111.1 Kg	110.8 Kg	163.3 Kg

*1997, 1998 seasons were June 15th to Sept. 15th.
"patrol" = days with only patrol or test flights and no seeding.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Two Cheyenne II aircraft
- One C-340 aircraft

Ministry of Transport operating authority granted File number 5260-10175 (AARX) and SA5000-5(RACH).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm which is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Jim Renick, M. Sc. Title: Project Director

Signature: J Renick Date: May 13, 2002

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Inc., Canada

Full name of certifying officer: Terry W. Krauss, Ph.D. Title: Project Manager

Signature: TW Krauss Date: May 13, 2002

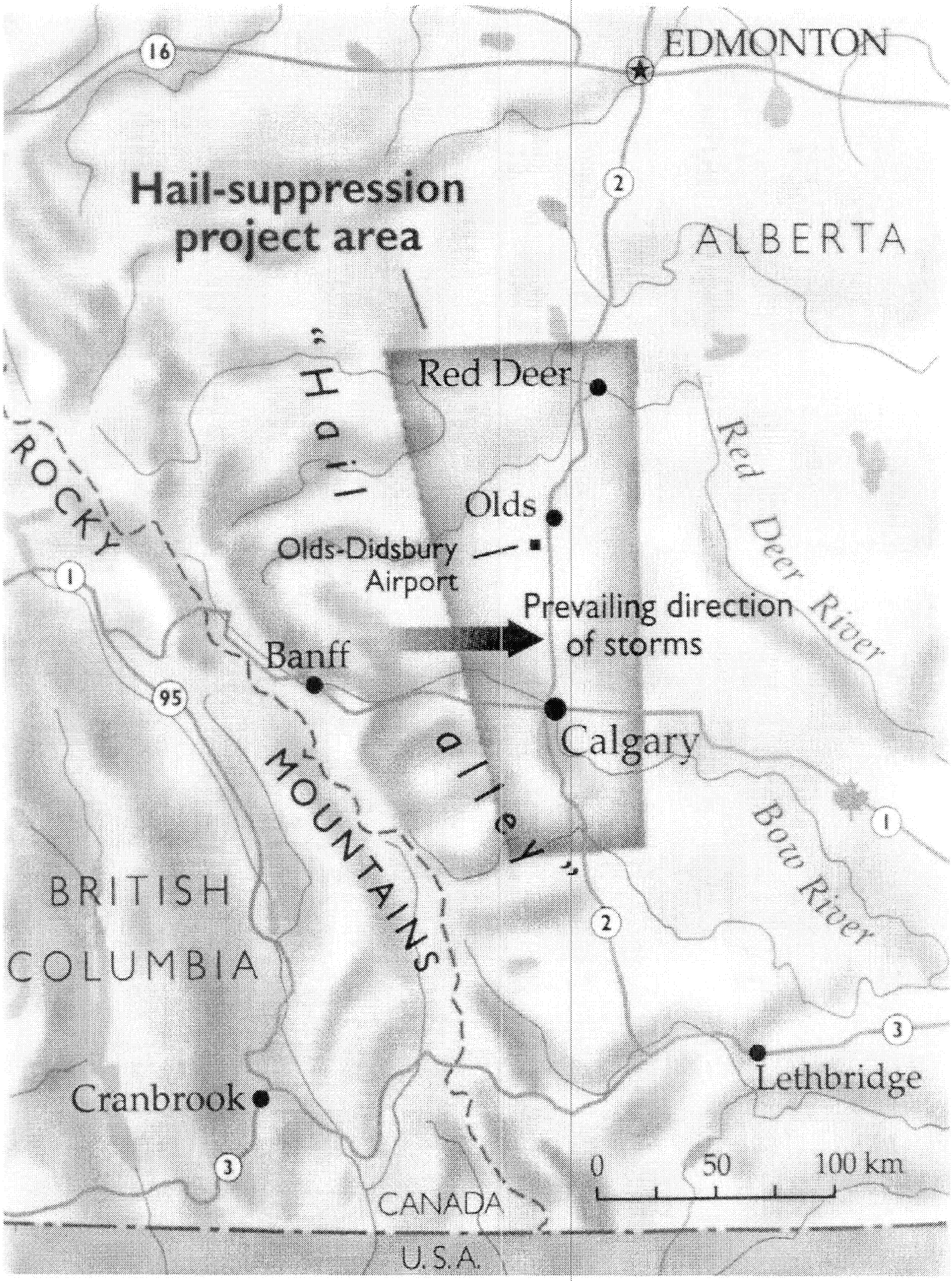

Figure 1: Map of southern Alberta showing the project area covered by the Hail Suppression activities.

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: Wednesday, April 30, 2003

Proposed starting date: June 1st, 2003
Expected duration: September 15th, 2003.

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermod.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification Canada Ltd.
P. O. Box 27177
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, General Manager
Ph.D. Atmospheric Science, 29 years experience
Tel: (403) 342-5685 and Fax: (403) 342-5685 Cell: (403) 318-0400
krausst@agt.net
(see Part 5 for details of qualifications and experience)

Primary activities of organization (see web page at www.weathermod.com):

- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CDN$50 million by the Alberta Severe Weather Management Society c/o Wawanesa Mutual Insurance Co. and US$5 million by Weather Modification Inc.

List of similar weather modification activities previously undertaken:

a. Canada

- With the Alberta Research Council, Jim Renick and Terry Krauss were actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984.

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years.
- WMI has conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2003.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Greece, Texas, California, Mexico, UAE, and Thailand within the last 5 years.
- With the Bethlehem Precipitation Research Project, South Africa, T. Krauss was director of the project over the period Sept. 1984 to April. 1986.
- With INTERA Technologies Ltd. of Calgary, AB, T. Krauss was involved as a scientist and manager for the Greek National Hail Suppression Project over the period March 1987 to June 1992.

4. References:

1. Mr. Jim Renick
11 Warwick Drive,
Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Darren Langerud, Director
State of North Dakota Atmospheric Resource Board
P.O. Box 1833
Bismarck, ND 58502 Tel. 701-224-2788
3. Mr. George W. Bomar, Director
Texas Natural Resource Conservation Commission
Austin, TX 78711 Tel. 512-239-0381
4. Mr. Michael E. Mathis, Chief, Planning and Management Division
Oklahoma Water Resources Board
3800 N. Classen Blvd.
Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 and Doug Boston, Calgary, AB (403) 250-3172 will be providing aircraft maintenance services to WMI.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)
#600, 708 - 11th Ave. S.W.
Calgary, AB T2R 0E4

Chief officers: Mr. Robin Seacombe, President Tel. 403-233-6910
Ms. Catherine Tagg, Secretary-Treasurer Tel. 403-260-9261

Director of ASWMS: Mr. Jim Renick, M.Sc.
11 Warwick Drive
Red Deer, AB T4N 6L4 Tel. 403-347-1545

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of assembling funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-3616 and 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-291-4426 or 403-250-8070
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (cellular)
e-mail: krausst@agt.net
home page: http://www.weathermod.com/

Qualifications of field officer in charge:

- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- Certified Manager of the Weather Modification Association
- American Meteorological Society Past Member of Technical Advisory Committee on Weather Modification.

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
c/o Olds-Didsbury Airport Commission
4911-51 ave., Olds, AB T4H 1R5

Field Telephone no. 403-335-3616 and 403-335-8359
Field personnel: full time = 5
part time = 10

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8
All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- storm radar echo data report and maps
- radar calibration report
- operations summary report
- daily radar operations log report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of more than $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers

and brokers, have donated about $15 million to conduct a hail suppression project over a 10 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 7 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry.

Secondary effects anticipated: Reductions in crop damage due to hail will also be realized. Seeding may also provide an increase in precipitation. The crop hail insurance data for the last five years indicates a drop in the loss-to-risk values on the order of 18% below the long term average. The net benefit for the hail insurance program over the five year seeding period has been estimated to be approximately $133 million.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year for 5 years.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used previously in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are

introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

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The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $2x10^{14}$ nuclei per g of AgI at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with a greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Two Cheyenne II prop-jet aircraft located at Calgary and Red Deer airports
- One C-340 aircraft in Calgary.

C. MATERIALS TO BE EMITTED:

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Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of pyrotechnic at -10°C.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past seven years is summarized in the following table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guide lines (even within the cloud seeding plume).

Table 1: Operational statistics for the past seven years.

	2002	2001	2000	1999	1998	1997*	1996*
STORM DAYS	40 (13 patrol)	43 (7 patrol)	46 (13 patrol)	45 (5 patrol)	36 (5 patrol)	43 (5 patrol)	30 (1 patrol)
AIRCRAFT MISSIONS	92	109	130	118	96	92	71
TOTAL FLIGHT TIME	157.4 HRS	208.3 HRS	265.2 HRS	251.3 HRS	189.9 HRS	188.1 HRS	159.1 HRS
STORMS SEEDED	54	98	136	162	153	108	75 (approx.)
FLARES							
Top	3108	5225	9653	4439	2023	2376	3817
Base	377	533	940	690	496	356	542
Acetone	32.1 HRS (80.3 US gallons)	56.3 HRS (140.8 US gallons)	56.5 HRS (141.3 US gallons)	119.0 HRS (297.5 US gallons)	77.5 HRS (193.8 US gallons)	57.7 HRS (144.3 US gallons)	32.2 HRS (80.5 US gallons)
SEEDING Mass	124.2 Kg	195.0 Kg	343.8 Kg	212.7 Kg	111.1 Kg	110.8 Kg	163.3 Kg

* June 15th to September 15th during 1996 and 1997.
"Patrol" = days with patrol or test flights and no seeding

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Two Cheyenne II aircraft
- One C-340 aircraft

Ministry of Transport operating authority granted File number 5260-10175 (AARX) and SA5000-5(RACH).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm that is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Jim Renick, M. Sc. Title: Project Director

Signature: [signature] Date: May 2, 2003.

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Inc., Canada

Full name of certifying officer: Terry W. Krauss, Ph.D. Title: VP - Project Manager

Signature: TW Krauss Date: April 30, 2003

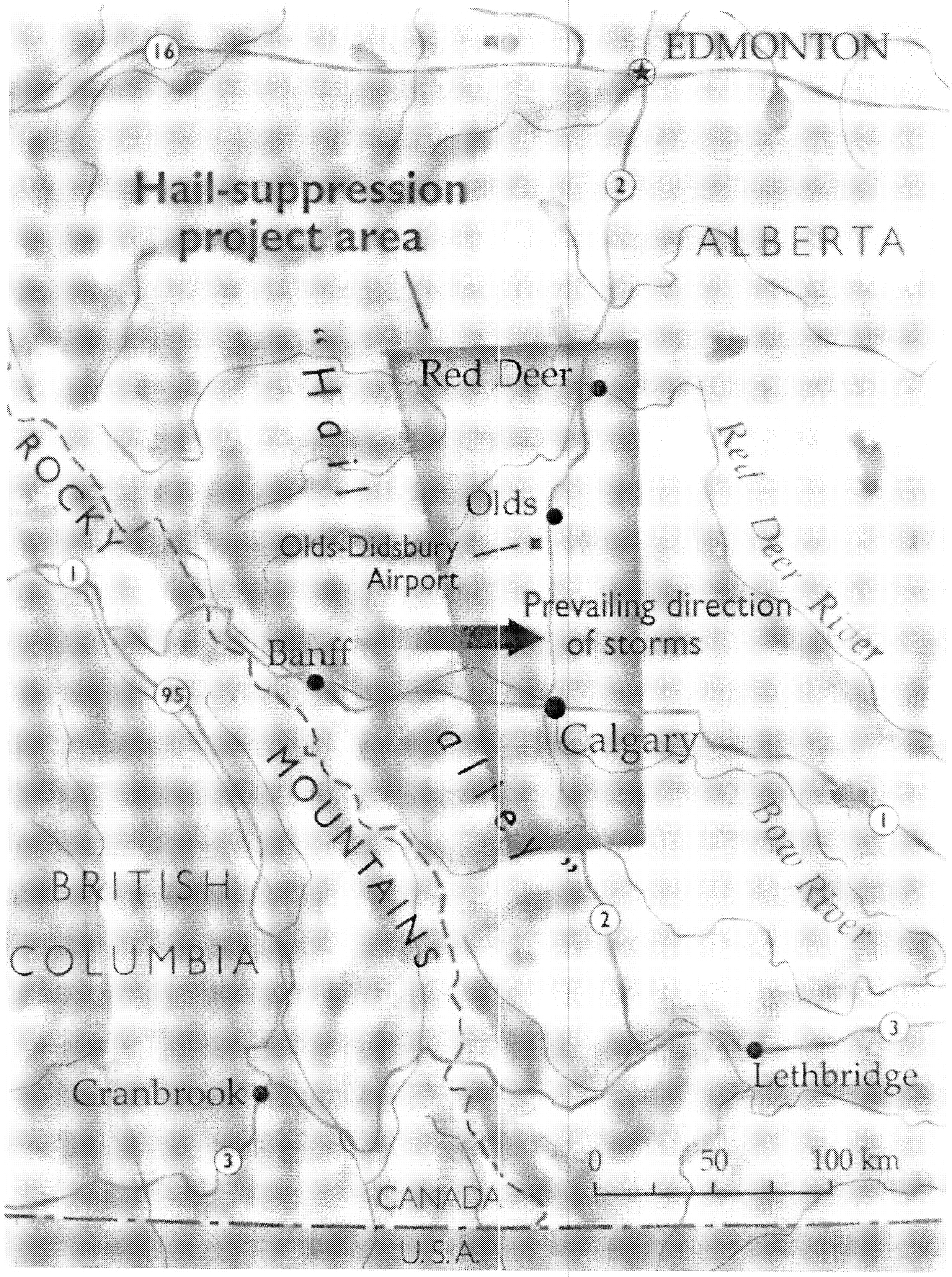

Figure 1: Map of southern Alberta showing the project area covered by the Hail Suppression activities.

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: Thursday, May 6, 2004

Proposed starting date: June 1st, 2004
Expected duration: September 15th, 2004

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermod.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification Inc., Canada Ltd.
P. O. Box 27177
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, General Manager
Ph.D. Atmospheric Science, 30 years experience
Tel: (403) 342-5685 and Fax: (403) 342-5685 Cell: (403) 318-0400
krausst@agt.net
(see Part 5 for details of qualifications and experience)

Primary activities of organization (see web page at www.weathermod.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CDN$50 million by the Alberta Severe Weather Management Society c/o Wawanesa Mutual Insurance Co. and US$5 million by Weather Modification Inc.

List of similar weather modification activities previously undertaken:

a. Canada

- With the Alberta Research Council, Jim Renick and Terry Krauss were actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984.

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years.
- WMI has conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Greece, Texas, California, Mexico, UAE, India, and Thailand within the last 5 years.
- With the Bethlehem Precipitation Research Project, South Africa, T. Krauss was director of the project over the period Sept. 1984 to April. 1986.
- With INTERA Technologies Ltd. of Calgary, AB, T. Krauss was involved as a scientist and manager for the Greek National Hail Suppression Project over the period March 1987 to June 1992.

4. References:

1. Mr. Jim Renick
   11 Warwick Drive,
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Darren Langerud, Director
   State of North Dakota Atmospheric Resource Board
   P.O. Box 1833
   Bismarck, ND 58502 Tel. 701-224-2788
3. Mr. George W. Bomar, Director
   Texas Natural Resource Conservation Commission
   Austin, TX 78711 Tel. 512-239-0381
4. Mr. Michael E. Mathis, Chief, Planning and Management Division
   Oklahoma Water Resources Board
   3800 N. Classen Blvd.
   Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 will be providing aircraft maintenance services to WMI. Mr. Barry Robinson (403) 886-2111, Central Digital Systems Ltd., Penhold, Alberta will be providing radar and seeding systems maintenance services.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)
#600, 708 - 11th Ave. S.W.
Calgary, AB T2R 0E4

Chief officers: Mr. Robin Seacombe, President Tel. 403-233-6910
Ms. Catherine Tagg, Secretary-Treasurer Tel. 403-260-9261

Director of ASWMS: Mr. Jim Renick, M.Sc.
11 Warwick Drive
Red Deer, AB T4N 6L4 Tel. 403-347-1545

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of assembling funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-3616 and 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-291-4426 or 403-250-8070
- Red Deer industrial airport tel. 403-886-4137

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (cellular)
e-mail: krausst@agt.net
home page: http://www.weathermod.com/

Qualifications of field officer in charge:

- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- Certified Manager of the Weather Modification Association
- American Meteorological Society Past Member of Technical Advisory Committee on Weather Modification.

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
c/o Olds-Didsbury Airport Commission
4911-51 ave., Olds, AB T4H 1R5

Field Telephone no. 403-335-3616 and 403-335-8359
Field personnel: full time = 3
part time = 10

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8
All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- storm radar echo data report and maps
- radar calibration report
- operations summary report
- daily radar operations log report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of more than $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers

and brokers, have donated about $15 million to conduct a hail suppression project over a 10 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 8 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry.

Secondary effects anticipated: Reductions in crop damage due to hail will also be realized. Seeding may also provide an increase in precipitation. The crop hail insurance data for the last five years indicates a drop in the loss-to-risk values on the order of 19.7% below the long term average. The net benefit for the hail insurance program over the five year seeding period has been estimated to be approximately $198 million.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year for 5 years.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are

introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -8 C and -12 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts >10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 end-burner flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $2x10^{14}$ nuclei per g of AgI at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with a greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- One Cheyenne II prop-jet aircraft located at Calgary airport.
- One C90 King Air prop-jet aircraft located at Red Deer airport.
- One C-340 aircraft in Calgary.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable)pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (end-burning) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of pyrotechnic at $-10^{\circ}C$.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past seven years is summarized in the following table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guide lines (even within the cloud seeding plume).

Table 1: Operational Statistics For The 8 Years

	2003	2002	2001	2000	1999	1998	1997*	1996*
STORM DAYS	29 (3 patrol)	40 (13 patrol)	43 (7 patrol)	46 (13 patrol)	45 (6 patrol)	36 (5 patrol)	43 (5 patrol)	30 (1 patrol)
AIRCRAFT MISSIONS	92	92	109	130	118	96	92	71
TOTAL FLIGHT TIME	163.6 HRS	157.4 HRS	208.3 HRS	265.2 HRS	251.3 HRS	189.9 HRS	188.1 HRS	159.1 HRS
STORMS SEEDED	79	54	98	136	162	153	108	75 (approx.)
FLARES **Top** **Base**	4465 518	3108 377	5225 533	9653 940	4439 690	2023 496	2376 356	3817 542
Acetone	37.1 HRS (92.6 US gallons)	32.1 HRS (80.3 US gallons)	56.3 HRS (140.8 US gallons)	56.5 HRS (141.3 US gallons)	119.0 HRS (297.5 US gallons)	77.5 HRS (193.8 US gallons)	57.7 HRS (144.3 US gallons)	32.2 HRS (80.5 US gallons)
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*** June 15th to September 15th during 1996 and 1997.**
"Patrol" = days with patrol of test flights only and no seeding

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- One Cheyenne II prop-jet aircraft located at Calgary airport.
- One C90 King Air prop-jet aircraft located at Red Deer airport.
- One C-340 aircraft in Calgary.

Ministry of Transport operating authority granted File number 5260-10175 (AARX) and SA5000-5(RACH).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

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WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Jim Renick, M. Sc. Title: Project Director

Signature: Date:

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Inc., Canada

Full name of certifying officer: Terrence W. Krauss, Ph.D. Title: VP - Project Manager

Signature: Date:

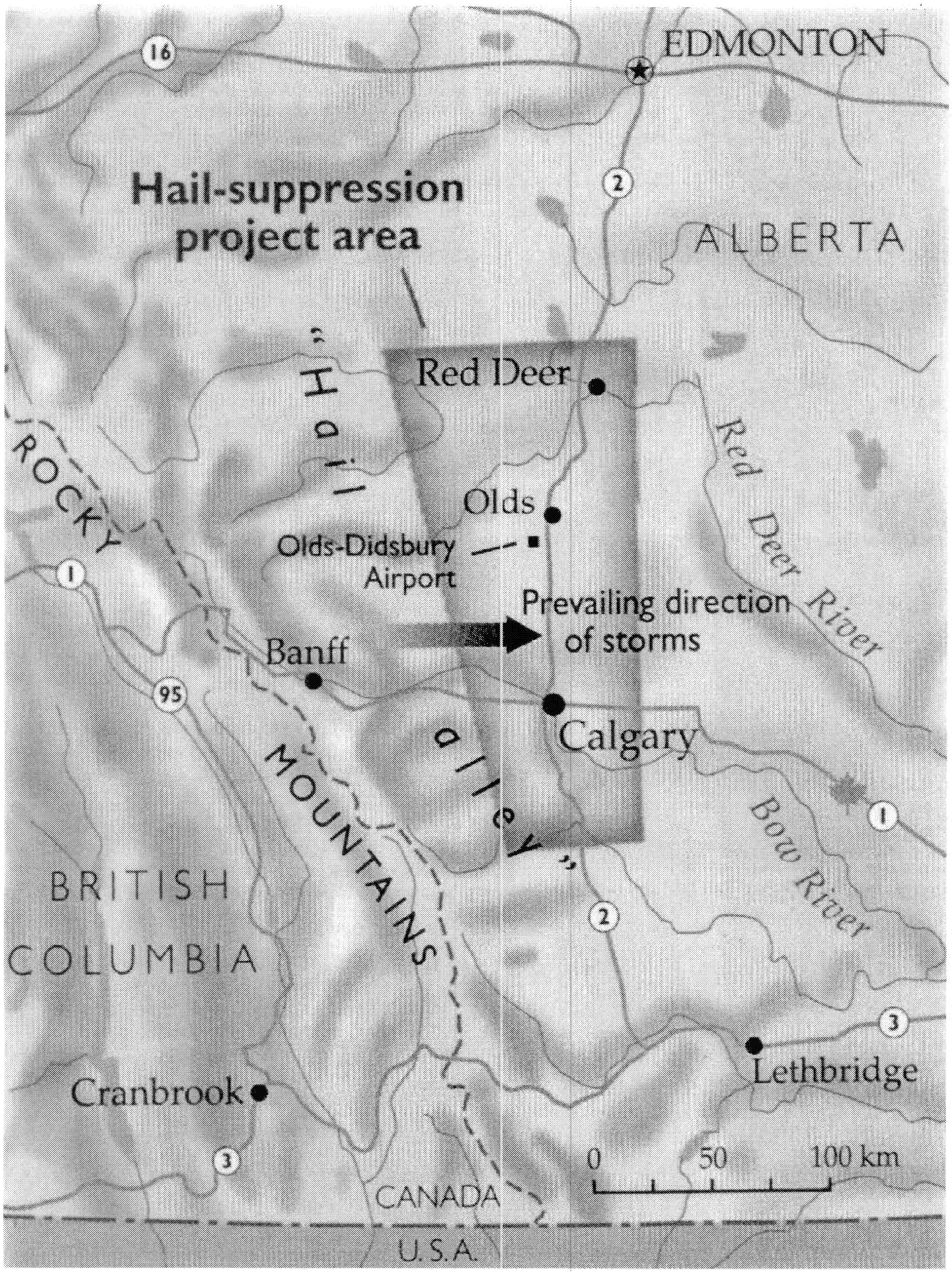

Figure 1: Map of southern Alberta showing the project area covered by the Hail Suppression activities.

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: April 14, 2005
Proposed starting date: June 1st, 2005
Expected duration: September 15th, 2005

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermod.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification Inc., Canada Ltd.
P. O. Box 27177
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, General Manager
Ph.D. Atmospheric Science, >30 years experience
Tel: (403) 342-5685 and Fax: (403) 342-5685 Cell: (403) 318-0400
krausst@agt.net
(see Part 5 for details of qualifications and experience)

Director of Meteorology Mr. Bruce Boe
MSc. Atmospehric Sciences, >20 years experience
Office Tel: (701) 673-3354, (701) 238-2577 (cell)

Vice-President, Operations Mr. Hans Ahlness
Chief Pilot, >20 years experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermod.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CDN$50 million by the Alberta Severe Weather Management Society c/o Wawanesa Mutual Insurance Co. and US$5 million by Weather Modification Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996.

- With the Alberta Research Council, Jim Renick and Terry Krauss were actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984.

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years.
- WMI conducted hail suppression in Mendoza, Argentina using 3 or 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Greece, Texas, California, Mexico, UAE, India, and Thailand within the last 5 years.

4. References:

1. Mr. Jim Renick
11 Warwick Drive,
Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Darren Langerud, Director
State of North Dakota Atmospheric Resource Board
P.O. Box 1833
Bismarck, ND 58502 Tel. 701-224-2788
3. Mr. George W. Bomar, Director
Texas Natural Resource Conservation Commission
Austin, TX 78711 Tel. 512-239-0381
4. Mr. Michael E. Mathis, Chief, Planning and Management Division
Oklahoma Water Resources Board
3800 N. Classen Blvd.
Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 will be providing aircraft maintenance services to WMI. Mr. Barry Robinson (403) 886-2111, Central Digital Systems Ltd., Penhold, Alberta will be providing radar and seeding systems maintenance services.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)
#600, 708 - 11th Ave. S.W.
Calgary, AB T2R 0E4

Chief officers: Mr. Robin Seacombe, President Tel. 403-278-0279 or 403-607-5903
Ms. Catherine Tagg, Secretary-Treasurer Tel. 403-260-9261

Director of ASWMS: Mr. Jim Renick, M.Sc.
11 Warwick Drive
Red Deer, AB T4N 6L4 Tel. 403-347-1545 or 403-357-8377

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-3616 and 403-335-8359
Address(es) and locations(s) of project secondary field base(s):
- Calgary international airport tel. 403-291-4426 or 403-250-8070
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (cellular)
e-mail: krausst@agt.net
home page: http://www.weathermod.com/

Qualifications of field officer in charge:
- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- Certified Manager of the Weather Modification Association
- American Meteorological Society Past Member of Technical Advisory Committee on Weather Modification.

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
c/o Olds-Didsbury Airport Commission
4911-51 ave., Olds, AB T4H 1R5

Field Telephone no. 403-335-3616 and 403-335-8359
Field personnel: full time = 3
part time = 10

Daily records of activities: Custodian = Dr. Terry Krauss,
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All records are maintained June 1st -Sept. 15th annually.
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- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of approximately $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers and brokers, have donated about $15 million to conduct a hail suppression project over a 10 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 9 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail will also be realized. Seeding may also provide an increase in precipitation. The crop hail insurance data for the last five years indicates a drop in the loss-to-risk values on the order of 16% below the long term average. The net benefit for the hail insurance program over the five year seeding period has been estimated to be approximately $144 million.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year for 5 years.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5 C and -10 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 end-burner flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $2x10^{14}$ nuclei per g of AgI at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- One Cheyenne II prop-jet aircraft located at Calgary airport.

- One Cheyenne II prop-jet aircraft located at Red Deer airport.
- One C-340 aircraft in Calgary.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable) pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (end-burning) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of pyrotechnic at $-10^{o}C$.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past seven years is summarized in the following table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guidelines.

Table 1: Operational Statistics for the last 7 Years

	2004	**2003**	**2002**	**2001**	**2000**	**1999**	**1998**
STORM DAYS	38 (9 patrol)	29 (3 patrol)	40 (13 patrol)	43 (7 patrol)	46 (13 patrol)	45 (6 patrol)	36 (5 patrol)
AIRCRAFT MISSIONS	105	92	92	109	130	118	96
TOTAL FLIGHT TIME	227.5 HRS	163.6 HRS	157.4 HRS	208.3 HRS	265.2 HRS	251.3 HRS	189.9 HRS
STORMS SEEDED	90	79	54	98	136	162	153
FLARES **Top**	6513	4465	3108	5225	9653	4439	2023
Base	877	518	377	533	940	690	496
Acetone	53.1 HRS (132.7 US gallons)	37.1 HRS (92.6 US gallons)	32.1 HRS (80.3 US gallons)	56.3 HRS (140.8 US gallons)	56.5 HRS (141.3 US gallons)	119.0 HRS (297.5 US gallons)	77.5 HRS (193.8 US gallons)
SEEDING Mass	270.9 Kg	173.4 Kg	124.2 Kg	195.0 Kg	343.8 Kg	212.7 Kg	111.1 Kg

"Patrol" = days with patrol or test flights without seeding

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- One Cheyenne II (N234K) prop-jet aircraft located at Calgary airport.
- One Cheyenne II (N232PS) prop-jet aircraft located at Red Deer airport.
- One C-340 (N123KK) aircraft in Calgary.

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm that is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Jim Renick, MSc. Title: Project Director

Signature: Date:

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Inc., Canada

Full name of certifying officer: Terrence W. Krauss, Ph.D. Title: VP – Meteorology

Signature: Date:

Figure 1: Map of southern Alberta showing the project area covered by the Hail Suppression activities.

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 4, 2006
Proposed starting date: June 1st, 2006
Expected duration: September 15th, 2006

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermod.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification Inc., Canada Ltd.
P. O. Box 27177
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, Vice-President, Meteorology
Ph.D. Atmospheric Science, >30 years experience
Tel: (403) 342-5685 Cell: (403) 318-0400
krausst@agt.net
(see Part 5 for details of qualifications and experience)

Director of Meteorology Mr. Bruce Boe
MSc. Atmospehric Sciences, >20 years experience
Office Tel: (701) 673-3354, (701) 238-2577 (cell)

Vice-President, Operations Mr. Hans Ahlness
Chief Pilot, >20 years experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermod.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

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List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 will be providing aircraft maintenance services to WMI. Mr. Harry Ewen (780) 988-7973, Sky-Trex Ltd., Edmonton, Alberta will be providing radar and seeding systems maintenance services.

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Name of organization: Alberta Severe Weather Management Society (ASWMS)
Attn: Dave Johnson
One Palliser Square
125 9th Ave. SE, Suite 1200
Calgary, Alberta T2G 0P6 Canada

Chief officers: Mr. Dave Johnson, President djohnson@melochemonnex.com
Ms. Catherine Janssen, Secretary-Treasurer
[mailto:Catherine.Janssen@economicalinsurance.com]

Director of ASWMS: Mr. Jim Renick, M.Sc.
11 Warwick Drive renick@telusplanet.net
Red Deer, AB T4N 6L4 Tel. 403-347-1545 or 403-357-8377

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

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- CMOS Accredited Consulting Meteorologist
- Certified Manager of the Weather Modification Association
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Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 10

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Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 10 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the last 10 years indicates a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. There are no significant changes in the crop damage within the target area for the last 10 years, compared with the previous 15 years. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year for 5 years.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

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For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20^{o}C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are

introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

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CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

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Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5 C and -10 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 end-burner flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $3x10^{13}$ nuclei per gm of pyrotechnic at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- One Piper Cheyenne II prop-jet aircraft located at Calgary airport.
- One Beechcraft C90 King-Air prop-jet aircraft located at Red Deer airport.
- One C-340 aircraft in Calgary.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable) pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (end-burning) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of AgI at -10^{o}C.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past ten years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- One Cheyenne II (N747RE) prop-jet aircraft located at Calgary airport.
- One C90 King-Air (N911FG) prop-jet aircraft located at Red Deer airport.
- One C-340 (N457DM) aircraft in Calgary.

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm that is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Jim Renick, MSc. Title: Project Director

Signature: Date:

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Inc., Canada

Full name of certifying officer: Terrence W. Krauss, Ph.D. Title: VP – Meteorology

Signature: Date:

Figure 1: Map of southern Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics For The Period 1996-2005

Alberta	2005	2004	2003	2002	2001	2000	1999	1998	1997*	1996*	Total	Average
Storm Days with Seeding	27	29	26	27	36	33	39	31	38	29	315	31.5
Aircraft Missions	80	105	92	92	109	130	118	96	92	71	985	98.5
Total Flight Time (hrs)	157.9	227.5	163.6	157.4	208.3	265.2	251.3	189.9	188.1	159.1	1968.3	196.8
Number of Storms Seeded	70	90	79	54	98	136	162	153	108	75	1025	102.5
Total Seeding Material (kg)	159.1	270.9	173.4	124.2	195.0	343.8	212.7	111.1	110.8	163.3	1864.3	186.4
AgI/day	5.9	9.3	6.7	4.6	5.4	10.4	5.5	3.6	2.9	5.6		6.0
AgI/hour	1.0	1.2	1.1	0.8	0.9	1.3	0.8	0.6	0.6	1.0		0.9
AgI/Storm	2.3	3.0	2.2	2.3	2.0	2.5	1.3	0.7	1.0	2.2		2.0
Eject Flares	3770	6513	4465	3108	5225	9653	4439	2023	2376	3817	45389	4539
BIP flares	515	877.0	518.0	377.0	533.0	940.0	690.0	496.0	356.0	542.0	5844	584
Acetone (gal)	94.2	132.7	92.6	80.3	140.8	141.3	297.5	193.8	144.3	80.5	1398	140

*** June 15th to September 15th during 1996 and 1997.**

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 15, 2007
Proposed starting date: June 1st, 2007
Expected duration: September 15th, 2007

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermod.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification Inc., Canada Ltd.
P. O. Box 27177
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, Vice-President, Meteorology
Ph.D. Atmospheric Science, >30 years experience
Tel: (403) 342-5685 Cell: (403) 318-0400
krausst@agt.net
(see Part 5 for details of qualifications and experience)

Director of Meteorology Mr. Bruce Boe
MSc. Atmospehric Sciences, >20 years experience
Office Tel: (701) 673-3354, (701) 238-2577 (cell)

Vice-President, Operations Mr. Hans Ahlness
Chief Pilot, >20 years experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermod.com):

- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CDN$50 million by the Alberta Severe

Weather Management Society and US$5 million by Weather Modification Inc.
List of similar weather modification activities previously undertaken:
a. Canada: The Alberta Hail Project has been operating in its present form since 1996.

- With the Alberta Research Council, Jim Renick and Terry Krauss were actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984.

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Greece, Texas, California, Mexico, UAE, India, Indonesia, Mali, and Saudi Arabia within the last 10 years.

4. References:
   1. Mr. Jim Renick
      11 Warwick Drive,
      Red Deer, AB T4N 6L4 Tel. 403-347-1545
   2. Mr. Darren Langerud, Director
      State of North Dakota Atmospheric Resource Board
      P.O. Box 1833
      Bismarck, ND 58502 Tel. 701-224-2788
   3. Mr. George W. Bomar, Director
      Texas Natural Resource Conservation Commission
      Austin, TX 78711 Tel. 512-239-0381
   4. Mr. Michael E. Mathis, Chief, Planning and Management Division
      Oklahoma Water Resources Board
      3800 N. Classen Blvd.
      Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 will be providing aircraft maintenance services to WMI. Mr. Barry Robinson (403) 886-2111, Central Digital Systems Ltd., Penhold, Alberta will be providing radar and seeding systems maintenance services.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Robin Seacombe, Co-President
robinseacombe@hotmail.com
Mr. Todd Klapak, Co-President
Todd.Klapak@ingcanada.com
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-8359 and 403-335-3616

Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-250-8070
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (mobile)
e-mail: krausst@agt.net
home page: http://www.weathermod.com/

Qualifications of field officer in charge:

- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- Certified Manager of the Weather Modification Association
- American Meteorological Society Past Member of Technical Advisory Committee on Weather Modification.

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB

Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 10

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- storm radar echo data report and maps
- radar calibration report
- operations summary report
- daily radar operations log report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of approximately $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers and brokers, have donated about $15 million to conduct a hail suppression project over a 10 year period.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 10 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the last 10 years indicates a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. There are no significant changes in the crop damage within the target area for the last 10 years, compared with the previous 15 years. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year for 5 years.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

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A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

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For cloud base seeding, a typical seeding rate of 1 end-burner flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately $3x10^{13}$ nuclei per gm of pyrotechnic at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- One Piper Cheyenne II prop-jet aircraft located at Calgary airport.
- One Beechcraft C90 King-Air prop-jet aircraft located at Red Deer airport.
- One C-340 aircraft in Calgary.

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable) pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (end-burning) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of AgI at $-10^{o}C$.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past ten years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- One Cheyenne II (N234K) prop-jet aircraft located at Calgary airport.
- One C90 King-Air (N911FG) prop-jet aircraft located at Red Deer airport.
- One C-340 (N457DM) aircraft in Calgary.

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm that is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title: Title:

(to be completed on or about June 1, 2007 at project start)

Signature: Date:

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Inc., Canada

Full name of certifying officer: Terrence W. Krauss, Ph.D. Title: VP – Meteorology

Signature: TW Krauss Date: May 15, 2007

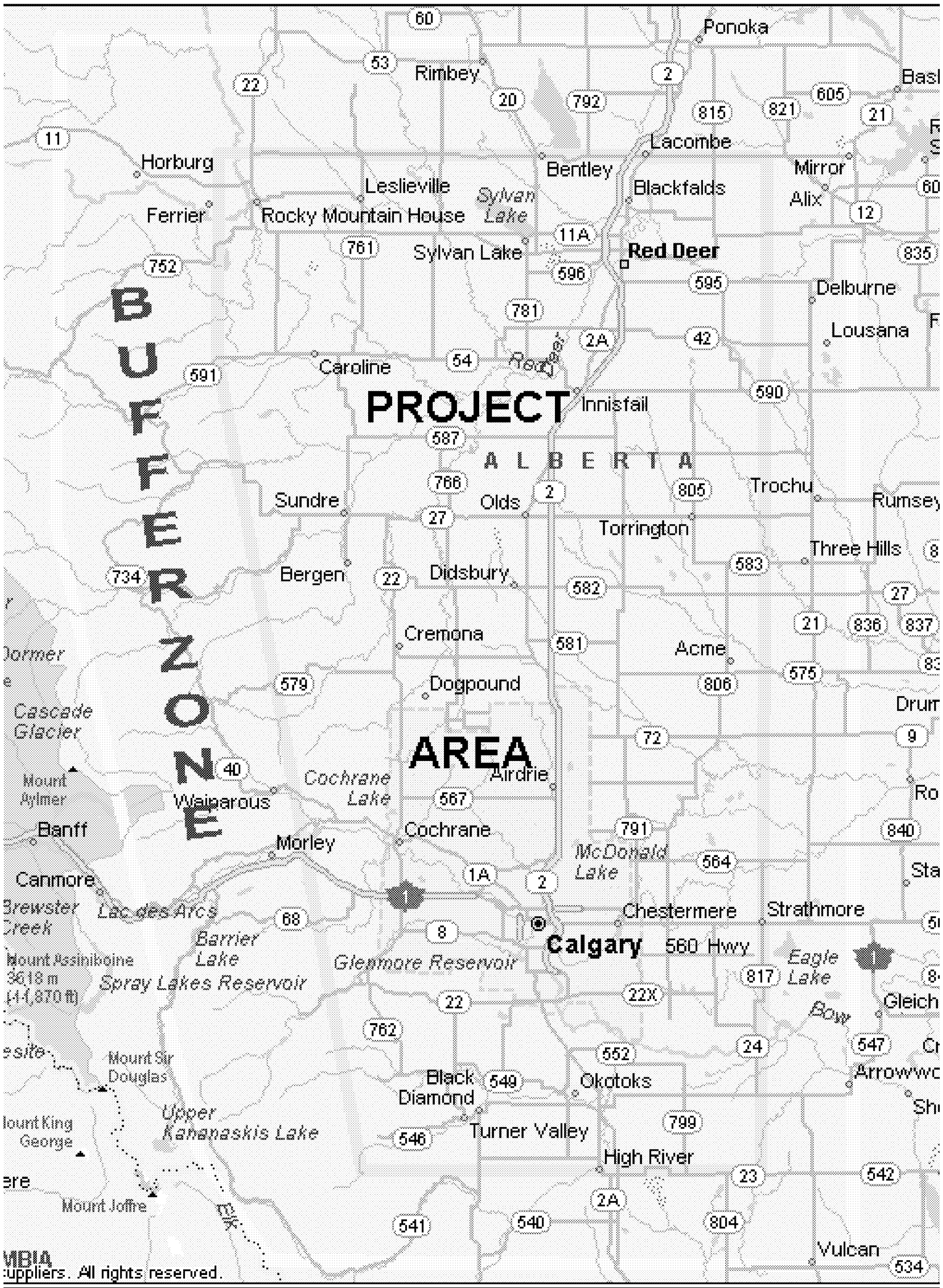

Figure 1: Map of southern Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2006.

Alberta	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**	**1999**	**1998**	**1997***	**1996***	**Total**	**Average**
Storm Days with Seeding	**28**	27	29	26	27	36	33	39	31	38	29	343	31.2
Aircraft Missions	**92**	80	105	92	92	109	130	118	96	92	71	1077	97.9
Total Flight Time (hrs)	**190.2**	157.9	227.5	163.6	157.4	208.3	265.2	251.3	189.9	188.1	159.1	2158.5	196.2
Number of Storms Seeded	**65**	70	90	79	54	98	136	162	153	108	75	1090	99.1
Total Seeding Material (kg)	**214**	159.1	270.9	173.4	124.2	195.0	343.8	212.7	111.1	110.8	163.3	2078.3	188.9
AgI/day	**7.6**	5.9	9.3	6.7	4.6	5.4	10.4	5.5	3.6	2.9	5.6		6.1
AgI/hour	**1.1**	1.0	1.2	1.1	0.8	0.9	1.3	0.8	0.6	0.6	1.0		0.9
AgI/Storm	**3.3**	2.3	3.0	2.2	2.3	2.0	2.5	1.3	0.7	1.0	2.2		2.1
Eject Flares	**4929**	3770	6513	4465	3108	5225	9653	4439	2023	2376	3817	50318	4574.4
BIP flares	**703**	515	877.0	518.0	377.0	533.0	940.0	690.0	496.0	356.0	542.0	6547	595.2
Acetone (gal)	**145.4**	94.2	132.7	92.6	80.3	140.8	141.3	297.5	193.8	144.3	80.5	1543.4	140.3

* **1996-1997 seasons ran from June 15th to September 15th.**

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 5, 2008
Proposed starting date: June 1st, 2008
Expected duration: September 15th, 2008

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermod.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification Inc., Canada Ltd.
P. O. Box 27177
Red Deer, Alberta T4N 6X8

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Dr. Terry W. Krauss, Vice-President, Meteorology
Ph.D. Atmospheric Science, >30 years experience
Tel: (403) 342-5685 Cell: (403) 318-0400
krausst@agt.net
(see Part 5 for details of qualifications and experience)

Director of Meteorology Mr. Bruce Boe
MSc. Atmospehric Sciences, >20 years experience
Office Tel: (701) 673-3354, (701) 238-2577 (cell)

Vice-President, Operations Mr. Hans Ahlness
Chief Pilot, >20 years experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermod.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CDN$50 million by the Alberta Severe

Weather Management Society and US$5 million by Weather Modification Inc.
List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996.

- With the Alberta Research Council, Terry Krauss was actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984.

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Greece, Texas, California, Mexico, UAE, India, Indonesia, Mali, and Saudi Arabia within the last 10 years.

4. References:

1. Mr. Jim Renick
   11 Warwick Drive,
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Darren Langerud, Director
   State of North Dakota Atmospheric Resource Board
   P.O. Box 1833
   Bismarck, ND 58502 Tel. 701-224-2788
3. Mr. George W. Bomar, Director
   Texas Natural Resource Conservation Commission
   Austin, TX 78711 Tel. 512-239-0381
4. Mr. Michael E. Mathis, Chief, Planning and Management Division
   Oklahoma Water Resources Board
   3800 N. Classen Blvd.
   Oklahoma City, Oklahoma 73118 Tel. 405-530-8800

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 will be providing aircraft maintenance services to WMI. Mr. Barry Robinson (403) 886-2111, Central Digital Systems Ltd., Penhold, Alberta will be providing radar and seeding systems maintenance services.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
Todd.Klapak@ingcanada.com
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-8359 and 403-335-3616
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-250-8070

- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Terry Krauss
P.O. Box 27177
Red Deer, AB T4N 6X8

tel. & fax. 403-342-5685 and 403-318-0400 (mobile)
e-mail: krausst@agt.net
home page: http://www.weathermod.com/

Qualifications of field officer in charge:

- Ph.D. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics
- 1974-1984 Alberta Research Council research officer on the Alberta Hail Project
- 1984-1986 Director, Bethlehem Precipitation Research Project, South Africa
- 1987-1992 Senior meteorologist for INTERA Technologies Ltd., Calgary on the Greek National Hail Suppression Project
- CMOS Accredited Consulting Meteorologist
- Certified Manager of the Weather Modification Association
- American Meteorological Society Member of Technical Advisory Committee on Weather Modification.

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB

Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 10

Daily records of activities: Custodian = Dr. Terry Krauss,
P.O. Box 27177, Red Deer, AB T4N 6X8

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report
- radar calibration report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of approximately $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers and brokers, have donated > $15 million to conduct a hail suppression project since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 10 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the last 10 years indicates a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. There are no significant changes in the crop damage within the target area for the last 10 years, compared with the previous 15 years. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

<u>OVERVIEW OF METHOD</u>

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are <u>considered to be a potential hail-threat</u> to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double to those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20^{o}C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.

Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5 C and -10 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn an end-burner flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and assures its optimum usage.

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Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- One Piper Cheyenne II prop-jet aircraft located at Calgary airport.
- One Beechcraft C90 King-Air prop-jet aircraft located at Red Deer airport.
- Two C-340 aircraft (one in Calgary and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable) pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (end-burning) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of AgI at $-10^{\circ}C$.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past ten years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are within the USA EPA guidelines.

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PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

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No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

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SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to assure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm that is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will assure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
Vice President - Personal Insurance, Western Region
ING Insurance Company of Canada, Calgary
(403) 231-1357
todd.klapak@ingcanada.com

Signature: Date:

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification Inc., Canada

Full name of certifying officer: Terrence W. Krauss, Ph.D. Title: VP – Meteorology

Signature: Date: May 5, 2008

TW Krauss

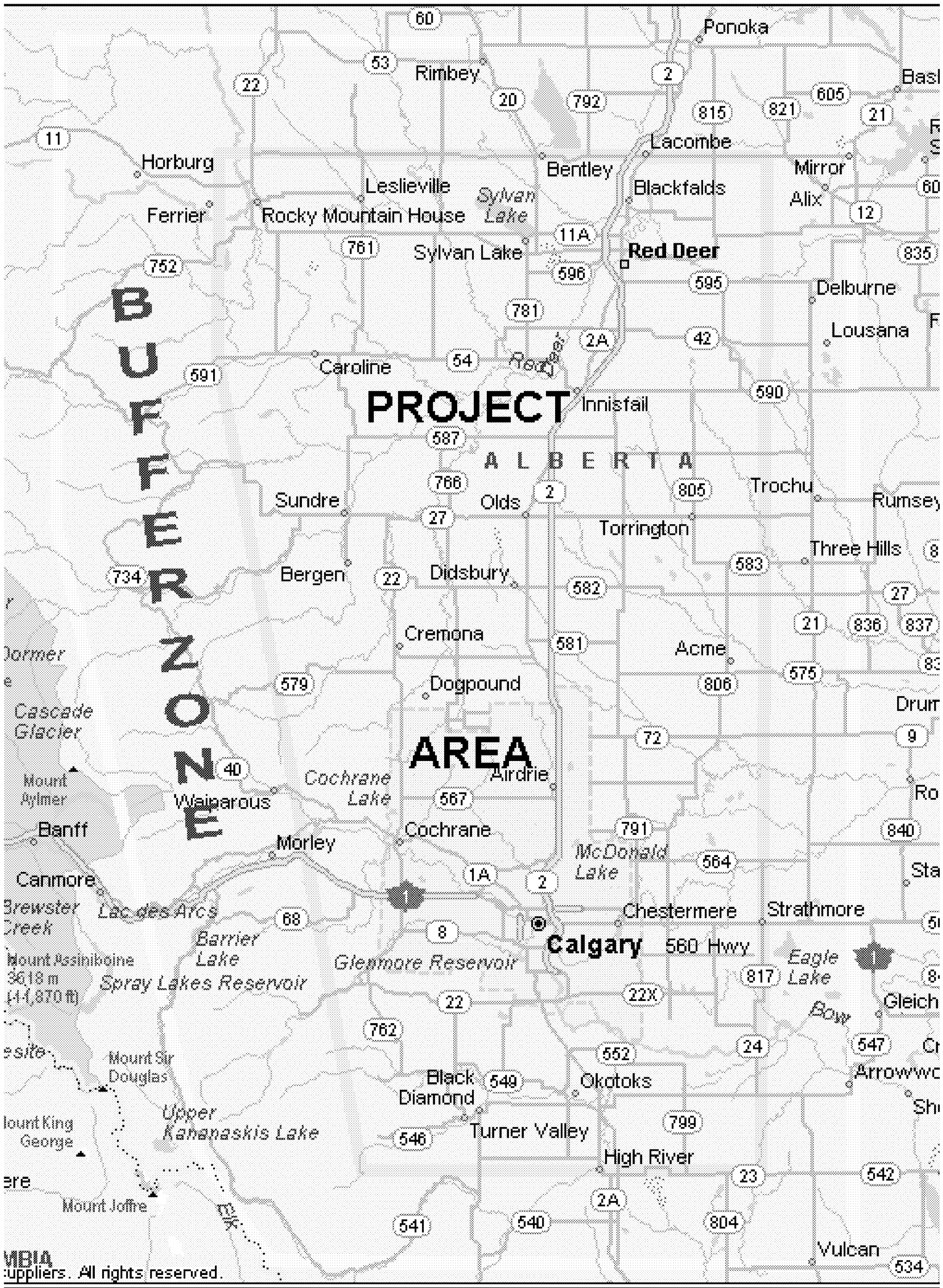


Figure 1: Map of southern Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2007.

Alberta	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**	**1999**	**1998**	**1997***	**1996***	**Total**	**Average**
Storm Days with Seeding	19	28	27	29	26	27	36	33	39	31	38	29	343	31.2
Aircraft Missions	76	92	80	105	92	92	109	130	118	96	92	71	1077	97.9
Total Flight Time (hrs)	115.3	190.2	157.9	227.5	163.6	157.4	208.3	265.2	251.3	189.9	188.1	159.1	2158.5	196.2
Number of Storms Seeded	41	65	70	90	79	54	98	136	162	153	108	75	1090	99.1
Total Seeding Material (kg)	99.7	214	159.1	270.9	173.4	124.2	195.0	343.8	212.7	111.1	110.8	163.3	2078.3	188.9
AgI/day	5.2	7.6	5.9	9.3	6.7	4.6	5.4	10.4	5.5	3.6	2.9	5.6		6.1
AgI/hour	0.9	1.1	1.0	1.2	1.1	0.8	0.9	1.3	0.8	0.6	0.6	1.0		0.9
AgI/Storm	2.4	3.3	2.3	3.0	2.2	2.3	2.0	2.5	1.3	0.7	1.0	2.2		2.1
Eject Flares	1622	4929	3770	6513	4465	3108	5225	9653	4439	2023	2376	3817	50318	4574.4
BIP flares	413	703	515	877.0	518.0	377.0	533.0	940.0	690.0	496.0	356.0	542.0	6547	595.2
Acetone (gal)	77	145.4	94.2	132.7	92.6	80.3	140.8	141.3	297.5	193.8	144.3	80.5	1543.4	140.3

*** June 15th to September 15th during 1996 and 1997**

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 15, 2009
Proposed starting date: June 1st, 2009
Expected duration: September 15th, 2009

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermod.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification, Inc. Tel. (403) 335-8359
Olds-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Mr. Bruce A. Boe, Director of Meteorology
M.Sc. Atmospheric Science, >30 years experience
Tel: (403) 335-8359 Cell: (701) 238-2577
bboe@weathermod.com
(see Part 5 for details of qualifications and experience)

Chief Meteorologist Mr. Jason Goehring
M.Sc. Atmospheric Sciences, 6 years experience
Office Tel: (403) 335-8359, (605) 216-5960 (cell)

Vice-President, Operations Mr. Hans Ahlness
Chief Pilot, >30 years experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermod.com):

- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CDN$50 million by the Alberta Severe Weather Management Society and US$5 million by Weather Modification Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996.
With the Alberta Research Council, WMI Senior Scientist Dr. Terry Krauss was actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984. Dr. Krauss continues to reside in Red Deer, and remains available for consultation on matters relative to the project.

b. Elsewhere:
- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 30 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Greece, Texas, California, Mexico, UAE, India, Indonesia, Mali, and Saudi Arabia within the last 10 years.

4. References:

1. Mr. Jim Renick
11 Warwick Drive,
Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Darin Langerud, Director
State of North Dakota Atmospheric Resource Board
900 E. Boulevard Ave.
Bismarck, ND 58505 Tel. 701-328-2788
3. Mr. George W. Bomar, Director
Texas Department of Licensing and Regulation
Austin, TX 78711 Tel. 512-936-4313
4. Dr. Paul L. Smith, Professor Emeritus
Institute of Atmospheric Sciences
South Dakota School of Mines & Technology
501 E. St. Joseph Street
Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Mr. Gary Hillman, Penhold, Alberta (403) 886-4187 will be providing aircraft maintenance services to WMI. Mr. Barry Robinson (403) 886-2111, Central Digital Systems Ltd., Penhold, Alberta will be providing radar and seeding systems maintenance services.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
Todd.Klapak@ingcanada.com
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-8359 and 403-335-3616
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-250-8070
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Bruce A. Boe
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359 and 701-238-2577 (mobile)
e-mail: bboe@weathermod.com
home page: http://www.weathermod.com/

Qualifications of field officer in charge:

- M.Sc. Univ. Wyoming, 1981 in Atmospheric Science with specialization in cloud physics.

- 2001-present: Director of Meteorology, Weather Modification, Inc., Fargo, ND.
- 1988-2000: Director, North Dakota Atmospheric Resource Board, State Water Commission, State of North Dakota. Managed North Dakota's hail suppression cloud seeding program.
- 1984-1988: Research Scientist, U.S. Bureau of Reclamation, Project Skywater, Montrose Skywater Office, Montrose, CO.
- 1981-1984: Field Meteorologist, North Dakota Cloud Modification Program (hail suppression, rainfall enhancement), Bowman, ND.
- 1978-1981: Aircraft data system operator, research associate, University of Wyoming, Laramie, WY.
- 1974-1978: Radar operator and rawinsonde technician, High Plains Experiment (HIPLEX), U.S. Bureau of Reclamation Project Skywater, Miles City, MT.

- Certified Manager of the Weather Modification Association (since 1991).
- American Meteorological Society: Member; Member and past-chair, Committee on Planned and Inadvertent Weather Modification.
- American Society of Civil Engineers: Affiliate Member, Chair, Atmospheric Water Management Standards Committee.
- Weather Modification Association: Chair, Nominating Committee; Member, Public Information Committee; past president.

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 10

Daily records of activities: Custodian = Mr. Jason Goehring, Chief Meteorologist,
WMI Project Operations Center
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps

- flight log report
- project aircraft maintenance report
- radar calibration report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of approximately $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers and brokers, have donated > $15 million to conduct a hail suppression project since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 10 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the last 10 years indicates a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. There are no significant changes in the crop damage within the target area for the last 10 years, compared with the previous 15 years. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and

1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.
Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the

inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5 C and -10 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gm of pyrotechnic, active at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- One Piper Cheyenne II prop-jet aircraft located at Calgary airport.

- One Beechcraft C90 King-Air prop-jet aircraft located at Red Deer airport.
- Two C-340 aircraft (one in Calgary and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable) pyrotechnic flares are 20 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150 gm AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of AgI at $-10^{o}C$.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past ten years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- One Cheyenne II (N234K) prop-jet aircraft located at Calgary airport.
- One C90 King-Air (N911FG) prop-jet aircraft located at Red Deer airport.
- Two C-340 (N457DM and N123KK) aircraft in Calgary (DM) and Red Deer (KK).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm that is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will ensure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
President, Alberta Severe Weather Management Society
(403) 231-1357, Todd.Klapak@ingcanada.com

Signature: Date:

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer: Bruce A. Boe, M.Sc. Title: Director of Meteorology

Bruce A. Boe
Signature: Date: May 15, 2009

Figure 1: Map of southern Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2008.

Alberta	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997*	1996*	Total	Average
Storm Days with Seeding	26	19	28	27	29	26	27	36	33	39	31	38	29	388	29.9
Aircraft Missions	112	76	92	80	105	92	92	109	130	118	96	92	71	1265	97.3
Total Flight Time (hrs)	194.7	115.3	190.2	157.9	227.5	163.6	157.4	208.3	265.2	251.3	189.9	188.1	159.1	2468	189.9
Number of Storms Seeded	56	41	65	70	90	79	54	98	136	162	153	108	75	1187	91.3
Total Seeding Material (kg)	122.9	99.7	214	159.1	270.9	173.4	124.2	195.0	343.8	212.7	111.1	110.8	163.3	2301	177.0
AgI/day	4.7	5.2	7.6	5.9	9.3	6.7	4.6	5.4	10.4	5.5	3.6	2.9	5.6		5.95
AgI/hour	1.0	0.9	1.1	1.0	1.2	1.1	0.8	0.9	1.3	0.8	0.6	0.6	1.0		0.95
AgI/Storm	2.2	2.4	3.3	2.3	3.0	2.2	2.3	2.0	2.5	1.3	0.7	1.0	2.2		2.11
Eject Flares	1648	1622	4929	3770	6513	4465	3108	5225	9653	4439	2023	2376	3817	53588	4122
BIP flares	548	413	703	515	877.0	518.0	377.0	533.0	940.0	690.0	496.0	356.0	542.0	7508	578
Acetone (gal)	113.5	77	145.4	94.2	132.7	92.6	80.3	140.8	141.3	297.5	193.8	144.3	80.5	1734	133.4

*** June 15th to September 15th during 1996 and 1997**

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 14, 2010
Proposed starting date: June 1st, 2010
Expected duration: September 15th, 2010

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermodification.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification, Inc. Tel. (403) 335-8359
Olds-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Dr. Viktor S. Makitov
Ph.D. Physics, >35 years experience
Tel: (403) 335-8359 Cell: (403) 559-6663
vsmakitov@hotmail.com
(see Part 5 for details of qualifications and experience)

Chief Meteorologist Mr. Dan Gilbert
B.S., 7 years experience
WMA Certified Weather Modification Operator #78
Office Tel: (403) 335-8359

Vice-President, Operations Mr. Hans Ahlness
Chief Pilot, >30 years experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermod.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe Weather Management Society and US$5 million by Weather Modification, Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996.
With the Alberta Research Council, WMI Senior Scientist Dr. Terry Krauss was actively involved in the hail suppression and rain enhancement activities of the Alberta Hail project over the period 1974 to 1984. Dr. Krauss continues to reside in Red Deer, and remains available for consultation on matters relative to the project.

b. Elsewhere:
- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 35 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Greece, Texas, California, Mexico, UAE, India, Indonesia, Mali, and Saudi Arabia within the last 10 years.

4. References:

1. Mr. Jim Renick
   11 Warwick Drive,
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
2. Mr. Darin Langerud, Director
   State of North Dakota Atmospheric Resource Board
   900 E. Boulevard Ave.
   Bismarck, ND 58505 Tel. 701-328-2788
3. Mr. George W. Bomar, Director
   Texas Department of Licensing and Regulation
   Austin, TX 78711 Tel. 512-936-4313
4. Dr. Paul L. Smith, Director
   Institute of Atmospheric Sciences
   South Dakota School of Mines & Technology
   501 E. St. Joseph Street
   Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project. Mr. Barry Robinson (403) 886-2111, Central Digital Systems Ltd., Penhold, Alberta will be providing radar and seeding systems maintenance services.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
Todd.Klapak@ingcanada.com
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel: 403-335-8359 and 403-335-3616
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-250-8070
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Dr. Viktor Makitov
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359, cell: 403-559-6663
e-mail: vsmakitov@hotmail.com
home page: http://www.weathermod.com/

Qualifications of field officer in charge (Makitov):

Meteorologist 2007 - 2010
Weather Modification Inc., Fargo, ND, USA
Saudi Arabian Rain Enhancement Project, Riyadh, Saudi Arabia.

- Conducting the cloud seeding operations using the TITAN radar system.
- Weather forecasting, satellite images, synopsis maps and radiosonde data analysis.

Meteorologist 2006 - 2010
Weather Modification Inc., Fargo, ND, USA
Alberta Hail suppression Project, Alberta Canada.

- Conducting the cloud seeding operations using the TITAN radar system.
- Weather forecasting, satellite images, synopsis maps and radiosonde data analysis.

Meteorologist 1999 –2004
Weather Modification Inc., Fargo, ND, USA
Argentinean Hail Suppression Project, Mendoza, Argentina

- Conducting the cloud seeding and hail suppression operations using the TITAN radar system.
- Weather forecasting, satellite images and synopsis maps analysis.
- Vaisala radiosonde equipment operations and data analysis.

Professor of Engineering Faculty, National University of Cuyo, Mendoza, Argentina.

- Courses of lectures titled "Investigations of Clouds and Precipitation with Weather Radars" and "Basics of Cloud Physics".

Science Director 1996-1999
Antigrad Latinoamericana S.A., Mendoza, Argentina.

- Conducting the cloud seeding and hail suppression operations using the Russian rockets technology.
- Development of the advanced system for weather modification.
- Development of methods for radar estimation of kinetic energy of hailfalls and rainfall rates.

Laboratory Chief 1987-1996
High Mountain Geophysical Institute, Hail Suppression Technology Division, Nalchik, Russia.

- *Development of methods for hail suppression and seeding efficiency.*
- *Development of algorithms of hail detection for automated rocket hail suppression system.*
- *Analysis of synoptic situations and thermodynamic conditions of the hail formation. Development of methods of hailstorm forecasting.*

Senior Scientist 1987-1991
High Mountain Geophysical Institute, Hail Suppression Technology Division,
Nalchik, Russia.

- Radar investigation of convective clouds, sever storms and conducting the weather modification projects.
  - *Analysis of hail formation in clouds with different radar reflectivity patterns.*
  - *Analysis of radar data using physical and mathematical methods.*

Research Scientist 1973-1976
Laboratory of Radar Meteorology, High Mountain Geophysical Institute, Nalchik, Russia.

- Radar observation and analysis of structure and dynamics of hailstorms.

EDUCATION

1992 Senior Scientist, Highest Attestation Committee of the Government of USSR (Diploma CN №076920 11.12.1992., protocol № 45C/14, Moscow, USSR).

1981 Doctor of Physics and Mathematics. Specialty: Geophysics, Cloud Physics, Weather Modification. St Petersburg Hydrometeorological Institute, St Petersburg, Russia. 18.06.81. (Diploma KD № 001662, 05.01.1983., Moscow)

1973 Physicist, Atmospheric Physics, Kabardino-Balkarian State University, Nalchik, USSR (Diploma U № 508545, 23.06.1973., Nalchik, USSR).

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 10

Daily records of activities: Custodian = Dr. Viktor Makitov
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report
- radar calibration report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of approximately $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers and brokers, have donated > $15 million to conduct a hail suppression project since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 10 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the last 10 years indicates a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. There are no significant changes in the crop damage within the target area for the last 10 years, compared with the previous 15 years. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20^{o}C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.
Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5 C and -10 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gm of pyrotechnic, active at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one EEC-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- One Piper Cheyenne II prop-jet aircraft located at Calgary airport.
- One Beechcraft C90 King-Air prop-jet aircraft located at Red Deer airport.
- Two C-340 aircraft (one in Calgary and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (droppable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Davenport, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at CSU indicate $>10^{14}$ ice crystals per gram of AgI at -10^{o}C.

Total flight hours and quantities to be dispersed: We estimate to use 5000 x 20 gm flares and 500 x 150 gm flares plus approx. 150 gallons of acetone (2% AgI solution). The number of operational days, flights, and amount of seeding material dispensed over the past ten years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background contamination levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- One Cheyenne II (N747RE) prop-jet aircraft located at Calgary airport.
- One C90 King-Air (N911FG) prop-jet aircraft located at Red Deer airport.
- Two C-340 (N457DM and N123KK) aircraft in Calgary (DM) and Red Deer (KK).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm that is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will ensure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
President, Alberta Severe Weather Management Society
(403) 231-1357, Todd.Klapak@intact.net

signature to be provided on hard copy submitted in late May 2010

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer: Bruce A. Boe, M.Sc. Title: Director of Meteorology

Bruce A. Boe

Signature: Date: May 14, 2010

Figure 1: Map of southern Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2009.

Alberta	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997*	1996*	Total	Average
Storm Days with Seeding	20	26	19	28	27	29	26	27	36	33	39	31	38	29	408	29.1
Aircraft Missions	37	112	76	92	80	105	92	92	109	130	118	96	92	71	1302	93.0
Total Flight Time (hrs)	109.3	194.7	115.3	190.2	157.9	227.5	163.6	157.4	208.3	265.2	251.3	189.9	188.1	159.1	2577.8	184.1
Number of Storms Seeded	30	56	41	65	70	90	79	54	98	136	162	153	108	75	1217	86.9
Total Seeding Material (kg)	48.4	122.9	99.7	214	159.1	270.9	173.4	124.2	195.0	343.8	212.7	111.1	110.8	163.3	2349.3	167.8
AgI/day	2.4	4.7	5.2	7.6	5.9	9.3	6.7	4.6	5.4	10.4	5.5	3.6	2.9	5.6		5.7
AgI/hour	0.84	1.0	0.9	1.1	1.0	1.2	1.1	0.8	0.9	1.3	0.8	0.6	0.6	1.0		0.94
AgI/Storm	1.6	2.2	2.4	3.3	2.3	3.0	2.2	2.3	2.0	2.5	1.3	0.7	1.0	2.2		2.07
Eject Flares	451	1648	1622	4929	3770	6513	4465	3108	5225	9653	4439	2023	2376	3817	54039	3860
BIP flares	237	548	413	703	515	877	518	377	533	940	690	496	356	542	7745	553
Acetone (gal)	56.5	113.5	77	145.4	94.2	132.7	92.6	80.3	140.8	141.3	297.5	193.8	144.3	80.5	1790.4	127.8

*** June 15th to September 15th during 1996 and 1997**

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 12, 2011
Proposed starting date: June 1st, 2011
Expected duration: September 15th, 20110

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermodification.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification, Inc. Tel. (403) 335-8359
Olds-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Mr. Daniel Gilbert
B.S., 8 years' experience
WMA Certified Weather Modification Operator #78
Office Tel: (403) 335-8359
(see Part 5 for details of qualifications and experience)

Director of Meteorology Mr. Bruce Boe
Project Manager/Meteorology, 37 years' experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermodification.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe Weather Management Society and US$5 million by Weather Modification, Inc.
List of similar weather modification activities previously undertaken:
a. Canada: The Alberta Hail Project has been operating in its present form since 1996. The

contractor (operator) for this entire period has been WMI.

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 35 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Alberta, California, Greece, Texas, California, Idaho, Mexico, UAE, India, Indonesia, Mali, Nevada, North Dakota, Oklahoma, Saudi Arabia, and Wyoming within the last 10 years.

4. References:

1. Dr. Terry Krauss
   Krauss Weather Services
   13 Roche Street
   Red Deer, AB T4P 3K8 Tel. 403-342-5685
2. Mr. Darin Langerud, Director
   State of North Dakota Atmospheric Resource Board
   900 E. Boulevard Ave.
   Bismarck, ND 58505 Tel. 701-328-2788
3. Mr. George W. Bomar, Director
   Texas Department of Licensing and Regulation
   Austin, TX 78711 Tel. 512-936-4313
4. Dr. Paul L. Smith, Director
   Institute of Atmospheric Sciences
   South Dakota School of Mines & Technology
   501 E. St. Joseph Street
   Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
Todd.Klapak@ingcanada.com
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel. 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Calgary international airport tel. 403-250-8070
- Red Deer industrial airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Daniel Gilbert
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359,
e-mail: dgilbert@weathermodifcation.com
home page: http://www.weathermodification.com/

Qualifications of field officer in charge (Gilbert):

Education
Bachelor of Science, Meteorology and Environmental Studies (double major) May 2004, Iowa State University, Ames, IA
Associate of Arts, Liberal Arts, May 2000, Iowa Central Community College, Fort Dodge, IA

Weather Modification Experience
Field Meteorologist, Weather Modification, Inc. (Wyoming and Alberta) - November 2009 to present
Forecaster, radar operator, rawinsondes, direction of seeding aircraft. Case declarations, wintertime (Wyoming) research program.
Meteorologist, RHS Consulting (Fresno, CA) – November 2008-February 2009
Directed airborne and ground based cloud seeding operations over portions of the central and southern Sierra Nevada Mountains. Set up and performed routine maintenance of ground based ice nucleus generators. Provided daily forecasts for clients and project personnel.
Meteorologist, Independent Contractor, (Boise, ID) – October 2007 to April 2008
Provided meteorological services to support Idaho Power Company's winter cloud seeding project in West Central Idaho, directed airborne and ground seeding operations, directed rawinsonde releases, provided short-term operational forecasts and nowcasts for pilots, communicated with aircraft via two-way radio
Field Meteorologist, North Dakota Cloud Modification Project, (Stanley or Bowman, ND) – Summers, 2003-2009
Operated 5 cm weather radar equipped with TITAN software package, launched and directed seeding aircraft using two-way radio and GPS tracking, performed data recording and documentation of cloud seeding operations, prepared silver iodide seeding solution, assisted with radar calibrations, prepared forecasts and briefed pilots daily, supervised intern meteorologists, presented case studies for ground school, operated cloud condensation nuclei counter for joint research with South Dakota School of Mines
Forecaster, Atmospherics Incorporated, (Fresno, CA) - October 2006 - May 2007
Field Meteorologist, Atmospherics, Inc. (Modesto, CA) - November 2005 - April 2006
Field Meteorologist, Atmospherics, Inc. (Paso Robles, CA) - December 2004 - February 2005
Provided daily forecasts for seeding operations and/or clients, operated 5cm weather radar, directed winter cloud seeding operations over the Sierra Nevada utilizing both glaciogenic and hygroscopic seeding agents, traced radar overlays, performed data recording of operations, wrote monthly and annual reports

Memberships and Honors
- Member, Weather Modification Association (certified operator #78)
- Member, American Meteorological Society
- Iowa Central Community College Honor Society, inducted April 27, 2000
- Wilbur E Brewer Professionalism Award, 2007 North Dakota Cloud Modification Project

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 10

Daily records of activities: Custodian = Ms. Erin Fischer
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report
- radar calibration report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of approximately $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers and brokers, have donated > $15 million to conduct a hail suppression project since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 10 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the last 10 years indicates a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. There are no significant changes in the crop damage within the target area for the last 10 years, compared with the previous 15 years. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD
For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail-threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI- Acetone burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS
The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES
Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude.
Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5 C and -10 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gm of pyrotechnic, active at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one WMI-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Two Beechcraft C90 King-Air prop-jet aircraft (one in Calgary and one in Red Deer).
- Two Cessna 340 aircraft (one in Calgary and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (ejectable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- A mixture of Acetone, Silver iodide, Sodium Perchlorate, Paradichlorobenzene, and Ammonium Iodide will also be dispensed by aircraft mounted burners for continuous seeding at cloud base.

Activation tests performed at Colorado State University indicate greater than10^{14} ice crystals per gram of seeding agent burned, active at $-10^{o}C$.

Total flight hours and quantities to be dispersed: We estimate the project may use 5000 twenty-gram flares and 500 one hundred-fifty gram flares, plus approximately 150 gallons of acetone (2% AgI solution) will be burned. The number of operational days, flights, and amount of seeding material dispensed over the past fifteen years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far, far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Two C90 King Air prop-jet aircraft, one in Calgary (N522JP) and one based in Red Deer (N422PM).
- Two Cessna 340 aircraft, one in Calgary (N123KK) and one in Red Deer (N37356).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

SPECIAL CLOUD PHYSICS INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels. The Cheyenne aircraft will be equipped with a limited cloud physics data acquisition system to measure liquid water cloud droplets using a hot-wire instrument. A special telemetry system is used to transmit the special aircraft data to the radar communications and control center where it will be displayed in real time and recorded at 1 s intervals. The data system does not require a separate operator. These critical meteorological and microphysical measurements will allow for improved documentation and strategic decision making during the cloud seeding missions regarding the growth and or decaying stages of the storm that is being seeded. These microphysical measurements will also help document in-situ cloud seeding "signatures" to confirm that the ice-nucleating agents are participating in the precipitation formation (and hail suppression) processes. These measurements, combined with the recorded radar data, will ensure that the project is conducted on a sound scientific basis.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract.

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
President, Alberta Severe Weather Management Society
(403) 231-1357, Todd.Klapak@intact.net

Signature: Date: May 16, 2011

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer:
Bruce A. Boe
Director of Meteorology
(701) 235-5500

Bruce A. Boe

Signature: Date: May 16, 2011

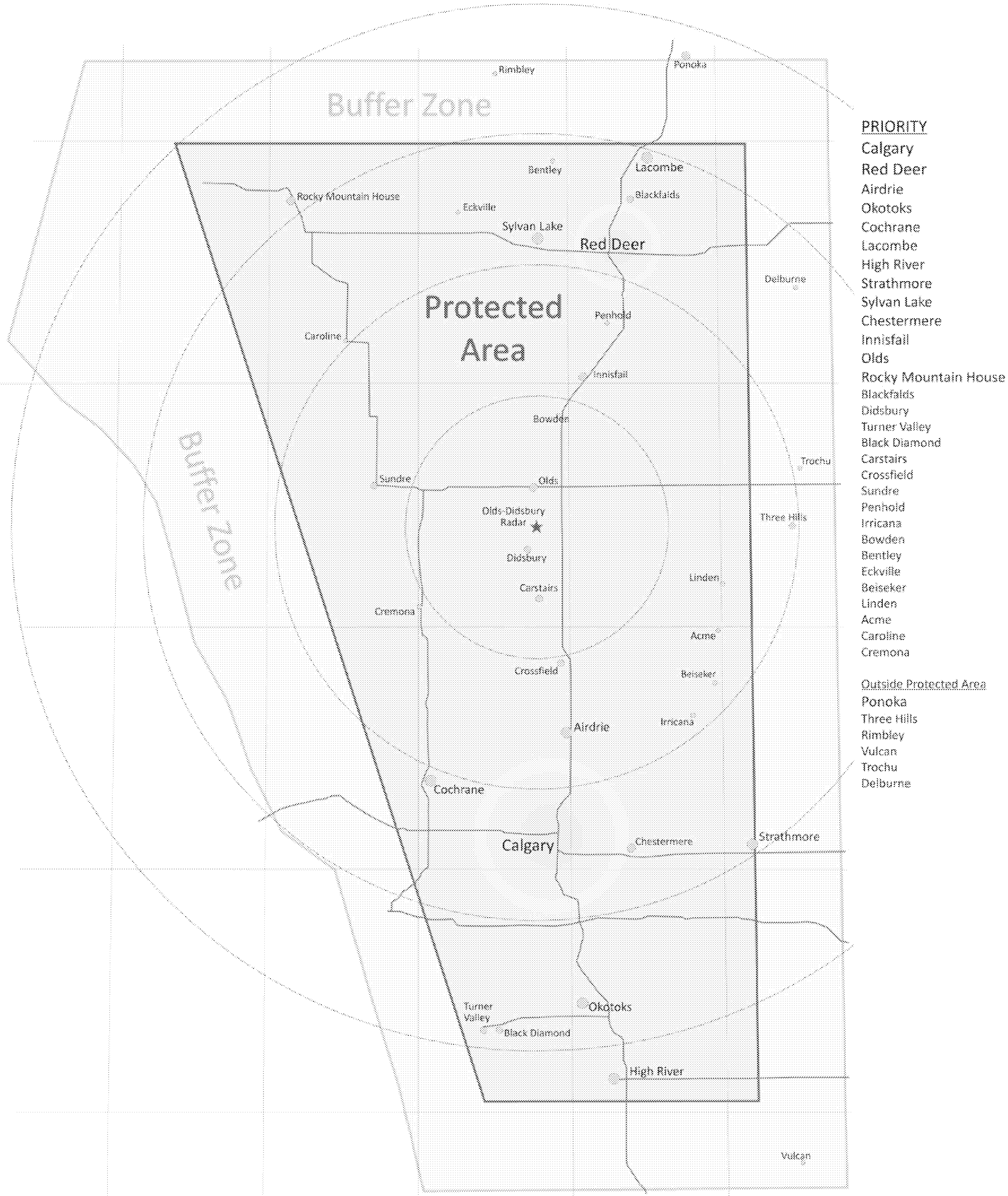


Figure 1: Map of southern Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2010.

	Mean	1996*	1997*	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Days with Seeding	30.0	29	38	31	39	33	36	27	26	29	27	28	19	26	20	42
Aircraft Missions	92.9	71	92	96	118	130	109	92	92	105	80	92	76	112	37	91
Flight Time (hours)	190.0	159.1	188.1	189.9	251.3	265.2	208.3	157.4	163.6	227.5	157.9	190.2	115.3	194.7	109.3	271.8
Seeded Storms	89.0	75	108	153	162	136	98	54	79	90	70	65	41	56	30	118
Seeding Agent (kg)	174.2	163.3	110.8	111.1	212.7	343.8	195.0	124.2	173.4	270.9	159.1	214.0	99.7	122.9	48.4	263.8
Seeding per Day (kg)	5.7	5.6	2.9	3.6	5.5	10.4	5.4	4.6	6.7	9.3	5.9	7.6	5.2	4.7	2.4	6.3
Seeding per Hour (kg)	0.95	1.00	0.60	0.60	0.80	1.30	0.90	0.80	1.10	1.20	1.00	1.10	0.90	1.00	0.84	1.10
Seeding per Storm (kg)	2.1	2.2	1.0	0.7	1.3	2.5	2.0	2.3	2.2	3.0	2.3	3.3	2.4	2.2	1.6	2.2
Ejectable Flares	3991.7	3817	2376	2023	4439	9653	5225	3108	4465	6513	3770	4929	1622	1648	451	5837
Burn-In-Place Flares	573.1	542	356	496	690	940	533	377	518	877	515	703	413	548	237	851
Seeding Solution (gal)	134.5	80.5	144.3	193.8	297.5	141.3	140.8	80.3	92.6	132.7	94.2	145.4	77.0	113.5	56.5	227.5
15-season Activity Rank		8th, 9th	12th	11th	5th	1st	6th	13th	7th	2nd, 3rd	10th	4th	14th	8th, 9th	15th	2nd, 3rd

*The 1996 and 1997 seasons were conducted from 15 June through 15 September only.

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 3rd, 2012
Proposed starting date: June 1st, 2012
Expected duration: September 15th, 2012

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: Airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name:	Weather Modification Inc. (WMI) http://www.weathermodification.com/	
Parent Organization:	Weather Modification Inc. (WMI) 3802 20th Street North Fargo, ND USA 58102	
Chief Officer:	Mr. Patrick H. Sweeney, President pat@weathermod.com	Tel: (701) 235-5500
Local Organization:	Weather Modification, Inc. Olds-Didsbury Airport, Highway 2A Olds, AB T4H 1A1	Tel. (403) 335-8359

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer:	Mr. Daniel Gilbert, Chief Meteorologist B.S., 9 years' experience WMA Certified Weather Modification Operator #78 Office Tel: (403) 335-8359 (see Part 5 for details of qualifications and experience)
Director of Meteorology	Mr. Bruce Boe Project Manager/Meteorology, 38 years' experience Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermodification.com):

- Cloud seeding
- Atmospheric research
- Air pollution monitoring
- Meteorological radar monitoring
- Equipment design and fabrication
- Aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe Weather Management Society and US$5 million by Weather Modification, Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996. The contractor (operator) for this entire period has been WMI.

b. Elsewhere:

- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 35 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Alberta, California, Greece, Texas, California, Idaho, Mexico, UAE, India, Indonesia, Mali, Nevada, North Dakota, Oklahoma, Saudi Arabia, and Wyoming within the last 10 years.

References:

1. Dr. Terry Krauss
   Krauss Weather Services
   13 Roche Street
   Red Deer, AB T4P 3K8 Tel. 403-342-5685
2. Mr. Darin Langerud, Director
   State of North Dakota Atmospheric Resource Board
   900 E. Boulevard Ave.
   Bismarck, ND 58505 Tel. 701-328-2788
3. Mr. George W. Bomar, Director
   Texas Department of Licensing and Regulation
   Austin, TX 78711 Tel. 512-936-4313
4. Dr. Paul L. Smith, Director
   Institute of Atmospheric Sciences
   South Dakota School of Mines & Technology
   501 E. St. Joseph Street
   Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
todd.klapak@intact.net
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:

- Olds-Didsbury Airport, Alberta tel. 403-335-8359

Address(es) and locations(s) of project secondary field base(s):

- Calgary International Airport tel. 403-250-8070
- Red Deer Industrial Airport tel. 403-886-4187

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Daniel Gilbert, Chief Meteorologist
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359,
e-mail: dgilbert@weathermodifcation.com
home page: http://www.weathermodification.com/

Qualifications of field officer in charge (Gilbert):

Education
Bachelor of Science, Meteorology and Environmental Studies (double major) May 2004, Iowa State University, Ames, IA
Associate of Arts, Liberal Arts, May 2000, Iowa Central Community College, Fort Dodge, IA

Weather Modification Experience
Chief Meteorologist, Weather Modification, Inc. (Wyoming and Alberta) - November 2009 to present
Forecaster, radar operator, rawinsondes, direction of seeding aircraft. Case declarations, wintertime (Wyoming) research program.
Meteorologist, RHS Consulting (Fresno, CA) – November 2008-February 2009
Directed airborne and ground based cloud seeding operations over portions of the central and southern Sierra Nevada Mountains. Set up and performed routine maintenance of ground based ice nucleus generators. Provided daily forecasts for clients and project personnel.
Meteorologist, Independent Contractor, (Boise, ID) – October 2007 to April 2008
Provided meteorological services to support Idaho Power Company's winter cloud seeding project in West Central Idaho, directed airborne and ground seeding operations, directed rawinsonde releases, provided short-term operational forecasts and nowcasts for pilots, communicated with aircraft via two-way radio
Field Meteorologist, North Dakota Cloud Modification Project, (Stanley or Bowman, ND) – Summers, 2003-2009
Operated 5 cm weather radar equipped with TITAN software package, launched and directed seeding aircraft using two-way radio and GPS tracking, performed data recording and documentation of cloud seeding operations, prepared silver iodide seeding solution, assisted with radar calibrations, prepared forecasts and briefed pilots daily, supervised intern meteorologists, presented case studies for ground school, operated cloud condensation nuclei counter for joint research with South Dakota School of Mines
Forecaster, Atmospherics Incorporated, (Fresno, CA) - October 2006 - May 2007
Field Meteorologist, Atmospherics, Inc. (Modesto, CA) - November 2005 - April 2006
Field Meteorologist, Atmospherics, Inc. (Paso Robles, CA) - December 2004 - February 2005
Provided daily forecasts for seeding operations and/or clients, operated 5cm weather radar, directed winter cloud seeding operations over the Sierra Nevada utilizing both glaciogenic and hygroscopic seeding agents, traced radar overlays, performed data recording of operations, wrote monthly and annual reports

Memberships and Honors

- Member, Weather Modification Association (certified operator #78)
- Member, American Meteorological Society
- Iowa Central Community College Honor Society, inducted April 27, 2000
- Wilbur E Brewer Professionalism Award, 2007 North Dakota Cloud Modification Project

Field Address:	Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no.	403-335-8359
Field personnel:	full time = 3
	part time = 10

Daily records of activities: Custodian = Ms. Erin Fischer
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- Daily weather synopsis and forecast report
- Radar echo storm data report and maps
- Daily operations summary report
- Chemical inventory report
- Equipment status report
- Aircraft flight track maps
- Flight log report
- Project aircraft maintenance report
- Radar calibration report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: Hailstorms cause an average of approximately $100 million damage to private and public property annually in Alberta. The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Over 40 major Alberta insurers, as well as reinsurers and brokers, have donated > $15 million to conduct a hail suppression project since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+/- 1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. After 10 years, the insurance industry is very encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the last 10 years indicates a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. There are no significant changes in the crop damage within the target area for the last 10 years, compared with the previous 15 years. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost: approx. $2 million per year.

Funds to be expended in Canada: est. $500,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5 C temperature level, and are considered to be a potential hail threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI-solution burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote, 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5 C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude. Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5 C and -10 C. The pencil flares fall approximately 1.5 km (approximately 10 C) during their 35-40 s burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5 C and - 10 C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g. 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gm of pyrotechnic, active at -10 C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gm flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- One WMI-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Two Beechcraft C90 King-Air prop-jet aircraft (one in Calgary and one in Red Deer).
- Two Cessna 340 aircraft (one in Calgary and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (ejectable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- A solution of acetone, silver iodide, sodium perchlorate, paradichlorobenzene, and ammonium iodide will also be burned for continuous seeding at cloud base.

Activation tests performed at Colorado State University indicate greater than 10^{14} ice crystals per gram of seeding agent burned, active at -10°C.

Total flight hours and quantities to be dispersed: We estimate the project may use 5000 twenty-gram flares and 500 one hundred-fifty gram flares, plus approximately 150 gallons of acetone (2% AgI solution) will be burned. The number of operational days, flights, and amount of seeding material dispensed over the past fifteen years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far, far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Two C90 King Air prop-jet aircraft, one in Calgary (N904DK) and one based in Red Deer (N522JP).
- Two Cessna 340 aircraft, one in Calgary (N457DM) and one in Red Deer (N123KK).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

TEMPERATURE INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

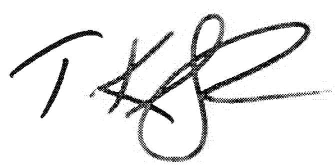
State type of working agreement entered into with the weather modifier: Contract.

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
President, Alberta Severe Weather Management Society
(403) 231-1357, Todd.Klapak@intact.net

Signature:  Date: May 3, 2012

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer:
Bruce A. Boe
Director of Meteorology
(701) 235-5500

Signature: Bruce A. Boe Date: May 3, 2012

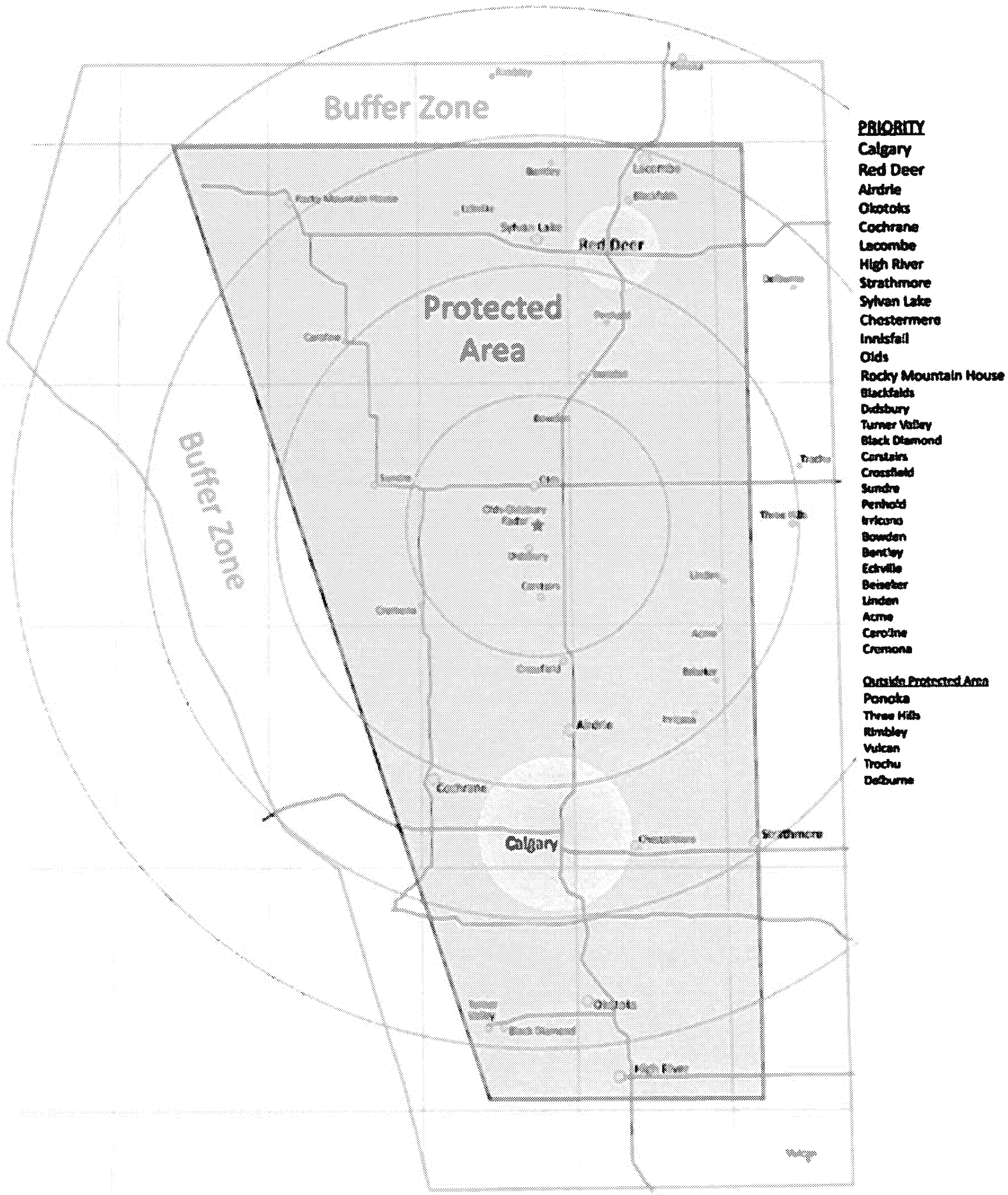


Figure 1: Map of southern Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2011.

Alberta	Mean	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Storm Days with Seeding	31.1	29	38	31	39	33	36	27	26	29	27	28	19	26	20	42	48
Aircraft Missions	95.4	71	92	96	118	130	109	92	92	105	80	92	76	112	37	91	134
Total Flight Time (hours)	202.0	159.1	188.1	189.9	251.3	265.2	208.3	157.4	163.6	227.5	157.9	190.2	115.3	194.7	109.3	271.8	383.0
Number of Storms Seeded	91.8	75	108	153	162	136	98	54	79	90	70	65	41	56	30	118	134
Total Seeding Agent (kg)	188.3	163.3	110.8	111.1	212.7	343.8	195.0	124.2	173.4	270.9	159.1	214.0	99.7	122.9	48.4	263.8	400.1
Seeding Agent per Day (kg)	5.9	5.6	2.9	3.6	5.5	10.4	5.4	4.6	6.7	9.3	5.9	7.6	5.2	4.7	2.4	6.3	8.3
Seeding Agent per Hour (kg)	0.96	1.00	0.60	0.60	0.80	1.30	0.90	0.80	1.10	1.20	1.00	1.10	0.90	1.00	0.84	1.10	1.13
Seeding Agent per Storm (kg)	2.1	2.2	1.0	0.7	1.3	2.5	2.0	2.3	2.2	3.0	2.3	3.3	2.4	2.2	1.6	2.2	3.0
Ejectable Flares	4415.9	3817	2376	2023	4439	9653	5225	3108	4465	6513	3770	4929	1622	1648	451	5837	10779
BIP Flares	601.0	542	356	496	690	940	533	377	518	877	515	703	413	548	237	851	1020
Seeding Solution (gal)	148.0	80.5	144.3	193.8	297.5	141.3	140.8	80.3	92.6	132.7	94.2	145.4	77.0	113.5	56.5	227.5	350.2

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES

PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice:	May 9, 2013
Proposed starting date:	June 1st, 2013
Expected duration:	September 15th, 2013
Province and area to be affected:	Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).
Weather elements to be modified:	Thunderstorms
Modification expected:	Hail Suppression
Class of operation:	Operational
Operating method:	Airborne
Class of economy to benefit:	Insurance Industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name:	Weather Modification Inc. (WMI) http://www.weathermodification.com/	
Parent Organization:	Weather Modification Inc. (WMI) 3802 20th Street North Fargo, ND USA 58102	
Chief Officer:	Mr. Patrick H. Sweeney, President pat@weathermod.com	Tel: (701) 235-5500
Local Organization:	Weather Modification, Inc. Olds-Didsbury Airport, Highway 2A Olds, AB T4H 1A1	Tel. (403) 335-8359

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer:	Mr. Daniel Gilbert, Chief Meteorologist B.S., 10 years' experience WMA Certified Weather Modification Operator #78 Office Tel: (403) 335-8359 (see Part 5 for details of qualifications and experience)
Director of Meteorology	Mr. Bruce Boe Project Manager/Meteorology, 39 years' experience Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermodification.com):

- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe Weather Management Society and US$5 million by Weather Modification, Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996. The contractor (operator) for this entire period has been WMI.

b. Elsewhere:
- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 50 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Alberta, Burkina Faso, California, California, Idaho, Mexico, UAE, India, Indonesia, Mali, Nevada, North Dakota, Saudi Arabia, Senegal, and Wyoming within the last 10 years.

4. References:

1. Dr. Terry Krauss
   Krauss Weather Services
   79 Irving Crescent
   Red Deer, AB T4R 3S3 Tel. 403-318-0400
2. Mr. Darin Langerud, Director
   State of North Dakota Atmospheric Resource Board
   900 E. Boulevard Ave.
   Bismarck, ND 58505 Tel. 701-328-2788
3. Mr. James Renick
   Alberta Severe Weather Management Society (ret.)
   11 Warwick Drive
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
4. Dr. Paul L. Smith, Director
   Institute of Atmospheric Sciences
   South Dakota School of Mines & Technology
   501 E. St. Joseph Street
   Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
todd.klapak@intact.net
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:

- Olds-Didsbury Airport, Alberta tel. 403-335-8359

Address(es) and locations(s) of project secondary field base(s):

- Springbank airport tel. 403-247-0001
- Red Deer industrial airport tel. 403-886-7857

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Daniel Gilbert, Chief Meteorologist
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax: 403-335-8359,
e-mail: dgilbert@weathermodifcation.com
home page: http://www.weathermodification.com/

Qualifications of field officer in charge (Gilbert):

Education
Bachelor of Science, Meteorology and Environmental Studies (double major) May 2004, Iowa State University, Ames, IA
Associate of Arts, Liberal Arts, May 2000, Iowa Central Community College, Fort Dodge, IA

Weather Modification Experience
Chief Meteorologist, Weather Modification, Inc. (Wyoming and Alberta) - November 2009 to present
Forecaster, radar operator, rawinsondes, direction of seeding aircraft. Case declarations, wintertime (Wyoming) research program.
Meteorologist, RHS Consulting (Fresno, CA) – November 2008-February 2009
Directed airborne and ground based cloud seeding operations over portions of the central and southern Sierra Nevada Mountains. Set up and performed routine maintenance of ground based ice nucleus generators. Provided daily forecasts for clients and project personnel.
Meteorologist, Independent Contractor, (Boise, ID) – October 2007 to April 2008
Provided meteorological services to support Idaho Power Company's winter cloud seeding project in West Central Idaho, directed airborne and ground seeding operations, directed rawinsonde releases, provided short-term operational forecasts and nowcasts for pilots, communicated with aircraft via two-way radio
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Operated 5 cm weather radar equipped with TITAN software package, launched and directed seeding aircraft using two-way radio and GPS tracking, performed data recording and documentation of cloud seeding operations, prepared silver iodide seeding solution, assisted with radar calibrations, prepared forecasts and briefed pilots daily, supervised intern meteorologists, presented case studies for ground school, operated cloud condensation nuclei counter for joint research with South Dakota School of Mines
Forecaster, Atmospherics Incorporated, (Fresno, CA) - October 2006 - May 2007
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Provided daily forecasts for seeding operations and/or clients, operated 5cm weather radar, directed winter cloud seeding operations over the Sierra Nevada utilizing both glaciogenic and hygroscopic seeding agents, traced radar overlays, performed data recording of operations, wrote monthly and annual reports

Memberships and Honors

- Meteorologist Distinguished Service Award, 2013, Weather Modification Association
- Member, Weather Modification Association (certified operator #78)
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- Iowa Central Community College Honor Society, inducted April 27, 2000
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Field Telephone no.	403-335-8359
Field personnel:	full time = 3
	part time = 12

Daily records of activities: Custodian = Ms. Erin Fischer
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Hailstorms in the City of Calgary caused >$500 Million in 2010 and again in 2012. In addition, hailstorms have caused >$100 Million damage to crops annually since 2007 and the damage to crops was >$400 Million in 2012. Hailstorms have now become a billion dollar problem to the economy of Alberta. The 20 largest insurance companies and their affiliates have banded together to conduct hail suppression operations in the "hail alley" of central Alberta to combat urban hail damage in the Calgary to Red Deer area. The current program has conducted cloud-seeding operations in central Alberta each summer since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. The insurance industry has been encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the first 10 years of the project indicated a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.

Approximate total cost:	approx. $3.1 million per year
Funds to be expended in Canada:	est. $500,000 per year
General period of operation:	June 1st - Sept. 15th annually

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5°C temperature level, and are considered to be a potential hail threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI-solution burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5°C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude. Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5°C and -10°C. The pencil flares fall approximately 1.5 km (approximately 10°C) during their 35-40 second burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5°C and - 10°C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g. 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gram of pyrotechnic, active at -10°C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gram flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT:

- One WMI-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Three Beechcraft C90 King-Air prop-jet aircraft (two in Springbank and one in Red Deer).
- Two Cessna 340 aircraft (one in Springbank and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (ejectable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- A solution of acetone, silver iodide, sodium perchlorate, paradichlorobenzene, and ammonium iodide will also be burned for continuous seeding at cloud base.

Activation tests performed at Colorado State University indicate greater than10^{14} ice crystals per gram of seeding agent burned, active at -10°C.

Total flight hours and quantities to be dispersed: We estimate the project may use 5000 twenty-gram flares and 500 one hundred-fifty gram flares, plus approximately 150 gallons of acetone (2% AgI solution) will be burned. The number of operational days, flights, and amount of seeding material dispensed over the past fifteen years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far, far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Three C90 King Air prop-jet aircraft, two in Springbank (N904DK and N518TS) and one based in Red Deer (N522JP).
- Two Cessna 340 aircraft, one in Springbank (N457DM) and one in Red Deer (N98585).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

TEMPERATURE INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract.

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
President, Alberta Severe Weather Management Society
(403) 231-1357, Todd.Klapak@intact.net

Signature: Date: May 28, 2013

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer:
Bruce A. Boe
Director of Meteorology
(701) 235-5500

Signature: Date: May 9, 2013

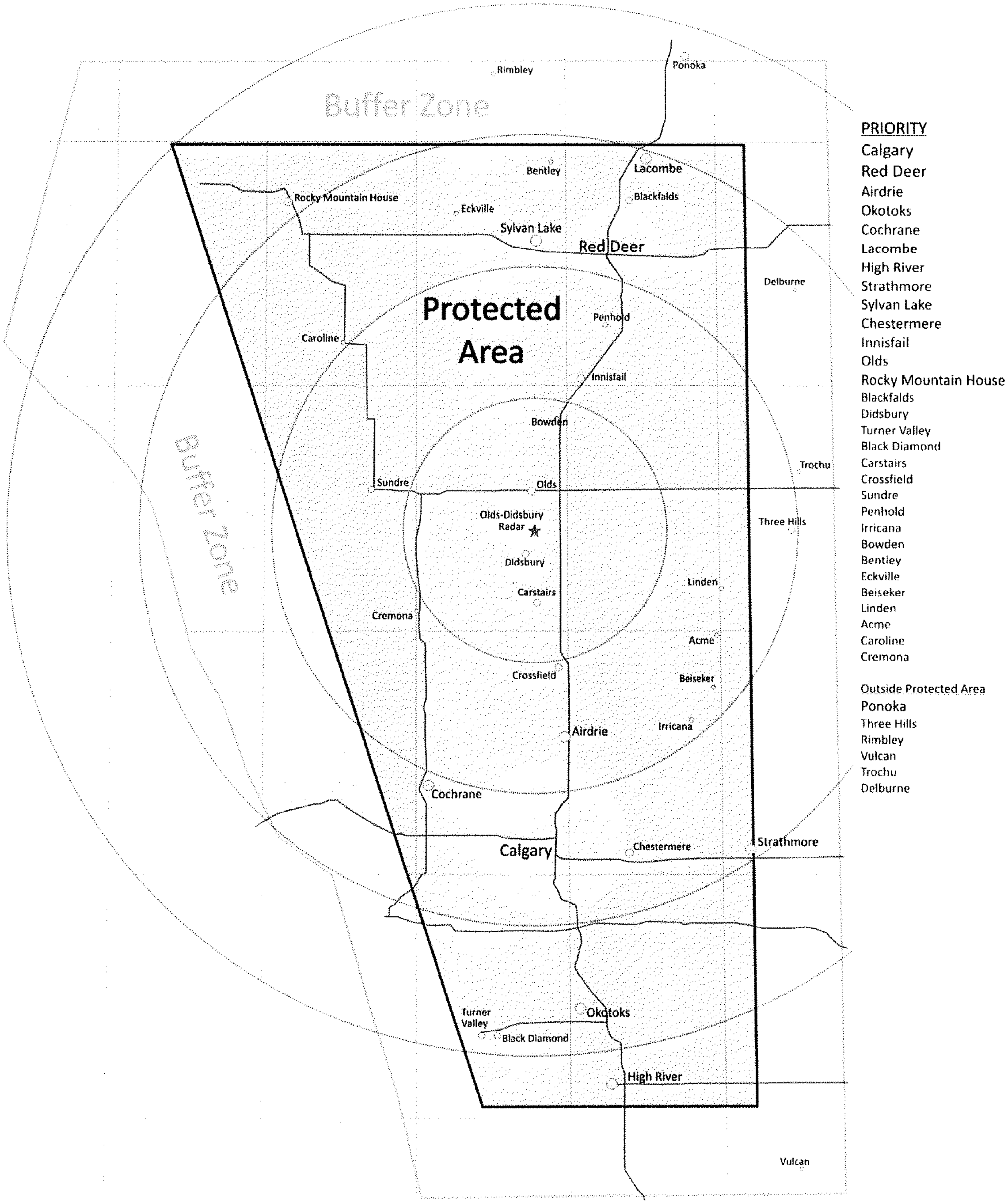

Figure 1: Map of south-central Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2012.

	Mean	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Storm Days with Seeding	31.5	29	38	31	39	33	36	27	26	29	27	28	19	26	20	42	48	37
Aircraft Missions (Seeding & Patrol)	101	71	92	96	118	130	109	92	92	105	80	92	76	112	37	91	134	143
Total Flight Time (hours)	207.8	159.1	188.1	189.9	251.3	265.2	208.3	157.4	163.6	227.5	157.9	190.2	115.3	194.7	109.3	271.8	383.0	300.1
Number of Storms Seeded	93	75	108	153	162	136	98	54	79	90	70	65	41	56	30	118	134	116
Total Seeding Agent (kg)	195.8	163.3	110.8	111.1	212.7	343.8	195.0	124.2	173.4	270.9	159.1	214.0	99.7	122.9	48.4	263.8	400.1	314.6
Seeding Agent per Day (kg)	6.1	5.6	2.9	3.6	5.5	10.4	5.4	4.6	6.7	9.3	5.9	7.6	5.2	4.7	2.4	6.3	8.3	8.5
Seeding Agent per Hour (kg)	0.97	1.00	0.60	0.60	0.80	1.30	0.90	0.80	1.10	1.20	1.00	1.10	0.90	1.00	0.84	1.10	1.13	1.16
Seeding Agent per Storm (kg)	2.2	2.2	1.0	0.7	1.3	2.5	2.0	2.3	2.2	3.0	2.3	3.3	2.4	2.2	1.6	2.2	3.0	2.7
Ejectable Flares	4610	3817	2376	2023	4439	9653	5225	3108	4465	6513	3770	4929	1622	1648	451	5837	10779	7717
BIP Flares	619	542	356	496	690	940	533	377	518	877	515	703	413	548	237	851	1020	914
Seeding Solution (gal)	154.6	80.5	144.3	193.8	297.5	141.3	140.8	80.3	92.6	132.7	94.2	145.4	77.0	113.5	56.5	227.5	350.2	260.3
Season Activity Rank	-	14	10	8	4	3	7	15	11	6	13	9	16	12	17	5	1	2

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 14, 2014
Proposed starting date: June 1st, 2014
Expected duration: September 15th, 2014

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermodification.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification, Inc. Tel. (403) 335-8359
Olds-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Mr. Daniel Gilbert, Chief Meteorologist
B.S., 11 years' experience
WMA Certified Weather Modification Operator #78
Office Tel: (403) 335-8359
(see Part 5 for details of qualifications and experience)

Director of Meteorology Mr. Bruce Boe
Project Manager/Meteorology, 40 years' experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermodification.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe

Weather Management Society and US$5 million by Weather Modification, Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996. The contractor (operator) for this entire period has been WMI.

b. Elsewhere:
- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 50 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Alberta, Burkina Faso, California, California, Idaho, Mexico, UAE, India, Indonesia, Mali, Nevada, North Dakota, Saudi Arabia, Senegal, and Wyoming within the last 10 years.

4. References:

1. Dr. Terry Krauss
   Krauss Weather Services
   79 Irving Crescent
   Red Deer, AB T4R 3S3 Tel. 403-318-0400
2. Mr. Darin Langerud, Director
   State of North Dakota Atmospheric Resource Board
   900 E. Boulevard Ave.
   Bismarck, ND 58505 Tel. 701-328-2788
3. Mr. James Renick
   Alberta Severe Weather Management Society (ret.)
   11 Warwick Drive
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
4. Dr. Paul L. Smith
   South Dakota School of Mines & Technology
   501 E. St. Joseph Street
   Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
todd.klapak@intact.net
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel. 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Springbank airport tel. 403-247-0001
- Red Deer industrial airport tel. 403-886-7857

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Daniel Gilbert, Chief Meteorologist
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359,
e-mail: dgilbert@weathermodifcation.com
home page: http://www.weathermodification.com/

Qualifications of field officer in charge (Gilbert):

Education
Bachelor of Science, Meteorology and Environmental Studies (double major) May 2004, Iowa State University, Ames, IA
Associate of Arts, Liberal Arts, May 2000, Iowa Central Community College, Fort Dodge, IA

Weather Modification Experience
Chief Meteorologist, Weather Modification, Inc. (Wyoming and Alberta) - November 2009 to present
Forecaster, radar operator, rawinsondes, direction of seeding aircraft. Case declarations, wintertime (Wyoming) research program.
Meteorologist, RHS Consulting (Fresno, CA) – November 2008-February 2009
Directed airborne and ground based cloud seeding operations over portions of the central and southern Sierra Nevada Mountains. Set up and performed routine maintenance of ground based ice nucleus generators. Provided daily forecasts for clients and project personnel.
Meteorologist, Independent Contractor, (Boise, ID) – October 2007 to April 2008
Provided meteorological services to support Idaho Power Company's winter cloud seeding project in West Central Idaho, directed airborne and ground seeding operations, directed rawinsonde releases, provided short-term operational forecasts and nowcasts for pilots, communicated with aircraft via two-way radio
Field Meteorologist, North Dakota Cloud Modification Project, (Stanley or Bowman, ND) – Summers, 2003-2009
Operated 5 cm weather radar equipped with TITAN software package, launched and directed seeding aircraft using two-way radio and GPS tracking, performed data recording and documentation of cloud seeding operations, prepared silver iodide seeding solution, assisted with radar calibrations, prepared forecasts and briefed pilots daily, supervised intern meteorologists, presented case studies for ground school, operated cloud condensation nuclei counter for joint research with South Dakota School of Mines
Forecaster, Atmospherics Incorporated, (Fresno, CA) - October 2006 - May 2007
Field Meteorologist, Atmospherics, Inc. (Modesto, CA) - November 2005 - April 2006
Field Meteorologist, Atmospherics, Inc. (Paso Robles, CA) - December 2004 - February 2005
Provided daily forecasts for seeding operations and/or clients, operated 5cm weather radar, directed winter cloud seeding operations over the Sierra Nevada utilizing both glaciogenic and

hygroscopic seeding agents, traced radar overlays, performed data recording of operations, wrote monthly and annual reports

Memberships and Honors

- Meteorologist Distinguished Service Award, 2013, Weather Modification Association
- Member, Weather Modification Association (certified operator #78)
- Member, American Meteorological Society
- Iowa Central Community College Honor Society, inducted April 27, 2000
- Wilbur E Brewer Professionalism Award, 2007 North Dakota Cloud Modification Project

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 12

Daily records of activities: Custodian = Ms. Erin Fischer
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Hailstorms in the City of Calgary caused >$500 Million in 2010 and again in 2012. In addition, hailstorms have caused >$100 Million damage to crops annually since 2007 and the damage to crops was >$400 Million in 2012. Hailstorms have now become a billion dollar problem to the economy of Alberta. The 20 largest insurance companies and their affiliates have banded together to conduct hail suppression operations in the "hail alley" of central Alberta to combat urban hail damage in the Calgary to Red Deer area. The current program has conducted cloud-seeding operations in central Alberta each summer since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. The insurance industry has been encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the first 10 years of the project indicated a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.
Approximate total cost: approx. $3.1 million per year.

Funds to be expended in Canada: est. $600,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

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Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude. Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5°C and -10°C. The pencil flares fall approximately 1.5 km (approximately 10°C) during their 35-40 second burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5°C and - 10°C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate

is used (e.g. 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.
A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gram of pyrotechnic, active at -10°C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gram flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:
- one WMI-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Three Beechcraft C90 King-Air prop-jet aircraft (two in Springbank and one in Red Deer).
- Two Cessna 340 aircraft (one in Springbank and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (ejectable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- A solution of acetone, silver iodide, sodium perchlorate, paradichlorobenzene, and ammonium iodide will also be burned for continuous seeding at cloud base. The products of combustion yield silver iodide (AgI) ice nuclei, carbon dioxide (CO_2), and water (H_2O).

Activation tests performed at Colorado State University indicate greater than10^{14} ice crystals per gram of seeding agent burned, active at -10°C.

Total flight hours and quantities to be dispersed: We estimate the project may use 5000 twenty-gram flares and 500 one hundred-fifty gram flares, plus approximately 150 gallons of the seeding solution (2% AgI by volume) will be burned. The number of operational days, flights, and amount of seeding material dispensed over the past fifteen years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far, far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Three C90 King Air prop-jet aircraft, two in Springbank (N904DK and N518TS) and one based in Red Deer (N522JP).
- Two Cessna 340 aircraft, one in Springbank (N457DM) and one in Red Deer (N98585).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

TEMPERATURE INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract.

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
President, Alberta Severe Weather Management Society
(403) 231-1357, Todd.Klapak@intact.net

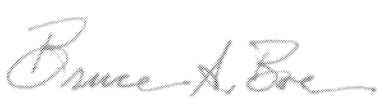
Signature: Date: May 14, 2014

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer:
Bruce A. Boe
Director of Meteorology
(701) 235-5500



Signature: Date: May 14, 2014

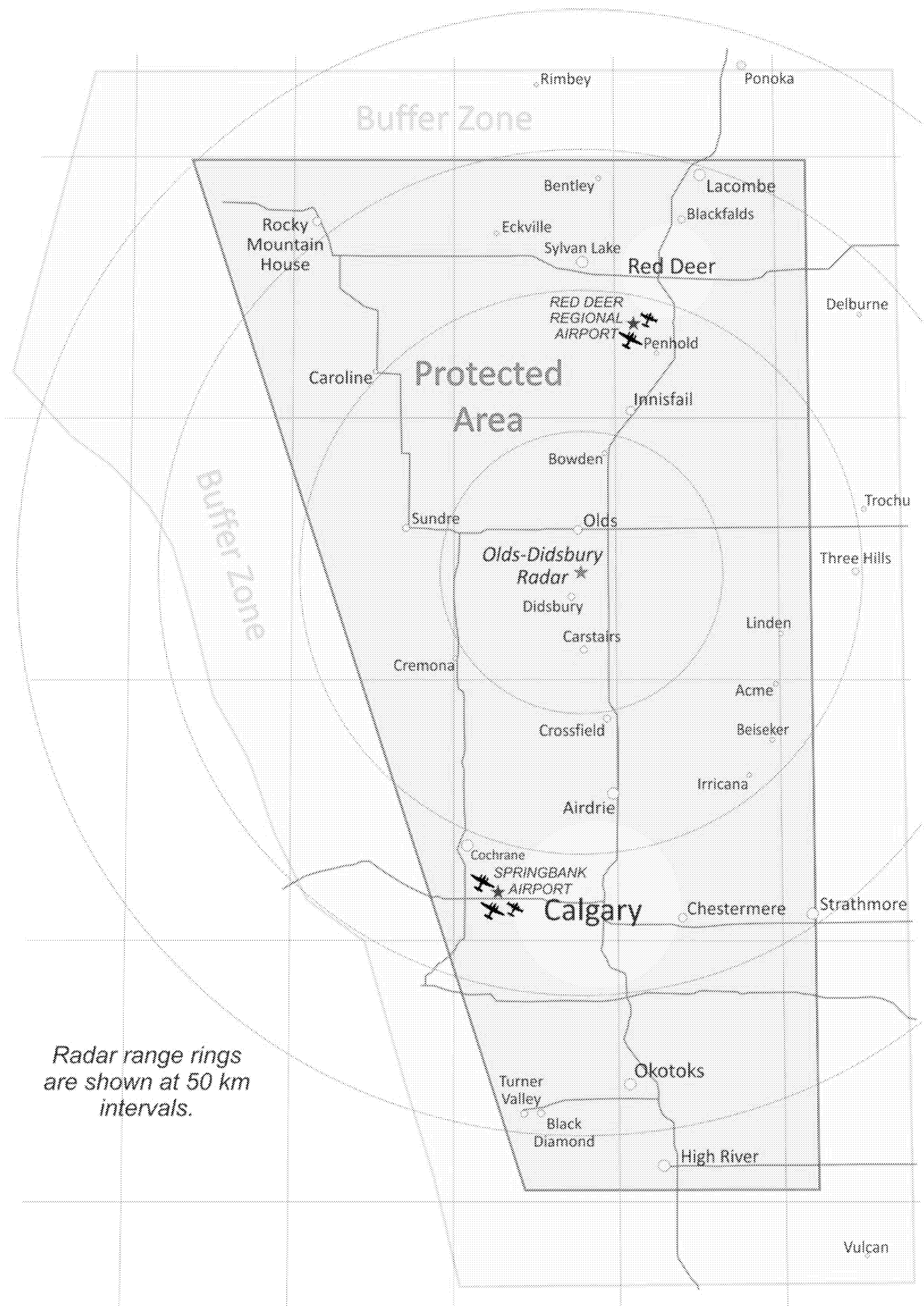


Figure 1: Map of south-central Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2013.

Table 1. Seeding Activity by Season

Season	*Storm Days With Seeding*	*Aircraft Missions (Seeding & Patrol)*	*Total Flight Time (hours)*	*Number of Storms Seeded*	*Total Seeding Agent (kg)*	*Seeding Agent Per Day (kg)*	*Seeding Agent Per Hour (kg)*	*Seeding Agent Per Storm (kg)*	*Ejectable Flares*	*Burn-in-place Flares*	*Seeding Solutions (gallons)*	*Season Activity Rank*
2013	26	103	229.6	70	233.3	9.0	1.02	3.33	6311	636	131.7	9
Mean	31.2	101.2	209.0	91.9	197.8	6.2	0.97	2.24	4705	620	153.3	
2012	37	143	300.1	116	314.6	8.5	1.16	2.70	7717	914	260.3	2
2011	48	158	383.0	134	400.1	8.3	1.13	3.00	10779	1020	350.2	1
2010	42	115	271.8	118	263.8	6.3	1.10	2.20	5837	851	227.5	5
2009	20	38	109.3	30	48.4	2.4	0.84	1.60	451	237	56.5	18
2008	26	112	194.7	56	122.9	4.7	1.00	2.20	1648	548	113.5	13
2007	19	76	115.3	41	99.7	5.2	0.90	2.40	1622	413	77	17
2006	28	92	190.2	65	214	7.6	1.10	3.30	4929	703	145.4	9
2005	27	80	157.9	70	159.1	5.9	1.00	2.30	3770	515	94.2	14
2004	29	105	227.5	90	270.9	9.3	1.20	3.00	6513	877	132.7	6
2003	26	92	163.6	79	173.4	6.7	1.10	2.20	4465	518	92.6	12
2002	27	92	157.4	54	124.2	4.6	0.80	2.30	3108	377	80.3	16
2001	36	109	208.3	98	195	5.4	0.90	2.00	5225	533	140.8	7
2000	33	130	265.2	136	343.8	10.4	1.30	2.50	9653	940	141.3	3
1999	39	118	251.3	162	212.7	5.5	0.80	1.30	4439	690	297.5	4
1998	31	96	189.9	153	111.1	3.6	0.60	0.70	2023	496	193.8	8
1997	38	92	188.1	108	110.8	2.9	0.60	1.00	2376	356	144.3	11
1996	29	71	159.1	75	163.3	5.6	1.00	2.20	3817	542	80.5	15

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 18, 2015
Proposed starting date: June 1st, 2015
Expected duration: September 15th, 2015

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermodification.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification, Inc. Tel. (403) 335-8359
Olds-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Mr. Daniel Gilbert, Chief Meteorologist
B.S., 12 years' experience
WMA Certified Weather Modification Operator #78
Office Tel: (403) 335-8359
(see Part 5 for details of qualifications and experience)

Vice President - Meteorology Mr. Bruce Boe
Project Manager/Meteorology, 41 years' experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermodification.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe Weather Management Society and US$5 million by Weather Modification, Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996. The contractor (operator) for this entire period has been WMI.

b. Elsewhere:
   - WMI has conducted the hail suppression cloud seeding in North Dakota for more than 50 years. This is an ongoing project.
   - WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
   - WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
   - WMI has conducted operational cloud seeding in Alberta, Burkina Faso, California, Idaho, Mexico, UAE, India, Indonesia, Mali, Nevada, North Dakota, Saudi Arabia, Senegal, and Wyoming within the last 10 years.

4. References:
   1. Dr. Terry Krauss
      Krauss Weather Services
      79 Irving Crescent
      Red Deer, AB T4R 3S3 Tel. 403-318-0400
   2. Mr. Darin Langerud, Director
      State of North Dakota Atmospheric Resource Board
      900 E. Boulevard Ave.
      Bismarck, ND 58505 Tel. 701-328-2788
   3. Mr. James Renick
      Alberta Severe Weather Management Society (ret.)
      11 Warwick Drive
      Red Deer, AB T4N 6L4 Tel. 403-347-1545
   4. Dr. Paul L. Smith
      South Dakota School of Mines & Technology
      501 E. St. Joseph Street
      Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
todd.klapak@intact.net
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel. 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Springbank airport tel. 403-247-0001
- Red Deer industrial airport tel. 403-886-7857

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Daniel Gilbert, Chief Meteorologist
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359,
e-mail: dgilbert@weathermodifcation.com
home page: http://www.weathermodification.com/

Qualifications of field officer in charge (Gilbert):

Education
Bachelor of Science, Meteorology and Environmental Studies (double major) May 2004, Iowa State University, Ames, IA
Associate of Arts, Liberal Arts, May 2000, Iowa Central Community College, Fort Dodge, IA

Weather Modification Experience
Chief Meteorologist, Weather Modification, Inc. (Wyoming and Alberta) - November 2009 to present
Forecaster, radar operator, rawinsondes, direction of seeding aircraft. Case declarations, wintertime (Wyoming) research program.
Meteorologist, RHS Consulting (Fresno, CA) – November 2008-February 2009
Directed airborne and ground based cloud seeding operations over portions of the central and southern Sierra Nevada Mountains. Set up and performed routine maintenance of ground based ice nucleus generators. Provided daily forecasts for clients and project personnel.
Meteorologist, Independent Contractor, (Boise, ID) – October 2007 to April 2008
Provided meteorological services to support Idaho Power Company's winter cloud seeding project in West Central Idaho, directed airborne and ground seeding operations, directed rawinsonde releases, provided short-term operational forecasts and nowcasts for pilots, communicated with aircraft via two-way radio
Field Meteorologist, North Dakota Cloud Modification Project, (Stanley or Bowman, ND) – Summers, 2003-2009
Operated 5 cm weather radar equipped with TITAN software package, launched and directed seeding aircraft using two-way radio and GPS tracking, performed data recording and documentation of cloud seeding operations, prepared silver iodide seeding solution, assisted with radar calibrations, prepared forecasts and briefed pilots daily, supervised intern meteorologists, presented case studies for ground school, operated cloud condensation nuclei counter for joint research with South Dakota School of Mines
Forecaster, Atmospherics Incorporated, (Fresno, CA) - October 2006 - May 2007
Field Meteorologist, Atmospherics, Inc. (Modesto, CA) - November 2005 - April 2006
Field Meteorologist, Atmospherics, Inc. (Paso Robles, CA) - December 2004 - February 2005
Provided daily forecasts for seeding operations and/or clients, operated 5cm weather radar, directed winter cloud seeding operations over the Sierra Nevada utilizing both glaciogenic and hygroscopic seeding agents, traced radar overlays, performed data recording of operations, wrote monthly and annual reports

Memberships and Honors

- Meteorologist Distinguished Service Award, 2013, Weather Modification Association
- Member, Weather Modification Association (certified operator #78)
- Member, American Meteorological Society
- Iowa Central Community College Honor Society, inducted April 27, 2000
- Wilbur E Brewer Professionalism Award, 2007 North Dakota Cloud Modification Project

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 12

Daily records of activities: Custodian = Ms. Erin Fischer
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Hailstorms in the City of Calgary caused >$500 Million in 2010 and again in 2012. In addition, hailstorms have caused >$100 Million damage to crops annually since 2007 and the damage to crops was >$400 Million in 2012. Hailstorms have now become a billion dollar problem to the economy of Alberta. The 20 largest insurance companies and their affiliates have banded together to conduct hail suppression operations in the “hail alley” of central Alberta to combat urban hail damage in the Calgary to Red Deer area. The current program has conducted cloud-seeding operations in central Alberta each summer since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. The insurance industry has been encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the first 10 years of the project indicated a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer,

Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.
Approximate total cost: approx. $3.1 million per year.

Funds to be expended in Canada: est. $600,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

<u>OVERVIEW OF METHOD</u>
For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5°C temperature level, and are considered to be a potential hail threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI-solution burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

<u>HAIL SUPPRESSION HYPOTHESIS</u>
The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave

unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5°C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude. Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5°C and -10°C. The pencil flares fall approximately 1.5 km (approximately 10°C) during their 35-40 second burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5°C and - 10°C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g. 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gram of pyrotechnic, active at -10°C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gram flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one Advanced Radar Corporation C-band Doppler weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Three Beechcraft C90 King-Air prop-jet aircraft (two in Springbank and one in Red Deer).
- Two Cessna 340 aircraft (one in Springbank and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (ejectable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- A solution of acetone, silver iodide, sodium perchlorate, paradichlorobenzene, and ammonium iodide will also be burned for continuous seeding at cloud base. The products of combustion yield silver iodide (AgI) ice nuclei, carbon dioxide (CO_2), and water (H_2O).

Activation tests performed at Colorado State University indicate greater than10^{14} ice crystals per gram of seeding agent burned, active at -10°C.

Total flight hours and quantities to be dispersed: We estimate the project may use 5000 twenty-gram flares and 500 one hundred-fifty gram flares, plus approximately 150 gallons of the seeding solution (2% AgI by volume) will be burned. The number of operational days, flights, and amount of seeding material dispensed over the past fifteen years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in

precipitation (above background levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far, far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Three C90 King Air prop-jet aircraft, two in Springbank (N904DK and N518TS) and one based in Red Deer (N522JP).
- Two Cessna 340 aircraft, one in Springbank (N457DM) and one in Red Deer (N37356).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

TEMPERATURE INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract.

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
President, Alberta Severe Weather Management Society
(403) 231-1357, Todd.Klapak@intact.net

Signature: Date: May 18, 2015

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer:
Bruce A. Boe
Vice President of Meteorology
(701) 235-5500

Bruce A. Boe

Signature: Date: May 18, 2015

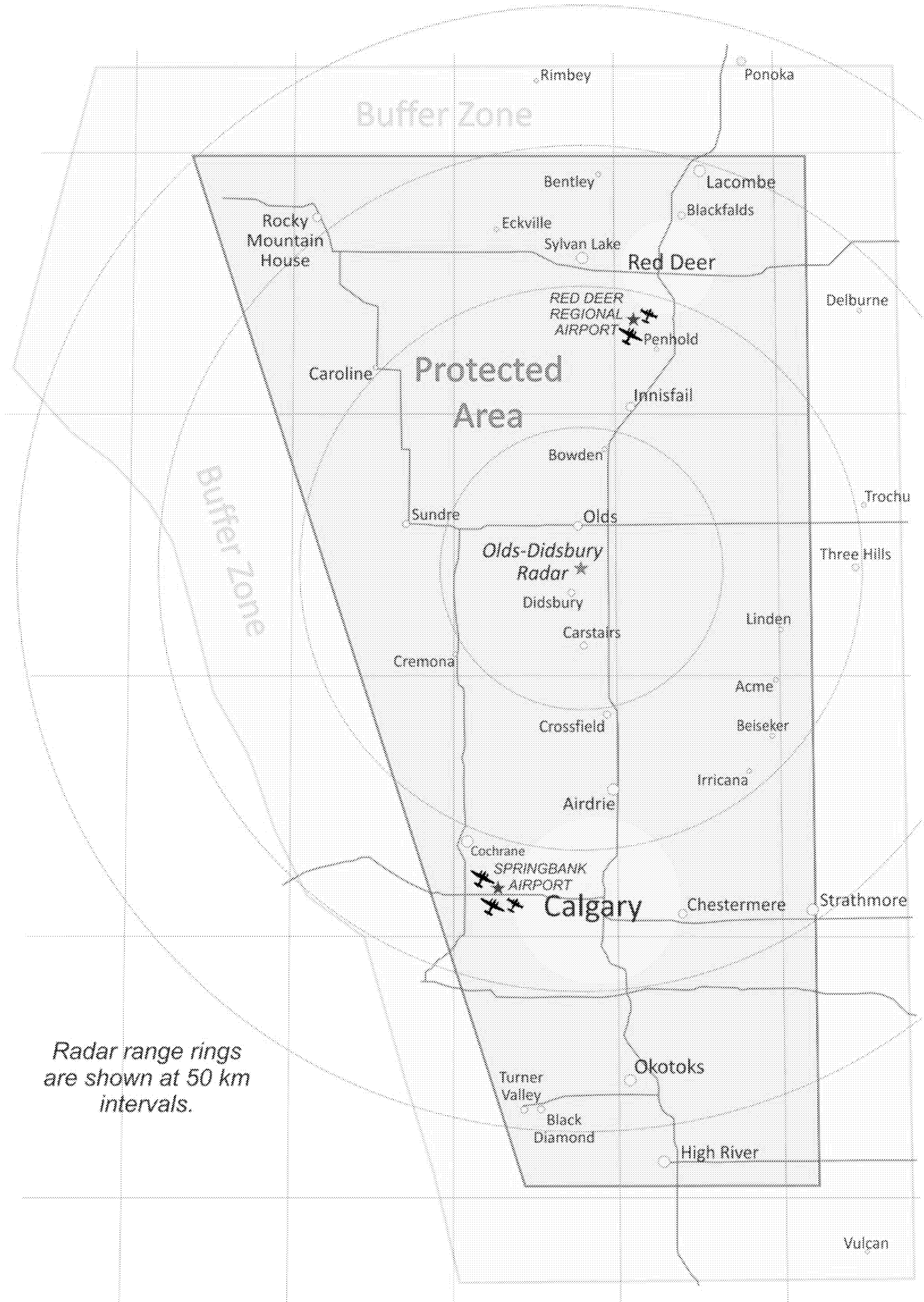


Figure 1: Map of south-central Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2014.

Seeding Activity by Season												
Season	**Storm Days With Seeding**	**Aircraft Missions (Seeding & Patrol)**	**Total Flight Time (hours)**	**Number of Storms Seeded**	**Total Seeding Agent (kg)**	**Seeding Agent Per Day (kg)**	**Seeding Agent Per Hour (kg)**	**Seeding Agent Per Storm (kg)**	**Ejectable Flares**	**Burn-in-place Flares**	**Seeding Solutions (gallons)**	**Season Activity Rank**
2014	32	128	259.5	101	382.5	12.0	1.47	3.79	10782	1020	228.6	3
Mean	31.2	102.6	211.7	92.4	207.6	6.5	1.00	2.32	5024.5	641.4	157.3	
2013	26	103	229.6	70	233.3	9.0	1.02	3.33	6311	636	131.7	10
2012	37	143	300.1	116	314.6	8.5	1.16	2.70	7717	914	260.3	2
2011	48	158	383.0	134	400.1	8.3	1.13	3.00	10779	1020	350.2	1
2010	42	115	271.8	118	263.8	6.3	1.10	2.20	5837	851	227.5	6
2009	20	38	109.3	30	48.4	2.4	0.84	1.60	451	237	56.5	19
2008	26	112	194.7	56	122.9	4.7	1.00	2.20	1648	548	113.5	14
2007	19	76	115.3	41	99.7	5.2	0.90	2.40	1622	413	77	18
2006	28	92	190.2	65	214	7.6	1.10	3.30	4929	703	145.4	11
2005	27	80	157.9	70	159.1	5.9	1.00	2.30	3770	515	94.2	15
2004	29	105	227.5	90	270.9	9.3	1.20	3.00	6513	877	132.7	7
2003	26	92	163.6	79	173.4	6.7	1.10	2.20	4465	518	92.6	13
2002	27	92	157.4	54	124.2	4.6	0.80	2.30	3108	377	80.3	17
2001	36	109	208.3	98	195	5.4	0.90	2.00	5225	533	140.8	8
2000	33	130	265.2	136	343.8	10.4	1.30	2.50	9653	940	141.3	4
1999	39	118	251.3	162	212.7	5.5	0.80	1.30	4439	690	297.5	5
1998	31	96	189.9	153	111.1	3.6	0.60	0.70	2023	496	193.8	9
1997*	38	92	188.1	108	110.8	2.9	0.60	1.00	2376	356	144.3	12
1996*	29	71	159.1	75	163.3	5.6	1.00	2.20	3817	542	80.5	16
**The 1996 and 1997 seasons began on June 15, not June 1, which has been the norm ever since.*												

NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 18, 2016
Proposed starting date: June 1st, 2016
Expected duration: September 15th, 2016

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermodification.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Neil Brackin, President Tel: (701) 235-5500
nbrackin@weathermod.com
Local Organization: Weather Modification, Inc. Tel. (403) 335-8359
Olds-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Mr. Daniel Gilbert, Chief Meteorologist
B.S., 13 years' experience
WMA Certified Weather Modification Operator #78
Office Tel: (403) 335-8359
(see Part 5 for details of qualifications and experience)

Vice President - Meteorology Mr. Bruce Boe
Project Manager/Meteorology, 42 years' experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermodification.com):
- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe Weather Management Society and US$5 million by Weather Modification, Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996. The contractor (operator) for this entire period has been WMI.

b. Elsewhere:
- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 50 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Alberta, Burkina Faso, California, Idaho, Mexico, UAE, India, Indonesia, Mali, Nevada, North Dakota, Saudi Arabia, Senegal, and Wyoming within the last 10 years.

4. References:

1. Dr. Terry Krauss
   Krauss Weather Services
   79 Irving Crescent
   Red Deer, AB T4R 3S3 Tel. 403-318-0400
2. Mr. Darin Langerud, Director
   State of North Dakota Atmospheric Resource Board
   900 E. Boulevard Ave.
   Bismarck, ND 58505 Tel. 701-328-2788
3. Dr. Ronald E. Rinehart
   4408 Greystone Drive
   St. Joseph, MO 64505 Tel. 816-233-1394
4. Dr. Paul L. Smith
   South Dakota School of Mines & Technology
   501 E. St. Joseph Street
   Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services. Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
todd.klapak@intact.net
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel. 403-335-8359
Address(es) and locations(s) of project secondary field base(s):

- Springbank airport tel. 403-247-0001
- Red Deer industrial airport tel. 403-886-7857

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Daniel Gilbert, Chief Meteorologist
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359,
e-mail: dgilbert@weathermodifcation.com
home page: http://www.weathermodification.com/

Qualifications of field officer in charge (Gilbert):

Education
Bachelor of Science, Meteorology and Environmental Studies (double major) May 2004, Iowa State University, Ames, IA
Associate of Arts, Liberal Arts, May 2000, Iowa Central Community College, Fort Dodge, IA

Weather Modification Experience
Chief Meteorologist, Weather Modification, Inc. (Wyoming and Alberta) - November 2009 to present
Forecaster, radar operator, rawinsondes, direction of seeding aircraft. Case declarations, wintertime (Wyoming) research program.
Meteorologist, RHS Consulting (Fresno, CA) – November 2008-February 2009
Directed airborne and ground based cloud seeding operations over portions of the central and southern Sierra Nevada Mountains. Set up and performed routine maintenance of ground based ice nucleus generators. Provided daily forecasts for clients and project personnel.
Meteorologist, Independent Contractor, (Boise, ID) – October 2007 to April 2008
Provided meteorological services to support Idaho Power Company's winter cloud seeding project in West Central Idaho, directed airborne and ground seeding operations, directed rawinsonde releases, provided short-term operational forecasts and nowcasts for pilots, communicated with aircraft via two-way radio
Field Meteorologist, North Dakota Cloud Modification Project, (Stanley or Bowman, ND) – Summers, 2003-2009
Operated 5 cm weather radar equipped with TITAN software package, launched and directed seeding aircraft using two-way radio and GPS tracking, performed data recording and documentation of cloud seeding operations, prepared silver iodide seeding solution, assisted with radar calibrations, prepared forecasts and briefed pilots daily, supervised intern meteorologists, presented case studies for ground school, operated cloud condensation nuclei counter for joint research with South Dakota School of Mines
Forecaster, Atmospherics Incorporated, (Fresno, CA) - October 2006 - May 2007
Field Meteorologist, Atmospherics, Inc. (Modesto, CA) - November 2005 - April 2006
Field Meteorologist, Atmospherics, Inc. (Paso Robles, CA) - December 2004 - February 2005
Provided daily forecasts for seeding operations and/or clients, operated 5cm weather radar, directed winter cloud seeding operations over the Sierra Nevada utilizing both glaciogenic and hygroscopic seeding agents, traced radar overlays, performed data recording of operations, wrote monthly and annual reports

Memberships and Honors

- Meteorologist Distinguished Service Award, 2013, Weather Modification Association
- Member, Weather Modification Association (certified operator #78)
- Member, American Meteorological Society
- Iowa Central Community College Honor Society, inducted April 27, 2000
- Wilbur E Brewer Professionalism Award, 2007 North Dakota Cloud Modification Project

Field Address:	Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no.	403-335-8359
Field personnel:	full time = 3
	part time = 14

Daily records of activities: Custodian = Ms. Erin Fischer
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Hailstorms in the City of Calgary caused >$500 Million in 2010 and again in 2012. In addition, hailstorms have caused >$100 Million damage to crops annually since 2007 and the damage to crops was >$400 Million in 2012. Hailstorms have now become a billion dollar problem to the economy of Alberta. The 20 largest insurance companies and their affiliates have banded together to conduct hail suppression operations in the "hail alley" of central Alberta to combat urban hail damage in the Calgary to Red Deer area. The current program has conducted cloud-seeding operations in central Alberta each summer since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. The insurance industry has been encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the first 10 years of the project indicated a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer,

Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.
Approximate total cost: approx. $3.1 million per year.

Funds to be expended in Canada: est. $600,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5°C temperature level, and are considered to be a potential hail threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI-solution burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave

unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5°C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude. Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5°C and -10°C. The pencil flares fall approximately 1.5 km (approximately 10°C) during their 35-40 second burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5°C and - 10°C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate is used (e.g. 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.

A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Wing-tip seeding solution burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

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Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gram flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one Advanced Radar Corporation C-band Doppler weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Three Beechcraft C90 King-Air prop-jet aircraft (two in Springbank and one in Red Deer).
- Two Cessna 340 aircraft (one in Springbank and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (ejectable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
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- A solution of acetone, silver iodide, sodium perchlorate, paradichlorobenzene, and ammonium iodide will also be burned for continuous seeding at cloud base. The products of combustion yield silver iodide (AgI) ice nuclei, carbon dioxide (CO_2), and water (H_2O).

Activation tests performed at Colorado State University indicate greater than10^{14} ice crystals per gram of seeding agent burned, active at -10°C.

Total flight hours and quantities to be dispersed: We estimate the project may use 5000 twenty-gram flares and 500 one hundred-fifty gram flares, plus approximately 150 gallons of the seeding solution (2% AgI by volume) will be burned. The number of operational days, flights, and amount of seeding material dispensed over the past fifteen years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in

precipitation (above background levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far, far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Three C90 King Air prop-jet aircraft, two in Springbank (N904DK and N518TS) and one based in Red Deer (N522JP).
- Two Cessna 340 aircraft, one in Springbank (N457DM) and one in Red Deer (N37356).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be deployed for the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

TEMPERATURE INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from the U.S. National Center for Atmospheric Research (NCAR).

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract.

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

~~Todd Klapak~~ KEN DE DECKER, BOARD MEMBER.
~~President~~, Alberta Severe Weather Management Society
~~(403) 231-1357, Todd.Klapak@intact.net~~
403-231-1300 KEN.DEDECKER@INTACT.NET.

Signature: Date: May 18, 2016

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer:
Bruce A. Boe
Vice President of Meteorology
(701) 235-5500

Bruce A. Boe

Signature: Date: May 18, 2016

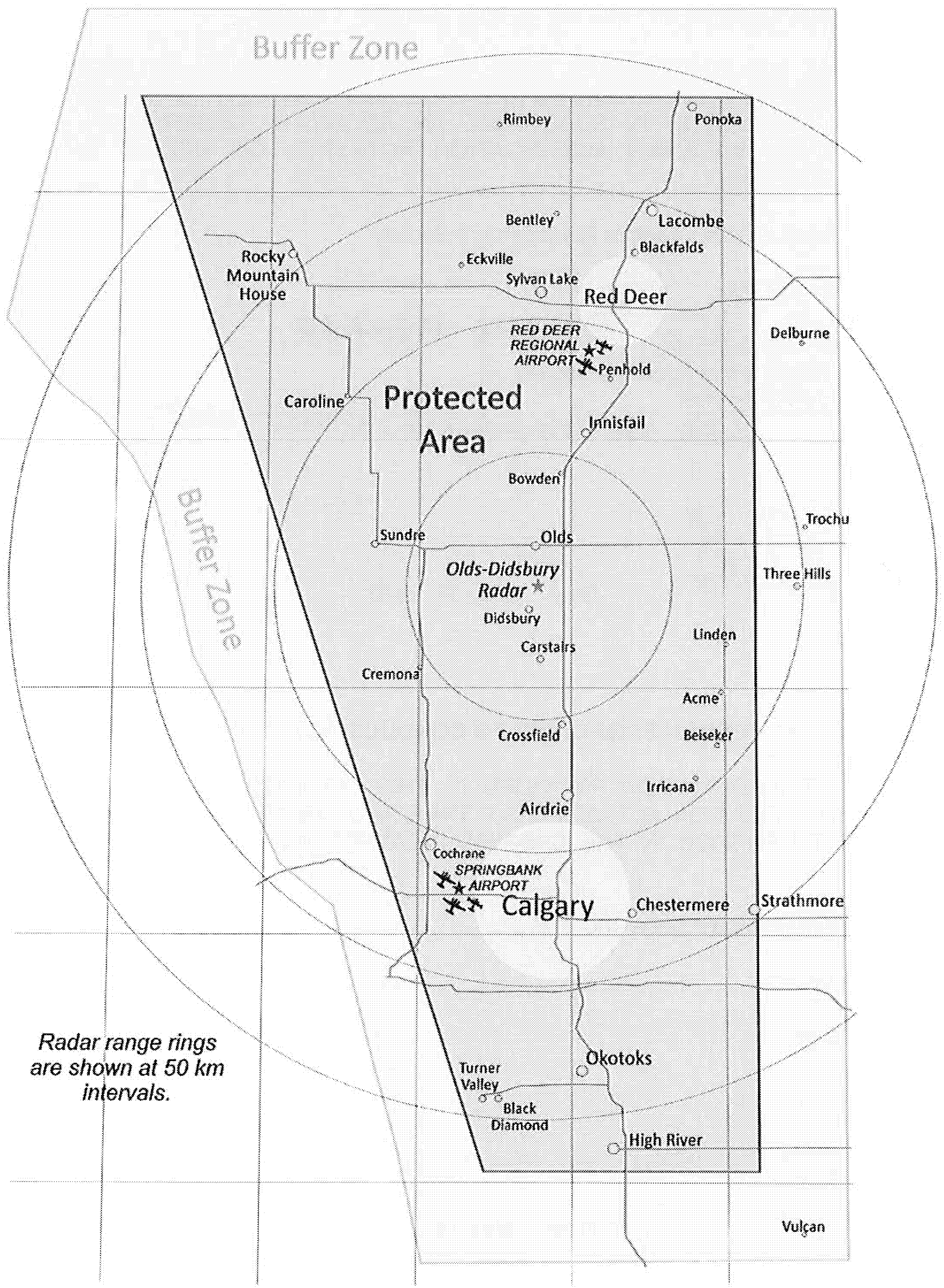

Figure 1: Map of south-central Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

Table 1: Operational Statistics for 1996 to 2015.

Seeding Activity by Season												
Season	*Storm Days With Seeding*	*Aircraft Missions (Seeding & Patrol)*	*Total Flight Time (hours)*	*Number of Storms Seeded*	*Total Seeding Agent (kg)*	*Seeding Agent Per Day (kg)*	*Seeding Agent Per Hour (kg)*	*Seeding Agent Per Storm (kg)*	*Ejectable Flares*	*Burn-in-place Flares*	*Seeding Solutions (gallons)*	*Season Activity Rank*
2015	25	117	233.3	79	349.2	14.6	1.37	4.42	8127	1138	262.9	6
Mean	30.9	103.4	212.8	91.8	214.6	6.9	1.02	2.4	5179.6	666.2	162.6	
2014	32	128	259.5	101	382.5	12.0	1.47	3.79	10782	1020	228.6	3
2013	26	103	229.6	70	233.3	9.0	1.02	3.33	6311	636	131.7	10
2012	37	143	300.1	116	314.6	8.5	1.16	2.70	7717	914	260.3	2
2011	48	158	383.0	134	400.1	8.3	1.13	3.00	10779	1020	350.2	1
2010	42	115	271.8	118	263.8	6.3	1.10	2.20	5837	851	227.5	7
2009	20	38	109.3	30	48.4	2.4	0.84	1.60	451	237	56.5	20
2008	26	112	194.7	56	122.9	4.7	1.00	2.20	1648	548	113.5	15
2007	19	76	115.3	41	99.7	5.2	0.90	2.40	1622	413	77	19
2006	28	92	190.2	65	214	7.6	1.10	3.30	4929	703	145.4	12
2005	27	80	157.9	70	159.1	5.9	1.00	2.30	3770	515	94.2	16
2004	29	105	227.5	90	270.9	9.3	1.20	3.00	6513	877	132.7	8
2003	26	92	163.6	79	173.4	6.7	1.10	2.20	4465	518	92.6	14
2002	27	92	157.4	54	124.2	4.6	0.80	2.30	3108	377	80.3	18
2001	36	109	208.3	98	195	5.4	0.90	2.00	5225	533	140.8	9
2000	33	130	265.2	136	343.8	10.4	1.30	2.50	9653	940	141.3	4
1999	39	118	251.3	162	212.7	5.5	0.80	1.30	4439	690	297.5	5
1998	31	96	189.9	153	111.1	3.6	0.60	0.70	2023	496	193.8	11
1997*	38	92	188.1	108	110.8	2.9	0.60	1.00	2376	356	144.3	13
1996*	29	71	159.1	75	163.3	5.6	1.00	2.20	3817	542	80.5	17

**The 1996 and 1997 seasons began on June 15, not June 1, which has been the norm ever since.*

s.19(1)

Jatar, Muriel (EC)

From:
Sent: November 22, 2013 4:26 PM
To: Cober, Stewart (EC)
Cc: 'George Isaac'
Subject: FW: Alberta Weather Modification
Attachments: AlbertaHailProject2007.pdf

Stewart,

Opps. I used our family e-mail address instead of the one. I read e-mail from both but the one does not get bothered with.

George

____
George Isaac

Telephone:
E-Mail:

From:
Sent: November 22, 2013 4:15 PM
To: Stewart Cober (stewart.cober@ec.gc.ca)
Subject: Alberta Weather Modification

Stewart,

I think you can find most of what you need in this CMOS Bulletin Article describing the early days in Alberta. It does not reference my stuff or all the unique material we did on nucleation, but it should be good for your purposes.

There is a new Linkedin page on the Alberta Hail Project and I simply asked if anyone had a review article and Bob Kochtubajda pointed out this one.

George

____
George Isaac

Telephone:
E-Mail:

ISSN 1195-8898

CMOS BULLETIN SCMO

Canadian Meteorological and Oceanographic Society

La Société canadienne de météorologie et d'océanographie

September / septembre 2007
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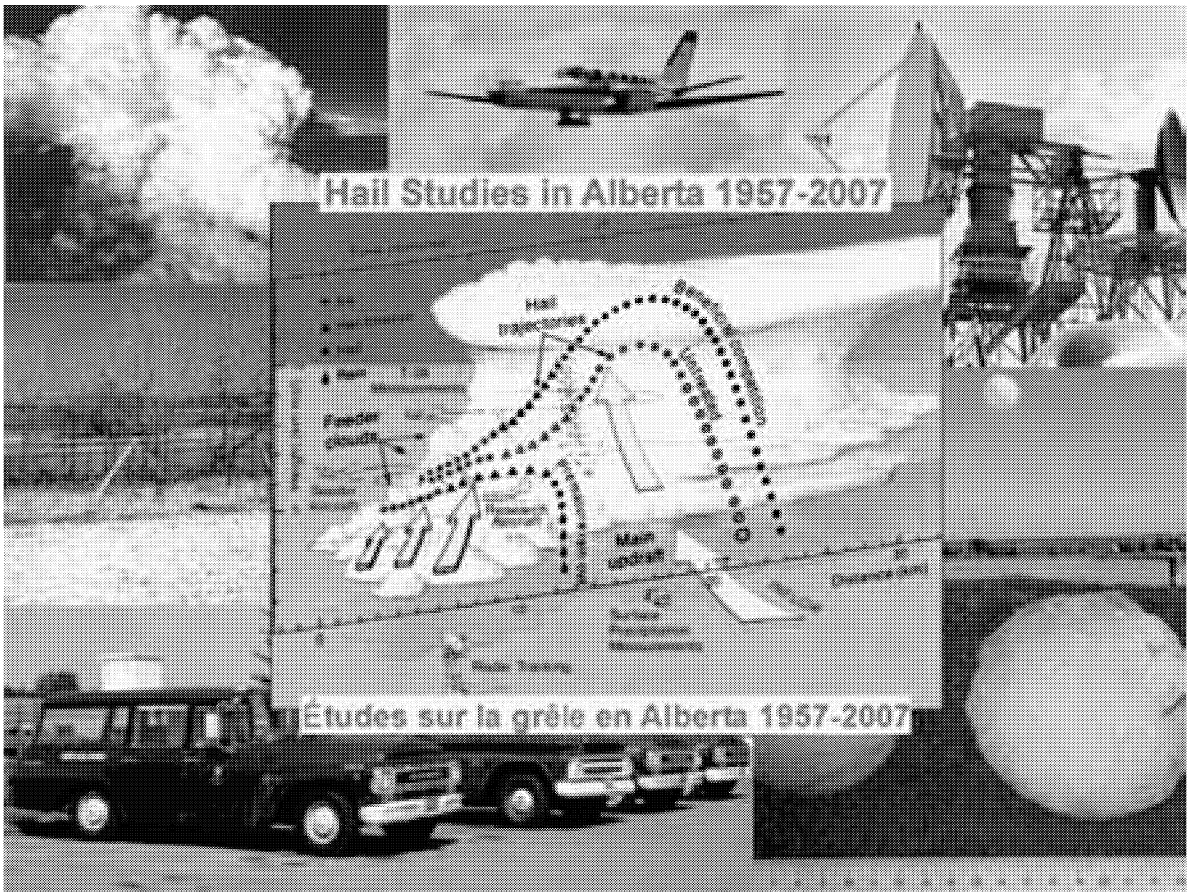

ALHAS ➠ AHP ➠ UNSTABLE

003106

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... from the *CMOS Bulletin SCMO* Editorial Board

Dear readers,

The *CMOS Bulletin SCMO* Editorial Board is pleased to join the scientific team celebrating this year 50 years in studying hail in Alberta. This scientific team, whose members have varied throughout the years, come from different universities, McGill University, University of Alberta, l'Université du Québec à Montréal, University of Wyoming, USA, and University of Essex, UK, and from different government organizations, federal and provincial. The impact of hail storms is catastrophic on this Canadian region and has economic consequences on major crops. The Editorial Board thought that, because of the importance of the study and of its longevity, it deserves a special publication. This special issue of the *CMOS Bulletin SCMO* provides an historical synopsis of this scientific adventure. It also lists its major accomplishments. Furthermore, it looks at the future in presenting a new study, now at an advance stage of planning, the UNSTABLE project.

We hope that you will enjoy reading this special issue and we look forward to reading your comments in a future issue of the *CMOS Bulletin SCMO*.

CMOS Bulletin SCMO Editorial Board

... du comité éditorial du *CMOS Bulletin SCMO*

Chers lecteurs,

L'équipe éditoriale du *CMOS Bulletin SCMO* est fière de se joindre à l'équipe scientifique qui célèbre cette année 50 ans de recherche sur un problème météorologique particulier, la grêle en Alberta. Cette équipe scientifique, dont les membres ont varié au cours des années, provient de milieux universitaires multiples: l'université McGill, l'université de l'Alberta, l'université du Québec à Montréal, l'université du Wyoming, États-Unis et l'université d'Essex au Royaume-Uni, et de différentes organisations gouvernementales, fédérale et provinciales. L'impact de la grêle sur cette région canadienne est catastrophique et a des répercussions économiques sur les principales récoltes. L'équipe éditoriale a donc jugé bon de publier ces textes en un numéro spécial étant donné l'importance du sujet traité et de sa longévité. Ce numéro spécial du *CMOS Bulletin SCMO* relate l'historique de cette brillante aventure scientifique. Il en énumère les accomplissements les plus significatifs. Et il jette un regard sur l'avenir en mettant en vedette une étude qui est présentement à un étape avancée de la planification, le projet UNSTABLE.

Nous souhaitons que vous apprécierez ce numéro spécial et il nous fera plaisir de lire vos commentaires dans un prochain numéro du *CMOS Bulletin SCMO*.

Comité éditorial du CMOS Bulletin SCMO

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Volume 35 Special Issue
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Inside / En Bref

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Le but de la SCMO est de stimuler l'intérêt pour la météorologie et l'océanographie au Canada.

CMOS Bulletin SCMO
"at the service of its members / au service de ses membres"

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Cover page : The composite picture on the front cover shows an artistic rendering of the conceptual model of seeding multi-cellular hailstorms (centre). Also shown, clockwise from top left are: the giant hailstorm photo of 11 August 1972 (Goyer 1978); INTERA-ARC research Aircraft; AHP S-, X-, and C-Band radars; radiosonde balloon release; tennis-ball size hailstone from 6 July 1975; *Project Hailstop* storm-chase vehicles; and hail-flattened crop (100% damage with trees 'defoliated' in background). Also appearing is the logo for project UNSTABLE. For more information on hail studies in Alberta, please read the two articles on **pages 3 and 20**.

Page couverture: La composition centrale de la page couverture est une interprétation artistique du modèle conceptuel de l'ensemencement de tempêtes de grêle multi-cellulaires. On voit aussi, dans le sens anti-cyclonique commençant en haut à gauche de la photo, la fameuse tempête de grêle géante du 11 août 1972; l'avion de recherche de INTERA-ARC; les radars en bandes AHP S-, X- et C; un lancement de ballon radiosonde; des grêlons de la taille de balles de tennis du 6 juillet 1975; les véhicules de poursuite de tempête de grêle du *projet Hailstop*; ainsi qu'une récolte abattue par la grêle (100% de dommage avec arbres défoilés en arrière-plan). On montre également le logo du projet UNSTABLE. Pour plus d'information sur ces deux études de grêle en Alberta, prière de lire les articles en **pages 3 et 20**.

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50th Anniversary of Hail Studies in Alberta Accomplishments and Legacy

by G.S. Strong[1], B. Kochtubajda[2], P.W. Summers[3],
J.H. Renick[4], T.W. Krauss[5],
R.G. Humphries[6] and E.P. Lozowski[7]

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[2] MSC, Environment Canada, Edmonton, AB *(1975-1986)*	[5] Weather Modification Inc., Red Deer, AB *(1974-1976, 1978-84)*
[3] Richmond Hill, ON *(1963-1973)*	[6] Richmond, BC *(1970-1972, 1974-1986)*
	[7] Edmonton, AB *(1972-1980)*

Note: In the above table, the years in parentheses after each author's location denote their participation on ALHAS, AHP, or AWMB.

ABSTRACT: This year marks the 50th anniversary of the start of hail studies in Alberta. There were two major projects during this period involving several agencies, the one constant being Alberta Research Council (ARC). The McGill University Stormy Weather Group, with federal funding support, was prominent in the early period, but phased out as weather modification emphasis increased after 1969. The radar facilities were originally provided and operated by the National Research Council. By 1973 the funding was provided mainly by Alberta Agriculture and ARC and continued until the field studies ended in 1985. This article provides a historical synopsis, summarizing the observational methods and many of the scientific accomplishments. Finally, the legacy of the hail studies in terms of research programs since 1985 is discussed. Full details of the scientific results can be found in the large body of published literature.

RÉSUMÉ: Cette année marque le 50ième anniversaire du début des études de grêle en Alberta. Pendant cette période, deux projets importants impliquaient plusieurs agences dont le fidèle Conseil de recherche de l'Alberta (l'ARC). Le groupe universitaire McGill sur la météorologie des tempêtes, avec le soutien financier du fédéral, était proéminent dans la première période, mais s'est désisté peu à peu avec l'accentuation en 1969 sur la modification du temps. À l'origine, l'équipement radar a été fourni et opéré par le Conseil national de recherche. À partir de 1973, le financement a été fourni surtout par le ministère de l'agriculture de l'Alberta et l'ARC et a continué jusqu'à la fin des études sur le terrain en 1985. Cet article présente un exposé historique, en énumérant les méthodes d'observations, et rappelle plusieurs accomplissements scientifiques réussis. Finalement, le legs des études de grêle en tant que programmes de recherche depuis 1985 est discuté. Les détails complets des résultats scientifiques peuvent être trouvés dans la littérature publiée.

1. Introduction

Central Alberta experiences thunderstorms on 55-75% of summer days, hail on 50% of days, and severe hail (bigger than walnut size) on 15% of days (Strong and Smith, 2001). The point frequency of hail over central Alberta varies from 2-6 days per year (Wojtiw, 1975). While these hail frequencies are comparable to those of the High Plains of the U.S. in the lee of the Rockies, tornadoes are not as common in Alberta as over the southern U.S. Alberta thunderstorms form predominantly over the foothills and track generally eastward (Figure 1). They are remarkable because of the high frequency of large hail, which causes widespread damage to economically significant grain crops such as wheat, canola, barley and oats.

Thus, economic losses due to hail have been a long-standing problem in Alberta. However, during the early-1950s a series of severe hailstorms caused more damage than usual in the central Alberta region between Calgary and Red Deer, where hail insurance was very limited or not available at all in many localities. This prompted farmers in central Alberta to approach the provincial government for help, including the possibility of using the newly discovered techniques of cloud seeding to mitigate hailstorm damage. The issue was passed on to the Alberta Research Council (ARC) for guidance, where research chemist Mac Elofson and the Director of Research, Nathaniel Grace, were already predisposed towards taking on the problem (Elofson, 1991). Weather modification science at that time was in its infancy. Consequently, following meetings with interested parties in Alberta, it was recommended that, because of the lack of scientific consensus on the viability of weather modification, a research program should be established to gain a better scientific understanding of hailstorms before any attempts were made at mitigation.

In June 1955, the Meteorological Branch of the Department of Transport convened a meeting with the Alberta Research Council (ARC), the provincial Department of Agriculture, and the University of Alberta to discuss the scientific issues. It was agreed that the Meteorological Branch and ARC should co-operate on a summer pilot program in the main hail belt of central Alberta during the summer of 1956. Elofson and Grace took on this pilot program, working out of Didsbury in central Alberta; they were joined by Dick Douglas from the McGill Stormy Weather Group (SWG). Their goal was to test the feasibility of using farmers as observers to provide valuable information on storms.

Postcard questionnaires were mailed out to some 6500 farmers in an area of 10,000 km^2 around Red Deer with a request to respond when they received hail. More than 500 volunteer reports were mailed in. The most surprising discovery from this was that hail occurred somewhere in the area on 42 days during the summer. This greatly exceeds the climatological point hailfall frequency of 4 days per year recorded at the meteorological stations in the test area. The hail occurrences could be plotted accurately since each farm was precisely located on the Dominion Land Survey grid system. This pilot project was considered a success, but the need for a radar storm-tracking system was immediately recognized. Hence, the McGill SWG was asked to take over scientific leadership of the project for 1957, with funding provided by the Meteorological Branch.

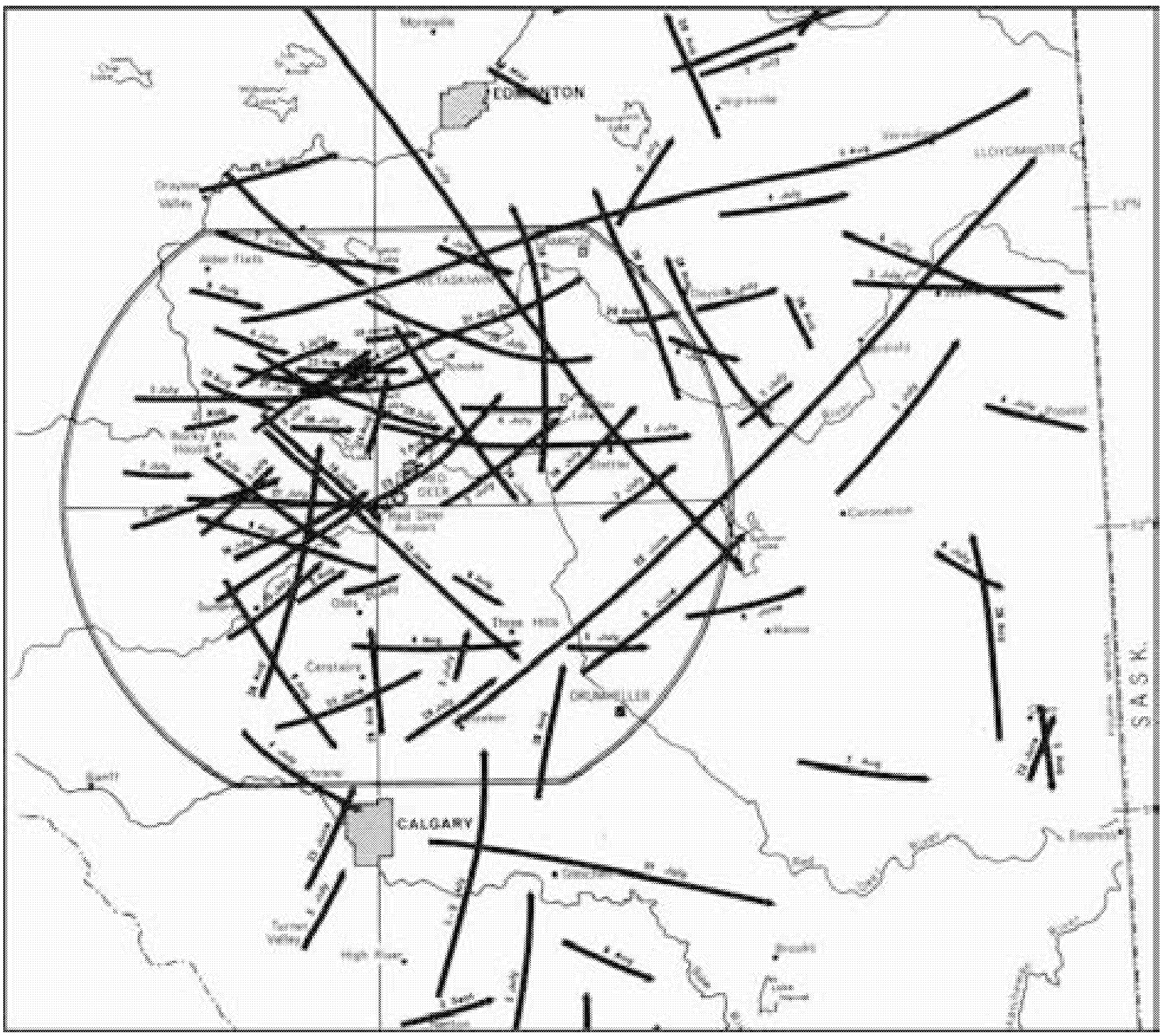

Figure 1: 1975 Hailswath tracks for storms with hail size greater than grape. Outlined area is the AHP (1974-85) research and operations region (after Deibert, ed., 1975).


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5c POSTAGE WILL BE PAID BY

Alberta Hail Studies,
P.O. Box 111,
R.C.A.F. Station Penhold,
Alberta.

Date of storm
Exact location of hail occurrence: ¼ N.W. S. T. R. W.
Hail began a.m.; p.m. Hail lasted minutes
Size of largest stones: Shot; pea; grape; walnut; golfball
(If larger than golfball, estimate diameter inches.)
Hail was accompanied by: Lightning; high winds
Hail began: before rain; after rain; at same time as rain
Remarks:
Name Address
If you have no more cards, check here ☐ Phone
Do not write below this line.

DAY	MO	YR			S	T	R	W	BGN	DUR	S	BRG	DIST			

Figure 2a

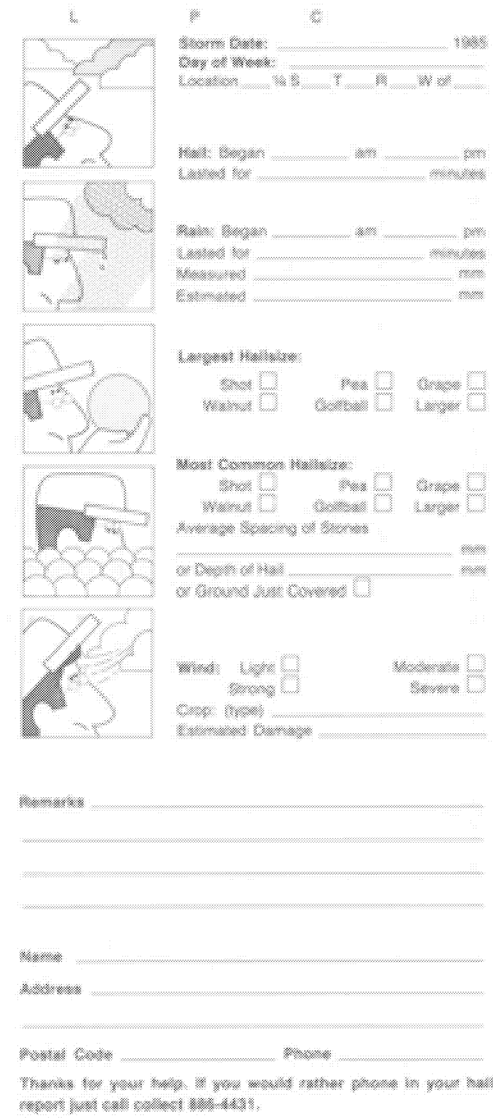
Storm Date: 1985
Day of Week:
Location ¼ S T R W of
Hail: Began am pm
Lasted for minutes
Rain: Began am pm
Lasted for minutes
Measured mm
Estimated mm
Largest Hailsize:
Shot ☐ Pea ☐ Grape ☐
Walnut ☐ Golfball ☐ Larger ☐
Most Common Hailsize:
Shot ☐ Pea ☐ Grape ☐
Walnut ☐ Golfball ☐ Larger ☐
Average Spacing of Stones mm
or Depth of Hail mm
or Ground Just Covered ☐
Wind: Light ☐ Moderate ☐
Strong ☐ Severe ☐
Crop: (type)
Estimated Damage
Remarks
Name
Address
Postal Code Phone
Thanks for your help. If you would rather phone in your hail report just call collect 886-4431.

Figure 2b

Figure 2: Hail reporting form for (a) 1959 Alberta Hail Studies, and (b) 1985 Alberta Hail Project.

2. Alberta Hail Studies, 1957-73

Hail research began in earnest in the spring of 1957 with the installation of a 3-cm Decca radar at RCAF Station Penhold (later called Red Deer Airport) by the SWG in collaboration with the National Research Council (NRC) and ARC. The Alberta Hail Studies (ALHAS) was thus born in 1957, and so began a program of systematic and continuous summer observations of hailstorms using three main tools: *radar* to study the internal structure of storms; *cloud photography* to study the visual morphology of cloud turrets and their growth rates; and volunteer *hail reports and samples* to study hailfall patterns on the ground. The airport site became the field research and operations base for the next 30 years. The research was initially concentrated in a quasi-rectangular region, roughly 350 km by 150 km, which included Red Deer and Calgary.

Figure 2a is a sample volunteer hail report from 1959, providing valuable information on storm date, location, time and duration of hail, maximum size and relevant storm comments. This type of hail reporting was continued with minor revisions and additions until the hail program ended in 1985 (Figure 2b). It was supplemented by telephone surveys immediately following storms.

The initial focus on precipitation particles established a certain mode of research that continued into the 1970s, based on five key questions:

1. What is the climatology of hail in central Alberta?
2. What are the characteristics of hail-producing storms observed by radar?
3. What are the freezing properties of water from hailstones and rain?
4. Using numerical models of the day, how does hail grow within a storm?
5. What synoptic weather phenomena are associated with hailstorms in Alberta?

		June	July	August	September	TOTAL
No. of hail days:	1957	22	26	19	10	77
	1958	21	19	16	4	60
No. of reports:	1957	1045	1444	585	124	3198
	1958	328	289	232	72	921

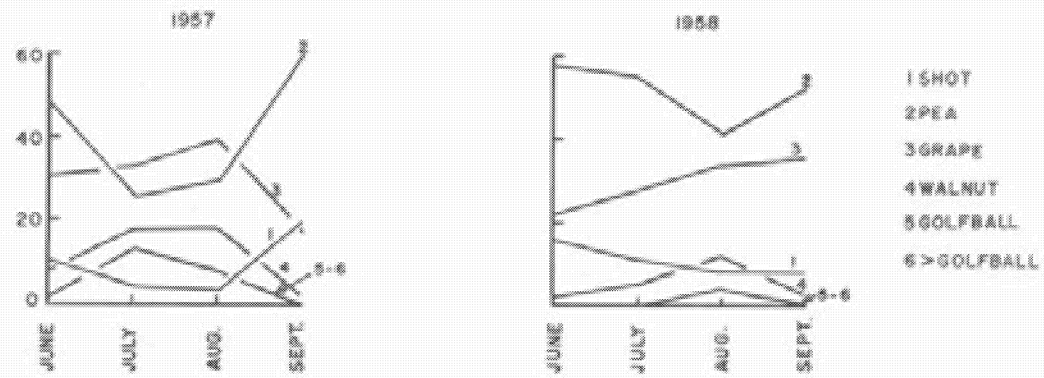

Figure 3: Numbers of hail days and reports and distribution of hail size in central Alberta, 1957-58 (reproduced from Douglas, 1959).

At that time, and up until the late 1970s, there was a general belief within the severe storm research community that while larger-scale (synoptic) processes *prepared the atmosphere* for storms to develop, once initiated, storms formed their own circulation, kinematics and life cycle virtually independent of synoptic processes. We now understand that thunderstorms are not independent entities, and that they, in turn, influence synoptic processes.

2.1 Some Early ALHAS Research Results, 1957-63

The Meteorological Branch continued its support of the program, committing a meteorologist for weather forecasting and related duties, from 1960 through 1975. With continued funding from the Meteorological Branch, McGill scientists conducted most of the research analysis during this early period, establishing the early climatology shown in Figure 3.

This period likely produced the earliest confirmation of organized hailswaths, as depicted in Figure 4 for a severe storm on 26 July 1962. This was an early step in recognizing that hail events were not sporadic outputs from the storm but organized features. In addition to hail reports and microphysical data obtained from actual hail samples (with subsequent laboratory analysis), radar was the major research tool in these early years of ALHAS.

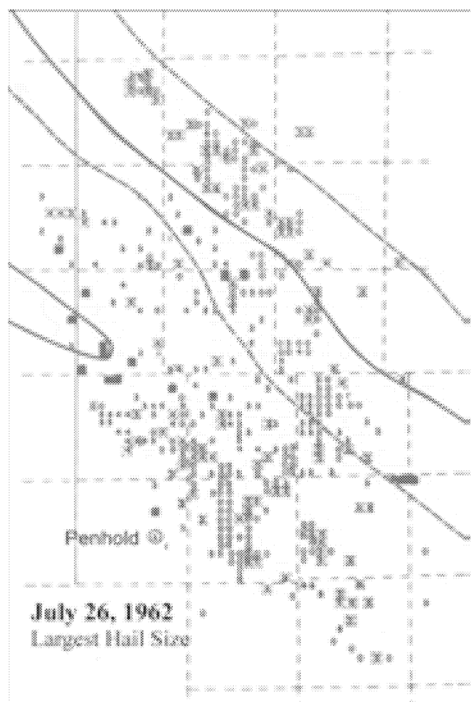

Figure 4: Two hailswaths (denoted by solid/broken lines) inferred from volunteer hail reports for severe hailstorm of 26 July 1962,with hail sizes indicated by plotted numbers: 1-shot; 2-pea; 3-grape; 4-walnut; 5-golfball; 6 >golfball; 0-unknown size (reproduced from Williams & Douglas, 1963).

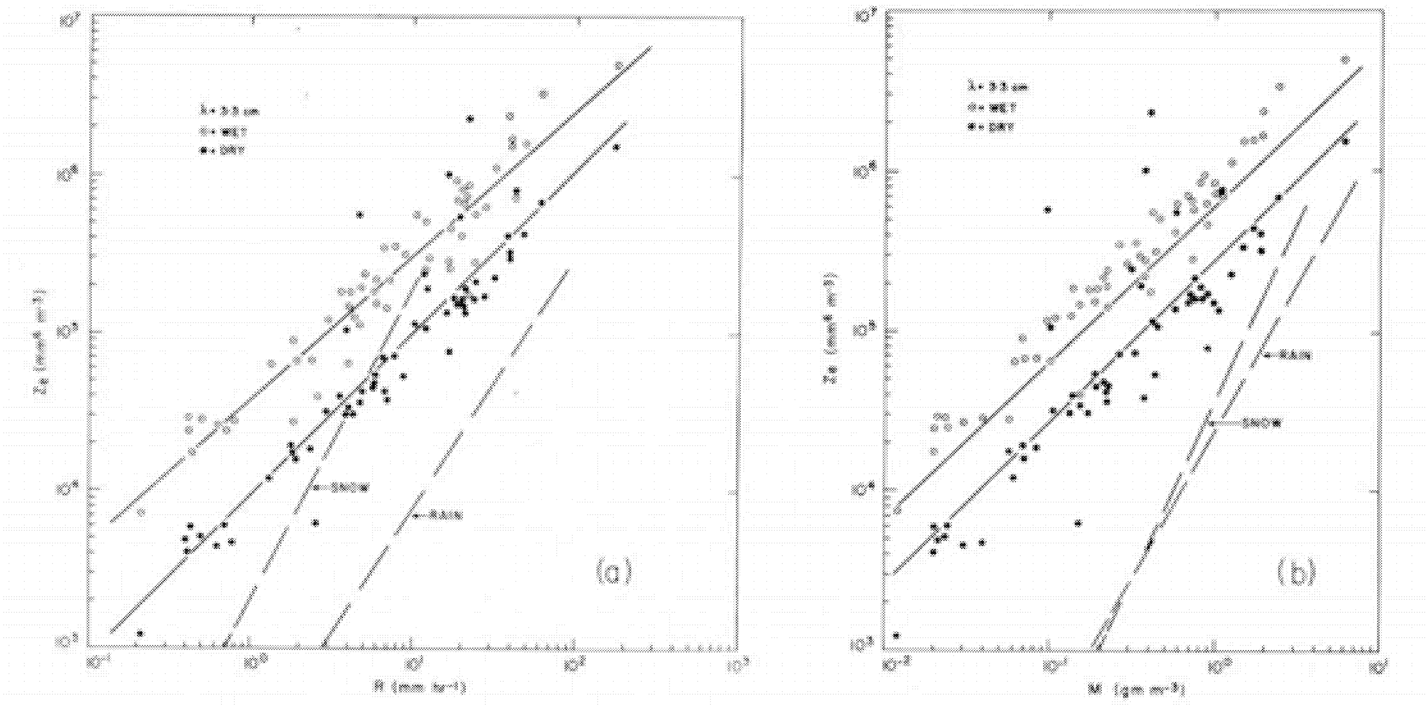

Figure 5: Equivalent reflectivity (3.3 cm) vs. precipitation rate (R) and hail mass concentration (M) (reproduced from Douglas, 1963).

The 3-cm radar was a crude meteorological tool with output consisting of photographs of the PPI scans. Nevertheless, it made it possible to relate the radar storm cells to ground-based hail data. A major improvement in radar analysis was introduced by the SWG in 1959, with the introduction of a 'grey-scale' that displayed radar echoes in quantized shades of grey corresponding to values of reflectivity. This allowed the detection and location of the highest intensity echoes. In spite of serious attenuation problems with the 3-cm band radar signal, SWG scientists carried out ground-breaking research, revealing relations between reflectivity and rainfall rate and between reflectivity and hail mass concentration (Figure 5).

Achievements during this period included:

- distinguishing between single-cell storms that gave a single burst of hail, and multi-cell storms where new cells formed on the southern flank, producing almost continuous hailswaths up to 100 km in length;
- quantifying the strong correlation between the height of the radar echo top and the probability of hail at the ground;
- developing an instability index (Slydex) for forecasting hail occurrence (Sly, 1964);
- developing a theory of accumulation zones of high liquid water content (LWC) to account for rapid hailstone growth;
- initiating laboratory and theoretical work on the drop freezing and nucleation processes (Vali, 1965).

2.2 Shift in Research Emphasis to Large-Scale Dynamics, 1964-68

The installation of a 10-cm, broad-beam radar in 1963 facilitated studies of storm dynamics. At the same time, an interest in extra-storm dynamics also arose. Several developments contributed to this new interest: having a trained forecaster on-site, early insights into storm and extra-storm dynamics observed with the old 3-cm, 'grey-scale' radar and via a continuing cloud photography program, the acquisition of a METOX radiosonde system in Calgary in 1966, to assess atmospheric instability and wind profiles, and the acquisition of a number of pilot balloon theodolites for measuring wind fields. The sounding systems allowed investigation of mesoscale dynamics beyond the storm boundaries. In 1967, the broad beam radar was replaced with a new 10-cm, pencil beam radar. This reduced the attenuation problem considerably and it quickly became apparent that research had to expand well beyond the 'visible storm' structure.

These new tools revealed that certain synoptic patterns favoured the formation of thunderstorms, such as a southwest flow at upper levels with an approaching shortwave trough (Longley and Thompson, 1965). The mean upper air charts from the Longley and Thompson study suggest that Alberta storms occur predominantly behind the low-level trough (or cold front), in the cold baroclinic zone, but ahead of the upper trough. This synoptic environment is significantly different, in general, from that of storms forming over the prairies to the east, where a cold front or frontal wave is often involved.

During this period, it also became apparent that the mountains and foothills played an important role in Alberta storms. This discovery resulted in moving the Calgary radiosonde system into the foothills at Rocky Mountain House around 1969. However, apart from the work of Derome (1965), who showed that environmental ascent, especially in the boundary layer, was related to storm formation, the primary research focus remained on storm scale processes, throughout the first 20 years.

Meanwhile, great strides were also being made elsewhere in radar and cloud physics research. As a result, the project gained international interest and participation, including exchange visits between U.S., Russian and Canadian scientists. The new 10-cm radar provided the highest resolution of any research radar in North America. A new signal display technique HARPI (Height-Azimuth-Range Position Indicator) was developed by the SWG (Zawadzki and Ballantyne, 1968). It provided 1-km resolution in echo intensity at a range of 60 km. These detailed measurements gave a whole new insight into storm structure, showing, for the first time, the weak echo region (WER) and high intensity overhang echoes associated with the updraft. The addition of polarization to the radar signal was a major advancement in radar technology that showed promise for identifying precipitation types. By combining echo polarization information with normal reflectivity, Barge (1972) was able to develop real time "hail detector" display. This proved to be invaluable for directing seeding aircraft and mobile precipitation samplers during subsequent seeding operations in 1972 and 1973.

During 1967, an instrumented Cessna turboprop aircraft from Meteorology Research Inc. made turbulence and ice nucleus measurements in and around cumulus clouds in the foothills. Such measurements were a necessary precursor to cloud seeding, providing an indication of the ice nucleus production rates that would be required. During 1968 and 1969, an instrumented C-45H Beechcraft aircraft from the University of Wyoming made extensive measurements of water vapor fluxes in the updraft regions of storms (Marwitz and Berry, 1971), enabling moisture budgets for a storm to be estimated.

Pell (1967) reviewed the concept that steady-state storms produce a near continuous swath of hail along their tracks. His work revealed 'gaps' in the hailswaths and he concluded that a much denser network of hail observations was necessary to determine the source of the gaps. Subsequently, Pell (1969) observed an echo-free region within a hailstorm; this observation was subsequently confirmed by Chisholm (1973), who identified these regions as a manifestation of a strong updraft in the storm. This weak echo feature remains an essential ingredient in nowcasting severe storms today, providing alerts for severe hail and potential tornado formation. Thyer (1970) and Ragette (1971) revealed new features of the boundary layer wind field in the pre-storm environment, as well as wind structures in and around storms.

2.3 Parallel Hail Suppression Program, 1956-68

During the first dozen years of ALHAS, weather modification was not part of the research effort. Frustrated by this perceived inaction on the part of government and research agencies, local farm groups, including the Alberta Weather Modification Co-op and the Wheatland Weather Modification Association, canvassed volunteer contributions and raised sufficient funds to contract Irving P. Krick Associates of Canada Ltd. to carry out cloud seeding operations. This program was initiated in July 1956, using a network of farmer-operated, ground-based generators, intended to deliver silver iodide into convective clouds via natural convection. There were claims that this seeding program produced dramatic reductions in hail damage losses. However, a subsequent evaluation of ground-based seeding, carried out by AHP in the 1980s, showed that, while plumes from ground-based generators occasionally reached cloud base, they typically were narrow and filled only a few percent of the target volume.

2.4 Project Hailstop, 1969-72

The first dozen years of hail research had yielded an appreciable scientific understanding of hailstorm behaviour. Meanwhile, the interest and pressure from the farming community was rising. The time seemed right to investigate cloud seeding for hail suppression. Phase 1 of Project Hailstop consisted of a series of cloud seeding experiments, conducted in July 1969, using a B-26 aircraft from the Desert Research Institute in Reno, Nevada (Renick, 1969). The experiments involved seeding in updraft areas below cloud base, using AgI and Indium Hydroxide (an inert tracer). Ground-based mobile units were deployed to collect precipitation samples. Also in 1969, a T-33 jet from the NRC was used to measure the upper-level winds and turbulence structure in the storm environment.

In order to implement the seeding more efficiently and precisely in 1970, a new cloud seeding concept was proposed. The idea was to seed newly developing towers at the appropriate time in their life cycle, in order to induce greater competition for the available water supply, thereby preventing the growth of large hail. To accomplish this, a new cloud seeding delivery system was developed jointly by ARC and NRC using the T-33 (Summers et al., 1972). Droppable pyrotechnic flares were used, fused to fall about 2 km before releasing the AgI in the final 1 km of fall. A unique feature was radar chaff released at flare burn-out, to enable seeding locations to be pinpointed. The required seeding heights were estimated from a real-time cloud model and the aircraft was directed to target cells at the correct altitude, on the basis of radar echoes and pilot visuals. Flares were then dropped at 300-m intervals across the target. These logistics were tested on 40 storms during 1970-72, with assistance from University of Wyoming aircraft. These experiments suggested that storms could be seeded successfully using droppable flares, since the radar recorded lower radar reflectivities and lower precipitation fall speeds from seeded cells than unseeded cells. These results suggested that there were smaller hailstones in the seeded cells and this was confirmed by smaller hail collected at the ground. The results also indicated that a capability existed to detect physical effects of seeding and use them as an evaluation tool, rather than relying solely on statistical analyses.

Renick (1966) developed a stereo, time-lapse cloud photography system that provided detailed information on the visual structure and growth rates of storms. Together with Warner et al. (1972), he associated the cloud towers of a hailstorm with updraft regions in the storm and with individual radar cells that developed every few minutes. This work led to the development of important kinematic models of single-cell, multicell and supercell storms (Chisholm and Renick, 1972). The evolution and wind profile of a typical multicell storm is shown in Figure 6. The identification of multiple, regenerating cells in storms helped to explain the 'gaps' in hailswaths noted by Pell (1967).

During this period, work also began on a dynamical hailstorm model (Srivastava, 1964; Takeda, 1969), and ground-based, mobile units were developed to chase storms, measure winds and collect hail and rain samples for laboratory analysis. Chisholm (1973) developed a simple, one-dimensional, steady-state model to estimate the vertical velocity, temperature, and liquid water content in storms, using single soundings. This proved useful both for short-term forecasting and for diagnostic studies of storms. English (1973) used a two-dimensional cloud model to estimate hail growth rates and size; the model also inferred radar reflectivities that were similar to values measured in four severe storms.

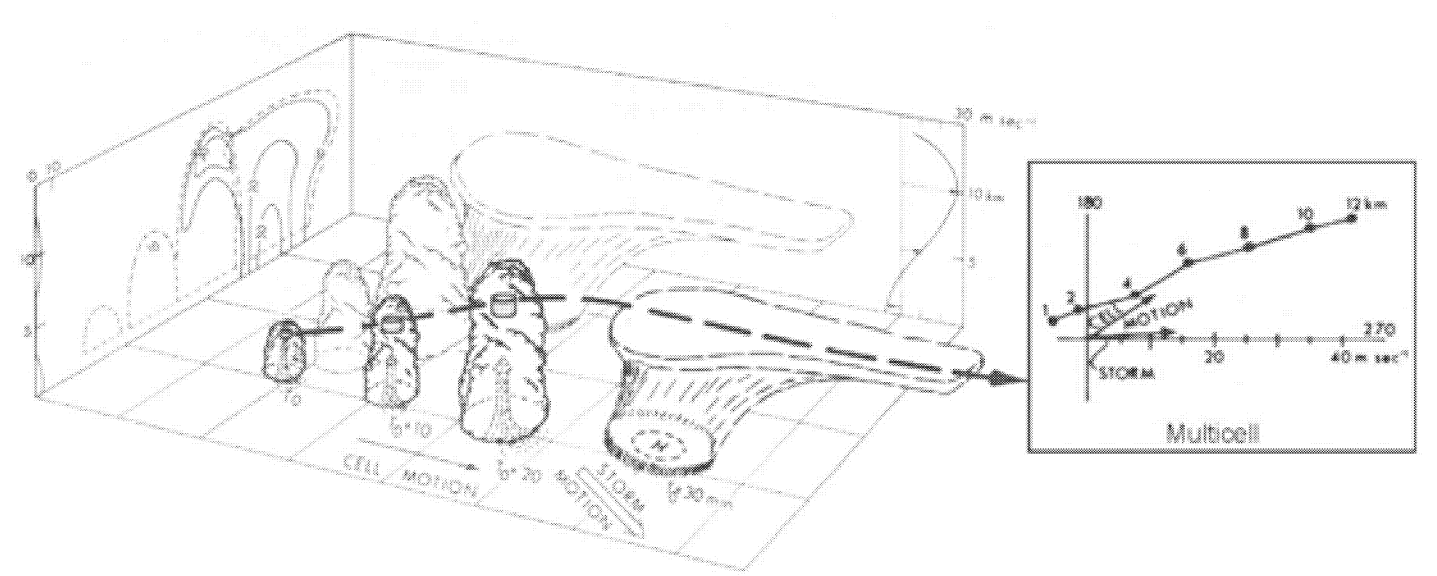

Figure 6: Kinematic model of an Alberta multicell storm and its wind hodograph (reproduced from Chisholm and Renick, 1972).

2.5 1973 - A Transition Year

Responding to increasing concerns expressed by farmers in central Alberta over continuing crop losses and their perceived lack of progress in implementing effective hail suppression techniques, the provincial government established a Special Legislative Committee in 1972, with a mandate to investigate crop insurance and weather modification in Alberta. After a series of hearings around the province, which included presentations from many sectors and from invited experts from outside the province, a report was tabled in the Legislature in November 1972. The main recommendation was that the province should finance a 5-year, active hail suppression program to begin in 1974. However, as plans were already in place for the 1973 ALHAS field program, an Interim Weather Modification Board was appointed to fund and oversee a pilot cloud-seeding project. The IWMB, which became the Alberta Weather Modification Board (AWMB), consisted of a dozen or so individuals, representing the farm community, the University of Alberta, ARC and Alberta Agriculture. INTERA Technologies Ltd. were chartered to seed all potential hail storms in a defined area south of Penhold, using three turbocharged Cessna aircraft. In 1973 seeding was carried out on 15 days.

2.6 Hailfall Analyses

Eighteen years of intensive hail survey data facilitated the formulation of a basic hailfall climatology (Wojtiw, 1975). Figure 7 shows that the highest point frequency of hail occurs over or near the foothills, with maxima near Rocky Mountain House (RM) and Sundre (SU). Wojtiw also demonstrated the important seasonal variation of hailfall, which appears to follow the summer crop emergence, growth and harvesting cycle. An updated version of the seasonal cycle for the full 29-year period (1957-85) of hail studies can be found in ARC (1986).

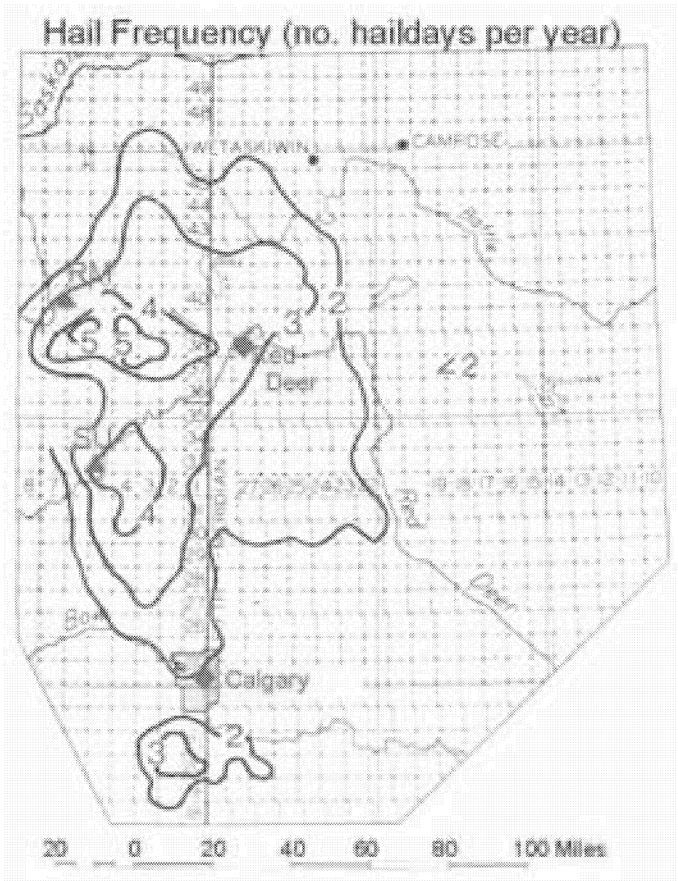

Figure 7: Annual point frequency of hail over central Alberta, based on 1957-73 ALHAS hail surveys (reproduced from Wojtiw, 1975).

The first attempt to quantify hail size distributions in Alberta using hailpads was carried out in 1973. Alberta hailpads were one foot square pieces of Styrofoam, fixed to the ground and calibrated to estimate the hail size distribution, ice mass, and impact energy density, from recorded hail dent sizes on the pads (Strong, 1974). Detailed objective data on hailswaths and hailstreaks, based on surface measurements, were now available for the first time (see Figure 8, after Strong and Lozowski, 1977). This program was discontinued after 1980 because the pad analysis was very labour-intensive; however, it could now be resurrected as an inexpensive but valuable analysis tool, in view of the advent of digital photography and automated analysis software that can easily be run on today's desktop computers.

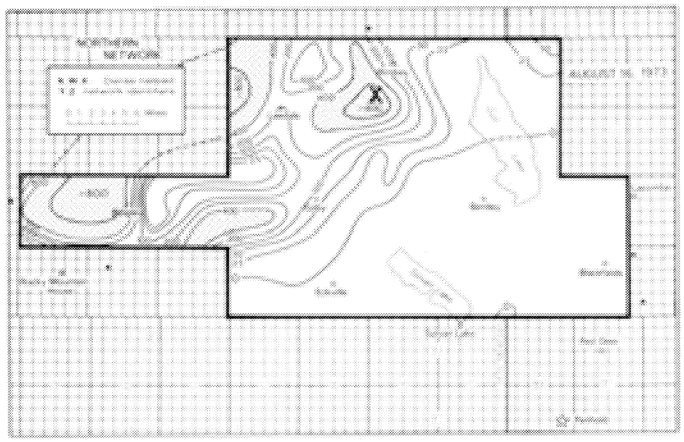

Figure 8a

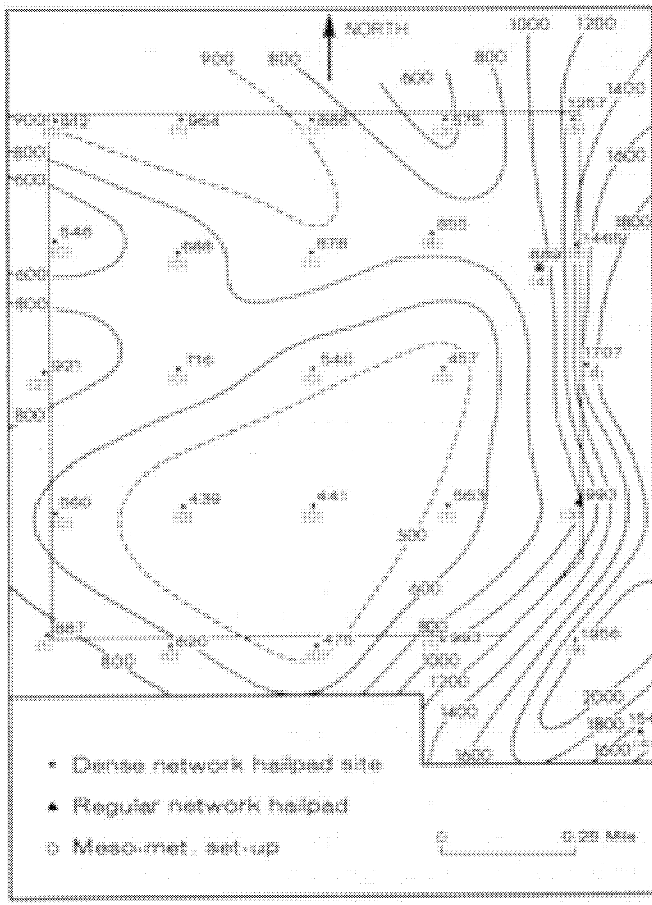

Figure 8b

Figure 8: (a) Mesoscale and (b) Cloud-scale analyses of hailswath impact kinetic energy density (J m-2) on August 16, 1973. Each small square in (a) is one section of land (1 square mile), with the 'X' marking the land section of (b) (reproduced from Strong and Lozowski, 1977).

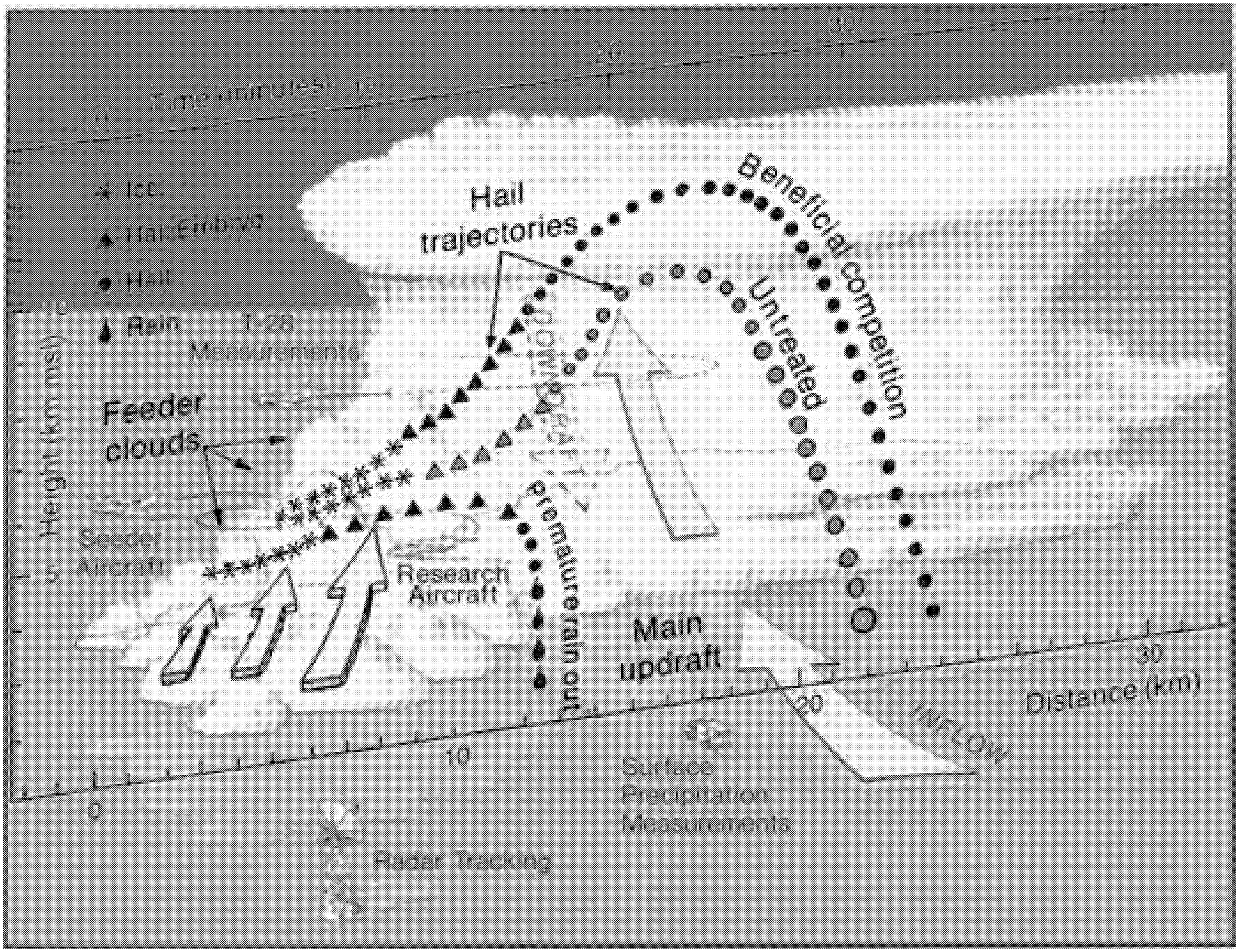

Figure 9: An artistic rendering of the hailstorm conceptual model, including effect of seeding, where "premature rainout" occurs in feeder clouds (lower-left flank), while seeding material (AgI) entering the rapidly-developing new cells leads to "beneficial competition", producing larger numbers of smaller hailstones (adapted from ARC, 1986).

3. Alberta Hail Project (AHP), 1974-85

The final dozen years of large-scale hail studies in Alberta began in 1974, under the rubric Alberta Hail Project (AHP). The AHP was operated by ARC and administered by the Alberta Weather Modification Board (AWMB), which had been established by the Alberta government, with primary funding from Alberta Agriculture. There were two 5-year programs, 1974-78 and 1981-85, with two interim years in 1979 and 1980. The second 5-year program differed slightly from the first in that it included exploratory studies of cloud seeding to increase rain and snow. These were managed by Guy Goyer (1975a,b) of ARC.

3.1 The Alberta Weather Modification Board (AWMB), 1974-85

The AWMB consisted of several farmers (5) and representatives from the University of Alberta (2), Alberta Agriculture (1) and ARC (2). Its mandate was to conduct both a research and an operational hail suppression program and to evaluate each. The 80 mile (~130 km) radar range ring was used to define the project area shown in Figure 1, with northern and southern sectors omitted due to heavy aircraft traffic around the Edmonton and Calgary International Airports. The plan was to conduct full-seed operations over the southern half of the project area and randomized experimental seeding over the northern half. This compromise seeding solution was formulated to satisfy the desire for "crop protection" coming from some farmers in the southern half of the project area (as expressed by their representatives on the AWMB). Like many compromises, it had its drawbacks. In particular, evaluation was confounded, because the AWMB mandated that storms moving northward from the southern half into the northern half should continue to be seeded across the boundary, while any northern storms threatening the southern half had to be seeded prior to crossing the boundary. Despite this additional complication introduced into the evaluation of the randomized seeding program, the AWMB did, nevertheless, provide a solid funding base for hailstorm research.

3.2 Cloud Seeding Operations

The AHP project facilities were located at the Red Deer Industrial Airport and consisted of weather and aircraft tracking radars and a computer system developed and operated under contract by the Alberta Research Council. Project aircraft were equipped with special transponders that enabled controllers at the site to identify, track and direct seeding aircraft to the hailstorms. A computer-generated, real-time radar and aircraft display system was developed for this purpose, and data were recorded for subsequent scientific analysis of storm characteristics. A 5-cm radar system was also added to provide an all-weather monitoring capability (for example, when on-site winds were too high to operate the 10 cm radar antenna).

INTERA Technologies Ltd of Calgary were contracted to conduct the cloud seeding operations, using seven twin-engined aircraft, from1974 to 1985. Two cloud seeding methods were used. Cloud-top seeding was executed with ejectable, short-burn, silver iodide (AgI) flares, dropped into growing convective turrets along the edges of the main storm. Cloud-base seeding was conducted just below cloud base, along the edge of the storm updraft area, using burning flares attached to the aircraft's wings. The seeding program ran from June 20 to September 10 each year, over a target area of 48,000 km^2, centered on Red Deer Airport. All potential hailstorms in the southern half of the area were seeded, while during the first 2 years, the northern half of the area was seeded on a 50-50 randomized basis. A partial analysis of the effect of the seeding operations on hail crop losses was presented by Goyer and Renick, (1979).

3.3 Cloud Microphysics and the Hailstorm Conceptual Model

During Project Hailstop, a conceptual model of the microphysics and multi-cellular structure of Alberta storms (Figure 9) had evolved from radar, aircraft and photogrammetric studies, which showed how the air and moisture flows interacted with precipitation in the storm (Renick, 1971; Summers and Renick, 1971; Renick et al, 1972; Chisholm, 1973). It was hypothesized that hailstorm embryos formed in feeder clouds that are seen, visually, as cloud towers and by radar as individual echo cells. These cells as they developed went on to become the main body of the storm. According to the model, the embryos grew rapidly on the abundant super-cooled liquid water carried aloft by the main updraft.

Later, this conceptual model was refined, based on the work of Barge and Bergwall (1976), who showed that radar storm cells contained fine scale reflectivity patterns (FSRPs). These FSRPs usually evolved more regularly than the larger storm cells. FSRPs were usually identified on the southern edge of storm radar echoes, and could be tracked from their formation through their intensification stages, as they moved through the high reflectivity region of the echo, until they finally became obscured in the echo dissipation zone. FSRPs were considered to be a radar manifestation of the new, rapidly growing cloud towers, visually observed on the southern flank of the storm.

Cumulus clouds forming along the southern edge of the storm (the new growth zone) usually persisted for 10 to 15 minutes before growing rapidly into large cloud turrets. The tops of these 'new-growth zone' cumuli were usually colder than 0°C and were considered to be the major source of hail embryos for the storm. The hail suppression hypothesis suggested that the introduction of ice nuclei into these developing towers would generate larger numbers of embryos that would compete with natural embryos for the available liquid water, resulting in reduced hailstone sizes.

In order to gain an understanding of the physical processes occurring in storms and the effects of cloud seeding on them, the Alberta Research Council and INTERA Technologies Ltd, jointly developed an instrumented cloud physics aircraft. Controlled, glaciogenic seeding experiments on the feeder clouds and growing towers in the new growth zone were conducted. The aim was to assess the impact of seeding treatments upon the growth of potential hailstone embryos within these towers and upon the production of hail by the main storm. In these experiments, feeder clouds meeting pre-specified cloud-top temperature, horizontal cloud dimensions, liquid water concentration, ice concentration and updraft criteria were seeded. The double blind, randomized seeding treatments used either a placebo, Silver Iodide (produced by droppable flares) or dry ice pellets. Following seeding, the treatment effects and the subsequent precipitation growth processes were simultaneously documented, by repeated penetrations of the treated cloud by the heavily instrumented research aircraft and by observation with the S-band radar system. Storm chase vehicles were also deployed to intercept the storm and collect time-resolved hailstone samples.

The results from the randomized hailstorm seeding experiments indicated that seeding increased precipitation within feeder clouds, (Krauss and Marwitz, 1984; Krauss and English, 1984). In some cases, cloud seeding appeared to cause hail embryos to precipitate out of the feeder cloud prematurely. However, limitations in the measuring and observing facilities did not allow conclusive proof that more hail embryos led to smaller hail on the ground, or that premature rain-out of embryos yielded fewer hailstones on the ground. However, some evidence from hailstone samples indicated that cloud seeding altered hailfall at the ground (Cheng et al., 1985).

During 1985 an 'armoured' T-28 aircraft from the South Dakota School of Mines and Technology flew cloud penetrations into the region where hailstone embryos were thought to enter the storm and become hailstones. Flights were coordinated with the Cessna Conquest research aircraft and mobile sampling on the ground.

3.4 Radar Research

Research with weather radar began in 1957, when the National Research Council (NRC) installed a 3.2-cm Decca DC-19 radar at Penhold. This was replaced in 1963 with a 10-cm FPS-502 (S-band) radar. Meanwhile, since NRC had developed a 1.8-cm polarization diversity radar (McCormick, 1964), they designed a dual polarization antenna for the FPS-502, using a feed horn that was scaled up from the 1.8-cm feed horn. The new antenna was installed in the spring of 1967 (Allan et al., 1967). The goal was to detect hail in convective storms by means of the circular depolarization ratio and the cross-correlation of simultaneously received signals of right and left circular polarization.

The Alberta polarization diversity radar was recognized at that time as the best of its kind. Up until the S-band was installed, the Soviets were the leaders in using polarization techniques to study precipitation. However, they were limited by the poor polarization qualities of the antennas used (Shupiatskii and Morgunov, 1963). As noted in previous sections, the S-band radar was used to further knowledge about the development and growth of hailstorms. As a result of polarization studies both in Alberta and in Ottawa it was determined that:

- Raindrops tend to fall with their symmetry axis vertical;
- The degree of correlation between the main and orthogonal components is higher for rain than for hail;
- The circular depolarization ratio (CDR) can help to distinguish rain from hail, but propagation effects cannot be ignored (Barge 1972; Humphries 1974);
- A combination of the CDR, the radar reflectivity factor, and the cross-correlation is sensitive to precipitation type and hence could be useful for identifying the hydrometeors present in the observed volume (Torlaschi et al., 1984, Al-Jumily et al., 1991).

The addition of a 5-cm weather radar in 1974 provided the opportunity to use both polarization and dual-wavelength techniques to study hydrometeors (Humphries and Barge, 1979). Initially, data from the radar systems were in the form of photographs of the radar PPI displays or in the form of tracings from a strip chart recorder. Ultimately systems for digital signal processing and recording were developed as well as methods for the display of the digitally recoded data. A weather research group in Brazil purchased this radar data processing and display technology in 1980. Although the last major field program of the Alberta Hail Project occurred in 1985, data from the polarization radar were used for research well after the radar was decommissioned (Holt et al., 1994, Humphries et al., 1991). The three radars used during AHP research and cloud-seeding operations are depicted in Figure 10.

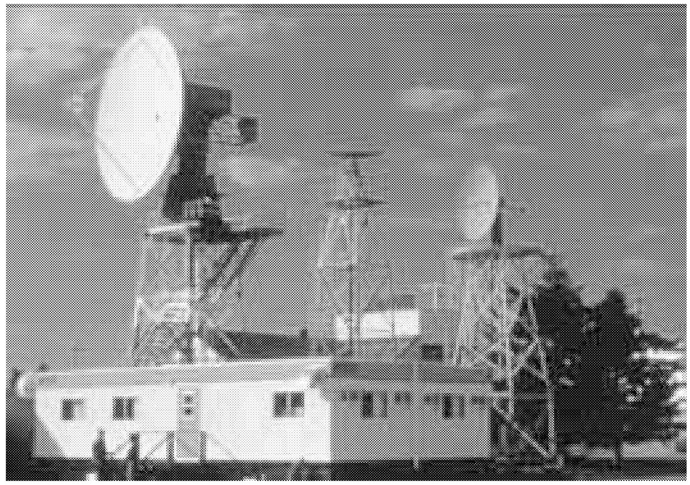

Figure 10: Radars used in AHP research and cloud-seeding operations, L-R: 10-cm S-Band polarization diversity radar, X-Band aircraft-tracking radar, 5-cm C-Band radar.

3.5 Mesoscale Research and Forecast Operations

One component of the AHP program included mesoscale studies of the storm environment, using atmospheric profile data from fixed and mobile sounding sites. Robitaille et al. (1979) investigated the representativeness of soundings in various storm quadrants and found that the most representative soundings lie within 20-100 km of the front quadrants, especially the right-front quadrant. Soundings in the northwest quadrant of a storm were generally unrepresentative of its convective potential. This finding has important implications for using soundings from Stony Plain, Alberta's only synoptic site, to estimate convective potential over central Alberta.

A statistical forecast technique called the Synoptic Index of Convection (SC4) was developed, based on two synoptic dynamic variables and two instability indices, which were correlated to the Convective Day Category (CDC). This technique predicted storm intensity over the AHP operations area as reliably as a trained forecaster (Strong, 1979; Strong & Wilson, 1983; Strong & Smith, 2001). It was later incorporated into a prototype artificial intelligence forecast system funded by the MSC, called METEOR (Elio et al., 1987). The forecast SC4 (or CDC) was reliable enough that it was used in the cloud-seeding decision process. The technique was later adapted in several other projects, including the Greek and Argentine hail programs, and the current Alberta hail suppression program.

A series of field experiments on the mesoscale storm environment, called the Limestone Mountain Experiments or LIMEX (Strong, 1989), was carried out from 1980-85. These were designed to test a multi-scale conceptual model of Alberta thunderstorms (Strong, 1986, 2000, 2001), which incorporates synoptic scale and topographic forcing, surface cyclogenesis, the formation of a capping lid from a nocturnal inversion, sensible and latent heat fluxes, and mesoscale convergence over the foothills. Mesoscale aspects of the model appear in Figure 11a. The LIMEX-85 experiment

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utilized nine radiosonde systems in a network with 50-60 km spacing, along with interspersed automatic weather stations. It focused on the formation and breakdown of the capping lid, prior to storm formation, and the important role that regional daily evapotranspiration plays in storm formation over the central Alberta foothills. One significant result was the revelation of how rapidly the pre-storm boundary layer changes, that this usually occurs over a 2-3 hour period during late morning (demonstrated in Figure 11b), and that it invariably goes undetected by synoptic (1200 and 0000 UTC) soundings. LIMEX also highlighted the importance of soundings in the storm formation region, namely over the foothills.

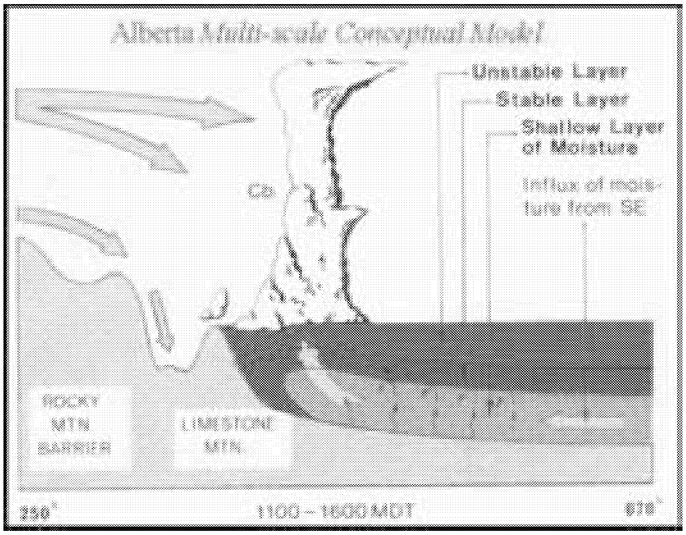

Figure 11a

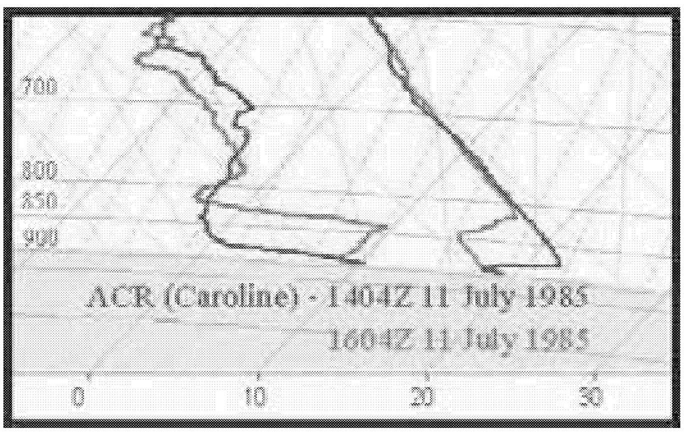

Figure 11b

Figure 11: (a) The multi-scale conceptual model of Alberta thunderstorms (after Strong, 1986, 2000), and (b) LIMEX-85 field test demonstrating typical rapid boundary layer change prior to severe storms on 11 July 1985.

3.6 Other Research

Part of the weather modification research mandate included exploratory field experiments for rain and snow enhancement, and an evaluation of ground-based seeding.

3.6.1 Rain Enhancement Experiments

During the period 1982-85, a series of cumulus seeding experiments was carried out. Treatment methods similar to the controlled, airborne, glaciogenic hail seeding experiments were applied to isolated towering cumulus clouds, in order to determine whether seeding could produce rain. Observations with the research aircraft showed that the class of cumulus clouds selected for the experiments does not naturally produce high concentrations of ice crystals. Seeding these clouds with either Silver Iodide or dry ice was effective in producing high ice crystal concentrations, which spread through the cloud and grew with time. It was demonstrated that some cumulus clouds, that would not rain naturally, could be made to rain by seeding with an ice nucleating material (Kochtubajda, 1986, 1995).

3.6.2 Snow Enhancement Experiments

Limited investigations of the feasibility of increasing snowfall over the southern sections of the Alberta Rocky Mountains, via cloud seeding, were carried out during the 1980-85 research program. Field observations were made over four two-week periods, during the winters of 1982-84, to gather meteorological and in-cloud data, as evidence of the modification potential of wintertime orographic clouds over the southern Rockies. In-cloud data were obtained via research aircraft flights over the mountains in the Pincher Creek to Cranbrook corridor. Rawinsonde observations were made at a valley location upstream of the mountain range.

A preliminary assessment of the snow climatology in the region was carried out. The snow climatology showed that there are different snowfall patterns on each side of the continental divide, with a notable Spring contribution. Meteorological conditions were found to be appropriate for cloud seeding. Measurements of in-cloud properties with an instrumented research aircraft showed evidence of liquid water in the clouds that did not precipitate. There was an increase in liquid water content near the barrier peaks. Estimates from three selected cases indicated that less than 1-16% of the available moisture was converted to snow. These results suggested that the precipitation process could potentially be made more efficient by seeding with additional ice nuclei.

3.6.3 Ground-based Seeding Evaluation

A project to evaluate the efficiency of seeding summer clouds, using ground-based Silver Iodide generators, was conducted by AHP in an area south of Calgary, between 1981 and 1985. Laboratory tests of the generators by Colorado State University showed that effective ice-forming nuclei were produced but at lower rates than with other systems. Mapping and plume-tracking flights over the test area showed that narrow plumes a few hundred metres wide were produced, occupying only a small fraction of the target volume. No evidence of a widespread seeding signature was found (Robitaille et al., 1986).

4. Post ALHAS/AHP Activities

Needless to say, the official end of the provincially-funded hail studies program in 1985 (due to reduced provincial budgets, less-than-outstanding cloud-seeding results, and farmer-scientist politics) did not bring an end to severe storms in Alberta. Nature regularly hits the province with devastating convective storms; notable post-AHP storms include: the Edmonton tornado of 31 July 1987, major Calgary hailstorms in 1991 and 1996, the Pine Lake tornado of 14 July 2000, and the Edmonton hailstorm of 11 July 2004. Each of these storms topped Environment Canada's Top Ten Weather Stories in their year (e.g., see Phillips, 2001). Several notable activities have been conducted and various technological advances have been made since formal termination of the hail studies program.

During the ALHAS/AHP period, an extensive archive of data was collected from several measurement platforms, including the S-band, C-band and X-band radars, an instrumented cloud physics research aircraft, mobile precipitation sampling, rainfall and hailfall telephone survey reports, upper-air soundings and surface precipitation networks. In the early 1990s, a data rescue effort was undertaken to save this unique dataset (Kochtubajda et al., 1996); the archive and related documentation can be found at http://datalib.library.ualberta.ca/AHParchive/.

Huge advances in remote sensing technology have also been made since the AHP was disbanded, including radar, satellite imagery, radiometer profiles of temperature and humidity, wind profilers, GPS moisture, and lightning networks, to mention a few. Figure 12 shows the short-term (1998-2000) climatology of lightning frequency across western Canada, determined using the Canadian Lightning Detection Network (Burrows et al., 2002). It shows that the highest incidence of lightning occurs over the Alberta foothills, closely corresponding to the hail frequency climatology of Figure 7.

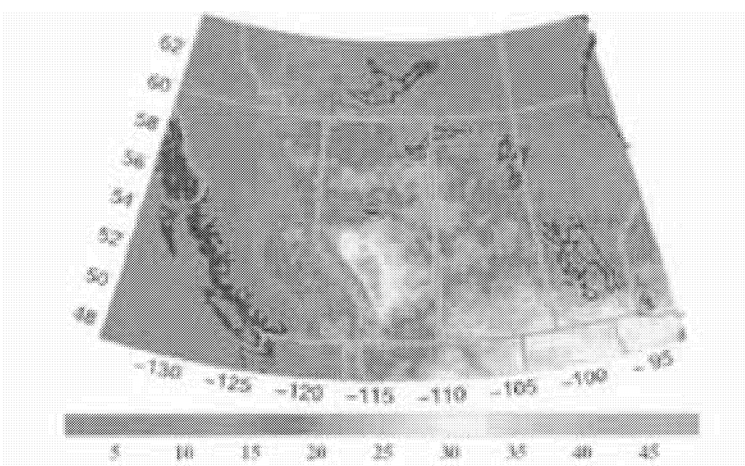

Figure 12: 1998-2002 Lightning frequency across western Canada (reproduced from Burrows et al., 2002).

4.1 The Alberta Hail Suppression Project, 1996-present

The current Alberta Hail Suppression Project was initiated in 1996 in response to the damages associated with the severe hailstorm that struck Calgary on September 7, 1991. Insured losses due to that storm were approximately $400 million (Charlton et al., 1995, Insurance Bureau of Canada, 2004). The Alberta Severe Weather Management Society was created in 1996 by the private insurance companies in Alberta, with the sole objective of conducting a cloud seeding program to reduce the damage to property by hail. It is the first project of its kind in the world to be funded privately, and it focusses on the reduction of damage to property and not agriculture. The current project area is defined by an area of high storm frequency and a rapidly increasing population base (the Calgary - Red Deer corridor). It is based upon the cloud seeding conceptual model, methods, and results of the long-term hail research project conducted by the AHP.

Weather Modification Incorporated (WMI) of Fargo, North Dakota was awarded the first contract to conduct the Alberta Hail Suppression Project in 1996. The project was made an on-going program of the Alberta insurance industry in 2001 because of the decrease in hail damage costs in Alberta, counter to the trend in the hail regions in the USA and the rest of the world. Although the new project does not include a research focus, it has been useful in providing infrastructure and data for scientists working on the project, and for several independent research projects (e.g. AGAME, UNSTABLE), graduate student theses, and publications in the formal scientific literature (Krauss and Santos, 2004; Milbrandt and Yau, 2006; Brimelow et al., 2006; Smith et al., 2007).

4.2 A-GAME, 2003-05

The Alberta GPS Atmospheric Moisture Evaluation (A-GAME) project was initiated in 2003 as an application of the GPS receiver network of the University of Calgary Geomatics Engineering Department (Skone and Hoyle, 2005). The primary objective involved using radiosonde data to evaluate the accuracy of precipitable water estimates retrieved from GPS (Skone and Hoyle, 2005). Sub-objectives included using GPS precipitable water data to study Alberta thunderstorm initiation, and building on the multi-scale conceptual model of Alberta thunderstorms (Strong, 1986, 2000) briefly described in Section 3.5 (and Fig. 11), by investigating the role of *drylines* interacting with the capping lid in storm genesis (Hill, 2006). This was the first ever field research study of drylines in Canada, and significant sharp dryline boundaries were recorded in some severe storm situations where mixing ratios dropped by 3-5 g kg^{-1} over distances as short as 1 km or less.

5. Accomplishments and Legacy

5.1 ALHAS/AHP Accomplishments

The hail studies programs (ALHAS/AHP) yielded an impressive number of results that improved the understanding and prediction of hailstorm and precipitation processes, and contributed to the development of severe weather expertise in Canada. A few important achievements are summarized here:

■ Provision of a *field facility* (unfortunately lost with the demise of AHP), with data systems and techniques for observing hailstorms and making other relevant measurements that were second to none;

■ Development of a sophisticated *polarization diversity weather radar system* for understanding hailstorm structure, behaviour, and detection of hail within storms;

■ Development of a technique that combined *CDR*, radar reflectivity factor, and the cross-correlation to distinguish precipitation type;

■ Development of an understanding of the *role of freezing nuclei* in initiating precipitation formation;

■ Development of one- and two-dimensional *computer simulation models* of storm development and precipitation growth used for operational cloud seeding decisions;

■ *Identification of three distinct storm types* (single-cell, multicell, and supercell) based on storm dynamics, structure, growth rates, precipitation development and hailfall patterns, and from which storm duration, propagation, hail/rain intensities and amounts, and potential storm damage can be estimated qualitatively;

■ Development of a *conceptual model of in-cloud storm processes*;

■ Development of a *practical system for seeding multicell hailstorms* that became the basis of operational hail suppression programs elsewhere in the world;

■ Demonstration of a *methodology for physical* (as opposed to statistical) *evaluation of cloud seeding* effects;

■ Development of a reliable *statistical forecast index* that improved storm forecasting, was incorporated into an AI model, and was adopted by other national and international programs;

■ Development of a *multi-scale conceptual model of Alberta thunderstorms* incorporating synoptic and mesoscale processes, orographic forcing, and surface fluxes and convergence;

■ Collection of a *mesoscale upper air dataset* (LIMEX-85) that continues to be used in mesoscale research more than 20 years later;

■ Compilation of a *comprehensive climatology of hail* for central Alberta (1957-1985) unparalleled by any other program; data were obtained from farmers' reports of hail size, hailfall amounts, hailfall durations, accompanying rain, wind, crop damage and relevant storm comments;

■ Finally, the project provided a unique *training ground for graduate students* who worked closely with Canadian and visiting scientists, observing and collecting data, while new studies using AHP data continue today thanks to the AHP data archive. To date, at least *47 M.Sc and 18 Ph.D theses* have been completed using AHP data at participating universities as listed below:

McGill University	20 M.Sc.	12 Ph.D.
University of Alberta	21 M.Sc.	3 Ph.D.
Université du Québec à Montréal	6 M.Sc.	
University of Wyoming, USA		1 Ph.D.
University of Essex, UK		2 Ph.D.

5.2 ALHAS/AHP Legacy

Hail studies in Alberta evolved over a thirty year period, beginning in 1957, when relatively little was known about hailstorms in Alberta except their destructive capacity. Starting with the most fundamental observations, investigators were able to determine the extent of the hail problem and to develop conceptual models of the hailstorm. Various seeding hypotheses were suggested in an attempt to develop a weather modification technology, and experimental procedures were designed to test the validity of the conceptual model and the seeding hypotheses.

It is difficult to gauge the full impact of the ALHAS/AHP program. It likely ranks as the largest and longest-running meteorological research program in Canada in terms of people and effort. During many summers, there were in excess of 100 scientists, technicians, pilots, students, administrative staff and short-term employees serving on the project. In addition to the many scientific achievements, the project served as a training ground for meteorologists and students, many of whom went on to careers in the Meteorological Service of Canada (MSC) and other organizations. Many ALHAS/AHP participants put their field experience to good use in later research programs, including CCOPE (1981), the Greek (1986-91) and Argentine (1998-2004) hail suppression programs, CASP (1986, 1992), RES (1991), the Mackenzie GEWEX Study (1997-2005), A-GAME (2003-04), and DRI (2005-present). Graduate students continue to use AHP data in their thesis work. AHP technology and knowledge transfer to other projects is also a significant part of the AHP legacy. The operational seeding program provided tremendous experience for dozens of AHP cloud-seeding pilots and controllers, many of whom went on to work in other international weather modification programs, major airlines and related areas of the airline industry.

Statistics Canada lists the Calgary-Edmonton corridor as the fastest-growing region of Canada (http://www.statcan.ca/start.html), suggesting that severe convective storms will likely have even greater economic and human impacts in the future. Environment Canada is reacting to this concern with a planned intensive field study on severe storms in 2008, called UNSTABLE (Understanding Severe Thunderstorms and Alberta Boundary Layers Experiment). Several former AHP participants are involved in the planning and research for this project. It is described in the current issue of the Bulletin (Taylor et al., 2007), and it is based partly on the scientific foundation established by the AHP LIMEX studies. Former ALHAS/AHP scientists can rest assured that many of their findings will be utilized in this and future field research.

6. Acknowledgements

The ALHAS/AHP projects of 1957-85 were initiated and continued for three decades, because of concerns from the farming community of Alberta. They were funded in large part by grants from Alberta Agriculture and the Alberta Research Council, with significant financial participation from McGill University, the Meteorological Service of Canada (under various previous names), the National Research Council and the Natural Sciences and Engineering Research Council of Canada. However, while these agencies provided the economic ingredients for hail studies, it must be acknowledged that little research could have happened without the pioneers at the Stormy Weather Group of McGill University. They started with little or no knowledge of hailstorms, but, in a very methodical way, using innovative field measurements, the meticulous analysis and interpretation of data and the development and testing of hypotheses, they made a major contribution to hail science.

The authors of this article take great pride in having been part of the ALHAS/AHP teams for significant periods of their careers. We dedicate this article to two groups - the many scientists, engineers, technicians, summer students and others, who contributed directly to this program for more than 30 years, and the Alberta farming community, who were the instigators, supporters and beneficiaries of the program. Alberta farmers were not only the original driving force behind both ALHAS and AHP, they also helped provide a tremendous amount of volunteer scientific data, through hail and rain surveys and samples, hailpads, instrumentation sites and more, often in the midst of suffering devastating losses due to hail damage. Finally, this article reminds us of those participants and supporters who are no longer with us. Their dedication and work will not be forgotten.

Finally, we wish to acknowledge the Alberta Research Council (http://www.arc.ab.ca/), Weather Modification Incorporated (http://www.weathermod.com/), and Levelton Engineering Solutions (http://www.levelton.com/) for their financial contributions towards the cost of producing this special issue of the *CMOS Bulletin SCMO*.

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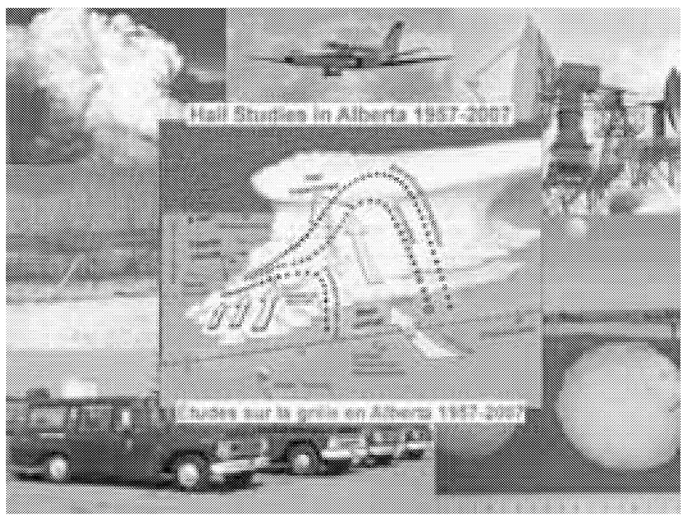

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The Understanding Severe Thunderstorms and Alberta Boundary Layers Experiment (UNSTABLE):

A Report Following the First Science Workshop 18-19 April 2007, Edmonton, Alberta

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Résumé (Traduit par la direction): Les chercheurs d'Environnement Canada et d'autres scientifiques intéressés venant du milieu universitaire et du secteur privé sont à concevoir une expérience sur les contreforts de l'Alberta afin d'examiner les processus de la couche limite atmosphérique associés au déclenchement convectif et à l'origine d'orages violents. Le projet "Comprendre les orages violents et l'expérience albertaine sur la couche limite («UNSTABLE»)", planifiée pour l'été 2008, fera usage d'un réseau à haute résolution d'instruments fixes et mobiles en surface, en altitude et en vol pour échantillonner les processus à la méso-échelle dans la zone de l'origine de ces orages. Des efforts pour rencontrer cet objectif seront faits pour transmettre les résultats aux prévisionnistes d'Environnement Canada dans le but d'accroître le temps d'attente et l'exactitude des avis et des veilles d'orages violents en Alberta et dans le reste du Canada. Faisant suite à des informations générales sur le projet, on présente un sommaire de la première rencontre scientifique d'UNSTABLE.

Introduction

Environment Canada researchers and other interested scientists from academia and the private sector are currently designing a field experiment over the Alberta foothills to investigate Atmospheric Boundary Layer (ABL) processes associated with convective initiation (CI) and severe thunderstorm genesis. The Understanding Severe Thunderstorms and Alberta Boundary Layers Experiment (UNSTABLE), planned for summer 2008 (funding permitting) or possibly 2009 (if funding delayed), will utilize a high-resolution network of fixed and mobile surface, upper air, and airborne instruments to sample mesoscale processes in this thunderstorm genesis zone. Targeted efforts will be made to transfer results to Environment Canada forecasters with the aim of increasing lead time and accuracy of severe thunderstorm watches and warnings in Alberta and the rest of Canada. Following some background information on the project, a summary of the first UNSTABLE science meeting is presented.

Rationale for UNSTABLE

The Canadian prairies are subject to a high frequency of thunderstorms and associated severe weather during the summer months. Based on severe weather reports received by the Prairie and Arctic Storm Prediction Centre (PASPC), the prairies experience an average of 203 severe weather events each summer (McDonald and Dyck 2006). Areas of the prairies experiencing a high frequency of thunderstorms are evident in climatological lightning data from the Canadian Lightning Data Network (CLDN). A map of the mean number of days with at least one cloud-to-ground lightning flash detected between 1999 and 2006 (Burrows 2006, personal communication) shows that the Rocky Mountain foothills region of Alberta experiences, on average, the most days with lightning (Fig. 1). A secondary maximum of lightning activity extends through the far southern portions of Saskatchewan and Manitoba.

> Note: In this paper, severe weather refers to the occurrence of tornadoes, hail with diameter **20 mm** or greater , convective wind gusts of **90 km h^{-1}** or greater and/or convective rainfall amounts of **50 mm** or greater in **1 h**.
>
> **ABL** = Atmospheric Boundary Layer.
> **CI** = Convective Initiation.

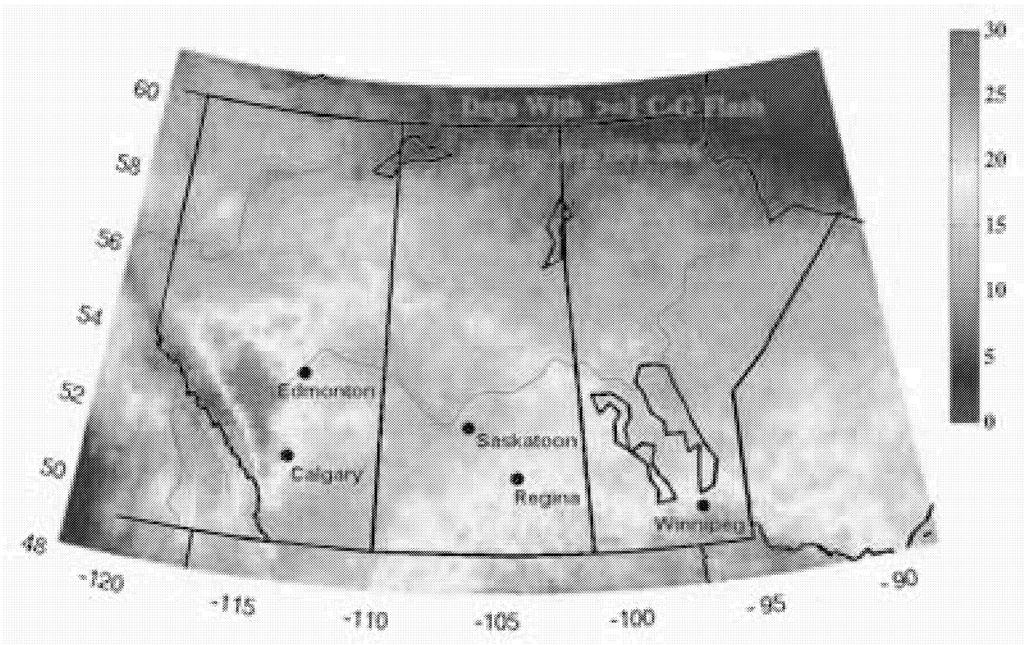

Figure 1: Climatological lightning activity over the Canadian Prairies showing the average number of days with at least one cloud to ground flash from 1999 to 2006 (Burrows 2006, personal communication).

Alberta has proven to be particularly susceptible to costly summer severe weather events. The most devastating event in the last half century is the Edmonton F4 tornado and hailstorm of 31 July 1987 resulting in 27 lives lost and damage estimates in the range of $660 M[1]. Public Safety and Emergency Preparedness Canada estimates that since 1980 more than 40 lives and $2 B have been lost in association with severe thunderstorms. Nearly all of these events occurred within the Edmonton to Calgary corridor which lies just east of the Alberta foothills. Thunderstorms developing on the foothills tend to move eastward with prevailing westerly winds aloft. Alberta contains 2 of Canada's 10 busiest airports (Calgary International 3rd and Edmonton International 6th, Transport Canada 2006) and the Edmonton to Calgary corridor is one of the most densely populated and fastest growing regions in Canada (Statistics Canada 2006, see Fig. 2). Given the above, the potential for further risk to life and property in southern Alberta due to summer severe weather events is clear. Improved understanding of processes associated with the development of severe thunderstorms in the Alberta foothills and application of that knowledge to operational forecast techniques will allow forecasters to maximize their ability to issue accurate and timely severe weather warnings and forecasts.

Meteorologists face numerous challenges with respect to forecasting severe thunderstorms. These include, though may not be limited to:

■ Limited knowledge of the ABL structure and evolution, especially with respect to the stratification of water vapour in the vertical;

■ Inadequate conceptual models to describe processes leading to CI and the development of severe thunderstorms;

■ Difficulty in detecting mesoscale boundaries and circulations in regions of interest and their behaviour in association with CI. In the absence of sufficient observations, appropriate techniques are needed to infer important atmospheric characteristics and their evolution, given available observations.

■ An incomplete understanding of important land-surface interactions with the convective ABL in the region of interest and their role in CI

■ Inconsistent performance of numerical models with respect to the above (e.g., strengths, weaknesses, systematic biases)

The foothills region of Alberta suffers from an inadequate observational network with respect to surface and upper-air measurements. The one radiosonde location in Alberta (Stony Plain, 53.52˚N 114.09˚W, 766m) is ~200 km from favoured CI regions in the foothills and is often not representative of the ABL in the pre-storm environment over the foothills region. Surface observations over the foothills region are sparse. During the summer of 2006 there was an area of ~30,000 km^2 without any real-time surface observations over the foothills west of the Edmonton – Calgary corridor (Fig. 3).

[1] Events prior to 2001 are adjusted to 1999 dollars.

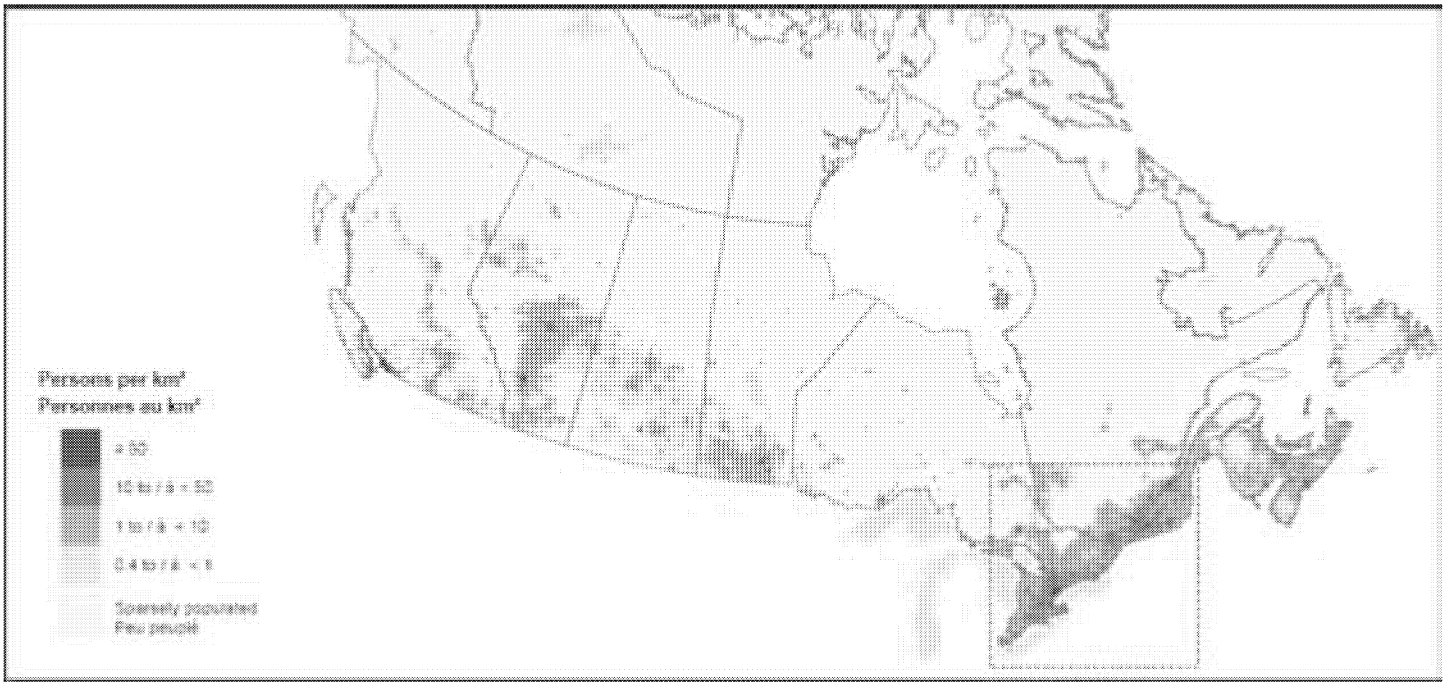

Figure 2a

Figure 2b

Figure 2: (a) Population density and (b), change in population from 2001 to 2006 over southern Canada from the Statistics Canada 2006 Census. The Edmonton – Calgary corridor is among the most densely populated and fastest growing regions in Canada.

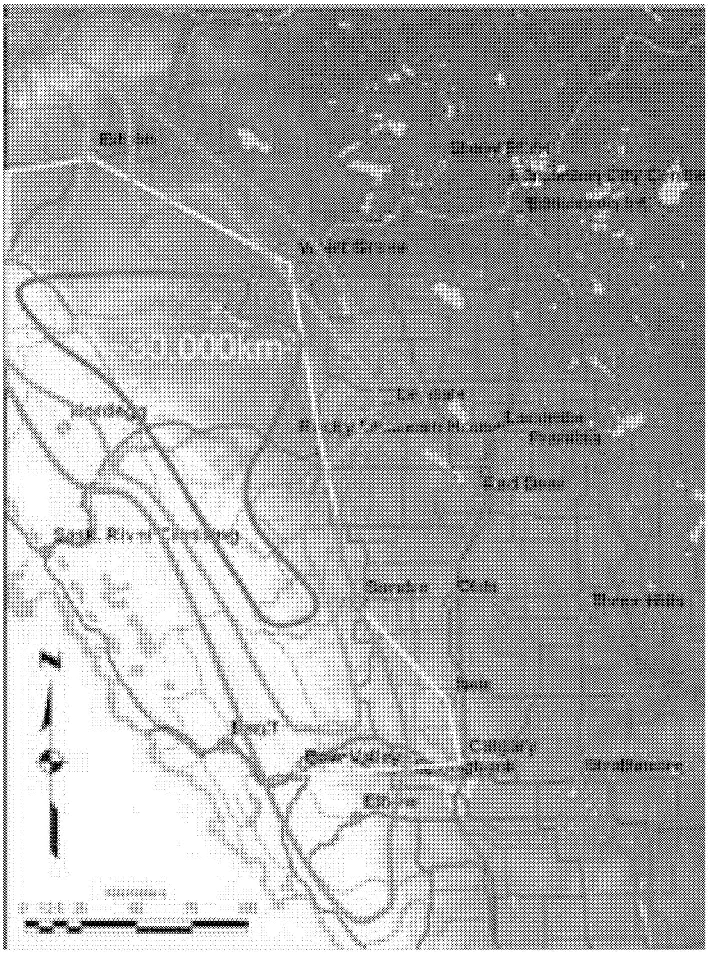

Figure 3: Hourly surface observation sites available to forecasters over the foothills region of Alberta. The yellow polygon denotes an area of just over 30,000 km^2 within which there are no real-time surface observations. Approximate contours of days with at least 1 cloud-ground lightning strike as in Fig. 1 are contoured at 22-26 (green), 27-32 (orange), and > 32 (red). We see that the area with the greatest number of lightning days corresponds to a void in surface observations within the current operational network.

A significant amount of severe thunderstorm research has occurred in Alberta dating back to the Alberta Hail Studies (ALHAS) and Alberta Hail Project (AHP) between 1957 and 1985. Later field experiments include the Limestone Mountain Experiments (LIMEX, Strong 1986, 1989) and the Alberta GPS Atmospheric Moisture Evaluation (A-GAME, Hill 2006). Research from these projects focussed mainly on hail and upper-air processes. More recent research in Canada and the U.S. has focussed on ABL moisture, convergence boundaries, and mesoscale circulations associated with CI and severe storms (e.g., Sills et al. 2002, Sills et al. 2004, Weckwerth et al. 2004, Weckwerth and Parsons 2006, Hill 2006). These findings indicate that more work is required both regionally and abroad to better understand the significance and influence of ABL processes on CI and the development of severe thunderstorms.

UNSTABLE Goals and Science Questions

UNSTABLE seeks to fill in some knowledge gaps with respect to ABL processes and severe thunderstorms. The overall goals of the UNSTABLE project can be summarized as:

- To better understand atmospheric processes leading to thunderstorm development over the Alberta foothills (both prior to and during CI) with an aim to extend results to the rest of Canada;

- To improve the accuracy and lead time for severe thunderstorm watches and warnings;

- To assess the utility of the GEM-LAM model in resolving physical processes over the Alberta foothills and its ability to provide useful numerical guidance for the forecasting of severe convection;

- To refine current existing conceptual models describing CI and the development of severe thunderstorms over Alberta and the western prairies through observational and numerical modeling studies.

A primary goal of UNSTABLE is to improve accuracy and lead time for severe thunderstorm watches and warnings. For this to be achieved, appropriate mechanisms must be in place to ensure knowledge gained from UNSTABLE is transferred to operational forecasters. Collaboration between the National Labs and Storm Prediction Centres within Environment Canada is increasing. Already, laboratory staff are involved in training workshops and seminars and have implemented Research Support Desks (RSDs, Sills 2005, Taylor 2006) directly in forecast operations within two of Canada's Storm Prediction Centres. The PASPC is anticipated to be involved in UNSTABLE during the field campaign and is involved to a lesser extent in the planning of the project. Following a period of data analysis, laboratory staff will work with the PASPC (and other Storm Prediction Centres) to incorporate results into operational conceptual models and forecast techniques. This will be accomplished through traditional means such as those listed above but also through the RSD where researchers can work with forecasters in real-time to apply UNSTABLE results to convective forecast and warning decisions.

To achieve the goals of the project, and for experiment planning purposes, three primary science questions have been formulated to investigate specific areas related to CI and severe thunderstorms. These involve ABL processes, land surface interactions, and numerical weather prediction. Scientific leads have been identified for each question to oversee their respective component of UNSTABLE including instrumentation / measurement strategies and data analysis. Each science question and a brief summary are included below.

1) What are the contributions of ABL processes to the initiation of deep moist convection and the development of severe thunderstorms in the Alberta Foothills region?

This first question deals with processes associated with ABL water vapour and convergence lines as they relate to CI and severe storm development. More specifically, we are interested in characterizing ABL diurnal evolution, water vapour stratification, and the role that mesoscale convergence boundaries and circulations play in CI. The influence of highly varied terrain and mesoscale circulations and boundaries on storm evolution will also be investigated. In recent years the dryline has been identified as an important feature for CI in the region. Four-dimensional characterization of the dryline prior to and during storm development will be a priority of the field campaign. UNSTABLE will result in a dataset of high-resolution observations that will be used to evaluate the utility of current observational networks and to modify existing conceptual models for CI and severe weather outbreaks in southern and central Alberta.

2) What are the contributions of surface processes to the initiation of deep moist convection and the development of severe thunderstorms in the Alberta Foothills region?

This question deals mainly with the effects of latent and sensible heat fluxes associated with varying soil moisture and evapotranspiration. We are interested in investigating effects of adjacent wet and dry soils (as defined by an agrometeorological model) on storm initiation and evolution. Attempts will be made to sample the development and evolution of moisture gradients and mesoscale circulations associated with surface discontinuities (e.g., land-land breezes). Targeted, high-resolution field observations will be compared with existing observations to evaluate the degree to which the current observational network can be used to detect these circulations sometimes associated with thunderstorm development.

3) To what extent can high-resolution numerical weather prediction models contribute to forecasting the initiation and development of severe convective storms that originate in the Alberta foothills?

The last science question relates to the use of high-resolution numerical modeling to forecast CI and severe thunderstorm development in the Alberta foothills. Specific questions address the ability of the Canadian Meteorological Centre's Global Environmental Multi-scale (GEM) Limited Area Model (LAM) at 2.5 km resolution to simulate ABL and surface processes investigated in questions one and two, observed storm structures, and microphysical fields. Also of interest are identifying any deficiencies in current physical parameterizations and the effects of performing nested model runs on higher-resolution grids (e.g., 1 km). Other areas to be investigated using the observational dataset from UNSTABLE include high-resolution ensemble forecasts of CI and the use of a high-resolution analysis to improve prediction of CI and subsequent storm development.

Figure 4: Environment Canada's Automated Transportable Meteorological Observing System (ATMOS).

Experimental Design

UNSTABLE will take place from 1 June to 31 August 2008 with a three-week Intensive Observation Period (IOP) planned from 9 July to 31 July. Fixed mesonet stations will be deployed prior to 1 June with all other supplementary instrumentation deployed during the IOP. The field campaign will utilize targeted, high-resolution fixed and mobile measurements from a variety of observation platforms. Central to the success of the project is a mesonet of surface weather stations, mobile surface observing platforms, multiple profilers, and an upper-air campaign utilizing multiple radiosondes, a tethersonde and, if sufficiently funded, a research aircraft. The surface mesonet is designed using both grid (~ 25 km spacing) and linear (~ 10 km spacing) configurations to resolve surface characteristics spatially and their evolution in time. The mesonet will consist of existing weather stations in cooperation with the Government of Alberta and Canadian universities and 10-15 Automated

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Transportable Meteorological Observing Systems (ATMOS, see Fig. 4). Mobile surface measurements will be used to resolve surface convergence and other boundaries in space and time. To do this we will deploy one or more Automated Mobile Meteorological Observing Systems (AMMOS, see Fig. 5) capable of atmospheric state variable measurements (including wind speed and direction) while stationary or in motion.

Figure 5: Environment Canada's Automated Mobile Meteorological Observation System (AMMOS), photo by David Sills.

Upper-air measurements during UNSTABLE will be conducted using up to 5 radiosonde systems (3 mobile and 2 fixed), a recently-purchased Vaisala tethersonde, and a number of profiling and total column water vapour instruments (radiometers and GPS precipitable water measurements) contributed by the University of Manitoba and the University of Calgary. The majority of these instruments will be deployed in fixed locations but the University of Manitoba Centre for Earth Observation Science will be participating with their Mobile Atmospheric Research System (MARS) trailer. The MARS contains a profiling radiometer, Atmospheric Emitted Radiance Interferometer (AERI) and Doppler sodar along with a surface weather station. The MARS will be deployed in conjunction with other mobile surface observations in the vicinity of mesoscale boundaries and favoured areas for CI.

The UNSTABLE study area is designed to take advantage of other existing observing networks. These include existing surface stations, the Stony Plain radiosonde station, the CLDN, Environment Canada radars at Carvel (53.56˚N, 114.14˚W) and Strathmore (51.21˚N, 113.40˚ W), and satellite imagery received by Environment Canada. Additional radar information is anticipated from the Weather Modification Inc. radar at the Olds-Didsbury airport (51.71˚N, 114.11˚W). The study area consists of a primary and a secondary domain. Most of the instrumentation described above will be deployed in the primary domain as indicated in Fig. 6. The secondary domain will allow for mobile measurements to be obtained when features of interest develop away from the foothills but in locations where storms could still impact densely populated areas. Final locations of instrumentation in Fig. 6 are still unconfirmed as mesonet and other equipment siting is under way.

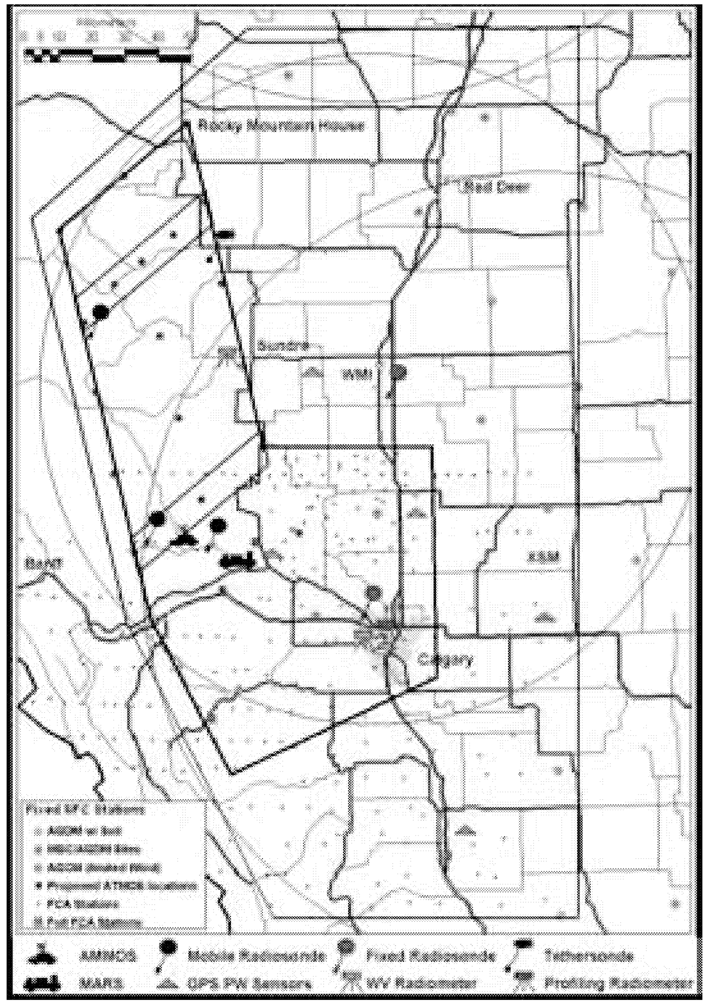

Figure 6: Map showing possible instrumentation locations within the UNSTABLE domain(s). Black circles are 120 km range rings for WHK and XSM radars and the 100 km range ring for the WMI radar. The heavy black line is the primary UNSTABLE domain enclosing the mesonet, the lighter black line is the secondary study domain. Black polygons within the primary domain are proposed locations for higher resolution lines of mesonet stations (the southern one will depend on station availability). Fixed surface mesonet and other stations are as indicated as is other instrumentation to be deployed. Final locations of fixed profiling / other platforms are to be determined. Mobile instrumentation will be deployed on Intensive Observation Days (IODs) within a specified target area. Aircraft (not shown) will be deployed on IODs when mesoscale circulations are expected to develop. Circuits and stepped traverses will be employed to sample the circulation spatially and in the vertical.

The Canadian Meteorological Centre will continue to run the GEM-LAM model in quasi-experimental forecast mode over the western 2.5 km grid during the summer of 2008. In support of UNSTABLE, the eastern boundary of this grid will likely be extended to approximately the Alberta-

Saskatchewan boarder. The full western grid (with the extended boundary) with model terrain is shown in Fig. 7. The real-time runs performed on this grid will be examined in detail during the experiment with close comparisons made to the measurements taken during the IOP period. Case study simulations and sensitivity experiments will be performed in hind-cast mode on this grid as well as finer resolution subdomains.

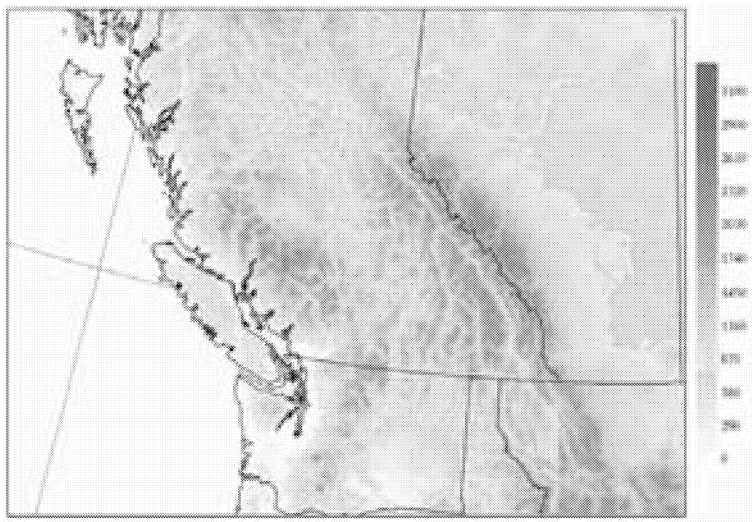

Figure 7: Western 2.5 km grid for the GEM-LAM to be used for the real-time NWP forecasting during the summer of 2008. Shading indicates model terrain elevation (m).

The First UNSTABLE Science Workshop, 18-19 April 2007

The first UNSTABLE science workshop was held in Edmonton, Alberta on 18-19 April 2007. The meeting brought together over thirty Canadian scientists from across the country representing various divisions of federal and provincial government agencies and Canadian universities. This workshop was an opportunity for interested participants in the experiment to share their interests and contributions to the project and to discuss the draft science questions along with strategies for answering them. The meeting allowed the principal investigators to confirm the level of contribution of participants and their involvement in the field campaign. Results of discussions from the meeting are being used to refine both the science questions and the UNSTABLE science plan. Organizations that were represented at the meeting are listed in the table shown below.

Organizations represented at the Science Workshop held in Edmonton, Alberta, 18-19 April, 2007

Hydrometeorology and Arctic Laboratory, Environment Canada
Cloud Physics and Severe Weather Research Section, Environment Canada
Prairie and Arctic Storm Prediction Centre (Edmonton and Winnipeg), Environment Canada
Climate Research Division, Environment Canada
Recherche en Prévision Numérique, Environment Canada
University of Manitoba
University of Alberta
University of Calgary
McGill University
Canadian Forest Service
Alberta Agriculture and Food
Alberta Environment

The workshop began with presentations on UNSTABLE observations. These included descriptions of the Foothills Orographic Precipitation Experiment (FOPEX, Smith 2005, 2007), The Alberta GPS Atmospheric Moisture Evaluation (Hill 2006), The Foothills Climate Array mesonet (M. Adams, University of Calgary), GPS measurements of precipitable water (S. Skone, University of Calgary), and the Province of Alberta surface weather stations. The second session of the meeting included presentations from UNSTABLE collaborators and included representatives from the University of Manitoba, University of Alberta, the Prairie and Arctic Storm Prediction Centre, and McGill University detailing their interest and contributions to the project.

Following the formal presentations, science leads summarized their respective science questions and strategies for answering them. Science leads are (1) Neil Taylor and David Sills (Environment Canada), (2) John Hanesiak (University of Manitoba), and (3) Jason Milbrandt (Environment Canada). These presentations served as an introduction to guided break-out sessions. Participants were asked to select one of the science questions and contribute to discussions on such things as:

- Refinement of specific science questions as presented in the draft science plan;
- Who plans to be directly involved in the field campaign and how?
- Funding strategies and opportunities for in-kind support;

- Data requirements, instrumentation and deployment strategies necessary to answer the science questions;

- 'Champions' for data analysis and quality control.

Break-out discussion results were presented to the group as a whole on the morning of 19 April followed by open discussion by participants.

The workshop achieved its goals and allowed potential UNSTABLE participants to discuss details of the project for an extended period of time. This workshop was invaluable to help refine the direction of the project with respect both to the science objectives and strategies to fulfill them. It also provided an opportunity for UNSTABLE participants to formalize their involvement and contributions to the project. Results from the discussions included identification of a lead for the upper-air campaign, clarification of instrumentation available from Canadian universities, preliminary agreements with respect to data sharing, and support from the PASPC.

Next Steps

Planning for UNSTABLE continues with many issues remaining to be addressed. The science plan is now being revised for submission to Environment Canada management for funding. Specifically, the science questions themselves will be finalized along with instrument requirements and measurement strategies. Beginning in fall 2007 the UNSTABLE field operations plan will be finalized including a data management strategy. This document will detail all logistics issues to be considered during the field campaign (e.g., people in the field, communications, instrumentation, training, occupational health and safety, etc.). Following the production of a draft operations plan, a small and focussed workshop will take place to refine the details. In early spring 2008 instrumentation land-use agreements for mesonet sites will be finalized leading up to deployment and testing in May 2008. Testing of mobile instrumentation and communications will occur in June prior to the intensive observation period scheduled to begin on 9 July 2008.

Summary

UNSTABLE is a collaborative project bringing together scientists from Environment Canada, Canadian universities, other federal and provincial government agencies, and the private sector to investigate severe thunderstorm development in Alberta. The focus on atmospheric boundary-layer phenomena reflects current knowledge gaps within the meteorological community in understanding how thunderstorms form. With a focussed transfer of results into Environment Canada forecast operations, there is an opportunity to enhance lead time and accuracy of severe weather watches and warnings, both in Alberta and across the country.

The first science meeting of the UNSTABLE project was an important step in developing the project. By bringing together the collective knowledge and experience of scientists working in related areas across the country, we can refine the scientific objectives of UNSTABLE and leverage their contributions to ensure its success.

Figure 8a

Figure 8b

Figure 8: Photos from the First UNSTABLE Science Workshop, (a) Hydrometeorology and Arctic Laboratory manager Gary Burke welcoming participants to the workshop, and (b) participants during one of the coffee breaks. Photos courtesy Jingang Wu.

Acknowledgements

Thanks to CMOS for providing hospitality for the first UNSTABLE science workshop, and for the opportunity to publish this article in the *CMOS Bulletin SCMO*. We would also like to thank all the participants in the UNSTABLE science workshop for helping to refine the science plan and for ongoing discussions and contributions to the project. Special thanks go to Stewart Cober, Gary Burke, and others in Environment Canada for supporting the project and ensuring that UNSTABLE will go ahead.

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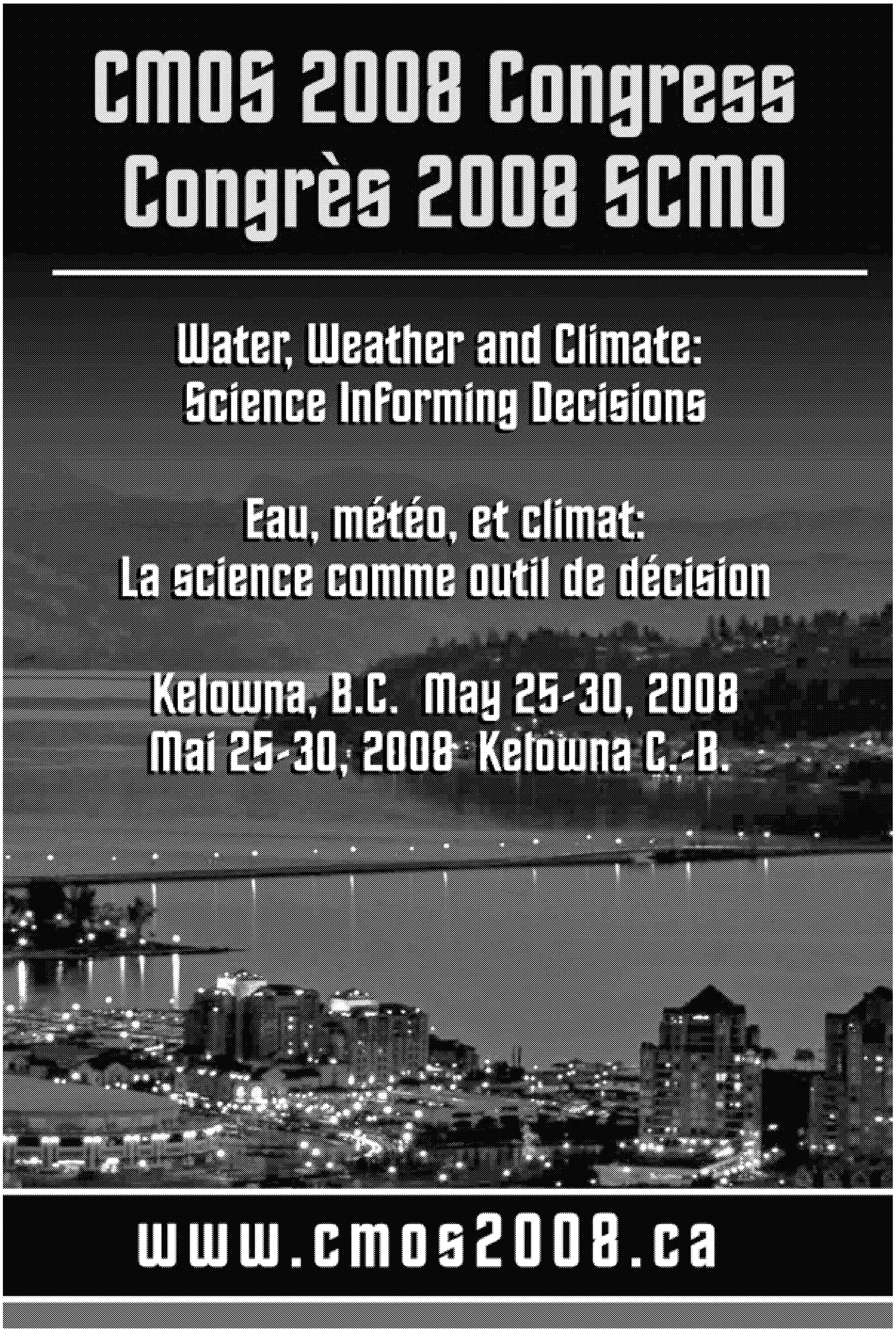
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Congrès 2008 SCMO
Water, Weather and Climate:
Science Informing Decisions
Eau, météo, et climat:
La science comme outil de décision
Kelowna, B.C. May 25-30, 2008
Mai 25-30, 2008 Kelowna C.-B.
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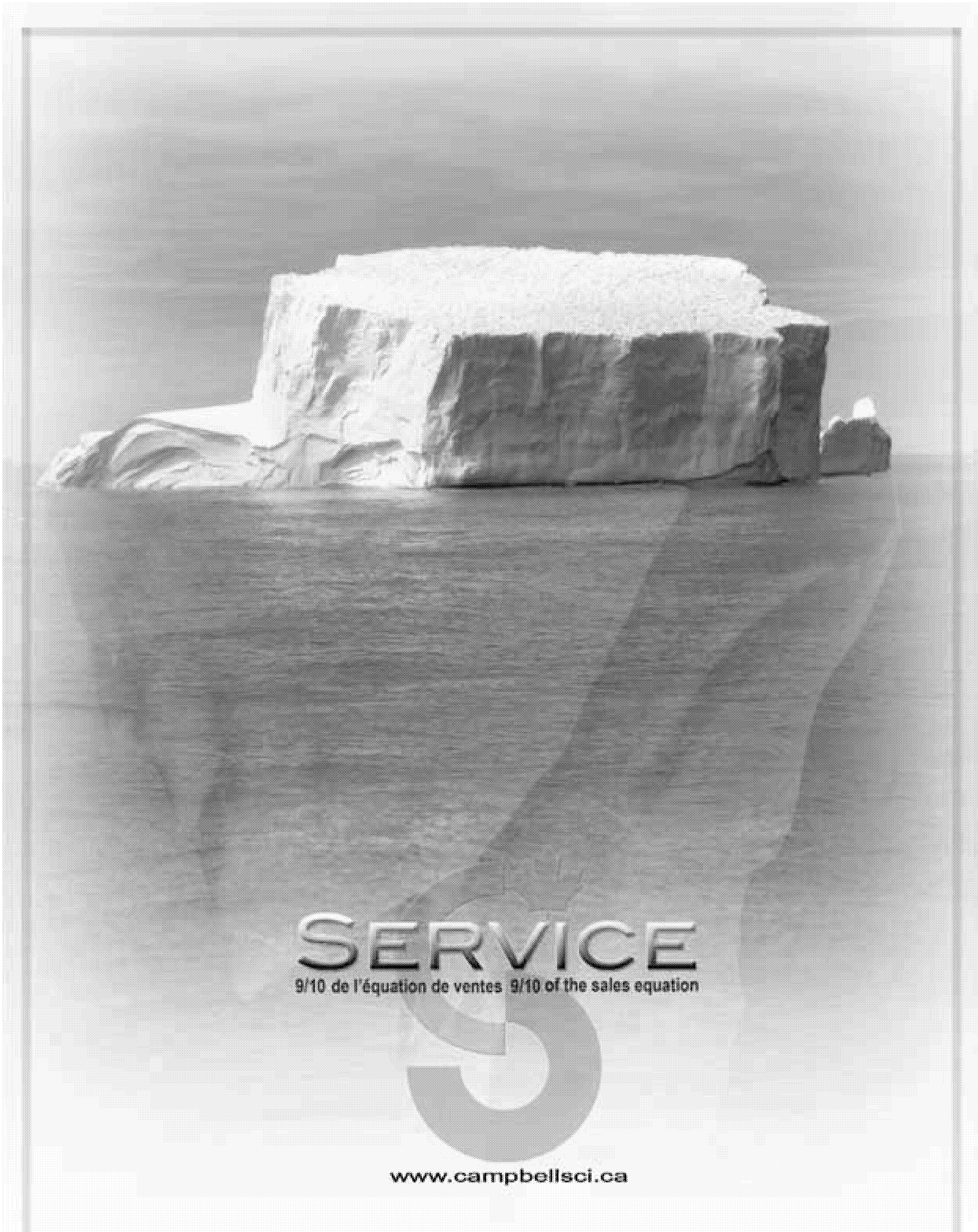
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Jatar, Muriel (EC)

From: George Isaac
Sent: November 21, 2013 8:02 AM
To: Cober, Stewart (EC)
Subject: Weather Modification
Attachments: MSC and Weather Modification2.doc

Stewart,

I found this in my files. It may be enough for you. Note sure how much material you need. This document was written in 2002 probably with my input. I could have been the main author but it does not look like my style.

Should I continue to look for the Chisholm document?

George

____

George Isaac
E-Mail:

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MSC and Weather Modification

Introduction:

Weather modification is the changing of natural weather conditions or systems by man. This can be done both in planned ways such as cloud seeding, and in ways that are unplanned such as creating urban heat islands. Our knowledge of weather modification is largely experimentally based. Advances in weather modification could have major economic and political consequences especially since, as climate change becomes more visible weather modification could offer a direct means of adapting to changes in the weather and particularly it could be viewed as part of an integrated water resources management strategy.

This sort of proposition is being actively discussed on an international basis, for example in the CMOS Bulletin Volume 30 Number 3 "*Can We Influence Global Weather? Some Scientists say Theoretically Yes, Practically, Not Yet*" in which Ross N. Hoffman with Atmospheric and Environmental Research Inc. (AER) is quoted as saying: "We believe there is good reason to pursue this research now at this early stage to set the stage for discussions about the social and political issues". His work has been funded by the NASA Institute for Advanced Concepts (NIAC), see http://niac.usra.edu/.

Several issues have arisen recently which have resulted in renewed Canadian interest in weather modification:

- the drought in the west, resulting in some concern in Saskatchewan that Alberta is removing rain from clouds
- weather modification projects are considered from time to time, currently one is being considered in B.C.
- the interest of the public in "chemtrails"
- the new CMOS policy on Weather Modification.

Issues related to weather modification are clearly increasing in visibility. Realization that the MSC is the federal lead for weather modification raises issues such as "What is our role in the science behind weather modification? What is our role in national policy?"

The purpose of this discussion paper is to provide some background on the issue and to begin to formulate some options for a way forward in this area.

Background:

In Canada, weather modification is covered by the Weather Modification Information Act, which is administrated by the ADM of the MSC. It has no duties attached to it with respect to actually modifying the weather or with respect to regulating weather modification activities, however it is our duty to report projects which do modify weather.

Currently, Jack Power is the Weather Modification Information Officer and has reported, as recently as June, 2002, to the WMO on the status of weather modification in Canada in 2001. Annual reports on Canada's activities in this area date back to 1975 and are available in the library.

The only project that is being reported to the WMO is one on hail suppression in an area near Calgary in Alberta. This project is supported by the Insurance Industry and utilizes three aircraft in summer cloud seeding. Jack's report states: "Any cloud deemed to be a 'hail threat' to a city or major town within the project area may be seeded. Radar criteria for objective hail potential is any cell having greater than 10 km^3 of 40dBZ reflectivity extending above 3 kms altitude and expected to reach a target area in less than 30 minutes."

The Atmospheric Environment Service was an active player in weather modification, especially to the Alberta Hail Studies Project. A Summary report by Dr. A. J. Chisholm completed in 1972 indicates that a total of $1,184,800 was spent on scientific support through McGill University and field support for the years between 1955 and 1973. During 1972, the Government of Alberta appointed a special committee to investigate crop insurance and weather modification in Alberta. AES and many others submitted briefs. The interim report recommended that the Alberta Government finance a 5 year active hail suppression program at a cost of about $1M per year. The program was envisaged to begin in 1974 under the umbrella of an Alberta Weather Modification Act. The Alberta Hail Project ended in the mid-eighties.

In addition, a large precipitation enhancement project was undertaken in Quebec by MSC from 1959 to 1963 inclusive (Godson et al., 1966). The results of this work indicated that the effects of seeding (dispersing silver iodide, AgI, from aircraft) were not statistically significant. In the 1970's, in cooperation with the Canadian Forestry Service, a project led by MSC in the Northwest Territories and Ontario determined that clouds could be modified by AgI seeding but that significant amounts of rainfall were not produced (Isaac et al., 1977). Since this work, MSC has not actively engaged in weather modification research, except fro some small studies in aid of the Alberta efforts. These essentially ceased when the Alberta Hail Project was cancelled by the Alberta Government.

The CMOS Policy Statement on Weather Modification, revised in February, 2002 and entitled "*Improved Knowledge Needed Before Tinkering With Nature*", states:

The Canadian Meteorological and Oceanographic Society, noting the longstanding controversy about local weather modification and more recent evidence of a changing climate, issues this policy statement for the information of all concerned.

Humans modify the weather deliberately and unintentionally. An example of deliberate weather modification is the attempted change in local weather conditions (fog, low clouds and precipitation) by means of controlled, scientifically-based cloud seeding. Unintentional weather modification includes the effects of industrial or agricultural activities on local weather, including air quality. The focus of this statement is limited to *deliberate or unintentional changes in local or regional weather conditions. CMOS has a separate statement on global climate change.*

CMOS recognizes that there are some clear cases of successful deliberate weather modification. An example is the dissipation of supercooled fog and low stratus through seeding with ice-forming agents at selected airports. However, clear statistical evidence and physical cause-and-effect relationships o f the outcomes of planned weather modification are frequently difficult to establish. Concerning unintentional weather modification, improved environmental monitoring and modelling capabilities have shown that human activities can have significant impacts on atmospheric parameters that influence our health and social infrastructure.

CMOS supports efforts aimed at improving our understanding of the physical processes and determining the effects of planned and inadvertent weather modification. Such studies have to be carried out on a scientific basis, in an environmentally responsible way. There should be a concerted effort to improve the knowledge ot the physical processes involved, to enlarge the data base, and to have an objective evaluation methodology of the impact.

In Canada also, there are a number of people who believe that the contrails from planes are, in fact "chemtrails" which will alter the weather/climate in profound ways and which are caused by additives in jet fuels or even by the military. Their thinking is reflected in a variety of web sites which provide picture galleries, case studies, newspaper articles and reports from various observers, for example; *http://www.chemtrailcentral.com/report.shtml and http.//www3.bc.sympatico.ca/Willthomas/chempics/chempics.htm.* In the past six months there have been 25 letters to the Minister of the Environment having this concern, enough to provoke the writing of a generic reply which states, in part:

You ask whether a new additive is being mixed with jet fuel. In Canada, the specification for jet fuel is controlled by a Canadian General Standards Board (CGSB) Committee that includes fuel suppliers, fuel users and other stakeholders. The specification sets limits on all important fuel parameters and prescribes test methods for ensuring consistent fuel quality.

Binationally, there is a *Canada-U.S. Agreement related to the Exchange of Information on Weather Modification Activities* which came in force in Canada in 1975. "This Agreement establishes obligations to facilitate cooperation and the exchange of information between the Parties regarding weather modification activities that may have transboundary effects. Weather modification activities as defined under the Agreement are those activities performed with the intention of producing artificial changes in the composition, behavior, or dynamics of the atmosphere. In the Agreement's preamble, it is noted that a diversity of weather modification activities are being carried out in both countries by private parties, provincial and state authorities and by the federal governments." The last letter from the U.S. was in 1991, indicating that this agreement is somewhat moribund.

Internationally there is interest in weather modification as well. A thorough review is beyond the scope of this report.

The World Meteorological Organization, under the Atmospheric Research and Environment Programme has "Physics and Chemistry of Clouds and Weather Modification Research". They have "Guidelines for advice and assistance related to the planning of weather modification activities", approved by the fifty-third session of the Executive Council in June 2001, and a "WMO statement on the status of weather modification". The Guidelines are careful to state:

> *Members wishing to develop activities in the field of weather modification should be aware that research and operational applications are still under development."*

In addition, there is a Register of National Weather Modification Projects (to which Jack's report contributes) and a series of WMO Scientific Conferences on Weather Modification, the seventh was held in Chiang Mai, Thailand in 1999.

Possible Options for the Future:

Given the level of interest and visibility, it is important to assess the current approach being taken by the MSC in administering the Act, in undertaking relevant science, in participating in international activities and in leading the federal government in the area of weather modification and develop an MSC position on the issue. Several options can be identified:

- Do nothing except continue to report to the WMO as demanded by the Act
- Adopt a more proactive stance including developing a research program in this area.
- In either case, a more thorough look at the policy options is required. Opportunities that could be realized through a more proactive approach need to be defined and risks and costs identified.

In defining the scope of this assessment, it will be necessary to discuss possible roles that the MSC may wish to play:

- status quo - deal with issues individually as they arise
- scientific leadership - appropriate level of scientific effort for the program.
- part of policy agenda - in a recent scan of policies pertaining to AES, no policies related to weather modification were found; a policy basis for this area could be developed.
- part of legislative/cabinet agenda - the Weather Modification Information Act could be reviewed with an eye to modernization. This activity could potentially underpin an approach to Cabinet for new authorities or resources.

In the near term, it is important to name a "champion" for this issue and assign the follow up to them, with responsibility to report back to ExCom, OMC, etc. on a regular basis.

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Jatar, Muriel (EC)

From: Isaac,George [Ontario]
Sent: March 21, 2013 1:20 PM
To: Lin, Charles (EC); Dodds, Karen (EC)
Cc: Bouchet, Véronique (EC); Joe, Paul (EC); Cober, Stewart (EC); Banic, Cathy (EC); Shepherd, Marjorie (EC)
Subject: IAMAS Statements on Geo-engineering

ICCP Radiation... StatementOnGe...

To All,

Here are two statements by two International Association of Meteorology and Atmospheric Sciences (IAMAS) organizations on Geo-engineering, prepared by the International Commission on Clouds and Precipitation and the International Ozone Commission.

Both have been written recently and you might not be aware of them.

The international community is taking this issue very seriously.

Regards…..George

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International Commission on Clouds and Precipitation (ICCP)

Statement on Radiation Management Climate Engineering

Draft, January 2013

Global average temperatures are rising due to human emissions of greenhouse gases (GHGs). This is helping to drive widespread melting of snow and sea ice and will result in significant changes in precipitation patterns that will be detrimental to humanity and to Earth's biodiversity.

Different strategies have been proposed to reduce climate change risks. Emissions reductions are a possible long-term solution, but it has been difficult to make progress in achieving such reductions. Adaptation is a second possible course of action, but is likely to be one that sees large reductions in biodiversity and would not be a suitable strategy in the event of catastrophic climate change such as rapid melting and disintegration of the Greenland or West Antarctic ice sheets. A third possible course of action, and the most radical, involves *climate engineering* (or *geoengineering*). This is the deliberate manipulation of the Earth's physical, chemical or biological processes to counteract deleterious effects of climate change.

This ICCP policy statement focuses upon a subset of climate engineering strategies called *Radiation Management* (RM) that attempt to reduce the amount of solar or infrared radiation reaching the Earth's surface. Proposed RM techniques include: 1) those designed to reflect more sunlight back to space, examples of which include space-based mirrors, introducing sulfate aerosols into the stratosphere and increasing the droplet concentration in marine low clouds; 2) reducing thin cirrus optical depth and cloud cover that prevents longwave radiation escaping to space.

Given the current state of understanding, RM could only be considered as a strategy of last resort should catastrophic climate change become unavoidable in the future. ICCP recognizes that current scientific research on RM techniques is in its infancy and that the current level of scientific knowledge about the feasibility of RM techniques is an inadequate basis for shaping policy decisions. Little is known about the potential risks of deliberate attempts to change the Earth's radiation budget. For example, it is becoming widely accepted that anthropogenic GHGs, ozone and absorbing aerosols may all be playing important roles in changing the latitude of storm tracks and the intertropical convergence zone. Further regional to global-scale adjustments caused by climate engineering would induce regional precipitation changes that would not necessarily cancel those caused by GHGs and therefore may not uniformly benefit all nations, peoples and ecosystems. This has major sociopolitical and ethical implications that have to be considered.

In addition to the potential risks of climate engineering applications, there are also major concerns that the development of RM strategies might be seen as an equivalent to emissions reduction strategies. Radiation management cannot substitute for GHG emissions reduction strategies for the following reasons: 1) the areal patterns of radiative forcing associated with GHGs is fundamentally different from those expected from RM, 2) RM management does not prevent other deleterious impacts of GHGs such as ocean acidification, and 3) the lifetimes of GHGs are much longer than the species of gases and particles that have been proposed as potential geoengineering agents.

The International Commission on Clouds and Precipitation recommends:

- That further research is pursued to better understand the fundamental science and possible efficacy of radiation management climate engineering schemes.
- That climate engineering research be conducted in an open and independent manner that engages public participation, and is used to properly assess the potential risks involved.
- That research activities must include studies of the human impacts, ethics, legal and political impacts of climate engineering

Given the poor state of the current knowledge on clouds, aerosols, precipitation and their interactions, the ICCP does not support the implementation of climate engineering and does not expect that climate engineering can solve the global warming problem. Climate engineering cannot substitute for aggressive emissions reduction. However, ICCP supports conducting research to improve our basic understanding of the processes needed to explore the possibility that climate engineering might contribute to a broad risk management strategy to temporarily reduce some of the dangerous effects of climate change.

International Association of Meteorology and Atmospheric Sciences (IAMAS)

International Ozone Commission (IO3C)

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March 15th, 2013

Statement on Geo-engineering (solar radiation management by the injection of aerosols into the stratosphere) for the reduction of climate change

Rising concerns about increased greenhouse gases have led to suggestions that various geo-engineering concepts be investigated as possible temporary "solutions" for moderating climate change[1]. In particular, solar radiation management (SRM) by the injection of aerosols into the stratosphere has been proposed as a technique to increase the reflectivity of the Earth's atmosphere, and thereby reduce the amount of solar energy passing through the atmosphere to the Earth's surface. This reduction of incoming solar energy could counteract the increase in surface temperatures caused by increasing abundances of greenhouse gases.

Early research has suggested that the deliberate injection of aerosols into the stratosphere would directly alter not only climate (as intended), but also stratospheric ozone levels and the climate in the lower stratosphere (unintended consequences). Ozone changes are of particular concern because ozone screens the Earth's surface from harmful solar ultraviolet radiation. The discovery of the Antarctic ozone hole in 1985 and subsequent scientific research demonstrated that the ozone layer has been endangered by massive emission of chlorine and bromine compounds into the atmosphere (the so-called ozone depleting substances – ODS, e. g., chlorofluorocarbons and halons) by human activities. This research revealed the important role of heterogeneous chemistry occurring on stratospheric aerosol and polar stratospheric clouds for ozone depletion in Polar Regions and at global scale (heterogeneous chemistry also occurs on surfaces of volcanic aerosols). The 1987 Montreal Protocol regulated the production and consumption of ODS, and the ozone layer should recover during this century.

The effects of aerosols in the stratosphere are broadly understood because of many years of research on the evolution of injections of volcanic plumes into the stratosphere. The Mt. Pinatubo eruption, in particular, which occurred in 1991 in a

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[1] Crutzen, P. J., Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?, *Climatic Change, 77*, 211-219, doi: 10.1007/s10584-006-9101-y, 2006

period of high ODS levels in the stratosphere, injected a sulfur dioxide cloud into the stratosphere that spread across the planet and led to reduced levels of ozone.

The Mt. Pinatubo eruption demonstrated the efficacy with which future deliberate injections of stratospheric aerosols could cool the Earth's surface. However, in spite of numerous studies of this massive injection, our ability to fully simulate the eruption remains relatively crude and a number of open questions about the eruption's impact in the stratosphere are still unanswered. For example, it is clear that while stratospheric chemistry was significantly altered in both hemispheres, only the Northern Hemisphere exhibited large stratospheric ozone losses. Current models of the stratosphere have been unable to simulate this basic difference in ozone losses. Hence, most current models are also not adequate to simulate the full effects of deliberately injected aerosols.

Closing this gap in modeling the effects of stratospheric aerosols from natural or anthropogenic sources will require a focused effort within the atmospheric modeling community. The Geo-engineering Model Intercomparison Project (GeoMIP) is a first effort to assess model simulations of geoengineering concepts such as direct aerosol injection. Continued observations of vertically highly resolved stratospheric composition and dynamics in the upper troposphere and lower stratosphere will be required to support a focused modeling effort by providing essential modeling constraints.

The understanding of aerosol and ozone changes gained from the Mt. Pinatubo eruption was a direct result of careful observations by ground stations, aircraft, balloons, satellites, and modeling studies conducted both before and after the eruption. Observations prior to an eruption provide a baseline for evaluating the ozone and climate perturbations caused by the volcanic aerosols. Large volcanic eruptions reaching the stratosphere are episodic on a multi-decadal timescale. Hence, maintaining global observational resources for ozone, aerosol and related atmospheric parameters is essential if we are to achieve a comprehensive understanding of the effects of aerosol injection into the stratosphere.

Based on the expertise of its members, the IO_3C recommends that research institutions around the world continue to support observational and modeling research related to stratospheric aerosol science in order to fill the known gaps in our current understanding and modeling skills and to respond fully to interest from the policy community in how stratospheric ozone may respond in an atmosphere changed by unexpected volcanic emissions or deliberate anthropogenic sulfur emissions.

Thanks to the Montreal Protocol, the levels of ODS are now declining in our atmosphere and it is expected that ozone levels will rebound back towards their natural levels in the coming few decades. However, the ozone layer is meanwhile very vulnerable, and deliberate injections of aerosols into the Earth's atmosphere have the potential to cause significant ozone reductions.

Jatar, Muriel (EC)

From: Cober, Stewart (EC)
Sent: April 4, 2012 11:15 AM
To: O'Brien, Lesley (EC)
Cc: Cober, Stewart (EC)
Subject: FW: Please advise: Weather Modification Information Act

Hello Lesley,

I made one minor change and added one comment to the letter. Otherwise it is fine. Note that we recently digitized all of the weather modification reports to make it easier to provide the information when requested by a member of the public.

Stewart

From: OBrien,Lesley [NCR]
Sent: 4-Apr-12 11:00 AM
To: Cober,Stewart [Ontario]
Cc: OBrien,Lesley [NCR]
Subject: Please advise: Weather Modification Information Act

Hello Stewart,

Back in July 2009, you helped MSC respond to a request from the Minister's staff regarding the Weather Modification Information Act and activities by Weather Modification Inc. (WMI). Simply for reference, I have attached the exchange that you had with MSC's Ministerial Services Unit.

RE: FOR URGENT ACTION&#; MI...

Well, almost three years later, we have a similar request from the Minister's staff for a backgrounder on the Act. I wanted to check with you to see if you were still the group that maintains the records related to weather modification activities. I am attaching a draft of the response that I am working on for the Minister's staff, in which I reference your group. Please confirm, and please do not hesitate to offer any comments on the response that I am proposing.

MOS 12280 - Weather Modifi...

We have a short turnaround time for this request, given that we are off on Friday and Monday, so if you could get back to me by COB tomorrow or early on Tuesday morning at the latest, it would be most appreciated.

Thank you for your time,
Lesley

Lesley O'Brien-Latham
Manager, Policy Development and Analysis | Gestionnaire, Analyse et élaboration des politiques
Strategic Integration Division | Division de l'intégration stratégique
Business Policy Directorate | Direction de la politique de l'entreprise
Meteorological Service of Canada | Service météorologique du Canada
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Government of Canada | Gouvernement du Canada
Website | Site Web www.ec.gc.ca

s.16(2)

From: Cober,Stewart [Ontario]
Sent: July 27, 2009 9:31 PM
To: Beauchamps,Jean-Max [NCR]
Cc: Ricketts,Steve [Edm]; O'Brien,Lesley [NCR]; Hood,Michelle [NCR]; Cober,Stewart [Ontario]; Burke,Gary [Edm]
Subject: RE: FOR URGENT ACTION; MIN-126521 - Alberta Weather Modification

Hello Jean-Max,

Yes, my Section (Cloud Physics and Severe Weather Research Section of Meteorological Research Division) is responsible for maintaining the weather modification file in Environment Canada. Under the weather modification information act any organization that intends to undertake weather modification in Canada has an obligation to report their intentions to Environment Canada. Following each weather modification campaign, the same organizations are responsible for submitting a report to Environment Canada. Each year the World Meteorological Organization asks each member to submit a report to them detailing the weather modification activities in the past year.

Weather Modification Inc. (WMI) has been undertaking weather modification in the foothills of Alberta in the Calgary-Red Deer corridor for the past several years and there is a campaign ongoing at the present time. They essentially seed each developing convective cloud system (during the summer months) that meets certain thresholds with respect to the potential for forming damaging hail. The intent is to reduce hail damage. They are funded by the insurance bureau of Canada. They have correctly submitted the intentions and post-campaign reports each year and I have records of each of these reports.

Environment Canada is not involved in these weather modification activities, nor is any other federal department.

During the summer of 2008, WMI participated in an Environment Canada research field study that was studying convective initiation in Alberta (the UNSTABLE project). This field project was not associated with the WMI weather modification activities.

I hope that this provides sufficient information. If you have any additional questions please call me at

Stewart

Stewart Cober
Chief, Cloud Physics and Severe Weather Research Section
Science and Technology Branch
Environment Canada
4905 Dufferin Street
Toronto, Ontario, Canada, M3H 5T4
Phone: 416-739-4618
Fax: 416-739-4211
Email: Stewart.Cober@ec.gc.ca

From: Beauchamps,Jean-Max [NCR]
Sent: 27-Jul-09 4:14 PM
To: Burke,Gary [Edm]
Cc: Cober,Stewart [Ontario]; Ricketts,Steve [Edm]; O'Brien,Lesley [NCR]; Hood,Michelle [NCR]
Subject: RE: FOR URGENT ACTION; MIN-126521 - Alberta Weather Modification
Importance: High

Thanks Gary,

s.19(1)

Hi Stewart,

Could you please confirm the information below ?

Thanks

Jean-Max

From: Burke,Gary [Edm]
Sent: July 27, 2009 4:03 PM
To: Beauchamps,Jean-Max [NCR]; Gadal,Jaymie [Ontario]
Cc: Jean,Michel [Montreal]; Lacasse,Danielle [NCR]; Crowe,Michael [NCR]; O'Brien,Lesley [NCR]; Hood,Michelle [NCR]; Grimes,David [NCR]; Ricketts,Steve [Edm]; Cober,Stewart [Ontario]
Subject: RE: FOR URGENT ACTION; MIN-126521 - Alberta Weather Modification

Jean-Max,

Jaymie is at the moment and will be returning on August 10th. Steve Ricketts is filling in for Jaymie while he is away.

However, I believe that this has come up in the past and Stewart Cober responded on behalf of the branch as I believe that it is his unit that is responsible for reporting on any weather modification activities.

I've copied Steve and Stewart on this note.

Gary

From: Beauchamps,Jean-Max [NCR]
Sent: Monday, July 27, 2009 1:58 PM
To: Gadal,Jaymie [Ontario]; Burke,Gary [Edm]
Cc: Jean,Michel [Montreal]; Lacasse,Danielle [NCR]; Crowe,Michael [NCR]; O'Brien,Lesley [NCR]; Hood,Michelle [NCR]; Grimes,David [NCR]
Subject: FOR URGENT ACTION; MIN-126521 - Alberta Weather Modification
Importance: High

Hi Jaymie and Gary,

My name is Jean-Max Beauchamps and I am the new manager of the Ministerial Services Unit for MSC.

MSC received an urgent request from the Minister's office to be responded to by **cob July 28**
The request addresses the following question :

Is there any federal involvement with the Alberta Weather Modification?
http://www.weathermod.com/projects/hail/alberta.php

Through some research, we were able to pull out some text from previous dated memos concerning the Weather Modification ACT which may be of assistance:

" Canada has the Weather Modification Information Act and Weather Modification Information Regulations. The Weather Modification Information Act of 1971 requires any person proposing to engage in weather modification activities in Canada to give notice of their intention, to keep full documented records of their activities, and submit a report to the Administrator of the Act on a monthly basis. The details are given in the Weather Modification Information Act Regulations of 1974. The Administrator is designated as the Assistant Deputy Minister, Atmospheric Environment Service".

Could you please provide us a brief and simple response to the question?

Thanks

Jean-Max Beauchamps
Senior Policy Advisor
Meteorological Service of Canada - Service météorologique du Canada
Ministerial Services Unit - Unité des services ministériels
Tel: (613) 943-5649

MOS 155980 –Weather Modification Information Act

PURPOSE:
To respond to a request from the Minister's Office to provide a backgrounder on the Weather Modification Act, which includes responses to the following questions:

- Who is the administrator?
- Who do people report to if they will be changing the weather?
- Who do they share reports with and where to people access the information?

RESPONSE:
The Assistant Deputy Minister, Meteorological Service of Canada (formerly Atmospheric Environment Service of Canada) of Environment Canada is the administrator of the *Weather Modification Information Act*.

Under this Act, any organization that intends to undertake weather modification activities in Canada has an obligation to give notice of their intention, to keep full documented records of their activities, and submit a report of the activity to Assistant Deputy Minister, Meteorological Service of Canada (formerly Atmospheric Environment Service of Canada) of Environment Canada.

The department (i.e. the Cloud Physics and Severe Weather Research Section, Science and Technology Branch) maintains records of these reports. The reports are not available in the public domain; however, as per the Act, the records may be made public or made available on request to any member of the public.

As a member of the World Meteorological Organization (WMO), each year Canada's Permanent Representative (ADM MSC, David Grimes) is asked to submit a report to them detailing the weather modification activities in the past year.

Environment Canada is not involved in weather modification activities, nor is any other federal department.

Jatar, Muriel (EC)

From: Isaac,George [Ontario]
Sent: April 2, 2012 11:12 AM
To: Joe, Paul (EC); Flato, Greg (EC); Cober, Stewart (EC); Vaccaro, Lisa Marie (EC); Brunet, Gilbert (EC); Carou, Silvina (EC)
Cc: Jayne, Lisa (EC); Walker, Anne (EC)
Subject: RE: Climate geo-engineering Memo to DM

To All.

Here are some suggested amendments to Paul's paragraphs:

"Geo-Engineering generally refers to modification of the climate and proposals have suggested such things as changing the global radiation budget (injecting dust into the stratosphere or spreading black carbon on snow) the hydrological cycle (making more low level clouds or increasing the number concentration of cloud droplets) or by carbon sequestration (seeding the ocean to grow plankton which update carbon dioxide and fall to ocean floor). This is relatively new and still mainly at the conceptual stage although some limited experiments have been done."

"Weather modification refers to a more local scale where clouds or cloud systems are modified for the enhancement of precipitation, hail suppression, dissipation of fog and more lately tornado and hurricane suppression. Weather modification has been around for many decades and there are many operational projects through out the world, including one in Alberta for hail suppression. However, very few of these projects, despite being supported by sophisticated numerical models and conceptual studies, have demonstrated any statistically significant findings. Supporters of weather modification techniques are now turning their attention to geo-engineering studies. There are many parallels between the approaches to weather modification and geo-engineering. In its early days, weather modification received a great deal of attention from major military organizations and this is likely occurring today with geo-engineering."

Some mention should be made of the various scientific bodies statements on geo-engineering. I also think that weather modification should be mentioned in this note because of the many parallels. Of particular note is the basic fact that you can modify the weather in sophistical numerical models, but so far most of these concepts cannot be proven to work in real life. We simply do not know enough about the overall physics of the atmosphere to make accurate predictions. So you might do a geo-engineering project and have consequences you have not foreseen. That is the real danger of trying out these ideas in practice.

Regards....George

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s.16(2)

George A. Isaac
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Site Web www.ec.gc.ca

From: Joe,Paul [Ontario]
Sent: Friday, March 30, 2012 3:15 PM
To: Flato,Greg [CCCMA]; Cober,Stewart [Ontario]; Vaccaro,Lisa-Marie [Ontario]; Brunet,Gilbert [ARD]; Carou,Silvina [Ontario]
Cc: Jayne,Lisa [Ontario]; Walker,Anne [Ontario]; Isaac,George [Ontario]
Subject: RE: Climate geo-engineering Memo to DM

Good point but there will be confusion between geo-engineering for climate modification and weather mod for precipitation modification regardless of whether wx mod is left out of the BN. Should make distinguish and separate the two in the BN.

I was speaking with Lisa-Marie on the phone as this came in.

THIS NEEDS TO BE VETTED. George/Greg, please review.

Maybe somewhere it should say....

Geo-Engineering is for modification of the cliimate by changing the global radiation or hydrological cycles. This is relatively new and still at the conceptual stage. No experiments have been done to test the concepts. <Is this true?>

Weather modication for modication of clouds or cloud systems generally for the enhancement of precipitation, hail suppression or dissipation of fog. This has been around for many decades and there are many projects through out the world. Studies are still needed to validate precipitation enhancment and hail suppression concpets and results. <Maybe this needs to be stated better.>

P
paul.joe@ec.gc.ca Telecon: - or + passcode

From: Flato,Greg [CCCMA]
Sent: March 30, 2012 2:52 PM
To: Joe,Paul [Ontario]; Cober,Stewart [Ontario]; Vaccaro,Lisa-Marie [Ontario]; Brunet,Gilbert [ARD]; Carou,Silvina [Ontario]

Cc: Jayne,Lisa [Ontario]; Walker,Anne [Ontario]
Subject: RE: Climate geo-engineering Memo to DM

My personal view is that we should not confuse briefing note by talking about weather modification. That is distinctly different from global scale climate geo-engineering.

Greg

From: Joe,Paul [Ontario]
Sent: March 30, 2012 11:43 AM
To: Cober,Stewart [Ontario]; Vaccaro,Lisa-Marie [Ontario]; Brunet,Gilbert [ARD]; Carou,Silvina [Ontario]
Cc: Jayne,Lisa [Ontario]; Walker,Anne [Ontario]; Flato,Greg [CCCMA]
Subject: RE: Climate geo-engineering Memo to DM

Lisa-Marie

Is this ok or are you asking for the scientific perspective of the effectiveness of weather modification?

P
paul.joe@ec.gc.ca Telecon: - or - passcode

From: Cober,Stewart [Ontario]
Sent: March 30, 2012 2:40 PM
To: Vaccaro,Lisa-Marie [Ontario]; Brunet,Gilbert [ARD]; Carou,Silvina [Ontario]
Cc: Jayne,Lisa [Ontario]; Walker,Anne [Ontario]; Joe,Paul [Ontario]; Flato,Greg [CCCMA]; Cober,Stewart [Ontario]
Subject: RE: Climate geo-engineering Memo to DM

Hello Lisa-Marie,

There are minimal weather modification activities in MRD, and no activities related to R&D. Canada has a Weather Modification Information Act which is administered by MRD, however this typically involves filing 2 reports per year and sending the WMO 1 report per year on weather modification activities in Canada (there is a single registered activity related to hail suppression in the Calgary area).

Given the nature of this BN, and the nature of the MRD involvement in weather modification activities, I do not see any requirement to add any weather modification information to the BN.

Stewart

From: Vaccaro,Lisa-Marie [Ontario]
Sent: 30-Mar-12 2:08 PM
To: Brunet,Gilbert [ARD]; Carou,Silvina [Ontario]
Cc: Jayne,Lisa [Ontario]; Walker,Anne [Ontario]; Cober,Stewart [Ontario]; Joe,Paul [Ontario]; Flato,Greg [CCCMA]
Subject: RE: Climate geo-engineering Memo to DM

Bonjour Gilbert,

International Affairs Branch provided the following input which includes a paragraph about the Environmental Modification Convention, mentioning weather modification. Could I kindly request a couple of bullets on this issues as it relates to MRD activities? Input by end of day today would be most appreciated. If this is not possible, please let me know.

Many thanks in advance,

Lisa

From: Brunet,Gilbert [ARD]
Sent: 23 March 2012 12:58
To: Carou,Silvina [Ontario]
Cc: Vaccaro,Lisa-Marie [Ontario]; Jayne,Lisa [Ontario]; Walker,Anne [Ontario]; Cober,Stewart [Ontario]; Joe,Paul [Ontario]
Subject: Re: Climate geo-engineering Memo to DM

Silvina,
If weather modification is excluded from geo-eng, no.
Gilbert

De : Carou,Silvina [Ontario]
Envoyé : Friday, March 23, 2012 12:11 PM
À : Brunet,Gilbert [ARD]
Cc : Vaccaro,Lisa-Marie [Ontario]; Jayne,Lisa [Ontario]; Walker,Anne [Ontario]
Objet : RE: Climate geo-engineering Memo to DM

Hi Gilbert,

Is MRD involved in climate geo-engineering at all? Please let me know if there is any information you could contribute to a Memo to the DM.

Thanks

Silvina

From: Carou,Silvina [Ontario]
Sent: March 22, 2012 4:28 PM
To: Walker,Anne [Ontario]
Cc: Vaccaro,Lisa-Marie [Ontario]; Jayne,Lisa [Ontario]
Subject: FW: Climate geo-engineering Memo to DM
Importance: High

Hi Anne,

We are being asked to prepare a Memo to DM on climate geo-engineering with input from others. Please indicate if this is something CRD can put together and who, if anyone, we need to contact for input. The deadline for ASTD input would have to be **by noon Tuesday March 27** as Charles will not be available to approve this on Wednesday.

Thanks

Silvina

From: Quinn,Eileen [NCR]
Sent: March 22, 2012 3:19 PM

To: Lin,Charles [Ontario]
Cc: Carou,Silvina [Ontario]
Subject: FW: Climate geo-engineering Memo to DM
Importance: High

Charles,

I missed this last week. Please see request below from DMO. We are to coordinate a note with input from others.

DMO knows we are just actioning now. They want to know when we could have the note to them. Do you think you could have this to Karen by next Wednesday?
Eileen

Executive Assistant to the ADM
Adjointe exécutive à la SMA
Science & Technology Branch
Direction générale des sciences et de la technologie
Environment Canada

Tel: 819-953-3473
Fax: 819-997-1541
email: Eileen.Quinn@ec.gc.ca

From: Frankel,Christopher [NCR]
Sent: March 22, 2012 2:40 PM
To: Quinn,Eileen [NCR]; Ednie,Sara [NCR]
Subject: FW: Climate geo-engineering Memo to DM
Importance: High

Sara,

Per our discussion.

thx

Chris Frankel
Policy Advisor, Deputy Minister's Office
Conseiller en politiques, Cabinet du sous-ministre

Environment Canada | Environnement Canada
christopher.frankel@ec.gc.ca

Office: 819-994-5160

Blackberry :

From: Frankel,Christopher [NCR]
Sent: March 15, 2012 3:44 PM
To: Dodds,Karen [NCR]; McDougall,Dan [NCR]; Hanson,Lawrence [NCR]; Beale,Mike [NCR]; Keenan,Michael [NCR]
Cc: Boudreault,Felix [NCR]; Zeleney,Adriana [NCR]; Hamilton,Christopher [NCR]; Ednie,Sara [NCR]; Quinn,Eileen [NCR]
Subject: Climate geo-engineering Memo to DM
Importance: High

Hi all,

Most of you joined the DM for his recent meeting with to speak on climate geo-engineering. The DM has also had some recent discussions with regarding the spike in interest on this issue, and possible policy implications.

Given this, he'd like a memo to DM covering what we know regarding the science elements, international discussions (e.g. IPCC, national-level) and activities (e.g. trial experiments), governance and policy considerations, etc.

This issue cuts across most/all of your areas, but we thought it might be best for Karen to lead given science focus, with input from other branches as appropriate.

March 29th in DMO would be great.

Thanks,

Chris

Chris Frankel
Policy Advisor, Deputy Minister's Office
Conseiller en politiques, Cabinet du sous-ministre

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Blackberry :

s.21(1)(b)

CCI Input to MtDM on Geoengineering

Canada recognizes that geoengineering is still subject to significant uncertainty and that the science and understanding of geoengineering continue to evolve. An important contribution in this regard will be the work of the IPCC, which is currently assessing geoengineering for its upcoming Fifth Assessment Report (AR5), though the results of this assessment will not be available for nearly two years. The IPCC is the definitive body for policy-neutral assessments of science for climate change issues.

Though geoengineering may have the potential to contribute to addressing the global issue of climate change, geoengineering is not a substitute for reducing emissions of greenhouse gas emissions, the only long-term definitive solution to the issue of climate change.

Due to the uncertainties surrounding geoengineering, it is important to reach international consensus on the need for and application of it. Geoengineering has not yet been addressed within the UNFCCC. As the IPCC is the main provider of scientific and technical expertise to the UNFCCC negotiations, the publication of IPCC AR5 and its chapters on geoengineering may precipitate a discussion of the issue with the UNFCCC.

Geoengineering has already been addressed through the UN Convention on Biological Diversity (CBD), where at its 10th Conference of Parties, the CBD adopted decisions stipulating that "*no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts*".

Geoengineering activities are also subject to the Environmental Modification Convention (ENMOD), an international treaty prohibiting the military or other hostile use of environmental modification techniques. ENMOD bans weather warfare, which is the use of weather modification techniques for the purposes of inducing damage or destruction, but does not hinder the use of environmental modification techniques for peaceful purposes. Signatories to ENMOD include Canada, US, Russia, most of Europe, India, Pakistan, Iran, and DPRK. Notable non-signatories include China and Israel.

BACKGROUND

IPCC

- The IPCC will assess the science of geoengineering for the first time in its upcoming Fifth Assessment Report (AR5). While the understanding of the physical science basis of geoengineering is still limited, Working Group I will assess this in several chapters of its contribution to AR5, while improved scientific understanding of the impacts of geoengineering proposals on human and natural systems will be assessed by WGII, and WGIII will take into account the possible impacts and side effects and their implications for mitigation cost in order to define the role of geoengineering within the portfolio of response options to anthropogenic climate change. WGIII will also evaluate options for appropriate governance mechanisms.

- A Joint IPCC Expert Meeting of WGI, WGII, and WGIII was held on Geoengineering, in June 2011 in Lima, Peru.

CBD

- The tenth meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD) adopted decision X/33 which includes, in paragraph 8 (w) and (x), a section on climate-related geo-engineering and its impacts on the achievement of the objectives of the CBD.

8. *Invites* Parties and other Governments, according to national circumstances and priorities, as well as relevant organizations and processes, to consider the guidance below on ways to conserve, sustainably use and restore biodiversity and ecosystem services while contributing to climate change mitigation and adaptation:

> (w) Ensure, in line and consistent with decision IX/16 C, on ocean fertilization and biodiversity and climate change, in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities** that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment;
>
> (x) Make sure that ocean fertilization activities are addressed in accordance with decision IX/16 C, acknowledging the work of the London Convention/London Protocol;

In addition to the above, the Conference of the Parties, in decision X/33 paragraph 9(l) and (m), requests the Executive Secretary to:

Compile and synthesize available scientific information, and views and experiences of indigenous and local communities and other stakeholders, on the possible impacts of geo engineering techniques on biodiversity and associated social, economic and cultural considerations, and options on definitions and understandings of climate-related geo-engineering relevant to the Convention on Biological Diversity; and

Taking into account the possible need for science based global, transparent and effective control and regulatory mechanisms, subject to the availability of financial resources, undertake a study on gaps in such existing mechanisms for climate-related geo-engineering relevant to the Convention on Biological Diversity, bearing in mind that such mechanisms may not be best placed under the Convention on Biological Diversity.

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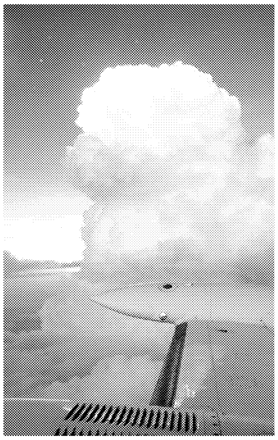
THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine



REPORT IN BRIEF

CRITICAL ISSUES IN WEATHER MODIFICATION RESEARCH

The impact of human activity on weather and climate has been of increasing national and international concern over the past few decades. In stark contrast, there has been little parallel research directed at understanding the ability of humans to intentionally modify the weather. Yet the fundamental physical principles underlying both inadvertent and advertent weather modification are, in many respects, the same.

In this same timeframe, remarkable progress has been made in our ability to observe atmospheric processes, record this information, and incorporate it into sophisticated mathematical models (see Box 1, p. 2). However, this power has not been collectively applied to the questions that can help us understand how or whether atmospheric systems can be intentionally changed.

We know that we can disperse cold fog, induce changes in clouds, and possibly increase snowpack. What we cannot do, with the exception of dispersing cold fog, is provide unequivocal scientific evidence of these changes and demonstrate that the effects are entirely reproducible. Despite this lack of proof, many weather modification programs are operating, spurred by water shortages and increasing weather-related damage and loss of life. People in drought- and hail-prone areas willingly spend significant resources on weather modification programs (see Figure 1), and in 2001 there were at least 66 operational programs being conducted in 10 states across the United States.

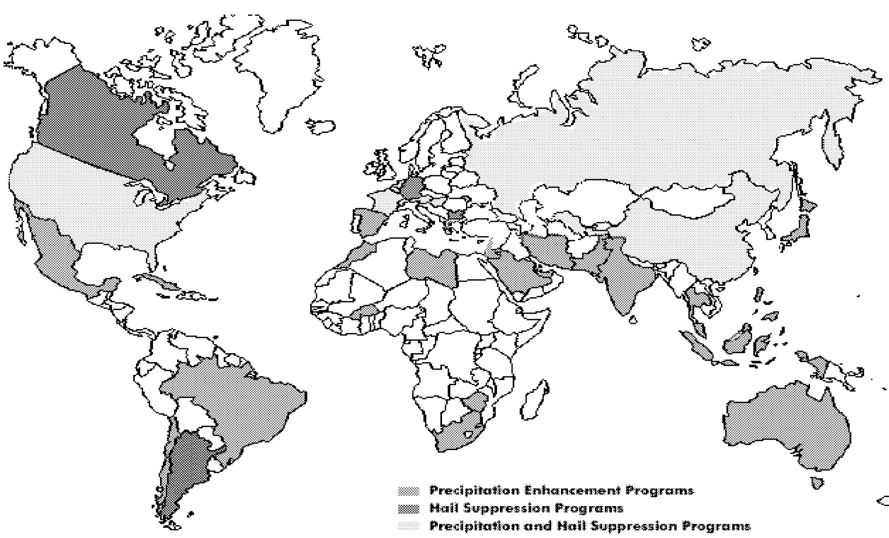


Figure 1. Precipitation and hail suppression programs are conducted in more than 24 countries worldwide. **Source**: Compiled with information from the World Meteorological Organization (1999) by R. Bruintjes.

At the same time, less than a handful of weather modification research programs are underway worldwide, and related research in the United States has dropped to less than $500,000 per year from a high of $20 million in the late 1970s. Resolving this disparity between our willingness to attempt to modify weather and our willingness to conduct research to understand whether such activities can succeed will occur only if the relevant funding agencies and scientific communities make a commitment to answer some of the fundamental underlying questions. The challenge is to find the right balance between reducing scientific uncertainties and the need for action to address pressing problems.

Box 1. Advances in Observational Technologies

In the past, the only way to measure the moisture content and other characteristics of a cloud was to strap instrumentation onto a plane and fly it into the cloud. Measurements were therefore limited to the path of the plane. The newest remote-sensing and *in situ* equipment—advanced by urgent needs in the areas of severe storm warnings, detection of aircraft icing conditions, and climate change—offers higher resolution "pictures" of clouds and cloud systems than ever before possible (see Figure 2).

These tools can now estimate in-cloud particle shapes and sizes, track the dispersion of seeding aerosols, and more accurately estimate precipitation. Millimeter-wave cloud radar can describe non-precipitating clouds. The national Doppler radar network (NEXRAD) provides opportunities for examining the evolution of radar signatures in all regions of the country and for applying cell tracking capabilities in field experiments. Although they have been nominally used in cloud-seeding observations, these tools have not yet been used as integral components of experiments designed to test and evaluate specific scientific hypotheses in weather modification.

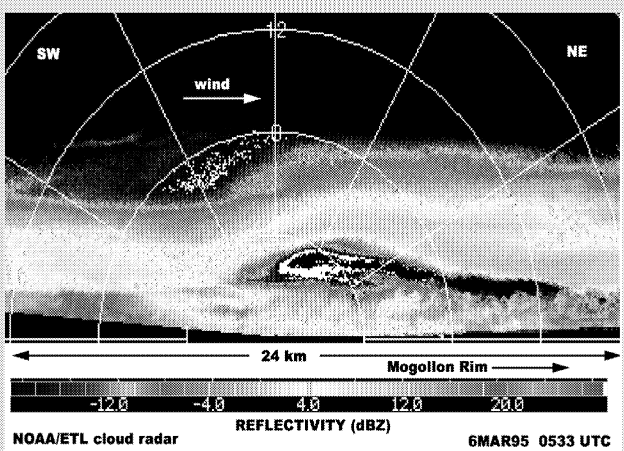


Figure 2. Observations from scanning cloud radar are converted to this "picture" of supercooled liquid in a wave cloud induced by the surrounding mountainous terrain. This is useful for locating good clouds to seed and then to monitor the ensuing changes in the cloud to better understand physical processes. **Source**: Reinking et al. (2000).

Critical Uncertainties Limiting Advancement

If progress in establishing our capability to modify the weather is to be made, intellectual and technical resources must be brought to bear on the key uncertainties (see Box 2) that currently hamper progress. For example, there are critical gaps in our understanding of the complex chain of physical processes that start with condensation of water vapor and end with precipitation. The processes that lead to the formation of a hailstone are equally complex and difficult to understand, especially when placed in the context of the convective field of motion of a violent thunderstorm.

Progress in obtaining answers to such questions depends on sustained and directed research in laboratories, on research centers dedicated to modeling, and on carefully designed and verifiable field experiments equipped with the most advanced observing tools. Identifying and addressing these critical uncertainties will focus future research where it will produce the most useful results.

Call for a Coordinated National Program

A coordinated national program of weather modification research designed to reduced key uncertainties is needed. This program should be the heart of a sustained research effort that uses a balanced approach of modeling, laboratory studies, and field measurements. Instead of focusing on near-term operational applications of weather modification, the program should address fundamental research questions that might include:

- What is the background aerosol concentration in various places, at different times of the year, and during different meteorological conditions? To what extent would weather modification operations be dependent on these background concentrations?

Box 2. Summary of Key Uncertainties

Cloud/Precipitation Microphysics Issues

Highest priority: Understand the background concentration, sizes, and chemical composition of aerosols that participate in cloud processes.

Other gaps: How nucleation processes relate to characteristics of aerosol particles; ice nucleation; Evolution of the droplet spectra in clouds; Relative importance of drizzle in precipitation processes.

Cloud Dynamics Issues

Highest Priority: Understand cloud-to-cloud and mesoscale interactions as they relate to updraft and downdraft structures and cloud evolution and lifetimes.

Other gaps: Cloud and sub-cloud dynamical interactions as they relate to precipitation amounts and the size spectrum of hydrometeors; Microphysical, thermodynamical, and dynamical interactions within clouds.

Cloud Modeling Issues

Highest priority: Combination of the best cloud models with advanced observing systems in carefully designed field tests and experiments.

Other gaps: Application of new cloud-resolving models to weather modification, including short-term predictive models; Predictive models for severe weather events; Cloud models capability to track dispersion of seeding material both within and outside of seeded areas.

Seeding-Related Issues

High priority: Targeting of seeding agents, diffusion and transport of seeding material, and spread of seeding effects throughout the cloud volume.

High priority: Measurement capabilities and limitations of cell-tracking software, radar, and technologies to observe seeding effects.

Other gaps: Using observations from new instruments of high concentrations of ice crystals; Interactions between different hydrometeors in clouds and how to best model them; Modeling and prediction of treated and untreated conditions for simulation; Mechanisms of transferring the storm-scale effect into an area-wide precipitation effect and tracking possible downwind changes at the single cell, cloud cluster, and floating target scales.

- What is the variability of cloud and cell properties (including structure, intensity, evolution, and lifetime) within larger clusters, and how do clouds and cells interact with larger-scale systems? What are the effects of localized seeding on the larger systems in which the seeded clouds are embedded?
- How accurate are radar reflectivity measurements in measuring the differences between accumulated rainfall in seeded and unseeded clouds? How does seeding affect the drop-size distribution that determines the relationship between the measured radar parameter and actual rainfall at the surface?

To take advantage of recent related research and advances in observational, computational, and statistical technologies, the program should attempt to:

- Capitalize on new remote and in situ observational tools to carry out exploratory and confirmatory experiments in a variety of cloud and storm systems
- Improve cloud model treatment of cloud and precipitation physics.
- Improve and use current computational and data assimilation capabilities.
- Capitalize on existing field facilities and develop partnerships among research groups and select operational programs.

Thus, the initiation of large-scale operational weather modification programs is premature, but a great opportunity exists to coordinate research efforts to address the fundamental questions that will lead to credible scientific results. It is not enough to expand present efforts that primarily analyze data from largely uncontrolled experiments. Instead, focused investigation of atmospheric processes, coupled with an exploration of the technological applications, will certainly advance understanding and bring many unexpected benefits and results. In time, this research will place us in a position to determine whether, how, and to what extent weather and weather systems can be modified.

Critical Issues in Weather Modification Research is the National Academies latest assessment of weather modification research. The report reviews the current state of the science with particular attention to recent advances, identifies the key scientific uncertainties limiting advances in the science, outlines future directions in weather modification research, and suggests actions to identify the impact of local weather modification on large-scale weather and climate patterns.

This report brief was prepared by the National Research Council based on the committee's report. For more information, contact the National Research Council's Board on Atmospheric Sciences and Climate at 202-334-3512. *Critical Issues in Weather Modification Research* is available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242 or 202-334-3313 (in the Washington area); www.nap.edu.

Committee on the Status and Future Directions in U.S. Weather Modification Research and Operations: Michael Garstang (*Chair*), University Of Virginia, Charlottesville; **Roscoe R. Braham, Jr**., North Carolina State University, Raleigh; **Roelof T. Bruintjes**, National Center For Atmospheric Research, Boulder, Colorado; **Steven F. Clifford**, University Of Colorado, Boulder; **Ross N. Hoffman**, Atmospheric & Environmental Research, Inc., Lexington, Massachusetts; **Douglas K. Lilly**, University Of Oklahoma, Norman; **Robert J. Serafin**, National Center For Atmospheric Research, Boulder, Colorado; **Paul D. Try**, Science & Technology Corporation, Silver Spring, Maryland; **Johannes Verlinde**, Pennsylvania State University, University Park, **Julie Demuth** (Research Associate), Board on Atmospheric Sciences and Climate.

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Jatar, Muriel (EC)

From: Bourque,Denis [NCR]
Sent: May 4, 2006 12:04 PM
To: Isaac,George [Ontario]
Cc: Cober, Stewart (EC); Paterson,Bob [Ontario]; Bourque,Denis [NCR]
Subject: Wx Modification and Senate Question

Importance: High

George (et al):

I would like a quick opinion (this afternoon would be ideal) on the attached Response (starting page 2) which I drafted using George's responses to some earlier e-mails, some research of my own, and contacts with the Cdn Embassy in Washington.

April 27 - Plamondon Ha...

Context: Our Senators (statesmen not hockey) got around to discussing Weather Modification last Thursday. (full transcript attached, from which it is easier to understand the questions).

Senate QP Highlights 04 A...

As you can probably tell, they have mixed Weather Modification and Climate Modification. During this discussion, Sen Lebreton promised a more full-some response, as is allowed by the system. This comes in the form of a "Delayed Response", which is usually in the form of a statement (~500 words) which would be read or at least distributed "formally" in the Senate. We have until tomorrpw, Friday May 5 to produce this bilingually. I wonder if you could ensure that I have not introduced any errors in substance into my draft proposal (already longer than 500 words).

My intention is to send this for translation overnight - but if your comments arrive in the morning, I will adapt both the English and the French versions as necvessary.

Hoping you can help

Denis

Denis A. Bourque

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Environment Canada	Environnement Canada
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QUESTION PERIOD IN THE SENATE
DELAYED ANSWER

SUBJECT:

Weather modification

Date asked: April 27, 2006	**Senate Debates Page No. 117-118**

By Senators:

Hon. Madeleine Plamondon, and Hon. Daniel Hays

ORAL QUESTION

Hon. Madeleine Plamondon: Honourable senators, my question is for the Leader of the Government in the Senate. Climate change has been making headlines daily and has resulted in natural disasters and drought. One of the proposed experimental solutions deserves our attention in particular. I am talking about weather modification, which creates clouds and generates rain for regions affected by drought or for places like Alberta that have to deal with devastating hail.

My question is the following: Has Canada assessed the impact on the Canadian economy of weather modification, which is currently being practiced in a number of the U.S. states?

Hon. Madeleine Plamondon: Honourable senators, last December, the reputable U.S. Office of Science and Technology Policy listed a host of political and legal issues in a letter to a U.S. senator. The office also warned of international and foreign policy implications, stating that small-and large-scale weather modifications could benefit the U.S. to the detriment of other countries, namely, Canada.

Have there been talks between Canada and the United States about the consequences of weather modifications even with peaceful purposes? In fact, who owns the weather? Does one country own the weather? Could one country or one province, using weather modification, be the subject of litigation for authorizing weather modification to the detriment of another area? Does Canada have a policy?

Hon. Daniel Hays (Leader of the Opposition): I have a supplementary question. The government's position is that it does not accept the conclusion of many scientists that greenhouse gases are causing global warming or the greenhouse gas effect. In other words, the position of the government of the day is identical to that of the current Government of the United States.

Do I correctly understand the minister's response to Senator Plamondon's question?

Senator Hays: Honourable senators, I would ask the minister to bring back to this place a more precise statement on this subject. I am still a little bit uncertain as to whether there is a change in the position of the new government, led by Prime Minister Harper, as compared to the position of the previous government.

I should like to know whether there is a change in the government's position. I would appreciate an official clarification. It seems to be hinted in the government leader's response that there are scientists who disagree with the idea of greenhouse gases causing the global warming phenomenon.

Senator Plamondon: I believe there was an agreement around 1978 or 1980 not to use weather modifications for war purposes because it is a very powerful weapon. It can be used to hinder communications. It can be used for many things. The bill being discussed in the United States is important, as it has implications, economic and otherwise, for Canada.

During my research on fresh water, as senators can see in the letter, I learned that weather modifications can affect the availability of water resources.

Before it is too late, I thought it would be wise to have talks with the U.S. government to determine the possible impact of what they are doing. A few states are using weather modification right now: Idaho, Utah, Nevada, California and Colorado. I believe that there could be implications for Canada.

RESPONSE

"Weather modification" is the subject of Senator Plamondon's several questions, whereas Senator Hays' question pertains to Climate Change. I will get to Senator Hays' question in a few minutes.

Climate Change and Weather Modification are two very distinct topics. "Weather Modification" refers to the active attempt to modify, within a few hours at most, existing weather by directly intervening with the current weather in order to, for example, reduce fog or increase precipitation. This is not science fiction. The UN World Meteorological Organization has had a program on Weather Modification Research since 1975 promoting the establishment of sound scientific foundations for weather modification and facilitating the exchange of information for both research and operational activities. It maintains this strong interest because of the possibility of beneficially modifying weather and thus contributing to the mitigation of the adverse effects of drought, hail, fog and severe weather.

Within the scientific community, discussion continues regarding the degree of success of weather modification. For example, the confidence level is very high when dealing with certain types of fog and moderate for increasing snowfall and precipitation from clouds. The confidence level is not high for suppressing hail.

Nonetheless, there are many nations currently conducting weather modification projects, particularly in arid and semi-arid regions all over the world, where the lack of sufficient water resources limits their ability to meet food, fibre, and energy demands. Obviously, there would be significant benefits for these regions resulting from the successful development of this type of technology.

There are also projects underway in Canada and the USA. In Canada, the Insurance industry invests funds annually in weather modification activities targeted at reducing hail damage in the prairies. Weather modification is conducted in several States in the USA, we believe, associated with severe weather suppression and water management issues. Although the federal government was extensively involved in this type of research in the 1970s, there is currently no federal funding in weather modification. We are informed that the situation is the same in the US federal system.

In addition, neither Canada nor the USA have a federal policy on Weather Modification. In Canada, there exists a federal Weather Modification Information Act (administered by the Minister of Environment) that requires any operator to "notify" the federal government of any action intended to modify the weather by chemicals. There is no license involved and no authority to stop the activity.

In the USA, there are currently Bills before the legislature which would "develop and implement a comprehensive and coordinated national weather modification research policy". These Bills are working their way through their system.

Within this context, you will understand that it is currently difficult, if not impossible, to credibly ascribe any specific economic or other values to weather modification activities. It is also clear that moral, ethical and legal considerations can be, and have been, be raised by various interests. This is already clearly acknowledged by practitioners including the WMO, mentioned earlier, the American Meteorological Society and the Canadian Meteorological Society, to name but a few. These organizations all promote the careful, scientifically sound pursuit of this research in order to ensure that all benefits and impacts are properly assessed.

Although the Canadian and American scientific communities have been exchanging scientific information for many years, there have been no recent formal Canada-USA discussions regarding this technology. As mentioned by Senator Plamodon, there was significant international policy activity through the late 1970s which resulted in the UN "Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques", which entered into force on October 5, 1978 and which Canada ratified on June 11, 1981.

Senator Hays' questions, on the other hand, refer to a different subject matter altogether, that of having permanently altered the climate via long-term human-based drivers such as greenhouse gases, a process which is termed these days as Climate Change. You will not find any disagreement in the scientific community that an increase in greenhouse gases will result in warming of the planet. The debate, if one can call it that, pertains only to the identification of the sources of GHGs, in particular whether they are man-made or natural, and the solutions which would work. Notwithstanding these discussions, the overall consensus amongst the global scientific community remains as provided in 2001 by the Intergovernmental Panel on Climate Change, namely that "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." This Government does not disagree with this position. This Government disagrees with the direction which the previous government had adopted to resolve this serious situation.

QUESTION PERIOD HIGHLIGHTS - SENATE
April 27, 2006

- Official Version -

The Environment

Climate Change—Effect on the Economy

Hon. Madeleine Plamondon: Honourable senators, my question is for the Leader of the Government in the Senate. Climate change has been making headlines daily and has resulted in natural disasters and drought. One of the proposed experimental solutions deserves our attention in particular. I am talking about weather modification, which creates clouds and generates rain for regions affected by drought or for places like Alberta that have to deal with devastating hail.

My question is the following: Has Canada assessed the impact on the Canadian economy of weather modification, which is currently being practiced in a number of the U.S. states?

Hon. Marjory LeBreton (Leader of the Government): Honourable senators, the Government of Canada is aware that the U.S. Congress is currently considering legislation on weather modification. Despite the alleged possibilities that were contained in some of the articles that the honourable senator gave me, weather modification is still considered experimental at best and continues to be debated in the scientific community. Given that weather modification remains unproven scientifically, it is difficult to determine the economic impact of such an activity locally, let alone internationally.

Climate Change—Negotiations with United States

Hon. Madeleine Plamondon: Honourable senators, last December, the reputable U.S. Office of Science and Technology Policy listed a host of political and legal issues in a letter to a U.S. senator. The office also warned of international and foreign policy implications, stating that small-and large-scale weather modifications could benefit the U.S. to the detriment of other countries, namely, Canada.

Have there been talks between Canada and the United States about the consequences of weather modifications even with peaceful purposes? In fact, who owns the weather? Does one country own the weather? Could one country or one province, using weather modification, be the subject of litigation for authorizing weather modification to the detriment of another area? Does Canada have a policy?

Hon. Marjory LeBreton (Leader of the Government): There is in Canada a federal Weather Modification Information Act administered by the Minister of the Environment. The Minister of the Environment has expressed concerns to the U.S. environmental people about chemicals in the environment, for instance. There is no licence involved and no authority to stop this activity at the moment.

With respect to the question about who owns the weather, we have been through this before with the acid rain treaty, and we successfully negotiated a treaty with the United States.

This issue is complex. As I mentioned earlier, scientists are still not in total agreement about the impacts on weather. I have read the letter sent to me by the honourable senator. Given that some people in the United States believe they have more jurisdiction over it than perhaps we do, I can say with certainty that our Minister of the Environment is making a very strong case for Canada in this area.

Hon. Daniel Hays (Leader of the Opposition): I have a supplementary question. The government's position is that it does not accept the conclusion of many scientists that greenhouse gases are causing global warming or the greenhouse gas effect. In other words, the position of the government of the day is identical to that of the current Government of the United States.

Do I correctly understand the minister's response to Senator Plamondon's question?

Senator LeBreton: I did not say that at all. I am saying that scientists are not in agreement. The Government of Canada is aware that the U.S. Congress is considering legislation on weather modification, but there is still some debate in the scientific community. I am not saying that we agree with either side of that debate. I personally believe that greenhouse gases have an impact.

Our Minister of the Environment is meeting with U.S. officials. The Mulroney government's record on issues of the environment stands tall. I do not want to leave the impression that this government will not continue to fight for our own environmental concerns.

Senator Hays: Honourable senators, I would ask the minister to bring back to this place a more precise statement on this subject. I am still a little bit uncertain as to whether there is a change in the position of the new government, led by Prime Minister Harper, as compared to the position of the previous government.

I should like to know whether there is a change in the government's position. I would appreciate an official clarification. It seems to be hinted in the government leader's response that there are scientists who disagree with the idea of greenhouse gases causing the global warming phenomenon.

Senator LeBreton: I shall bring back clarification. However, it is clear from events last week and from meetings the Minister of the Environment has had with United States officials that we believe this to be a serious issue.

The previous government has a record that is not to be boasted about or to be proud of, and I will bring back clarification from the Minister of the Environment on our latest negotiations on this front.

Senator Plamondon: I believe there was an agreement around 1978 or 1980 not to use weather modifications for war purposes because it is a very powerful weapon. It can be used to hinder communications. It can be used for many things. The bill being discussed in the United States is important, as it has implications, economic and otherwise, for Canada.

During my research on fresh water, as senators can see in the letter, I learned that weather modifications can affect the availability of water resources.

Before it is too late, I thought it would be wise to have talks with the U.S. government to determine the possible impact of what they are doing. A few states are using weather modification right now: Idaho, Utah, Nevada, California and Colorado. I believe that there could be implications for Canada.

Senator LeBreton: I will take that question as notice. I could not agree more. Weather modification could have serious implications for Canada. I will ask that the appropriate people let us know, from their knowledge, the state of the legislation in the United States.

L'ENVIRONNEMENT

LES CHANGEMENTS CLIMATIQUES—LES EFFETS SUR L'ÉCONOMIE

L'honorable Madeleine Plamondon : Honorables sénateurs, ma question s'adresse au leader du gouvernement au Sénat. Les changements climatiques font la manchette quotidiennement et nous amènent à vivre des catastrophes et des sécheresses. Une des solutions proposées et expérimentées mérite une attention particulière : c'est la modification du temps, qui crée des nuages et qui génère de la pluie pour les régions touchées par la sécheresse ou bien pour des endroits comme l'Alberta, qui doivent affronter une grêle parfois dévastatrice.

Ma question est la suivante : Le Canada a-t-il évalué l'impact sur l'économie canadienne de la modification du temps qui se pratique actuellement dans plusieurs États aux États-Unis?

L'honorable Marjory LeBreton (leader du gouvernement) : Honorables sénateurs **,** le gouvernement du Canada sait que le Congrès américain étudie actuellement un projet de loi sur la modification du temps. En dépit des possibilités présumées dans certains des articles que madame le sénateur m'a donnés, la modification du temps est encore, au mieux, au stade expérimental et les milieux scientifiques restent divisés. Étant donné qu'elle n'a pas encore fait ses preuves, il est difficile de déterminer ses répercussions économiques à l'échelle locale, et encore plus à l'échelle internationale.

LES CHANGEMENTS CLIMATIQUES—LES NÉGOCIATIONS AVEC LES ÉTATS-UNIS

L'honorable Madeleine Plamondon : Honorables sénateurs, en décembre dernier, l'organisme de renom des États-Unis appelé Office of Science and Technology Policy a dressé une liste des problèmes politiques et juridiques dans une lettre à un sénateur américain. Il a en outre averti qu'il pourrait y avoir des répercussions internationales et diplomatiques, c'est-à-dire que les modifications du temps, que ce soit à grande ou à petite échelle, pourraient profiter aux États-Unis, au détriment d'autres pays, à savoir le Canada.

Y a-t-il eu des pourparlers entre le Canada et les États-Unis au sujet des conséquences des modifications du temps, même si celles-ci visent des fins pacifiques? En fait, à qui appartient le temps? Est-ce un pays qui en est propriétaire? Un pays ou une province qui pratique la modification du temps s'expose-t-il à un procès pour avoir causé un préjudice à une autre région? Le Canada a-t-il une politique à ce sujet?

L'honorable Marjory LeBreton (leader du gouvernement) : Il existe au Canada une loi fédérale sur les renseignements en matière de modification du temps, dont l'application relève du ministre de l'Environnement. Ce dernier a exprimé des préoccupations aux responsables américains de l'environnement quant à la présence de produits chimiques dans l'environnement, par exemple. La modification du temps n'est pas assujettie à un régime d'autorisation et il n'y a à l'heure actuelle aucun organisme qui a le pouvoir de l'interdire.

Quant à la question de savoir qui est propriétaire du temps, elle s'est déjà posée lors du traité sur les pluies acides, que nous avons réussi à négocier avec les États-Unis.

Cette question est complexe. Comme je l'ai dit plus tôt, les scientifiques ne n'entendent pas encore complètement sur les incidences sur le climat. J'ai lu la lettre que l'honorable sénateur m'a envoyée. Comme certaines personnes aux États-Unis considèrent que cette question relève peut-être davantage de la compétence des États-Unis que du Canada, je peux affirmer avec certitude que notre ministre de l'Environnement défend vigoureusement la position du Canada à ce sujet.

L'honorable Daniel Hays (leader de l'opposition) : J'ai une question complémentaire. La position du gouvernement est qu'il n'accepte pas la conclusion de nombreux scientifiques selon laquelle les gaz à effet de serre sont à l'origine du réchauffement de la planète. En d'autres termes, sa position est identique à celle du gouvernement actuel des États-Unis.

Est-ce bien cela la réponse de madame le ministre à la question du sénateur Plamondon?

Le sénateur LeBreton : Ce n'est pas du tout ce que j'ai dit. Je dis que les scientifiques ne s'entendent pas. Le gouvernement du Canada sait que le Congrès américain envisage l'adoption d'une mesure sur la modification des conditions météorologiques, mais le débat se poursuit dans le milieu scientifique. Je ne dis pas que nous privilégions un camp ou l'autre. Personnellement, je crois que les gaz à effet de serre ont un impact.

Notre ministre de l'Environnement a des réunions avec des représentants américains. En matière d'environnement, le bilan du gouvernement Mulroney se défend très bien et je ne voudrais pas donner l'impression que l'actuel gouvernement ne continuera pas à faire valoir nos préoccupations environnementales.

Le sénateur Hays : Honorables sénateurs, j'aimerais que la ministre rapporte au Sénat une déclaration plus précise sur ce sujet. Des doutes subsistent encore dans mon esprit quant à savoir s'il y a eu un changement de position de la part du nouveau gouvernement, dirigé par le premier ministre Harper, par rapport à la position du précédent gouvernement.

J'aimerais savoir si un changement a été opéré dans la position du gouvernement. J'aimerais avoir des éclaircissements officiels. La réponse du leader du gouvernement donne à penser que des scientifiques ne croient pas que le réchauffement de la planète est le résultat des gaz à effet de serre.

Le sénateur LeBreton : J'obtiendrai les éclaircissements nécessaires. Je tiens toutefois à ajouter que les événements de la semaine dernière ainsi que les réunions que la ministre de l'Environnement a eues avec des représentants américains indiquent clairement que nous prenons la question au sérieux.

Le précédent gouvernement n'avait pas de quoi se vanter ni être fier de son bilan en matière d'environnement. Je m'enquerrai auprès de la ministre de l'Environnement de l'état des négociations sur ce front et je fournirai des éclaircissements au sénateur.

Le sénateur Plamondon : Je crois qu'il y a eu un accord en 1978 ou 1980 pour interdire d'utiliser la modification du climat comme arme dans un conflit. C'est une arme très puissante parce qu'elle peut servir à brouiller les communications et à bien d'autres choses. Le projet de loi à l'étude aux États-Unis est très important, puisqu'il aura des répercussions économiques et autres sur le Canada.

Pendant ma recherche sur l'eau douce, j'ai appris, comme les sénateurs peuvent le voir dans la lettre, que la modification du climat peut se répercuter sur les ressources en eau.

Avant qu'il ne soit trop tard, j'ai pensé qu'il serait sage d'avoir des discussions avec le gouvernement des États-Unis afin de déterminer les conséquences possibles de leurs gestes. Quelques États modifient déjà le climat, notamment l'Idaho, l'Utah, le Nevada, la Californie et le Colorado. Je crois que cela peut avoir des répercussions au Canada.

Le sénateur LeBreton : Je prends note de la question. Je suis entièrement d'accord avec vous. La modification du climat a de graves répercussions pour le Canada. Je demanderai aux personnes informées de nous faire savoir où en est l'étude du projet de loi aux États-Unis.

Page 3249

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15(1)

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Pages 3250 to / à 3252

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sont retenues en vertu des articles

13(1)(a), 13(1)(b), 15(1)

of the Access to Information Act

de la Loi sur l'accès à l'information

Jatar, Muriel (EC)

From: Isaac,George [Ontario]
Sent: December 7, 2004 4:21 PM
To: Cober, Stewart (EC)
Subject: MSC and Weather Modification

MSC and Weather Modification2....

Stewart,

Here is the document we discussed. You might want to add some more references, but the material here should give you some ideas.

George
P.S. I have added some of our papers on weather modification below. The 1982 paper summarizing the results from Thunder Bay and Yellowknife is the best paper to reference for our recent weather modification stuff. We did do work in HIPLEX and CCOPE out of Miles City Montana (1979-81 approximately), but although this work was in preparation for weather modification, it was never started.

Isaac. G.A., 1986: Summer cumulus cloud lifetime - Importance to static mode seeding. Precipitation Enhancement--A Scientific Challenge. AMS Monograph, 21, No. 43, 25-28.

Schemenauer, R.S., and G.A. Isaac, 1984: The importance of cloud top lifetime in the description of natural cloud characteristics. Journal of Climate and Applied Meteorology, 23, 267-279.

Isaac, G.A., J.W. Strapp, R.S. Schemenauer and J.I. MacPherson, 1982: Summer cumulus cloud seeding experiments near Yellowknife and Thunder Bay, Canada. Journal of Applied Meteorology, 21, 1266-1285.

Isaac, G.A., and R.S. Schemenauer, 1979: Comments on "Some factors governing ice particle multiplication". Journal of Atmospheric Sciences, 36, 2271-2272.

Strapp, J.W., H.G. Leighton, and G.A. Isaac, 1979: A comparison of model calculations with observations following silver iodide seeding. Atmosphere-Ocean, 17, 234-252.

Isaac, G.A., and R.S. Schemenauer, 1979: Large particles in supercooled regions of northern Canadian cumulus clouds. Journal of Applied Meteorology, 18, 1056-1065.

Isaac, G.A., R.S. Schemenauer, C.L. Crozier, A.J. Chisholm, J.I. MacPherson, N.R. Bobbitt, and L.B. MacHattie, 1977: Preliminary tests of a cumulus cloud seeding technique. Journal of Applied Meteorology, 16 949-958.

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Jatar, Muriel (EC)

From: Isaac,George [Ontario]
Sent: October 16, 2003 4:08 PM
To: Cober, Stewart (EC); Abraham,Jim [Dartmouth]; Beland,Michel [DG ACSD]; Power,Jack [Ontario]
Subject: U.S. National Academy of Sciences Report on Weather Modification

To All,

The U.S. National Academy of Sciences just released (13 October) a report on Weather Modification (see http://www.nas.edu/). I have attached the summary of that report for your information. It basically states that the "initiation of large-scale operational weather modification programs is premature, but a great opportunity exists to coordinate research efforts to address the fundamental questions that will lead to credible scientific results. Focused investigation of atmospheric processes, coupled with an exploration of the technological applications, will certainly advance understanding and bring many unexpected benefits and results. In time, this research will place us in a position to determine whether, how, and to what extent weather and weather systems can be modified."

Regards....George

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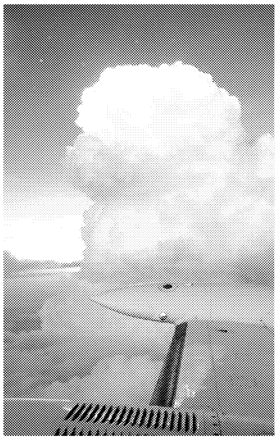
THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine



REPORT IN BRIEF

CRITICAL ISSUES IN WEATHER MODIFICATION RESEARCH

The impact of human activity on weather and climate has been of increasing national and international concern over the past few decades. In stark contrast, there has been little parallel research directed at understanding the ability of humans to intentionally modify the weather. Yet the fundamental physical principles underlying both inadvertent and advertent weather modification are, in many respects, the same.

In this same timeframe, remarkable progress has been made in our ability to observe atmospheric processes, record this information, and incorporate it into sophisticated mathematical models (see Box 1, p. 2). However, this power has not been collectively applied to the questions that can help us understand how or whether atmospheric systems can be intentionally changed.

We know that we can disperse cold fog, induce changes in clouds, and possibly increase snowpack. What we cannot do, with the exception of dispersing cold fog, is provide unequivocal scientific evidence of these changes and demonstrate that the effects are entirely reproducible. Despite this lack of proof, many weather modification programs are operating, spurred by water shortages and increasing weather-related damage and loss of life. People in drought- and hail-prone areas willingly spend significant resources on weather modification programs (see Figure 1), and in 2001 there were at least 66 operational programs being conducted in 10 states across the United States.

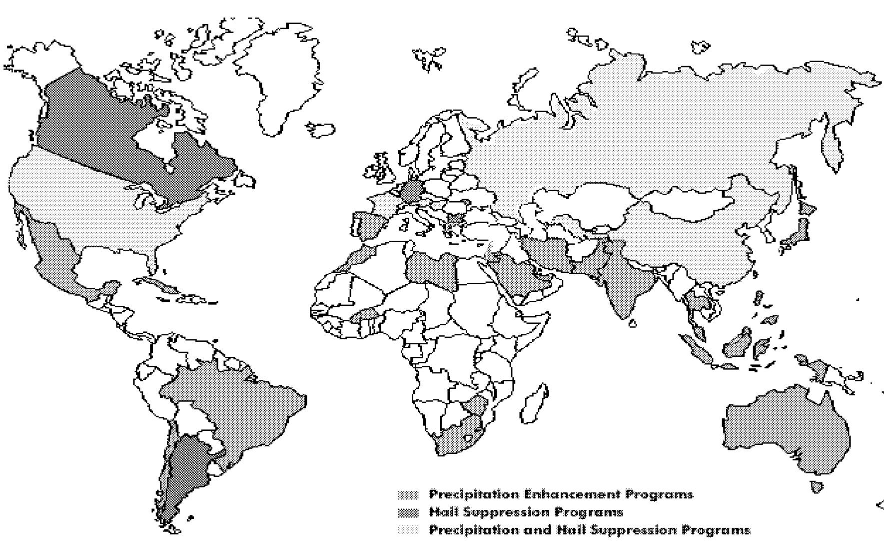


Figure 1. Precipitation and hail suppression programs are conducted in more than 24 countries worldwide. **Source**: Compiled with information from the World Meteorological Organization (1999) by R. Bruintjes.

At the same time, less than a handful of weather modification research programs are underway worldwide, and related research in the United States has dropped to less than $500,000 per year from a high of $20 million in the late 1970s. Resolving this disparity between our willingness to attempt to modify weather and our willingness to conduct research to understand whether such activities can succeed will occur only if the relevant funding agencies and scientific communities make a commitment to answer some of the fundamental underlying questions. The challenge is to find the right balance between reducing scientific uncertainties and the need for action to address pressing problems.

Box 1. Advances in Observational Technologies

In the past, the only way to measure the moisture content and other characteristics of a cloud was to strap instrumentation onto a plane and fly it into the cloud. Measurements were therefore limited to the path of the plane. The newest remote-sensing and *in situ* equipment—advanced by urgent needs in the areas of severe storm warnings, detection of aircraft icing conditions, and climate change—offers higher resolution "pictures" of clouds and cloud systems than ever before possible (see Figure 2).

These tools can now estimate in-cloud particle shapes and sizes, track the dispersion of seeding aerosols, and more accurately estimate precipitation. Millimeter-wave cloud radar can describe non-precipitating clouds. The national Doppler radar network (NEXRAD) provides opportunities for examining the evolution of radar signatures in all regions of the country and for applying cell tracking capabilities in field experiments. Although they have been nominally used in cloud-seeding observations, these tools have not yet been used as integral components of experiments designed to test and evaluate specific scientific hypotheses in weather modification.

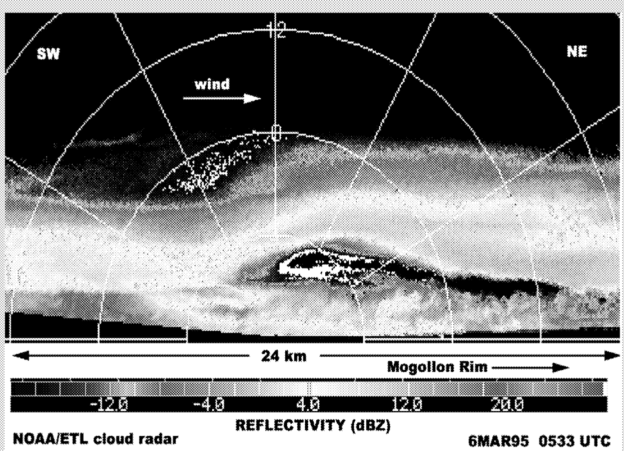


Figure 2. Observations from scanning cloud radar are converted to this "picture" of supercooled liquid in a wave cloud induced by the surrounding mountainous terrain. This is useful for locating good clouds to seed and then to monitor the ensuing changes in the cloud to better understand physical processes. **Source**: Reinking et al. (2000).

Critical Uncertainties Limiting Advancement

If progress in establishing our capability to modify the weather is to be made, intellectual and technical resources must be brought to bear on the key uncertainties (see Box 2) that currently hamper progress. For example, there are critical gaps in our understanding of the complex chain of physical processes that start with condensation of water vapor and end with precipitation. The processes that lead to the formation of a hailstone are equally complex and difficult to understand, especially when placed in the context of the convective field of motion of a violent thunderstorm.

Progress in obtaining answers to such questions depends on sustained and directed research in laboratories, on research centers dedicated to modeling, and on carefully designed and verifiable field experiments equipped with the most advanced observing tools. Identifying and addressing these critical uncertainties will focus future research where it will produce the most useful results.

Call for a Coordinated National Program

A coordinated national program of weather modification research designed to reduced key uncertainties is needed. This program should be the heart of a sustained research effort that uses a balanced approach of modeling, laboratory studies, and field measurements. Instead of focusing on near-term operational applications of weather modification, the program should address fundamental research questions that might include:

- What is the background aerosol concentration in various places, at different times of the year, and during different meteorological conditions? To what extent would weather modification operations be dependent on these background concentrations?

Box 2. Summary of Key Uncertainties

<u>Cloud/Precipitation Microphysics Issues</u>
Highest priority: Understand the background concentration, sizes, and chemical composition of aerosols that participate in cloud processes.
Other gaps: How nucleation processes relate to characteristics of aerosol particles; ice nucleation; Evolution of the droplet spectra in clouds; Relative importance of drizzle in precipitation processes.

<u>Cloud Dynamics Issues</u>
Highest Priority: Understand cloud-to-cloud and mesoscale interactions as they relate to updraft and downdraft structures and cloud evolution and lifetimes.
Other gaps: Cloud and sub-cloud dynamical interactions as they relate to precipitation amounts and the size spectrum of hydrometeors; Microphysical, thermodynamical, and dynamical interactions within clouds.

<u>Cloud Modeling Issues</u>
Highest priority: Combination of the best cloud models with advanced observing systems in carefully designed field tests and experiments.
Other gaps: Application of new cloud-resolving models to weather modification, including short-term predictive models; Predictive models for severe weather events; Cloud models capability to track dispersion of seeding material both within and outside of seeded areas.

<u>Seeding-Related Issues</u>
High priority: Targeting of seeding agents, diffusion and transport of seeding material, and spread of seeding effects throughout the cloud volume.
High priority: Measurement capabilities and limitations of cell-tracking software, radar, and technologies to observe seeding effects.
Other gaps: Using observations from new instruments of high concentrations of ice crystals; Interactions between different hydrometeors in clouds and how to best model them; Modeling and prediction of treated and untreated conditions for simulation; Mechanisms of transferring the storm-scale effect into an area-wide precipitation effect and tracking possible downwind changes at the single cell, cloud cluster, and floating target scales.

- What is the variability of cloud and cell properties (including structure, intensity, evolution, and lifetime) within larger clusters, and how do clouds and cells interact with larger-scale systems? What are the effects of localized seeding on the larger systems in which the seeded clouds are embedded?
- How accurate are radar reflectivity measurements in measuring the differences between accumulated rainfall in seeded and unseeded clouds? How does seeding affect the drop-size distribution that determines the relationship between the measured radar parameter and actual rainfall at the surface?

To take advantage of recent related research and advances in observational, computational, and statistical technologies, the program should attempt to:

- Capitalize on new remote and in situ observational tools to carry out exploratory and confirmatory experiments in a variety of cloud and storm systems
- Improve cloud model treatment of cloud and precipitation physics.
- Improve and use current computational and data assimilation capabilities.
- Capitalize on existing field facilities and develop partnerships among research groups and select operational programs.

Thus, the initiation of large-scale operational weather modification programs is premature, but a great opportunity exists to coordinate research efforts to address the fundamental questions that will lead to credible scientific results. It is not enough to expand present efforts that primarily analyze data from largely uncontrolled experiments. Instead, focused investigation of atmospheric processes, coupled with an exploration of the technological applications, will certainly advance understanding and bring many unexpected benefits and results. In time, this research will place us in a position to determine whether, how, and to what extent weather and weather systems can be modified.

Critical Issues in Weather Modification Research is the National Academies latest assessment of weather modification research. The report reviews the current state of the science with particular attention to recent advances, identifies the key scientific uncertainties limiting advances in the science, outlines future directions in weather modification research, and suggests actions to identify the impact of local weather modification on large-scale weather and climate patterns.

This report brief was prepared by the National Research Council based on the committee's report. For more information, contact the National Research Council's Board on Atmospheric Sciences and Climate at 202-334-3512. *Critical Issues in Weather Modification Research* is available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242 or 202-334-3313 (in the Washington area); www.nap.edu.

Committee on the Status and Future Directions in U.S. Weather Modification Research and Operations: Michael Garstang (*Chair*), University Of Virginia, Charlottesville; **Roscoe R. Braham, Jr.**, North Carolina State University, Raleigh; **Roelof T. Bruintjes**, National Center For Atmospheric Research, Boulder, Colorado; **Steven F. Clifford**, University Of Colorado, Boulder; **Ross N. Hoffman**, Atmospheric & Environmental Research, Inc., Lexington, Massachusetts; **Douglas K. Lilly**, University Of Oklahoma, Norman; **Robert J. Serafin**, National Center For Atmospheric Research, Boulder, Colorado; **Paul D. Try**, Science & Technology Corporation, Silver Spring, Maryland; **Johannes Verlinde**, Pennsylvania State University, University Park, **Julie Demuth** (Research Associate), Board on Atmospheric Sciences and Climate.

Jatar, Muriel (EC)

From: Cober, Stewart (EC)
Sent: July 23, 2002 2:43 PM
To:
Cc: Mackey, Heather (EC)
Subject: Weather Modification

Hello

Attached is the WMO statement on weather modification.

WMO_Weather_...

With respect to the subject of hail cannons, you might want to visit the following web sites:

http://www.hailshield.com and http://www.hailstop.com

The following article was published in the Bulletin of the American Meteorological Society a few years ago. It shows how the subject of hail cannons has been around for some time.

hailcannons.pdf

The Canadian weather modification act can be found at the following web sites:

http://lois.justice.gc.ca/en/W-5/index.html

http://laws.justice.gc.ca/en/W-5/C.R.C.-c.1604/index.html

The information listed below is from our web site. Unfortunately, you cannot access our web site at present because it is under development.

Weather Modification Information Act
And Regulations

Administrative Guidelines

1. LEGISLATION BACKGROUND AND AUTHORITY

The WEATHER MODIFICATION INFORMATION ACT, being Chapter 59 of the Statutes of Canada 1970-71-72, was passed by parliament and given Royal Assent 15 December 1971. Under provisions of the Act, the Act was proclaimed to come into force and have effect upon, from and after the 21 June 1974 and duly made public in The Canada Gazette, Part I, 22 June 1974 (p. 2405-6)

A copy of the Act is provided as Annex 'A'.

Under Section 6 of the WEATHER MODIFICATION INFORMATION ACT, the Governor in Council is authorized to make Regulations that may be presented under the Act. These Regulations were prescribed and enacted to become effective on 23 July 1974 and were made public in the Canada Gazette, Part II, 14 August 1974 (p. 2217-23).

A copy of the Regulations is provided as Annex 'B'.

The Act and Regulations apply to any person or corporation who proposes to engage in weather modification activities as defined under the Act, and every person or corporation who carries out any weather modification activities in Canada, including all the Provinces of Canada, all the Territories, the Arctic Islands, the Territorial Sea of Canada and all internal waters of Canada.

2. PURPOSE OF THE ACT

The Act and Regulations are aimed at: collecting information on all weather modification activities in Canada; keeping the Government and the Public informed on those activities; measuring the extent and development of the activities; and assisting in establishing the scientific basis for weather modification.

The Act does not control or prohibit weather modification activities beyond stating that the requirements of the Act and Regulations are that persons proposing to engage in or to carry out weather modification activities must provide adequate advance notice of their intentions, maintain certain records and report on their activities, all in accordance with the prescribed form, Notice of Intent to Engage in Weather Modification Activities, form AE0063-2370, or in that manner and content.

A copy of the reporting form AE0063-2370 is provided as Annex 'E'.

3. ADMINISTRATION OF THE ACT

Under the terms of the Act (Section 2.(a)) and the Regulations (Section 3.) the Assistant Deputy Minister, Atmospheric Environment Service, Department of the Environment is designated Administrator for the purposes of the Act and Regulations. A Weather Modification Information Officer carries out the administrative provisions of the Act and Regulations on behalf of the Assistant Deputy Minister.

Information provided in compliance with the Act and Regulations including proposals or Notices of Intent to Engage in Weather Modification Activities must be sent to the Administrator by registered letter. Reports and correspondence of a general or specific nature relating to the Act, Regulations and Activities, may be sent by normal mail. The following address should be used in all communications:

Assistant Deputy Minister
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario
M3H 5T4
Attention: Weather Modification Information Officer

4. PROCEDURES FOR MODIFIERS

Under the Act, the Administrator is delegated the responsibility of collecting and retaining information prescribed by the Act; of specifying certain observations and information that will be reported; of inspecting records concerning activities; of supplying information to the public, and of conducting other implicit associated administrative matters. The information content and the manner of supplying information in compliance with the Act and Regulations should conform to the Act and Regulations.

To assist in administering the Act, for the sake of uniformity in reporting and to reduce the task of information provision for the weather modifiers as provided under Section 3 of the Act, a set of reporting forms (AE0063-2370) are available that should be used by persons complying with this section of the Act. These forms are available by contacting the Weather Modification

Information Officer, or any regional Atmospheric Environment Service office.

5. PURPOSE OF THE ADMINISTRATIVE GUIDELINES

As indicated in the Procedures in Section 4 of this document the Administrator is responsible for specific matters described in the Acts and Regulations. For persons complying with the Act, notwithstanding the Act and Regulations, the Administrative Guidelines are provided to explain administrative procedures and interpretations. They also specify certain information that must be provided under authority of Section 4.(1) (b) (iv) of the Act. These Guidelines will be amended or revised from time to time by and within the authority given to the Administrator, as experience with the administration of the Act develops and as the need arises.

The information that shall be provided by the weather modifier to the Administrator in the Monthly Report of Weather Modification Activity Operations, as referred to in Section 4.(1) (b) (i) to (iii) of the Act, is specified in Annex 'C'.

Certain administrative requirements authorized under the Act and administrative interpretations and explanations of the Act and Regulations are specified in Annex 'D'.

EFFECTIVE DATE

These Administrative Guidelines are effective upon, from and after the 1st January 1979.

Finally, should you have any further questions, you can contact me, or after 31 August, our senior scientist Dr. George Isaac at george.isaac@ec.gc.ca

Stewart

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13(1)(a), 13(1)(b), 15(1)

of the Access to Information Act

de la Loi sur l'accès à l'information

History Repeated: The Forgotten Hail Cannons of Europe

Stanley A. Changnon, Jr., and
J. Loreena Ivens

Illinois State Water Survey
Champaign, Ill. 61801

Abstract

A major weather modification effort at the turn of the century went unnoticed by the "pioneers" of 1950–70. There are several amazing similarities between the two periods that point to two key truths, the need for scientific resolution of weather modification questions, and for awareness by all scientists that events of the past are often relevant to new research considered to be of a pioneering nature.

1. Introduction

Almost everyone realizes at least once in a lifetime that some bright "new" finding is but an old truth rediscovered. So may it be also with a series of events, one falling after another in apparent unprecedented fashion to some unexpected conclusion, only to be discovered as a repetition of another set of events in history.

Weather modification seems an unlikely field for such historical reenactments—it's too new. Its *scientific* history is generally marked as starting only after Vincent J. Schaefer's 1946 cold box discoveries about the production of ice embryos from dry ice (Schaefer, 1968). In the some 30 years since, those involved believed they were at the "cutting edge," discovering new truths and fallacies not only about clouds and seeding nuclei, but also about people's attitudes toward changing the weather. The incantations, sacrifices, bell ringing, and gun firings of ancient times were vaguely known—the legends of primitive civilizations trying to cope with the devastations of the weather. The real science had just begun!

Review of the modern activities of the last 30 years during a multidisciplinary technology assessment of hail suppression (Changnon *et al.*, 1977) revealed a fairly well defined chronology of events in hail suppression and weather modification. First was the concept of cloud seeding, but with slowly developing scientific interest and understanding. Almost immediately, however, came rapid development of seeding devices and instruments to measure clouds, along with an eager public willing to buy and use an uncertain technology. Operational seeding projects were started in small areas around the nation by entrepreneurs. Meanwhile, numerous concepts and hypotheses as to how seeding works were purported. State and federal government agencies moved to fund a few studies and experiments, and proponents (and later scientists) gathered at "weather modification conferences." At some later time, the local sponsors' initial optimism gradually turned to doubt and disenchantment. Then came the controversies—over how to modify the weather, whether it worked, whether it caused droughts, how to evaluate projects, and whether it should be done at all (Changnon, 1977). By the mid-1970s there was some scientific proof that the snow and rain had been modified, but essentially no proof for hail suppression. By 1977 public use of hail suppression had been reduced. Federal support of all weather modification research, which had become the prime input with a high of more than $20 million, dwindled to about $10 million by 1979. Hail suppression research funded at $5 million per year in the early 1970s had totally disappeared by 1978. Dejected and doubting practitioners of hail suppression had only the comfort of believing their mistakes and ignorance might be excused because they were the *first* to explore the new and complex issues.

No new experiences, these! At the close of the 19th century a serious investigation of hail suppression, surprisingly postulated on a concept that agrees with one modern-day scientific hypothesis, took place. The story of these events reveals that many of our 1946–79 experiences were not new ones. Its retelling reveals several similarities to the modern era of weather modification and the attempts to use a technique without scientific understanding. Its review may teach us to avoid several past pitfalls before they happen yet again. Before retelling the events of the 1895–1906 period of hail suppression, it is important to recognize that the modern era of weather modification has had a stronger scientific base than existed in 1895–1906. There has been a considerable development of understanding of cloud physics since 1906 (understanding of the role of supercooled water and ice nuclei, and systematic and direct observations of seeding effects on clouds) and a greater application of sophisticated statistical tests, to name two of the differences.

2. Devices and success

In 1880 an Italian professor of mineralogy stated that it was conceivable that the formation of hailstones could be prevented by injecting smoke particles (to serve as condensation nuclei) by means of cannons fired at thunderstorms. The concept of using cannons to provide nuclei to suppress hail was experimented with in 1896 by M. Albert Stiger, the Burgomaster of Windisch-Feistritz (a municipality in the province of Syria, Austria) and a famous wine grower (Plumandon, 1902). Stiger was an inventive promoter, a politician who was inspired by a desire to help relieve the enormous hail losses in his province. Using backyard tests over a period of several years, he had evolved a vertical-pointing muzzle-loading mortar, resembling a very large upright megaphone (Fig. 1). When fired, it produced a large smoke ring that whistled loudly as it rose to a height of typically 300 m above the cannon. The final design for his cannon (or mortar) was

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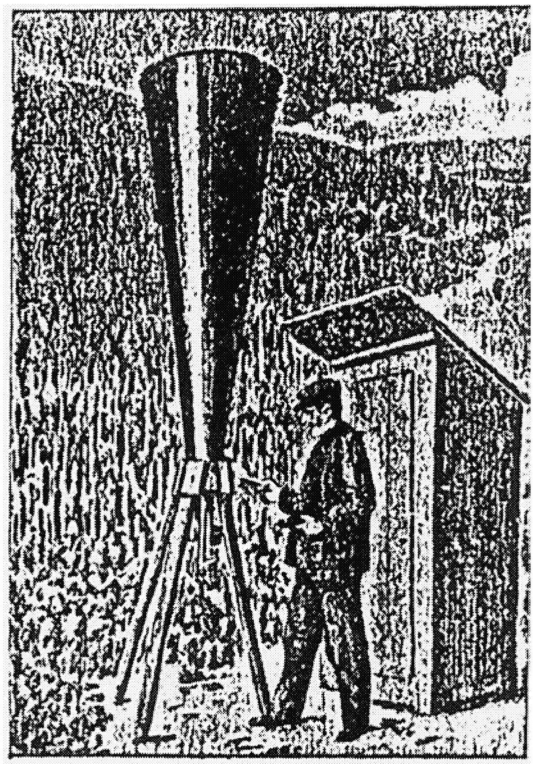

FIG. 1. A typical hail cannon and shed for storing the powder (from Plumandon, 1901).

achieved by 1895; it was funnel-shaped with a 2 m high barrel made of 2 mm thick sheet metal mounted on a large wooden block. The top opening was 69 cm in diameter, with the funnel decreasing to 20 cm at the base.

When Stiger had what he considered the best design and operation (amount of powder) for the cannon, he launched his first "experimental test," operating six cannons in his province during the 1896 hail season. It did not hail at all, and the local enthusiasm led to construction of 30 cannons, which were installed in this Austrian municipality in time for the 1897 hail season. Again, no damaging hail fell in Windisch-Feistritz, while severe hail losses occurred in surrounding provinces during that year. Two years of experimentation in a target-control mode suggested a major solution to the hail problem.

The stage was set for wide interest in this technology. It was believable as a new version of the centuries old "weather shooting" because the firing was done *before* the storm developed and rain began (a new concept), and because Stiger's cannon was vastly different from any before it. (We also saw after 1946 that new seeding devices and concepts brought forth public utilization and new scientific hope.) It is worth noting that in the same general time period experimentation with explosives to make rain was being pursued in Texas (Byers, 1974). This effort, supported by the Department of Agriculture, ended after two years of trials and no apparent success.

Another important factor behind interest in Stiger's cannons was the enormity of the hail-induced crop losses in Austria, France, and Italy. The losses were a bigger problem in the 19th century than they are today because there was little affordable hail insurance (Morgan, 1973). Frequent hail in areas of high value crops (largely vineyards) of these European nations made them likely candidates for development of techniques to suppress hail. For years, village priests had rung church bells and called for prayers and contributions to shield the local village and farms from hail. Moreover, in 1575 Pope Urban VIII authorized a prayer for consecrating church bells that called for "driving away the harmful storms, hail and strong winds" (Oddie, 1965).

History reveals the intensity with which man has longed to alter the weather, and particularly to dissipate severe storms and droughts. Midwestern Indians even developed a practice for trying to dispel fogs (Harrington, 1894). The use of weather shooting for hail suppression had been practiced in Europe since the 14th century, operating on the theory that the noise produced a change. The shooting became so popular and so extensive in Austria and Italy that the peasants were wounding and killing each other. In 1750 Empress Maria Theresa outlawed the use of cannons by the Austrian peasantry because of the accidents and because of complaints that firing in one area resulted in more hail or less rain in another area (Anonymous, 1900). Today, this type of complaint about downwind or extra-area effects is still a largely unanswered scientific issue. People still perceive that hail altered in one place affects the weather adversely somewhere else, and this helped lead to the termination of hail suppression projects in Texas and Colorado in the 1970s (Changnon *et al.*, 1977). The Austrian ban against weather shooting (and the ringing of church bells to ward off storms) was revoked in the late 18th century, opening the way for Stiger's experimentation.

Word of Stiger's local success in 1896–97 spread to Italy. Dr. E. Ottaviri of Italy visited Windisch-Feistritz in 1897 and became a convert, taking cannons back to Italy (Pernter, 1900). The firings in 1898 in Austria and Italy appeared successful, and the use of Stiger's mortars to suppress hail widened rapidly. The mortar became well known as the "grelifugue" (hail preventing) cannon and was advertised as making its firing "convenient and rapid." Importantly, a local Austrian manufacturer of munitions became interested in 1896, and by 1898 the Greinitz and Nephews Company was busy manufacturing and selling cannons in Italy, France, and in other areas in Austria.

Not everyone was totally convinced yet. M. Ottavi, deputy of the Italian Parliament, made the following statement in an official report (Plumandon, 1903) on the results obtained during 1898:

> It may be stated that the firing has produced good results only at Windisch-Feistritz where the success of the two preceding years [1896–1897] has been maintained. In the other localities, it has not been at all satisfactory. The negative results are all the more surprising since the firing was begun in time and carried on perseveringly. However, although the experiments of 1898 do not justify us in coming to a definite conclusion as to the practice of firing into the clouds, it is necessary to continue what has begun.

Nevertheless, by 1899, word of the appreciable use of hail cannons spread to other high hail loss areas in Europe.

Enthusiasm about how man was finally able to solve the hail problem grew. Failures to suppress hail were generally blamed on improper firing of cannons. Users and buyers came to Austria from everywhere in Europe! Hail prevention associations developed in four provinces of Italy, and French and German farmers began to buy the cannons. By 1899 major programs existed in four nations. The fervor in Italy was so great that 2000 cannons were operating there in that year.

The adoption of use of the hail cannons during 1897–99 took on two other interesting characteristics common to the modern era of cloud seeding. First, the modification effort was based on a grid of shooting stations manned by volunteers, an approach commonly used in the operation of ground-based seeding devices since 1950. Second, the Italian, Austrian, Swiss, and French governments set up governmental units within provinces for hail control (to raise funds and to manage the operation). Similar state or district units were organized in the 1970s in North Dakota, South Dakota, and Utah (Changnon *et al.,* 1977).

3. Concepts and cookbooks

As usage grew rapidly during 1898–99, still other activities similar to those seen in the United States during the 1950s occurred. First, the techniques for cannon "seeding" became very specific (thanks to Stiger and the cannon manufacturer), which made it appear well founded. Second, hypotheses about how the modification worked were stated, questioned, and further clarified. Some of these 19th century hypotheses and techniques, in their retelling, are similar to those of our so-called modern era.

Three hail suppression hypotheses had been offered by 1899. Interestingly, none was based on the concept of shattering already-existing hailstones because, as one Austrian scientist stated, "That [cannon induced] vibrations can destroy hail has no foundation in physics" (Pernter, 1900). This lesson and wisdom somehow escaped several modern scientists, who in the 1950s pursued investigations of shattering hailstones by shock waves (Vittori, 1960; Stout, 1961). In fact, a major rocket industry developed in Italy after World War II; it annually sold a million dollars worth of explosive rockets to Italian farmers from the late 1940s until the rockets were outlawed in the early 1970s (Morgan, 1973).

Stiger offered two concepts of how the prestorm firing altered hail. First, the shock disturbed the atmospheric motions and the intense stillness that preceded a hailstorm. The second concept, developed after study of the vortices emitted by the cannons, was that they formed a very strong whirlwind extending upward at least 600 m, which altered (dynamically) the formation of the hail in the approaching cloud. We now know it would be possible for some effect on the updraft of air at cloud base to exist, but Stiger and his associates were unaware of that important aspect of cloud and storm formation.

The third hypothesis of how the cannon suppressing technique worked was described in 1900 by Abbé (1900). We quote this hypothesis because it relates well to modern seeding concepts. Abbé wrote:

> . . . the energy of the movements within the vortex is too slight, in comparison with the energy within a hail cloud, to justify us in expecting any appreciable mechanical disturbance. On the other hand, the European experiments show that the Stiger vortex is essentially a white cloud of fine particles resulting from the explosion of the gunpowder. Now, a cumulus cloud is, as is well known, composed of aqueous particles condensed primarily upon dust nuclei. The condensation of moisture within a rising cloud is hindered until a state of extreme supersaturation is attained because the condensing moisture has no nuclei on which to collect, except the small drops of water already formed. Now, the mortar vortex brings to the cloud a fresh accession of innumerable dust nuclei and, moreover, nuclei that are especially favorable to the condensation of moisture. This must, therefore, to a moderate degree, facilitate the formation of new drops of water and the prevention of that stage of supersaturation as the result of which large drops of water, or large hailstones, or large snowflakes, and balls of snow are formed.

Scientists of today must stand a little abashed—cloud seeding to suppress hail by the promotion of coalescence was first hypothesized in 1900, not in recent years (and it still has not been resolved)! Young (1977) considers hygroscopic seeding to promote coalescence in the warm part (>0°C) of the cloud, so as to reduce the water available for hailstone growth; a feasible approach to hail suppression.

The technique of "how to modify storms" also became very well specified as early as 1898. This is particularly intriguing when one realizes that there were many uncertainties about what happened after the cannons were fired. It is interesting how specific the "recipe" can get for use of an uncertain product, as we still see today. One way to make an uncertain technology look impressive is to prepare a very specific description of how to do it.

The Austrian innovators and the promoters of the hail cannon technology evolved a variety of cannons and developed a very detailed set of instructions, including a printed pamphlet. They specified various arrays of the cannons to be used in an area, the types of cannons to be used (they manufactured five sizes), and the types of explosives. Following is their advice (Suschnig, 1900):

> If there be any small region peculiarly liable to destructive hail, the Stiger method could be satisfactorily tried by covering this region with cannon stations arranged in four lines, each 10 kilometers long and 1 kilometer apart, so as to cover 40 square kilometers. The type of cannon chosen should be based on ground elevation [and hence distance from cloud base]. We would recommend placing in the first of these lines the apparatus of type E-400; in the second line, type D-350; in the third line, type C-300; and in the fourth line, type B-250; we believe that type A-200 can only be used to advantage at places of high altitude [700–1000 meters above sea level].

Costs of the cannons ranged from 110 to 240 crowns ($300 to $700).

By 1899 a sizable hail cannon suppression effort had developed in Europe. Americans were even asking questions about importing cannons. Then another activity similar to that of weather modification in the modern era began—scientific and user conferences.

4. Assessment by conversation

The first of the hail suppression conferences occurred during November 1899 in Casale, Italy, an area of great hail losses where suppression cannons had just been widely introduced (Pernter, 1900). Five hundred delegates came from various provinces of Germany, Italy, Austria, and all Italian ministries of government. After four days of papers and testimonies, four professors were chosen to summarize the Hail Congress. They drafted the following conclusions (Plumandon, 1902):

> The Congress, after having inquired into the results obtained by the experiments carried on in Syria, Dalamatia, Piedmont, Lombardy, Venice, Emilia, and Tuscany is convinced.
>
> 1. That the cannonading has made the prospect for the solution of the great problem of preventing hail very encouraging.
> 2. That the results attained this year [1899] could not be more full of promise.
>
> The Congress expresses the hope that the regions in which the first experiments have taken place this year may succeed in perfecting the means of protection, taking as a basis the experience already acquired.

M. Ottavi, who had been a major Italian skeptic, was the organizer of this "investigative" Congress. The optimism and evidence of success influenced him, and he helped write these positive comments.

The prevailing 1899 optimism of the users, who had spent large sums to protect their vineyards and who had used this new service only one or two years, is not atypical of the users of modern weather modification. Questions asked in 1898–99 were related to technique differences, since it was a "given" that it worked. The discussions dwelt on how many cannons of type "X" to put in area "A."

A review of what had happened in Europe at this stage is revealing:

1) A suppression concept had been offered (1880).

2) It had been used as a basis for an Austrian project for four years without major crop losses or adverse effects (1896–99).

3) A manufacturer of the seeding systems (cannons) had become involved (1897–99).

4) Use had spread widely and rapidly (1898–99).

5) Reasonable (for then) sounding hypotheses based on observations had been offered (1897–99).

6) A supposedly definitive technique to modify storm clouds was available (1898).

7) Users and scientists had met to exchange views and sharpen modification approaches (1899).

Many parallels to this sequence of events can be found in the United States in the 1946–67 period. However, the next few years of cannonading, 1899–1902, brought another set of events common to the modern era of weather modification.

The conclusions of the 1899 Hail Congress in Casale were so optimistic that they raised the enthusiasm of the European vine growers to a high pitch. The use of cannonading spread into Hungary, Spain, and southeastern France. But it was especially in Italy that the number of cannons increased. As examples, between 1899 and 1900 the number of cannons in the province of Venice increased from 466 to 1630; in Brescia from 260 to 1455; and in Treviso from 87 to 1334. At the end of 1900, 10000 cannons were distributed among the vineyards of upper Italy, and 9 500 000 firings had taken place in that year. This tremendous agricultural artillery, unfortunately, did not work without accidents. In Venice and Brescia, where there were 3000 cannons, seven deaths and 78 injuries due to firing accidents were reported in 1900.

The increase in cannonading and the great European interest led to the calling of a second international congress. It took place at Padua, Italy, at the end of November 1900, and was under the presidency of M. Alpe, a professor at the school of agriculture in Milan. Sixty different models of cannons were displayed; the largest weighed 9000 kg, was 9 m long, and pivoted in all directions (Fig. 2). Another very extraordinary model functioned without powder and without a gunner. It was an acetylene cannon in which an electric fuse caused an explosive mixture to be detonated in the air. A clockwork movement regulated the firing of the cannon, and it could also cause all the cannons in a vast region to be fired at the same moment by a connecting wire.

Quotes from two representatives at the Congress (Plumandon, 1903) are typical of the optimism in 1900. M. Tamaro, Director of the Agricultural College in Lombardy, maintained that "recent facts confirmed by thousands of stations, serve to establish perfect confidence in the protection of the crops by cannon." M. Sandri, Director of the Agricultural College of Brescia, called for "a vote recommending a law that should render obligatory the protection by cannonading when this protection is demanded by a majority of those interested." However, one Italian scientist present declared that "it is impossible to pronounce, from a scientific point of view, as to the efficacy of the firing, and that this question can only be really practically demonstrated by statistics of actual damages, studied with care and impartiality, with the aid of observations collected for several years." Similar declarations have been issued at every weather modification conference convened in the United States, including the first one in 1968.

The 1900 Padua Congress adopted this concluding statement: "This Congress, after having heard the reports and successive discussions upon the results obtained during the year 1900, in Italy and in other countries, considers the great

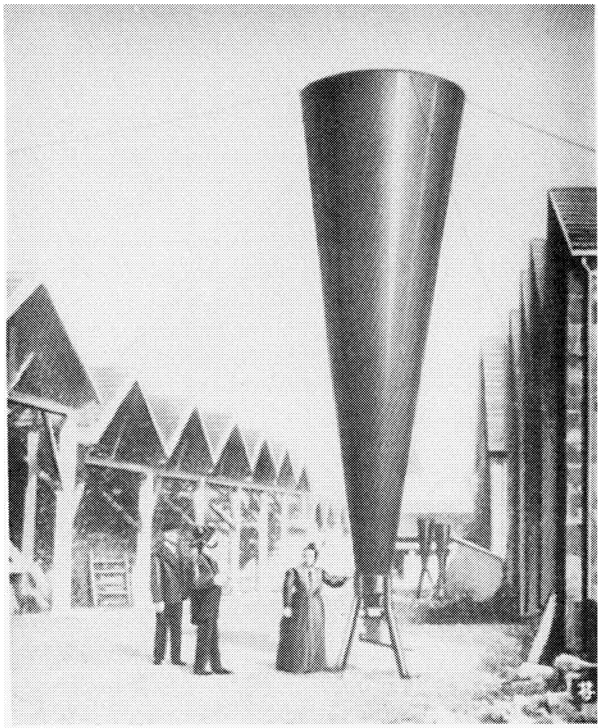

FIG. 2. One of the larger models of hail cannon (from Morgan, 1973).

efficiency of shooting as a protection against hail as having been proved beyond all question."

The third International Congress on Hail Shooting was convened in Lyons, France, in 1901. By this time, government agencies had become heavily involved in the hail cannonading and bureaucrats had become the prime spokesmen for this exciting new technology. A similar evolution from user leadership to state government control has been occurring in weather modification in the United States during the 1970s.

The beliefs of the government representatives, as expressed in their papers given at this Congress, varied widely (Plumandon, 1903). The Austrian representative said, "In general, every one is thoroughly satisfied with the results and no one doubts but that systematic shooting has accomplished good results." The Italian report was mixed: "In many cases the shooting seems to be effective against hail, but in many others not so." The French minister of agriculture reported, "The shooting stations generally report good results, but cases of failure are believed to be the consequence of poor organization, feeble cannon or delay in shooting; nevertheless the severe misfortune at Mantua [one 1901 area of great loss] occurred in spite of perfect shooting and can not be excused."

After a lively discussion, the 1901 Congress adopted four resolutions that called for: 1) earnest attention and study on the part of science; 2) extended stations and uniformity of apparatus and operations; 3) earlier forecasting of thunderstorms by central stations to local groups and investigation of methods of protection against hail by meteorological observatories; and 4) formation of a permanent international committee to bring together all persons and societies interested in the subject, to publish the proceedings, and to call a fourth congress at the proper time (shades of the World Meteorological Organization, circa 1979).

An exhibit of the apparatus was held and judged during the 1901 Congress (Fig. 3). In the competitive trials, which were in the presence of a jury, accidental explosions occurred, necessitating the amputation of the right arm of an

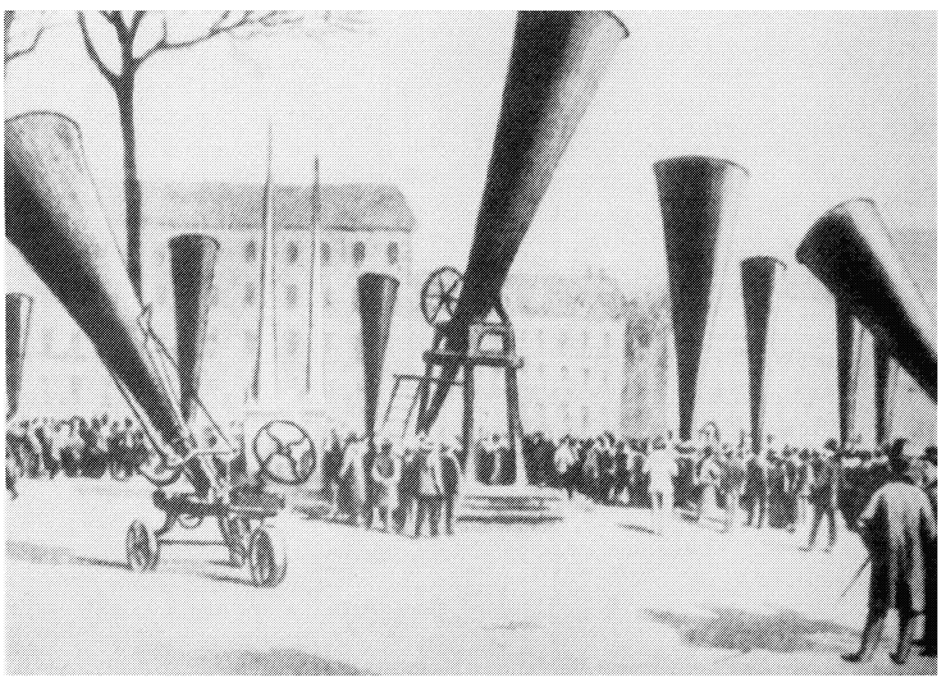

FIG. 3. The exposition of hail cannons at the third International Congress on Hail Shooting, held in Lyons in 1901 (from Plumandon, 1901).

operator. Similar "sacrifices" during the field operations had already become numerous in Europe. In Lombardy in 1901 five deaths and 30 severe accidents had occurred. As a result, the prefect of the Vicenza (Italy) had forbidden any further shooting.

5. Doubts and demise

In 1900 and 1901, new feelings were arising. More scientists were getting involved and concerned. Results from several areas that had been employing hail cannon had become mixed—bad storms occurred after one or two years of "good experience." Several scientists had made calculations and performed experiments with vortex rings, and they had shown that the rings were too weak to affect the forces at cloud bases.

The 1901 comments of Professor Plumandon (1901):

> If we wish to judge of the results obtained against hail by the discharge of cannon, fusees, petards, or any other method which has for its object the combating against storm, it is, of course, necessary to be acquainted with the experiments that have already been made. But it is none the less necessary to have in addition and above all (apart from all preconceived theories), rational ideas of the atmospheric conditions which produce hailstones. Let us take, for example, a case which has been frequently observed: In a locality well organized for defense, a storm approaches unexpectedly. By the blackness of the cloud, the darkness produced by it, the intensity of the lightning, and the continuous roll of thunder coming nearer and nearer, it seems as though it must acquire extraordinary violence, and menace the region with disaster. The artillerymen are at their posts, and fire the hail cannon methodically. Soon the strength of the storm diminishes and it passes away, discharging over the region only a rain that is more beneficial than harmful.
>
> Is it the firing of the cannon that has dissipated the storm? This is not absolutely impossible, but who can affirm that it is so, since dissipation occurs very frequently without any cannon at all being fired? It would be necessary to have a very large number of favorable observations in order to place any confidence in such a bold assertion.

The issue of a serious evaluation was finally being raised.

Uncertainty also began to occur in Italy, where a 1901 Italian National Congress declared: "The good results of hail shooting during the years 1899 and 1900 have only held good for the season of 1901 in those places where the shooting has been conducted rationally and with sufficiently powerful apparatus and where thunderstorms of unusual severity have not occurred." Reality was setting in. Reasons for failure were being sought. The failures were attributed to extraordinary circumstances, i.e., the firing began too early or too late; a lack of ammunition; the inability of the shooters; too violent storms; shooting stations too widely spaced, or not numerous enough—many not unlike reasons given for cloud seeding failures now.

It appears likely that a quite natural temporal distribution of annual hail losses in a small area had occurred providentially in Austrian and Italian areas where cannons had been used for two or three years. Recent research shows that, typically, major hail loss years are random events, often occurring alone or in pairs after two, three, four, or more years of little or no loss (Fig. 4). If hail suppression efforts are begun in a run of low loss years, they can appear to be very "effective."

Another call for objective evaluation was issued by the Head of the Austrian Meteorological Service, J. M. Pernter (1901). He called attention to the seeding failures. He said, "It is to be regretted that the Weather Shooting Congress in Padua did not take advantage of the opportunity to investigate these cases more fully." He also recognized an opportunity that many modern scientists have espoused in the name of weather modification. Pernter noted that the "delusion with cannons" offered an admirable chance to promote the general study of thunderstorms and hail.

The scientific doubts, the problems of fatal cannon accidents, and the evaluation uncertainties were now out in the open. Even M. Susching, the director of the main cannon manufacturing works of Greinitz and Nephews in Austria (and a major promoter since 1896), spoke out in 1901, saying

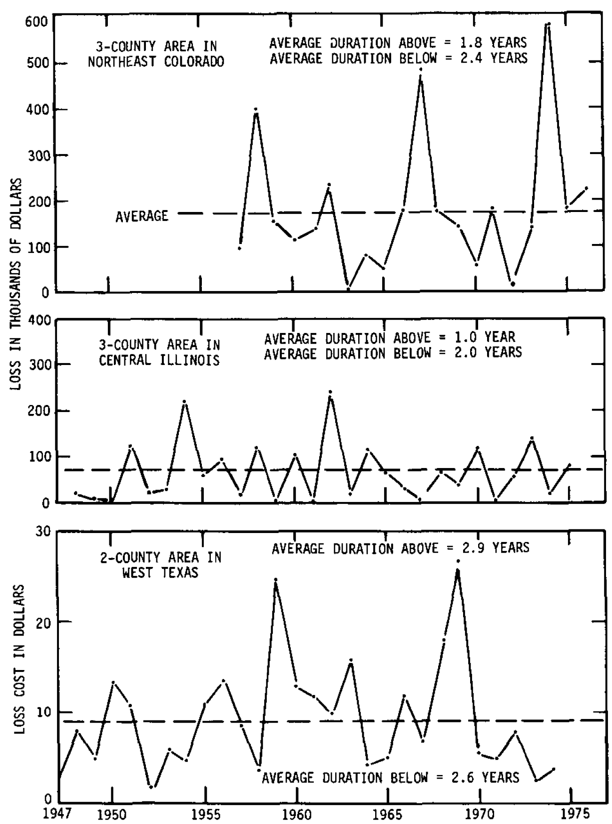

FIG. 4. The temporal distribution of hail loss in small areas (5000–10000 km^2) in various parts of the United States (from Changnon *et al.*, 1977).

"that it is necessary to seek to explain the effects of cannonading, which are still largely unknown to us."

The next relevant event was the fourth Hail Congress, held at Gratz, Austria. It was a conference of 50 government officials and scientists (no users), held under the auspices of the Austrian Minister of Agriculture. One interesting outcome was a vote by the attendees about the status of hail suppression in 1902. The distribution of attitudes (Table 1) indicates the preponderance of some doubt. This Delphi-type experiment yielded results similar to those of a recent sampling, which shows a wide distribution of attitudes about the status of hail suppression capabilities in 1975 (Changnon, 1977).

The fourth Congress concluded that efficacy of hail cannonading was not proven or disproven and they recommended field tests. In a statement heard often in the 1970s, Plumandon (1901) stated, "What is the protective influence which has been credited to cannon firing? If one is to respond rationally, it is seen that it would be necessary to carry out a number of well organized, controlled, and nicely coordinated experiments, in order to know whether the cannons have actually protected crops from hail." As a result, the Austrian government set up an experiment in Windisch-Feistritz (the area of the original development), and the Italian government started an experiment with 222 cannons in Castelfranco-Veneto (Oddie, 1965). After experimenting for two years (1903–04), both areas had experienced damaging hail and the cannons were declared a failure. Success in stopping *all* hail was not found in these experiments (Abbé, 1907). Unfortunately, the experimentation tested the unlikely hypothesis that the cannonading would totally eliminate hail, and the possibility that the cannons reduced *some* hail was not tested or evaluated. The Italians continued small experiments through 1907 with several different cannons, and rockets of various types (that shoot charges aloft, which explode at various heights) have been used intermittently in Europe ever since 1907.

There were major outbreaks of damaging hailstorms in Austria, France, and Italy during 1902–04, and many cannon-protected vineyards were badly damaged. The use of cannons to suppress hail was largely abandoned in Europe by 1905. The end had come.

The inability of the cannon system to stop *all* hail led to the demise of its use. In a similar vein, a sociological assessment of a four-year statewide program of hail suppression (and rainmaking) in South Dakota showed that it ended in 1975 because 1) the user (public) still experienced hail losses (if there was a hail reduction, it was imperceptible to the average citizen), and 2) a good scientific evaluation was not made (Farhar and Mewes, 1976).

As the use of hail cannons to suppress hail in Europe ended during 1905–06, the cannon manufacturers turned to other weapons as the military buildup for World War I began. Burgomaster Stiger and others who had conceived it, those who used it, and the scientists who questioned the use of cannons for hail suppression died, taking their interesting experiences and valuable lessons with them.

Hail suppression efforts essentially ended until they were reawakened in the late 1940s and 1950s in the United States (using aircraft and ground-based cloud seeding); in Italy and France (using exploding rockets to shatter hail, Byers, 1974); and in the Soviet Union (using cannons and rockets to seed clouds). The use of explosive rockets in Europe became extremely widespread in the 1950s and 1960s, partially because of the development of inexpensive devices by a French general (Byers, 1974; Morgan, 1973).

TABLE 1. *Comparison of attitudes of weather modification experts in 1902 and in 1975.*

1902 Experts	
Number of experts in whose opinion cannonading is efficacious	8
Number of experts in whose opinion the efficacy is still doubtful, but probable	9
Number of experts in whose opinion the efficacy is only doubtful	13
Number of experts in whose opinion the efficacy is not only doubtful, but improbable	15
Number of experts in whose opinion cannonading is entirely inefficacious	5
Total	50

1975 Experts
(Survey of U.S. experts in weather modification.)

	Number of scientists
Who do not know if there is any capability to suppress hail	318
Who believe the technology is a failure	27
Who believe the suppression capability is between 1 and 25% reduction	95
Who believe the suppression capability is between 26 and 82% reduction	94
Total	534

6. Message for today

Hail suppression efforts involving the agricultural cannons ended in Europe after 10 years of use. It was easily the largest effort in weather modification research, in development of rational scientific concepts and hypotheses, and in wide usage until the modern era of weather modification began in 1946.

It is amazing that such a major weather modification effort has largely gone unnoticed, particularly since one of its concepts of modification is similar to one of today, and since it produced a sequence of activities seen relived today. The identical sequences include: 1) problem-solving using techniques based on unproven concepts; 2) public usage; 3) initial scientific support, opportunism, and later questioning; 4) bureaucratic involvement and support; 5) manufacturer involvement; and 6) widespread disillusionment of everyone when evaluation shows failure and scientific understanding is lacking.

Professor Plumandon (1903) offered an assessment that is so relevant to conditions of today that it deserves repetition:

> The history of the bombardment with cannon against hail, will suffice to show how circumspectly we must proceed when we wish to judge the efficacy of human intervention against the great forces called into play by nature for the production of thunderstorms. They also show that we should not discount too quickly the scientific advantages that we may hope to derive from such enterprises. If it were necessary to conclude by a plain unvarnished admonition, the following is what I would say: "Before undertaking the protection of your crops by cannonading or other means, wait until the method of protection has furnished good results where it is being tested."

It may be comforting, or discomforting, for the weather modification "pioneers" of the 1950s and 1960s to realize that others preceded them by 60 years. The amazing similarities in the sequence of events of both periods suggest that man, given a problem and a potential—though unproven—technological solution, will adopt it and initially believe it works, but quit its use unless clear scientific proof evolves.

Prolonged use of a less than totally effective means of changing the weather will terminate in a given area unless it is rooted in 1) scientific understanding through field and laboratory experimentation, and 2) scientific evaluation. These are the keys—the two things that halted hail suppression usage in 1905 and its research in the United States in 1979. The message is clear—the science of weather modification must be resolved before its meaningful use can occur. "Those who cannot remember the past are condemned to repeat it" Santayana (1905).

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announcements (*continued from page 367*)

FEMA Emergency Management Institute

To provide instruction in comprehensive emergency management, the Federal Emergency Management Agency (FEMA) recently established the Emergency Management Institute (EMI) in Emmitsburg, Md. Students at the school will be primarily senior government officials, but some classes will be open to leaders in the academic, industrial, research, and business communities. The Institute will function as a focal point for the collection and dissemination of knowledge on hazard identification, mitigation, preparedness, response, and recovery.

EMI's Director is Ralph C. Bledsoe, formerly a professor and senior faculty member of the Federal Executive Institute in Charlottesville, Va. Twenty-eight full-time faculty and support personnel are augmented by four professionals on rotating detail from FEMA headquarters. Three departments operate under the Director's office: State and Local Curriculum and Instruction; Federal and Technical Curriculum and Instruction; and Management and Media Development.

Instruction at the Institute began in January 1981. No tuition is charged for courses, and application for attendance at EMI courses, seminars, and other activities can be made on FEMA Form 95-2, obtainable from: Assistant Director of Training and Education, FEMA, Washington, D.C. 20472 (tel: 202-254-9557) or Emergency Management Institute, Emmitsburg, Md. 21727 (tel: 301-447-6801).

(*continued on page 380*)

s.19(1)

Jatar, Muriel (EC)

From: Isaac, George [Ontario]
Sent: July 16, 2002 8:37 AM
To: 'Jock McIntosh'
Cc: Power, Jack [Ontario]; Cober, Stewart (EC)
Subject: RE: Cloud Seeding

Jock McIntosh,

I did speak to both Janet McLean and [redacted] I explained to Mr. [redacted] it was unlikely that the hail suppression project was doing anything in terms of modifying hail or rainfall. At least nothing that could be measured scientifically. The drought that he was concerned about was probably caused by other factors. Of course, strictly speaking, one cannot be 100% sure, but my opinion would likely be the consensus of most scientists.

I did express some sympathy to him regarding licensing of weather modification and the ability of companies to do whatever they liked without controls. However, the Federal Government only collects information on weather modification because of possible inter-provincial concerns and questions from our neighbour to the south. Licensing remains the responsibility of the provinces. I believe that Quebec is the only province that licenses weather modification projects, and to my knowledge they have never issued one. So I did suggest to Mr. [redacted] that he contact the Alberta Government over this issue, as I also encouraged him to put his concerns in writing to the Federal Government. I indicated to him that the impact of a written letter would likely be greater than a telephone call.

Given all the concerns each year that are raised in Alberta regarding weather modification, it would seem reasonable that Alberta license such activities. That is my opinion and, of course, not necessarily the opinion of my Department.

Regards....George Isaac

George A. Isaac
Senior Scientist
Cloud Physics Research Division
Meteorological Service of Canada
4905 Dufferin Street
Toronto, Ontario, M3H5T4
Tel: (416) 739-4605
Fax: (416) 739-4211
E-Mail: george.isaac@ec.gc.ca

-----Original Message-----
From: Jock McIntosh [mailto:Jock.McIntosh@gov.ab.ca]
Sent: Monday, July 15, 2002 6:05 PM
To: 'george.isaac@ec.gc.ca'
Subject: Cloud Seeding

Dr. Isaac,

You are likely aware that Alberta Environment has been receiving some concerns regarding the effects of cloud seeding on the weather from Mr . A colleague of mine, Janet McLean, apparently contacted you earlier in July and we had heard that you were going to speak to Mr. As Mr. is currently pursuing his concerns further with our Assistant Deputy Minister, our ADM was interested in what came of your telephone conversation with Mr. and the information you were able to provide to him.

To our knowledge cloud seeding should not impact the weather and is not responsible for furthering the current drought we are experiencing in that area of the province. We are aware there are differing opinions on this and after speaking with Jack Power, he felt that you were the best authority on this matter. In addition, Mr. Is this something that you advise should be regulated on a provincial basis?

Jock McIntosh
Alberta Environment
Science and Standards Branch
4th Flr. 9820 106 Street
Edmonton AB T5K 2J6
780 427-0031

s.19(1)

Jatar, Muriel (EC)

From: Isaac, George [Ontario]
Sent: July 2, 2002 10:38 AM
To: 'janet.mclean@gov.ab.ca'
Cc: Cober, Stewart (EC); Power, Jack [Ontario]
Subject: Weather Modification in Alberta

Janet,

As I mentioned on the telephone, Canada has a Weather Modification Information Act which requires people performing weather modification to report it to the federal government. It only collects information, and does not license people or stop groups from performing weather modification. That is left to the provinces. To my knowledge, the only weather modification project currently running in Canada is the hail suppression project in Alberta.

The most recent statement of the World Meteorological Organization (WMO) on the Status of Weather Modification is attached. There are many Hail Suppression Projects being conducted around the world. Virtually all of them have no scientifically credible evaluation. There were two large research projects more than a decade ago (one in Europe and one in Colorado) designed to provide scientific evidence (e.g. statistical significance) that hail suppression either worked or did not. Both projects ended in failure. Several projects run by local insurance groups (e.g. France and North Dakota among others) have claimed success, but you cannot evaluate a project using crop insurance statistics. There are just too many non meteorolgical factors that go into determining crop loss to risk ratios, or hail damage to risk ratios in the case of general property damage. It is my understanding that the Alberta group is not attempting to perform any scientific evaluation of their effectiveness.

I will try and call Mr. [redacted] later today. I hope this information is of some assistance.

Regards....George

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WMO STATEMENT ON THE STATUS OF WEATHER MODIFICATION

INTRODUCTION

For thousands of years people have sought to modify weather and climate so as to augment water resources and mitigate severe weather. The modern technology of weather modification was launched by the discovery in the late 1940s that supercooled cloud droplets could be converted to ice crystals by insertion of a cooling agent such as dry ice or an artificial ice nucleus such as silver iodide. Over 50 years of subsequent research have greatly enhanced our knowledge about the microphysics, dynamics and precipitation processes of natural clouds (rain, hail, snow) and the impacts of human interventions on those processes.

Currently, there are dozens of nations operating more than 100 weather modification projects, particularly in arid and semi-arid regions all over the world, where the lack of sufficient water resources limits their ability to meet food, fibre, and energy demands. The purpose of this document is to present a review of the status of weather modification.

The energy involved in weather systems is so large that it is impossible to artificially create rainstorms or to alter wind patterns to bring water vapour into a region. The most realistic approach to modifying weather is to take advantage of microphysical sensitivities wherein a relatively small human-induced disturbance in the system can substantially alter the natural evolution of atmospheric processes.

The ability to influence cloud microstructures has been demonstrated in the laboratory, simulated in numerical models, and verified through physical measurements in some natural systems such as fogs, layer clouds and cumulus clouds. However, direct physical evidence that precipitation, hail, lightning, or winds can be significantly modified by artificial means is limited. The complexity and variability of clouds result in great difficulties in understanding and detecting the effects of attempts to modify them artificially. As knowledge of cloud physics and statistics and their application to weather modification has increased, new assessment criteria have evolved for evaluating cloud-seeding experiments. The development of new equipment - such as aircraft platforms with microphysical and air-motion measuring systems, radar (including Doppler and polarization capability), satellites, microwave radiometers, wind profilers, automated raingauge networks, mesoscale network stations - has introduced a new dimension. Equally important are the advances in computer systems that permit large quantities of data to be processed. New data sets, used in conjunction with increasingly sophisticated numerical cloud models, help in testing various weather modification hypotheses. Chemical and chaff tracer studies help to identify airflow in and out of clouds and the source of ice or hygroscopic nucleation as the seeding agent. With some of these new facilities, a better climatology of clouds and precipitation can be prepared to test seeding hypotheses prior to the commencement of weather modification projects.

If one were able to predict precisely the precipitation from a cloud system, it would be a simple matter to detect the effect of artificial cloud seeding on that system. The expected effects of seeding, however, are almost always within the range of natural variability (low signal-to-noise ratio) and our ability to predict the natural behaviour is still limited.

Comparison of precipitation observed during seeded periods with that during historical periods presents problems because of climatic and other changes from one period to another, and therefore is not a reliable technique. This situation has been made even more difficult with the mounting evidence that climate change may lead to changes in global precipitation amounts as well as to spatial redistribution of precipitation.

In currently accepted evaluation practice, randomization methods (target/control, crossover or single area) are considered most reliable for detecting cloud-seeding effects. Such randomized tests require a number of cases readily calculated on the basis of the natural variability of the

precipitation and the magnitude of the expected effect. In the case of very low signal-to-noise ratios, experiment durations in the range of five to over ten years may be required. Whenever a statistical evaluation is required to establish that a significant change resulted from a given seeding activity, it must be accompanied by a physical evaluation to:

1. Confirm that the statistically observed change is likely due to the seeding; and

2. Determine the capabilities of the seeding method to produce desired effects under various conditions.

The effect of natural precipitation variability on the required length of an experiment can be reduced through the employment of physical predictors, which are effective in direct proportion to our understanding of the phenomenon. The search for physical predictors, therefore, holds a high priority in weather modification research. Physical predictors may consist of meteorological parameters (such as stability, wind directions, pressure gradients) or cloud quantities (such as liquid water content, updraught speeds, concentrations of large drops, ice-crystal concentration or radar reflectivity).

Objective measurement techniques of precipitation quantities are to be preferred for testing weather modification methods. These include both direct ground measurements (e.g. rain gages and hail pads) and remote sensing techniques (e.g. radar, satellite). Secondary sources, such as insurance data (as have in the past been employed to show changes in hail intensity) are, at least by themselves, not held to be satisfactory in most situations.

Operational programmes should be conducted with recognition of the risks inherent in a technology which is not totally developed. For example, it should not be ignored that, under certain conditions, seeding may cause more hail or reduce precipitation. However, properly designed and conducted operational projects seek to detect and minimize such adverse effects. Therefore, weather modification managers are encouraged to add scientifically accepted evaluation methodologies to be undertaken by experts independent of the operators.

Brief summaries of the current status of weather modification are given in the following sections. These summaries were restricted to weather modification activities that appear to be based on acceptable physical principles and which have been tested in the field.

FOG DISPERSAL

Different techniques are being used to disperse warm (i.e. at temperatures greater than 0°C) and cold fogs. The relative occurrence of warm and cold fogs is geographically and seasonally dependent.

The thermal technique, which employs intense heat sources (such as jet engines) to warm the air directly and evaporate the fog has been shown to be effective for short periods for dispersal of some types of warm fogs. These systems are expensive to install and to use. Another technique that has been used is to promote entrainment of dry air into the fog by the use of hovering helicopters or ground based engines. These techniques are also expensive for routine use.

To clear warm fogs, seeding with hygroscopic materials has also been attempted. An increase in visibility is sometimes observed in such experiments, but the manner and location of the seeding and the size distribution of seeding material are critical and difficult to specify. In practice the technique is seldom as effective as models suggest. Only hygroscopic agents should be used that pose no environmental and health problems.

Cold (supercooled) fog can be dissipated by growth and sedimentation of ice crystals. This may be induced with high reliability by seeding the fog with artificial ice nuclei from ground-based or airborne systems. This technique is in operational use at several airports and highways where there is a relatively high incidence of supercooled fog. Suitable techniques are dependent upon

wind, temperature and other factors. Dry ice has commonly been used in airborne systems. Other systems employ rapid expansion of compressed gas to cool the air enough to form ice crystals. For example, at a few airports and highway locations, liquid nitrogen or carbon dioxide is being used in ground-based systems. A new technique, which has been demonstrated in limited trials, makes use of dry ice blasting to create ice crystals and promote rapid mixing within the fog. Because the effects of this type of seeding are easily measured and results highly predictable, randomized statistical verification generally has been considered unnecessary.

PRECIPITATION (RAIN AND SNOW) ENHANCEMENT

This section deals with those precipitation enhancement techniques that have a scientific basis and that have been the subject of research. Other non-scientific and unproven techniques that are presented from time to time should be treated with the required suspicion and caution.

Orographic mixed-phase cloud systems

In our present state of knowledge, it is considered that the glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects for increasing precipitation in an economically viable manner. These types of clouds attracted great interest in their modification because of their potential in terms of water management, i.e. the possibility of storing water in reservoirs or in the snowpack at higher elevations. There is statistical evidence that, under certain conditions, precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of surface precipitation records from some long-term projects indicate that seasonal increases have been realized.

Physical studies using new observational tools and supported by numerical modelling indicate that supercooled liquid water exists in amounts sufficient to produce the observed precipitation increases and could be tapped if proper seeding technologies were applied. The processes culminating in increased precipitation have also been directly observed during seeding experiments conducted over limited spatial and temporal domains. While such observations further support the results of statistical analyses, they have to date been of limited scope. The cause and effect relationships have not been fully documented, and thus the economic impact of the increases cannot be assessed.

This does not imply that the problem of precipitation enhancement in such situations is solved. Much work remains to be done to strengthen the results and produce stronger statistical and physical evidence that the increases occurred over the target area and over a prolonged period of time, as well as to search for the existence of any extra-area effects. Existing methods should be improved in the identification of seeding opportunities and the times and situations in which it is not advisable to seed, thus optimizing the technique and quantifying the result.

Also, it should be recognized that the successful conduct of an experiment or operation is a difficult task that requires qualified scientists and operational personnel. It is difficult and expensive to fly aircraft safely in supercooled regions of clouds. It is also difficult to target the seeding agent from ground generators or from broad-scale seeding by aircraft upwind of an orographic cloud system.

Stratiform clouds

The seeding of cold stratiform clouds began the modern era of weather modification. Shallow stratiform clouds can be under certain conditions made to precipitate, often resulting in clearing skies in the region of seeding. Deep stratiform cloud systems (but still with cloud tops warmer than -20°C) associated with cyclones and fronts produce significant amounts of precipitation. A number of field experiments and numerical simulations have shown the presence of supercooled water in some regions of these clouds and there is some evidence that precipitation can be increased.

Cumuliform clouds

In many regions of the world, cumuliform clouds are the main precipitation producers. These clouds (from small fair weather cumulus to giant thunderclouds) are characterized by strong vertical velocities with high condensation rates. They can hold the largest condensed water contents of all cloud types and can yield the highest precipitation rates. Seeding experiments continue to suggest that precipitation from single-cell and multicell convective clouds have produced variable results. The response variability is not fully understood.

Precipitation enhancement techniques by glaciogenic seeding are utilized to affect ice phase processes while hygroscopic seeding techniques are used to affect warm rain processes. Methods to assess these techniques vary from direct measurements with surface precipitation gauges to indirect radar derived precipitation estimates. Both methods have inherent advantages and disadvantages.

During the last ten years there has been a thorough scrutiny of past experiments using glaciogenic seeding. The responses to seeding seem to vary depending on changes in natural cloud characteristics and in some experiments they appear to be inconsistent with the original seeding hypothesis.

Experiments involving heavy glaciogenic seeding of warm-based convective clouds (bases about +10°C or warmer) have produced mixed results. They were intended to stimulate updraughts through added latent heat release, which, in turn, was postulated to lead to an increase in precipitation. Some experiments have suggested a positive effect on individual convective cells but conclusive evidence that such seeding can increase rainfall from multi-cell convective storms has yet to be established. Many steps in the postulated physical chain of events have not been sufficiently documented with observations or simulated in numerical modelling experiments.

In recent years, the seeding of warm and cold convective clouds with hygroscopic chemicals to augment rainfall by enhancing warm rain processes (condensation/collision-coalescence/break-up mechanisms) has received renewed attention through model simulations and field experiments. Two methods of enhancing the warm rain process have been investigated: first, seeding with small particles (artificial CCN with mean sizes about 0.5 to 1.0 micrometers in diameter) is used to accelerate precipitation initiation by stimulating the condensation-coalescence process by favourably modifying the initial droplet spectrum at cloud base, and second, seeding with larger hygroscopic particles (artificial precipitation embryos about 30 micrometers in diameter) to accelerate precipitation development by stimulating the collision-coalescence processes. A recent experiment utilizing the latter technique indicated statistical evidence of radar estimated precipitation increases. However, the increases were not as contemplated in the conceptual model but seem to occur at later times (1-4 hours after seeding), the cause of this effect is not known.

Recent randomized seeding experiments with flares that produce small hygroscopic particles in the updraught regions of continental, mixed-phase convective clouds have provided statistical evidence of increases in radar-estimated rainfall. The experiments were conducted in different parts of the world and the important aspect of the results was the replication of the statistical results in a different geographical region. In addition, physical measurements were obtained suggesting that the seeding produced a broader droplet spectrum near cloud base that enhances the formation of large drops early in the lifetime of the cloud. These measurements were supported by numerical modelling studies.

Although the results are encouraging and intriguing, the reasons for the duration of the observed effects obtained with the hygroscopic particle seeding are not understood and some fundamental questions remain. Measurements of the key steps in the chain of physical events associated with hygroscopic particle seeding are needed to confirm the seeding conceptual models and the range of effectiveness of these techniques in increasing precipitation from warm and mixed-phase convective clouds.

Despite the statistical evidence of radar estimated precipitation changes in individual cloud systems in both glaciogenic and hygroscopic techniques, there is no evidence that such seeding can increase rainfall over significant areas economically. There are no evidence of any extra-area effects.

HAIL SUPPRESSION

Hail causes substantial economic loss to crops and property. Many hypotheses have been proposed to suppress hail, and operational seeding activities have been undertaken in many countries. Physical hypotheses include the concepts of beneficial competition (creating many additional hail embryos that effectively compete for the supercooled water), trajectory lowering (intended to reduce the size of hailstones), and premature rainout. Following these concepts, seeding methods concentrate on the peripheral regions of large storm systems, rather than on the main updraught.

Our understanding of storms is not yet sufficient to allow confident prediction of the effects of seeding on hail. The possibilities of increasing or decreasing hail and rain in some circumstances have been discussed in the scientific literature. Supercell storms have been recognized as a particular problem. Numerical cloud model simulations have provided insights into the complexity of the hail process, but the simulations are not yet accurate enough to provide final answers. Scientists in operational and research programs are working to delineate favourable times, locations, and seeding amounts for effective modification treatments.

A few randomized trials have been conducted for hail suppression using such measures as hail mass, kinetic energy, hailstone number, and area of hailfall. However, most attempts at evaluation have involved non-randomized operational programs. In the latter, historical trends in crop hail damage have often been used, sometimes with target and upwind control areas, but such methods can be unreliable. Large reductions have been claimed by many groups. The weight of scientific evidence to date is inconclusive, neither affirming nor denying the efficacy of hail suppression activities. This situation is motivation for operational programs to strengthen the physical and evaluation components of their efforts.

In recent years anti-hail activities using cannons to produce loud noises have re-emerged. There is neither a scientific basis nor a credible hypothesis to support such activities.

Significant advances in technology during the last decade have opened new avenues to document and better understand the evolution of severe thunderstorms and hail. New experiments on storm organization and the evolution of precipitation including hail are needed.

OTHER SEVERE WEATHER MODERATION

Tropical cyclones contribute significantly to the annual rainfall of many areas, but they are also responsible for considerable damage to property and for a large loss of life. Therefore, the aims of any modification procedure should be to reduce the wind, storm surge, and rain damage, but not necessarily the total rainfall. Hurricane modification experiments were conducted in the 1960s and early 1970s. However, there is no generally accepted conceptual model suggesting that hurricanes can be modified.

While modification of tornadoes or of damaging winds is desirable for safety and economical reasons, there is presently no accepted physical hypothesis to accomplish such a goal.

There has been some interest in the suppression of lightning. Motivation includes reducing occurrences of forest fires ignited by lightning and diminishing this hazard during the launching of space vehicles. The concept usually proposed involves reducing the electric fields within thunderstorms so that they do not become strong enough for lightning discharges to occur. To do this, chaff (metallized plastic fibres) or silver iodide have been introduced into thunderstorms. The chaff is postulated to provide points for corona discharge which reduces the electric field to values

below those required for lightning, whereas augmenting the ice-crystal concentration is postulated to change the rate of charge build up and the charge distribution within the clouds. Field experiments have used these concepts and limited numerical modelling results have supported them. The results have no statistical significance.

INADVERTENT WEATHER MODIFICATION

There is ample evidence that biomass burning, agricultural and industrial activities modify local and sometimes regional weather conditions. Land-use changes (e.g. urbanization and deforestation) also modify local and regional weather. Air quality, visibility, surface and low-level wind, humidity and temperature, and cloud and precipitation processes are all affected by large urban areas. As environmental monitoring and atmospheric modelling capabilities are improved, it is increasingly evident that human activities have significant impacts on meteorological parameters and climatological mechanisms that influence our health, productivity and societal infrastructure. Inadvertent effects need to be considered in design and analyses of weather modification experiments and operations (e.g. changes in background aerosol distributions affect the cloud structure and may affect precipitation processes).

ECONOMIC, SOCIAL AND ENVIRONMENTAL ASPECTS OF WEATHER MODIFICATION

Weather modification is sometimes considered by countries when there is a need to improve the economy in a particular branch of activity (for example: increase in water supply for agriculture or power generation) or to reduce the risks that may be associated with dangerous events (frosts, fogs, hail, lightning, thunderstorms, etc.). Besides the present uncertainties associated with the capability to reach such goals, it is necessary to consider the impacts on other activities or population groups. Economical, social, ecological and legal aspects should be taken into account. Thus, it is important to consider all the important complexity and recognize the variety of possible impacts, during the design stage of an operation.

Legal aspects may be particularly important when weather modification activities are performed in proximity to borders of different countries. However, any legal system aimed at promoting or regulating weather modification must recognize that scientific knowledge is still incomplete.

The implications of any projected long-term weather modification operation on ecosystems need to be assessed. Such studies could reveal changes that need to be taken into account. During the operational period, monitoring of possible environmental effects should be undertaken as a check against anticipated impacts.

SUMMARY STATEMENT AND RECOMMENDATIONS

To answer the need for more water and less hail in many regions of the world, some progress has been made during the past ten years in the science and technology of weather modification. Large numbers of programmes in fog dispersion, rain, snow enhancement and hail suppression are in operation. Several research experimental programmes are supported in some countries and include randomized statistical evaluations. Improved observational facilities, computer capabilities, numerical models, and understanding now permit more detailed examination of clouds and precipitation processes than ever before, and significant advances are consequently possible. New technologies and methods are starting to be applied and will help to lead to further understanding and development in this field.

In the light of this review of the status of weather modification, the following recommendations are made to interested Members of WMO:

(a) Cloud, fog and precipitation climatologies should be established in all countries as vital information for weather modification and water resource studies and operations;

(b) Operational cloud-seeding projects should be strengthened by allowing an independent evaluation of the results of seeding. This should include measurements of physical response variables and a randomized statistical component;

(c) Education and training in cloud physics, cloud chemistry, and other associated sciences should be an essential component of weather modification projects. Where the necessary capacity does not exist advantage should be taken of facilities in other Members;

(d) It is essential that basic measurements to support and evaluate the seeding material and seeding hypothesis proposed for any weather modification experiments be conducted before and during the project;

(e) Weather modification programmes are encouraged to utilize new observational tools and numerical modelling capabilities in the design, guidance and evaluations of field projects. While some Members may not have access or resources to implement these technologies, collaboration between member states (e.g. multinational field programmes, independent expert evaluations, education, etc.) are encouraged that could provide the necessary resources for implementing these technologies.

GUIDELINES FOR ADVICE AND ASSISTANCE RELATED TO THE PLANNING OF WEATHER MODIFICATION ACTIVITIES

1. These guidelines are addressed to Members requesting advice or assistance on weather modification activities. They include recommendations that are based on present knowledge gained through the results of worldwide theoretical studies as well as laboratory and field experiments. A synthesis of the main basic concepts and main results obtained in the weather modification programmes is given in the "WMO Statement on the Status of Weather Modification". This statement was revised during the twentieth session of the Executive Council Panel of Experts/CAS Working Group on Physics and Chemistry of Clouds and Weather Modification Research and was approved by the fifty-third session of the Executive Council in June 2001.

2. Members wishing to develop activities in the field of weather modification should be aware that research and operational applications are still under development. It should not be ignored that under certain conditions seeding may be ineffective or may even enhance an undesirable effect (increase of hail, reduction in rain). However, properly designed and conducted projects seek to detect and minimize such adverse effects. It is recognized that scientific evaluation may be a difficult task, but this is the only way presently known to avoid negative results, quantify positive economic effects, and allow improvements in the understanding and methodology that is used. The revised WMO Statement on the Status of Weather Modification referred to in paragraph 1 distinguishes the various types of weather modification and the degree of confidence one has in obtaining the desired effect from cloud seeding. The confidence level is very high for operational dissipation of supercooled fog <u>and</u> moderate for increasing snowfall from orographic clouds. The confidence level is not high for suppressing hail.

3. WMO recommends that operational cloud seeding projects for precipitation modification be designed to allow evaluation of the results of seeding through physical measurements and statistical controls associated with some randomization of the seeding events. The physical measurements should include characterization of the seeding material. Care should be taken to engage qualified operators. The objective evaluation should be performed by a group independent of the operational one. Such programmes should be planned on a long-duration basis because precipitation variability is generally much greater than the increases or decreases claimed for artificial weather modification. The use of appropriate numerical models may help in reducing the time required to evaluate the project.

4. WMO recommends that a detailed examination of the suitability of the site for cloud seeding should be conducted similar to that done in the Precipitation Enhancement Project (PEP), for which WMO reports are available. To increase the chances of success in a specific situation, it should be verified through preliminary studies that:

- The climatology of clouds and precipitation at the site indicates the possibility of favourable conditions for weather modification;
- Conditions are suitable for the available modification techniques;
- Modelling studies support the proposed weather modification hypothesis;
- For the frequency with which suitable conditions occur, the changes resulting from the modification technique can be detected at an acceptable level of statistical significance;
- An operational activity can be carried out at a cost acceptably lower than the socio-economic benefit that is likely to result.

All prospective studies require expert judgement and the results are expected to depend on the site chosen and on the season.

5. There are no quantitative criteria for the acceptance of the results of a weather modification experiment. Acceptance will depend on the degree of the scientific objectivity and the consistency with which the experiment was carried out and the degree to which this is demonstrated. Also important are the physical plausibility of the experiment, the degree to which bias is excluded from the conduct and analysis of the experiment, and the degree of statistical significance achieved. There have been few weather modification experiments that have met the requirements of the scientific community with respect to these general criteria. However, there are exciting possibilities now for making progress in our understanding of weather modification issues using modern research tools, including advanced radar, new aircraft instruments and powerful numerical models.

6. Weather modification should be viewed as a part of an integrated water resources management strategy. Instant drought relief is difficult to achieve. In particular, if there are no clouds, precipitation cannot be artificially stimulated. It is likely that the opportunities for precipitation enhancement will be greater during periods of normal or above normal rainfall than during dry periods.

7. The Members should be aware that the scope of efforts involved in the design, conduct or evaluation of a weather modification programme precludes the WMO Secretariat from giving detailed advice. However, if requested, the Secretary-General may assist (by obtaining advice from scientists on other weather modification projects or with special expertise) on the understanding that:

(i) Costs will be met by the requesting country;

(ii) The Organization can take no responsibility for the consequences of the advice given by any invited scientist or expert;

(iii) The Organization accepts no legal responsibility in any dispute that may arise.

Jatar, Muriel (EC)

From: Isaac, George [Ontario]
Sent: January 10, 2002 1:58 PM
To: 'Ron Bothe'
Cc: Cober, Stewart (EC); Power, Jack [Ontario]
Subject: RE: Cloud Seeding

Ron,

Sorry about that. This message is getting quite messy. Theoretically you could "dry" out the atmosphere significantly to create less precipitation downwind. However, I doubt that would happen when you consider that most of the seeding effects amount to perhaps precipitation increases of 10-15%, and less of an impact on the water vapour content. However, a modeling study could be performed to determine the possibilities in this case for this geographical region, with assumptions about the seeding frequency, amount, etc. Then one could put in realistic evaoporation rates, etc, and get an idea of the impacts. Although many assumptions would have to be made, it would be better than an off-the-cuff opinion by myself.

What you really need is an environmental impact assessment by an independent group, rather than a quick impression or opinion regarding these issues. As you might guess, I am becoming more and more uncomfortable with providing quick answers. So, I guess if you are worried about possible effects, then such an assessment should be done, with appropriate literature reviews, expert opinions and perhaps some model simulations.

Regards....George

____

George A. Isaac
Senior Scientist
Cloud Physics Research Division
Meteorological Service of Canada
4905 Dufferin Street
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CANADA
Tel: (416) 739-4605
Fax: (416) 739-4211
E-Mail: george.isaac@ec.gc.ca

-----Original Message-----
From: Ron Bothe [mailto:Ron.Bothe@gov.ab.ca]
Sent: Thursday, January 10, 2002 10:59 AM
To: 'George.Isaac@ec.gc.ca'
Subject: RE: Cloud Seeding

George: I did not see a response from you to my question of cumulative effects. I have highlighted it for you.

Ron Bothe
Director, Environmental Operations

Alberta Environment
Voice: (780) 427-8646
Fax: (780) 422-0262

-----Original Message-----
From: George.Isaac@ec.gc.ca [mailto:George.Isaac@ec.gc.ca]
Sent: Wednesday, January 09, 2002 11:23 AM
To: Ron Bothe
Cc: Jack.Power@ec.gc.ca
Subject: RE: Cloud Seeding

Ron,

My answers are below. By cop of this note, I am asking our Weather Modification Information Officer (Jack Power) to send you a copy of the old Canada/U.S. agreement on the exchange of information on weather modification.

Regards....George

____

George A. Isaac
Senior Scientist
Cloud Physics Research Division
Meteorological Service of Canada
4905 Dufferin Street
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CANADA
Tel: (416) 739-4605
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-----Original Message-----
From: Ron Bothe [mailto:Ron.Bothe@gov.ab.ca]
Sent: Tuesday, January 08, 2002 2:37 PM
To: 'George.Isaac@ec.gc.ca'
Subject: RE: Cloud Seeding

George, thanks for your response. Further comments and questions are noted in the text.

Ron Bothe
Director, Environmental Operations
Alberta Environment
Voice: (780) 427-8646
Fax: (780) 422-0262

-----Original Message-----
From: George.Isaac@ec.gc.ca [mailto:George.Isaac@ec.gc.ca]

Sent: Monday, January 07, 2002 2:01 PM
To: Ron Bothe
Subject: RE: Cloud Seeding

Ron,

I have attempted to quickly respond to your questions below. Let me know if you need further information. Obviously, I could spend a great deal of time on these issues, and I am not certain that the effort is needed.

Regards....George

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-----Original Message-----
From: Ron Bothe [mailto:Ron.Bothe@gov.ab.ca]
Sent: Monday, January 07, 2002 11:37 AM
To: George Isaac (E-mail)
Subject: Cloud Seeding

Hi George:

I am trying to pull together a basic understanding of the issues on this topic, particularly from a policy standpoint. Alberta has written British Columbia and has opened a dialogue. One Alberta objective may well be to reach an agreement between the two governments that addresses use of atmospheric moisture. While it may be concluded that the one BC Hydro project does not have discernible impact on Alberta, the concern is that it is the thin edge of the wedge.

I have a number of questions for you. To start:

* Are you aware of any international or interjurisdictional agreements
pertaining to precipitation enhancement?
THE ONLY AGREEMENT THAT I AM FAMILIAR WITH WAS BETWEEN CANADA AND THE U.S.
WE HAD AN AGREEMENT TO INFORM EACH OTHER ABOUT PROJECTS BEING CONDUCTED NEAR THE BORDER. THAT AGREEMENT HAS FALLEN INTO DISUSE BECAUSE OF LACK OF INTEREST ON THE U.S. PART. THAT IS, THEY HAVE NOBODY DOING THIS TASK AT THE MOMENT. HOWEVER, WE COULD SHOW YOU THE TEXT OF THE AGREEMENT.
Yes, that might be of interest.

I WILL SEND YOU A COPY OF THE AGREEMENT.

*	Are there any studies on the downwind impacts from cloud seeding?
Any on the scale of what BC Hydro is proposing for the Columbia?
THERE ARE MANY STUDIES ON THE DOWNWIND IMPACTS FROM CLOUD SEEDING. THAT IS, IMPACTS BEYOND THE INTENDED TARGET AREA. MOST OF THEM ARE INCONCLUSIVE, BUT THESE STUDIES DO EXIST. I WOULD NEED TO DO A LITERATURE SEARCH TO GET APPROPRIATE REFERENCES. This would be very helpful. GENERALLY WEATHER MODIFICATION EXPERIMENTS, IF DONE AS PLANNED, DO NOT "USE UP" MUCH OF THE AVAILABLE WATER. MUCH MORE IS ALWAYS AVAILABLE THROUGH EVAPORATION.
Please explain these last two sentences further. I am not clear on your point. BC Hydro suggests that their efforts may use 2% of the moisture in the air mass. Are you saying that evaporation will quickly replace this moisture thereby diminishing the downwind effect? What if there were 5 such projects over a series of ridges. Would the effect on the air mass be cumulative, i.e. 10%, or would evaporation quickly restore conditions such that the effect would be little more than 2%? Is there ever a point where multiple projects become a concern? Or have I completely missed your point?

*	If BC Hydro was to conduct a pilot study, what monitoring should be requested to determine the impact on the air mass entering Alberta and the downwind precipitation? In other words, what should the study look for?

ONE COULD EFFECTIVELY MONITOR THE WATER VAPOUR IN THE ATMOSPHERE, BUT THIS IS PROHIBITIVELY EXPENSIVE TO BE DONE CORRECTLY (SEE BELOW). ONE COULD MONITOR PRECIPITATION PATTERNS USING THE EXISTING NETWORK, PERHAPS AUGMENTED BY A FEW STATIONS. THIS IS FEASIBLE, BUT IT WOULD ONLY DETECT LARGE CHANGES BECAUSE OF THE NATURAL VARIABILITY OF PRECIPITATION. I DO NOT HAVE A GOOD GRASP OF THE NATURAL VARIABILITY, BUT I ASSUME YEAR TO YEAR DIFFERENCES ARE LARGE. IF SILVER IODIDE IS USED AS THE SEEDING AGENT, THEN ONE COULD MONITOR THE SILVER IODIDE CONTENT OF PRECIPITATION DOWNWIND. THAT WOULD ALERT PEOPLE TO ANY POSSIBLE TRANSBORDER EFFECTS. HOWEVER, IF SILVER IODIDE IS FOUND, THEN IT COULD BE ARGUED THAT THE SEEDING MIGHT BE INCREASING PRECIPITATION OUT OF THE TARGET AREA. IF NONE IS FOUND, THERE IS NO CONCLUSION.
I assume that the presence of silver iodide does not imply that the precipitation occurred solely due to seeding. But am I correct in saying that it would confirm that the precipitation came from the seeded air mass?
Could such monitoring of silver iodide content in precipitation help to define 1) the maximum extent of the zone of precipitation from the air mass and thereby 2) the potential downwind impact zone? Is there anything along this line of thinking that could help further focus in on the magnitude and zone of potential change, i.e. a change in precipitation patterns as you suggest?
YES, MONITORING SILVER IODIDE WILL GIVE YOU AN IDEA OF THE POTENTIAL DOWNWIND IMPACT ZONE. IT WOULD INDICATE THAT THE PRECIPITATION CAME FROM THE SEEDED AIR MASS. HOWEVER, IF THE SILVER IODIDE SEEDING ACTUALLY REMOVED ENOUGH CLOUD WATER TO CAUSE LESS PRECIPITATION DOWNWIND, THEN MOST OF THE SILVER IODIDE MIGHT HAVE BEEN REMOVED AND NONE WOULD TRAVEL DOWNWIND. THIS IS UNLIKELY BUT POSSIBLE. IN SHORT, THE DEPOSITION OF SILVER IODIDE OUTSIDE THE TARGET AREA DOES NOT NECESSARILY INDICATE THE COMPLETE IMPACT ZONE.
HOWEVER, I BELIEVE IT IS A GOOD TRACER BECAUSE USUALLY ALL OF IT IS NOT REMOVED. IT WOULD REQUIRE SENSITIVE WATER ANALYZES, AND A GOOD COLLECTION METHODOLOGY.
ONE COULD ALSO DO SOME EXPERIMENTS WITH A BETTER TRACER, SUCH AS ONE THAT DID NOT PARTICIPATE IN THE PRECIPITATION FORMATION PROCESS. BUT THAT ALSO HAS PROBLEMS ASSOCIATED WITH IT.

*	Can change be quantified by using current weather forecasting models? i.e. adjust moisture content of past weather systems by 2%, 5%, 10%, etc and determine the change in precipitation from observed.

THEORETICALLY, THIS COULD BE DONE. HOWEVER, ONE OF THE WEAKEST PARTS OF WEATHER FORECASTING MODELS IS THE HUMIDITY FIELD. WE SIMPLY DO NOT HAVE MUCH IN THE WAY OF OBSERVATIONS OTHER THAN BALLOON RELEASES EVERY 12 HOURS ON A DISTANCE SCALE OF 100S OF KILOMETERS. DATA FROM SATELLITES COULD BE USED, BUT I AM NOT AWARE OF THIS BEING DONE EFFECTIVELY. (THIS WOULD REQUIRE MORE LITERATURE SEARCHES) BASICALLY, A ERROR AS SMALL AS 10% IN HUMIDITY IN WEATHER FORECASTING MODELS WOULD BE CONSIDERED

GREAT. SO SUCH A STUDY WOULD BE LOOKING IN THE NOISE OF SUCH MODELS. OUR ABILITY TO QUANTITATIVELY FORECAST PRECIPITATION FROM WEATHER FORECASTING MODELS IS AN AREA OF ACTIVE RESEARCH,

AGAIN, A 10% ERROR IS WELL WITHIN EXISTING ERRORS.
I conclude that modelling is not the approach to use. It takes me back to the previous point.

I would also appreciate it if you would resend your last email as in saving it offline, I managed to miss portions of it.

MY LAST E-MAIL IS ATTACHED.

I look forward to hearing from you.

Ron Bothe
Director, Environmental Operations
Alberta Environment
Voice: (780) 427-8646
Fax: (780) 422-0262

<< Message: RE: Cloud Seeding and Weather Modification Expert. >>

Jatar, Muriel (EC)

From: Isaac, George [Ontario]
Sent: November 19, 2001 8:38 AM
To: Greer, Barry [Ontario]; 'ron.bothe@gov.ab.ca'
Subject: RE: Cloud Seeding and Weather Modification Expert.

Barry and Ron,

I will try to provide as much assistance as possible. I have attached the latest WMO Statement on Weather Modification which might be of some use.

Regards......George
P.S. I am hard to reach via telephone, because I am travelling a lot and alternate between Downsview and King for my office. It is probably best to use e-mail.

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-----Original Message-----
From: Greer, Barry [Ontario]
Sent: Friday, November 16, 2001 5:14 PM
To: 'ron.bothe@gov.ab.ca'
Subject: Cloud Seeding and Weather Modification Expert.

Ron
As discussed.
The most knowledgeable expert on cloud seeding and related weather modification results in the MSC is Dr. George Isaac.
George.Isaac@ec.gc.ca
416-739-4605

regards
Barry

WMO STATEMENT ON THE STATUS OF WEATHER MODIFICATION

INTRODUCTION

For thousands of years people have sought to modify weather and climate so as to augment water resources and mitigate severe weather. The modern technology of weather modification was launched by the discovery in the late 1940s that supercooled cloud droplets could be converted to ice crystals by insertion of a cooling agent such as dry ice or an artificial ice nucleus such as silver iodide. Over 50 years of subsequent research have greatly enhanced our knowledge about the microphysics, dynamics and precipitation processes of natural clouds (rain, hail, snow) and the impacts of human interventions on those processes.

Currently, there are dozens of nations operating more than 100 weather modification projects, particularly in arid and semi-arid regions all over the world, where the lack of sufficient water resources limits their ability to meet food, fibre, and energy demands. The purpose of this document is to present a review of the status of weather modification.

The energy involved in weather systems is so large that it is impossible to artificially create rainstorms or to alter wind patterns to bring water vapour into a region. The most realistic approach to modifying weather is to take advantage of microphysical sensitivities wherein a relatively small human-induced disturbance in the system can substantially alter the natural evolution of atmospheric processes.

The ability to influence cloud microstructures has been demonstrated in the laboratory, simulated in numerical models, and verified through physical measurements in some natural systems such as fogs, layer clouds and cumulus clouds. However, direct physical evidence that precipitation, hail, lightning, or winds can be significantly modified by artificial means is limited. The complexity and variability of clouds result in great difficulties in understanding and detecting the effects of attempts to modify them artificially. As knowledge of cloud physics and statistics and their application to weather modification has increased, new assessment criteria have evolved for evaluating cloud-seeding experiments. The development of new equipment - such as aircraft platforms with microphysical and air-motion measuring systems, radar (including Doppler and polarization capability), satellites, microwave radiometers, wind profilers, automated raingauge networks, mesoscale network stations - has introduced a new dimension. Equally important are the advances in computer systems that permit large quantities of data to be processed. New data sets, used in conjunction with increasingly sophisticated numerical cloud models, help in testing various weather modification hypotheses. Chemical and chaff tracer studies help to identify airflow in and out of clouds and the source of ice or hygroscopic nucleation as the seeding agent. With some of these new facilities, a better climatology of clouds and precipitation can be prepared to test seeding hypotheses prior to the commencement of weather modification projects.

If one were able to predict precisely the precipitation from a cloud system, it would be a simple matter to detect the effect of artificial cloud seeding on that system. The expected effects of seeding, however, are almost always within the range of natural variability (low signal-to-noise ratio) and our ability to predict the natural behaviour is still limited.

Comparison of precipitation observed during seeded periods with that during historical periods presents problems because of climatic and other changes from one period to another, and therefore is not a reliable technique. This situation has been made even more difficult with the mounting evidence that climate change may lead to changes in global precipitation amounts as well as to spatial redistribution of precipitation.

In currently accepted evaluation practice, randomization methods (target/control, crossover or single area) are considered most reliable for detecting cloud-seeding effects. Such randomized tests require a number of cases readily calculated on the basis of the natural variability of the

precipitation and the magnitude of the expected effect. In the case of very low signal-to-noise ratios, experiment durations in the range of five to over ten years may be required. Whenever a statistical evaluation is required to establish that a significant change resulted from a given seeding activity, it must be accompanied by a physical evaluation to:

1. Confirm that the statistically observed change is likely due to the seeding; and

2. Determine the capabilities of the seeding method to produce desired effects under various conditions.

The effect of natural precipitation variability on the required length of an experiment can be reduced through the employment of physical predictors, which are effective in direct proportion to our understanding of the phenomenon. The search for physical predictors, therefore, holds a high priority in weather modification research. Physical predictors may consist of meteorological parameters (such as stability, wind directions, pressure gradients) or cloud quantities (such as liquid water content, updraught speeds, concentrations of large drops, ice-crystal concentration or radar reflectivity).

Objective measurement techniques of precipitation quantities are to be preferred for testing weather modification methods. These include both direct ground measurements (e.g. rain gages and hail pads) and remote sensing techniques (e.g. radar, satellite). Secondary sources, such as insurance data (as have in the past been employed to show changes in hail intensity) are, at least by themselves, not held to be satisfactory in most situations.

Operational programmes should be conducted with recognition of the risks inherent in a technology which is not totally developed. For example, it should not be ignored that, under certain conditions, seeding may cause more hail or reduce precipitation. However, properly designed and conducted operational projects seek to detect and minimize such adverse effects. Therefore, weather modification managers are encouraged to add scientifically accepted evaluation methodologies to be undertaken by experts independent of the operators.

Brief summaries of the current status of weather modification are given in the following sections. These summaries were restricted to weather modification activities that appear to be based on acceptable physical principles and which have been tested in the field.

FOG DISPERSAL

Different techniques are being used to disperse warm (i.e. at temperatures greater than 0°C) and cold fogs. The relative occurrence of warm and cold fogs is geographically and seasonally dependent.

The thermal technique, which employs intense heat sources (such as jet engines) to warm the air directly and evaporate the fog has been shown to be effective for short periods for dispersal of some types of warm fogs. These systems are expensive to install and to use. Another technique that has been used is to promote entrainment of dry air into the fog by the use of hovering helicopters or ground based engines. These techniques are also expensive for routine use.

To clear warm fogs, seeding with hygroscopic materials has also been attempted. An increase in visibility is sometimes observed in such experiments, but the manner and location of the seeding and the size distribution of seeding material are critical and difficult to specify. In practice the technique is seldom as effective as models suggest. Only hygroscopic agents should be used that pose no environmental and health problems.

Cold (supercooled) fog can be dissipated by growth and sedimentation of ice crystals. This may be induced with high reliability by seeding the fog with artificial ice nuclei from ground-based or airborne systems. This technique is in operational use at several airports and highways where there is a relatively high incidence of supercooled fog. Suitable techniques are dependent upon

wind, temperature and other factors. Dry ice has commonly been used in airborne systems. Other systems employ rapid expansion of compressed gas to cool the air enough to form ice crystals. For example, at a few airports and highway locations, liquid nitrogen or carbon dioxide is being used in ground-based systems. A new technique, which has been demonstrated in limited trials, makes use of dry ice blasting to create ice crystals and promote rapid mixing within the fog. Because the effects of this type of seeding are easily measured and results highly predictable, randomized statistical verification generally has been considered unnecessary.

PRECIPITATION (RAIN AND SNOW) ENHANCEMENT

This section deals with those precipitation enhancement techniques that have a scientific basis and that have been the subject of research. Other non-scientific and unproven techniques that are presented from time to time should be treated with the required suspicion and caution.

Orographic mixed-phase cloud systems

In our present state of knowledge, it is considered that the glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects for increasing precipitation in an economically viable manner. These types of clouds attracted great interest in their modification because of their potential in terms of water management, i.e. the possibility of storing water in reservoirs or in the snowpack at higher elevations. There is statistical evidence that, under certain conditions, precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of surface precipitation records from some long-term projects indicate that seasonal increases have been realized.

Physical studies using new observational tools and supported by numerical modelling indicate that supercooled liquid water exists in amounts sufficient to produce the observed precipitation increases and could be tapped if proper seeding technologies were applied. The processes culminating in increased precipitation have also been directly observed during seeding experiments conducted over limited spatial and temporal domains. While such observations further support the results of statistical analyses, they have to date been of limited scope. The cause and effect relationships have not been fully documented, and thus the economic impact of the increases cannot be assessed.

This does not imply that the problem of precipitation enhancement in such situations is solved. Much work remains to be done to strengthen the results and produce stronger statistical and physical evidence that the increases occurred over the target area and over a prolonged period of time, as well as to search for the existence of any extra-area effects. Existing methods should be improved in the identification of seeding opportunities and the times and situations in which it is not advisable to seed, thus optimizing the technique and quantifying the result.

Also, it should be recognized that the successful conduct of an experiment or operation is a difficult task that requires qualified scientists and operational personnel. It is difficult and expensive to fly aircraft safely in supercooled regions of clouds. It is also difficult to target the seeding agent from ground generators or from broad-scale seeding by aircraft upwind of an orographic cloud system.

Stratiform clouds

The seeding of cold stratiform clouds began the modern era of weather modification. Shallow stratiform clouds can be under certain conditions made to precipitate, often resulting in clearing skies in the region of seeding. Deep stratiform cloud systems (but still with cloud tops warmer than -20°C) associated with cyclones and fronts produce significant amounts of precipitation. A number of field experiments and numerical simulations have shown the presence of supercooled water in some regions of these clouds and there is some evidence that precipitation can be increased.

Cumuliform clouds

In many regions of the world, cumuliform clouds are the main precipitation producers. These clouds (from small fair weather cumulus to giant thunderclouds) are characterized by strong vertical velocities with high condensation rates. They can hold the largest condensed water contents of all cloud types and can yield the highest precipitation rates. Seeding experiments continue to suggest that precipitation from single-cell and multicell convective clouds have produced variable results. The response variability is not fully understood.

Precipitation enhancement techniques by glaciogenic seeding are utilized to affect ice phase processes while hygroscopic seeding techniques are used to affect warm rain processes. Methods to assess these techniques vary from direct measurements with surface precipitation gauges to indirect radar derived precipitation estimates. Both methods have inherent advantages and disadvantages.

During the last ten years there has been a thorough scrutiny of past experiments using glaciogenic seeding. The responses to seeding seem to vary depending on changes in natural cloud characteristics and in some experiments they appear to be inconsistent with the original seeding hypothesis.

Experiments involving heavy glaciogenic seeding of warm-based convective clouds (bases about +10°C or warmer) have produced mixed results. They were intended to stimulate updraughts through added latent heat release, which, in turn, was postulated to lead to an increase in precipitation. Some experiments have suggested a positive effect on individual convective cells but conclusive evidence that such seeding can increase rainfall from multi-cell convective storms has yet to be established. Many steps in the postulated physical chain of events have not been sufficiently documented with observations or simulated in numerical modelling experiments.

In recent years, the seeding of warm and cold convective clouds with hygroscopic chemicals to augment rainfall by enhancing warm rain processes (condensation/collision-coalescence/break-up mechanisms) has received renewed attention through model simulations and field experiments. Two methods of enhancing the warm rain process have been investigated: first, seeding with small particles (artificial CCN with mean sizes about 0.5 to 1.0 micrometers in diameter) is used to accelerate precipitation initiation by stimulating the condensation-coalescence process by favourably modifying the initial droplet spectrum at cloud base, and second, seeding with larger hygroscopic particles (artificial precipitation embryos about 30 micrometers in diameter) to accelerate precipitation development by stimulating the collision-coalescence processes. A recent experiment utilizing the latter technique indicated statistical evidence of radar estimated precipitation increases. However, the increases were not as contemplated in the conceptual model but seem to occur at later times (1-4 hours after seeding), the cause of this effect is not known.

Recent randomized seeding experiments with flares that produce small hygroscopic particles in the updraught regions of continental, mixed-phase convective clouds have provided statistical evidence of increases in radar-estimated rainfall. The experiments were conducted in different parts of the world and the important aspect of the results was the replication of the statistical results in a different geographical region. In addition, physical measurements were obtained suggesting that the seeding produced a broader droplet spectrum near cloud base that enhances the formation of large drops early in the lifetime of the cloud. These measurements were supported by numerical modelling studies.

Although the results are encouraging and intriguing, the reasons for the duration of the observed effects obtained with the hygroscopic particle seeding are not understood and some fundamental questions remain. Measurements of the key steps in the chain of physical events associated with hygroscopic particle seeding are needed to confirm the seeding conceptual models and the range of effectiveness of these techniques in increasing precipitation from warm and mixed-phase convective clouds.

Despite the statistical evidence of radar estimated precipitation changes in individual cloud systems in both glaciogenic and hygroscopic techniques, there is no evidence that such seeding can increase rainfall over significant areas economically. There are no evidence of any extra-area effects.

HAIL SUPPRESSION

Hail causes substantial economic loss to crops and property. Many hypotheses have been proposed to suppress hail, and operational seeding activities have been undertaken in many countries. Physical hypotheses include the concepts of beneficial competition (creating many additional hail embryos that effectively compete for the supercooled water), trajectory lowering (intended to reduce the size of hailstones), and premature rainout. Following these concepts, seeding methods concentrate on the peripheral regions of large storm systems, rather than on the main updraught.

Our understanding of storms is not yet sufficient to allow confident prediction of the effects of seeding on hail. The possibilities of increasing or decreasing hail and rain in some circumstances have been discussed in the scientific literature. Supercell storms have been recognized as a particular problem. Numerical cloud model simulations have provided insights into the complexity of the hail process, but the simulations are not yet accurate enough to provide final answers. Scientists in operational and research programs are working to delineate favourable times, locations, and seeding amounts for effective modification treatments.

A few randomized trials have been conducted for hail suppression using such measures as hail mass, kinetic energy, hailstone number, and area of hailfall. However, most attempts at evaluation have involved non-randomized operational programs. In the latter, historical trends in crop hail damage have often been used, sometimes with target and upwind control areas, but such methods can be unreliable. Large reductions have been claimed by many groups. The weight of scientific evidence to date is inconclusive, neither affirming nor denying the efficacy of hail suppression activities. This situation is motivation for operational programs to strengthen the physical and evaluation components of their efforts.

In recent years anti-hail activities using cannons to produce loud noises have re-emerged. There is neither a scientific basis nor a credible hypothesis to support such activities.

Significant advances in technology during the last decade have opened new avenues to document and better understand the evolution of severe thunderstorms and hail. New experiments on storm organization and the evolution of precipitation including hail are needed.

OTHER SEVERE WEATHER MODERATION

Tropical cyclones contribute significantly to the annual rainfall of many areas, but they are also responsible for considerable damage to property and for a large loss of life. Therefore, the aims of any modification procedure should be to reduce the wind, storm surge, and rain damage, but not necessarily the total rainfall. Hurricane modification experiments were conducted in the 1960s and early 1970s. However, there is no generally accepted conceptual model suggesting that hurricanes can be modified.

While modification of tornadoes or of damaging winds is desirable for safety and economical reasons, there is presently no accepted physical hypothesis to accomplish such a goal.

There has been some interest in the suppression of lightning. Motivation includes reducing occurrences of forest fires ignited by lightning and diminishing this hazard during the launching of space vehicles. The concept usually proposed involves reducing the electric fields within thunderstorms so that they do not become strong enough for lightning discharges to occur. To do this, chaff (metallized plastic fibres) or silver iodide have been introduced into thunderstorms. The chaff is postulated to provide points for corona discharge which reduces the electric field to values

below those required for lightning, whereas augmenting the ice-crystal concentration is postulated to change the rate of charge build up and the charge distribution within the clouds. Field experiments have used these concepts and limited numerical modelling results have supported them. The results have no statistical significance.

INADVERTENT WEATHER MODIFICATION

There is ample evidence that biomass burning, agricultural and industrial activities modify local and sometimes regional weather conditions. Land-use changes (e.g. urbanization and deforestation) also modify local and regional weather. Air quality, visibility, surface and low-level wind, humidity and temperature, and cloud and precipitation processes are all affected by large urban areas. As environmental monitoring and atmospheric modelling capabilities are improved, it is increasingly evident that human activities have significant impacts on meteorological parameters and climatological mechanisms that influence our health, productivity and societal infrastructure. Inadvertent effects need to be considered in design and analyses of weather modification experiments and operations (e.g. changes in background aerosol distributions affect the cloud structure and may affect precipitation processes).

ECONOMIC, SOCIAL AND ENVIRONMENTAL ASPECTS OF WEATHER MODIFICATION

Weather modification is sometimes considered by countries when there is a need to improve the economy in a particular branch of activity (for example: increase in water supply for agriculture or power generation) or to reduce the risks that may be associated with dangerous events (frosts, fogs, hail, lightning, thunderstorms, etc.). Besides the present uncertainties associated with the capability to reach such goals, it is necessary to consider the impacts on other activities or population groups. Economical, social, ecological and legal aspects should be taken into account. Thus, it is important to consider all the important complexity and recognize the variety of possible impacts, during the design stage of an operation.

Legal aspects may be particularly important when weather modification activities are performed in proximity to borders of different countries. However, any legal system aimed at promoting or regulating weather modification must recognize that scientific knowledge is still incomplete.

The implications of any projected long-term weather modification operation on ecosystems need to be assessed. Such studies could reveal changes that need to be taken into account. During the operational period, monitoring of possible environmental effects should be undertaken as a check against anticipated impacts.

SUMMARY STATEMENT AND RECOMMENDATIONS

To answer the need for more water and less hail in many regions of the world, some progress has been made during the past ten years in the science and technology of weather modification. Large numbers of programmes in fog dispersion, rain, snow enhancement and hail suppression are in operation. Several research experimental programmes are supported in some countries and include randomized statistical evaluations. Improved observational facilities, computer capabilities, numerical models, and understanding now permit more detailed examination of clouds and precipitation processes than ever before, and significant advances are consequently possible. New technologies and methods are starting to be applied and will help to lead to further understanding and development in this field.

In the light of this review of the status of weather modification, the following recommendations are made to interested Members of WMO:

(a) Cloud, fog and precipitation climatologies should be established in all countries as vital information for weather modification and water resource studies and operations;

(b) Operational cloud-seeding projects should be strengthened by allowing an independent evaluation of the results of seeding. This should include measurements of physical response variables and a randomized statistical component;

(c) Education and training in cloud physics, cloud chemistry, and other associated sciences should be an essential component of weather modification projects. Where the necessary capacity does not exist advantage should be taken of facilities in other Members;

(d) It is essential that basic measurements to support and evaluate the seeding material and seeding hypothesis proposed for any weather modification experiments be conducted before and during the project;

(e) Weather modification programmes are encouraged to utilize new observational tools and numerical modelling capabilities in the design, guidance and evaluations of field projects. While some Members may not have access or resources to implement these technologies, collaboration between member states (e.g. multinational field programmes, independent expert evaluations, education, etc.) are encouraged that could provide the necessary resources for implementing these technologies.

GUIDELINES FOR ADVICE AND ASSISTANCE RELATED TO THE PLANNING OF WEATHER MODIFICATION ACTIVITIES

1. These guidelines are addressed to Members requesting advice or assistance on weather modification activities. They include recommendations that are based on present knowledge gained through the results of worldwide theoretical studies as well as laboratory and field experiments. A synthesis of the main basic concepts and main results obtained in the weather modification programmes is given in the "WMO Statement on the Status of Weather Modification". This statement was revised during the twentieth session of the Executive Council Panel of Experts/CAS Working Group on Physics and Chemistry of Clouds and Weather Modification Research and was approved by the fifty-third session of the Executive Council in June 2001.

2. Members wishing to develop activities in the field of weather modification should be aware that research and operational applications are still under development. It should not be ignored that under certain conditions seeding may be ineffective or may even enhance an undesirable effect (increase of hail, reduction in rain). However, properly designed and conducted projects seek to detect and minimize such adverse effects. It is recognized that scientific evaluation may be a difficult task, but this is the only way presently known to avoid negative results, quantify positive economic effects, and allow improvements in the understanding and methodology that is used. The revised WMO Statement on the Status of Weather Modification referred to in paragraph 1 distinguishes the various types of weather modification and the degree of confidence one has in obtaining the desired effect from cloud seeding. The confidence level is very high for operational dissipation of supercooled fog and moderate for increasing snowfall from orographic clouds. The confidence level is not high for suppressing hail.

3. WMO recommends that operational cloud seeding projects for precipitation modification be designed to allow evaluation of the results of seeding through physical measurements and statistical controls associated with some randomization of the seeding events. The physical measurements should include characterization of the seeding material. Care should be taken to engage qualified operators. The objective evaluation should be performed by a group independent of the operational one. Such programmes should be planned on a long-duration basis because precipitation variability is generally much greater than the increases or decreases claimed for artificial weather modification. The use of appropriate numerical models may help in reducing the time required to evaluate the project.

4. WMO recommends that a detailed examination of the suitability of the site for cloud seeding should be conducted similar to that done in the Precipitation Enhancement Project (PEP), for which WMO reports are available. To increase the chances of success in a specific situation, it should be verified through preliminary studies that:

- The climatology of clouds and precipitation at the site indicates the possibility of favourable conditions for weather modification;
- Conditions are suitable for the available modification techniques;
- Modelling studies support the proposed weather modification hypothesis;
- For the frequency with which suitable conditions occur, the changes resulting from the modification technique can be detected at an acceptable level of statistical significance;
- An operational activity can be carried out at a cost acceptably lower than the socio-economic benefit that is likely to result.

All prospective studies require expert judgement and the results are expected to depend on the site chosen and on the season.

5. There are no quantitative criteria for the acceptance of the results of a weather modification experiment. Acceptance will depend on the degree of the scientific objectivity and the consistency with which the experiment was carried out and the degree to which this is demonstrated. Also important are the physical plausibility of the experiment, the degree to which bias is excluded from the conduct and analysis of the experiment, and the degree of statistical significance achieved. There have been few weather modification experiments that have met the requirements of the scientific community with respect to these general criteria. However, there are exciting possibilities now for making progress in our understanding of weather modification issues using modern research tools, including advanced radar, new aircraft instruments and powerful numerical models.

6. Weather modification should be viewed as a part of an integrated water resources management strategy. Instant drought relief is difficult to achieve. In particular, if there are no clouds, precipitation cannot be artificially stimulated. It is likely that the opportunities for precipitation enhancement will be greater during periods of normal or above normal rainfall than during dry periods.

7. The Members should be aware that the scope of efforts involved in the design, conduct or evaluation of a weather modification programme precludes the WMO Secretariat from giving detailed advice. However, if requested, the Secretary-General may assist (by obtaining advice from scientists on other weather modification projects or with special expertise) on the understanding that:

(i) Costs will be met by the requesting country;

(ii) The Organization can take no responsibility for the consequences of the advice given by any invited scientist or expert;

(iii) The Organization accepts no legal responsibility in any dispute that may arise.

Jatar, Muriel (EC)

From: Isaac, George [Ontario]
Sent: October 2, 2001 10:46 AM
To: Power, Jack [Ontario]; Cober, Stewart (EC)
Subject: Satement on Weather Modification

Jack and Stewart,

This is the latest WMO Statement on Weather Modification as approved by the Executive Committee last June.

It will be very useful to us when questions come up on this subject. I am trying to find a formal WMO document that we can reference it from.

George

George A. Isaac
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WMO STATEMENT ON THE STATUS OF WEATHER MODIFICATION

INTRODUCTION

For thousands of years people have sought to modify weather and climate so as to augment water resources and mitigate severe weather. The modern technology of weather modification was launched by the discovery in the late 1940s that supercooled cloud droplets could be converted to ice crystals by insertion of a cooling agent such as dry ice or an artificial ice nucleus such as silver iodide. Over 50 years of subsequent research have greatly enhanced our knowledge about the microphysics, dynamics and precipitation processes of natural clouds (rain, hail, snow) and the impacts of human interventions on those processes.

Currently, there are dozens of nations operating more than 100 weather modification projects, particularly in arid and semi-arid regions all over the world, where the lack of sufficient water resources limits their ability to meet food, fibre, and energy demands. The purpose of this document is to present a review of the status of weather modification.

The energy involved in weather systems is so large that it is impossible to artificially create rainstorms or to alter wind patterns to bring water vapour into a region. The most realistic approach to modifying weather is to take advantage of microphysical sensitivities wherein a relatively small human-induced disturbance in the system can substantially alter the natural evolution of atmospheric processes.

The ability to influence cloud microstructures has been demonstrated in the laboratory, simulated in numerical models, and verified through physical measurements in some natural systems such as fogs, layer clouds and cumulus clouds. However, direct physical evidence that precipitation, hail, lightning, or winds can be significantly modified by artificial means is limited. The complexity and variability of clouds result in great difficulties in understanding and detecting the effects of attempts to modify them artificially. As knowledge of cloud physics and statistics and their application to weather modification has increased, new assessment criteria have evolved for evaluating cloud-seeding experiments. The development of new equipment - such as aircraft platforms with microphysical and air-motion measuring systems, radar (including Doppler and polarization capability), satellites, microwave radiometers, wind profilers, automated raingauge networks, mesoscale network stations - has introduced a new dimension. Equally important are the advances in computer systems that permit large quantities of data to be processed. New data sets, used in conjunction with increasingly sophisticated numerical cloud models, help in testing various weather modification hypotheses. Chemical and chaff tracer studies help to identify airflow in and out of clouds and the source of ice or hygroscopic nucleation as the seeding agent. With some of these new facilities, a better climatology of clouds and precipitation can be prepared to test seeding hypotheses prior to the commencement of weather modification projects.

If one were able to predict precisely the precipitation from a cloud system, it would be a simple matter to detect the effect of artificial cloud seeding on that system. The expected effects of seeding, however, are almost always within the range of natural variability (low signal-to-noise ratio) and our ability to predict the natural behaviour is still limited.

Comparison of precipitation observed during seeded periods with that during historical periods presents problems because of climatic and other changes from one period to another, and therefore is not a reliable technique. This situation has been made even more difficult with the mounting evidence that climate change may lead to changes in global precipitation amounts as well as to spatial redistribution of precipitation.

In currently accepted evaluation practice, randomization methods (target/control, crossover or single area) are considered most reliable for detecting cloud-seeding effects. Such randomized tests require a number of cases readily calculated on the basis of the natural variability of the

precipitation and the magnitude of the expected effect. In the case of very low signal-to-noise ratios, experiment durations in the range of five to over ten years may be required. Whenever a statistical evaluation is required to establish that a significant change resulted from a given seeding activity, it must be accompanied by a physical evaluation to:

1. Confirm that the statistically observed change is likely due to the seeding; and

2. Determine the capabilities of the seeding method to produce desired effects under various conditions.

The effect of natural precipitation variability on the required length of an experiment can be reduced through the employment of physical predictors, which are effective in direct proportion to our understanding of the phenomenon. The search for physical predictors, therefore, holds a high priority in weather modification research. Physical predictors may consist of meteorological parameters (such as stability, wind directions, pressure gradients) or cloud quantities (such as liquid water content, updraught speeds, concentrations of large drops, ice-crystal concentration or radar reflectivity).

Objective measurement techniques of precipitation quantities are to be preferred for testing weather modification methods. These include both direct ground measurements (e.g. rain gages and hail pads) and remote sensing techniques (e.g. radar, satellite). Secondary sources, such as insurance data (as have in the past been employed to show changes in hail intensity) are, at least by themselves, not held to be satisfactory in most situations.

Operational programmes should be conducted with recognition of the risks inherent in a technology which is not totally developed. For example, it should not be ignored that, under certain conditions, seeding may cause more hail or reduce precipitation. However, properly designed and conducted operational projects seek to detect and minimize such adverse effects. Therefore, weather modification managers are encouraged to add scientifically accepted evaluation methodologies to be undertaken by experts independent of the operators.

Brief summaries of the current status of weather modification are given in the following sections. These summaries were restricted to weather modification activities that appear to be based on acceptable physical principles and which have been tested in the field.

FOG DISPERSAL

Different techniques are being used to disperse warm (i.e. at temperatures greater than 0°C) and cold fogs. The relative occurrence of warm and cold fogs is geographically and seasonally dependent.

The thermal technique, which employs intense heat sources (such as jet engines) to warm the air directly and evaporate the fog has been shown to be effective for short periods for dispersal of some types of warm fogs. These systems are expensive to install and to use. Another technique that has been used is to promote entrainment of dry air into the fog by the use of hovering helicopters or ground based engines. These techniques are also expensive for routine use.

To clear warm fogs, seeding with hygroscopic materials has also been attempted. An increase in visibility is sometimes observed in such experiments, but the manner and location of the seeding and the size distribution of seeding material are critical and difficult to specify. In practice the technique is seldom as effective as models suggest. Only hygroscopic agents should be used that pose no environmental and health problems.

Cold (supercooled) fog can be dissipated by growth and sedimentation of ice crystals. This may be induced with high reliability by seeding the fog with artificial ice nuclei from ground-based or airborne systems. This technique is in operational use at several airports and highways where there is a relatively high incidence of supercooled fog. Suitable techniques are dependent upon

wind, temperature and other factors. Dry ice has commonly been used in airborne systems. Other systems employ rapid expansion of compressed gas to cool the air enough to form ice crystals. For example, at a few airports and highway locations, liquid nitrogen or carbon dioxide is being used in ground-based systems. A new technique, which has been demonstrated in limited trials, makes use of dry ice blasting to create ice crystals and promote rapid mixing within the fog. Because the effects of this type of seeding are easily measured and results highly predictable, randomized statistical verification generally has been considered unnecessary.

PRECIPITATION (RAIN AND SNOW) ENHANCEMENT

This section deals with those precipitation enhancement techniques that have a scientific basis and that have been the subject of research. Other non-scientific and unproven techniques that are presented from time to time should be treated with the required suspicion and caution.

Orographic mixed-phase cloud systems

In our present state of knowledge, it is considered that the glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects for increasing precipitation in an economically viable manner. These types of clouds attracted great interest in their modification because of their potential in terms of water management, i.e. the possibility of storing water in reservoirs or in the snowpack at higher elevations. There is statistical evidence that, under certain conditions, precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of surface precipitation records from some long-term projects indicate that seasonal increases have been realized.

Physical studies using new observational tools and supported by numerical modelling indicate that supercooled liquid water exists in amounts sufficient to produce the observed precipitation increases and could be tapped if proper seeding technologies were applied. The processes culminating in increased precipitation have also been directly observed during seeding experiments conducted over limited spatial and temporal domains. While such observations further support the results of statistical analyses, they have to date been of limited scope. The cause and effect relationships have not been fully documented, and thus the economic impact of the increases cannot be assessed.

This does not imply that the problem of precipitation enhancement in such situations is solved. Much work remains to be done to strengthen the results and produce stronger statistical and physical evidence that the increases occurred over the target area and over a prolonged period of time, as well as to search for the existence of any extra-area effects. Existing methods should be improved in the identification of seeding opportunities and the times and situations in which it is not advisable to seed, thus optimizing the technique and quantifying the result.

Also, it should be recognized that the successful conduct of an experiment or operation is a difficult task that requires qualified scientists and operational personnel. It is difficult and expensive to fly aircraft safely in supercooled regions of clouds. It is also difficult to target the seeding agent from ground generators or from broad-scale seeding by aircraft upwind of an orographic cloud system.

Stratiform clouds

The seeding of cold stratiform clouds began the modern era of weather modification. Shallow stratiform clouds can be under certain conditions made to precipitate, often resulting in clearing skies in the region of seeding. Deep stratiform cloud systems (but still with cloud tops warmer than -20°C) associated with cyclones and fronts produce significant amounts of precipitation. A number of field experiments and numerical simulations have shown the presence of supercooled water in some regions of these clouds and there is some evidence that precipitation can be increased.

Cumuliform clouds

In many regions of the world, cumuliform clouds are the main precipitation producers. These clouds (from small fair weather cumulus to giant thunderclouds) are characterized by strong vertical velocities with high condensation rates. They can hold the largest condensed water contents of all cloud types and can yield the highest precipitation rates. Seeding experiments continue to suggest that precipitation from single-cell and multicell convective clouds have produced variable results. The response variability is not fully understood.

Precipitation enhancement techniques by glaciogenic seeding are utilized to affect ice phase processes while hygroscopic seeding techniques are used to affect warm rain processes. Methods to assess these techniques vary from direct measurements with surface precipitation gauges to indirect radar derived precipitation estimates. Both methods have inherent advantages and disadvantages.

During the last ten years there has been a thorough scrutiny of past experiments using glaciogenic seeding. The responses to seeding seem to vary depending on changes in natural cloud characteristics and in some experiments they appear to be inconsistent with the original seeding hypothesis.

Experiments involving heavy glaciogenic seeding of warm-based convective clouds (bases about +10°C or warmer) have produced mixed results. They were intended to stimulate updraughts through added latent heat release, which, in turn, was postulated to lead to an increase in precipitation. Some experiments have suggested a positive effect on individual convective cells but conclusive evidence that such seeding can increase rainfall from multi-cell convective storms has yet to be established. Many steps in the postulated physical chain of events have not been sufficiently documented with observations or simulated in numerical modelling experiments.

In recent years, the seeding of warm and cold convective clouds with hygroscopic chemicals to augment rainfall by enhancing warm rain processes (condensation/collision-coalescence/break-up mechanisms) has received renewed attention through model simulations and field experiments. Two methods of enhancing the warm rain process have been investigated: first, seeding with small particles (artificial CCN with mean sizes about 0.5 to 1.0 micrometers in diameter) is used to accelerate precipitation initiation by stimulating the condensation-coalescence process by favourably modifying the initial droplet spectrum at cloud base, and second, seeding with larger hygroscopic particles (artificial precipitation embryos about 30 micrometers in diameter) to accelerate precipitation development by stimulating the collision-coalescence processes. A recent experiment utilizing the latter technique indicated statistical evidence of radar estimated precipitation increases. However, the increases were not as contemplated in the conceptual model but seem to occur at later times (1-4 hours after seeding), the cause of this effect is not known.

Recent randomized seeding experiments with flares that produce small hygroscopic particles in the updraught regions of continental, mixed-phase convective clouds have provided statistical evidence of increases in radar-estimated rainfall. The experiments were conducted in different parts of the world and the important aspect of the results was the replication of the statistical results in a different geographical region. In addition, physical measurements were obtained suggesting that the seeding produced a broader droplet spectrum near cloud base that enhances the formation of large drops early in the lifetime of the cloud. These measurements were supported by numerical modelling studies.

Although the results are encouraging and intriguing, the reasons for the duration of the observed effects obtained with the hygroscopic particle seeding are not understood and some fundamental questions remain. Measurements of the key steps in the chain of physical events associated with hygroscopic particle seeding are needed to confirm the seeding conceptual models and the range of effectiveness of these techniques in increasing precipitation from warm and mixed-phase convective clouds.

Despite the statistical evidence of radar estimated precipitation changes in individual cloud systems in both glaciogenic and hygroscopic techniques, there is no evidence that such seeding can increase rainfall over significant areas economically. There are no evidence of any extra-area effects.

HAIL SUPPRESSION

Hail causes substantial economic loss to crops and property. Many hypotheses have been proposed to suppress hail, and operational seeding activities have been undertaken in many countries. Physical hypotheses include the concepts of beneficial competition (creating many additional hail embryos that effectively compete for the supercooled water), trajectory lowering (intended to reduce the size of hailstones), and premature rainout. Following these concepts, seeding methods concentrate on the peripheral regions of large storm systems, rather than on the main updraught.

Our understanding of storms is not yet sufficient to allow confident prediction of the effects of seeding on hail. The possibilities of increasing or decreasing hail and rain in some circumstances have been discussed in the scientific literature. Supercell storms have been recognized as a particular problem. Numerical cloud model simulations have provided insights into the complexity of the hail process, but the simulations are not yet accurate enough to provide final answers. Scientists in operational and research programs are working to delineate favourable times, locations, and seeding amounts for effective modification treatments.

A few randomized trials have been conducted for hail suppression using such measures as hail mass, kinetic energy, hailstone number, and area of hailfall. However, most attempts at evaluation have involved non-randomized operational programs. In the latter, historical trends in crop hail damage have often been used, sometimes with target and upwind control areas, but such methods can be unreliable. Large reductions have been claimed by many groups. The weight of scientific evidence to date is inconclusive, neither affirming nor denying the efficacy of hail suppression activities. This situation is motivation for operational programs to strengthen the physical and evaluation components of their efforts.

In recent years anti-hail activities using cannons to produce loud noises have re-emerged. There is neither a scientific basis nor a credible hypothesis to support such activities.

Significant advances in technology during the last decade have opened new avenues to document and better understand the evolution of severe thunderstorms and hail. New experiments on storm organization and the evolution of precipitation including hail are needed.

OTHER SEVERE WEATHER MODERATION

Tropical cyclones contribute significantly to the annual rainfall of many areas, but they are also responsible for considerable damage to property and for a large loss of life. Therefore, the aims of any modification procedure should be to reduce the wind, storm surge, and rain damage, but not necessarily the total rainfall. Hurricane modification experiments were conducted in the 1960s and early 1970s. However, there is no generally accepted conceptual model suggesting that hurricanes can be modified.

While modification of tornadoes or of damaging winds is desirable for safety and economical reasons, there is presently no accepted physical hypothesis to accomplish such a goal.

There has been some interest in the suppression of lightning. Motivation includes reducing occurrences of forest fires ignited by lightning and diminishing this hazard during the launching of space vehicles. The concept usually proposed involves reducing the electric fields within thunderstorms so that they do not become strong enough for lightning discharges to occur. To do this, chaff (metallized plastic fibres) or silver iodide have been introduced into thunderstorms. The chaff is postulated to provide points for corona discharge which reduces the electric field to values

below those required for lightning, whereas augmenting the ice-crystal concentration is postulated to change the rate of charge build up and the charge distribution within the clouds. Field experiments have used these concepts and limited numerical modelling results have supported them. The results have no statistical significance.

INADVERTENT WEATHER MODIFICATION

There is ample evidence that biomass burning, agricultural and industrial activities modify local and sometimes regional weather conditions. Land-use changes (e.g. urbanization and deforestation) also modify local and regional weather. Air quality, visibility, surface and low-level wind, humidity and temperature, and cloud and precipitation processes are all affected by large urban areas. As environmental monitoring and atmospheric modelling capabilities are improved, it is increasingly evident that human activities have significant impacts on meteorological parameters and climatological mechanisms that influence our health, productivity and societal infrastructure. Inadvertent effects need to be considered in design and analyses of weather modification experiments and operations (e.g. changes in background aerosol distributions affect the cloud structure and may affect precipitation processes).

ECONOMIC, SOCIAL AND ENVIRONMENTAL ASPECTS OF WEATHER MODIFICATION

Weather modification is sometimes considered by countries when there is a need to improve the economy in a particular branch of activity (for example: increase in water supply for agriculture or power generation) or to reduce the risks that may be associated with dangerous events (frosts, fogs, hail, lightning, thunderstorms, etc.). Besides the present uncertainties associated with the capability to reach such goals, it is necessary to consider the impacts on other activities or population groups. Economical, social, ecological and legal aspects should be taken into account. Thus, it is important to consider all the important complexity and recognize the variety of possible impacts, during the design stage of an operation.

Legal aspects may be particularly important when weather modification activities are performed in proximity to borders of different countries. However, any legal system aimed at promoting or regulating weather modification must recognize that scientific knowledge is still incomplete.

The implications of any projected long-term weather modification operation on ecosystems need to be assessed. Such studies could reveal changes that need to be taken into account. During the operational period, monitoring of possible environmental effects should be undertaken as a check against anticipated impacts.

SUMMARY STATEMENT AND RECOMMENDATIONS

To answer the need for more water and less hail in many regions of the world, some progress has been made during the past ten years in the science and technology of weather modification. Large numbers of programmes in fog dispersion, rain, snow enhancement and hail suppression are in operation. Several research experimental programmes are supported in some countries and include randomized statistical evaluations. Improved observational facilities, computer capabilities, numerical models, and understanding now permit more detailed examination of clouds and precipitation processes than ever before, and significant advances are consequently possible. New technologies and methods are starting to be applied and will help to lead to further understanding and development in this field.

In the light of this review of the status of weather modification, the following recommendations are made to interested Members of WMO:

(a) Cloud, fog and precipitation climatologies should be established in all countries as vital information for weather modification and water resource studies and operations;

(b) Operational cloud-seeding projects should be strengthened by allowing an independent evaluation of the results of seeding. This should include measurements of physical response variables and a randomized statistical component;

(c) Education and training in cloud physics, cloud chemistry, and other associated sciences should be an essential component of weather modification projects. Where the necessary capacity does not exist advantage should be taken of facilities in other Members;

(d) It is essential that basic measurements to support and evaluate the seeding material and seeding hypothesis proposed for any weather modification experiments be conducted before and during the project;

(e) Weather modification programmes are encouraged to utilize new observational tools and numerical modelling capabilities in the design, guidance and evaluations of field projects. While some Members may not have access or resources to implement these technologies, collaboration between member states (e.g. multinational field programmes, independent expert evaluations, education, etc.) are encouraged that could provide the necessary resources for implementing these technologies.

GUIDELINES FOR ADVICE AND ASSISTANCE RELATED TO THE PLANNING OF WEATHER MODIFICATION ACTIVITIES

1. These guidelines are addressed to Members requesting advice or assistance on weather modification activities. They include recommendations that are based on present knowledge gained through the results of worldwide theoretical studies as well as laboratory and field experiments. A synthesis of the main basic concepts and main results obtained in the weather modification programmes is given in the "WMO Statement on the Status of Weather Modification". This statement was revised during the twentieth session of the Executive Council Panel of Experts/CAS Working Group on Physics and Chemistry of Clouds and Weather Modification Research and was approved by the fifty-third session of the Executive Council in June 2001.

2. Members wishing to develop activities in the field of weather modification should be aware that research and operational applications are still under development. It should not be ignored that under certain conditions seeding may be ineffective or may even enhance an undesirable effect (increase of hail, reduction in rain). However, properly designed and conducted projects seek to detect and minimize such adverse effects. It is recognized that scientific evaluation may be a difficult task, but this is the only way presently known to avoid negative results, quantify positive economic effects, and allow improvements in the understanding and methodology that is used. The revised WMO Statement on the Status of Weather Modification referred to in paragraph 1 distinguishes the various types of weather modification and the degree of confidence one has in obtaining the desired effect from cloud seeding. The confidence level is very high for operational dissipation of supercooled fog and moderate for increasing snowfall from orographic clouds. The confidence level is not high for suppressing hail.

3. WMO recommends that operational cloud seeding projects for precipitation modification be designed to allow evaluation of the results of seeding through physical measurements and statistical controls associated with some randomization of the seeding events. The physical measurements should include characterization of the seeding material. Care should be taken to engage qualified operators. The objective evaluation should be performed by a group independent of the operational one. Such programmes should be planned on a long-duration basis because precipitation variability is generally much greater than the increases or decreases claimed for artificial weather modification. The use of appropriate numerical models may help in reducing the time required to evaluate the project.

4. WMO recommends that a detailed examination of the suitability of the site for cloud seeding should be conducted similar to that done in the Precipitation Enhancement Project (PEP), for which WMO reports are available. To increase the chances of success in a specific situation, it should be verified through preliminary studies that:

- The climatology of clouds and precipitation at the site indicates the possibility of favourable conditions for weather modification;
- Conditions are suitable for the available modification techniques;
- Modelling studies support the proposed weather modification hypothesis;
- For the frequency with which suitable conditions occur, the changes resulting from the modification technique can be detected at an acceptable level of statistical significance;
- An operational activity can be carried out at a cost acceptably lower than the socio-economic benefit that is likely to result.

All prospective studies require expert judgement and the results are expected to depend on the site chosen and on the season.

5. There are no quantitative criteria for the acceptance of the results of a weather modification experiment. Acceptance will depend on the degree of the scientific objectivity and the consistency with which the experiment was carried out and the degree to which this is demonstrated. Also important are the physical plausibility of the experiment, the degree to which bias is excluded from the conduct and analysis of the experiment, and the degree of statistical significance achieved. There have been few weather modification experiments that have met the requirements of the scientific community with respect to these general criteria. However, there are exciting possibilities now for making progress in our understanding of weather modification issues using modern research tools, including advanced radar, new aircraft instruments and powerful numerical models.

6. Weather modification should be viewed as a part of an integrated water resources management strategy. Instant drought relief is difficult to achieve. In particular, if there are no clouds, precipitation cannot be artificially stimulated. It is likely that the opportunities for precipitation enhancement will be greater during periods of normal or above normal rainfall than during dry periods.

7. The Members should be aware that the scope of efforts involved in the design, conduct or evaluation of a weather modification programme precludes the WMO Secretariat from giving detailed advice. However, if requested, the Secretary-General may assist (by obtaining advice from scientists on other weather modification projects or with special expertise) on the understanding that:

(i) Costs will be met by the requesting country;

(ii) The Organization can take no responsibility for the consequences of the advice given by any invited scientist or expert;

(iii) The Organization accepts no legal responsibility in any dispute that may arise.

Jayne, Lisa (EC)

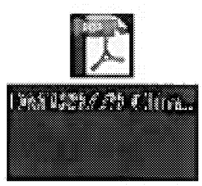
From: Vaccaro,Lisa-Marie [Ontario]
Sent: June 5, 2015 9:36 AM
To: S&T - ADMO [NCR]
Cc: Shepherd,Marjorie [Ontario]; Jayne,Lisa [Ontario]
Subject: FYI - DM question on the Weather Modification Act

Follow Up Flag: Follow up
Flag Status: Flagged

Hello S&T ADMO:

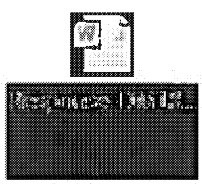
PURPOSE: The purpose of this email is simply to keep ADMO abreast of ASTD input provided to a question posed by the DM concerning weather modification, in response to a memo prepared on climate engineering governance.

CONTEXT: Yesterday, ASTD program staff received an email from MSC, though the original email came from ESB (Legislative Governance), about a proposed response to a question the DM has posed arising out of DM-189779 Legislative Governance of Climate Engineering and Next Steps (see PDF below). The turnaround time was very tight.

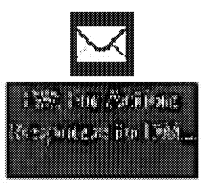


ISSUE: The DM's question was as follows: " I would like to learn more about the scope of the Weather Modification Information Act to limit or proscribe specific activities. This may be an area where international discussion proceed more rapidly than domestic action."

RESPONSE: Attached in the WORD doc below, is STB (ASTD) and MSC's (PPD) input and response to the DM's question. NOTE:



BACKGROUND: Attached also is the email trail of yesterday, demonstrating the correspondence and consultations.



Should you have any questions, please do not hesitate.

Kindly,
Lisa

Lisa-Marie Vaccaro
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Environment Canada Environnement Canada

JUIL JUL 0 4 2011

MOS-147485

MEMORANDUM TO MINISTER'S STAFF

BRIEFING NOTE ON CLOUD SEEDING ACTIVITIES

(For Information)

PURPOSE

As requested, to inform you on cloud seeding activities in Canada.

SUMMARY

- Cloud seeding is normally undertaken to attempt to enhance precipitation or suppress damage caused by hail.
- One company in Canada, Weather Modification Inc. (WMI), is funded by the Insurance Bureau of Canada to seed developing thunderstorms in the Calgary-Red Deer region during May to September of each year, in order to attempt to suppress hail damage. This is the only known weather modification activity in Canada.
- Silver iodide is the seeding agent used for this program.
- As required under the Weather Modification Information Act, and on a yearly basis, WMI notifies EC in advance of their seeding campaign and provides documentation to EC at the completion of their seeding campaign.
- EC's Science and Technology Branch (STB) maintains information on weather modification activities.

CURRENT STATUS

WMI uses aircraft to inject silver iodide into some developing thunderstorms in Alberta. Silver Iodide acts as an ice nucleation agent and it causes an increase in ice crystal concentrations in the clouds. This is presumed to lead to larger numbers of smaller hailstones, and thereby presumed to reduce damage to infrastructure and crops.

Members of the public and the media have asked Environment Canada whether or not Silver Iodide poses a health risk and what Environment Canada's responsibilities are in regards to weather modification activities. EC maintains information on weather modification activities within the Science & Technology Branch. EC does not undertake any weather modification activities. EC is not aware of any evidence that suggests silver iodide poses a threat to safety.

ISSUES

Significant meteorological or hydrological events (e.g. drought, flooding, severe thunderstorms, significant hail damage) that occur in the vicinity of regions where weather modification activities are conducted, often lead to requests for information to EC from the public or media outlets. Information requests are frequently based on the impression that these events are caused or influenced by the weather modification activities.

DEPARTMENTAL POSITION

Environment Canada collects and maintains information on weather modification activities as required under the Weather Modification Information Act.

Environment Canada does not evaluate the risks of silver iodide to human health. This would need to be coordinated with Health Canada.

Karen Dodds, ADM of Science & Technology Branch

BACKGROUND

In Canada, weather modification is under the auspices of the Canadian Weather Modification Information Act (CWMIA). The CWMIA does not deal directly with modifying the weather or with regulating weather modification activities; rather it requires reporting on projects which modify weather.

Under the Canadian Weather Modification Information Act, any weather modification activities undertaken over Canada need to be formally reported to Environment Canada. A coordinator in Environment Canada collates these results and reports them to the World Meteorological Organization each year. Records exist back to 1975.

There is currently one known weather modification activity in Canada. This project is undertaken by Weather Modification Inc. and it is designed to reduce hail damage in the Calgary to Red Deer region of Alberta during the summer months. Silver iodide is used as the cloud seeding agent in this project.

Silver iodide is very commonly used for cloud seeding because it has a crystal structure similar to that of an ice crystal. This allows silver iodide to serve as an ice nucleation agent in clouds which leads to increased concentrations of ice crystals and which may increase precipitation or decrease hail sizes. Material safety sheets for silver iodide are readily available. These indicate that this substance can cause skin irritation.

Statements on weather modification have been published by the Canadian Meteorological and Oceanographic Society, the U.S. National Academy of Sciences and the World Meteorological Organization.

Environment Canada's active weather modification R&D programs ceased in the early 1980s and no work has been done in this field within EC since that time.

Drafting Officer's Name:	Stewart Cober
Directorate/ Branch:	MRD/ASTD/STB
Phone No:	416-739-4618
Date Drafted:	4 July 2011

Weather Modification

Weather Modification Act

- Administered by the Assistant Deputy Minister of MSC.
- No duties with respect to actually modifying the weather.
- Duty to report on projects which undertake weather modification activities.
- Any group that undertakes weather modification activities in Canada has an obligation to report on the project to the MSC.

Current Activities in Canada

- Weather Modification Inc. is funded by the Insurance Industry to seed clouds in the Calgary region that are deemed to be a hail threat. This activity has been ongoing during the summer months for the past 7 years.
- There are no R&D activities in weather modification being undertaken by any Canadian government departments.

Past Activities in Canada

- MSC undertook a large precipitation enhancement project in Quebec during the period 1959 to 1963. They concluded that the effects of seeding were not statistically significant.

  (Godson, W.L., C.L. Crozier and J.D. Holland, *An Evaluation of Silver Iodide Cloud Seeding by Aircraft in Western Quebec, Canada, 1960-1963",* JAM, Vol 5, pp 500-512.)
- MSC undertook cloud seeding activities in Ontario and the Northwest Territories during the 1970s. They concluded that significant amounts of rainfall could not be produced.
- (Isaac, G.A., J.W. Strapp, R.S. Schemenauer and J.I. MacPherson, 1982: Summer cumulus cloud seeding experiments near Yellowknife and Thunder Bay, Canada. Journal of Applied Meteorology, 21, 1266-1285.)
- The Alberta Hail Studies Project ran from 1974 through the mid 1980s. Suppression of hail was not demonstrated statistically.

CMOS Policy Statement

- "Clear statistical evidence and physical cause-and-effect relationships of the outcomes of planned weather modification are frequently difficult to establish."
- "CMOS supports efforts aimed at improving our understanding of the physical processes and determining the effects of planned and inadvertent weather modification."

WMO Statement

- "The ability to influence cloud microstructures has been demonstrated in the laboratory, simulated in numerical models, and verified through physical measurements in some natural systems such as fogs, layer clouds and cumulus clouds. However, direct physical evidence that precipitation, hail, lightning, or winds can be significantly modified by artificial means is limited. The complexity and variability of clouds result in great difficulties in understanding and detecting the effects of attempts to modify them artificially."

WMO Recommendations

- (a) Cloud, fog and precipitation climatologies should be established in all countries as vital information for weather modification and water resource studies and operations;
- (b) Operational cloud-seeding projects should be strengthened by allowing an independent evaluation of the results of seeding. This should include measurements of physical response variables and a randomized statistical component;
- (c) Education and training in cloud physics, cloud chemistry, and other associated sciences should be an essential component of weather modification projects. Where the necessary capacity does not exist advantage should be taken of facilities in other Members;
- (d) It is essential that basic measurements to support and evaluate the seeding material and seeding hypothesis proposed for any weather modification experiments be conducted before and during the project;
- (e) Weather modification programmes are encouraged to utilize new observational tools and numerical modelling capabilities in the design, guidance and evaluations of field projects. While some Members may not have access or resources to implement these technologies, collaboration between member states (e.g. multinational field programmes, independent expert evaluations, education, etc.) are encouraged that could provide the necessary resources for implementing these technologies.

s.19(1)

Jatar, Muriel (EC)

From: Shepherd, Marjorie (EC)
Sent: September 9, 2003 9:22 AM
To: Cober, Stewart (EC)
Subject: FW: Weather Modification - Discussion at MSC EXCOM

You may wish to keep a record of the fact that this was distributed to the RDs.

Marjorie

-----Original Message-----
From: Beland,Michel [DG ACSD]
Sent: September 9, 2003 8:53 AM
To: Abraham,Jim [Dartmouth]; Béland, Michel; Graham, Jason; Grittani,Louis [Ontario]; MacIver,Don; Masterton,Joan [Ontario]; McCulloch,Dave [Ontario]; Morais,Nathalie [Ontario]; Phillips, Marlene; Puckett,Keith [Ontario]; Shepherd,Marjorie [Ontario]; Stone,John [NCR]; Whelpdale,Douglas [Ontario]
Subject: FW: Weather Modification - Discussion at MSC EXCOM

fyi. That's it.

-----Original Message-----
From: Legros,Chantale [NCR] **On Behalf Of** Everell,Marc Denis [NCR]
Sent: 09 septembre, 2003 08:31
To: Breton,Mimi [SteFoy]; Mills,John [Ontario]; Fast,Don [PYR]; Vollmershausen,Jim [Edm]; Bangay,Garth [Dartmouth]
Cc: MSC Ex-Com MSC Executive Committee
Subject: Weather Modification - Discussion at MSC EXCOM

(English follows French)

Le 13 juin 2003, le Comité exécutif du SMC a examiné et accepté la note documentaire ci-jointe, qui décrit comment le SMC traite actuellement la modification du temps et les sujets connexes. Le SMC reconnaît que la préoccupation semble prendre de l'ampleur et qu'il est important de réagir aux interrogations du public d'une façon manière cohérente.

Veuillez vous assurer que vos employés qui sont susceptibles d'être contactés à propos de la modification du temps et de sujets connexes sont au courant de l'approche que le SMC a adoptée.

Merci de votre attention.

=====================================

On 13 June 2003, MSC Executive Committee reviewed and accepted the attached briefing note describing how the MSC deals with Weather Modification and related topics at the present time. Recognizing that public concern in this area appears to be increasing, it is important that the MSC respond in a consistent manner to public inquiries and the like.

Please ensure that your staff who are likely to be contacted on weather modification and related issues are aware of the approach that the MSC has decided on.

Thank you for your attention to this matter.

Original signé par/signed by:

Marc Denis Everell
SMA, Service Météorologique du Canada /
ADM, Meteorological Service of Canada

MODIFICATION DU TEMPS

1. La Direction générale des sciences atmosphériques et climatiques (DGSAC) est responsable de fournir à l'échelle nationale des conseils scientifiques en ce qui a trait aux questions de modification du temps. De plus, la DGSAC assure un suivi des activités de modification du temps au Canada, conformément à la *Loi sur les renseignements en matière de modification du temps*, et fait rapport à tous les ans des activités canadiennes de modification du temps à l'Organisation météorologique mondiale (OMM). Voici les trois personnes-ressources de la DGSAC :

    a. George Isaac, Scientifique principal, Chef des conseils scientifiques en matière de modification du temps; Téléphone : (416) 739-4605; Tél cell : Courriel : George.Isaac@ec.gc.ca

s.16(2)

    b. Stewart Cober, Chef, Division de la recherche sur la physique des nuages, fournit des conseils scientifiques en matière de modification du temps; Téléphone : (416) 739-4618, Courriel : Stewart.Cober@ec.gc.ca

    c. Jack Power, Agent d'information en matière de modification du temps; Téléphone : (416) 739-4610, Courriel : Jack.Power@ec.gc.ca

2. Politiques et affaires ministérielles (PCAD) est responsable à l'échelle nationale d'élaborer des politiques sur les questions de modification du temps. Voici les deux personnes-ressources de PCAD :

    a. Ann McMillan, Chef, Politiques et affaires internationales; Téléphone : (819) 997-4290, Courriel : Ann.McMillan@ec.gc.ca

    b. Denis Bourque; Téléphone : (819) 997-8177, Courriel : Denis.Bourque@ec.gc.ca

3. Voici les sujets fréquemment abordés relativement à la modification du temps :

    a. Lutte contre la grêle au moyen de bangs supersoniques ou d'injection d'ions à la base des nuages. Il existe une entreprise au Canada (Hail Stop Inc.) qui vend des canons de lutte antigrêle. Les employés d'Environnement Canada (EC) se font demander à l'occasion leur opinion sur cette technologie.

    b. Lutte contre la grêle dans la région de Calgary par ensemencement de nuages par Weather Modification Inc. Cette organisation a conclu un contrat avec l'industrie de l'assurance pour l'ensemencement de nuages dans le but de provoquer des orages aux fins de lutte contre la grêle. Elle œuvre dans l'ensemencement de nuages depuis sept ans et prétend connaître un énorme succès. On demande souvent aux employés d'EC leur avis sur le succès de ce programme.

c. Ensemencement de la tempête de Pine Lake. La tempête de Pine Lake a été ensemencée avant la tornade et certaines personnes ont suggéré l'existence d'un lien.

d. Sécheresse de Calgary. On a tenté de nombreuses fois d'établir un lien entre la sécheresse du Manitoba et l'ensemencement de tempêtes à Calgary. Les commentaires d'EC son souvent sollicités.

e. Traînées chimiques. On établit, au sein du ministère, un lien constant entre les traînées de condensation des aéronefs et la santé. Un groupe de personnes croient que les additifs chimiques dans le carburant des aéronefs sont responsables d'un vaste éventail d'effets sur la santé des être humains. Ces personnes croient également que ces additifs chimiques sont utilisés pour refléter la lumière du soleil et contrer les effets du réchauffement de la planète. On demande souvent à EC de commenter.

4. L'approche adoptée par le Service Météorologique du Canada (SMC) pour administrer la *Loi sur les renseignements en matière de modification du temps* est appropriée et aucune modification n'est nécessaire. Stewart Cober est la personne-ressource en ce qui concerne les questions d'ordre scientifique. Normalement, il achemine celles-ci à George Isaac, mais quand George est absent, ou quand les délais sont très serrés, il les traite lui-même. George et Stewart discutent fréquemment de la science de la modification du temps et leur point de vue est constant. Ils utilisent fréquemment du matériel de l'OMM pour appuyer leurs arguments. George est le principal conseiller scientifique du SMC depuis de nombreuses années et est au fait des dernières nouveautés. Ann est la personne-ressource pour les questions qui peuvent devenir politique. Elle demande souvent à George ou à Stewart leurs avis de scientifique avant de répondre à un représentant des médias ou en cas d'enquête politique. Encore une fois, puisque ces questions sont toujours traitées par des scientifiques, nous (le SMC) assurons une cohérence des actions prises.

5. Les régions sont priées d'acheminer toutes les questions de modification du temps aux personnes-ressources dont le nom figure ci-dessus, pour que le SMC maintienne une cohérence des actions et des opinions. Faute de quoi, le SMC pourrait facilement être mis dans l'embarras. Beaucoup de gens seraient très heureux ai un représentant d'EC suggérait qu'un lien existe entre la sécheresses du Manitoba et l'ensemencement de nuages en Alberta, ou que les traînées chimiques au-dessus de l'Alberta sont dangereuses, ou encore que les canons antigrêle utilisés au Niagara arrêtent vraiment la grêle, etc. Des

représentants régionaux d'EC ont été invités à des démonstrations liées à la modification du temps, leurs organisateurs espérant que la présence d'un représentant d'EC les rendent plus crédibles. Il faut que les personnes-ressources nationales, leurs coordonnées et leurs numéros de téléphones soient connues des régions. Ces renseignements doivent être diffusés aux échelons inférieurs puisque c'est normalement à ce niveau que le premier contact avec les médias se produit. Une vaste diffusion de la présente note dans l'organisation pourrait servir de premier pas pour sensibiliser les intervenants.

6. En ce qui a trait à l'avenir de la science, le SMC atteindra peut-être dans quelques années, grâce aux radars polarisés, au GOES à cent canaux, au GEM-LAM 2.5 et à d'autres initiatives scientifiques, un point où il sera opportun pour lui d'effectuer un retour dans le domaine de la modification du temps (remarquez que la Division de la recherche sur la physique des nuages a été formée en 1960 pour s'occuper des questions de modification du temps, et que nous avons effectué les dernières expériences de modification du temps à la fin des années 1970). Toutefois, nous n'en sommes pas encore là. Si l'approche des futures initiatives de modification du temps repose sur une fondation scientifique solide, la question n'a pas à être traitée séparément de nos autres plans ou initiatives scientifiques. Nous estimons que les mérites des activités de modification du temps ont été exagérés et que la preuve scientifique des résultats positifs de lutte contre la grêle ou de production de pluie est très mince, malgré les nombreux projets qui ont été réalisés dans le monde. La recherche dans ces domaines est très coûteuse. Par conséquent, nous ne songeons pas actuellement à inclure des objectifs liés à la modification du temps dans le plan stratégique de recherche de la DGSAC.

Préparé par : Stewart Cober
Chef
Division de la recherche sur la physique des nuages

WEATHER MODIFICATION

1. Atmospheric and Climate Science directorate (ACSD) maintains a national responsibility for providing scientific advice on weather modification issues. In addition, ACSD maintains a record of weather modification activities in Canada, as required by the *Canadian Weather Modification Act*, and reports to the World Meteorological Organization (WMO) yearly on Canadian weather modification activities. There are three contacts in ACSD including:

    a. George Isaac, senior scientist, lead on provision of scientific advice for weather modification; phone: 416-739-4605 cell: e-mail: George.Isaac@ec.gc.ca **s.16(2)**

    b. Stewart Cober, Chief Cloud Physics Research Division, provision of scientific advice for weather modification, phone: 416-739-4618, e-mail: Stewart.Cober@ec.gc.ca

    c. Jack Power, information officer for weather modification, phone: 416-739-4610, e-mail: Jack.Power@ec.gc.ca

2. Policy and Corporate Affairs directorate (PCAD) maintains a national responsibility for providing policy on weather modification issues. There are two contacts for PCAD including:

    a. Ann McMillan, Chief Policy and International Affairs, phone: 819-997-4290, e-mail: Ann.McMillan@ec.gc.ca

    b. Denis Bourque, phone: 819-997-8177, e-mail: Denis.Bourque@ec.gc.ca

3. Frequent weather modification issues include:

    a. Hail suppression through either sonic booms or injection of ions into cloud base. There is a company in Canada (Hail Stop Inc.) that sells cannons for the purposed of hail suppression. EC is occasionally asked for an opinion on this technology.

    b. Hail suppression in the Calgary area by cloud seeding by Weather Modification Inc. This organization has a contract through the insurance industry to seed developing thunderstorms for the purposes of hail suppression. They have been seeding storms for the past seven years and claiming enormous successes. EC is frequently asked to comment on the success of this program.

    c. Seeding of the Pine Lake storm. The Pine Lake storm was seeded prior to the tornado and some individuals have attempted to suggest a link.

d. Drought downstream of Calgary. There have been numerous attempts to link drought in Manitoba to the seeding of storms in Calgary. EC is frequently asked to comment.

e. Chem Trails. There is constant correspondence at the ministerial level with respect to linking aircraft contrails with health. There is a group of individuals who believe that chemical additives to aviation fuel is responsible for a large array of human health effects. They further believe that these chemical additives are being used to reflect sunlight and counter the effects of global warming. EC is frequently asked to comment.

4. The Meteorological Service of Canada (MSC) approach to administering the *Weather Modification Act* is appropriate and does not need to be changed. Stewart Cober is the point of contact for scientific inquiries. Normally, he directs these to George Isaac, however when George is not around, or when timings are very tight, he handles them himself. George and Stewart have frequent discussions of the science of weather modification and have a consistent viewpoint. They frequently use WMO material to support their statements. George has been the primary scientific advisor for MSC on weather modification for many years and is current on the subject. Ann is the point of contact for issues that may become political. She often asks George or Stewart for scientific guidance before responding to a media or political inquiry. Again, since these issues are always addressed from a scientific basis, we (MSC) have consistency of action.

5. The regions are requested to defer all weather modification issues to the contacts listed above, in order that MSC maintains a consistency of action and opinion. If this was not to happen, there could be a significant potential to cause MSC some embarrassment. There are lots of people out there who would very much like for an EC representative to suggest that drought in Manitoba is linked to cloud seeding in Alberta, or that Chem trails over Alberta are hazardous, or that hail cannons used in Niagara are really stopping hail, etc. EC has had regional representatives invited to weather modification related demonstrations, where the organizers hoped that the presence of an EC representative would provide a higher level of credibility. The regions need to be informed who the national contacts are, why, and what their contact details and phone: numbers are. This information needs to get to the lowest levels since normally the first media contacts occur at these lower levels. Wide circulation of this note within the organization could serve as a first step for raising awareness.

6. With respect to future science, perhaps with polarized radar, 100 channel GOES, 2.5 GEM-LAM and other scientific initiatives, MSC may reach a point in a few years where it feels comfortable getting back into the weather

modification business (note that the Cloud Physics Research Division was actually formed in 1960 in order to address weather modification issues, and we last conducted weather modification experiments in the late 1970s). However, we are not there yet. If future weather modification science initiatives are approached based on a firm foundation of science, then the issue does not need to be discussed separately from our other science plans or initiatives. Our position is that weather modification activities have been oversold and the scientific evidence for positive results of hail suppression or rain enhancement is very meager, despite the many projects that have been conducted world wide. Doing research on these topics is very expensive. Consequently, we are not currently considering weather modification types of objectives in the ACSD research strategic plan.

Prepared by : Stewart Cober
Chief
Cloud Physics Research Division

Sent: 20-July-2017 15:59:22

From: Grimes, David (EC)

To:

Cc:

Bcc:

Subject: Weather Modification - April 9 Request for Information

Attachments:

Dear Mr.

On behalf of the Honourable Catherine McKenna, Minister of Environment and Climate Change, I am responding to your email message of April 9, 2017, and attachment, concerning weather modification. I regret the delay in responding.

Starting in 1948, the federal government was involved in weather modification experiments. Most of these activities took place in the 1960s and 1970s. The conclusions were that there was no statistical or physical evidence demonstrating that the weather modification activities were effective. The research programs declined in the second half of the 1970s and ended in the early 1980s.

Under the Weather Modification Information Act, any weather modification activities undertaken over Canada need to be formally reported to Environment and Climate Change Canada. As Assistant Deputy Minister for the Meteorological Service of Canada, I am the Administrator of the Act.

Currently, there is one hail suppression program operating in Alberta. The activities are conducted by Weather Modification Inc. Since 1996, in an attempt to reduce damage caused by hail, the company seeds some developing thunderstorms in the Calgary Red Deer area between May and September of each year. It uses silver iodide as a seeding agent. Weather Modification Inc. has been the only company undertaking weather modification activities in Canada during the past 20 years, and it provides the necessary reports to the Department on a yearly basis.

The emissions produced by silver iodide, as a seeding agent, are considered to have negligible environmental or human health impacts. Material safety data sheets (MSDS) for silver iodide, which include information on environmental and health impacts, are readily available online. MSDS hazard categorizations are related to occupational health and safety guidelines on the handling of substances and exposure risks at associated high concentrations, not atmospheric concentrations. According to the most recent reports from Weather Modification Inc., the episodic emissions of silver iodide as a seeding agent are not expected to have environmental or human health impacts given the considerably small quantities used. Measurements of silver iodide concentrations in regions where weather modification activities using this compound have occurred have not found concentrations that were above the natural background concentrations.

I trust that this information is of assistance, and I extend my best wishes.

Sincerely,

David Grimes

Assistant Deputy Minister

Meteorological Service of Canada

An Evaluation of Silver Iodide Cloud Seeding by Aircraft in Western Quebec, Canada, 1960–1963

W. L. GODSON, C. L. CROZIER AND J. D. HOLLAND

Meteorological Service of Canada, Toronto

(Manuscript received 29 September 1965, in revised form 28 March 1966)

ABSTRACT

A precipitation physics project aimed at discovering basic relationships in the chain of cause and effect in precipitation mechanisms was operated in western Quebec province, Canada, from 1959 to 1963 inclusive. In addition to many physical measurements taken from an aircraft and on the ground, randomized cloud seeding was employed as one method of study. Clouds over one of two test areas were seeded with silver iodide released from an aircraft during the passage of synoptic-scale weather systems, with the choice of area by a random selection. Comparison of storm rainfall in the two test areas measured by a dense network of raingages was used to evaluate the effect of the cloud seeding. Statistical tests of the relationship of precipitable water and instability with the seeding effect were also conducted. A small negative seeding index was computed and a slight correlation was found between both precipitable water and instability and the seeding index ratio. However, none of these relationships was found to be statistically significant.

1. Introduction

From 1959 to 1963 inclusive a precipitation physics project was conducted in western Quebec province in Canada, aimed at discovering basic relationships in precipitation mechanisms. In addition to extensive measurement of physical parameters both on the ground and in the air, cloud seeding with silver iodide by aircraft was used as one of the methods of study. Clouds over one test area, chosen by a random selection, were seeded with silver iodide released from an aircraft during the passage of synoptic-scale weather systems. Measurement of rainfall at the ground by a dense network of raingages permitted a comparison of rainfall in the seeded area and the control area and an evaluation of the effect of the cloud seeding. Statistical analysis of the differences in rainfall between the seeded and unseeded areas has now been completed and is reported in this paper.

2. Design of experiment

The seeding experiment was designed in such a way as to provide for a test of cloud seeding with silver iodide and at the same time to provide ample opportunity for investigation of the concomitant precipitation mechanisms. The seeding operations were therefore combined with an observation program of atmospheric conditions both at the ground and in the air.

Test areas. Two test areas 32 nautical miles square and separated by 32 nautical miles were selected in western Quebec province. They were chosen so as to be normal to the seasonal cloud-bearing winds, of similar terrain, free from marked orographic features and at a latitude affected by a good number of weather systems during the summer season. Other factors considered in making the choice were the necessity that the seeding tracks be reasonably distant from main airplane routes and that the areas be accessible by road and sufficiently populated to provide a source of volunteer observers.

Seeding technique. The seeding was carried out using aircraft to ensure that the silver iodide crystals were placed at levels where it was certain they could act as freezing nuclei, to allow the best possible control of the seeding material in the areas and to reduce the exposure time of the crystals to direct sunlight which might result in deactivation.

The seeding material was placed upwind from the target area at a distance equivalent to 30 minutes of air travel time at the seeding altitude. This time choice was based on experiments of Warner and Twomey (1956) on the time of release of precipitation after seeding, taking into account the seeding altitude and the type of clouds under consideration in this test. The silver iodide smoke was released into and around clouds as close to the −5C level as possible. Over the 5-yr study period this level varied from 5000 to 19,000 ft but was most commonly within 1000 ft of 13,000 ft, with an average temperature at the seeding level of about −3C.

Seeding unit. The project was designed to provide a test of cloud seeding on the organized synoptic-scale weather systems which provide a substantial proportion of the rainfall in Canada at all times of the year. Because of the great areal variability of rainfall resulting from air mass showers, this type of precipitation occurring by itself was excluded from the seeding test, though cumulus type clouds occurring in conjunction with or embedded in synoptic weather systems were not ex-

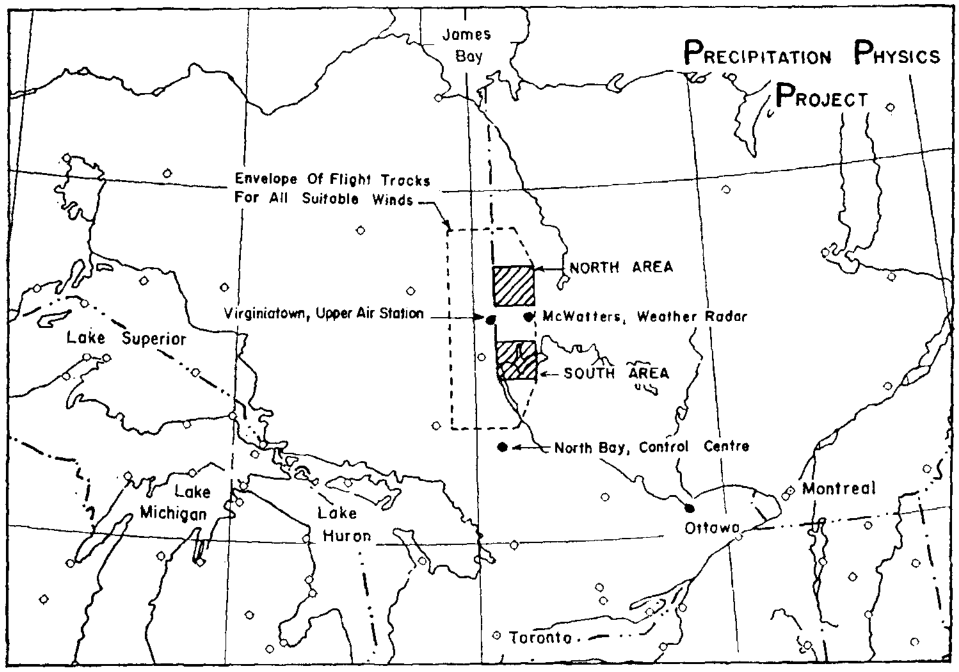

Fig. 1. The test areas and operations centers.

cluded. Seeded situations thus consisted generally of organized cloud systems associated with a front, low pressure center, or trough, already showing an active precipitation mechanism and expected to affect both areas approximately equally. The criteria under which seeding was conducted are given in Section 6. The seeding unit was the individual "storm" or synoptic system, and seeding was conducted on the system as long as it affected the areas, was producing suitable cloud conditions and was operationally feasible. The evaluation of seeding was based on a statistical treatment of rainfall measured in the target area and in the control area for each storm period. Details of the evaluation are given in Section 9.

Randomization. To minimize the time required to accumulate a sizeable sample of seeded storms and to satisfy other statistical requirements, a randomized cross-over technique was employed similar to one used in Australia (Smith *et al.*, 1963). One area (the target) was seeded in each suitable weather situation while the other area (the control) was left unseeded. On each occasion of seeding, the target area was determined by a random selection process based on a set of random numbers (Snedecor, 1946).

To eliminate problems encountered in snow measurement and to confine the test to a more or less constant seasonal synoptic regime, the operating season was considered to be from 15 May to 15 September each year. Seeding was conducted when required at any time of the day or night, seven days per week. Almost all of the suitable storm situations meeting the seeding criteria were thus seeded. However, it should be noted that more than half of the precipitation in these areas during the operating season of the project normally falls in the form of air-mass showers or from systems which do not meet the seeding criteria. During the period 1960 to 1963 the average precipitation recorded in seeded storms in the two test areas was 28.496 inches, whereas the average total precipitation in the two areas for the whole seeding season was 60.11 inches. The precipitation in seeded storms for the four years was thus 47.4 per cent of the total precipitation. The duration of seeding during the 4-yr period was 147 hr 3 min, while the duration of precipitation in seeded storms as determined from the recording raingage charts was 864 hr, so that on the average the seeding was carried on during 17 per cent of the actual duration of storm rainfall. The limiting factors preventing the continuation of seeding during a greater proportion of the duration of seeded storms were aircraft endurance and wind direction. Seeding was terminated whenever the wind shifted to a direction where contamination of the control area might occur.

Although operational planning dictated that initial storm selection be made on the basis of synoptic analysis, unnecessary dilution of the statistical sample was avoided by stipulating that seeding would be conducted only when clouds in the seeding track area reached at least to the −5C level, were 3000 ft or more thick and covered at least 50 per cent of the track length.

3. Areas of operation

The area in which the project was conducted, and the various operational bases are shown in Fig. 1. The two test areas were located in western Quebec province

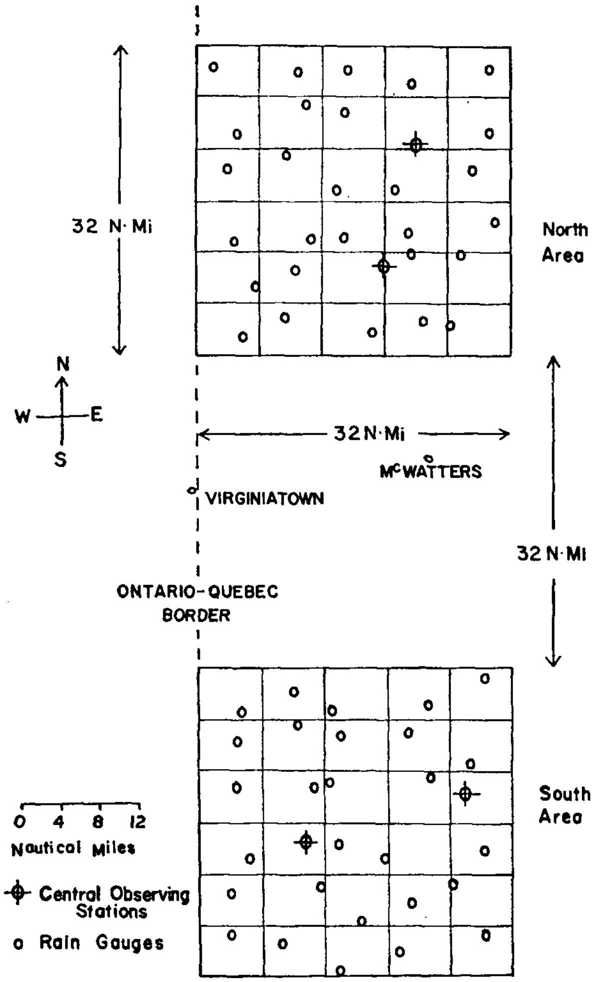

FIG. 2. The ground observation network.

along the border of Ontario in relatively flat terrain, with their axis normal to the prevailing upper wind flow. Project control was exercised from North Bay (later Ottawa), while McWatters served as a weather radar base and ground operations control center and Virginiatown as an upper air sounding station and radar navigation aid base.

4. Ground observations network

Fig. 2 shows in schematic fashion the location of the various ground observation stations and the raingage network of the project.

Raingage network. Rainfall in the test areas was measured by a dense network of recording and ordinary raingages. The basic network consisted of 30 raingage stations per area, each equipped with an ordinary and a recording raingage. The standard of measurement was the Meteorological Service of Canada standard ordinary raingage, while the recording gages served to monitor beginning and ending of rainfall. A number of the raingage sites in remote parts of the areas could only be visited once each week and these were accordingly equipped with 7-day recording instruments. Most of the stations were equipped with 1-day recording raingages tended by volunteer observers who changed recording charts and measured standard gage rainfall daily at 0800 local time. A typical raingage installation is shown in Fig. 3.

Changes in raingage network. The raingage network initially installed in the test areas in 1959 consisted of 16 ordinary raingages in each area, and a total of 14 recording raingages. Measurement of rainfall in the standard gages was made once daily at 0800 local time. This network was found to be inadequate in density, and the single measurement of rainfall at 0800, even when combined with the measurements of the recording gages, was found to be unsatisfactory for delineation of storm periods. Consequently, the density of the raingages was increased in 1960 to that of the basic network shown in Fig. 2, and readings of the standard gages were taken at both 0800 and 2000 local time. The number of recording gages was increased to 27 in 1960 and to 60 in 1961. Beginning with 1961, charts were changed and standard gage rainfall measured once daily at 0800. The standard ordinary raingage continued as the standard of measurement throughout the project.

Central observing stations. Recording instruments at four central observing stations (see Fig. 2) and also at the operations bases (McWatters and Virginiatown) measured pressure, temperature, relative humidity, wind direction and speed and hours of bright sunshine as well as rainfall.

Special observations. Lightning stroke counters were installed at one central observing station in each test area and at McWatters. Ice nuclei observations were made at McWatters from 1960 to 1963, inclusive. A rawinsonde station was established at Virginiatown, providing two upper air ascents daily and special ascents upon the request of the project control center. A programmed 3-cm weather radar at McWatters provided a film record of weather echoes over the test areas. The McWatters radar base is shown in Fig. 4.

FIG. 3. Typical raingage installation.

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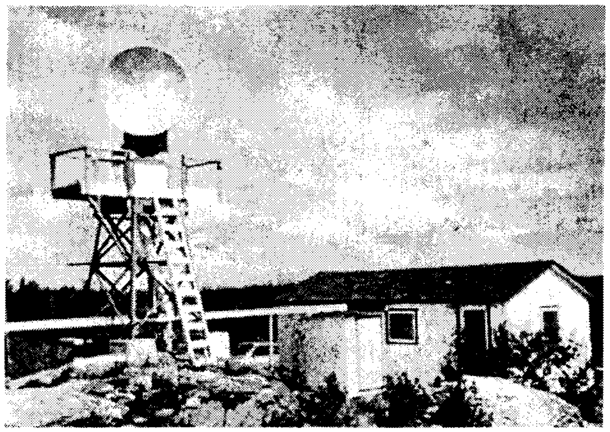

FIG. 4. The McWatters 3-cm weather radar base.

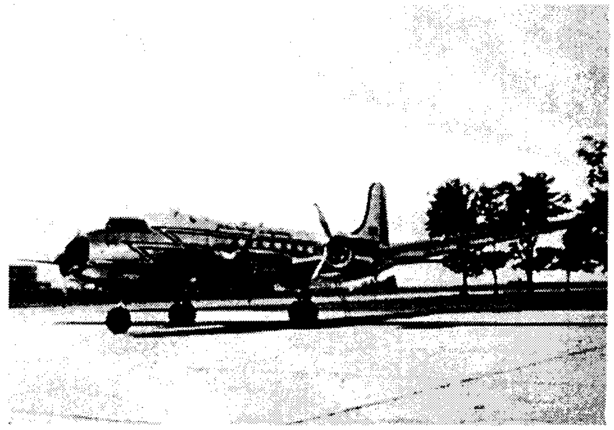

FIG. 5. The project DC-4M North Star aircraft.

5. Airborne equipment and observations

Aircraft and navigation. Seeding flights were conducted using one of two B-25 Mitchell aircraft for the first four seasons and a single DC-4M North Star in the fifth year (see Fig. 5). All aircraft proved extremely airworthy, flying in all weather conditions encountered. In 1959 a low power Decca 2-slave survey chain was established to accurately position the aircraft in the areas. In 1960 this was replaced by the establishment of a radar air surveillance station at Virginiatown to provide an aircraft tracking and vectoring facility. At the same time the aircraft was equipped with a Marconi CMA 623 Doppler sensor and CMA 601 computer. The Doppler radar facility, in addition to providing navigational assistance, allowed flight level winds to be calculated accurately and frequently.

Silver iodide smoke generator. The silver iodide smoke generator was constructed following closely the design of the Commonwealth Scientific and Industrial Research Organization equipment described by Smith *et al.* (1958). The burner, fuel pumps and ignition system were all compactly housed in a pod together with a 22-gallon fuel tank and slung under the wing on a bomb rack (Fig. 6). Full control of the burner, including a jettison facility, was maintained by the crew from a multi-position cabin instrument panel. The fuel mixture of silver iodide, sodium iodide and acetone was burned at a rate to produce about 2×10^{15} nuclei min^{-1} active at $-17C$.

Meteorological instrumentation and observations. The aircraft was equipped to record a number of meteorological observations, either manually or automatically. Liquid water was measured using a hot wire device. Temperature was measured using a thermistor mounted in a de-iced, baffled, reverse flow housing. An accelerometer measured aircraft vertical accelerations. Icing and icing rate were measured using a calibrated type T 260 Mk 8 ice detector probe system. These measurements were recorded on a continuous trace photographic recorder along with air speed, altitude, burner-on times, coding signal and other instrument characteristics.

As frequently as possible while in cloud an observer collected and photomicrographed cloud droplet samples on an oiled slide. Facilities for sampling freezing nuclei during flight using both the Bigg-Warner expansion chamber and cellulose filter techniques were under development in 1963.

The pilot, navigator, instrument technician and weather observer monitored the instruments and recorded other observations along with flight details. A second pilot and crewman completed the crew complement. The weather observer supplemented cloud observations with 35-mm color photographs when feasible.

A communication system provided direct voice contact at all times between the aircraft, control office, radar base and rawinsonde/aircraft tracking base.

6. Operational procedures

The Project Control Office continually monitored the synoptic weather charts and forecasts for the test areas. When a suitable weather system (i.e., a system ex-

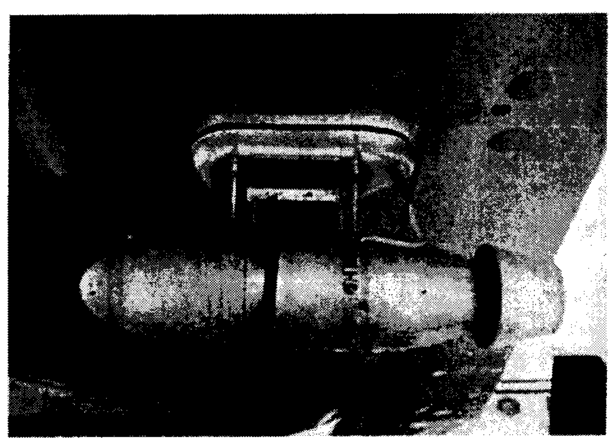

FIG. 6. The silver iodide smoke generator.

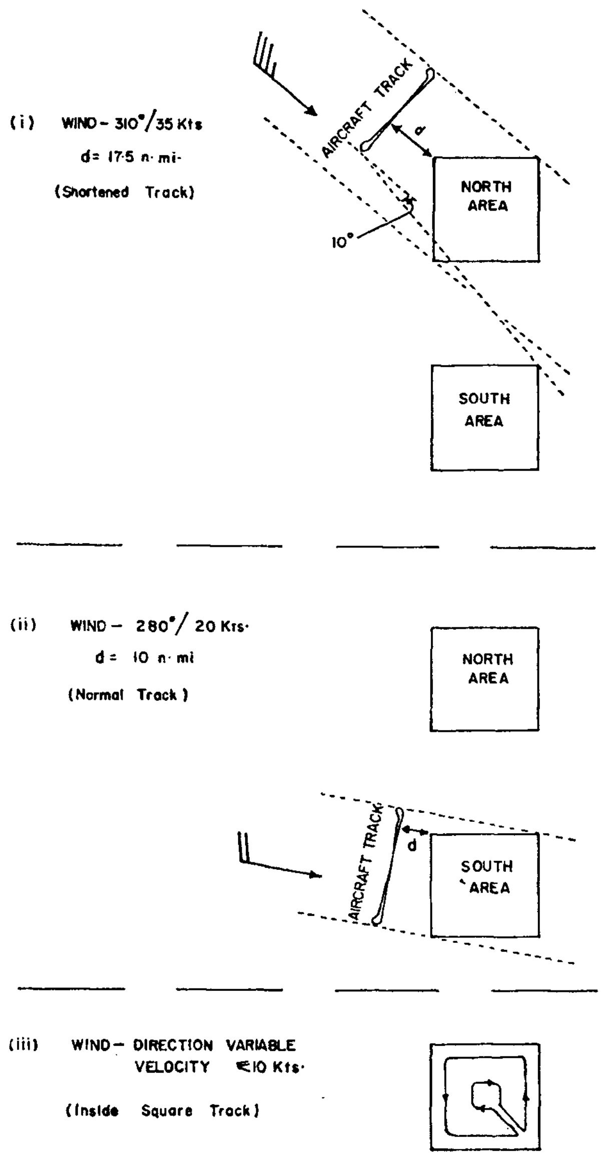

FIG. 7. Seeding tracks: (i) shortened track; (ii) normal track; (iii) inside square track.

pected to affect the test areas as outlined in Section 2) was detected, the seeding aircraft was dispatched to the test areas with a planned arrival to coincide with the arrival of the system. Upon confirmation that suitable cloud and wind conditions prevailed, seeding was begun upwind from the randomly selected target area, the location of which was not disclosed to the Project Control Office. Seeding continued until the cloud or wind conditions became unsuitable or the aircraft endurance was exhausted. In some cases, in which the weather system was of sufficiently long duration, the aircraft returned to the area to conduct a second seeding on the same system in the same area.

Seeding criteria. It was not the intention to seed air completely devoid of cloud, or synoptic situations which did not have sufficient cloud to be capable of producing significant rainfall over the bulk of the areas. It was felt that such seeding would only cause an unnecessary decrease in the sensitivity of the test and contribute nothing to the statistics. It was therefore necessary to define minimum acceptable cloud conditions for seeding, i.e., the clouds had to: a) be at least 3000 ft thick near the seeding altitude, b) have tops extending at least to the −5C level, c) cover at least 50 per cent of the seeding track, and d) show some evidence of an active precipitation mechanism in the areas or vicinity.

In addition, the winds had to be such that the clouds treated with silver iodide would not drift or be advected over the control area. In order to ensure complete separation between successive seeded storms, a minimum of 24 hours elapsed time was required between the end of one seeded storm and the beginning of the next.

Seeding track. The seeding track was normal to the winds at seeding altitude. The length of the track was determined by the projection of the target area upwind (Fig. 7). At each end of the track the aircraft always turned upwind with a minimum turning radius. To maintain the control area free from silver iodide, the seeding was limited to cases where the winds were between 230 and 310 deg true. At the extremes of the acceptable wind limits the track was shortened slightly so that lateral diffusion of up to 10 deg from the direction of the wind flow would not cause seeding material to reach the control area (see Fig. 7). The seeding track was revised regularly with any significant change in winds at the seeding level.

When winds at all levels below 30,000 feet were $\leqslant$10 knots, seeding was conducted without any restriction as to direction but the seeding track was varied from the standard figure 8 to a double inside square as illustrated in Fig. 7.

Seeding over a fixed track placed the silver iodide both in and around clouds. Few diversions were required because of severe weather although occasionally a very active cumulonimbus cloud necessitated some minor track deviations.

Seeding duration. Seeding was begun, continued and discontinued on the basis of direct discussion between the pilot and the project meteorologist without any reference as to which area was being seeded. The determining factors, other than operational difficulties, were the seeding criteria.

It was common to encounter synoptic systems which were marginal in meeting the seeding criteria because of critical winds or cloud amounts. In such cases, the aircraft was usually dispatched to the areas for confirmation. This system of operation resulted in many flights which did not find acceptable storm situations but kept the losses of suitable situations to a minimum.

Seeding altitude. The intention was to seed always at the level where the temperature was −5C and on a fixed track over the ground dependent on the wind and area geometry. Failure to get air space reservation sometimes limited the maximum altitude attainable but in these cases, if seeding was conducted at temperatures one to two degrees warmer, it was possible to confirm that clouds did in fact reach at least to the −5C level.

7. Selection of storm periods and estimation of rainfall

Data used in evaluation. The rainfall data used in this evaluation of the effect of cloud seeding were the standard gage data collected during 1960 to 1963 inclusive. Difficulties encountered in the measurement of rainfall in the test areas during 1959 were outlined in Section 4. Because of these difficulties, particularly the problem of delineation of storm periods on the basis of 24-hr rainfall data, it was found that the data from 1959 could not be used in the analysis.

Evaluation criteria. The criteria used in determining whether a seeded storm was suitable for evaluation of the effect of cloud seeding were the same as those laid down for seeding, as described in Section 6. It was not always possible under field conditions to adhere rigidly to the criteria, and there were times when it was necessary to proceed with the seeding and determine later whether the case was suitable for evaluation. In order to avoid possible bias on the part of the seeding team, this evaluation was conducted independently by an evaluator who had not taken part in the seeding operations. The information passed to the evaluator by the project meteorologist gave the date and time of each seeding, the description of the synoptic situation seeded, the approximate beginning and ending of the storm precipitation, information on the clouds encountered by the flight, the seeding level and winds, but no information as to which area was seeded. The evaluator reviewed each storm to make certain that the conditions laid down for seeding in Section 6 had been met. No reference was made at this stage to rainfall network information, but only to the synoptic information normally available. It was found that the seeding criteria had been met in nearly all seeded cases, except that there were a number of cases where the winds were such as to permit the drift of some seeding material into the control area. Seeded cases were thus divided into two categories: category A with no contamination of the control area and category B where the winds were such as to permit some contamination. Category A and category B storms were analyzed separately for evidence of an effect from seeding. Thirty-nine storms in category A and six in category B were found suitable for evaluation over the 4-yr period 1960–63 inclusive. On this basis none of the seeded storms submitted by the project meteorologist for evaluation was found to be unacceptable. On completion of the analysis, no significant differences were found between category A and B storms. Hence, they have been grouped together in chronological order in this report.

Storm rainfall. Storm periods were defined in terms of consecutive 12-hr precipitation intervals, 0800–2000 and 2000–0800, local time, consistent with the times of measurement of rainfall, and corresponding as closely as possible with the passage of the weather system seeded. The storm period was further defined to be the same in both test areas, no overlap of actual precipitation across the boundary marking the beginning or end of a storm period was permitted, and the actual precipitation in the two areas was required to begin (and to end) in the same or adjacent regular 12-hr observation periods. Strict adherence to these objective criteria was maintained in order to ensure complete objectivity in the abstracting of storm rainfall from the total rainfall data. Because of the strict criteria adopted regarding separation of storms when seeding (see Section 6), no difficulty was experienced in separation of the actual rainfall of one seeded storm from the next. Storm rainfall for each of the sixty gages in the raingage network was determined and abstracted from the total rainfall data according to the above criteria for each of the 45 storms accepted for evaluation.

Mean areal rainfall. Mean areal rainfall for each of the two test areas for each of the 45 seeded storms was computed by an adaptation of the Thiessen polygon method of weighting (Thiessen, 1911). In this adaptation, subdivision of the area by the right bisectors of the lines joining adjacent gages was replaced by an electronic computer program which calculated the proportion of the total area represented by each gage. Using these values as weighting factors, the mean areal rainfall and the standard error of the mean were calculated. Missing rainfall data were interpolated linearly among data from the immediately surrounding gages of the dense raingage network. Mean areal rainfall figures for each of the 45 seeded storms and the standard errors of the means are shown in Tables 1 and 2.

8. Storm data

Tables 1 and 2 show, in addition to the mean areal rainfall in inches for each storm and the standard error of the mean, the case number in chronological order, the storm identification number and the time of beginning, ending and duration of the storm period and of the seeding. Data for north-seeded storms are given in Table 1 and for south-seeded storms in Table 2.

9. Statistical analysis

Several statistical tests were carried out on the storm rainfall data to determine possible effects from the cloud seeding. A measure of the effect of seeding, termed the seeding influence index ratio (short form: seeding index ratio), was computed by the method

TABLE 1. Storm data and mean areal rainfall, North area seeded.

Case serial no.	Date of seeding	Storm no.	Seeding period date/time (GCT)	Seeding duration (hr:min)	Storm period date/time (GCT)	Storm duration (hr)	Mean areal rainfall North area (inches)	Mean areal rainfall South area (inches)	Standard error of mean North area (inches)	Standard error of mean South area (inches)
	1960									
3	19 June	60031	190702–191004	3:02	181200–200000	36	0.452	0.652	0.047	0.022
5	5 July	60071	050031–050249	2:18	041200–060000	36	0.538	0.430	0.023	0.035
6	15 July	60081	151751–151938	1:47	151200–161200	24	0.001	0.243	0.001	0.024
8	29 July	60111	290800–290932	1:32	290000–311200	60	0.693	0.880	0.043	0.080
9	1 Aug.	60131	011612–012017	4:05	010000–021200	36	0.422	0.255	0.044	0.017
12	28–29 Aug.	60191	{281142–281304 {282220–290151	4:53	280000–300000	48	0.741	0.553	0.033	0.067
	1961									
13	24 May	61011	241635–241943	3:08	241200–260000	36	0.100	0.187	0.007	0.009
15	1–2 June	61031	{011533–011807 {012329–020135	4:40	010000–031200	60	1.031	0.951	0.055	0.027
17	6–7 July	61121	062140–070057	3:17	061200–081200	48	0.157	0.327	0.021	0.023
18	27 July	61151	270717–271030	3:13	270000–280000	24	0.119	0.275	0.013	0.025
22	14 Sept.	61221	140215–140625	4:10	130000–151200	60	2.495	3.484	0.073	0.045
	1962									
23	20 May	62011	200116–200359	2:43	191200–210000	36	0.580	0.265	0.017	0.018
26	18–19 June	62061	182130–190054	3:24	181200–200000	36	0.215	0.197	0.024	0.015
28	28 July	62121	281655–281802	1:07	281200–291200	24	0.257	0.038	0.021	0.015
30	16 Aug.	62171	160120–160518	3:58	151200–161200	24	0.202	0.059	0.012	0.004
32	24–25 Aug.	62191	{241507–241618 {250005–250050	1:56	231200–261200	72	1.235	0.581	0.075	0.053
	1963									
34	6–7 July	63071	062208–070041	2:33	061200–080000	36	0.625	1.225	0.042	0.032
35	15 July	63081	151634–152123	4:49	141200–161200	48	0.054	0.471	0.013	0.070
36	4 Aug.	63111	040050–040137	0:47	031200–051200	48	1.989	1.601	0.088	0.110
38	9 Aug.	63131	{090100–090219 {090256–090655	5:18	081200–101200	48	0.812	0.897	0.037	0.035
42	22–23 Aug.	63171	{221850–230132 {231559–231712	7:55	220000–241200	60	1.010	1.578	0.076	0.083
44	7 Sept.	63201	070650–070918	2:28	070000–080000	24	0.133	0.053	0.009	0.005

described in the following paragraph, and, in more detail, in the Appendix. Significance tests were performed on the seeding index ratio, and probability statements on the true effect of the seeding deduced. Regression analyses were also performed to determine possible relationships between the individual seeding index ratio and each of the following: a) percentage of storm period seeded, b) precipitable water and c) instability. A chi-square test was performed on the relationship between instability and precipitable water for seeded storms. The results of these tests are given in the paragraphs which follow.

Seeding influence index ratio. The seeding influence index ratio R was defined as the ratio of the precipitation in the seeded area to that which would have occurred in that area if no seeding had taken place. The value of R was calculated by using the ratios of the actual precipitation in the seeded area and the unseeded control area, taking logarithms of these individual ratios to normalize their distribution, applying appropriate statistical weights based on the variance of the ratios, and averaging the weighted ratios. Assuming R to be a constant for the class of storms under consideration, and making certain other simplifying assumptions, the value of $\log/R$ can be shown to equal one-half the difference between the mean weighted ratio when one area is seeded and the mean weighted ratio when the other area is seeded. The variance of $\log/R$ was also calculated, giving a measure of the statistical significance of the value of R, through application of Student's "t" test for significance (Snedecor, 1946). Details of the method of calculation of $\log/R$ and its variance are given in the Appendix. R was also expressed as a seeding influence index or seeding index I, where $I=100\ (R-1)$ per cent, and represents the percentage influence of seeding on precipitation.

On the basis of 45 storms accepted for evaluation over the period 1960–1963, the value of $\log/R$ was calculated to be -0.010894, whence $R=0.975$ and $I=-2\frac{1}{2}$ per cent. The value of Student's "t" for $\log/R$ in a two-tailed test of significance was -0.22, with 42 degrees of freedom, which corresponds to a significance level of 0.82. The variation of the seeding index I and the significance level (Student's "t") over the period of the experiment with the storms arranged in chronological order is shown in Fig. 8. In this diagram

TABLE 2. Storm data and mean areal rainfall, South area seeded.

Case serial no.	Date of seeding	Storm no.	Seeding period date/time (GCT)	Seeding duration (hr:min)	Storm period date/time (GCT)	Storm duration (hr)	Mean areal rainfall (inches) North area	South area	Standard error of mean (inches) North area	South area
	1960									
1	11 June	60011	110924–111240	3:16	110000–120000	24	0.024	0.021	0.006	0.004
2	17 June	60021	170123–170259	1:36	161200–180000	36	1.976	1.441	0.073	0.102
4	23 June	60041	230337–230657	3:20	221200–240000	36	0.121	0.029	0.044	0.010
7	26–27 July	60101	{261720–261955 270020–270300	5:15	261200–280000	36	0.386	1.655	0.035	0.067
10	7–8 Aug.	60141	{071858–071955 080342–080638	3:53	070000–081200	36	1.573	0.750	0.070	0.031
11	14 Aug.	60161	{140148–140415 140505–140541	3:03	131200–150000	36	0.636	0.398	0.033	0.035
	1961									
14	27–28 May	61021	272103–280037	3:34	271200–281200	24	0.009	0.001	0.002	0.001
16	8 June	61051	080027–080435	4:08	071200–081200	24	0.223	0.030	0.008	0.007
19	5 Aug.	61171	051941–052225	2:44	050000–070000	48	0.292	0.534	0.024	0.042
20	10 Aug.	61191	101550–101825	2:35	100000–111200	36	1.102	0.489	0.049	0.042
21	11 Sept.	61211	110508–110812	3:04	101200–120000	36	0.849	0.479	0.049	0.043
	1962									
24	24 May	62021	241915–242240	3:25	231200–251200	48	0.260	0.507	0.018	0.026
25	10 June	62041	100420–100804	3:44	091200–111200	48	0.209	1.470	0.014	0.053
27	29 June	62081	292110–292301	1:51	291200–301200	24	0.089	0.049	0.017	0.011
29	4 Aug.	62151	040007–040350	3:43	030000–051200	60	1.133	0.272	0.076	0.047
31	19 Aug.	62181	191506–191721	2:15	190000–210000	48	0.214	0.600	0.018	0.033
	1963									
33	19–20 June	63051	{191509–191939 200708–200743	5:05	190000–211200	60	3.378	1.594	0.069	0.073
37	6 Aug.	63121	060408–060742	3:34	060000–061200	12	0.080	0.317	0.010	0.022
39	10–11 Aug.	63141	102144–110100	3:16	101200–121200	48	0.343	0.297	0.020	0.017
40	17 Aug.	63151	170308–170434	1:26	160000–181200	60	0.762	1.983	0.046	0.064
41	19–20 Aug.	63161	{192109–192259 192356–200312	5:06	191200–201200	24	0.110	0.058	0.007	0.006
43	28–29 Aug.	63181	282350–290222	2:32	280000–310000	72	0.322	0.454	0.044	0.021
45	8 Sept.	63211	081916–082051	1:35	081200–091200	24	0.227	0.183	0.011	0.007

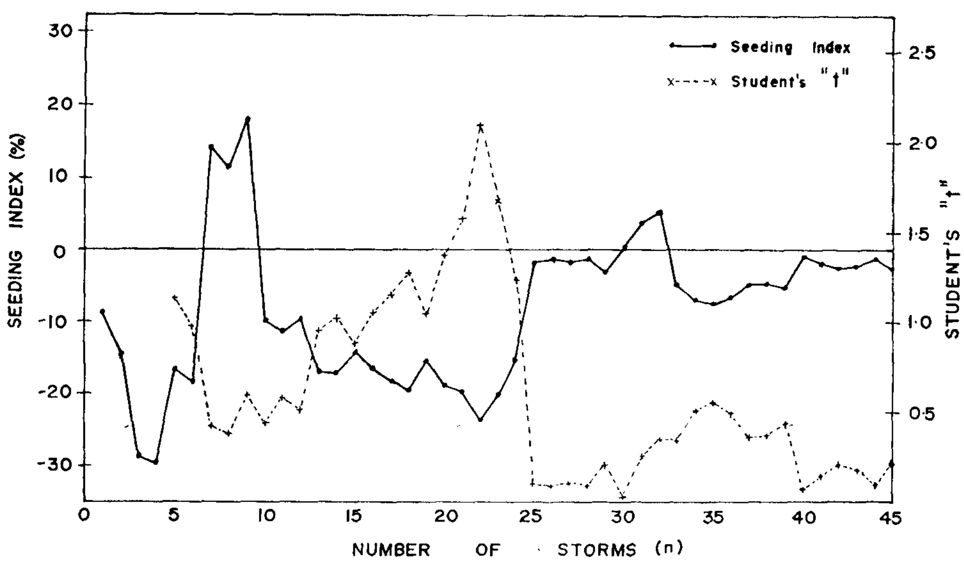

FIG. 8. Cumulative seeding index and significance (Student's "t"; degrees of freedom $= n-3$) by number of storms in chronological order.

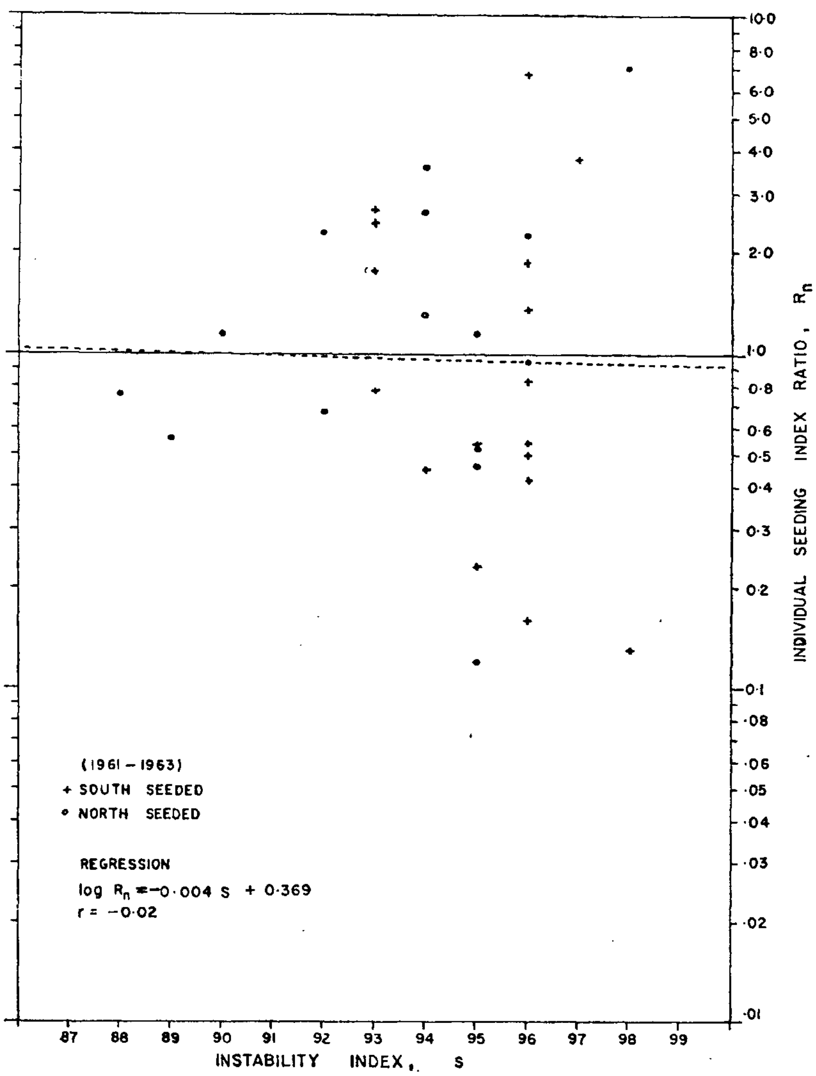

FIG. 9. Relationship between individual seeding index ratio R_n and Boyden instability index S.

the seeding index and the significance (Student's "t") are plotted on a cumulative basis with the values plotted being those after n storms. Obviously, the first few values of the seeding index have little meaning, and indeed the method does not permit a calculation of significance until at least two north-seeded and two south-seeded storms have been processed.

Individual seeding influence index ratio. An individual seeding influence index ratio, R_n (short form: individual seeding index ratio), defined as the ratio of the precipitation in the seeded area to that in the unseeded area, divided by the mean (all storms) areal ratio with potential seeding effects removed, was calculated for each storm.

Correlation with percentage of storm seeded. A least squares analysis of the relationship between the logarithm of the individual seeding index ratio and the percentage of the storm period seeded showed virtually no relationship between the two, with a correlation coefficient of −0.05.

Instability. The instability of the air mass at the time of seeding was also examined for any association with $\log/R_n$. The simple objective parameter selected was the instability index S, devised by Boyden (1963) for use in the vicinity of fronts and in mobile situations.

If the layer between 1000 and 700 mb is in a state of neutral static stability (that is, with dry bulb temperatures along a saturated adiabat), then the difference between the 1000–700 mb thickness (in decameters) and the 700 mb temperature (°C) is very nearly a constant and approximately equal to 294. In the Boyden approach to instability assessment, if the 700-mb temperature is low for the thickness, the air is classed as unstable and if the 700-mb temperature is high for the thickness the air is classed as stable.

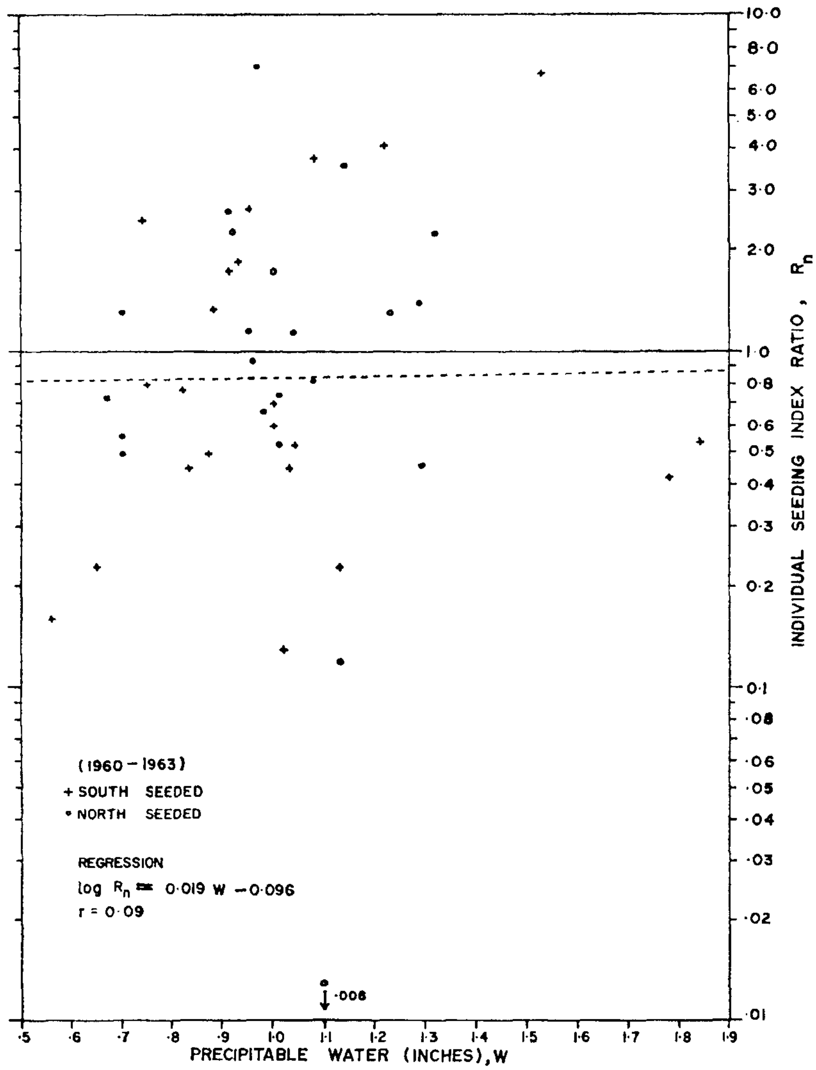

FIG. 10. Relationship between individual seeding index ratio R_n and precipitable water W.

The precise formula for the instability index S is

$$S = Z - T - 200,$$

where, $Z = 1000 - 700$ mb thickness in decameters, $T = 700$-mb temperature (°C), and 200 is a convenient constant inserted to restrict the index to two figures. S is strictly a measure of the mean stability in the layer below 700 mb, with a value of 94 considered as indicating neutral stability.

A least squares analysis showed little correlation of $\log/R_n$ with S, with a correlation coefficient of -0.02. (See Fig. 9.) Inspection of the plot of $\log/R_n$ versus S shows that there was a fairly wide scatter of points as might be expected from the correlation coefficient. However, it is noticeable that for greater instability there was a much greater dispersion of S values about $R_n = 1$, the line of no seeding affect. This seems to say that for higher instability values, there is a greater effect from seeding, and that this effect can be either positive or negative.

Precipitable water. Values of the precipitable water W were calculated from the Virginiatown radiosonde for a time closest to the mean seeding time of each storm. The sounding time did not usually differ from the mean seeding time by more than ± 2 hr. W was defined, as usual, as the depth of water in inches (per unit area) which would accrue if all the water vapor in the column from the surface to 500 mb were condensed and precipitated. The W values were calculated using a method devised by Ferguson (1962) for rapid calculation using the plotted ascent curve on a Canadian tephigram. It is basically a 3-layer method of calculation and has been shown to give values generally within 2 per cent of those obtained using 25-mb layers for a comparable 150–200 mb layer for the middle range of W values.

An examination of the relationship between the log of the individual seeding index ratio R_n and W was made using a least squares analysis. The regression of log/R_n on W is illustrated in Fig. 10. There was found to be very little relationship, with a correlation coefficient of 0.09. Thus, while as one might assume, there was a positive correlation and hence a tendency for higher W values to be associated with higher R_n values, there was not a close association.

Because of the type of statistical evaluation, it was decided at the outset that the tests should be as completely objective as possible and not to deviate or perform unwarranted exploratory tests which might by chance alone finally provide a statistically significant result. In any case, inspection of the log/R_n vs. W plot showed such a scatter that there was no obvious suggestion of any other test which might have provided a better relationship. Stratification of the data into synoptic types or air masses might provide better relationships, but the resultant smaller samples for each class would make the results non-significant.

Stratification of data. An attempt was made to determine the possible relationship between R_n, S, W and synoptic type and air mass through stratification of data. With a sample of only 45 storms the data cannot be stratified into many classes with much hope of getting significant relationships. A tetrachoric table was drawn up for the storms for $S \leqslant 95$ and >95 and $W < 1.00$ inch and $\geqslant 1.00$ inch. A chi-square test on this classification indicated no significant relation between S and W for the seeded storms, with about an equal distribution of cases in the four classes. Further, within each class, R_n varied widely.

The storms were classified by synoptic type as cold front, warm front, stationary front, trough or closed low. In addition, the synoptic types could be related to the associated air masses according to the classification tropical, maritime polar, maritime arctic or continental arctic. Stratification of the storms by synoptic type and/or air mass within the four classes delineated by the S vs. W limits, described in the previous paragraph, resulted in quite small samples and showed no particular pattern. As might be expected there was a slight tendency for the warmer air masses to have higher W values.

A qualitative examination of R_n by synoptic type and air mass showed that 90 per cent of the cold fronts (8 cases) and 70 per cent of the maritime arctic systems (20 cases) had R_n values less than one. The reason for this is not immediately clear but may be revealed by a more detailed synoptic and physical analysis. Continental arctic systems rarely were found suitable for seeding because of cloud deficiencies.

It should be noted that clouds associated with no frontal systems and commonly referred to as air mass type are relatively frequent in the test areas. While these may have considerable potential for silver iodide treatment, this situation did not meet the design criteria and was therefore not considered in this experiment.

10. Physical analysis

Considerable effort in this project was expended on the development of operational techniques and instrumentation for both ground and air, not only as it pertained to the cloud seeding evaluation, but also to the study of precipitation physics in general. A large volume of physical observations was collected both at the surface and aloft. A detailed physical and synoptic analysis of these observations will continue.

11. Discussion of results

Analysis of the data of 45 storms seeded with silver iodide between 1960 and 1963 indicates a slight negative effect from the seeding. However, the probability of obtaining the same result by chance if seeding had no effect is very high. Hence the result must be regarded as inconclusive, i.e., there is no evidence that the cloud seeding influenced the mean precipitation. Nevertheless, the probability is high that the effect of the seeding could not have been greater than 22 per cent either positive or negative since the fiducial limits of I at the 0.05 significance level are ± 22 per cent.

There is virtually no evidence of a relationship between the individual seeding index ratio of a storm and the instability of the air or between the individual seeding index ratio and the precipitable water. The correlation coefficients are low and were found by calculation to carry a low significance level as well.

No indication was found of a relationship between the individual seeding index ratio and the duration of seeding relative to the duration of storm rainfall.

Acknowledgments. The authors are indebted to a number of cooperative agencies who participated in this large scale project. In particular, we thank the National Research Council, who developed, maintained and operated the aircraft instrumentation, the Royal Canadian Air Force, who provided the aircraft and flight crews, the Canadian Pulp and Paper Association, who provided funds and much field assistance through the Canadian International Paper Company, the Canadian Army, who tracked the aircraft, the many volunteer observers in the field, the Department of Forestry and the provincial Departments of Lands and Forests.

APPENDIX

Method of calculation of log$R$ and its variance

The problem can be stated as follows: given a series of pairs of mean areal storm rainfall measurements on synoptic-scale weather systems for two test areas A and B with one of the two areas seeded with silver iodide in a random selection, calculate an index of the effect of the cloud seeding on the rainfall.

Let the mean areal rainfall measurements be designated A_n^*, B_n, A_m and B_m^* where A_n^* represents the rainfall in area A (A seeded), B_n the rainfall in area B (A seeded), A_m the rainfall in area A (B seeded) and B_m^* the rainfall in area B (B seeded), i.e., the subscript n refers to A-seeded storms and the subscript m to B-seeded storms, while the asterisk refers to storm rainfall in areas which have actually been seeded. Let A_n and B_m without asterisk designate the precipitation which would have occurred in areas A and B, respectively, on seeded occasions if in fact they had not been seeded, and let the ratio of the actual precipitation in a seeded area to the precipitation which would have occurred there if no seeding had taken place be defined as the seeding index ratio R. Assuming R to be constant for the class of storms under consideration, then

$$R=A_n^*/A_n=B_m^*/B_m. \tag{1}$$

The ratios A_m/B_m^* and A_n^*/B_n, which are immediately calculable from the storm rainfall measurements, can be written

$$A_m/B_m^*=(A_m/B_m)(B_m/B_m^*)=(1/R)(A_m/B_m), \tag{2}$$

and,

$$A_n^*/B_n=(A_n/B_n)(A_n^*/A_n)=R(A_n/B_n). \tag{3}$$

Taking logarithms so as to normalize the distributions of A_n^*/B_n and A_m/B_m^*, which are known to be markedly non-normal, we have

$$\log(A_m/B_m^*)=\log(A_m/B_m)-\log R, \tag{4}$$

and

$$\log(A_n^*/B_n)=\log(A_n/B_n)+\log R. \tag{5}$$

The ratios of A-precipitation to B-precipitation, A_m/B_m and A_n/B_n assuming no seeding in either area, would actually differ from the mean value for this ratio, $\overline{(A/B)}$, by variable factors, ρ_m, ρ_n, so that

$$A_m/B_m=\rho_m\overline{(A/B)}, \tag{6}$$

and

$$A_n/B_n=\rho_n\overline{(A/B)}, \tag{7}$$

where $\log\rho_m$ and $\log\rho_n$ can be assumed to be approximately normally distributed about a mean of zero.

Since R has been assumed constant and $\overline{(A/B)}$ can also be assumed to be constant for the class of storms under consideration, ρ_m and ρ_n will contain both the effects of errors in A_m, A_n, B_m and B_n and hence in the ratios, and also of the departures of A_m/B_m and A_n/B_n for the particular storm in question from the overall mean $\overline{(A/B)}$.

Substituting (6) in (4), and introducing appropriate statistical weights w_m (see below), we get

$$w_m\log(A_m/B_m^*)=w_m\log\overline{(A/B)}-w_m\log R+w_m\log\rho_m. \tag{8}$$

Similarly (5) and (7), with appropriate statistical weighting, yield

$$w_n\log(A_n^*/B_n)=w_n\log\overline{(A/B)}+w_n\log R+w_n\log\rho_n. \tag{9}$$

On averaging, subtracting (9) and (8), and rearranging terms, we get

$$2\log R=\left\{\frac{\sum_n w_n\log(A_n^*/B_n)}{\sum_n w_n}-\frac{\sum_m w_m\log(A_m/B_m^*)}{\sum_m w_m}\right\}+\left\{\frac{\sum_m w_m\log\rho_m}{\sum_m w_m}-\frac{\sum_n w_n\log\rho_n}{\sum_n w_n}\right\}. \tag{10}$$

Since $\log\rho_m$ and $\log\rho_n$ have been assumed normally distributed about a mean of zero, the second term on the right hand side of (10) is zero, and we get

$$2\log R=\frac{\sum_n w_n\log(A_n^*/B_n)}{\sum_n w_n}-\frac{\sum_m w_m\log(A_m/B_m^*)}{\sum_m w_m}. \tag{11}$$

In similar fashion, by averaging and adding (8) and (9), there results

$$2\log\overline{(A/B)}=\frac{\sum_m w_m\log(A_m/B_m^*)}{\sum_m w_m}+\frac{\sum_n w_n\log(A_n^*/B_n)}{\sum_n w_n}. \tag{12}$$

We are therefore able to compute $\log R$ from (11) and $\log\overline{(A/B)}$ from (12).

Once this has been done we can compute individual values of ρ_m and ρ_n from (1), (2), (3), (6) and (7), and from these we can compute the variance of $\log\rho_{m,n}$ and hence the variance of $\log R$.

The total variance (external) of $\log\rho_{m,n}$ is given by the formula

$$2\sigma^2_{(E)}\log\rho_{m,n}=\frac{\sum_m w_m(\log\rho_m)^2}{(m-1)\sum_m w_m}+\frac{\sum_n w_n(\log\rho_n)^2}{(n-1)\sum_n w_n}. \tag{13}$$

Assuming this variance can be ascribed half to $\log R$ and half to $\log\overline{(A/B)}$, the variance of $\log R$ is given by

$$\sigma^2_{(E)}\log R=\frac{\sum_m w_m(\log\rho_m)^2}{4(m-1)\sum_m w_m}+\frac{\sum_n w_n(\log\rho_n)^2}{4(n-1)\sum_n w_n}, \tag{14}$$

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and the degrees of freedom will be $(m-1)+(n-1)-1$, or $m+n-3$.

The statistical weights for $\log(A_m/B_m^*)$ and $\log(A_n^*/B_n)$ are determined from the variance of these quantities in the normal fashion (Brooks and Carruthers, 1953), as follows:

$$w_m = \frac{K}{\underset{(E)}{\sigma^2} \log(A_m/B_m^*)}, \tag{15}$$

$$w_n = \frac{K}{\underset{(E)}{\sigma^2} \log(A_n^*/B_n)}. \tag{16}$$

K is an arbitrary constant, assigned so as to give manageable values to the relative weights. Hence $\ln \equiv \log_e$ can be substituted for $\log_{10}$, and the difference incorporated in K. It can then easily be shown, since small changes in A and B are relatively uncorrelated and are normally distributed with respect to zero, that

$$\underset{(E)}{\sigma^2} \ln(A_m/B_m^*) \cong \left(\frac{\underset{(E)}{\sigma A_m}}{A_m}\right)^2 + \left(\frac{\underset{(E)}{\sigma B_m^*}}{B_m^*}\right)^2, \tag{17}$$

and

$$\underset{(E)}{\sigma^2} \ln(A_n^*/B_n) \cong \left(\frac{\underset{(E)}{\sigma A_n^*}}{A_n^*}\right)^2 + \left(\frac{\underset{(E)}{\sigma B_n}}{B_n}\right)^2, \tag{18}$$

which permits easy calculation of the weights.

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Large Particles in Supercooled Regions of Northern Canadian Cumulus Clouds

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ABSTRACT

Measurements have been made of the concentration and phase of large particles (>70 μm) within the supercooled regions of northern Canadian cumulus clouds. During June and July, for the years 1975 and 1976, a total of 58 cumulus clouds near Yellowknife, N.W.T., were examined with a specially equipped Twin Otter aircraft. The cumulus clouds studied were mainly 1–3 km deep with most of the 130 cloud penetrations being made within 300 m of cloud top, at temperature levels between −1 and −11°C. The median penetration average (Johnson-Williams) liquid water content was 0.3 g m^{-3}. The median penetration average concentration of particles >70 μm and >350 μm was 0.9 ℓ^{-1} and 0.015 ℓ^{-1}, respectively. The concentration of large particles was not well correlated with J-W liquid water content or temperature, and considering all the clouds, no consistent change in the concentration was observed in successive cloud penetrations. These large particles were predominantly water drops. Ice was only found in clouds with summit temperatures colder than −8°C. Clouds containing ice had significantly higher concentrations of large particles than did all-water clouds. The data suggest that both cold and warm rain precipitation formation mechanisms were present in some of these clouds.

1. Introduction

Considerable attention in recent years has been focused on the concentration of large water drops and ice crystals within the supercooled regions of cumuliform clouds. These particles are important because they have the potential of growing to precipitable sizes. In addition, if the concentration of these particles is low, then the clouds might be suitable for artificial stimulation of precipitation.

During 1975 and 1976 the concentration and phase of large particles in summer cumulus clouds within 350 km of Yellowknife, N.W.T., (67°27′N, 114°21′W) were routinely measured using an instrumented DHC-6 Twin Otter aircraft of the National Aeronautical Establishment (NAE). This aircraft was equipped and the measurements were taken to help fulfil the objectives of a precipitation enhancement experiment which has been described by Isaac *et al.* (1977). Cloud-top and cloud-base measurements were sometimes available from two other NAE project aircraft: a T-33 and a Beechcraft D-18. The results of this two-year experiment, to investigate the supercooled regions of unseeded Canadian cumuliform clouds, are discussed in this paper.

2. Cloud physics instrumentation

In any experiment of this type, the suitability and reliability of the cloud physics instrumentation is one of the major considerations. The desire was to measure the sizes and concentrations of the large particles in the cloud and to distinguish between the ice and water phases. The reliability of the data is affected by instrument choice, mounting locations, instrument errors and instrument unserviceabilities. These are discussed below. All discussions of particle sizes refer to measured drop diameters or ice particle maximum dimensions.

The available instrumentation and mounting locations were as follows: a Particle Measuring Systems (PMS) 1D-C probe (~20–300 μm) and a Mee Industries model 120 ice particle counter located beneath the port wing of the Twin Otter; a PMS 1D-P probe (~300–4500 μm) and a PMS FSSP (~2–30 μm) mounted beneath the starboard wing; a Mee Industries model 101 continuous cloud particle replicator located on top of the fuselage back of the wing; a large particle collector similar to that of Schreck *et al.* (1974) positioned on top of the fuselage just back of the windscreen; a Johnson-Williams liquid water content meter and standard temperature, altitude and air speed probes mounted on the aircraft nose (see Isaac *et al.*, 1977).

Drummond (1977) examined the four wing mounting locations and concluded that any aircraft or probe induced concentration errors were less than 6%. In addition, he concluded that the replicator is a poor instrument for measuring particle concentrations. This

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was a result of the structural geometry of the instrument, not because of its mounting location. In this project the replicator data are only used to determine the ice/water phase of particles and ice crystal habits.

Two known problems affect the PMS 1D cloud droplet and precipitation probes. The first channel of the 1D-P probe, which has a nominal size range interval from 300–450 μm, only detects ~0.4 of the particles passing through the sample area (Curry and Schemenauer, 1979). Therefore, the concentration data for this channel have been increased by a factor of 2.5. Second, since the first three channels of the 1D-C probe detect, size and count particles with an unknown accuracy (Isaac *et al.*, 1977), data from these channels (~20–70 μm) have not been presented. While several other problems were discovered when operating the PMS 1D-C and 1D-P probes (Isaac *et al.*, 1977), none of the data presented suffers from these defects. At typical aircraft speeds, nominal sampling rates for the 1D-C and 1D-P probes are 1 and 100 ℓ s^{-1}, respectively. The concentrations reported are believed to have an absolute accuracy within a factor of 2. Detailed data from the third PMS probe, the FSSP, will not be presented since uncertainties due to changing probe calibrations have affected the reliability of the measurements.

Knollenberg (1976) pointed out that the PMS 2D-C probe imagery shows particles splashing or shedding off the probe tips. Though the authors know of no thorough discussion of the problem in the refereed literature, it could be argued that these artifacts might also be counted by the 1D-C probe. Since this could seriously affect the results of particle sizes and concentrations determined from the PMS probes, the data were examined for a shedding effect. If shedding results from the buildup of cloud water on probe tips and ports then one would expect that a correlation might exist between liquid water content and 1D-C or 1D-P probe concentrations. In fact, the correlations between liquid water content and probe concentrations >70 and >450 μm were negative. In some cases where cloud liquid water contents were high, no particles >70 μm were counted. An examination of the particle size distributions from the 1D-C and 1D-P probes also showed a continuity that would be unlikely if one or both probes were seriously affected by shedding. To further examine the problem, during flights in supercooled clouds in 1977 near Thunder Bay, Ontario, a PMS 2D-C probe (~25–800 μm) and the 1D-C probe were operated together in similar mounting locations underneath the wing. These probes had identical shapes near the sample area but differed electronically. In each of 49 selected penetrations in a total of 17 clouds at temperature levels between −1 and −11°C, with a median and a maximum penetration average J-W liquid water content of 0.8 and 3.0 g m^{-3}, respectively, the 1D-C probe measured <0.01 ℓ^{-1} of particles >70 μm in size. The PMS 2D-C probe consistently imaged shed particles during these penetrations with concentrations of spurious images typically >3 ℓ^{-1}. Clearly, the electronics of the 1D-C probe (end element rejection and depth of field rejection) eliminates these artifacts from the particles counted.

One further possible effect on the sizing and concentration data should be mentioned. It could be postulated that drops thrown off the propellors will affect the measurements. However, the very low concentrations during the 49 Thunder Bay penetrations discussed above indicate that this problem, if it exists, produces negligible particle counts >70 μm.

Schemenauer and Curry (1979) discuss calibrations performed with the Mee Industries ice particle counter prior to the 1976 field year, as well as the use of the IPC in mixed-phase clouds. Only data collected in the 1976 field year are discussed in this report. The scattered light pulse registered by the IPC as a particle passes through the sample area is produced primarily through specular reflection off the particle surface. As such, the counting efficiency of the IPC is related to the average size of the ice particles and to the threshold voltage setting of the instrument. Examples are given of comparative IPC and PMS 1-D probe response in clouds composed of small droplets, in rain, and in clouds with moderately high concentrations of large ice particles. The IPC was effective in determining particle phase except in cases where the particles were too small (generally ≲150 μm) for detection or where the concentration of large particles was very low (generally ≲0.1 ℓ^{-1}). It is difficult to put error bars on the in-cloud ice particle concentrations measured by the IPC since the "true" value is never known. However, the IPC concentrations are almost always equal to or lower than the PMS 1-D particle concentrations. The IPC will respond to millimeter sized water drops but this results in very low concentrations when averaged over a cloud penetration. The sampling rate for the IPC is ~7 ℓ s^{-1} for typical Twin Otter speeds.

The continuous formvar replicator is a model 101 replicator made by Mee Industries Inc. of San Gabriel, California. The instrument transports a formvar-coated clear mylar leader past a sample slit located 1 m above the roof of the aircraft cabin. Under normal operating conditions ~20 min of in-cloud sampling time is available per flight. The replicator sampling rate depends on aircraft speed, film transport speed and film coverage, but is ~2.5 ℓ s^{-1}. A sampling tube mounted on the upper fuselage is also used to document the presence of ice. It is a modified version of that described by Schreck *et al.* (1974) and has a sampling rate of ~30 ℓ s^{-1}. The interior of the tube is teflon-coated; the polyethylene sample bottles are used either empty or partially filled with chilled silicone oil.

3. General observations and data characteristics

All clouds examined were located within 350 km of Yellowknife, N.W.T. The immediate vicinity of Yellowknife is a relatively flat, treed area with numerous lakes and rock outcroppings. To the south of the city is Great Slave Lake, the fifth largest lake in North America with an area of 28 900 km^2, and ~230 km west of the city is a plateau rising ~500 m above the countryside. Both the lake and plateau were observed to affect the formation of cumuli. Mountain ranges further to the west interact with air from the normal source region over the Pacific Ocean to affect the synoptic-scale weather over the project area.

The clouds examined were usually 1–3 km deep. Generally they were not towering in appearance but had cloud widths larger than their depths. At the time of selection and first penetration, the clouds had a vigorous, growing or bubbling appearance. However, because of short cloud lifetimes, successive penetrations would sometimes be performed while the cloud was dissipating. Most, but not all, of the penetrations were made within 300 m of the cloud top at temperature levels between −1 and −11°C. Because of the high latitude of Yellowknife, the height of the 0°C isotherm was relatively low, being 2750 m MSL. Cloud base heights were typically 2300 m MSL with cloud-base temperatures of +3°C. Because of the distance of Yellowknife from the sea (~1200 km) and the PMS FSSP measurements which indicate median total droplet concentrations >400 cm^{-3} averaged over a cloud penetration, the summer cumuli examined can be classified as being continental.

MacPherson and Isaac (1977) and Isaac *et al.* (1978) describe dynamical/turbulence measurements made within 15 Yellowknife cumuli during the summers of 1975 and 1976. The cloud characteristics and penetration levels for the dynamical and microphysical (described below) data sets are very comparable, although microphysical data were collected in many more cumulus clouds. The majority of cloud penetrations for dynamical measurements were made a few hundred meters below cloud top at a median temperature level of −8.5°C. Most of the peak vertical gusts encountered near cloud top were downgusts, which appeared to be preferentially located near the cloud edge. Clouds at this level appeared to be quite turbulent and could not be represented as a simple smooth updraft. The median turbulent energy dissipation rate and the median rms vertical velocity were 190 $cm^2\ s^{-3}$ and 1.7 m s^{-1}, respectively.

From the periods 17–25 July 1975 and 28 June–17 July 1976, on a total of 12 separate days, microphysical measurements were made within 58 cumuli near Yellowknife. Sixteen of these clouds were seeded but only penetrations made within the clouds before seeding commenced are included. No penetration data are used if there was any possibility that seeding material was within the cloud at the time of measurement. The Twin Otter was flown through the 58 clouds for a total of 130 cloud penetrations with 101 of the penetrations being performed during 1976.

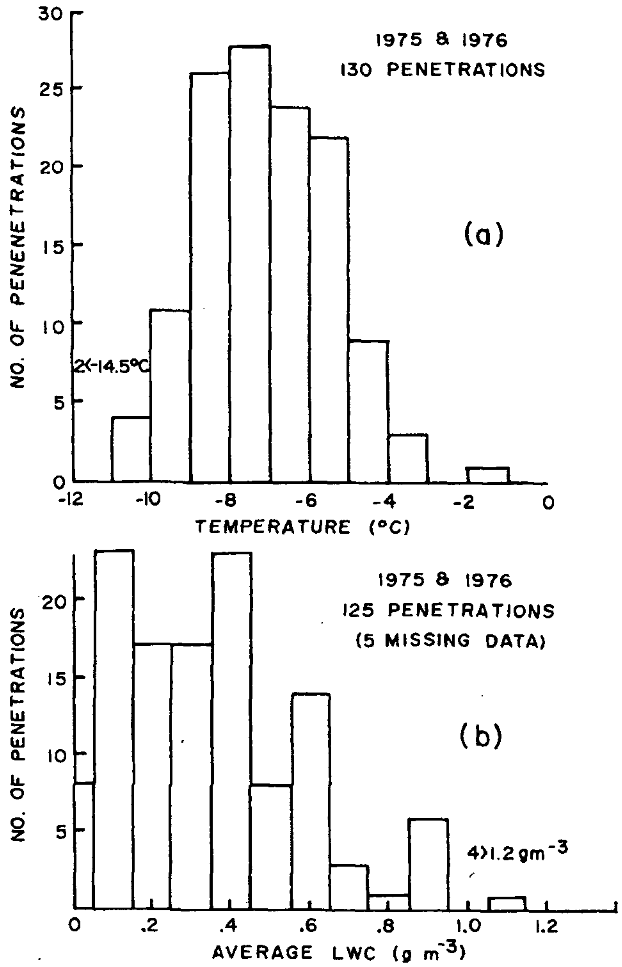

FIG. 1. Histograms of conditions at the penetration level where the particle concentrations of Figs. 2 and 3 were measured: (a) out-of-cloud temperature, (b) average liquid water content for the penetration.

For 12 of the 58 clouds, the Twin Otter was only flown through the cloud once; 32 were penetrated twice, and for 14 clouds three or more aircraft passes were made. The time between the first and last penetration in a cloud was >5 min for 11 of the 58 clouds with two clouds being examined for periods longer than 20 min.

The co-pilot defined cloud boundaries by activating an event marker upon entering and exiting the cloud. Because the cumuli walls were usually very distinct, these boundaries agree well with measurements made with the Johnson-Williams meter and the PMS FSSP probe. Approximately 80% of the penetrations were between 500 and 4500 m in length. The median penetration length was 25 s, which at typical Twin Otter airspeeds (65 m s^{-1}) was 1.6 km. For a sampling period of 25 s, assuming only one particle is detected, the lower limit for defined concentrations is approximately 40, 0.4, 6, 20 and 1 m^{-3} for the PMS 1D-C, 1D-P, IPC, replicator and sampling tube probes, respectively.

4. Large particle summary

Fig. 1a shows a histogram of the environmental temperature at the penetration level for the 130 cases of 1975 and 1976. Environmental values are used because in-cloud temperatures are not believed to be as accurate. The histogram maximum occurs between −7 and −8°C with all but seven penetrations being performed between −3 and −10°C. The average liquid water content measured for each penetration by a Johnson-Williams meter is given in histogram form in Fig. 1b, with the median penetration average value being 0.3 g m^{-3}.

A histogram of the concentration of particles >70 μm (as determined from PMS 1D-C and 1D-P probe measurements) is displayed in Fig. 2. Logarithmic intervals have been chosen because of the wide range of concentrations. Both the logarithmic mean and the median concentration >70 μm are 0.9 ℓ^{-1}.

Fig. 3 illustrates the 90, 75, 50 and 25 percentile values for the penetration average concentration of particles greater than the specified size (70–1050 μm). For example, 50% of the penetrations had average concentrations <0.6 ℓ^{-1} for particles >150 μm. For particles >1 mm (1050 μm), the 50 percentile value is approximately 2 m^{-3}. Both Figs. 2 and 3 show the wide range of average concentrations possible. The 90 percentile values for the concentration of particles

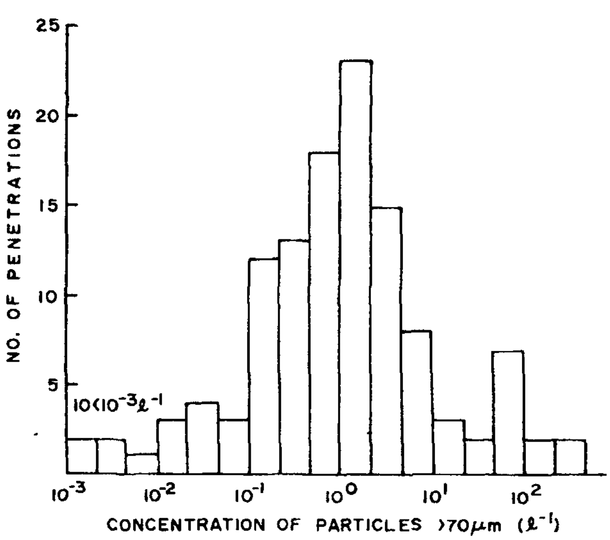

FIG. 2. Histogram of the average concentration of particles >70 μm measured during each of 130 penetrations in 1975 and 1976.

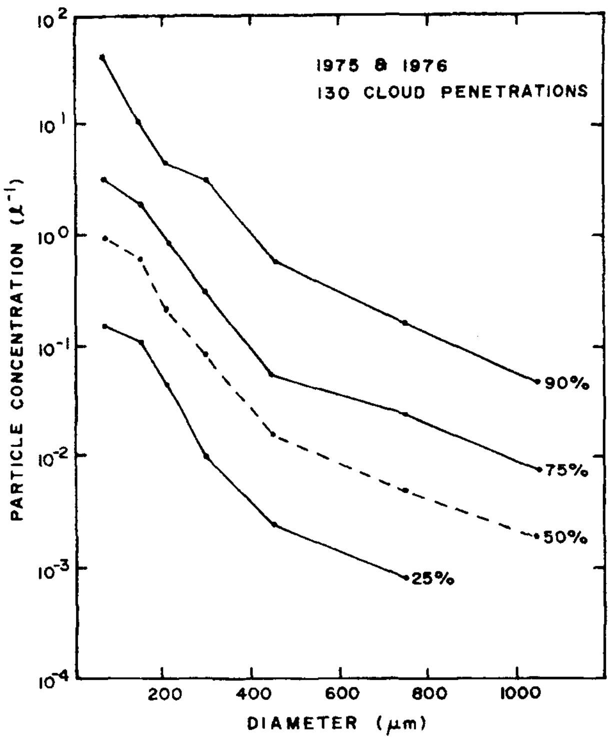

FIG. 3. The 90, 75, 50 and 25 percentile values for the concentration of particles greater than a specified size. For example, for particles >150 μm, 90% of the penetrations had average concentrations <11 ℓ^{-1}. All particles are assumed to be spherical, although it is known that some ice particles were present.

>150 and >1050 μm are 11 ℓ^{-1} and 49 m^{-3}, respectively. Fig. 3 shows a relatively smooth transition (at ~300 μm) in concentrations between those measured by the PMS 1D-C and 1D-P probes. As was noted in Section 2, channel 1 of the 1D-P has been corrected according to Curry and Schemenauer (1979). There remains, however, a slight change in slope at ~300 μm which may be real or instrumental.

In order to determine whether the data based on the set of 130 penetrations were internally consistent, the data were divided into five subsets. The 29 penetrations of 1975 and the 101 penetrations of 1976 formed the first and second subsets. The third and fourth subsets consisted of the 24 runs before seeding in seeded clouds and the 77 runs in unseeded clouds in 1976. For the fifth subset, the maximum value of the average concentration for a penetration within each of the 58 clouds was determined. None of these subsets had median concentrations of particles >70, 150, 210, 300, 450, 750 or 1050 μm which were more than a factor 2 different than the median values for the 130 cloud penetrations. The similarity of these subsets indicate that Fig. 3 provides representative values for particle concentrations within supercooled regions of cumulus clouds near Yellowknife. The question of the phase of these particles is addressed in Section 5.

The real and logarithmic values of the 130 penetration average concentrations of particles >70 μm and >450 μm were examined to see if correlations existed with other cloud parameters. The logarithmic value of the concentration was used because this parameter appeared to be more normally distributed (Fig. 2). No strong correlations were obtained. The concentrations of particles >70 μm and >450 μm are very weakly negatively correlated with liquid water content and temperature ($r > -0.38$). A weak correlation with temperature at the penetration level may be due to the limited range of temperatures observed (-1 to -11°C). A stronger positive correlation ($r > 0.47$) was found with penetration length. Since the cumuli were usually penetrated within 300 m of cloud top, penetration length is not directly related to cloud-top temperature or cloud depth. However, penetration length might be a function of cloud lifetime since clouds tended to get thicker with time.

In order to test the hypothesis that more large particles appeared in a cloud as it got older, 46 clouds were examined where more than one penetration was made with the Twin Otter. In 21 of the 32 clouds that were penetrated twice, the maximum penetration average concentration >70 μm was measured on the first pass. Of the 14 clouds penetrated three or more times, the maximum penetration average concentration >70 μm was recorded on the first pass three times and on the last pass six times. Similar numbers were obtained when the above analysis was performed using the concentration of particles >450 μm. These cases give no indication of an increase in concentrations with time. However, in seven clouds followed for periods >5 min, with three or more penetrations, and with the average concentration of particles >70 μm being >2 ℓ^{-1}, the concentrations tended to increase with time; the maximum increase being a factor of 10 in 7.5 min. Six of these seven clouds contained ice and at least three produced rain. When all the data are considered, no strong conclusions can be made regarding the change of large particle concentrations with time. It appears, though, that clouds containing large ice particles may develop increased particle concentrations as the cloud matures.

5. Phase summary

a. General comments

Three instruments were used in determining the phase of the cloud particles: the Mee ice particle counter, the Mee cloud particle replicator, and a sampling tube particle collector. The Mee IPC, described in Section 2, was the principal instrument for phase determination. The Mee continuous replicator was only operated during 13 of the 101 penetrations reported on here, since its use on the aircraft was primarily for a parallel, seeded cloud experiment. In each of these 13 cases the data confirmed the phase determination from the IPC. The sampling tube described in Section 2 was operated during each penetration to check for the presence of ice particles several hundred microns in diameter and larger.

The phase of the particles $\gtrsim 150$ μm encountered during each of the 101 penetrations of 1976 was determined from the IPC data using the technique of Schemenauer and Curry (1979). In accordance with this technique, if the particle concentration on the PMS probes was $\lesssim 0.1$ ℓ^{-1}, the phase of the particles (if present) could not be established. This results in the data being assigned to one of four categories: ice, if all of the particles $\gtrsim 150$ μm were ice; water, if all of these particles were water; ice/water, if there was reason to believe both phases were present; $\lesssim 0.1$ ℓ^{-1}, if there were negligible concentrations of particles $\gtrsim 150$ μm.

In 23% of all the 1976 penetrations some ice was present in sizes $\gtrsim 150$ μm; about one-half of the penetrations with ice also contained some large water drops. In 44% of the penetrations all of the large particles were water drops. In addition, in 33% of the 101 cloud penetrations, the concentrations of large particles was $\lesssim 0.1$ ℓ^{-1}. Therefore, in two-thirds of the cloud penetrations where large particles were present in significant concentrations, they were water drops. Ice was the exception, rather than the rule in these supercooled clouds.

In 12 of the 13 penetrations where continuous formvar replicator data were available, the maximum drop size observed was $\gtrsim 60$ μm. These data confirm the presence of large drops in the Yellowknife clouds but are not well correlated with the PMS 1D-C data. This might be expected since large drops become badly distorted on impact with the replicator film and therefore the sizing of drops with diameters of 100–200 μm is unreliable. The 1D-C probe detected particles on 9 of the 13 penetrations and on each of these penetrations indicated the presence of drops 200–300 μm in diameter. The PMS 1D-P probe indicated the presence of even larger drops but in concentrations so low that it is unlikely they would be sampled effectively by the replicator.

No graupel were ever observed in the sampling tube containers when the aircraft was flown through the unseeded clouds described above. This instrument is definitely capable of collecting graupel since such particles were observed after seeding in some seeded clouds. Considering the median penetration length of 26 s, and the tube sampling rate of 30 ℓ s^{-1}, the concentration of graupel in the unseeded clouds would be $\lesssim 1$ m^{-3}. Gagin (1975) found similar results in his observations of continental cumuli. He noted that graupel concentrations were almost always below the detection limits (1 m^{-3}) of his instruments for clouds with summit temperatures between -3 and -11°C.

b. Ice detection versus cloud-top temperature

It is perhaps preferable to examine the phase data on a cloud by cloud and summit temperature basis as in Table 1. Of the 44 clouds for which particle phase and summit temperature data are available, nine (20.5%) contained ice. Strictly speaking, this only applies to particles $\gtrsim 150$ μm. However, since ice particles would grow to this size rapidly in these clouds, it is probably a good estimate of the percentage of clouds containing ice of any size at the penetration level (within 300 m of cloud top).

The data from Table 1 are plotted in Fig. 4. There is an approximately linear increase in the percentage of clouds containing ice as the temperature decreases. No clouds warmer than −8°C at the top contained ice at the penetration level, in good agreement with measurements of McPartland *et al.* (1977) near Miles City, Montana, 2000 km south of Yellowknife, N.W.T. Fig. 4 indicates that there is a 50% probability that clouds with a summit temperature of −14°C will contain ice. If the data were extrapolated to colder temperatures, the 100% value would be at −21°C. Cumuli in south-central Missouri were found to contain solid hydrometeors in about one-third of the clouds whose tops reached −10°C (Braham, 1964).

Morris and Braham (1968) examined 92 Minnesota cumuli at the −5°C level. Only their data representing summit temperatures from −8 to −17°C were plotted in Fig. 4 as they felt that clouds outside of this temperature range might fall into a different classification. The data of Morris and Braham also shows a linear increase in the percentage of clouds containing ice as the summit temperature decreases. They found that relatively few clouds contained ice particles until their tops were colder than −8 to −10°C and that the 50% likelihood was found with cloud top temperatures of about −11°C. If these data are extrapolated to temperatures $\lesssim -18$°C, the likelihood is greater than 90%. The similarity to the Yellowknife results is striking.

TABLE 1. Phase of particles >150 μm as determined by the Mee Industries ice particle counter for 44 clouds in 1976.

Summit temperature (°C)	Number of clouds with some ice	Number of clouds with only water	Number of clouds with concentration $\lesssim 0.1$ ℓ^{-1}	Total number of clouds	Percent of clouds with ice
−4.0 to −5.9		4		4	0
−6.0 to −7.9		8	1	9	0
−8.0 to −9.9	2	8	3	13	15.4
−10.0 to −11.9	1	1	2	4	25.0
−12.0 to −13.9	4	3	4	11	36.4
−14.0 to −15.9	1	1	}	3	66.7
−16.0 to −17.9	1				

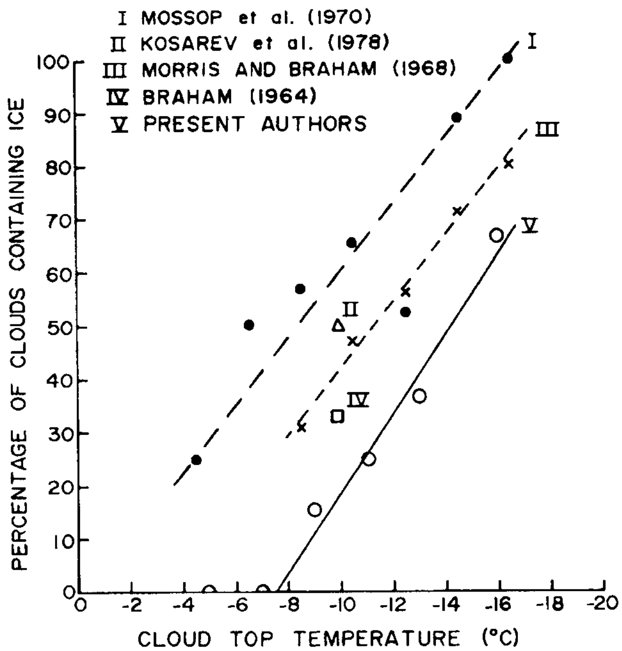

FIG. 4. The percentage of clouds containing ice as a function of cloud top temperature. Data for I and III have been analyzed in a similar manner to V (Table 1). II and IV refer to approximate numbers quoted by the authors.

Fig. 4 shows that the data of Mossop *et al.* (1970), for maritime cumuli in Tasmania, have a similar slope to that presented here but are about 6°C warmer. Even in light of the errors present in determining the summit temperature (Mossop *et al.*, 1970: ±2°C; present work: ±1–2°C) this difference is significant. Mossop *et al.* (1970), in agreement with Findeisen (1942), noted that maritime cumuli were more efficient ice producers than continental cumuli. Findeisen claimed that continental cumuli had to be 4 or 5°C colder than maritime cumuli in order to have the same chance of containing ice particles. Although Morris and Braham's data are halfway between those of Mossop *et al.* and the present work, it is not clear whether this indicates the Minnesota clouds were more maritime than the Yellowknife clouds or whether it merely reflects differences in the temperature measurements. A difference in the ice content of continental and maritime cumuli is also apparent in the work of Kosarev *et al.* (1978). They noted that 50% of midlatitude clouds in the U.S.S.R. reaching −10°C contained ice, whereas pure droplet clouds in the eastern tropical Atlantic area were rarely observed at temperature < −10°C.

In conclusion, the probability that a cumulus cloud will contain ice at a particular temperature appears to be quite similar for different midlatitude locations. The above American, Soviet and Canadian work for continental clouds indicates that a cloud needs a summit temperature of ∼ −8°C for the initial detection of ice, ∼ −12°C for a 50% chance and ∼ −20°C for

TABLE 2. The median (2a) and mean (2b) concentrations of particles in clouds containing ice, ice and/or ice-water, and water only. The phase determination was only made for particles >150 μm.

Particle phase	Number of clouds	Concentration (ℓ^{-1}) >size (μm) 70	150	210	300	450	750	1050
				2a.				
I	7	7.1	1.9	0.74	0.63	0.19	0.053	0.034
I+I−W	9	7.1	2.3	1.5	0.64	0.19	0.053	0.034
W	25	1.3	1.1	0.54	0.16	0.028	0.012	0.0038
				2b.				
I	7	40.0	18.0	9.8	5.7	0.96	0.37	0.15
I+I−W	9	32.0	15.0	8.0	4.7	0.78	0.30	0.12
W	25	1.6	1.2	0.56	0.18	0.034	0.018	0.0061

a 100% chance of containing ice. Clouds of maritime origin appear capable of producing ice about 5°C warmer than the thresholds listed above.

c. Ice particle and water drop concentrations

Particle concentrations within the seven Yellowknife cumulus clouds that contained only ice (>150 μm), and the nine clouds that were known to contain some ice, were compared with the concentrations within the 25 clouds that contained only water (Tables 2a and 2b). Only the maximum penetration average concentration (i.e., the penetration with the highest average concentration) measured within each of these 34 clouds was considered. The 10 clouds with low concentrations (<0.1 ℓ^{-1}) of particles >150 μm were not included in this comparison. For the clouds containing ice, the median concentration of particles >70 μm and >450 μm was 7.1 ℓ^{-1} and 0.19 ℓ^{-1}, respectively. The corresponding median values for the clouds containing water were 1.3 and 0.03 ℓ^{-1}. Clouds containing ice had significantly higher concentrations of large particles within them.

A comparison with other measurements of the concentrations of large particles in the supercooled regions of cumuli is not necessarily straightforward. This is due in part to the variable nature of the particles described by different authors. In some cases they are all ice, sometimes all water, sometimes ice and water, and often they are unknown. In addition, concentrations are reported in different ways and for different size ranges. Table 2a contains the median concentrations of particles greater than a series of sizes from the present work. This is an appropriate parameter to characterize the concentrations because of the skewness of the concentration distributions (Fig. 2). The skewness in Fig. 2 would be more evident if linear concentration intervals had been used. However, since mean rather than median concentrations are usually reported in the literature, Table 2b has been included for comparison purposes. For the 9 clouds containing some or all ice particles, the mean concentrations are about an order of magnitude higher than the median concentrations.

Table 3 lists some examples of large particles reported by other authors in the literature. The measurements in these cases were the result of aircraft penetrations in the supercooled regions of convective clouds. The presence of some large particles, water or ice, seems to be normal in clouds that reach ~−10°C. When ice particles are detected they appear to be present in higher concentrations than are large drops in all-water clouds. This is in agreement with the results of the present work.

The ice particle concentrations in Yellowknife clouds seem to be comparable to the ice pellet concentrations reported by Braham (1964) and possibly somewhat higher than the ice particle concentrations in Montana clouds reported by McPartland *et al.* (1977). The results reported by Kosarev *et al.* (1978) are perhaps the most easily compared to Table 2b. Their concentrations of "superlarge particles" (drops and crystals) >200, 300, 400 and 1000 μm are within a factor of 3 of these reported in this paper for all water clouds. These results are for cloud thicknesses of 2–3 km, similar to those observed in Yellowknife. For thicker (3–5 km) Ukranian convective clouds they report higher concentrations, while thinner clouds (0.5–2 km) have lower concentrations. Although it is recognized that cloud-base temperature may be an important variable, Kosarev *et al.* classified their clouds according to thickness and this variable was chosen as the basis for intercomparison.

It is apparent that many factors such as cloud type, cloud-top and cloud-base temperatures, cloud thickness and particle phase affect the sizes and concentrations of large particles in the supercooled regions of convective clouds. To the extent that comparisons are possible, the clouds near Yellowknife (62°27′N, 114°21′W) are similar to those reported elsewhere in continental North America and in the continental U.S.S.R.

6. Rain formation

Rain was detected falling from 4 of 33 natural cumuli (12%) during the project period. Three of the four raining clouds contained ice at the Twin Otter observation level near cloud top. Clouds that were subsequently seeded were not included in this analysis. Cloud base observations (three cases) by the Beech D-18 and the Twin Otter weather radar data (one case) were used to verify the rain below these clouds. However, since Twin Otter or Beech D-18 observations were not always available, it is possible a slightly greater percentage of the clouds studied were raining.

In one of these four cases, no ice >150 μm was detected as the Twin Otter penetrated the cloud three times over a period of 8 min at a temperature level of −8°C. Cloud top was at 5000 m (−13°C)

TABLE 3. Examples of large-particle concentrations observed by other authors in supercooled regions of convective clouds. Concentrations are usually averages for a number of penetrations or clouds.

Authors	Location	Particle type	Concentration (ℓ^{-1})	Size (μm)	Comments
Koenig (1963)	Southern Missouri	Water drops	~0.05	~1000	In clouds that develop ice quickly
		Water drops	65% ≥ 0.1	> 250	Occnl. 2-3 ℓ^{-1}
Brown and Braham (1963)	S. Central Missouri	Water drops	43% ≥ 0.1	> 250	Cumulus congestus, tops 4270–6400 m
		Water drops	20% ≥ 1.0	> 250	
Braham (1964)	S. Central Missouri	Ice pellets	≤ 10	> 250	Found freq. in clds. with tops −10°C & warmer
Mossop *et al.* (1970)	Tasmania	Water drops	0.5, 1.2	300–540	2 clouds
		Water drops	0.7	> 300	In all water clouds
		Water drops	0.13	> 300	In clouds with occnl. ice
		Graupel	0.15	> 250	
		Crystals	1.1		
		Graupel	1.2	> 250	Clouds with graupel, crystals and water
		Crystals	60		
		Graupel	0.2	> 250	Glaciated clouds
		Crystals	210		
Mossop *et al.* (1972)	Australian mainland	Water drops	0–0.3	250	21 clouds, 10 with zero conc.
		Water drops	0–0.4	500	21 clouds, 9 with zero conc.
		Water drops	0–0.2	1000	21 clouds, 9 with zero conc.
		Ice particles	0.005–2.3	250	37 clouds, 0 with zero conc.
		Ice particles	0–1.7	500	37 clouds, 1 with zero conc.
		Ice particles	0–0.1	1000	37 clouds, 7 with zero conc.
Gagin (1975)	Israel	Graupel	< 0.001	> 250	0 to −10°C summit temperature
		Graupel	< 0.3	> 250	−13°C summit temperature
		Graupel	< 0.7	> 250	−16°C summit temperature
		Graupel	< 0.9	> 250	−19°C summit temperature
McPartland *et al.* (1977)	Montana	Ice particles	77% < 0.5	≳ 50	Penetrations in isolated feeder cells
		Ice particles	70% < 1.0	≳ 50	Penetrations in isolated mature cells
		Ice particles	70% < 1.0	≳ 50	Penetrations in isolated decaying cells
Kosarev *et al.* (1978)	Ukrainian U.S.S.R.	Drops & crystals	0.18	> 200	Cloud thickness 2–3 km
		Drops & crystals	0.065	> 300	Cloud thickness 2–3 km
		Drops & crystals	0.033	> 400	Cloud thickness 2–3 km
		Drops & crystals	0.008	> 1000	Cloud thickness 2–3 km
	Arctic U.S.S.R.	Drops & crystals	1.3	> 200	70°–80°N, Sc & Ac clouds
		Drops & crystals	0.038	> 1000	70°–80°N, Sc & Ac clouds

with cloud base being measured at 2300 m MSL (~+5°C). Light rain falling from the cloud was observed from the Beech D-18. The measurements suggest a warm rain process may have been operative in this continental cloud. It should be mentioned that Braham (1964) also concluded that a warm rain process was possible in Missouri summer cumulus clouds, and that one-third to one-half of his clouds developed warm rain particles in concentration sufficient to cause a radar echo on a ground based radar.

The one raining cloud without Beech D-18 observations at the base was followed for 41 min, produced an echo on the Twin Otter radar, and had high concentrations (>5 ℓ^{-1} of particles >450 μm) at the Twin Otter penetration level (~−7.5°C, 4200 m). The maximum recorded cloud-top height was 5030 m (−13°C) and the cloud-base height was 1500 m (~+9°C). Although ice was present in this cloud, the IPC measurements and the heavy aircraft icing rates indicated that most of the large particles were water drops. Average J-W liquid water contents in the cloud were ≤ 0.5 g m^{-3} for eight of the nine penetrations with one penetration having an average of 0.9 g m^{-3}. These J-W values are not nearly high enough to account for the icing rates experienced. It appears that precipitation in this cloud was being partially or totally produced by a warm rain process.

Three other clouds contained high enough concentrations of large particles (>0.1 ℓ^{-1} of particles >450 μm) near cloud top to suggest that they might be raining at cloud base, although confirmation from cloud-base measurements was not obtained. In two of these clouds the large particles were ice; in the third only water drops were present near cloud top.

In conclusion, three and perhaps five of seven clouds containing ice particles >150 μm rained, while one and perhaps two of 18 clouds containing only large water drops rained. It appears that the presence of ice particles >150 μm was neither sufficient nor necessary for the production of rain, but was highly preferred. None of the eight clouds containing $<0.1\ \ell^{-1}$ of particles $>150\ \mu m$ rained. The average summit temperature for the clouds producing rain was $-12.9 \pm 2.7°C$ and for the clouds that did not rain, it was $-8.6 \pm 2.4°C$.

7. Conclusions

Fig. 3 summarizes the concentration of particles 70–1050 μm in size within 58 cumulus clouds. Most of the measurements were made 300 m below cloud top at temperature levels between -1 and $-11°C$ with a median penetration level of $-7°C$ and a median Johnson-Williams liquid water content of 0.3 g m^{-3}. Based on PMS probe size distribution measurements in all water clouds, the cloud liquid water content in sizes $>70\ \mu m$ was never >0.2 g m^{-3}.

Table 1 and Fig. 4 indicate that clouds with tops warmer than $-8°C$ did not contain ice but almost 50% of the clouds with tops between -12 and $-18°C$ did. The percentage of clouds containing ice appeared to be directly related to cloud-top temperature. Approximately twice as many clouds contained large water drops as contained large ice particles. The existence of very large water drops (median value 4 $m^{-3} > 1$ mm, Table 2a) within these clouds is puzzling, even though other authors (Section 5) have reported similar or higher values. The clouds examined appear to have had short life spans and it would be difficult to explain drop growth from nuclei size by a condensation-accretion-coalescence mechanism in the apparent time available (<30 min). The presence of these drops, although unexplained, is quite significant and may imply longer cloud lifetimes. Such large drops might accelerate any rain-forming process, although the observations imply that rain development in all-water clouds is inefficient in northern Canada.

As was noted in Section 4, wider and perhaps older clouds tended to have higher large particle concentrations. For some clouds followed for periods >5 min, there was a tendency for the concentration of particles to increase with time. However, in general, no consistent change in the concentration of large particles was observed in successive penetrations within these cumulus clouds.

For 50% of the 58 clouds, the average concentration of particles $>150\ \mu m$ was never $>1\ \ell^{-1}$ (Table 1). The critical concentration of ice crystals or large particles ($>150\ \mu m$) required to start the precipitation process is often given as $1\ \ell^{-1}$ (Twomey, 1958); the concentration which would produce precipitation efficiently is probably $>1\ \ell^{-1}$. Because of the low particle concentrations and the lack of ice particles, most of the observed Yellowknife cumuli appear to be seedable and would not naturally produce significant quantities of rain.

The possibility that an ice multiplication mechanism was operative in these clouds was considered. Ice nuclei measurements made using filters suggest that the concentration of deposition nuclei in environmental air at the penetration level was $<0.03\ \ell^{-1}$ at $-20°C$. Ice crystals were detected in 21% of Yellowknife cumuli in concentrations $>0.1\ \ell^{-1}$ and likely were the result of nucleation in cloud air that originated at warmer temperatures where ice nuclei measurements were not available. Mossop *et al.* (1970) observed high concentrations of ice crystals in maritime clouds with tops warmer than $-8°C$ but colder than $-5°C$ (Fig. 4). This observation stimulated and supported the laboratory work of Mossop (1976) which concluded that ice multiplication occurs between -3 and $-8°C$ with the simultaneous presence of drops $>24\ \mu m$ diameter being required. Unfortunately, the concentration of drops $>24\ \mu m$ could not be determined accurately in the Yellowknife clouds. However, if an ice multiplication mechanism was operative in Yellowknife cumuli, it was apparently not present in clouds that existed at temperatures of $-8°C$ or warmer since none of these clouds contained any ice. This may imply that these clouds needed to reach colder temperatures before ice multiplication could be triggered. It is also possible that the ice multiplication mechanism, as postulated by Mossop (1976), was not operative in the continental cumuli studied.

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A comparison of model calculations of ice crystal growth with observations following silver iodide seeding

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A Comparison of Model Calculations of Ice Crystal Growth with Observations Following Silver Iodide Seeding

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ABSTRACT *Past theoretical investigations have reported that observed peaks in the diffusional growth of ice crystals in the vicinity of −5 and −15°C could be qualitatively modelled assuming certain specific crystal properties. This study re-examines the ice crystal diffusional growth model using more recently available observations of pertinent crystal parameters. The results, indicative of the growth of average crystals, imply a much weaker dependence of the diffusional mass growth rate on temperature in the range of −5 to −15°C. Extension of the model to include growth by accretion, also suggests that the mass of heavily rimed crystals is not very sensitive to the original crystal habit. The results of the calculations are compared with observed crystal sizes in cumulus clouds following seeding on three different days. The observations indicate that small crystals were continuously being produced as long as 15 min after seeding. In two cases, crystals much larger than those predicted by the model for any reasonable set of parameters suggest that crystal aggregation may have been occurring at a significant rate.*

RÉSUMÉ *Des recherches théoriques antérieures ont montré que les maximums observés lors de la croissance des cristaux par diffusion au voisinage de −5 et −15°C pourraient être qualitativement représentés par un modèle considérant certaines propriétés spécifiques aux cristaux. Cette étude reconsidère le modèle de croissance des cristaux par diffusion en utilisant des observations plus récentes des paramètres appropriés de ces cristaux. Les résultats, représentatifs de la croissance des cristaux moyens, impliquent une dépendence plus faible du taux de croissance de la masse par diffusion dans le domaine de −5 a −15°C. Une extension du modèle incluant la croissance par accrétion, suggère également que la masse des cristaux fortement givrés n'est pas très sensible aux propriétés initiales de ces cristaux. Les résultats de*

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ces calculs sont comparés avec les dimensions observées pour des cristaux se développant a l'intérieur de cumulus après ensemencement, et ce pour trois journées différentes. Les observations indiquent que de petits cristaux étaient produits continuellement sur des périodes s'étendant jusqu'à 15 minutes après l'ensemencement. Dans deux cas, des cristaux beaucoup plus grands que ceux prévus par le modèle pour tout ensemble raisonnable de paramètres, suggère que l'agrégation des cristaux aurait pu se produire à un taux substantiel.

1 Introduction

In order to develop and test a cloud seeding technique to suppress forest fires, the Atmospheric Environment Service, the Canadian Forestry Service, and the National Aeronautical Establishment have been cooperating in performing silver iodide cloud seeding experiments. These experiments monitored the changes in the microphysical properties of cumulus clouds following seeding. The first trials were begun in the summer of 1975 in the area of Yellowknife, N.W.T., and were resumed in June 1976.

Three aircraft were employed in the seeding programme: a T-33 jet to measure turbulence and to seed the cloud with end-burning silver iodide flares mounted in racks beneath the wings, a DHC-6 Twin Otter to perform cloud microphysical measurements, and a Beechcraft 18 to monitor precipitation at cloud base. A detailed description of the Twin Otter cloud physics instrumentation, the seeding technique, and results of preliminary tests are given by Isaac et al. (1977). Of special relevance to the work reported here are 2 Particle Measuring Systems (PMS) probes: a 1D-C probe counting particles in 15 intervals, 20-μm wide, up to a maximum size of approximately 300 μm, and a 1D-P probe counting particles in 15 intervals, 300-μm wide, up to approximately 4500 μm. In addition, a Mee Industries ice particle counter and a continuous film formvar replicator installed on the Twin Otter were used to determine particle phase.

A typical seeding experiment involved first selecting a relatively isolated cumulus cloud that had a depth of greater than 1 km, appeared to be growing, and had a cloud-top temperature between −5 and −20°C. Next the microphysical properties of the selected cloud were measured from the Twin Otter by flying 2 or 3 pre-seeding passes at an altitude 300 m below cloud top or at the −10°C level, whichever was lower. Provided the measurements indicated that the cloud did not have a high concentration ($> 10\,\ell^{-1}$) of large particles (> 100 μm), and the cloud base aircraft did not encounter precipitation, the cloud was seeded by burning AgI flares onboard the T-33 at the altitude where the previous measurements had been made. Following seeding, the T-33 left the cloud and was flown at cloud top for as long as possible, while the Twin Otter re-entered making successive cloud penetrations at the seeding level allowing microphysical measurements to be continued.

In some of the clouds, high concentrations of ice particles were observed consistently on successive passes through the cloud after seeding. The measurements clearly show that the AgI seeding material initiated the growth of the ice particles. The information supplied by the PMS probes in these cases has provided a detailed description of ice crystal growth in cloud following seeding, and some of these results are presented here.

To aid in the analysis of the results an ice crystal growth model has been developed. Previous models of diffusional growth (Jayaweera, 1971; Koenig, 1971; Houghton, 1972; Pruppacher and Klett, 1978) differ by between 1 and 2 orders of magnitude in the mass of the crystals predicted after 1000 s of growth at temperatures between −5 and −10°C. Such discrepancies may be especially significant in situations where riming is important, since the onset of riming depends on crystal size. The availability of more recent information on ventilation coefficients compiled by Hall and Pruppacher (1976), on dimensional relationships compiled by Davis (1974), and on crystal fall velocities by Davis (1974) and Heymsfield (1972), warrants a re-examination of the ice crystal growth problem. Satisfactory direct verification of the present and previous growth models is not possible because of the scarcity of observations on the growth of freely falling crystals. Instead, the validity of the model must be based on the validity of the diffusional growth equations and on the assumed properties of the crystals such as density, axial ratio, ventilation factor, etc. Laboratory measurements (Ryan et al., 1976; Fukuta, 1969) are of little help in this regard because of the importance of kinetic effects during the short growth times available in diffusion chambers.

Strong peaks in the growth rates of ice crystals at −5 and −15°C have been observed in the laboratory measurements mentioned above. Jayaweera and Koenig have shown that the peaks at these temperatures can be produced qualitatively in calculations if certain crystal properties are assumed. Such peaks might have a significant influence upon the outcome of seeding experiments, so that a secondary purpose of the present model is to determine whether the more recent observations still support that kind of a temperature dependence of the growth rate.

The following section contains a description of the diffusional growth model. The results of the model are compared in Section 3 with the results of Jayaweera and of Koenig in terms of mass after 1000 s as a function of temperature, and explanations for the differences between the three sets of results are given. Furthermore, in order to estimate the importance that accretion might be expected to have, the model is extended in a highly simplified manner to consider simultaneous growth by diffusion and accretion.

In Section 4, the results of seeding experiments are described in terms of the observed crystal growth following seeding. The observed ice crystal sizes are compared with model predicted sizes. Hoffer and Warburton (1970) and Davis and Auer (1974) attempted to verify the accuracy of diffusional ice crystal growth equations by comparing crystals observed after seeding with theoretically produced crystals. This paper does not use the field measurements for model verification. However, the model is useful for interpreting the measurements and for determining the importance of various cloud parameters and processes.

2 Ice crystal growth model

The ice crystal growth model describes the growth of a single crystal by diffusion and accretion. Diffusional growth is calculated from the solution of the diffusional growth equations as first applied to ice crystal growth by Houghton (1950), and extended by Koenig (1971) and Jayaweera (1971) to include the effects of ventilation. The equations of diffusional growth used in this study are the following

$$\frac{dm}{dt} = 4\pi CD(\rho_\infty - \rho_c(T_c))f_m$$

$$\frac{dq}{dt} = 4\pi CK(T_c - T_\infty)f_q$$

where f_m and f_q are the ventilation coefficients for mass and heat diffusion, respectively, and the other symbols have their usual meanings. This model incorporates ventilation coefficients suggested by Hall and Pruppacher (1976), who assembled the most recent information on the ventilation of spheres and oblate spheroids by Beard and Pruppacher (1971), Pitter et al. (1974) and Masliyah and Epstein (1971). Ventilation of dendritic crystals is modelled in a manner suggested by Houghton (1972) which is designed to be consistent with the observations of Thorpe and Mason (1966).

Since crystal habit has been shown to be a function of temperature and supersaturation, the following crystal shapes from the Magono and Lee (1966) classification have been chosen for study: Nla, Cle, Clg, Pla, Plc and Ple. Information on the length-width and diameter-thickness relationships of columns and plates, respectively, have been taken from the observations of Auer and Veal (1970), and the compilation by Davis (1974) of observations by Auer and Veal (1970), Kajikawa (1972) and Ono (1970). Fall velocities of the unrimed crystals have also been taken from the experimental values compiled by Davis and the theoretical values determined by Heymsfield (1972). Crystal capacitances are approximated for columnar crystals by analytical expressions for prolate spheroids and for plate crystals by experimental values suggested by McDonald (1963). Crystal densities have been extracted from various sources. Solid columns (Cle) and solid plates (Pla, Clg) have been assigned densities of $0.9\,g\,cm^{-3}$. Following arguments of Davis (1974), Plc crystals have been assigned a density of $0.7\,g\,cm^{-3}$. Needles (Nla) are assumed to have the densities observed by Ono (1970), which are a function of crystal length; dendrites (Ple) are given densities suggested by Heymsfield (1972), which vary with crystal diameter. With the above parameters defined, the heat- and mass-transfer equations are solved simultaneously, and the growth of the crystal is calculated by numerical integration.

The model of accretional growth is similar to those used in previous studies. The crystal is assumed to add accreted mass in such a way as to only increase the length of its minor axis, at a rate proportional to the product of its cross-sectional area normal to flow and its fall velocity. The following simplified equation is used to calculate the accreted mass during each step of the time integration

$$\Delta M_a = AU\Delta t \sum_{i=1}^{n} E_i Q_i$$

where M_a is the accreted mass, U is the particle fall velocity (droplet fall velocity assumed negligible), Δt is the time step in integration, E_i is the collection efficiency of ice particle with droplets of size category i, and Q_i is the liquid water content of droplet spectrum size category i. A crystal grows by diffusion alone until it is large enough to capture droplets. Collision efficiencies of unrimed columns and idealized thin plates have been calculated by Schlamp et al. (1975) and Pitter and Pruppacher (1974). These efficiencies agree well with the observations of Ono (1969), who deduced riming thresholds of roughly 50 μm for the diameter of columns and 300 μm for the diameter of plates. Since efficiencies for rimed crystals are not known, the theoretical efficiencies are used only to derive the minimum crystal size before riming commences; thereafter riming continues with a constant value of collection efficiency. As this minimum crystal size is a function of cloud droplet size, an appropriate cloud droplet spectrum is divided into a small number of size intervals, each with its own cut-off size for the onset of riming. The constant value of collection efficiency is absorbed into an average collection efficiency – liquid water content product, $\overline{EQ}$. There is experimental evidence that the value of E may be much lower than unity. Pflaum and Pruppacher (1976) have determined in wind-tunnel studies that the average collection efficiencies of graupel particles, growing by accretion from frozen drops of initial diameter 500 μm for a 3-min growth period, were between 0.25 and 0.35. Therefore an $\overline{EQ}$ value of 1.0 g m^{-3} may correspond to a liquid water content several times greater than 1.0 g m^{-3}, if the values of Pflaum and Pruppacher are applied. The rime is added uniformly to the sides of column crystals and the faces of plate crystals at a density of 0.5 g cm^{-3} for crystals with diameters less than 1 mm, reducing to 0.25 g cm^{-3} at 2-mm and 0.15 g cm^{-3} at 3-mm diameter. These values are based on the measurements of graupel density by Zikmunda and Vali (1972). When the crystal minor axis is as large as the major axis, the particle continues to grow as a spherical graupel particle. Fall velocities of graupel particles are also taken from Zikmunda and Vali (1972); fall velocities of rimed crystals are found by interpolating between the velocities of graupel and unrimed crystals. The effect of the latent heat of fusion from frozen accreted droplets is incorporated into the heat balance using a method suggested by Young (1974); thus the diffusional growth rate may be affected by an accretional heating term. A more complete discussion of the equations and the parameters used in the model is given by Strapp (1977).

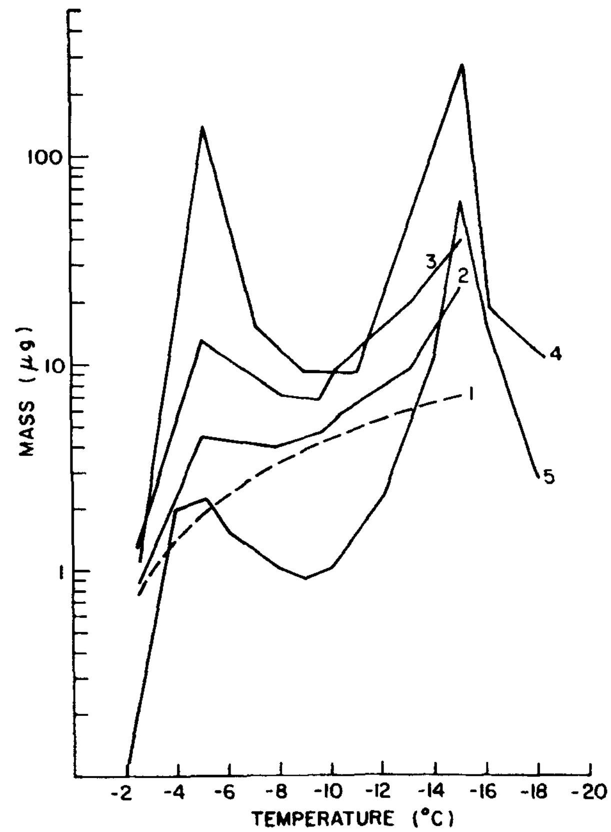

Fig. 1 Mass of an ice crystal growing by diffusion at water saturation at 600 mb, for 1000 s. Curve 1 is for ice spheres with ventilation coefficients from Hall and Pruppacher. Curve 2 shows the results of the present model, the points at temperatures of −2.5, −5, −8, −9.5, −10, −13 and −15°C correspond to Pla, Nla, Cle, Clg, Pla, Plc, and Ple crystals, respectively. Curve 3 is the same as curve 2 but with ventilation coefficients from Jayaweera. Curve 4 is from Jayaweera and curve 5 from Koenig after 900 s.

3 Results of calculations

To compare the temperature dependence of the diffusional growth rate to that in previous calculations, the crystal habit corresponding to a particular temperature has been taken from Magono and Lee (1966). In Fig. 1, the masses of crystals growing by diffusion at water saturation for 1000 s are plotted, along with the corresponding results of Jayaweera (1971) and Koenig (1971). The present results (curve 2) are, over most of the temperature range considered, intermediate between those of Jayaweera (curve 4) and Koenig (curve 5). The difference between the present results and those of Koenig is partially due to the different expressions used here to relate crystal axis ratio and density to habit and size, and partially due to Koenig's reduction of the crystal growth rate by a factor 2 to account for kinetic effects (Fukuta, 1969). More recent calculations by Fukuta and Walter (1970) suggest that Koenig's correction is much too strong. The results of Jayaweera, however, are based on crystal shapes that are similar to those adopted in this study at the same temperature.

The most significant results of this model are the much weaker peaks in the diffusional growth at −5 and −15°C than those from Jayaweera's or Koenig's calculations. The disagreement with Koenig's results can be attributed mainly to the difference in crystal densities and axial ratios, as well as the overcorrection for kinetic effects. The difference from Jayaweera's calculations is attributed to two factors. Firstly, Jayaweera based the axial ratios of needle crystals on the observations of Ono (1970), who reported that, on the average, needle crystals tended to cease growth along the minor axis when a diameter of 40 μm was reached. Furthermore, the dendrites associated with the peak at −15°C were based on the observations of Nakaya and Terada (1935), which implied that dendritic crystals ceased growing along their minor axis once they reached a thickness of 11 μm. Stopping the growth of one axis allows the crystal shape to become highly eccentric, and the growth rates to accelerate rapidly. Jayaweera acknowledged this as a strong factor influencing the growth peak.

The axial ratios of needle crystals and dendrites employed in this study are extracted from observations of Auer and Veal (1970), which cover a wider range of crystal sizes, and do not display a cessation in the growth of the minor axis in either crystal type. This observation is supported for needle crystals by the measurements of Iwai (1973) and Hobbs et al. (1974). In both of these sets of measurements on needle dimensions, some needle crystals were found to exceed a 100 μm-diameter, and commonly exceeded 40 μm. There is some indication of a limiting average needle diameter of 70 μm in the measurements of Hobbs et al. However, this is significantly larger than the limiting value proposed by Ono. The dendrite observations of Auer and Veal (1970) and Kajikawa (1972) show that dendrite thickness continues to increase with increasing diameter; at a diameter of 3 mm, thicknesses of 60 μm were common, however, thicknesses as small as 11 μm were not reported. These differences in crystal axial ratios are very significant in calculations of crystal growth, as may be seen by comparing curve 4 with curve 3 of Fig. 1 which employs Jayaweera's ventilation factors but has the revised crystal shapes.

A second difference between the calculations of this study and those of Jayaweera is introduced by the use of a more recently derived expression for ventilation. Jayaweera's formulation for ventilation allows more eccentric crystals (e.g. needles) to benefit more from ventilation than low axial ratio particles (e.g. spheres). Recent careful numerical and experimental determinations of the ventilation of oblate spheroids and spheres (Pitter et al. 1974; Masliyah and Epstein, 1971; Beard and Pruppacher, 1971) suggest that for low Reynolds Numbers the opposite is probably true.

The calculations of this study, based on the recent observations of average crystal shapes and recent formulations of ventilation, result in greatly suppressed peaks at −5 and −15°C. Curve 1 in Fig. 1 represents the growth of ice

TABLE 1. Ratios of masses of column and plate crystals growing by simultaneous diffusion and accretion at −10°C, 600 mb, to the masses of these crystals growing by diffusion alone after 1000 s

$\overline{EQ}$ ($g\,m^{-3}$)	Mass Ratio Column	Mass Ratio Plate
0.5	8	6
1.0	37	20
2.0	950	300
3.0	16000	4000

spheres of density $0.9\,g\,cm^{-3}$, using ventilation coefficients determined by Beard and Pruppacher (1971). The variation in mass with temperature in this case reflects only the difference between the saturation vapour pressures over ice and water, since there is no variability in particle shape or density. In the region from −8 to −9.5°C the growth of the stubbier crystals is only slightly favoured over ice spheres. In temperature regions of lower crystal density and higher crystal axial ratio (−5 and −15°C), more significant growth advantages over ice spheres are found.

Calculations were also performed for simultaneous accretional and diffusional growth in order to give an indication of the sensitivity of the total ice crystal growth rate in cloud to crystal habit. Because of different fall velocities, cross-sectional areas, and the sizes required for the onset of accretion, it was speculated that significant differences in the abilities of different crystal geometries to accumulate mass in cloud could exist. Since there was a lack of complete information on the parameters affecting accretional growth for each of the crystal types studied for diffusional growth, calculations incorporating accretion were only carried out for thin plates (Pla) and solid columns (Cle) with dimensions given by Auer and Veal (1970). Information from both observations and calculations on the sizes required for the onset of accretion is available for both crystal geometries. For comparison Table 1 contains ratios of the mass attained by columns and plates at −10°C for various liquid water concentrations for unit collection efficiency (or equivalently, average values of the collection efficiency – liquid water content product, $\overline{EQ}$) to the mass attained by crystals by diffusional growth alone for a time period of 1000 s. This reveals the extent to which accretion can determine mass accumulation, and implies that the diffusional growth advantages may be of little consequence to the growth of ice crystals in cloud. Fig. 2 displays results of calculations of simultaneous diffusional and accretional growth of columns and plates at −10°C for a range of average collection efficiency – liquid water content products. Although under these conditions columns begin to accrete mass earlier (e.g. about 3 min after nucleation as opposed to about 7 min for plates), the advantage is offset by a much faster initial accretion rate by plates.

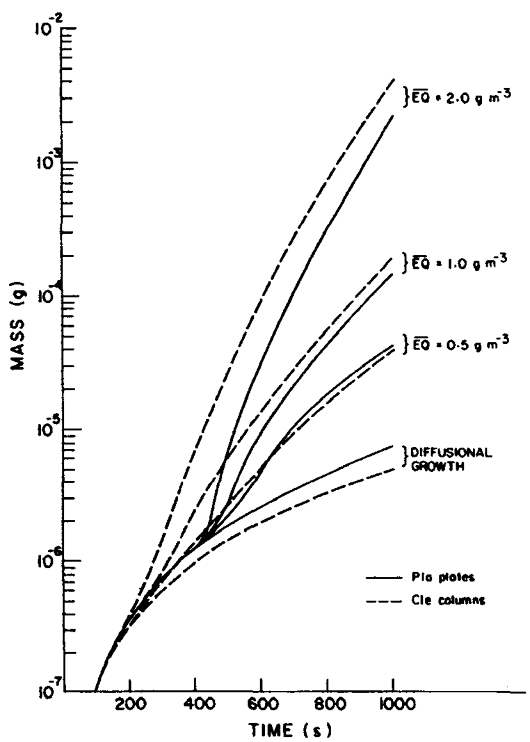

Fig. 2 Masses of plate and column crystals growing at −10°C, 600 mb, by diffusion and accretion for various average collision efficiency – liquid water content products.

Evidently no large differences in the abilities of these crystals to accumulate mass by diffusion and accretion are revealed. Although it cannot be concluded with certainty that ice crystal growth in mixed-phase cloud is insensitive to original crystal habit, the calculations of the growth of these two geometrically very different crystals do not provide any indication that strong sensitivities exist.

4 Observations of ice crystal growth in seeded clouds

During the 1976 field experiments in Yellowknife, three clouds were seeded in which high ice crystal concentrations and rapid particle growth were observed after seeding. Plotted aircraft flight paths and visual contact between the seeding aircraft (T-33) and the observation aircraft (Twin Otter) ensured that for each case only the seeded cloud was examined. For the three cases, ice nucleus measurements using millipore filters indicated that the plume of AgI was penetrated by the Twin Otter after seeding. For the one case analysed, atomic absorption spectrometer measurements showed that filters exposed after seeding had high Ag concentrations on them. Scanning electron microscope analysis for another case indicated that replicator impressions of ice crystals (11 of 20 analysed) observed after seeding contained Ag (Shewchuk, 1978). The large particle concentrations observed after seeding were anomalously high, being $> 100\,\ell^{-1}$ for particles $> 70\,\mu$m. For comparison, measure-

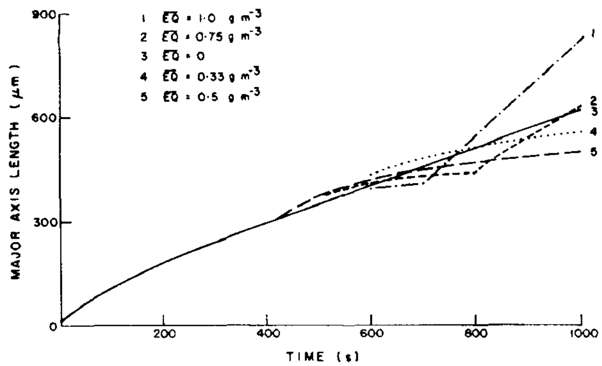

Fig. 3 Diameter of Pla crystals growing by diffusion and accretion at −10°C, 600 mb, for different values of the product $\overline{EQ}$.

ments from 101 cloud penetrations at temperature levels between −1 and −11°C in 47 different cumulus clouds that were not seeded in 1976, or were examined prior to seeding, showed 50 and 90 percentile average penetration concentrations of 0.9 and 12 ℓ^{-1}, respectively, for particles >70 μm (Isaac et al., 1978). In each of the three seeded cases examined below, the concentration of particles >70 μm increased by a factor greater than 100 over a 2- to 3-min period. No comparable change was ever observed in unseeded clouds. In conclusion, all available evidence for the three cases reported below indicates that high concentrations of ice crystals were generated by AgI seeding.

In most of the cumulus clouds investigated, including the three cases studied here, the average liquid water contents measured by the Johnson-Williams liquid water content measuring system was below 1.0 g m^{-3}. Furthermore, almost all crystals observed were plate type crystals. In Fig. 3 the growth of the major axis of Pla plates at −10°C is plotted as a function of time for various values of $\overline{EQ}$ less than 1.0 g m^{-3}. The maximum dimensions of the crystals are found to change by less than 300 μm within the 1000-s time period. This is due to the fact that the accreted mass is added to the minor axis until the graupel stage is reached. A small reduction in plate diameter with light accretion is also evident from Fig. 3 (curves 4 and 5). As the plate rimes on the basal plane, its surface area increases, and the diffusional mass is spread over this larger area. In light riming conditions, this results in a slower growth rate for the major axis even though the diffusional mass growth rate increases. Whether this is an accurate description of what actually happens is uncertain. Nevertheless, provided accretion is limited to the crystal faces presenting the greatest cross-sectional area to the direction of motion until the major and minor crystal dimensions are approximately the same, for times up to about 1000 s, accretion can only account for about a 300-μm increase in particle size.

The PMS probes measure the approximate projection of the crystal major axis on the detector, and the resolution of the 1D-P probe is only 300 μm. Consequently, with this size resolution, comparisons of model calculations of plate growth with observed crystal spectra are somewhat insensitive to accretional growth effects within time intervals of the order of 15 min after seeding at the moderate accretion rates described in Fig. 3. The 1D-C probe, which measures particle major dimensions in a size range (approximately 20–300 μm) at which accretion is not yet started in plates, and is only just starting in columns, is therefore also insensitive to accretional effects. Therefore calculations of a plate major dimension growing by diffusion alone are used in the comparisons, and these calculations of major dimension differ insignificantly from calculations of riming crystals at moderate accretion rates and time intervals of less than about 15 min.

On 16 July a cumulus cloud was seeded with approximately 250 g of AgI. Figure 4 summarizes the sizes and average concentrations of particles detected before and after seeding by the 1D-C and the 1D-P probes. Each vertical bar represents a pass through the cloud by the instrumented Twin Otter, its width being the approximate time in cloud. The vertical axis designates particle size, and average particle concentrations over the cloud width are indicated by the hatching.

General information on the aircraft flight pattern and the cloud properties is given in Table 2. Before seeding, the cloud was growing and had a vertical depth of about 2.5 km, with a measured base at 2250 m (MSL). After the second Twin Otter pass, the cloud was seeded on a penetration by the T-33 at a temperature of about −10°C. This was followed by 6 Twin Otter passes at or near the seeding level. The cloud liquid water content had its highest value of 0.7 g m^{-3} on the pass prior to seeding, and decreased in time after seeding to 0.3 g m^{-3} on the last pass at the seeding level.

The first two passes indicated in Fig. 4 and Table 2 are pre-seeding passes. Unfortunately the cloud had 2 turrets, the first of which was flown through on the pre-seeding passes, and the second of which was seeded and flown through on the following passes. The properties of the two turrets before seeding are assumed to be similar. On the first 2 pre-seeding passes no particles were detected by the 1D-C probe. For the first pass after seeding the concentrations and sizes of particles are similar to the first two passes before seeding. To account for the absence of particles on the first pass after seeding, it is hypothesized that the aircraft missed the AgI plume and thus no apparent seeding effect was observed at this time. On the second pass after seeding, a burst of particles was detected by both the 1D-C and the 1D-P probes, with total average concentrations of particles >70 μm of 190 ℓ^{-1}. Only data for crystals larger than 70 μm are indicated because of instrumental counting problems in the first 3 channels of the 1D-C probe. The subsequent passes exhibit similar high total concentrations of particles (Table 2). It is also apparent from Fig. 4 that particles are growing in time. For example, about 5 min after seeding, particles >450 μm are present in concentrations of 0.1 ℓ^{-1}, which is the same concentration for particles >1950 μm observed 12 min after seeding. Although the particles are seemingly growing, it can also be seen that small particles are continually present in each pass after seeding with the highest concentration of particles at the smallest sizes.

Replicator impressions of particles in the cloud reveal very high concentrations of hexagonal plate crystals. On the second pass after seeding, high concentrations of Pla plates are observed at sizes in agreement with the probe data. There is also evidence of unbroken Plc crystals at sizes up to about 250 μm on the replicator film, and probably larger ones which have shattered. The larger particles on this pass seem to be the more complex branched-plate crystals. These data verify that the particles detected in high concentrations by the 1D-C and 1D-P probes are indeed ice. This is further substantiated by the concomitant large increases in concentration detected by the ice particle counter (Table 2).

The temperature (−10°C) at which these Pla crystals were observed is somewhat warmer than the temperature of approximately −12°C suggested by Magono and Lee (1966) for thin plate growth at water saturation. More complex structures (i.e. Plc) observed at the same level indicate that the crystals may have initially grown at colder temperatures.

Figure 4 includes the results of calculations of the diameters of thin plates as a function of time. Referring to the 1D-C data, it can be seen that very high concentrations of particles smaller than this are present on each pass after seeding. On the second pass after seeding, 94% of the particles >70 μm have sizes smaller than those predicted for thin plates growing from the seeding time. On the last pass 98% of the particles >70 μm are smaller than the thin plate prediction based on the seeding time. The persistence of such small crystals so long after seeding suggests that crystals are continuing to be produced either as a result of delayed nucleation by silver iodide, or by an ice crystal multiplication mechanism. Order of magnitude estimates, as well as measurements showing that the liquid water concentration remained constant for the first several minutes, allows one to discount the possibility of vapour depletion retarding the growth of some ice crystals. Figure 4 also includes model calculations of the Plc and Ple diameters based on crystal nucleation at the seeding time and growth at water saturation for the temperatures indicated. Evidently the majority of the particles are also smaller than these model calculations, consistent with the continuous production of particles in time after seeding.

Considerable concentrations of ice particles much larger than the model calculations are not expected if growth is by diffusion and accretion alone. However, particles with sizes several times those predicted by the model are detected in concentrations significantly higher than those detected before seeding. For example, second-by-second data at 12 min after seeding showed particles >3000 μm in concentrations up to $0.2\,\ell^{-1}$ in parts of the cloud; model calculations predict Pla and Plc diameters of roughly 600 and 800 μm, respectively, at this time. Many conditions could enhance the growth of some crystals in the population, resulting in larger crystals than predicted from

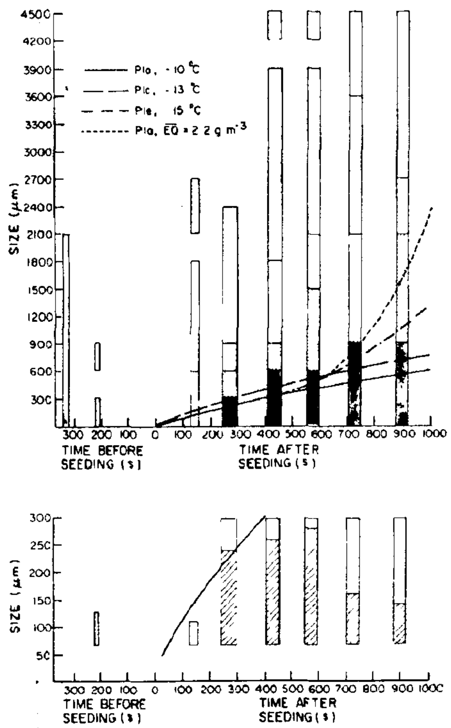

Fig. 4 Particle sizes and concentrations before and after seeding on 16 July 1976.

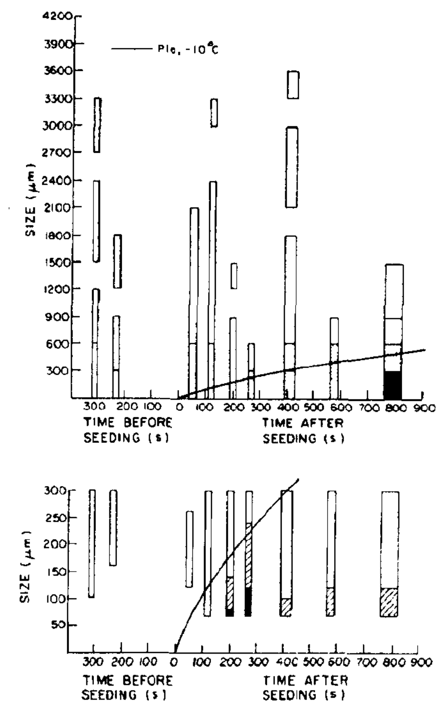

Fig. 5 The same as Fig. 4 except for the observations of 11 July 1976.

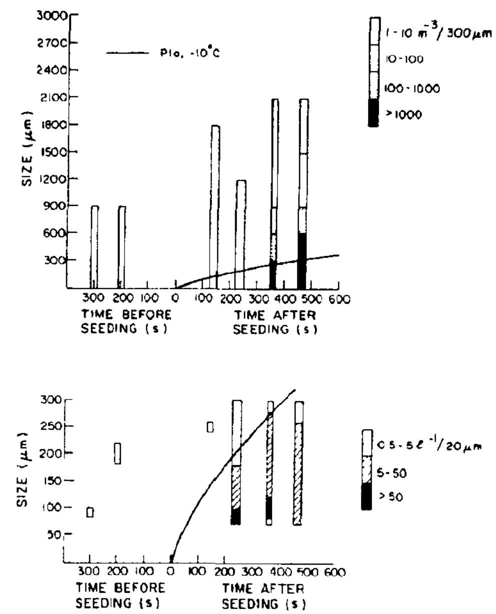

Fig. 6 The same as Fig. 4 except for the observations of 15 July 1976.

The lower diagrams give concentrations for the 1D-C probe per 1000 cm³ per 20 µm averaged over the length of the pass in cloud. Concentrations of particles smaller than 70 µm are not shown because of instrumental problems. The upper diagrams show similarly averaged concentrations for the 1D-P probe per m³ per 300-µm size interval. The lines show the results of model calculations. The concentrations are slightly different than those presented by Isaac et al. (1978) because the correction recommended by Curry and Schemenauer (1979) for the first channel of the PMS 1D-P probe has not been made.

TABLE 2. Summary of data describing the seeded cumulus of 16 July, 1976. The cloud was seeded at 2213:35. Cloud base was measured before seeding as 2250 m (MSL), 2°C.

Penetration Entry Time	Temp. (°C)	Heading (°T)	Alt. (m)	Cloud Top (m)	Width (m)	Liquid Water (g m^{-3})	IPC* Conc. (ℓ^{-1})	PMS** Conc. > 70μm (ℓ^{-1})
2207:57	−9.6	352	4280	4820	1500	0.6	0	0.3
2209:53	−9.2	262	4280	4880	760	0.7	0	3.9
2215:43	−9.2	082	4290	4820	2200	0.6	0	1.6
2217:35	−9.8	177	4290	4880	4400	0.4	0.1	185.0
2220:25	−9.7	272	4300	5270	3550	0.6	2.5	113.3
2222:43	−9.5	357	4280	5300	3630	0.4	9.9	152.0
2225:03	−9.7	092	4310	5240	4590	0.6	25.0	73.9
2228:12	−9.9	177	4280	5210	3170	0.3	27.2	109.5

*The Mee Industries Ice Particle Counter (IPC) only detects a fraction of the crystals (Schemenauer and Curry, 1979). Most, if not all, of the large particles observed after seeding were ice particles.

**These concentrations are measured with the PMS 1D-C and 1D-P probes.

TABLE 3. Summary of the data describing the seeded cumulus of 11 July, 1976. The cloud was seeded at 2157:50. Cloud base was measured at 2221 GMT as 2000 m (MSL), 7°C.

Penetration Entry Time	Temp. (°C)	Heading (°T)	Alt. (m)	Cloud Top (m)	Width (m)	Liquid Water (g m^{-3})	IPC Conc. (ℓ^{-1})	PMS conc. > 70 μm (ℓ^{-1})
2152:44	−6.9	392	3990	—	1180	0.8	0.0	2.9
2154:00	−6.9	122	3990	—	1410	0.5	0.0	1.3
2158:40	−4.6	275	3890	—	1550	0.5	0.0	0.7
2159:49	−6.5	163	4020	4570	1450	1.2	0.0	4.9
2201:14	−6.7	302	3980	4720	1390	0.8	0.0	91.5
2202:20	−6.9	162	3970	—	1720	0.6	0.0	326.8
2204:34	−7.0	302	3980	4880	2960	1.4	0.0	27.8
2207:25	−6.5	332	3980	—	1570	0.6	0.8	55.0

TABLE 4. Summary of the data describing the seeded cumulus of 15 July, 1976. The cloud was seeded at 0013:10. Cloud base was measured at 0041 as 2440 m (MSL), 1°C.

Penetration Entry Time	Temp. (°C)	Heading (°T)	Alt. (m)	Cloud Top (m)	Width (m)	Liquid Water (g m^{-3})	IPC Conc. (ℓ^{-1})	PMS conc. > 70 μm (ℓ^{-1})
0008:14	−8.2	142	3960	—	1780	0.6	0.0	1.1
0009:53	−8.4	242	3960	4570	1240	0.6	0.0	0.2
0015:24	−8.6	052	3970	—	1630	0.6	0.0	0.1
0016:47	−8.9	322	3950	4420	2720	0.3	0.0	243.6
0018:57	−8.5	052	3950	4430	1760	0.1	0.4	326.4
0020:47	−8.3	147	3960	—	2450	0.4	4.7	153.5

calculations. These include crystal growth in areas of the cloud where the liquid water content was much higher than the average value, with colder temperatures, lower crystal densities, and higher crystal axial ratios.

Referral to second-by-second data reveals that certain areas in the cloud have a local liquid water content of up to 2.2 g m^{-3}. Assuming a unit collection efficiency for optimum growth, the resulting calculation of maximum dimension is not as large as the particles observed in this cloud (Fig. 4). On the fifth pass after seeding, when particles greater than 3 mm were observed in concentrations as high as $0.2\,\ell^{-1}$ in parts of the cloud, calculations based on 2.2 g m^{-3} of cloud liquid water produce graupel particles up to 0.9 mm at this time. Secondly, large particles are present even before accretion should be starting. On passes about 5 and 7 min after seeding, when Pla plate crystals nucleated at the seeding time should not yet be large enough to have commenced riming, particles several times larger than predicted are already present. Seven minutes after seeding, 1.8-mm particles in concentrations significantly higher than those detected before seeding are observed, whereas calculations predict Pla plate diameters of roughly 300 μm.

Diffusional growth can be enhanced by moving to colder temperatures, with a maximum growth rate in the vicinity of −15°C where the difference between the saturation vapour pressures over ice and water is a maximum. Calculations of the growth of Ple dendritic crystals, which are likely to be found at this temperature, and which are low in density, are displayed in Fig. 4. These calculations show that ordinary dendritic crystals do not grow fast enough to explain the very large particles observed after seeding.

The calculations of plate diameters depend strongly on the dimensional relationship determined from the observations of Auer and Veal (1970). The diameter-thickness relationships are representative of average crystal dimensions, but a considerable spread of axial ratios for a particular plate diameter was observed by Auer and Veal (1970). Crystals of the highest axial ratio are most favoured for growth along the major axis. Thus, calculations were performed to investigate the growth of thinner than average crystals. The diameter-thickness relationship of plates was chosen such that the thinnest crystals from the Auer and Veal data could be represented. Results of these calculations show that the maximum plate diameter is roughly twice that of the average plate crystal grown for the same time interval. Unless the crystal sample collected by Auer and Veal is not representative of the crystals in this cloud, natural variations in crystal thickness probably do not account for the large particles observed after seeding.

The question arises as to whether these large particles may be accounted for by the growth of particles present before seeding. For instance, from Fig. 4 it is seen that 5 min before seeding, particles were present with sizes as large as 2100 μm. While it is clear that such particles are large enough to explain the presence of particles larger than the model calculations, their low concentration (0.1–1 m^{-3}) cannot account for the much higher concentration of large particles after seeding.

Since ordinary diffusional and accretional growth approximations cannot explain the large particles observed in cloud following seeding, it may be possible that another growth mechanism such as aggregation may be operating. Hobbs et al. (1974) have compiled statistics on the probability of aggregates being present in clouds as a function of crystal concentration and cloud temperature. They suggest that the probabilities of finding aggregates in clouds of total ice particle concentrations of 100 and 1000 ℓ^{-1} at $-10°C$ are roughly 35% and 50%, respectively. In this seeded cloud 3 to 5 min after seeding, concentrations of ice particles >70 μm exceeded 100 ℓ^{-1} on the average and 500 ℓ^{-1} locally. Magono and Tazawa (1972) have reported on an experiment in which a natural fog (-13 to $-16°C$) was seeded with AgI, resulting in high concentrations of ice crystals. Some of their observations showed aggregates composed of small numbers of hexagonal plates similar to the plates observed in this cloud. Therefore, on the basis of the observations of Hobbs et al. and Magono and Tazawa, crystal aggregation may have occurred in this cloud, and may thus explain the appearance of large particles difficult to account for by calculations based on diffusional and accretional growth alone. Unfortunately, the presence of such aggregates could not be verified from the replicator film, since the absence of a decelerator tube caused particles larger than about 300 μm to shatter.

Figures 5 and 6 and Tables 3 and 4 summarize the particle size distribution, the cloud properties, and the aircraft flight information for two further clouds seeded on 11 and 15 July near Yellowknife with approximately 80 and 260 g of AgI, respectively. The particles detected in cloud after seeding on 11 July were identified from replicator impressions as Pla, Plc, and Clf crystals, with Pla in highest abundance. Replicator data were not available for the cloud seeded on 15 July, but increases in the ice particle counter readings imply that the particles were ice. Since the predominant crystal habit observed in the other seeded clouds was Pla, and since the seeding level and the after-seeding penetrations were at a temperature consistent with the growth of Pla crystals, calculations have been presented for Pla crystal growth.

In the case of the 11 July data, the growth of the leading edge of the particle spectrum agrees very well with the calculations of Pla growth. Furthermore, as in the cloud of 16 July, small ice crystals are continuously present after seeding in high concentrations.

The 15 July data exhibit similar characteristics. Again high concentrations of small particles persist through each pass. Even though the growth curve of the Pla is at a size larger than a great majority of the particle population, significant concentrations of particles exist with sizes several times those predicted by calculation.

5 Summary and conclusions

An ice crystal growth model similar to those of Koenig (1971) and Jayaweera (1971) was designed in order to investigate the variation of the diffusional growth of ice crystals with temperature. Koenig and Jayaweera revealed that under certain assumptions concerning crystal shape and density, growth peaks at −5 and −15°C, previously observed in laboratory experiments, could be qualitatively produced in calculations. Using recent observations of average crystal axial ratios, densities and more recent estimates of ventilation effects, this model yields estimates of the growth rates of crystals which are presumably more similar to those observed in nature than those proposed by Jayaweera and Koenig. The model produces crystal growth rates, as a function of temperature, intermediate to those of Koenig and Jayaweera over most of the temperature range from −5 to −15°C. The most significant difference in the results of the present model is the much weaker temperature dependence of the growth rate, and in particular the absence of a significant peak in the vicinity of −5°C. One implication of these results is that diffusional growth advantages do not justify seeding at −5°C rather than at a colder temperature in a cloud-seeding experiment. Allowing growth by accretion for two widely different shapes (plates and columns) resulted in similarly sized particles over a range of liquid water concentrations. So for accretional growth, there does not appear to be any advantage in selecting the seeding temperature in order to attempt to nucleate preferentially crystals of a particular habit. In view of the increasing nucleating efficiency of AgI with decreasing temperature, and the increase in the diffusional growth rate, at least down to temperatures of −15°C, it seems that the most suitable seeding temperature for the kinds of clouds considered here is at the coldest temperature possible.

Comparison of the model calculations with ice crystal growth following seeding reveal that high concentrations of crystals much smaller than those of model predictions persist through each pass after seeding, suggesting either a continuous nucleation of silver iodide after seeding, or a multiplication process. In two of the three cases studied, significant concentrations of particles were observed which were several times larger than can be accounted for by diffusional growth of the most favoured crystals, and larger than can be accounted for under the most favourable assumptions of accretional growth. A likely explanation is that crystal aggregation is an important growth mode. This possibility should be investigated experimentally and theoretically in future work.

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The Importance of Cloud Top Lifetime in the Description of Natural Cloud Characteristics

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ABSTRACT

The microphysical and dynamical characteristics of 156 natural summer cumulus clouds have been documented for three locations in North America: Yellowknife, Northwest Territories; Thunder Bay, Ontario; and Miles City, Montana. The measurements (469 aircraft penetrations) were made in six consecutive years from 1975 to 1980 using state-of-the-art cloud physics instrumentation. All measurements discussed were obtained near $-7°C$. Yellowknife clouds had low liquid water contents (0.3 g m^{-3}) and high large (>70 μm) particle concentrations (0.9 L^{-1}). Thunder Bay clouds had higher liquid water contents (1 g m^{-3}) and low large particle concentrations (0.04 L^{-1}). Miles City clouds, which were similar in dimensions to those near Yellowknife, had low liquid water contents (0.3 g m^{-3}) and low large particle concentrations (0.1 L^{-1}). Yellowknife and Thunder Bay clouds produced precipitation through the warm and cold rain processes but the observed Miles City clouds did not precipitate naturally. Measurements of cloud top lifetime appear to be useful in explaining the differences between locations. Cloud top lifetime is defined in this paper in terms of the persistence of cloud liquid water at the penetration altitude near $-7°C$. Lifetime was found to increase with cloud width in each location but did not appear closely related to initial LWC, cloud depth, cloud base temperature, inside–outside cloud temperature difference, environmental humidity, turbulent energy dissipation rate, energy flux, heat flux nor wind shear.

1. Introduction

It is perhaps obvious that in order for a cloud to rain it must exist long enough for a precipitation formation process to begin, evolve and continue to completion. However, except for the early work of Braham (1960), quantitative measurements of cloud lifetime have been absent in the literature. Braham (1960, 1981) and Warner (1977) have emphasized the importance of understanding the variation of cloud parameters with age of the cloud. It is in this context that a cloud lifetime derived from measured parameters provides a useful summation of the many processes operative in a convective cloud. This paper presents and examines data from six years of aircraft studies of natural clouds in three locations (Fig. 1) in central North America. The lifetimes of the supercooled portions of cumulus clouds in each year are calculated and intercompared. This combination of natural cloud measurements and calculated lifetimes is essential for the understanding of natural precipitation processes and for the assessment of the potential of cloud seeding for rainfall increases.

The important portion of a cumulus cloud, from the point of view of seeding with an ice nucleant to initiate the cold rain process, is that portion colder than $\approx -5°C$. The lifetime to be discussed here is therefore the extrapolated lifetime of the region near cloud top starting from the time of the first penetration, not the total cloud lifetime. In order to obtain cloud top lifetime information, the natural cloud dataset was examined and all clouds where two or more penetrations were made within ± 100 m of the same altitude were chosen. A rate of change of liquid water content (LWC) was then calculated by subtracting the average Johnson–Williams LWC in the first penetration from that in the last penetration and dividing by the time between the midpoints of the penetrations. The mean first pass LWC for the field season is then divided by the mean LWC change for the field season to obtain a cloud top lifetime (to 0.0 or 0.1 g m^{-3}) for each project period. The cloud top lifetime is therefore the time between the first aircraft measurements and the measured (or projected) disappearance of the cloud at the penetration level.

There is no claim made that this is the only definition possible of cloud top lifetime or that it is necessarily more "correct" than others that might be used. It is, however, readily derivable from aircraft measurements, involves few assumptions, produces values that conform to the subjective impressions of the aircrews and proves useful in understanding rain forming processes.

2. Natural cloud dataset

a. Discussion

Before presenting calculations of lifetimes, it is important to examine the overall nature of the clouds in

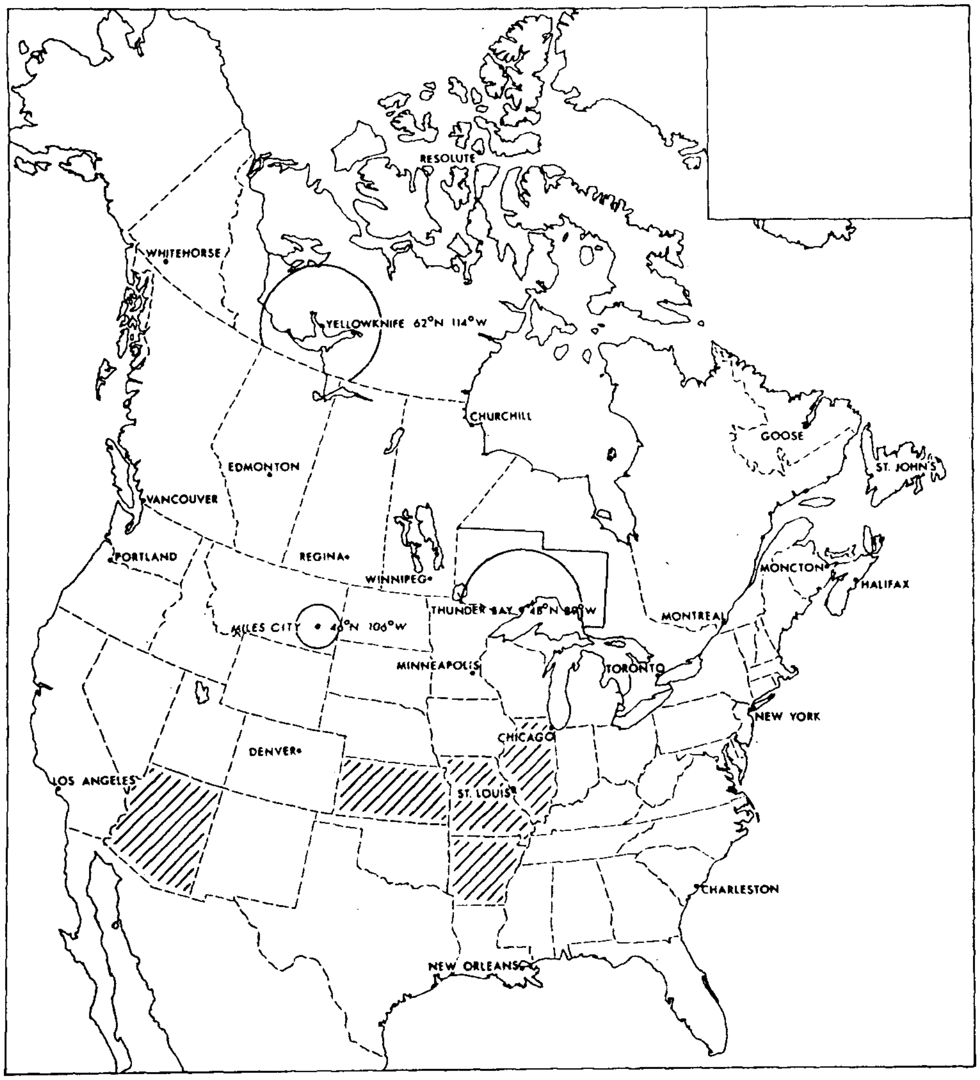

FIG. 1. Location of the 1975 and 1976 projects near Yellowknife, the 1977 and 1978 projects near Thunder Bay and the 1979 and 1980 projects near Miles City. The data of Braham (1960) were collected in the hatched areas.

the different locations. A discussion of the characteristics of clouds near Yellowknife (62°N, 114°W) in the Northwest Territories of Canada has been presented by Isaac and Schemenauer (1979a). Table 1 summarizes these measurements as well as those from Thunder Bay (48°N, 89°W), Ontario and Miles City (46°N, 106°W), Montana. Table 1 consists of median values of penetration-averaged cloud parameters based on 469 penetrations of 156 clouds over the six years. Approximately 50 of these penetrations were made before seeding in clouds that were eventually seeded with AgI. Isaac *et al.* (1982) show that this subset of the data has characteristics similar to those for natural clouds which were never seeded. All other penetrations reported on here were made in unseeded clouds.

Certain constraints were placed on the cumulus clouds that make up the datasets of natural clouds. A cloud had to have the following characteristics at the time of selection:

i) a depth greater than 1 km,
ii) a cloud top with a solid and growing appearance,
iii) a cloud top temperature between −5 and −20°C and
iv) isolation from neighboring clouds.

The penetration altitude was 300 m below cloud top or −10°C, whichever was lower. In order to confirm the absence of ice in clouds with tops warmer than −5°C, a few clouds with summit temperatures between −2 and −5°C were also examined. The study of a cloud was terminated when 1) the cloud top fell below the penetration altitude or the average LWC < 0.1 g m^{-3}, or 2) operational considerations dictated termi-

TABLE 1. Median values of penetration averaged cloud parameters for: Yellowknife, Northwest Territories, Canada; Thunder Bay, Ontario, Canada; and Miles City, Montana, U.S.A. *The turbulence data for 1975 to 1978 are from the T-33 and Twin Otter aircraft. All data in 1979 and 1980 were collected by the Twin Otter.

		Yellowknife		Thunder Bay		Miles City	
Parameter	Units	1975	1976	1977	1978	1979	1980
Number of clouds		11	47	25	41	15	17
Max cloud top height	m (MSL)	4000	4400	4900	5200	5500	5600
Min cloud top temperature	°C	−9	−9	−9	−9	−10	−13
Min cloud base height	m (MSL)	~1550	2300	1700	1800	3000	3200
Max cloud base temperature	°C	+6	+3	+11	+13	+4	+3
Number of Twin Otter penetrations		29	101	80	115	71	73
Penetration height	m (MSL)	3800	4200	4300	4600	5120	4790
Penetration temperature	°C	−7	−7	−7	−5	−7	−7
Penetration length	m	2000	1600	1650	1100	1750	1540
Liquid water content, J-W	g m^{-3}	0.4	0.3	0.7	1.1	0.6	0.2
Cloud droplet concentration, FSSP	cm^{-3}	—	>400	>400	>550	345	270
Droplet concentration 24–45 μm, FSSP	cm^{-3}	—	—	>26	>7	1	0.1
Particle concentration > 70 μm, PMS 1D	L^{-1}	0.8	0.9	0.04	0.05	0.17	0.10
Ice particle concentration	L^{-1}	—	0.0	0.0	0.0	0.0	0.0
Cloud top turbulence runs*		14	60	84	81	37	70
rms vertical velocity	m s^{-1}	1.6	1.6	1.4	1.7	1.6	1.3
Turbulent dissipation rate	cm^2 s^{-3}	110	160	180	360	170	100
Peak up gust	m s^{-1}	4.2	3.9	3.7	3.8	3.2	3.0
Peak down gust	m s^{-1}	−4.5	−4.1	−4.1	−4.6	−4.0	−3.4

nation, i.e., low aircraft fuel level or drifting of the cloud out of the area assigned by Air Traffic Control. Fig. 2 gives the frequency distribution of coldest cloud top and warmest cloud base temperatures for each of the three locations. Table 2 gives the mean and median cloud top and base temperatures by location. The average time (min) between penetrations for the six years beginning with 1975 was: 3.5, 3.0, 3.8, 2.2, 2.6 and 2.6. The mean yearly time was 3.0 ± 0.6 min. One of the main causes of the differences from year to year was the variation in cloud penetration length.

Details of the instrumentation used on the Twin Otter to acquire the data in Table 1 will not be given here. Isaac *et al.* (1982) provide a summary for the years 1975–78. In 1979 and 1980 the major changes were a redesign of the turbulence system, a new color digital weather radar and the addition of an on-board computing capability. The basic microphysical instrumentation package remained the same: 3 PMS 1D and 2 PMS 2D probes (4 flown at one time), a highly modified Mee Industries ice particle counter, a Mee 101 continuous formvar replicator and a Johnson–Williams Liquid Water Content meter.

The liquid water contents discussed below were measured with the Johnson–Williams Liquid Water Content (J–W LWC) meter. Potential sources of error and expected accuracy of this probe are discussed by Strapp and Schemenauer (1982). The J–W LWC systems used on the Twin Otter have been calibrated since 1979 in the high speed icing tunnel operated by the National Research Council of Canada in Ottawa. Prior to that, data quality was maintained through routine maintenance and repair and through regular comparisons with the PMS FSSP data. The estimated error in J–W LWC measurements is ±20% from 1975 to 1978 and ±10% in 1979 and 1980. Values below 0.2 g m^{-3} have an uncertainty of at least ±0.03 g m^{-3}. The errors in the LWC differences used to calculate the decay rates and lifetimes in this paper are probably less than those quoted above, since the procedure used serves to minimize systematic errors.

The cloud droplet concentrations obtained from the FSSP probe for 1975–78 contain dead-time errors for which a precise correction is not possible. The errors will make the concentrations too low by as much as a factor of 2. Even with such a large uncertainty, the numbers do have information value. Because of this problem, for 1975–78 a greater than sign has been used when reporting FSSP droplet concentration and LWC data in Tables 1 and 3.

Table 3 presents some additional statistics generated from the same data as Table 1. The median or 50 percentile of the pass averages for the first penetration in each cloud, as well as the 10, 50 and 90 percentile values for all penetration averages, and the 50 and 90 percentile values for penetration maxima are shown for some microphysical parameters. It is noteworthy that most medians of the first penetration values are the same or slightly higher than the median values for all penetrations. Since the first penetration of each cumulus was made when the cloud appeared vigorous and growing, this similarity of the two 50 percentile

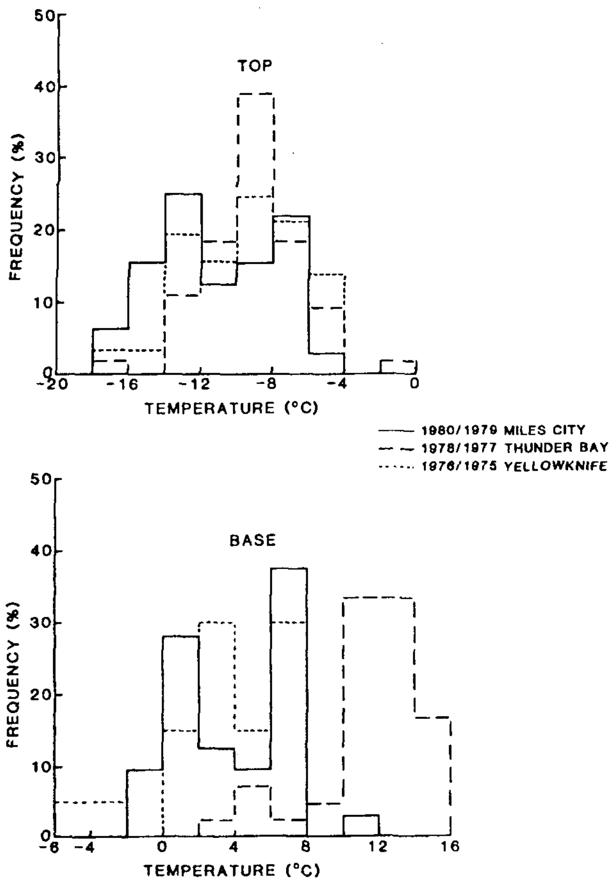

FIG. 2. Frequency distribution of cloud top and cloud base temperatures separated by location.

penetration average values of Table 3 implies that time variations were small over the period that the typical cloud was examined. This is not surprising since each cloud was penetrated an average of three times and penetrations were about 3 minutes apart. However, the median first penetration average LWC values are slightly higher than the median values for the averages of all penetrations and this suggests the typical cloud was dissipating after selection. The lack of difference in the 50 percentile average values (first pass versus all penetrations) for cloud particle concentrations (>24 μm) clearly indicates no strong trend toward generation of large water drops or ice crystals. Isaac *et al.* (1982) showed that large particle (>70 μm) concentration changes were negative as often as positive in the non-seeded Yellowknife and Thunder Bay clouds.

The 10 and 90 percentile penetration average values show the extremes of low and high concentrations of liquid water or cloud particles. The 90 percentile value for particle concentrations > 70 μm is also indicative of the potential for natural rain formation and may be a guide to the number of artificial ice crystals that must be formed if seeding concentrations are to greatly exceed background. It is clear from these numbers that the most promising 10% of Yellowknife clouds show a strong potential to form rain naturally, the most promising 10% of Thunder Bay clouds show less potential and Miles City cumulus are the least likely to produce precipitation.

It is important to give an idea of the magnitude of fluctuations during each penetration. One method would be to compare the penetration average values with the 1 or 0.5 s penetration maxima. This is done for Thunder Bay and Miles City data in Table 3 for the 50 and 90 percentile values. The 0.5 or 1 s median maxima for liquid water content are higher than the median average by approximately a factor of 2. For large particle concentrations (>70 μm), the difference in the medians is a factor 10 or greater. Similar differences are seen in the comparison of the 90 percentile maxima and penetration averaged liquid water contents and large particle concentrations. The maxima of Table 3 must be interpreted with caution because the sample volumes are approximately 2–5% of those used for the penetration averages. Consequently, the potential sampling errors or uncertainties are much larger.

b. General observations

An examination of Table 1 shows that there are some distinct differences between Thunder Bay and Yellowknife clouds. The clouds in Yellowknife have colder bases (~ +4°C), higher bases (~2200 m), lower tops (~4300 m) and greater widths (~1700 m) than do Thunder Bay clouds (~ +12°C, ~1800, ~5100 and ~1300 m, respectively). These differences are at least in part responsible for the microphysical differences in the clouds. Yellowknife clouds have lower liquid water contents (0.3 g m^{-3}) than do Thunder Bay clouds (1.0 g m^{-3}). This difference is largely due to the colder cloud base temperature and the lower cloud thickness below the penetration level in Yellowknife (~2000 as opposed to ~2700 m in Thunder Bay). Yellowknife clouds also had much higher concentrations of particles > 70 μm diameter. Isaac and

TABLE 2. Mean and median cloud top and cloud base temperatures.

	Yellowknife 1975–76	Thunder Bay 1977–78	Miles City 1979–80
Top			
mean	−9.1°C	−8.9°C	−11.1°C
median	−8.5	−9.0	−10.5
Base			
mean	4.0°C	12.0°C	4.0°C
median	3.9	12.5	3.9
Number of clouds			
top	57	54	32
base	20	42	32

TABLE 3. Some additional statistics for the microphysical data collected during penetrations of the clouds of Table 1. For Yellowknife, the concentration of particles > 70 μm includes particles > 310 μm, but this does not affect comparisons with Thunder Bay or Miles City because the concentration always decreases rapidly with size and thus the fraction of particles > 310 μm is small. The penetration maxima refer to the maximum 1 s (for J–W, 0.5 s) value detected by the respective instruments.

	Yellowknife				Thunder Bay						Miles City					
	Penetration average				Penetration average				Maximum		Penetration average				Maximum	
	50% 1st	10% All	50% All	90% All	50% 1st	10% All	50% All	90% All	50% All	90% All	50% 1st	10% All	50% All	90% All	50% All	90% All
Temperature (°C)	−7.3	−5.0	−7.1	−9.0	−5.9	−1.7	−5.8	−9.2			−7.2	−2.1	−6.7	−10.0		
LWC (g m^{-3}), J–W	0.3	0.1	0.3	0.7	1.1	0.2	1.0	1.8	1.8	3.4	0.5	0.1	0.3	0.8	0.8	1.5
LWC (g m^{-3}), FSSP					>0.9	>0.2	>0.8	>1.3	>1.3	>1.8	0.6	0.1	0.5	0.7	0.9	1.2
Cloud droplet concentration (cm^{-3}), FSSP			>300		>500	>2	>480	>720	>700	>920	360	120	300	500	570	670
Droplet concentration 24–45 μm (cm^{-3}), FSSP					>13	>0.3	>11	>53	>22	>86	1.1	0.0	0.5	7.4	1.4	14
Particle concentration 70–310 μm (L^{-1}), PMS 1D	0.8	0.0	0.9	43.	0.06	0.00	0.04	5.0	1.0	19.0	0.19	0.00	0.13	0.53	1.3	3.8
Particle concentration 150–310 μm (L^{-1}), PMS 1D	0.6	0.0	0.6	11.	0.00	0.00	0.00	2.4	0.00	11.0	0.15	0.00	0.06	0.19	0.88	1.7
Particle concentration 210–310 μm (L^{-1}), PMS 1D	0.2	0.0	0.2	4.7	0.00	0.00	0.00	1.4	0.00	7.0	0.06	0.00	0.03	0.13	0.88	1.3
Ice particle concentration (L^{-1}), MEE					0.1	0.0	0.0	2.5	0.8	12.0	0.0	0.0	0.0	0.6	0.5	3.3

Schemenauer (1979a) show that these particles were predominantly water drops. The concentrations in Yellowknife were 0.9 L^{-1} and in Thunder Bay, 0.04 L^{-1}. As will be seen below, this could result from the longer lifetimes of Yellowknife clouds. The concentration of drops from 24 to 45 μm is not available for the Yellowknife clouds but was quite high in both years in Thunder Bay (>26 and >7 cm^{-3}). Since penetrations were typically made near −7°C, the environment may be suitable for a riming-splinter (Hallett–Mossop) ice particle multiplication process. An examination of the data, however, suggests that the concentration of even larger drops plays an important role in the initiation of ice multiplication (Isaac and Schemenauer, 1979b; Mossop, 1979).

In examining the data obtained in the third geographical area, Miles City, one finds that the clouds were not exactly the same as those in either Canadian location. It may also be useful to note that even though the selection criteria were different, the clouds were in some ways similar (dimensions, temperature range, LWC) to the HIPLEX 1 type clouds used in the randomized seeding experiment in the High Plains Cooperative Program (Schemenauer *et al.*, 1980, 1981). The clouds examined for this study near Miles City exhibited very high cloud bases, tops and penetration heights as might be expected in a hot, dry environment. However, there were some marked similarities to clouds in Yellowknife. In particular, the cloud base temperatures (~ +4°C), the cloud depth below the penetration height (~1800 m) and the cloud width (~1600 m) were almost identical in the two areas. The Miles City median liquid water content (LWC) of 0.3 g m^{-3} was the same as that of Yellowknife and distinctly lower than that of Thunder Bay (1.0 g m^{-3}). Unfortunately, the Yellowknife PMS FSSP droplet concentrations are not considered accurate enough for comparison purposes. However, the reason for the Miles City LWC values being lower than those in Thunder Bay appears to be both a lower total droplet concentration and a lower concentration of droplets in the 24–45 μm diameter range. The median concentrations of particles > 70 μm were lower than those in Yellowknife but higher than the Thunder Bay values. The median ice particle concentrations were below the detection limits (~0.1 L^{-1}) of the instruments, as was the case at the other locations.

The turbulence measurements show a remarkable consistency over the six year period. Certainly, the rms vertical velocities and the peak up and down gusts change little from year to year. The turbulent dissipation rates show somewhat more variation. Nevertheless, except for a very high value of 360 cm^2 s^{-3} in 1978, all of the median values range from 100 to 180 cm^2 s^{-3}. It should be noted that the measurements from 1975 to 1978 were made from mid-June to mid-July. In 1979 they were made during a very hot July in Miles City. In 1980 they were made from late May to late June. Therefore, the somewhat higher turbulence values in the 1979 Miles City data (as opposed to 1980 data) may be reflecting the different atmospheric temperature structure in the two project periods.

c. *Ice phase*

All locations had median ice particle concentrations of 0.0 L^{-1} (Table 1). This reflects the fact that most of the clouds examined did not contain ice particles in concentrations above the limit of detection (~0.1 L^{-1}). Clouds with summit temperatures warmer than −7°C did not contain ice and the probability of a cloud containing ice increased as the cloud top temperature decreased. In Fig. 3 the combined Canadian data as well as the Miles City data are compared to similar measurements in other parts of the world. The Canadian data are similar to those from other locations with continental clouds, e.g. Kosarev *et al.* (1978) in the U.S.S.R. and Braham (1964) and Morris and Braham (1968) in the United States. The data agree to within the errors of the respective measurements. This is somewhat surprising given the wide geographical dispersion of the clouds. The results of Mossop *et al.* (1970) are for maritime clouds. Their data show similar probabilities at temperatures about 5°C warmer than the continental clouds in Canada. This is not unexpected since the clouds have very different droplet spectra. This point is discussed further in the paper by Mossop *et al.* (1970) and in Isaac and Schemenauer (1979a) where the Yellowknife data are examined in detail. The smaller dataset from Miles City appears to agree quite well with the measurements from the two Canadian locations, shown in Figs. 3 and 4. There is, however, one anomaly. Clouds with summit temperatures from −14.0 to −17.9°C were grouped together due to their small number and the point was plotted at −16°C. This point (43%) is well below what would be expected from the Canadian data (~68%).

In the Miles City area 31% of clouds (10 of 32) contained some ice particles. The overall percentage from the two Canadian locations was 22% (22 of 98). Given the size of the samples, it is probably only safe to say that about the same percentage (~25%) of clouds in the two locations contained ice.

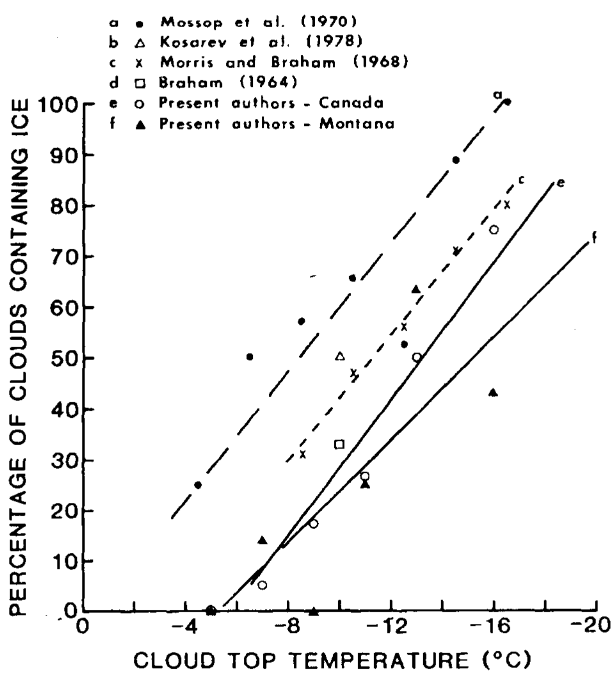

FIG. 3. Survey of the percentage of clouds containing ice as a function of cloud top temperature. Data for a and c have been reanalyzed (different temperature bins) in a manner similar to e. The points from b and d refer to approximate numbers quoted by the authors.

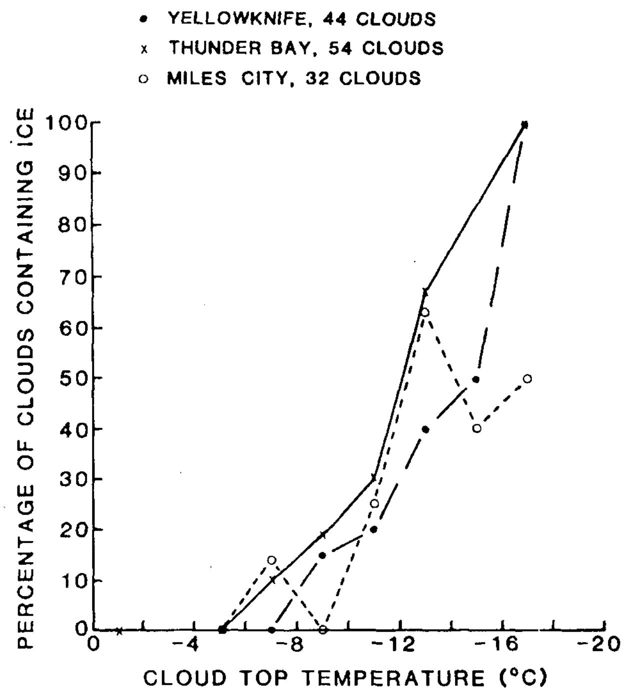

FIG. 4. The percentage of clouds containing ice as a function of cloud top temperature for each of the three project locations.

d. Rain

Determination of particle phase in natural rain-forming clouds is important in understanding the precipitation process and in assessing the results of cloud seeding experiments. Table 4 summarizes the results of an examination of 87 natural clouds in 1976, 1977 and 1978. Only 20 of the 87 clouds contained some ice particles, but of these 10 (50%) produced rain. Of the 67 clouds containing only water droplets, 7 (10%) rained. Clouds containing ice had a much higher probability of raining but because of the preponderance of all-water clouds, the numbers of clouds producing precipitation by cold and warm rain processes were nearly equivalent. However, six of the 7 warm rain cases were observed in 1977 and four of these were on one day. It appears that the warm rain process requires a unique environment before it is operative in Canadian clouds.

TABLE 4. The appearance of rain in 87 clouds in 1976, 1977 and 1978 (Yellowknife and Thunder Bay). The columns indicate whether the clouds contained some ice or were all water.

	Some ice	All water
Rain	10	7
No rain	10	60

In contrast, about half of the clouds in each of the three years that contained ice also produced rain.

There is certainly no equivalency when rain from the observed Canadian and Montana clouds are compared. About 20% (17 of 87 where cloud base information was available) of the natural clouds examined near Yellowknife and Thunder Bay rained. None of the 32 clouds studied near Miles City rained. Obviously some towering cumuli of this size in the Miles City area do rain. The important point is that the sample of 32 clouds was chosen and studied in the same manner as were the 87 clouds in Canada, and none were observed by the aircraft, aircraft radar or ground radar to produce rain. In Section 2b, the relative absence of particles > 70 μm near cloud top was noted. Further details of the rain processes in the three areas are discussed in Section 3.

3. Cloud top lifetime

a. Calculation and discussion

As described in the introduction, the cloud top lifetime was determined in the following manner. A rate of change of LWC was calculated by taking the difference between the average Johnson–Williams LWC in the last and first penetrations at a constant altitude and dividing by the time between the midpoints of the penetrations. The mean first pass LWC for the field season was then divided by the mean rate of LWC change for the field season to obtain a cloud top lifetime (to 0.0 or 0.1 g m^{-3}) for each project period. This method was chosen after examining a number of other possibilities. It has the advantage of being easily produced from the aircraft data and most importantly, produces lifetimes consistent with the experiences of the aircraft crews actually flying the missions. The concept of using a measured liquid water decay rate as defined by Schemenauer and Isaac (1980) was followed by Lawson (1981) for clouds during the Miles City HIPLEX project.

The difference between the last and first penetration LWC values was used in calculating the rate of change of LWC because it involves the simplest of assumptions. There is no obvious nonlinear trend in LWC that produces a value better suited for extrapolating LWC to zero. For clouds in which two penetrations were made, the linear trend is obviously the only choice. For clouds with three or more penetrations, a nonlinear trend might be hypothesized or only a portion of the study period might be used to determine the trend. However, the data do not support any such hypotheses. Likewise, given the small number of sampling points in each cloud and the irregular sampling interval, smoothing and filtering techniques do not seem appropriate. Fig. 5 shows the time variation of pass-averaged LWC for the 13 clouds in which five or more observations were made. A simple straight line drawn between the first and last penetration appears to be a reasonable approximation to the LWC change with time. Although Fig. 5 presents a small subset of the data, it is clear that any selection of a nonlinear trend to characterize the data would be difficult.

The possibility that the allowance of a 100 m difference in the first and last penetration altitudes could have led to a consistent bias in the LWC change was examined. This is most likely to be a problem in areas such as Miles City where predominantly dissipating cloud tops may have caused the aircraft to fly at lower altitudes and thus lower LWCs. In fact, the bias is very small, an average of $-15 + 57$ m in 1979 and $-26 + 32$ m in 1980. Even if the LWCs were adiabatic (usually they are 0.3 to 0.5 adiabatic) near cloud top, this would only result in a bias of ~0.03 to 0.05 g m^{-3} in the LWC. This leads to the lifetimes being, at most, 5–10% too low in the case of the Miles City data with a smaller effect for the other locations. This error is small compared to the uncertainty introduced by the large standard deviations associated with the mean first pass LWC and mean rate of change of LWC. The maximum expected error in cloud lifetime was calculated to be approximately ±50%, i.e., from 2 to 10 min depending on the number of clouds and the lifetime (see data in this section).

Figures 6, 7 and 8 show the rate of change of cloud top LWC, for each of three project locations, plotted against the time between the first and last penetrations. Each point represents one cloud. There are some striking differences between the figures. The Yellowknife data show a fairly even split between positive (increasing LWC) and negative LWC changes with fairly small absolute values. Only 47% (20 of 43) of the clouds exhibited a decreasing LWC over the period followed. The characteristic shape of the figures represents the fact that clouds with long periods between the first and last penetrations at the same altitude have either small negative LWC changes to prevent the clouds from quickly disappearing, or small positive values to prevent the final LWC from exceeding the adiabatic value. The subset of clouds with LWC changes near zero, that were only examined for short time periods, were those with initial LWC values only marginally above 0.1 g m^{-3}. Therefore, a small decrease in average LWC would lead to termination of the study. Fig. 7 for Thunder Bay clouds is quite different from Fig. 6 for Yellowknife clouds. There is a preponderance (79%, 30 of 38) of negative decay rates with much higher absolute values. Both years have similar distributions of the points as was the case in Yellowknife. The Miles City data in Fig. 8 also show a preponderance (86%, 18 of 21) of negative values. The range of absolute values is almost exactly the same as for Yellowknife but Miles City lacks the large number of positive values that were observed in Yellowknife. In fact, 1980 was unique in being the only year that did not have a single cloud with a positive LWC change. On the average,

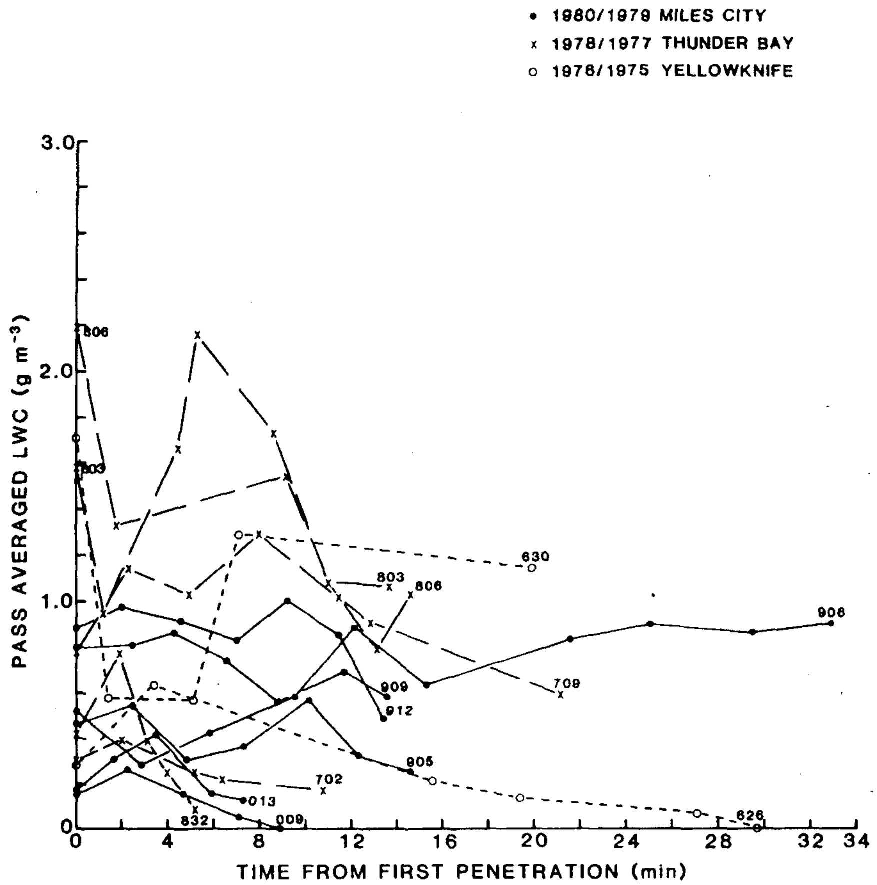

FIG. 5. Rate of change of pass averaged LWC for 13 clouds in which 5 or more penetrations were made. The first digit of the cloud number specifies the year of the measurement.

the clouds in the six year study could be characterized as being in a state of dissipation.

Table 5 gives the mean values of the rate of change of LWC for each of the six project years, which are

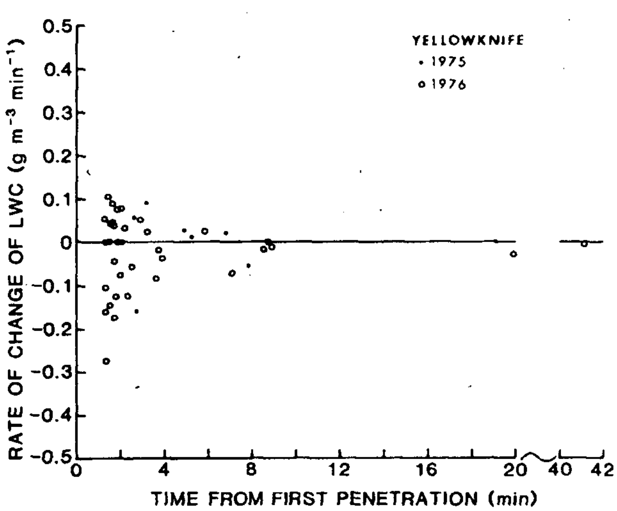

FIG. 6. Rate of change of cloud liquid water content for 43 clouds near Yellowknife, NWT, Canada.

converted to representative cloud top lifetimes by dividing the average first pass LWC by the average rate of change of LWC. Two lifetime values are shown: to 0.0 g m^{-3}, representing the complete dissipation of the supercooled cloud region and to 0.1 g m^{-3}, giving the approximate time available for rapid growth of ice crystals after a seeding event.

Table 5 data fall naturally into three groups by location. The Yellowknife clouds had long lifetimes (>20 min and 16 min) in both years. The Thunder Bay clouds had very short lifetimes (8 min and 6 min) in both years. The first year in Miles City the average lifetime was long (15 min) but in 1980 this dropped to the lowest value (4 min) of the six year investigation. It should be noted that the sample size for Miles City is about one-half that at the other two locations and therefore, possibly less representative of the area.

Clearly, these dramatic differences in cloud lifetime will significantly affect the rain formation mechanisms and seedability of the clouds in the different locations. In Section 2 it was shown that the measured natural cloud parameters are insufficient in themselves to explain the difference in rain production and rain production mechanisms in the three areas. If one chooses definitions to fit the data available, i.e., long lifetimes

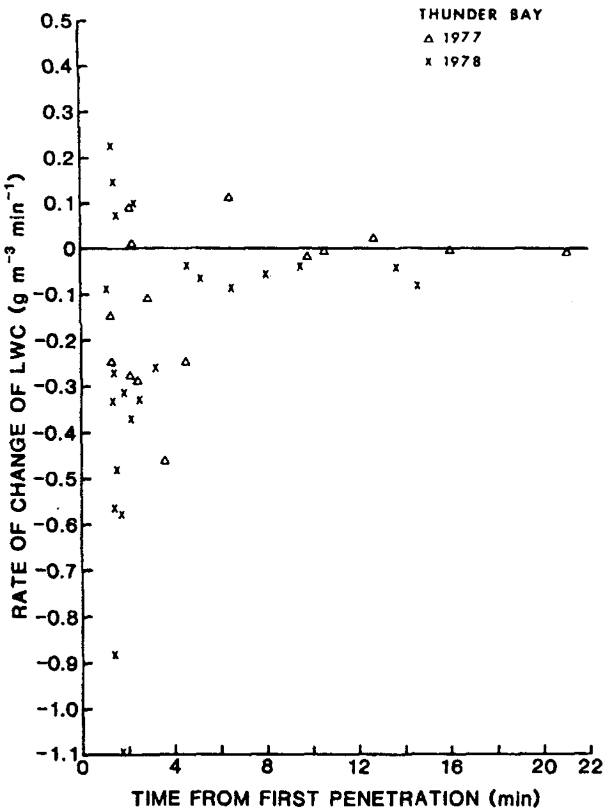

FIG. 7. Rate of change of cloud liquid water content for 38 clouds near Thunder Bay, Ontario, Canada.

are those >15 min; high LWCs are those >0.75 g m^{-3}, then by these criteria, Yellowknife clouds have long lifetimes and low LWCs. This provided conditions for both warm and cold rain processes to be active and for ice multiplication to occur (Isaac and Schemenauer, 1979a). Thunder Bay clouds were exactly the opposite, having short lifetimes and high LWCs. This again provides an environment where warm and cold rain processes as well as ice multiplication can occur (Isaac and Schemenauer, 1979b; Mossop, 1979). Miles City

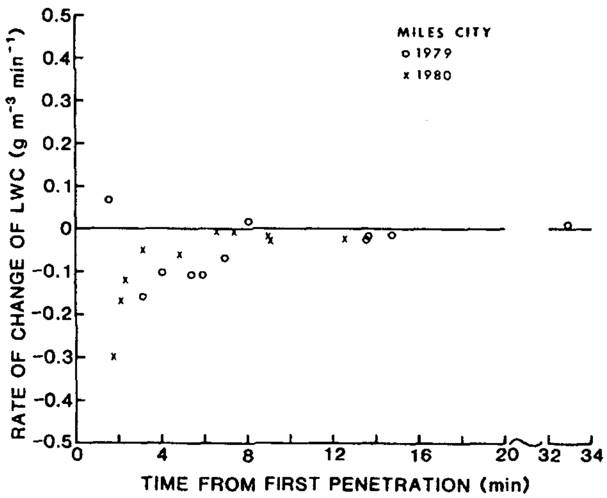

FIG. 8. Rate of change of cloud liquid water content for 21 clouds near Miles City, Montana, U.S.A.

clouds exhibited both moderate and short lifetimes and low LWCs. This provided an environment where rain formation was rare enough that it was not observed in the cloud sample obtained in the 2-year project periods. Long lifetimes and high LWCs were not characteristics of any of the locations but would certainly be expected to provide conditions for rain producing clouds.

The results of the AgI seeding experiments in Yellowknife and Thunder Bay are discussed by Isaac *et al.* (1982). The seeded clouds in Yellowknife exhibited significantly longer lifetimes than those in Thunder Bay as would be expected from the natural cloud data presented here. About 40% of the seeded clouds in Yellowknife rained, whereas none of the Thunder Bay clouds produced rain as a result of seeding. Since Thunder Bay clouds had significantly higher LWCs which would be beneficial to ice crystal growth and rain formation and had greater cloud depths, this must mean that cloud lifetime is a controlling factor in AgI seeding for rainfall augmentation. Unless the

TABLE 5. Representative cloud top lifetimes for clouds examined in three locations. Calculations are based on the mean first pass LWC and the mean rate of change of LWC for 102 clouds. The standard deviations of the individual measurements about the mean are also shown.

		Mean 1st pass LWC (g m^{-3})	Mean $\frac{d\,(\mathrm{LWC})}{dt}$ (g m^{-3} min^{-1})	Cloud top lifetime to 0.0 g m^{-3} (min)	Cloud top lifetime to 0.1 g m^{-3} (min)	Number of clouds
Yellowknife	1975	0.50 ± 0.43	−0.00038 ± 0.077	>20	>20	8
	1976	0.40 ± 0.30	−0.025 ± 0.085	16	12	35
Thunder Bay	1977	0.88 ± 0.55	−0.104 ± 0.17	8	8	15
	1978	1.44 ± 0.69	−0.231 ± 0.32	6	6	23
Miles City	1979	0.68 ± 0.22	−0.045 ± 0.068	15	13	11
	1980	0.34 ± 0.20	−0.078 ± 0.095	4	3	10

supercooled portion of the cloud persists for ~15 min or more, it appears that there is insufficient time for AgI to nucleate ice particles and for them to grow to precipitable sizes. On this basis the AgI seedability of the clouds was assessed as: good in Yellowknife, poor in Thunder Bay, moderate in Miles City 1979, poor in Miles City 1980, and very good in some "ideal" location with wet, long-lived clouds (provided these were not already efficient natural rain producers). It would seem that the use of an instantaneously acting nucleant such as dry ice pellets would improve the seedability of clouds which have marginal cloud top lifetimes.

There were 12 raining clouds in the 73 cloud group making up the 1976, 1977 and 1978 lifetime study, 4 in 1976, 5 in 1977 and 3 in 1978. Seven of the clouds contained some ice near cloud top, 5 clouds only water drops. Of the clouds containing ice, 2 had cloud top lifetimes greater than the yearly average, 5 had shorter lifetimes. Of the 5 clouds containing only water drops, all 5 had lifetimes longer than the corresponding yearly average. Half of the raining clouds had first-pass LWC values greater than the respective yearly average, half did not. This includes 4 of the 7 clouds with ice and 2 of the 5 clouds with only water drops. Based on this small dataset, a number of tentative conclusions seem possible. First, the average first-pass LWC near cloud top does not seem important to the natural rain formation process. Second, Schemenauer and Isaac (1980) showed that 50% of clouds containing ice near cloud top rained in Yellowknife and Thunder Bay, whereas 10% of those that contained only water drops rained. It now appears that the warm rain process requires longer than average cloud top lifetimes; a requirement that may be unnecessary for the natural cold rain process.

If 15 min is arbitrarily taken as a "long" cloud top lifetime which would be suitable for a rainfall augmentation program, then the natural cloud population can be examined to see how often these long-lived clouds occur. Including clouds with positive rates of change of LWC (infinite lifetimes) gives for 1975–80: 88, 60, 53, 39, 55 and 20% with a mean of 53 ± 23% of the clouds with greater than 15 min lifetime. Using only clouds with finite calculated cloud top lifetimes gives for 1975–80: 50, 22, 36, 26, 38 and 20% with a mean of 32 ± 11%. Thus a third, or perhaps more, of the clouds encountered can be expected to be long-lived. The year-to-year variation is large, but the minimum fraction is about one-fifth of the clouds even in areas where the representative yearly lifetime was determined to be quite short. It does not seem that this is directly translatable to a percentage of naturally raining clouds, since as noted above, other factors such as the rain forming mechanism must be considered.

Braham (1960) plotted (Braham, 1981, reprinted) a frequency distribution of 63 cumulus clouds of various durations. He defined duration as "the total life of the cloud beyond the time its top reached the −5°C level", though the author (private communication, 1982) notes these were, in fact, observed lifetimes. The data were collected in Illinois, Missouri, Arkansas, Kansas and Arizona during the summers 1954, 1955. The cloud duration of Braham, therefore, refers to a cloud region similar to that represented by the data in this paper. He found that about 75% of the clouds lasted longer than 7 min, 50% lasted longer than 10 min and 25% lasted longer than 15 min. The median total duration value of 10 min is comparable to and perhaps a bit longer than the observed lifetimes in three of the four years at Thunder Bay and Miles City (Table 5). Fig. 1 shows that the states in which Braham made measurements were midcontinental, as were the areas where the data shown here were collected. It is impossible to do more than remark on the compatibility of Braham's data since details of his measurements and potential errors are not known. Braham also shows that natural precipitation development is dependent on the duration of the cumulus cloud tops but his frequencies are far higher than those discussed in Section 2; he found 33% of clouds which were never colder than −5°C rained, 50% with durations of 11 min rained and 75% lasting 19 min rained. The explanation for this difference may be associated with the fact that Braham used an aircraft radar to indicate the presence of rain and accepted an echo anywhere in the cloud for the purposes of his dataset. The present dataset refers only to measured rain from cloud base.

Warner (1977) and Sax and Keller (1980) show the LWC variation with time for a number of small and moderate sized cumuli. These papers illustrate that there is information in the literature that can be used to calculate cloud lifetimes. When the original measurements were made under similar conditions, comparisons should be possible.

b. Influencing factors

It is not clear what the determining factors are for the lifetime of the supercooled portion of a cumulus cloud, or perhaps more importantly, how this could be predetermined for a particular area. On a comparison of yearly values, cloud top lifetime (taken to be 20 min in 1975) does not appear to be closely related to any of the calculated turbulence parameters (see below), to initial LWC ($r = 0.39$), to cloud depth ($r = -0.55$) or to cloud base temperature ($r = -0.39$).

An examination of three years of data documenting the difference between the environmental temperature immediately before cloud entry and the in-cloud temperature on the first penetration shed little light on the question of cloud lifetime. Neither on a cloud-by-cloud nor an annual average basis was there a significant correlation of temperature difference (in–out) with LWC decay rate. The correlation coefficients between cloud top lifetime and average temperature difference in the three years were −0.01, 0.58 and −0.08.

The same three years of data were examined to see if cloud top lifetime was related to the temperature–dewpoint spread in the near-cloud environment (5 to 10 s before the first penetration). The correlation coefficients were low in each of the years: −0.19 in 1978, −0.31 in 1979 and −0.44 in 1980. That is, the cloud top lifetime is generally shorter if the near-cloud air is dry at the penetration level (~300 m below cloud top), but it is apparently not the only, and probably not even the most important, determinant of lifetime.

If the cloud top lifetimes from Table 5 are plotted against the median turbulent energy dissipation rates from Table 1, there is little correlation ($r = -0.37$). If 1980 is excluded, there is a reasonably good inverse correlation ($r = -0.82$) of the form

$$L = 22.5 - 0.049\epsilon,$$

where ϵ is in $cm^2\ s^{-3}$ and L in min. There does not appear any good reason to do this, however, other than that these measurements were made somewhat earlier in the year. The vertical energy flux in the cloud and the near environment was calculated for the first penetration of each cloud in the lifetime study in 1980. This is the parameter used by Isaac *et al.* (1982) to effectively partition seeded clouds into those that showed an effect and those that did not. It is equal to the average vertical velocity in the cloud times the square of the three gust components. Unfortunately, the natural cloud data are only available for 1980. When lifetime is plotted as a function of energy flux for individual clouds, there is little suggestion of more energetic clouds lasting longer ($r = 0.32$). A plot of lifetime versus heat flux (average velocity × difference between the measured temperature and that at the start of the cloud run) for the 1980 clouds again exhibits a low correlation ($r = 0.50$).

One may speculate that it is airmass characteristics, or properties of the cloud environment such as wind shear that are dictating the degree of dry air entrainment that determines the lifetime of the cloud top. Unfortunately, soundings in the near cloud environment are not routinely available for Yellowknife or Thunder Bay and the Miles City data alone are unlikely to provide the answers. Using the best available soundings for the three locations, the daily averaged rate of change of LWC was compared to the 500–850 mb speed and directional shear. No correlation was seen with speed shear. However, all 6 days (out of 36) that exhibited net positive LWC changes occurred on days with a directional shear of <25° in this layer (values as high as 125° were seen). This was not a sufficient condition, however, as many negative LWC changes were also seen in this category. Perhaps a much more extensive study of aircraft turbulence and sounding data combined with a model of the evolution of the cloud top will shed some light on this problem in the future.

If the representative cloud top lifetimes from Table 6 are plotted versus the median value of all penetration lengths from Table 1, then in each of the locations there is an increase in lifetime with an increase in cloud width. The linear correlation coefficient for the six years is $r = 0.74$. The absolute values vary considerably between the locations but there is a relatively consistent message. Clouds with diameters of ~1 km at approximately the −7°C level have very short lifetimes. If this width increases to ~1.8 km, then lifetimes in excess of 15 min may be expected. The use of the mean of all penetration lengths or the mean or median of the first pass through only those clouds included in the lifetime study does nothing to improve the relationship. The errors in the median penetration lengths are small but the large errors in the lifetimes discussed above clearly are going to obscure any precise relationship.

McCarthy (1974) has correlated the widths of six carefully selected cumulus clouds with a calculation of the entrainment rate. The clouds were sampled with an aircraft over the Mississippi Delta and all had tops warmer than 0°C. His field measurements showed a strong inverse dependence between the entrainment rate and the cloud diameter, in conformance with theory. This is in general agreement with the results of this paper, i.e., lifetime (which is inversely related to entrainment rate) is directly related to cloud diameter. This suggests the interesting possibility of using satellite or aircraft observations to measure cloud widths at the −5 to −7°C level and thus getting an indirect estimate of whether cloud lifetimes are suitable for possible weather modification programs.

4. Conclusions

Data representing a summary of 469 aircraft penetrations, of 156 natural cumulus clouds in three locations over six years, in central North America, have been presented. The data were collected in a consistent manner by the same aircraft and crew enabling reliable comparison of most cumulus characteristics in the three areas. Distinct differences were found between the clouds in the two Canadian project areas. The clouds in Yellowknife have colder and higher bases, lower tops, lower liquid water contents and higher concentrations of particles > 70 μm than did clouds near Thunder Bay. Miles City clouds had similar depths, cloud base temperatures and liquid water contents to those in Yellowknife but were displaced to higher altitudes above ground. The turbulence characteristics and the probability of clouds containing ice as a function of cloud top temperature were reasonably similar in all three locations.

The observed cloud top lifetimes (as defined in Section 1) of the supercooled regions of the clouds varied markedly from area to area. Cloud top lifetime is a parameter of fundamental concern to weather modifiers and is a useful way for the cloud physicist to represent the integrated effect of cloud dynamics and the environment on the cloud. Clouds near Yellowknife were long-lived (>20 min and 16 min in each of two years), near Thunder Bay they were short-lived (8 and 6 min) and near Miles City they had moderately long cloud top lifetimes in July 1979 (15 min) and very short lifetimes (4 min) in June 1980. The Yellowknife conditions of long lifetimes and low LWCs (<0.75 g m^{-3}) led to both warm and cold rain processes being active and to a good environment for AgI seeding. Warm and cold rain processes were also observed in the short-lived, high LWC Thunder Bay clouds, but cloud seeding (Isaac *et al.* 1982) was ineffective in producing rain. No rain forming processes were observed in the Miles City clouds but cumulus and towering cumulus clouds of the scale studied were considered to have moderate AgI seedability in July 1979 and a low seedability in June 1980 in the Miles City area.

Twelve of the 73 clouds in the 1976, 1977 and 1978 portion of the lifetime study produced rain. Whether the initial first pass LWC was above or below the yearly average value did not seem critical to the natural rain formation process. However, all five of the clouds with only water drops near cloud top had lifetimes longer than the corresponding yearly average in contrast to only two of the seven clouds containing ice particles. As Table 4 indicates, 50% of the clouds containing ice in Yellowknife and Thunder Bay produced rain, while only 10% of the all-water clouds rained. This now can be at least partly explained on the basis of cloud top lifetime. The natural cold rain process can be initiated even if the calculated cloud top lifetime is only a few minutes at temperatures colder than −5°C. This can be sufficient for the initial nucleation and growth of ice particles. The warm rain process is active only in those clouds that persist for periods longer than normal at cloud top. The importance of this may be in the provision of sufficient cloud depth for the condensation–coalescence process to be effective in producing large drops. However, it should be mentioned that the majority of clouds examined had neither the ice to initiate a cold rain process nor the lifetime to support a warm rain process.

Cloud top lifetime was found to increase with cloud width in each of the three geographical areas but the measurements implied a different degree of dependence on cloud width in each location. Lifetime did not appear to be closely related to initial LWC, cloud depth, cloud base temperature, inside–outside cloud temperature difference, environmental humidity, median seasonal turbulent energy dissipation rate, cloud-by-cloud dissipation rate, energy flux, heat flux nor wind shear. Clearly, one factor that obscures potential relationships is the large error associated with the small number of clouds (8–35) in each project year. The problem of finding suitable clouds and then studying them long enough to determine a rate of LWC change is very time consuming. The most desirable situation would certainly be to have several similarly equipped aircraft available to fly near cloud top on each suitable day.

One final note. A quick perusal of some recent cloud physics texts (Mason, 1971; Pruppacher and Klett, 1978; Rogers, 1979) shows a complete absence of both discussions and data concerning cloud lifetimes. The formation of clouds and precipitation is discussed in great detail. But the question of "How long does a summer cumulus cloud last?" rates only a passing mention at best. This is especially striking in a book by Dennis (1980) on weather modification. The standard procedure seems to be to assume that the cloud lasts long enough for the process being examined or modeled to run its course. Hopefully, more specific information on the duration of different cloud types and regions of interest will be obtained in the near future for input into the hands of modelers, as well as experimental and operational weather modifiers.

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INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

IPCC Expert Meeting on Geoengineering

Lima, Peru
20-22 June 2011

Meeting Report

Edited by:
Ottmar Edenhofer, Ramón Pichs-Madruga, Youba Sokona, Christopher Field, Vicente Barros, Thomas F. Stocker, Qin Dahe, Jan Minx, Katharine Mach, Gian-Kasper Plattner, Steffen Schlömer, Gerrit Hansen, Michael Mastrandrea

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IPCC Expert Meeting on Geoengineering

Lima, Peru, 20-22 June 2011

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Preface

Geoengineering, encompassing a broad set of methods and technologies, has been an increasing focus of scientific research, and the scientific basis of geoengineering options, risks, and impacts will be assessed across the three contributions to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). In preparation of this task, Working Groups I, II, and III (WGI, WGII, and WGIII) of the IPCC held a joint Expert Meeting on Geoengineering in Lima, Peru, from 20 to 22 June 2011. The Expert Meeting provided a valuable opportunity for experts from a wide range of disciplines and across WGI, WGII, and WGIII to discuss terminology, to clarify concepts and definitions, and to consider emerging issues. Overall the meeting enabled a better understanding and coordination across the three IPCC Working Groups in the context of AR5 assessment efforts underway.

This meeting report summarizes discussions of the Expert Meeting. At its core is a summary of the synthesis session and main outcomes of the meeting. It also contains summaries of meeting discussions of geoengineering approaches and cross-cutting issues, as well as extended abstracts for the meeting's keynote and poster presentations.

We thank the Ministerio de Relationes Exteriores del Peru for hosting the meeting and providing careful arrangements. In particular, we are grateful for the extensive efforts of Professor Eduardo Calvo, Minister Augusto Arzubiaga, and Pilar Castro Barreda. The meeting could not have succeeded without the guidance of the members of the Scientific Steering Group. Finally, we thank all the participants, who contributed to constructive and fruitful dialogue. We also acknowledge the excellent work of the Technical Support Units of the three Working Groups who provided important service during the preparation and execution of the meeting, as well as in the compilation and technical edition of this report.

This successful and stimulating meeting brought together key communities to discuss topics relevant for the assessment of geoengineering. We are convinced that this meeting report will be of great value in the preparation of the AR5, and we hope that it will also provide useful information to the wider scientific community.

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Prof. Youba Sokona

Prof. Christopher Field

Prof. Vicente Barros

Prof. Thomas Stocker

Prof. Dahe Qin

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Summary of the Synthesis Session

Summary of the Synthesis Session and Main Outcomes of the IPCC Expert Meeting on Geoengineering

20-22 June 2011

Lima, Peru

Authored by O. Boucher, N. Gruber and J. Blackstock

Citation:

Boucher, O., Gruber, N. and Blackstock, J., 2011, Summary of the Synthesis Session In: *IPCC Expert Meeting Report on Geoengineering.* [O. Edenhofer, C. Field, R. Pichs-Madruga, Y. Sokona, T. Stocker, V. Barros, Q. Dahe, J. Minx, K. Mach, G.-K. Plattner, S. Schlömer, G. Hansen, M. Mastrandrea (eds.)] IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam, Germany, pp.7.

The summary that follows, authored by three members of the Scientific Steering Group (SSG), characterizes the main points that were presented and discussed during the synthesis session of the IPCC Expert Meeting on Geoengineering, 20-22 June 2011, Lima, Peru. The synthesis session was prepared by the SSG and aimed to summarise the discussions that took place in plenary as well as breakout sessions. This summary reflects the authors' perceptions of meeting discussions, but may not reflect their personal views. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups.

1. Key Terminology

A substantial amount of time in the Expert Meeting was spent in discussing terminology in and around geoengineering. This underlines the ambiguities associated with the term geoengineering and the range of opinions on the subject.

The concept of geoengineering can be traced back to the 1960s with a US report calling for research on "possibilities to deliberately bringing about countervailing climatic changes" to that of CO_2 (Marchetti, 1977). The term geoengineering itself was originally used in the 1970s by Marchetti (1977) to describe the context of the idea of injecting CO_2 into the ocean to reduce the atmospheric burden of this greenhouse gas. Since that time, the term has evolved considerably, coming to encompass a broad, and ill-defined, variety of concepts for *intentionally* modifying the Earth's climate *at the large scale* (Keith, 2000). As a result, discussions of geoengineering in both academic and public contexts have sometimes convoluted characteristics from different techniques in ways that have unhelpfully confused discussions. Nonetheless, since Paul Crutzen's 2006 editorial essay (Crutzen, 2006), scientific, policy and media attention to geoengineering concepts has grown rapidly. Several assessments have been conducted at the national level (The Royal Society, 2009; GAO, 2011; Rickels et al., 2011).

Box 1 - Background information

At the Expert Meeting, an attempt was made to provide a set of common definitions for the most important terms related to geoengineering. These definitions are intended for consideration by the author teams of the IPCC's Fifth Assessment Report (AR5). Many of the definitions below reflect the broad usage of these terms in climate science. While some terms are occasionally used interchangeably in the literature, the definitions presented here attempt to provide clear distinctions between them:

Geoengineering refers to a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate the impacts of climate change. Most, but not all, methods seek to either (a) reduce the amount of absorbed solar energy in the climate system (*Solar Radiation Management*) or (b) increase net carbon sinks from the atmosphere at a scale sufficiently large to alter climate (*Carbon Dioxide Removal*). Scale and intent are of central importance. Two key characteristics of geoengineering methods of particular concern are that they use or affect the climate system (e.g., atmosphere, land or ocean) globally or regionally and/or could have substantive unintended effects that cross national boundaries. Geoengineering is different from weather modification and ecological engineering, but the boundary can be fuzzy.

Solar Radiation Management (SRM) refers to the intentional modification of the Earth's shortwave radiative budget with the aim to reduce climate change according to a given metric (e.g., surface temperature, precipitation, regional impacts, etc). Artificial injection of stratospheric aerosols and cloud brightening are two examples of SRM techniques. Methods to modify some fast-responding elements of the longwave radiative budget (such as cirrus clouds), although not strictly speaking SRM, can be related to SRM. SRM techniques do not fall within the usual definitions of mitigation and adaptation.

Carbon Dioxide Removal (CDR) methods refer to a set of techniques that aim to remove CO_2 directly from the atmosphere by either (1) increasing natural sinks for carbon or (2) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration. CDR methods involve the ocean, land, and technical systems, including such methods as iron fertilization, large-scale afforestation, and direct capture of CO_2 from the atmosphere using engineered chemical means. Some CDR methods fall under the category of geoengineering, while this may not be the case for others, with the distinction being based upon the magnitude, scale, and impact of the particular CDR activities. The boundary between CDR and mitigation is not clear and there could be some overlap between the two given current definitions.

It is useful in this context to refer back to the definition of mitigation and adaptation previously used by the IPCC in its Fourth Assessment Report. It should be noted that the expert meeting did not address the question of whether these definitions should be updated to differentiate them better from geoengineering.

Mitigation refers to "technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks" (IPCC, 2007: 84).

Adaptation refers to "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. *anticipatory* and *reactive*, *private* and *public* and *autonomous* and *planned*. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones etc." (IPCC, 2007: 76).

Based upon the above definitions, the following schematic represents an illustration of the conceptual relationship between SRM, CDR, mitigation and adaptation, in the context of the interdependent human and climatic systems (Figure 1.1).

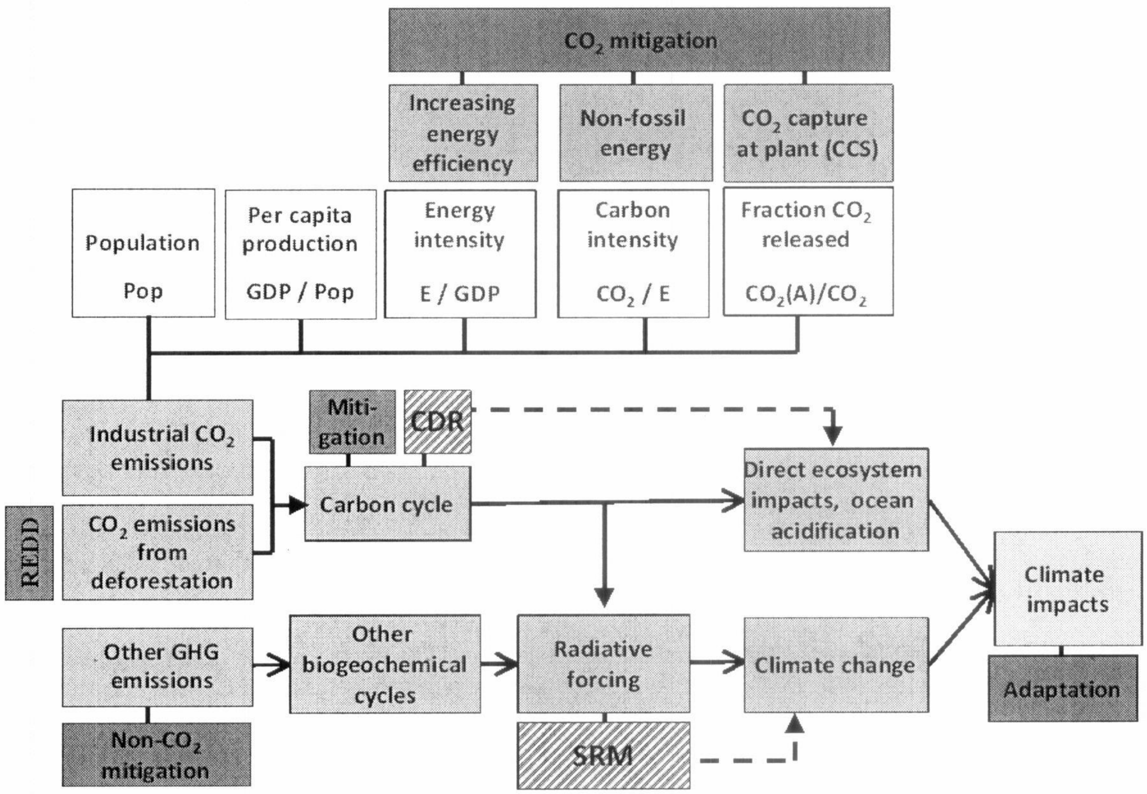

Figure 1.1: *Illustration of mitigation, adaptation, Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) methods in relation to the interconnected human, socio-economic and climatic systems and with respect to mitigation and adaptation. The top part of the figure represents the Kaya identity. REDD stands for Reduced Emissions from Deforestation and forest Degradation. The Figure has been revised after the meeting.*

2. Emerging Issues for Consideration in the AR5

A number of points arose repeatedly in breakout and plenary sessions and were therefore highlighted during the synthesis session.

Because of the longstanding ambiguity surrounding the term geoengineering, it is suggested that in the AR5, when assessing geoengineering options, the individual methods discussed might be referred to more specifically, i.e., by CDR and SRM rather than geoengineering, or when appropriate by the specific terms, e.g., cloud brightening, stratospheric aerosols, ocean fertilization, etc. The term geoengineering could be introduced at the beginning of each WG report and the synthesis report.

- The risks and impacts of geoengineering techniques might be best assessed within the context of the risks and impacts of climate change and other responses to climate change such as mitigation and adaptation, rather than in isolation.
- CDR and SRM methods might be assessed with a common framework of criteria; for a holistic (i.e., inclusive of all potentially relevant aspects) comparison of response options, it could be valuable if the framework were also applied simultaneously to mitigation and adaptation responses. The following list of criteria is proposed for consideration by AR5 authors but is likely not to be comprehensive and would need to be carefully evaluated as part of the assessment process:
    - Effectiveness – could assess how effective the technique would be at achieving its specified goal (i.e., in removing CO_2 out of the atmosphere for CDR methods, or changing the radiative budget and/or reducing specific climate change impacts for SRM methods);
    - Feasibility – could assess the state of technological/engineering readiness for deployment of the technique (at a small scale; i.e., separate from assessing the physical or social challenges of expanding it to large-scale deployment);
    - Scalability – could combine assessments of both physical (i.e., climatic, environmental, resource-related) and social (i.e., economic, political) limits on how much and how fast deployment of the technique could be scaled up to achieve a specified goal;
    - Sustainability – could combine assessments of the reversibility of impacts and assumed longer-term commitments associated with deployment of the technique, evaluated against baseline scenarios for climate change and diverse socioeconomic pathways. Links to the precautionary principle could be considered;
    - Environmental risks – could identify and assess the physical, chemical, biological and climatic risks associated with the technique (including, but not limited to, residual climate change impacts, unintended consequences, risks inherent in the irreversibility or termination issues assessed in the sustainability criteria);
    - Costs and affordability – could combine assessments of (a) the costs of implementing and operating the technique (direct costs) with (b) the cost valuations for potential social and environmental externalities generated by the technique or its failure (indirect costs). Costs would need to be evaluated against a set of baseline mitigated and unmitigated climate scenarios;
    - Detection and attribution – could assess the extent to which both targeted and unintended consequences of the technique could be detected and attributed to its deployment (i.e., verification of CO_2 withdrawal for CDR, or identification of climatic impacts for SRM);
    - Governance challenges – could assess the legal and regulatory issues (local, national and international) that are or could be associated with the technique, along with an assessment of whether/how current institutions address these issues;
    - Ethical issues – could identify the variety of ethical issues that are or could be raised by the technique;
    - Social acceptability – could assess current knowledge of the social acceptability of the technique;
    - Uncertainty related to all of the above mentioned criteria.
- In order to ensure consistency in the treatment of geoengineering in the AR5 using a common framework, an informal group of AR5 Lead Authors from all three working groups might be formed. This might help to arrive at a 'holistic' assessment of geoengineering in the AR5.
- Once sufficient knowledge and published literature on SRM and CDR methods become available, the IPCC might want to consider a joint Special Report on Geonengineering post AR5.
- As the deployment of some geoengineering technologies could have profound long-term implications for global society, assessment of the proposed methods will need to consider timescales extending at least up to, and likely well beyond, 2100.

3. Specific Discussion Points on Solar Radiation Management Methods

As defined above, SRM refers to the intentional modification of the Earth's shortwave radiative budget with the aim of reducing climate change with respect to a given set of criteria. Specific examples include the artificial injection of stratospheric aerosols, low-level cloud brightening through the injection of sea-salt particles in the marine boundary layer, or brightening of the Earth's surface. No attempt was made to assess or further categorize these methods during the Expert Meeting; such attempts have been made elsewhere, most prominently in Royal Society (2009). A number of discussion points during the Expert Meeting were specific to SRM methods and are summarised here.

One suggestion was that the costs, benefits and risks associated with SRM techniques might be treated 'holistically' whenever possible. For assessing costs, this would require simultaneously considering both the costs of implementation and the costs of social and environmental externalities, which cover the (intended and unintended) costs of the impacts of implementing SRM. Similarly, for assessing the risks, the potential risks of implementing SRM would be evaluated alongside the potential risks of other climate change scenarios. For costs and risks, issues of residual climate change (e.g., components of climatic change left or even exacerbated after SRM implementation), expected and unintended consequences, and long-term issues of reversibility and termination would be considered.

AR5 authors might want to consider using a coherent framework for assessing SRM techniques across the IPCC Working Groups. Such a framework would require at least two components: (1) a common set of criteria for evaluation (the list provided in Section 3 could be a starting point for this); and (2) an agreement on baselines for comparisons (or at least an explicit statement of assumptions about baselines). Particularly for (2), modelling or discussions of SRM could compare scenarios with SRM against a variety of baselines – pre-industrial (i.e., a world with no climate change), present-day, or various future-climate scenarios. A holistic treatment of SRM would require examining the costs, benefits and risks of SRM in conjunction with mitigation and adaptation measures.

The expert meeting participants identified a variety of gaps in current understanding that AR5 authors will need to contend with as part of a comprehensive assessment. Those are presented here in terms of the prospective evaluation criteria suggested in Section 3. The current literature on the effectiveness, feasibility and scalability of SRM techniques is based on limited theoretical and modelling studies, with very limited empirical data (with the exception of the natural analogue of volcanic eruptions for stratospheric aerosols and ship tracks for marine cloud brightening). Knowledge gaps are more pronounced for the assessment of sustainability or environmental risks. Comparability of existing modelling studies is limited, and potential regional climate responses to SRM remain largely unexplored, but the Geoengineering Modelling Intercomparison Project (GeoMIP) is now underway (Kravitz et al., 2011). Existing literature on the costs and affordability of SRM are limited primarily to implementation (direct) costs, and even then there is limited literature for even the most prominent techniques; indirect costs and possible impacts are poorly explored, particularly in relative comparisons against ongoing climate change. There are very few studies discussing the potential for detection and attribution of SRM impacts. At present there is a small but rapidly growing body of literature on the governance challenges and ethical issues associated with SRM techniques. Literature on social acceptability and perceptions is only starting to emerge.

4. Specific Discussion Points on Carbon Dioxide Removal Methods

As defined above, CDR includes a broad set of methods involving the land, the ocean, and technological systems, all aiming to increase the rate of net removal of CO_2 from the atmosphere. One may want to expand CDR to include all greenhouse gases, such as CH_4 and N_2O, but this was not further discussed at the meeting. No assessment was undertaken at the meeting, but an attempt was made to categorize the CDR methods into a set of broad categories.

Ocean-based methods to remove CO_2 from the atmosphere fall into two broad sets, i.e., those that employ changes in the ocean's chemistry to enhance the absorption of CO_2 from the atmosphere and those that employ changes in the ocean's biological pump. The latter might be accomplished either by fertilizing the ocean with micronutrients, such as iron, or by fertilizing it with macronutrients, such as nitrate and/or phosphate.

The physically based method of direct CO_2 injection in the ocean, such as direct injection of CO_2 with subsequent dissolution or direct injection with the addition of alkalinity to neutralize the CO_2, is also commonly discussed in the framework of geoengineering and CDR. In comparison to the chemical and biological CDR methods, which directly remove CO_2 from the atmosphere and store (part of it) in the ocean, direct injection covers the storage part of the process only and therefore requires first an engineered capture process. Therefore, in order to compare this method with other CDR methods, where the capture process is inherently included, direct injection needs to be considered together with the capture process (IPCC, 2005). However, the experts at the meeting did not make a specific recommendation how exactly this should be accomplished.

Land-based methods can be categorized into those that enhance natural sinks and those that reduce natural sources, particularly by reducing terrestrial respiration. Sink-enhancing CDR methods include afforestation/reforestation, bioenergy with Carbon Capture and Storage (IPCC, 2011), fertilization of land plants, and enhanced weathering on land. Source reduction CDR methods include the production and deployment of "biochar", the application of no till and conservation agriculture, and biomass burial. This list is not exhaustive and no attempt was made at the meeting to provide a complete one.

Direct air capture by various methods is technologically closely related to the capture of CO_2 at a point emission source, but since it involves the atmosphere as a transport and storage agent, it needs to be considered as a CDR method. In order for direct air capture to work as a CDR, the captured CO_2 needs to be stored (see IPCC, 2005).

A large part of the discussion on CDR in breakout and plenary sessions centered around the question: Which CDR methods can and should be generally considered as geoengineering? Not all CDR methods automatically fall into the category of geoengineering, but at least two key characteristics separate CDR methods and particular applications that ought to be considered as geoengineering from those that ought not to be. These two criteria are scale of deployment and scale of impact, particularly with regard to transnational impacts and consequences (Figure 1.2). No conclusions were reached on the exact location of the boundary, i.e., what specific scale and what specific impact separate geoengineering from non-geoengineering methods. It was mentioned that this boundary also depends on the type of impact as well as the timescale under consideration.

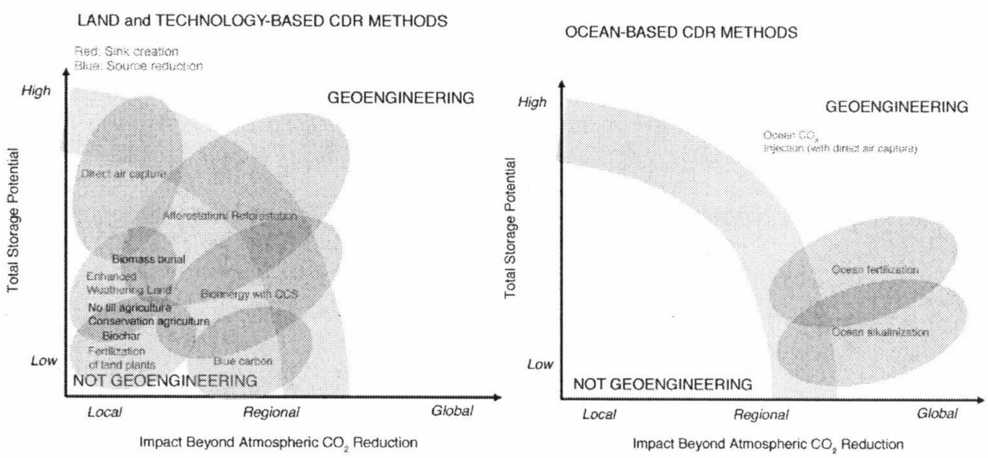

Figure 1.2: *Scale and impact are important determinants of whether a particular CDR method and specific application should be considered as geoengineering or not. Note that the specific positioning of the different methods is only illustrative and does not constitute a consensus view of the experts participating in the meeting.*

This framework also implies that a particular method per se does not fall inside or outside the realm of geoengineering, since any CDR method theoretically can fall on either side of the boundary. It is really the scale of deployment and the scale of impact that determines where a method falls.

The expert meeting-participants identified the following gaps, among others, in understanding with regard to CDR. There is highly limited understanding of the relationship between the scale of deployment and the scale of impact, and there is little knowledge of the nature of the large-scale impact beyond the CO_2 benefit for most methods. Important issues are associated with the longevity of a particular method, i.e., what fraction of the removed carbon will return back to the atmosphere after a particular time. Very little is known about the economic costs of many methods, especially when deployed at the large scale. Finally, social acceptability is recognized as a potentially important regulator of the potential future application of CDR, but only a few methods have been assessed.

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Annex 1: Meeting Proposal

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INTERGOVERNMENTAL PANEL ON climate change

THIRTY-SECOND SESSION OF THE IPCC

Busan, 11-14 October 2010

IPCC-XXXII/Doc. 5

(3.IX.2010)

Agenda Item: 4.2

ENGLISH ONLY

THE IPCC FIFTH ASSESSMENT REPORT (AR5)

Proposal for an IPCC Expert Meeting on Geoengineering

(Submitted by the Co-Chairs of Working Group I, II and III)

IPCC Secretariat

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WMO UNEP

PROPOSAL FOR AN IPCC EXPERT MEETING ON GEOENGINEERING

(Submitted by the Co-Chairs of Working Group I, II and III)

Background

Geoengineering, or the deliberate large-scale manipulation of the planetary environment, is increasingly being discussed as a potential strategy to counteract anthropogenic climate change. Prevailing uncertainty in the sensitivity of the climate system to anthropogenic forcing, inertia in both the coupled climate-carbon cycle and social systems, and the potential for irreversibilities and abrupt, nonlinear changes in the Earth system with possible significant impacts on human and natural systems call for research into possible geoengineering options to complement climate change mitigation efforts.

Geoengineering methods can be largely classified into two main groups: Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR). While both approaches aim to reduce global temperatures, they clearly differ in their modes of action, the timescales over which they are effective, their effects on temperature and other climate variables (e.g., precipitation), and other possible consequences.

SRM techniques attempt to offset the effects of increased greenhouse gas concentrations by reducing the amount of solar radiation absorbed by the Earth. This may be achieved by increasing the surface reflectivity of the planet, for example by brightening human structures, planting crops with a higher albedo, or covering deserts with reflective material. Other techniques aim to enhance marine cloud reflectivity by introducing sea salt aerosols in low clouds, mimic the effects of volcanic eruptions by injecting sulphate aerosols into the lower stratosphere, or place shields or deflectors in space to reduce the amount of incoming solar radiation.

CDR techniques aim to address the cause of climate change by removing greenhouse gases from the atmosphere. This would include advanced land use management strategies to protect or enhance land carbon sinks, and the use of biomass for both carbon sequestration (including biochar) and as a carbon neutral energy source. The removal of carbon dioxide from the atmosphere, either through the enhancement of natural weathering processes or direct capture from ambient air are further examples, as well as the enhancement of oceanic CO_2 uptake through ocean fertilisation with scarce nutrients or the enhancement of upwelling processes.

Major uncertainties exist regarding the effects of these techniques on the physical climate system and on biogeochemical cycles, their possible impacts on human and natural systems, and their effectiveness and costs. SRM, for example, could impact regional precipitation patterns while offering no solution for CO_2-induced ocean acidification. Unilateral action may have environmental side effects on other countries and regions, and may not appropriately address the global scale of the issue. Thus, geoengineering itself may constitute "dangerous anthropogenic interference with the climate system" (Article 2, UNFCCC), and consideration needs to be given to international governance frameworks.

Expert Meeting

Current discussions that suggest geoengineering as an option to support climate mitigation efforts remain rather abstract and lack comprehensive risk assessments that take into account possible adverse impacts over short and longer time frames. The understanding of the physical science basis of geoengineering is still limited and IPCC will, for the first time, assess this in several chapters of the WGI contribution to AR5. Improved scientific understanding of the impacts of geoengineering proposals on human and natural systems will be assessed by WGII. WGIII needs to take into account the possible impacts and side effects and their implications for mitigation cost in order to define the role of geoengineering within the portfolio of response options to anthropogenic climate change. Furthermore, this includes an evaluation by WGIII of options for appropriate governance mechanisms.

Objectives

The aim of the proposed expert meeting is to discuss the latest scientific basis of geoengineering, its impacts and response options, and to identify key knowledge gaps. The expert meeting would be organised by Working Group III with a cross-Working-Group focus. The following issues will be discussed in more detail:

- different geoengineering options, their scientific basis and associated uncertainties;
- associated potential risks and related knowledge gaps;
- effect of impacts and side effects on mitigation cost and the role within the portfolio of mitigation options;
- suitability of existing governance mechanisms for managing geoengineering, including social, legal and political factors;
- key knowledge gaps that could be filled in the shorter and longer terms.

Expected Outcome

The expert meeting will provide a platform for exchange and discussion among experts from the different disciplines in order to better address the important cross-cutting issue of geoengineering. This should also encourage the consistent treatment of geoengineering options across the WGs' assessments that will build the basis for the AR5 Synthesis Report.

The Expert Meeting will produce a report that could include summaries of keynote presentations, abstracts of expert contributions, reports from breakout group discussions, and a non-comprehensive bibliography of recent literature related to geoengineering.

Organization

A Scientific Steering Group will be formed with relevant experts in geoengineering from the IPCC Working Groups.

Timing: first half of 2011

Duration: 2 to 3 days

Participants: About 40 invited experts, with broad international representation. It is proposed that 25 journeys for experts from developing countries and economies in transition including Co- and Vice-Chairs from all Working Groups are allocated as part of the line item "expert meetings related to the AR5" in the IPCC Trust Fund budget for 2011. Participants will be needed with expertise in:

- WGI: clouds/aerosols & climate, carbon cycle & climate, coupled climate - carbon cycle projections
- WGII: impacts on human and natural systems
- WGIII: bottom-up modelling experts, risk analysis, integrated assessment modelling groups, governance and international cooperation.

Annex 2: Agenda

Agenda for the Joint IPCC WGI/WGII/WGIII Expert Meeting on Geoengineering

Lima, Peru, 20-22 June 2011

Monday, 20 June 2011

8:00 Registration

8:30 Welcome and Introduction

- Welcome Address (Local Host)
- Welcome Address (WG I, II & III Co-Chairs)

8:45 FRAMING PLENARY: Overview on Current State of Science, Geoengineering Options, Current Activities (Chair: Ramon Pichs-Madruga)

8:45-9:00	Framing Keynote F-1: The Joint Expert Meeting on Geoengineering in the Context of the IPCC's Fifth Assessment Cycle (Ottmar Edenhofer, Thomas Stocker, Christopher Field)
9:00-9:30	Framing Keynote F-2: Geoengineering: A few basic ideas to start our discussion (Granger Morgan)
9:30-10:45	Panel Reactions and Discussion (Moderator: Nicolas Gruber; Panelists: Alan Robock, Granger Morgan, Robert Scholes, Shreekant Gupta)

10:45 Coffee Break

11:15 PLENARY SESSION I: Solar Radiation Management (Chair: Thomas Stocker)

11:15-11:35	Keynote I-1: Science and Technology of Solar Radiation Management (Alan Robock)
11:35-11:55	Keynote I-2: Residual Climate Change and Unintended Consequences of Solar Radiation Management (Thomas Peter)
11:55-12:15	Keynote I-3: A Primer on the Economics of Solar Radiation Management (Scott Barrett)
12:15-12:45	Discussion

12:45 Lunch

13:45 PLENARY SESSION II: Carbon Dioxide Removal (Chair: Chris Field)

13:45-14:05	Keynote II-1: Carbon Dioxide Removal in the Oceans: Biological, Chemical, and Physical (Nicolas Gruber)
14:05-14:25	Keynote II-2: Carbon Dioxide Removal on Land: Biological and Chemical (Peter Cox)

14:25-14:45 Keynote II-3: Industrial CO_2 Removal: CO_2 Capture from Ambient Air and Geological Sequestration (James Dooley)

14:45-15:15 Discussion

15:15 Introduction to Breakout Groups (BOGs) (Ottmar Edenhofer)

15:30 Coffee Break

16:00 BREAKOUT GROUPS I: Options, Scope and Key Approaches

17:30 Poster Presentations: Short introduction of poster topics (Chair: Youba Sokona)

18:00 Poster Session

19:00 Adjourn

Reception (On-Site)

Tuesday, 21 June 2011

8:30 Summary of Day 1 and Introduction to Day 2 (IPCC Co-Chairs)

8:35 BOG I Reports and Plenary Discussion (Chair: Ramon Pichs-Madruga)

9:30 PLENARY SESSION III: Cross-cutting Issues: Risk, Time Scales and Governance

(Chair: Ottmar Edenhofer)

9:30-9:50 Keynote III-1: Policy, Governance and Socio-Economical Aspects of Geoengineering (Catherine Redgwell)

9:50-10:10 Keynote III-2: International Cooperation and the Governance of Geoengineering (Arunabha Ghosh)

10:10 Coffee Break

10:40 PLENARY SESSION III: Cross-cutting Issues: Risk, Time Scales and Governance (Cont'd)

(Chair: Youba Sokona)

10:40-11:00 Keynote III-3: Geoengineering in a Risk Management Framework (Granger Morgan)

11:00-11:20 Keynote III-4: The Role of Different Geoengineering Options in Long-Term Responses to Climate Change (Jason Blackstock)

11:20-12:00 Discussion

12:00 Lunch

13:00 BREAKOUT GROUPS II: Cross-cutting Issues: Risk, Time Scales and Governance

14:30 BOG II Reports and Plenary Discussion (Chair: Chris Field)

15:30 Coffee Break

16:00 BREAKOUT GROUPS III: Working Group I, II, III Perspectives

17:30 BOG III Reports and Plenary Discussion (Chair: Thomas Stocker)

18:30 Adjourn

Reception (Off-Site)

Wednesday, 22 June 2011

9:00 SYNTHESIS PLENARY: Synthesis of previous talks and BOG discussions (Chair: Chris Field)

9:00 Synthesis Presentation S-1: Meeting perspectives for SRM (by SSG Members) & Discussion

9:30 Synthesis Presentation S-2: Meeting perspectives for CDR (by SSG Members) & Discussion

10:00 Plenary Discussion

10:30-11:00 Coffee Break

11:00-13:00 FINAL PLENARY (Chair: Ottmar Edenhofer)

- Final discussion and approval of any recommendations to AR5 authors, including suggestions for potential glossary entries for the AR5
- Closing remarks by Co-Chairs

13:00 Lunch

14:00 Adjourn

Annex 3: Keynote Abstracts

FRAMING PLENARY: Overview on Current State of Science, Geoengineering Options, Current Activities

Chair of Session: Ramon Pichs-Madruga

Framing Keynote F-1: The Joint Expert Meeting on Geoengineering in the Context of the IPCC's Fifth Assessment Cycle
Presenters: Ottmar Edenhofer, Thomas Stocker and Christopher Field[1]*

Framing Keynote F-2: Geoengineering: A few basic ideas to start our discussion
Presenter: Granger Morgan

PLENARY SESSION I: Solar Radiation Management

Chair of Session: Thomas Stocker

Keynote Presentation I-1: Science and Technology of Solar Radiation Management
Presenter: Alan Robock

Keynote Presentation I-2: Residual Climate Change and Unintended Consequences of Solar Radiation Management
Presenter: Thomas Peter

Keynote Presentation I-3: A Primer on the Economics of Solar Radiation Management
Presenter: Scott Barrett

PLENARY SESSION II: Carbon Dioxide Removal

Chair of Session: Chris Field

Keynote Presentation II-1: Carbon Dioxide Removal in the Oceans: Biological, Chemical, and Physical
Presenter: Nicolas Gruber

Keynote Presentation II-2: Carbon Dioxide Removal on Land: Biological and Chemical
Presenter: Peter Cox

Keynote Presentation II-3: Industrial CO_2 Removal: CO_2 Capture from Ambient Air and Geological Sequestration
Presenter: James Dooley

* The abstract for Framing Keynote F-1 is not provided in this compilation.

PLENARY SESSION III: Cross-cutting Issues: Risk, Time Scales and Governance

Chair: Ottmar Edenhofer

Keynote Presentation III-1: Policy, Governance and Socio-Economical Aspects of Geoengineering
Presenter: Catherine Redgwell

Keynote Presentation III-2: International Cooperation and the Governance of Geoengineering
Presenter: Arunabha Ghosh

PLENARY SESSION III: Cross-cutting Issues: Risk, Time Scales and Governance (Cont'd)

Chair of Session: Youba Sokona

Keynote Presentation III-3: Geoengineering in a Risk Management Framework
Presenter: Granger Morgan

Keynote Presentation III-4: The Role of Different Geoengineering Options in Long-Term Responses to Climate Change
Presenter: Jason Blackstock and Ken Caldeira

Keynote F-2: Geoengineering: A few basic ideas to start our discussion

M. Granger Morgan
Department of Engineering and Public Policy, Carnegie Mellon University, USA

There are basically three ways to change the climate. Adding greenhouse gases (GHGs) warms it. Humans have been doing this in a major way since the industrial revolution. To cool it one can reduce the concentration of GHGs. This is inherently slow, and probably pretty costly. The other thing one can do is increase the albedo (the fraction of incident sunlight that is reflected back to space). This is a very "high leverage" activity and could probably be done quickly and at relatively low cost. The first of these cooling strategies is now generally referred to as CDR, the second as SRM.

Strategies to persue CDR include: 1. Engaging in afforestation and/or reforestation; 2. Employing no-till agriculture; 3. Using biomass fuel with CCS; 4. Engaging in ocean fertilization to increase biotic up-take; 5. Enhancing natural weathering (e.g., add alkalinity to soils); and 6. Directly scrubbing from the air with engineered systems. In the talk, each is described and critiqued briefly.

Strategies to persue SRM include: 1. Adding small reflecting particles in the stratosphere; 2. Adding more clouds in the lower part of the atmosphere; 3. Placing various kinds of reflecting objects or diffraction gratings in space either near the earth or at a stable location (the L1 point) between the earth and the sun; and 4. Changing large portions of the planet's land cover from things that are dark and absorbing, such as trees, to things that are light and reflecting, such as open snow-cover or grasses. Again, in the talk, each is described and critiqued briefly.

Of the four SRM options, adding fine reflective particles to the stratosphere is the most feasible in terms of cost and effectiveness. For this reason, the balance of the talk focuses on this strategy which has the characteristic that it is fast, cheap and imperfect. The discussion focuses in particular on the ways in which SRM is imperfect. It argues that while learning more about SRM carries dangers, today the risks of not knowing more outweigh those risks.

The talk was assembled quickly after David Keith, who was originally going to present the opening keynote, got stuck in Calgary, and then Ken Caldeira, who had agreed to replace him, got stuck in Houston. The talk concludes with summary views from both of them. The author then argues that, while it is very important to do research, great caution must be exercised about doing anything more than that in the case of CDR that has large-scale ecosystem impacts, and of SRM.

Keynote I-1: Science and Technology of Solar Radiation Management

Alan Robock[1]
Philip J. Rasch[2]
[1]*Department of Environmental Sciences, Rutgers University, New Brunswick, NJ, USA*
[2]*Atmospheric Science and Global Change Division, Pacific Northwest National Laboratory, Richland, WA, USA*

In response to the global warming problem, there has been a recent renewed interest in geoengineering "solutions" involving "solar radiation management" (SRM) by injecting particles into the stratosphere, brightening clouds, brightening the surface, or blocking sunlight with satellites between the Sun and Earth. This class of geoengineering is distinct from carbon dioxide removal (CDR) strategies that counter climate change by reducing the concentration of CO2. A quite comprehensive discussion of both classes of methods can be found in a special report by the Royal Society (2009) and a volume of papers edited by Launder and Thompson (2010). The scientific issues associated with SRM will be explicitly discussed in Chapters 1 and 7 of the WGI contribution to the 5th IPCC Assessment.

Although weather and climate modification has been considered for at least a century, the idea of deliberately cooling the planet by increasing its reflectivity probably dates back to Budyko (1974), who proposed that if global warming ever became a serious threat, society could counter it with airplane flights in the stratosphere burning sulphur to make aerosols (small particles), similar to those found after a volcanic eruption. These small particles would reflect some sunlight away, increasing the planetary albedo and cooling the planet, ameliorating some (but as discussed below, not all) of the effects of increasing CO2 concentrations. Many other suggestions have been made since that time. Among them are methods to increase the reflectivity of clouds (Latham and Smith, 1990) introduce space based reflectors located at the L1 point (the orbital position where the gravitational attraction of the Earth and Sun are equal; Early, 1989); and significantly change the albedo of vegetated surfaces by replacing crops or grassland species with more reflective varieties (e.g., Lenton and Vaughan, 2009), of deserts by coating them with brighter material, or of producing bubbles in water to brighten the ocean. New ideas are being considered frequently, and this list is not comprehensive.

The various methods have been evaluated by attempting to estimate the efficacy, cost, and consequences (safety, risks, and benefits) to the planet through economic, engineering and scientific studies. These studies have used computer (economic, scientific and engineering) models to estimate the practicality, costs and outcomes of these SRM strategies. At the time of this writing, there have not been any field activities to explore implementation or testing strategies at a practical level.

While volcanic eruptions have been suggested as innocuous examples of stratospheric aerosols cooling the planet, the volcano analog actually argues that stratospheric geoengineering would produce ozone depletion and regional hydrologic responses. In this talk, I describe different proposed geoengineering designs, and then show climate model calculations that evaluate both their efficacy and their possible adverse consequences. No such systems to conduct geoengineering now exist, but a comparison of different proposed stratospheric injection schemes, using airplanes, balloons, and artillery, shows that using airplanes to put sulfur gases into the stratosphere would not be expensive. Nevertheless, it would be very difficult to create stratospheric sulfate particles with a desirable size distribution. We have just started a GeoMIP project to conduct standard stratospheric aerosol injection scenarios in the context of CMIP5, so as to examine the robustness of the few experiments conducted so far (Kravitz et al., 2011).

If there were a way to continuously inject SO2 into the lower stratosphere, it would produce global cooling, stopping melting of the ice caps, and increasing the uptake of CO2 by plants. But there are many other possible negative consequences that should be considered. These include possible changes to precipitation (e.g., monsoons), ozone depletion, a reduction in the "blueness of the sky," and impacts on solar power production. Furthermore, if SRM were employed to counter a strong greenhouse gas forcing and then stopped abruptly, the planet would warm very rapidly with serious consequences. There are other issues associated with governance and society that need to be considered (informed by the scientific topics described in this talk).

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Keynote I-2: Residual Climate Change and Unintended Consequences of Solar Radiation Management

Thomas Peter
Swiss Federal Institute of Technology (ETH), Zurich, Switzerland

This presentation will address consequences of geoengineering options based on solar radiation management (SRM) introduced in the previous keynote. It will focus on residual climate change and unintended consequences on the climate system from these technologies in the light of current uncertainties.

Using SRM methods it should in principle be feasible to balance the globally averaged radiative forcing from greenhouse gases as precisely as necessary. However, the cancellation of the global mean forcing will not lead to restoring climate change at any given location, with likely residual net impacts on regional climates.

In their report on geoengineering the Royal Society (2009) summarized aspects of residual climate change and unintended consequences of SRM techniques – besides ongoing ocean acidification – as follows:

1. Surface albedo via brightening of human settlements:
    a. Minimal environmental side-effects from materials
    b. Effects on small spatial scales, unlikely to modify weather patterns etc.
2. Surface albedo via brightening of forest canopies, grassland or deserts:
    a. Potentially major environmental and ecological effects on plant ecosystems
    b. Major environmental and ecological effects on desert ecosystems
    c. Localized and non-uniform effect on large scale, probably affecting weather patterns, rainfall etc.
3. Cloud albedo enhancement:
    a. Non-uniformity of effects may change weather patterns, in particular rainfall, on regional scales
    b. Non-uniformity may affect ocean currents
    c. Possible pollution by CCN material (if not sea-salt)
4. Stratospheric aerosol albedo enhancement:
    a. Residual regional effects, particularly on hydrological cycle (rainfall)
    b. Possible adverse effect on stratospheric ozone
    c. Possible effects on high-altitude tropospheric clouds
    d. Shift of partitioning of direct/diffuse light, potential effects on biological productivity
5. Space-based methods (mirrors etc.):
    a. Residual regional climate effects, particularly on hydrological cycle
    b. No known direct biochemical effects on environment beyond possible effects of reduced insolation

Since the publication of the Royal Society report a proposal for one additional potential geoengineering technique has been made (Evans et al., 2010; Seitz, 2011), whose unintended side effects and consequences in terms of residual climate change can presently only be speculated on:

6. Surface albedo enhancement via brightening of oceans:
    a. Reduction of light transmission to lower ocean levels with potential impact on marine ecobalance
    b. Significant ecological effects if artificial surfactants were to be used
    c. Non-uniformity of effects may change weather patterns, rainfall etc. on regional scales
    d. Induced changes in oceanic circulation and anomalous evaporation, which would in turn affect atmospheric heating and atmospheric circulation

While all these proposed techniques should be considered, techniques (3) and (4) have so far found particular interest given their potential advantages in terms of their combined effectiveness, timeliness and affordability (The Royal Society, 2009), and first quantitative comparisons have been published (e.g., Jones et al., 2011). This contribution aims at reviewing all the above techniques in terms of their regional climate effects and unintended side effects: Where do we stand? What are the uncertainties?

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Keynote I-3: A Primer on the Economics of Solar Radiation Management

Scott Barrett
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'Solar radiation management' (SRM) is a term sometimes used for engineering interventions that seek to alter the Earth's climate without affecting the atmospheric concentration of greenhouse gases. Put very crudely, the idea involves an engineering intervention that either increases the reflectivity of the Earth or that reduces the amount of incoming solar radiation before it reaches the Earth (Keith, 2000; Crutzen, 2006). Though engineering serves as a means for accomplishing the end of influencing the climate, "management" may not be the best word to describe its application. There may be sharp disagreement about the circumstances in which this engineering intervention should be considered—or even if it should be considered at all (Robock, 2008). There may also be disagreement about the desired end. (What is the ideal global climate?) The central social, political, legal, and ethical challenges posed by this technology all concern governance (Schelling, 2006; Bodansky, 1996; Barrett, 2008; Victor, 2008). The economics of this form of geoengineering is important mainly because it makes this challenge of governance acute: some forms of geoengineering are very inexpensive (Barrett, 2009).

Possible use of this form of geoengineering should be considered in the context of the other ways in which climate change, and the effects of climate change, can be influenced. Emissions of greenhouse gases can be reduced, to limit increases in atmospheric concentrations; R&D can be undertaken, to lower the costs of reducing emissions in the future; affected parties can adapt, to lower the damages (and possibly to augment the advantages) attributable to climate change; and techniques for "direct carbon removal" can be used to limit concentrations directly.

Anything that affects the climate will have global implications. Countries not involved in the effort will also be affected, for better or worse (making these interventions a global public good or a global public bad). For these reasons, countries have weak incentives individually to reduce their emissions—even though they may have great incentives collectively to do so (Barrett, 2007). This is known as the "free riding" problem. Similarly, because the benefits of R&D are derived from the likelihood that technologies embodying the R&D will be deployed for the purpose of reducing emissions, if the incentives to deploy are weak, the incentives to invest in R&D will be weak (Barrett, 2006). The incentives to adapt will be very powerful. A substantial portion of the benefits from adaptation can be captured by the parties that invest in it. Much of the rest involves the supply of local public goods (dikes being an example), which can be provided by national (or even local) governments, with no need for international cooperation. The incentives to deploy direct carbon removal are mixed. Some approaches are inexpensive, but also limited in scale. Other approaches can potentially be undertaken at a great scale, but are very expensive (Barrett, 2009).

It is sometimes said that SRM creates a "moral hazard"—since SRM can be used to lower temperature in the future, there will be incentives for countries to expend less effort in reducing emissions today (Victor et al., 2009). As Robock (2008) says, "This is the oldest and most persistent argument against geoengineering."

However, while it's true that that these incentives exist, this is an incorrect use of the term. (An example of moral hazard is the International Monetary Fund's role in offer financing to avert a financial crisis—a role that is believed to make such crises more likely to occur.) Moral hazard normally describes a situation in which there are different parties (the IMF and various government) with different interests (the IMF wants not to have to intervene, whereas the government wants to spend money more freely) and information (the IMF can't tell if the government is managing its economy well). Moral hazard results in an economic inefficiency. By contrast, while knowledge that geoengineering could be used to limit climate change in the future will likely influence emissions policy today, that effect need not be inefficient. If SRM were expected to work, and without harmful consequences, it would be desirable for countries to use it—and to ease up on their efforts to reduce emissions today.

There are other reasons why too little effort will be devoted to reducing emissions, perhaps the main one being free riding. Moreover, since the costs of deploying SRM are low, the incentives to deploy it unilaterally or minilaterally will be strong. We will tend to substitute more geoengineering for less emission reductions not because of moral hazard but because of collection action failures (Barrett, 2008).

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Keynote II-1: Carbon Dioxide Removal in the Oceans: Biological, Chemical, and Physical

Nicolas Gruber
Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich, Zurich, Switzerland

Over the last 250 years, the ocean has taken up more than 25% of all anthropogenic emissions (Sabine et al., 2004). While substantial, this is much less than its long-term uptake potential, which corresponds to an uptake fraction of approximately 80% of all emissions on a time-scale of ~500 years, and more than 95% on time-scales longer than 100'000 years. The former potential involves primarily the solution of CO_2 into seawater and subsequent reactions with its dissolved constituents, while the latter involves also interactions with the marine and terrestrial carbonate system. Given the large potential of the ocean carbon sink and the slowness with which this potential is being realized, it is not surprising that the idea of shortcutting the slow process of ocean uptake by injecting CO2 directly into the ocean emerged already in the late 1970s (Nordhaus, 1975; Marchetti, 1977). Recognizing that such a direct injection of CO_2 would lead to a massive decrease in oceanic pH and saturation state of the seawater with regard to mineral forms of $CaCO_3$ (ocean acidification), it was later suggested to add alkalinity in the form of limestone to the injected CO_2 to compensate (Rau and Caldeira, 1999). Even later, the direct addition of limestone to the ocean was proposed, which would not only compensate for ocean acidification, but also increase the uptake of CO_2 from the atmosphere (Harvey, 2008). An entirely different family of proposed options to use the ocean to remove CO_2 from the atmosphere emerged in the late 1980s, i.e., those that attempt to enhance the ocean's biological pump by fertilizing the ocean with limiting nutrients, in particular iron (Martin, 1990). This fertilization is meant to increase the near-surface photosynthetic fixation of CO_2 by marine algae into organic matter, part of which would escape respiration and remineralization and sink down to great depths, where it would remain sequestered from the atmosphere. This net removal of dissolved CO_2 from the surface ocean would then be compensated by uptake of CO_2 from the atmosphere, creating a net removal of CO_2 from the atmosphere. Several modification of this hypothesis have been suggested since then, including the addition of macronutrients such as phosphorus to the ocean, the enhancement of oceanic nitrogen fixation, and an increase in upper ocean mixing to provide higher levels of nutrients to surface ocean algae.

In summary, we can categorize the ocean-based methods to remove CO_2 from the atmosphere into three broad sets:

- physically-based methods: primarily direct injection of liquid CO_2 into the ocean
- chemically-based methods: primarily based on the addition of alkalinity to the ocean
- biologically-based methods: primarily based on the enhancement of the ocean's biological pump.

This plenary talk aims to provide a short introduction to each of the three main categories and will make an attempt to assess their technical potential, their effectiveness, their technical readiness, and the main benefits and risks involved. It will draw extensively on the rich literature that exists on ocean-based CO_2 removal methods. In particular, the physically-based methods have been investigated and assessed in detail in IPCC's special report on carbon capture and storage (IPCC, 2005), while the chemically and biologically-based methods have been summarized in the Royal Society Report on Geoengineering (The Royal Society, 2009).

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Keynote II-2: Carbon Dioxide Removal on Land: Biological and Chemical

Peter Cox
University of Exeter, UK

This talk will review land-based Carbon Dioxide Removal (CDR) techniques based on chemical and biological approaches. Free-air capture of CO_2 through physical processes will be covered in a subsequent talk.

The Royal Society (2009) considered CDR approaches to be relatively low risk compared to SRM geoengineering, as CDR deals with the primary cause of anthropogenic climate change and ocean acidification. Nevertheless, many of the proposed land-based CDR techniques imply land-use changes that could have consequences for regional climates and ecosystem services. Such issues cut across all three of the Working Groups of the IPCC AR5.

Chemical approaches to CDR rely on accelerating the natural processes of rock weathering, which removes CO_2 from the atmosphere on multi-millenial timescales. One land-based approach would involve spreading Olivine (Mg2SiO4) over agricultural fields to enhance weathering by one or two orders of magnitude (Schuiling and Krijgsman, 2006). Some studies suggest that the carbon sink produced would be relatively small: 0.1 to 1% of current global CO_2 emissions (Hartmann and Kempe, 2008; Hangx and Spiers, 2009). In general, **enhanced weathering** methods typically involve mining and moving a larger mass of minerals than the CO_2 captured, so they may also be expensive (The Royal Society, 2009).

Land-based biological CDR involves diverting carbon captured by plants to long-lived reservoirs. The different approaches are typically distinguished by the nature of the long-lived carbon store:

> **Afforestation** involves planting new forests to accumulate and store carbon. Although relatively benign, in the absence of harvesting, the ultimate accumulated sink is limited by the additional carbon "carrying capacity" of the land, which is probably of the order of 150-200 GtC.
>
> **Biochar** (or charcoal) can be created by thermally-decomposing biomass in a low oxygen environment. Most proposals involve adding biochar to soil to increase carbon storage and improve agricultural productivity. The potential sink by 2100 has been estimated to be significant at 5.5-9.5 GtC/yr (Lehmann et al., 2006). However, the long-term effects on land ecosystems are not well known, and there are few estimates of economic costs.
>
> **Biomass Burial** is an alternative which involves burying wood in anoxic environments (e.g. deep in the soil, Zeng, 2008) where decomposition would be much slower. Estimates of the size of the sink are disputed but are likely to be limited by the cost of burial and competition for biomass with other approaches (e.g. Biochar and BECCS). Lenton (2010) estimates a potential carbon sink of less than 1 GtC/yr, and warns of the possibility of counter-productive emissions of methane from anaerobic decomposition.
>
> **Bioenergy with Carbon Sequestration (BECS)** is a hybrid approach in which bioenergy crops are grown and used as fuel, and the CO_2 emissions are captured and stored. BECS could yield a large potential carbon sink (3-10.5 GtC/yr; Lenton, 2010), and might even be used to lower atmospheric CO_2. However, it has the same issues as biofuels and conventional CCS, namely potential conflicts for food production and the requirement for safe geological CO_2 storage. BECS will be considered in more detail in a subsequent talk, but is included here for comparison.

The Royal Society (2009) evaluated each of the CDR approaches based on their climate effectiveness, affordability, and safety, concluding that most were likely to be significantly more expensive than conventional CCS. A recent review by Lenton (2010) attempted to quantify the potential contribution of the various biological CDR approaches to stabilization of atmospheric CO_2 (see Figure A.3.1, which is based on the upper limits given by Lenton, 2010). These figures suggest that biochar and BECS could together contribute a carbon sink of 14 GtC/yr by 2100.

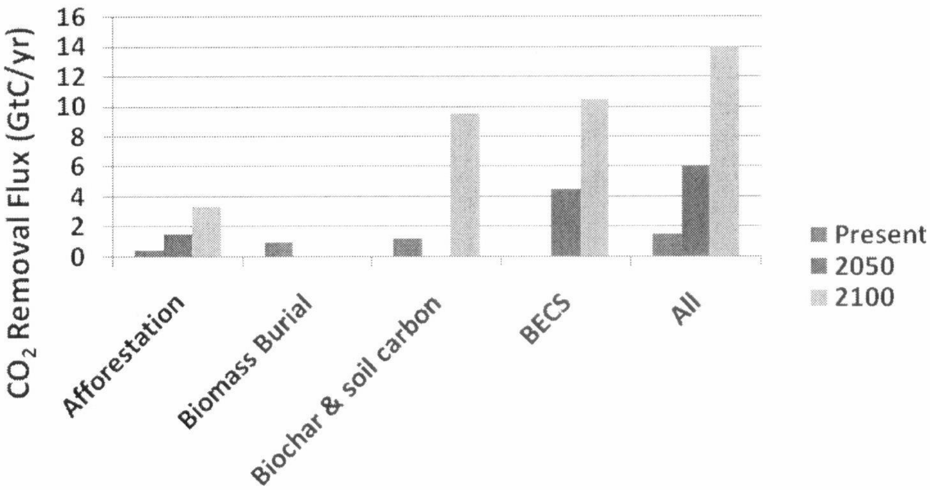

Figure A.3.1: *Potential effectiveness of land –based biological CDR (based on upper limits from Lenton, 2010).*

This talk will summarise these studies and finish by identifying some discussion points concerning the treatment of land-based CDR in the IPCC 5th Assessment Report.

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Keynote II-3: Industrial CO_2 Removal: CO_2 Capture from Ambient Air and Geological

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INTRODUCTION This abstract and its accompanying presentation, which were prepared as inputs for the IPCC's June 2011 Expert Meeting on Geoengineering, will provide an overview of two distinct industrial processes for removing carbon dioxide (CO_2) from the atmosphere as a means of addressing anthropogenic climate change. The first of these is carbon dioxide capture and storage (CCS) coupled with large-scale biomass production (hereafter referred to as bioenergy with carbon dioxide capture and storage (BECSS)). The second CCS coupled to a system that captures CO_2 from ambient air via industrial systems (hereafter referred to as direct air capture (DAC)). In both systems, the captured CO_2 would be injected into deep geologic formations so as to isolate it from the atmosphere. The technical literature is clear that both BECSS and DAC (including their necessary CCS components) are technically feasible as of today (IPCC, 2005; Keith et al., 2006; Lackner, 2009; Luckow et al., 2010; Ranjan and Herzog, 2011; The Royal Society, 2009). The technical literature on DAC and BECSS typically envisions these systems being deployed after the middle of this century and typically in "overshoot scenarios" or in scenarios that stabilize radiative forcing at very low levels (Azar et al., 2010; K. Calvin et al., 2009). What is uncertain is the relative cost of BECSS and DAC systems when compared to other emissions mitigation measures, the ultimate timing and scale of their deployment, net lifecycle emissions from these systems, and the resolution of potential site specific constraints that would impact their ultimate commercial deployment.

BECCS: Considerable concern has been expressed in the technical literature about the inherent conflict between using land to grow food to feed a growing global population and using land to grow energy crops. Concerns have been expressed in terms of: broad sustainability issues including environmental justice and equity concerns (see for example, Adger et al., 2006; Toth, 1999), whether or not there will be net reductions in greenhouse gas emissions from large scale bioenergy production and consumption (Melillo et al., 2009), whether it is possible to move the required volumes of biomass (Richard, 2010) and even in terms of technical feasibility given a changing climate that could result in lower net primary productivity over large swaths of the earth's prime agricultural areas (Lobell and Asner, 2003; Solomon et al., 2009). While not minimizing these concerns, it is important to note that most of these adverse impacts will become manifest at large levels of bioenergy production (e.g., on the order of 100s of EJ/year) and there are steps that can be taken to minimize the worst of these impacts. For example Wise et al. (2009) demonstrated that a climate policy that places an equal value on carbon emissions from the industrial sector as well as from agriculture and land use can simultaneously incentivize the large scale production of bioenergy as well as incentivize afforestation and protect carbon already stored in above ground and below ground biomass and soils. While Luckow et al (2010) make it clear that "The ability to draw on a diverse set of biomass-based feedstocks helps to reduce the pressure for drastic large-scale changes in landuse and the attendant environmental, ecological, and economic consequences those changes would unleash." However, to support BECSS on the scale of 100s of EJ/year would require large bioenergy plantations and significant international trade in bioenergy feedstocks, which could imply significant changes in key global ecosystems (see for example, Thomson et al., 2010). However by adopting technologies that would push densification, dehydration, and pelletization of the purpose grown biomass early into the harvesting process large scale international trade in biomass should be possible and thus there would not need to be a strict correspondence between where the bioenergy crops are grown and where the bioenergy crops are used and therefore where the CO_2 needs to be stored in suitable deep geologic formations (Hamelinck et al., 2005; Luckow et al., 2010). The extent to which there are continued improvements in crop productivity including efforts to enhance the efficiency of natural photosynthesis will be a significant determinant in the extent to how much bioenergy can be produced (Berndes et al., 2003; Blankenship et al., 2011; Thomson et al., 2010; Wise et al., 2009) and therefore on the cost and market potential for BECSS. According to the literature surveyed here, large scale BECSS production on this scale should be well underway at carbon permit prices less than \$100/tCO_2 (Krey and K. Riahi, 2009; Luckow et al., 2010).

DAC: There are a number of excellent recent summaries of various DAC system concepts that can provide a robust introduction to DAC technologies (IPCC, 2005; Ranjan and Herzog, 2011; Socolow et al., 2011; The Royal Society, 2009). At their most basic level, DAC systems use a chemical solvent to selectively remove CO_2 from the ambient air, that solvent is then regenerated releasing a concentrated CO_2 stream, which then is compressed most likely to a supercritical fluid and then injected into the deep subsurface and monitored for long-term permanence. Ranjan and Herzog (2011) as well as Socolow et. al., (2011) estimate that the cost of deploying DAC systems capable of removing hundreds of millions to billions of tCO_2/year from the atmosphere in the range of \$600-\$1200/tCO_2, while others have placed the cost of DAC systems within a much lower range. Keith et al., (2006) reports a cost of \$50-130tCO_2, while Lackner (2009) reports costs in the range of \$30-\$200/tCO_2. The difference in costs between these two views as to the ultimate economic feasibility of

DAC systems is remarkable and speaks to the lack of real world experience with large DAC systems. It is clear that there are significant differences in the way a number of key factors are parameterized in the DAC literature which helps to explain this large disparity in the estimated cost of DAC deployment: (1) major differences in assumptions as to the pressure drop across the entire DAC system and therefore the amount of energy needed to run the DAC system, (2) the degree to which to which the cost of separation scales inversely with the concentration of the sought after compound is in the original starting mixture, (i.e., it should be cheaper – potentially much cheaper—to separate concentrated CO_2 from a biomass gasification system than from dilute CO_2 in the ambient air), and (3) the very large physical scale of DAC systems and whether economies of scale or diseconomies of scale would dominate.

DAC systems differ from BECSS in another important respect. As carbon permit prices increase, BECSS systems produce two very valuable commodities, carbon free electricity and certified negative emissions permits (i.e., tradeable offsets for carbon emissions in other parts of the global energy and economic system). At some point, the relative value of these two commodities will change and could change to the point where the more valuable commodity is the certified negative emissions permits, but the carbon free electricity would still remain an important product from these systems. DAC systems on the other hand produce no electricity and in fact would be net (perhaps significant) energy consumers as they would need some form of energy to regenerate the solvent used to remove the CO_2 from the ambient air, run pumps, filters, compress the captured CO_2 for injection into the deep subsurface as well as many other ancillary energy loads at the DAC facility. Thus, the DAC systems produce only one product, certified negative emissions permits. The lack of a revenue stream from being able to provide carbon free electricity could be an impediment that further complicates the early commercial deployment of DAC systems.

CONCLUDING POINTS:

1. DAC and BECSS can be seen as "backstop" emissions mitigation technologies in that they should set a ceiling on the cost of CO_2 emissions abatement. Developing a better understanding of the cost to deploy these systems and the potential scale of their deployment could be a vital input into societal decisions about the relative mix of mitigation and adaptation as response strategies to anthropogenic climate change (Socolow et al., 2011).

2. As noted by Azar et al. (2010) as well as others, the critical role that BECSS systems would play is in making it potentially possible to stabilize atmospheric concentrations of CO_2 at low levels near 400 ppm. For stabilization targets that are above this threshold but yet still stringent (e.g., 450-550 ppm), BECSS could be important in significantly lowering the cost of stabilization. For example, Azar et al (2010) note that the ability to deploy BECSS on a large scale allows atmospheric concentrations of CO_2 to be stabilized at a level 50 to 100 ppm lower than what would be attainable without BECSS for roughly the same cost.

3. Large scale deployment of BECSS or DAC systems would likely increase demand for deep geologic CO_2 storage reservoirs. The total demand for geologic storage reported in the literature is a small fraction of total theoretical deep geologic storage space (Dooley and K.V. Calvin, 2010; IPCC, 2005; Krey and K. Riahi, 2009) and therefore it seems unlikely that any increased demand for geologic storage space would be a significant deployment barrier for BECSS and DAC.

4. For either large scale BECSS or DAC deployment to the point where there would be negative net global emissions for perhaps decades, there would be a need to remove more than one ton of CO_2 from the atmosphere for each ton removed by these systems as the oceans and perhaps terrestrial systems would release CO_2 stored in them until an equilibrium is reached. The magnitude, speed, and duration of these releases from the ocean are all issues that need to be better understood.

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Keynote III-1: Policy, Governance and Socio-Economical Aspects of Geoengineering

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Increasingly it is apparent that some geoengineering methods may be technically possible, though with major uncertainties regarding their effectiveness, cost and socio-economic and environmental impacts (The Royal Society, 2009). This presentation explores the regulation of geoengineering and the principles which should guide the establishment of the governance structure necessary to guide research in the short term and to ensure that any decisions ultimately taken with respect to deployment occur within an appropriate governance framework. The uncertainties and controversies surrounding geoengineering have recently been considered both nationally (UK House of Commons, 2010; U.S. House of Representatives, 2010) and internationally. In the latter context, the State parties to the 1972 London Convention and 1996 Protocol and to the 1992 Convention on Biological Diversity, have each actively debated the consistency of ocean iron fertilization activities with convention obligations, inter alia, to protect and preserve the marine environment, and in late 2010 the CBD considered the matter of geogengineering more broadly. Thus both domestically and internationally it is clear that governance of geoengineering is moving up the legal and policy agenda.

To date there has been little comprehensive assessment of the international regulation of geoengineering. Indeed, absent from the current legal landscape is a single treaty or institution addressing all aspects of geoengineering; rather, the regulatory picture is a diverse and fragmented one both at the international and national levels (Bracmort et al., 2010; Hester, 2011). Thus a major strand in the sparse legal literature addressed to geoengineering is an assessment of the extent to which existing rules may be adapted to regulate geoengineering actors and activities (e.g. Bodansky, 1996; Michaelson, 1998; Rayfuse et al., 2008; Zedalis, 2010; Redgwell, 2011; Lin, 2011).This relies on the flexible adaptation, or possible amendment, of existing treaty rules or the application of customary international law rules, seeking to employ the legal tools at hand to regulate geoengineering activities, whether field trials or potential deployment. The difficulty of drawing a sharp distinction between these in terms of the nature of the activity and its effects, especially where large-scale field trials are in question, is significant, An example of a cautious graduated approach is found in the response by the parties to the 1972 London Convention and 1996 Protocol to ocean iron fertilization to prohibit all but small-scale scientific field trials pending further development of a regulatory framework.

Assessment of existing instruments should also take into account the dynamism of the norm-generating process, particularly in the environmental context. Existing instruments may be divided between those potentially applicable to all geoengineering methods (e.g. the 1977 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques and the 1992 UN Framework Convention on Climate Change) and those potentially applicable to particular methods (e.g. the 1972 London Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter and 1996 Protocol, for ocean iron fertilization, and the 1985 Convention for the Protection of the Ozone Layer and 1987 Montreal Protocol with respect to stratospheric aerosols.)

There are a number of alternatives for geoengineering governance. The first would be the conclusion of a "bespoke" legal instrument or instruments to address geoengineering. However, a multilateral geoengineering treaty is neither likely nor desirable. It is unlikely because the appetite for law-making, particularly in the climate change context as evidenced by the Copenhagen and Cancun meetings, is low (D. Bodansky and Diringer, 2010; Werksman and Herbertson, 2010; Rajamani, 2010, 2011). It seems inconceivable that the political will would be generated for law-making on this scale and where such a degree of controversy exists. Achieving consensus on all but the lowest common denominator – if that – seems very unlikely.

Such a route is also undesirable, for two reasons. The first is that international law hardly presents a blank slate, with a plethora of potentially applicable instruments where "regime legitimacy" has been established over time. The swift response to carbon capture and storage by the parties to the global LC/LP and regional OSPAR regime is an illustration of what can be done when there is clear consensus regarding the need for international regulation, the political will to do so, and appropriate instruments to adapt. Existing instruments can, and likely will, regulate aspects of geoengineering which fall within their treaty mandate. By the same token, there are gaps, most obviously with respect to the regulation in areas beyond national jurisdiction of SRM methods. A single treaty on geoengineering is also undesirable owing to the range of methods, where they may be carried out, and by whom. There can be no "one size fits all" approach to geoengineering regulation beyond the identification of key guiding principles or concerns of general application. Amongst other things, these could inform the interpretation and application of existing instruments.

One step forward could be the adoption of guiding principles for geoengineering governance, not as a template for an international treaty instrument but as an example of potential guidance, which could be embedded in soft or hard law and used by the key geoengineering stakeholders to guide decision-making on geoengineering research in particular. These might comprise the following (Rayner, et al., 2009; Asilomar Scientific Organizing Committee, 2010):

- Principle 1: Geoengineering to be regulated as a public good
- Principle 2: Public participation in geoengineering decision-making
- Principle 3: Disclosure of geoengineering research and open publication of results
- Principle 4: Independent assessment of impacts
- Principle 5: Governance before deployment

Such guiding principles could sit well against the backdrop of a moratorium on deployment pursuant to ENMOD or a General Assembly resolution, for example. Unlike a binding legal instrument, such guidance can be adopted "instantly" through endorsement by relevant actors (UNGA resolution; UNEP guidelines; endorsement by national legislatures; professional bodies etc). Nor is the adoption of guiding principles in "soft" form and the simultaneous negotiation of binding rules mutually exclusive, with the possibility of "twin-track soft-hard" rules (Redgwell, 2011). Such principles are also adaptable to the multi-scalar multi-level – local, national and international - governance architecture needed successfully to combat climate change (Osofsky, 2008; Scott, 2011).

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Keynote III-2: International Cooperation and the Governance of Geoengineering

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The case for the international governance of geoengineering is unclear for several reasons: why governance is needed; what to govern; how widely would international governance work. This presentation asks: If geoengineering were to be governed at the international level, what would be the underlying motivations and what forms could such governance take? The purpose is two-fold: to inquire into the explicit and implicit concerns and interests that motivate countries to demand or oppose international governance; and secondly, to inquire into the functional forms that international governance could take depending on varied motivations. Not only is international cooperation on geoengineering not a given; its design and effectiveness would depend on the ultimate goals for promoting governance at the international level.

Why govern?

Demands for governing geoengineering derive from a mix of interests and ethical concerns. On interests, states are motivated by at least two competing pressures, both stemming from uncertainty over the science of geoengineering. Without further research, the state of knowledge on geoengineering will not be robust enough for policymakers to make informed decisions. An individual country might want to retain the freedom to experiment with geoengineering technologies, so that its scientific community may build an advanced knowledge base on yet unproven technologies. Viewed in this way, international rules could be considered 'status quo-ist', a constraint on a single country's freedom of manoeuvre in future. But uncertainties associated with geoengineering also mean that the actions of other countries might have unforeseen consequences. Could geoengineering offer a technological edge to some countries? Could deployment of certain techniques outside one's borders adversely affect weather patterns within one's territory? With the current state of knowledge, it is hard to answer such questions with certainty. Viewed in this way, international rules could be considered a useful tool to rein in runaway, unilateral action in an uncertain technological field. Thus, countries would favour rules that offered them maximum flexibility while keeping other countries off balance. But the demand for rules also derives from ethical concerns. Countries (and/or their citizens) could seek governance over geoengineering technologies because they oppose interference with nature, or because they want to ascertain the intent behind research into these technologies, or simply because they claim a say over actions that have international impact. Process-related concerns include: having the opportunity to participate in forums where rules might be drawn up, having the power to influence rules, and being sufficiently aware to offer informed consent or dissent. Outcome-related concerns include: capability to conduct geonengineering research and/or deployment; intentions and actions deriving from such capability; the manner in which actions are monitored and reviewed; and how disputes are adjudicated and resolved.

Why cooperate?

Even the most powerful of countries need international regimes at least under three conditions: the lack of a framework establishing legal liability for state actions; positive transaction costs; and imperfect information. The presentation will distinguish between forms of international cooperation depending on the motivations of countries demanding governance arrangements. Cooperation over scientific experiments would entail decisions about funding, building capacity, coordinating research, reviewing results, and ensuring transparency. Such cooperation could bypass national governments, at least for small scale or laboratory experiments. International cooperation gets trickier when geoengineering research is not only funded from public resources but also where intentionality is hard to identify and responsibility is hard to attribute. Even if intentions were benign, some would argue that since geoengineering is a response to climate change (an issue the burden of responsibility), the international community should have a say in why and how it is researched and deployed. Whatever the motivation, the case for international cooperation is based on: firstly, imperfect information about geoengineering activities, their intent and impact; and, secondly, the absence of a framework to establish legal liability over actions.

Which functions for what motivations?

It is unclear a priori what institutional form international cooperation would take in order to influence geoengineering activities. At least four options may be identified: one, national-level governance; two, ad hoc codes of conduct and principles developed by the scientific community; three, adapting the mandates of existing international treaties, such as the Convention on Long Range Transboundary Air Pollution, the Convention on Biological Diversity and the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques; and four, creating a new regime to govern aspects of geoengineering that other regimes or national institutions cannot handle. Each governance option has merits and demerits. In order to understand the conditions under which different options might emerge, the presentation will use a framework to identify the functions that are necessary to promote international cooperation and respond to differing motivations. Three relevant governance functions may be identified: making decisions, monitoring actions, and resolving disputes. The motivations may be broadly grouped into interest-based and ethical concerns. The former seek a balance between maintaining flexibility for oneself while constraining others' actions. Ethical concerns ask whether the processes and outcomes of geoengineering governance are considered legitimate and for whom.

Table A.3.1: The design of international governance of geoengineering will depend on functions and motivations

	Interest-based concerns		Ethical concerns	
	Maintain flexibility	Constrain others	Process legitimacy	Outcome legitimacy
Making decision	Scope of international governance limited	Scope of international governance broad	Inclusive process vs. Ease of decision-making in small groups	Equally weighted voting rules vs. Capability-driven voting
Monitoring actions	Self-reporting	Institutional reporting plus verification	Inclusiveness of review procedures	Quality and timeliness of reporting
Resolving disputes	Decentralised adjudication	Centralised adjudication plus centralised/decentralised enforcement	Ease of access to dispute settlement forums	Ability to enforce decisions

The interplay of functional demands for international cooperation and interest-based and ethical concerns offers choices for regime design (Table A.3.1). Decision-making depends on the scope of issues that would be governed internationally, who has a seat at the table, and the rules to aggregate votes and positions. Inclusive processes give countries without capacity to have a say in activities that have international consequences, but this approach competes against the efficiency of small group settings. Influence over outcomes depends on different voting rules. Monitoring actions is highly contested. Self-reporting may be preferred by sovereignty-protecting states. But regulating other's actions needs some form of institutional reporting with independent verification. Ethical concerns also drive options for monitoring depending on how broad review procedures are and whether reporting offers timely, accurate and salient information. Resolving disputes is perhaps hardest because intentions are hard to define and responsibility not attributed easily. To preserve flexibility, countries would prefer domestic courts for disputes over activities in their territories but international mechanisms for those arising elsewhere. Enforcement may be either decentralised (leaving it to countries to pursue means of influencing other) or centralised (using sanctions stemming from an international institution). For ethical concerns, barriers to entry in the formal dispute resolution arrangement could include lack of information and/or lack of resources. Outcome legitimacy depends on disputants having the ability to enforce rules against more powerful countries.

The presentation will draw upon the experience of and lessons from other international regimes and with the international coordination of research activities. By combining motivations and governance functions, the presentation suggests ways in which international cooperation might evolve depending on the balance of power, interests and ethics.

Keynote III-3: Geoengineering in a Risk Management Framework

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Conventional tools of risk analysis and decision support (including the use of failure mode and effects analysis and fault trees, combined with modern methods for assessing risk perceptions and engaging in risk communication) are entirely appropriate for use in risk management of that subset of CDR that uses engineered systems designed to scrub CO_2 from the atmosphere. After a few general preliminaries about the state of modern risk analysis and management, the talk will briefly outline strategies that can be used for risk management of engineered systems for CDR. These systems lie in region A of Figure A.3.2.

In contrast, conventional tools for risk analysis and management, and more critically tools for decision support, are only partly adequate to assess CDR that involves large-scale long-term modification of ecosystems. Many conventional tools for risk management are not adequate to make decisions related to SRM. Aspects of these strategies lie in region B of Figure A.3.2. After articulating some of the reasons for this assertion, a number of important gaps in available analytical methods will be outlined. A few alternative strategies for framing and thinking about the problem of risk management of SRM research, and possible future SRM deployment, will be suggested and discussed.

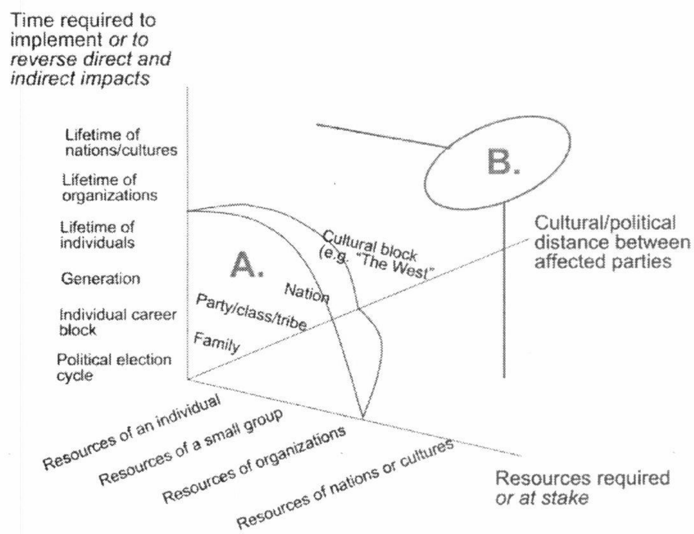

Figure A.3.2: *Conventional tools for risk analysis and risk management have been developed to address problems that fall within the space labeled A. In contrast, aspects of CDR that involves large-scale long-term modification of ecosystems, and aspect of all SRM strategies, lie in the space labeled B. Before applying conventional tools and methods for risk analysis and management in this space, one must examine carefully the underlying assumptions on which they have been based. Figure modified from Morgan et al. (1999).*

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Keynote III-4: The Role of Different Geoengineering Options in Long-Term Responses to Climate Change

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While proposed geoengineering techniques offer new potential response options to addressing climate change, the relationship between these techniques and more familiar response option – specifically mitigation and adaption – has thus far been poorly explored. Particularly over decadal time scales, different response options (or portfolios of options) are likely to generate significant differences in climatic and societal outcomes. This talk overviews some relevant technical characteristics of currently proposed geoengineering techniques, and contrasts them with the characteristics of the climate challenge and prominent mitigation and adaption response options. Because Carbon Geoengineering (also, Carbon Dioxide Removal or CDR) proposals differ dramatically from Solar Geoengineering (also Solar Radiation Management or SRM) proposals they are treated separately throughout.

The long-term nature of the anthropogenic climate change problem are associated with long-lived radiatively active substances added to the atmosphere (including CO_2; Archer et al., 2009) as well as long time scales associated with transformation of global systems of energy production and use and patterns of land use (Davis et al., 2010). Discussions focused on CO_2 may be extended to consider other anthropogenic emissions of radiatively active substances. In the IPCC AR4, the term "long term" was used to refer to the period after year 2030 (see for example IPCC AR4, Working Group III, Summary for Policy Makers, Section D; IPCC, 2007). That usage will be adopted here.

Proposed CDR techniques attempt to reverse the effects of CO_2 emissions by diminishing atmospheric CO_2 concentrations. From the perspective of the climate system, if CO_2 were removed from the atmosphere and then isolated from the atmosphere forever, this would closely approximate the effect of an avoided emission. An important issue is the amount of time that the CO_2 would remain isolated from the atmosphere. This issue of permanence of storage has been discussed within the IPCC both in reference to Carbon Capture and Storage (IPCC, 2005) and with regard to land use practices (IPCC, 2000). Permanence (or longevity) of storage is an important issue that is relevant to the potential of various CDR approaches to reduce long-term risks associated with climate change. Impermanent storage is largely equivalent to a delayed emission (Herzog et al., 2003). Delayed emission can be valuable in slowing rates, and in some cases maximum amounts, of warming. Issues of impermanence of storage are most commonly raised with respect to various biologically-oriented strategies to remove CO_2 from the atmosphere, such as ocean iron fertilization or proposals to increase organic carbon storage in plants or soils. Impermanence of storage also raises issues of intergenerational equity and transfers of responsibility. Most of these issues already have been addressed by the IPCC in other contexts. Furthermore, after removal of excess CO_2 from the atmosphere, excess CO_2 will tend to continue degassing from the oceans and land biosphere (Cao and Caldeira, 2010); thus, the long lifetime of CO_2 in these reservoirs indicates a long-term commitment to CO_2 removal if atmospheric CO_2 concentrations are to be maintained at very low levels.

If it were possible to deploy CDR techniques with permanence of capture at sufficient scales to reduce net atmospheric emissions or even draw down atmospheric concentrations, from the perspective of the climate system, this could effectively reduce anthropogenic climatic change. However, according the 2009 report of the UK Royal Society (The Royal Society, 2009) and 2011 report of the American Physical Society (Socolow et al., 2011), while there may be some relatively low-cost CDR options that can be deployed at scales that are small relative to that of global emissions, deployment at the scale of global emissions is likely to be more costly than emissions avoidance options.

SRM techniques aim to diminish the amount of climatic change by reducing the solar energy absorbed by the atmosphere, surface and/or oceans, thereby reducing global warming. Because some proposed SRM techniques (specifically stratospheric aerosols and cloud whitening) appear to offer the technical capacity to reduce globally absorbed solar radiation on the order of 1% (or more) within a few months, and for deployment costs on the order to \$1B to \$10B (McClellan et al., 2012)these techniques provide potentially fast leverage over the global climate. However, SRM techniques would not address non-climate effects increased atmospheric CO_2, such as ocean acidification (Matthews et al., 2009). Moreover, because SRM alters a different component than CO_2 of the energy flow driving the climate system (shortwave for SRM versus longwave for CO_2), the climatic conditions produced by offsetting CO_2-induced global warming with SRM would not be equivalent to climatic conditions under lower atmospheric CO_2 concentrations; differences in various climatic conditions, specifically including the hydrologic cycle, are expected. Moreover, were an SRM deployment to be terminated abruptly, rapid warming could ensue (Matthews and Caldeira, 2007; Robock et al., 2008), and thus deployment of an SRM system might be considered to pose an intergenerational transfer of this risk of sudden warming. These characteristics of SRM techniques – that they could act quickly, be cheap to deploy and by imperfectly offset anthropogenic climate change (Keith et al., 2010) – have led to varying perspectives on potential uses for SRM, ranging from being part of a "portfolio" of climate response options that seek to reduce costs of mitigation of climate change risks (Nordhaus, 1992; Wigley, 2006), to being a response reserved to address specific climate threats or climate "emergencies" (Blackstock et al., 2009; Caldeira and Keith, 2010).

Based on these characteristics, the relationship between existing geoengineering proposals and current mitigation and adaptation frameworks are explored in a preliminary way. As a starting point, the wedges framework of Socolow and Pacala (2004) and the framework for considering adaptation outlined in IPCC AR4 (IPCC AR4, Working Group II, Chapter 18; IPCC, 2007) are used to consider CDR and SRM, identifying where similar and differentiating characteristics exist. This approximate comparison demonstrates notable similarities between CDR and mitigation, while also identifying some unique characteristics of SRM that are dissimilar to both mitigation and adaptation options; specifically, SRM focuses on reducing exposure of populations and ecosystems to climatic changes, rather than their vulnerability to that change (which is the focus of adaptation). The potential climatic and societal implications of these overlaps and differences, along with the emergence of CDR and SRM techniques into mainstream climate policy discussions are explored briefly through the application of scenarios methods.

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Annex 4: Poster Abstracts

Albedo enhancement over land to counteract global warming: Impacts on hydrological cycle

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Increasing the land surface albedo via whitening the roofs and pavements in the urban area (Akbari et al., 2009; Oleson et al., 2010), covering deserts with more reflective polyethylene-aluminium to increase albedo (Gaskill, 2004) and making the color of crops lighter (Doughty et al., 2011; Ridgwell et al., 2009) are a few examples for land surface based Solar Radiation Management (SRM) schemes to counter global warming. Assuming these schemes are capable of countering global mean warming, what are the hydrological implications of large land albedo modification?

Recent modelling studies have shown that Solar Radiation Management (SRM) schemes that counteract global warming by increasing the planetary albedo uniformly (no differentiation of land versus oceans) will cause a reduction in the intensity of the global water cycle when they cancel the global mean warming exactly (Bala et al., 2009, 2008). However, precipitation and runoff over land have been shown to increase when reduction in solar insolation is applied only over the oceans by increasing the reflectivity of marine clouds (Bala et al., 2011). This most recent study implies that large scale albedo modification should lead to drying of the continental regions.

In this study, we perform idealized simulations using NCAR CAM3.1 to quantify the effect of SRM schemes that increase the albedo over land. We find that an increase in reflectivity over land that mitigates the global mean warming from a doubling of CO_2 leads to significant unmitigated warming in the southern hemisphere and cooling in the northern hemisphere since most of the land is located in northern hemisphere. Precipitation and runoff over land decrease by 13.4 and 22.3%, respectively because of a large residual sinking motion over land (see Figure A.4.1). The magnitude of hydrological changes are much larger than in the marine cloud albedo enhancement case (Bala et al., 2011) since the radiative forcing over land needed to counter global mean radiative forcing from a doubling of CO_2 is approximately twice the forcing needed over the oceans. Our results imply that albedo enhancement over oceans is superior to land albedo changes when the consequences on land hydrology are considered. Our study also has important implications for any intentional or unintentional large scale changes in land surface albedo such as deforestation/ afforestation/ reforestation, and desert and urban albedo modification.

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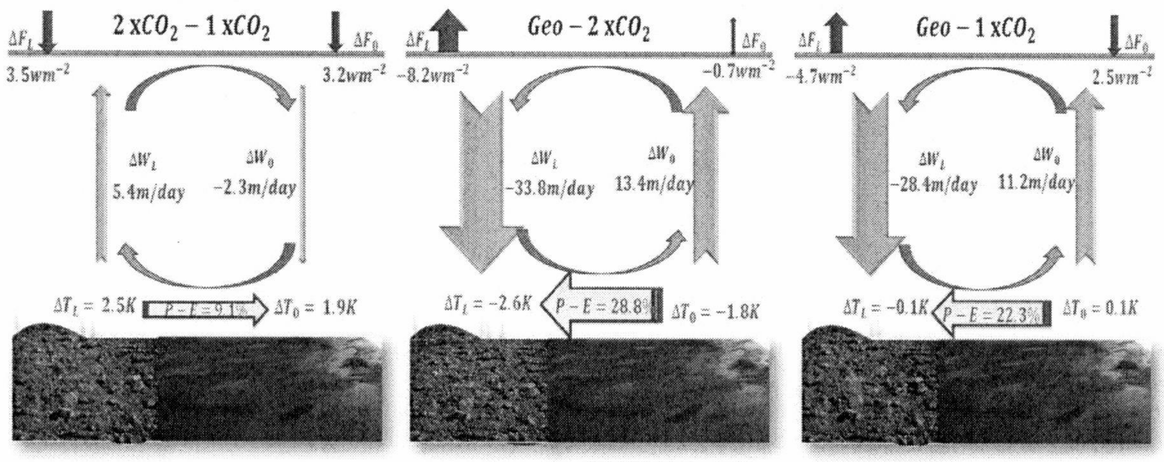

Figure A.4.1: *Schematic diagram illustrating the changes in vertical motion at 500 mb over land and oceans when CO2 is doubled (left panel, 2xCO2-1xCO2), albedo over land is enhanced (middle panel, enhanced albedo case: Geo-2xCO2) and when CO2 is doubled and land albedo is enhanced (right panel, the geoengineered case: Geo-1xCO2) cases. Radiative forcings over land and oceans in each case are shown at the top. Vertical motion in height coordinates (w, meter/day) is obtained from $w = -\omega/(\rho g)$ where ω is the model simulated pressure velocity. Changes in surface temperature and precipitation minus evaporation are also shown. Strong downward motion and the consequent decline in runoff and drying over land are indicated for the enhanced land albedo and geoengineering cases.*

Categorization of policy responses to climate change with a focus on geoengineering

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Potential policy responses to anthropogenic climate change can be broadly classified into four categories: additional research into climate sciences and carbon-free or carbon-neutral sources of energy, mitigation (i.e. reduction in anthropogenic emissions of greenhouse gases), adaptation (i.e. reduction of the impacts of climate change on natural and societal systems), and geoengineering.

Geoengineering is usually defined as the intentional large-scale manipulation of some element of the Earth system, in an attempt to counteract the effects of anthropogenic climate change. It is sometimes also referred to as climate intervention, climate engineering or planetary engineering. To qualify as geoengineering, an intervention into the Earth system has to deliberately attempt to tackle climate change by a method that does not seek to reduce anthropogenic emissions of greenhouse gases or other warming agents. For instance, the emission of anthropogenic aerosols from burning fossil fuels, although responsible for a cooling effect, is not considered to be geoengineering because it is a by-product of our industrial and transportation systems rather than a deliberate action. The intervention, although it can be localized, also has to have a large-scale effect on the climate system. This clearly distinguishes geoengineering from, e.g., weather modification or other sorts of environmental engineering which attempt to modify the atmosphere or the land surface on a much smaller scale.

A number of geoengineering schemes have been proposed in the scientific literature. Their technological maturity, effectiveness, scalability, residual impacts, unintended consequences and cost vary a great deal and remain uncertain. The Royal Society report (2009) on geoengineering categorized geoengineering schemes into solar radiation management (SRM) and carbon dioxide removal (CDR) techniques. SRM schemes seek to artificially modify the solar radiation budget to cool the planet. CDR schemes seek to artificially remove carbon dioxide from the atmosphere and store it in some form. While the distinction between SRM and CDR is useful, it does not cover all potential geoengineering schemes one can think of. For instance, it has been suggested that the terrestrial radiation budget could also be artificially modified through changes in cirrus clouds and/or atmospheric water vapor in order to decrease the greenhouse effect. Carbon dioxide is not the only long-lived greenhouse gas in the atmosphere, and air removal can also be envisaged for methane (Boucher and Folberth, 2009) or other gases.

Figure A.4.2 lists a large number of approaches to climate change and attempts to refine their groupings into distinct categories. It appears that there is not always a clear division between geoengineering and adaptation or between geoengineering and conventional mitigation. For instance, it has been suggested that the Earth's albedo could be artificially increased over land by increasing the reflectivity of human dwellings (Akbari et al., 1999) or cropland (Ridgwell et al., 2009). These modifications may actually be more relevant to local and regional adaptation to climate change than geoengineering. Furthermore the frontier between geoengineering and mitigation is not very clear when it comes to biofuels. The large-scale exploitation of biofuels associated with carbon capture and storage (CCS) has the potential to remove CO_2 from the atmosphere and qualifies as a CDR scheme, even though biofuels and CCS on their own are usually considered as conventional mitigation tools.

In conclusion we argue that it is important to develop a clear terminology on policy responses to climate change, while recognizing that the frontier between these responses is not always clear-cut. We will provide in this presentation a first attempt at developing such a terminology. This will help to decide how geoengineering should fit (or not) in the portfolio of existing climate change policies. Multiple factors have to be considered when comparing these policy responses, including their technological maturity, effectiveness, scalability, timescale for implementation, risk, residual climate change, unintended consequences, degree of interference with the climate system, the policy and governance challenges they pose, and their cost.

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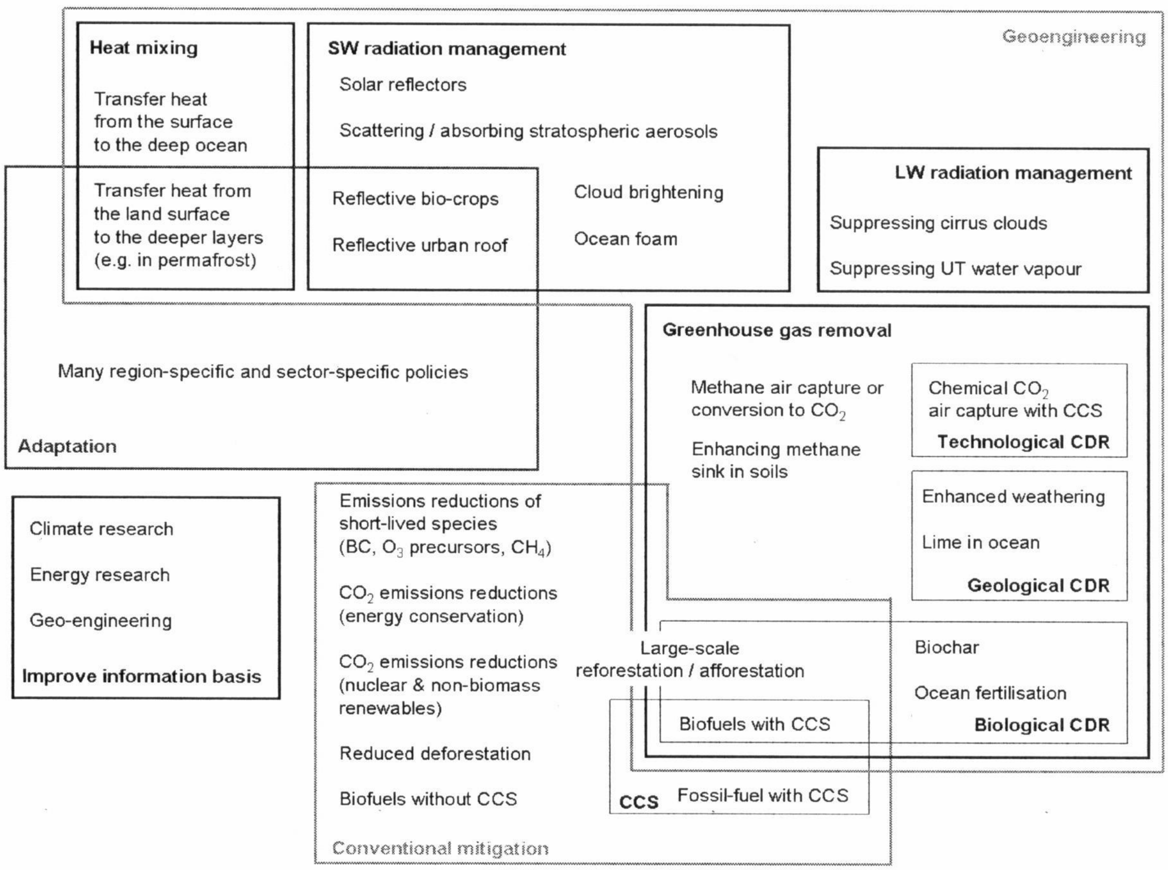

Figure A.4.2: *Categorization of existing and proposed policy responses to climate change with a focus on geoengineering techniques.*

Climate change adaptation through the development of a sensor-based early warning system for landslides

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Many poor communities in the Philippines are threatened by landslides mainly due to extreme rainfall. The frequency and scale of landslides have increased during the last decades. Given the high economic cost of relocation of communities and the use of conventional engineering mitigation methods, a low cost, sensor-based early warning system for landslides is being developed in the Philippines in order to warn communities of impending landslides. The system is composed of a sensor column array consisting of a triaxial accelerometers and soil moisture that is buried vertically underground. A modified version of the Casagrande type piezometer is also integrated into the sensor column to measure excess pore pressure. Measurements taken in each segment are accessed via the Controller Area Network (CAN) communications protocol. The sensor columns are capable of transmitting data via Short Message Service (SMS) and sending it to a base station. The sensors were initially tested on a small-scale slope model in which failure was induced through water seepage. Changes in the tilt and saturation measured by the sensors are consistent with visual observations. On November 2010, the system is being tested and was deployed in an active landslide area in Brgy. Puguis, La Trinidad, Benguet, Northern Philippines. If the prototype system is found accurate and effective, it will be deployed in other landslide-prone areas in the Philippines.

An Integrated Assessment of Geoengineering Proposals

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There is currently insufficient information to inform the emerging debate about geoengineering, this work will begin to address the gaps in our knowledge about effectiveness and side effects of geoengineering schemes. Integral to the assessment process is active and ongoing engagement with stakeholders, including science policy experts and the general public, to produce objective and informed policy-relevant science.

The Integrated Assessment of Geoengineering Proposals (IAGP) is a new four year research project that started on 1st October 2010 and is funded by the UK Engineering and Physical Sciences Research Council (EPSRC) and the Natural Environment Research Council (NERC). IAGP brings together a broad range of expertise, from climate modelling to philosophy and engineering to public perceptions to conduct an objective, policy-relevant assessment of geoengineering proposals. IAGP has the following core research objectives: to evaluate the effectiveness and side-effects of a broad range of geoengineering proposals, to evaluate the controllability of global climate using these proposals and to elicit and include stakeholder and public values into the evaluation. Key sub-objectives will be to examine in detail the public acceptability of different geoengineering solutions and to evaluate the possibility of preventing tipping points via geoengineering control.

Previous assessments of proposals (e.g. Lenton and Vaughan, 2009) have been somewhat preliminary and have been largely based on a physical science evaluation of solar radiation management techniques. For this assessment we are being more rigorous. This involves a) comparing different proposals (including solar reduction and carbon management technologies) within the same modelling framework, and b) engaging with the public and stakeholder community prior to running the climate models to help create an objective set of policy-relevant metrics to evaluate both the effectiveness and side effects of a given proposal (Corner and Pidgeon, 2010).

At this stage in the project we have run preliminary workshops with both the public and stakeholders.

The second stage will be to use these workshop findings to create a set of metric criteria for climate model evaluation. A repeat stakeholder workshop in October 2011 will decide on these metrics and climate model integrations will then start to evaluate the physical science based metrics. A further deliberative workshop towards the end of the project will feedback and interpret climate model results to stakeholders and the public. Readers are encouraged to visit the project website (www.iagp.ac.uk) to find out more about what we to keep up to date with our publications.

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Aerosols impact on dynamic of the West African monsoon: direct effects

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Aerosols play an important role in the radiative balance of the atmosphere. While sulphate aerosols are recognized as the most dominant contributor of tropospheric aerosols over and near the industrialized regions. One of the most important aerosols source in the world is West African region and is also influenced by anthropogenic aerosols from European industry (Chin and Diehl, 2005). The West African rainfall depends strongly on the activation of the monsoon circulation, which is influenced by radiative balance of the atmosphere. This fact determines the importance of this system in the agricultural activity, based on pluvial agriculture, and consequently in the economy of the region. This study examines the effect of dust and anthropogenic aerosol on dynamic of the West African monsoon using regional climate model (RegCM3) coupled with dust and anthropogenic aerosol module.

The results show the reduction of the West African rainfall under effects of cooling induced by dust and anthropogenic aerosols. This cooling reduces the meridional gradient of the moist static energy, which causes the weakening of the energy of the monsoon flux contributing for a reduction of the West African rainfall as cited by Konare et al. (2008). Also, the impact of aerosols on these systems and the precipitation was greater in the simulation with anthropogenic aerosols (Figure A.4.3, a) than simulation with dust only (Figure A.4.3, b). In general, the interaction of aerosols with radiation budget was able to influence the seasonal and the interannual variation of the West African circulation.

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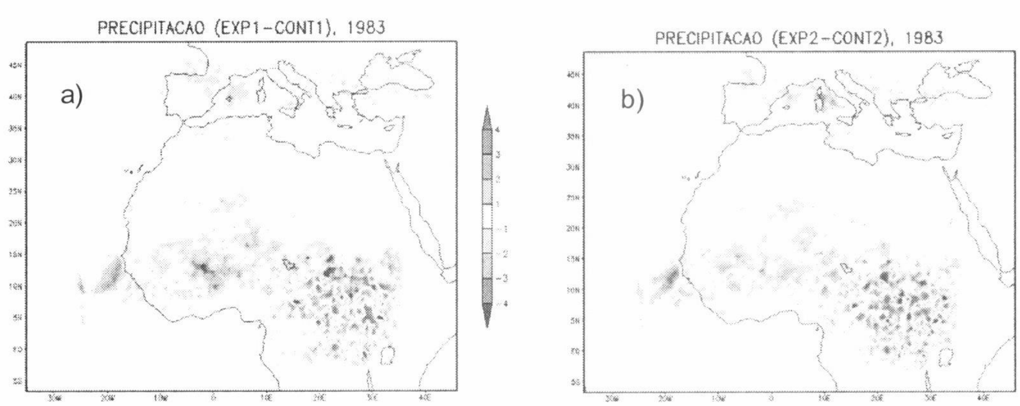

Figure A.4.3: *a) Reduction of rainfall by dust and anthropogenic aerosols, b) reduction of rainfall by only dust aerosols during the dry year.*

Sea spray geoengineering: global model simulations with explicit aerosol microphysics

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One much discussed technique for solar radiation management (SRM) is to use artificial sea spray emissions from wind powered vessels to increase the concentration of submicron sea salt particles in the marine boundary layer (Latham, 1990). It has been hypothesized that these artificially emitted aerosol particles could act as cloud condensation nuclei (CCN) and thus increase the cloud droplet number concentration (CDNC) in the marine stratocumulus clouds. This in turn would lead, at least in theory, to a higher cloud albedo and thus planetary cooling.

Using a detailed aerosol microphysics model (GLOMAP) within a global chemical transport model, we have recently shown that artificial sea spray emissions are unlikely to lead to homogeneous CDNC fields over vast oceanic areas (Korhonen et al., 2010). Our results also indicated that the relative enhancement of CDNC in low-level clouds is likely to be lower than assumed in previous climate model studies.

We have now repeated a similar set of simulations in ECHAM-HAM aerosol-climate model in order to quantify the direct and indirect effects from sea spray injections as well as to study the effect of the particle injection size on the resulting planetary cooling (Partanen et al., 2011). ECHAM-HAM includes an explicit and prognostic calculation of cloud microphysics and interaction of aerosol particles with clouds. We assume a wind-speed dependent number flux for the injected particle population and follow its transport and transformation due to microphysical processes in the atmosphere. This additional flux is assumed either over all the oceans or in three optimized regions covering 3.3% of the planet's surface area.

Applying the baseline scenario (i.e. injected particle size 250 nm) in the optimized regions, we predict a global mean radiative flux perturbation (RFP) of -0.8 Wm^{-2}. This compares well with an earlier published estimate of -0.97 Wm^{-2} which assumed a fixed prescribed CDNC of 375 cm^{-3} in the geoengineered regions (Jones et al., 2009). In our simulations the mean regional CDNC varies between 194 and 286 cm^{-3} but cloud cover increases by 2-5 percentage points. It is noteworthy that both the absolute CDNC values as well as their relative changes (74-80%) are clearly higher than predicted in an earlier study using similar emission fluxes. In the ECHAM simulations, multiples of the baseline sea spray flux cause almost a linear increase in CDNC but the RFP is clearly sublinear (global mean RFP with 5 times the baseline flux is -2.2 Wm^{-2}).

Since the three optimal geoengineering regions are characterized with persistent stratocumulus decks, inside them practically all of the radiative effect originates from aerosol indirect effects. However, the direct effect can be significant outside these regions: when all oceanic regions are seeded, the direct effect is about 65% of the aerosol indirect effects.

For a constant volume emission flux of sea spray, the size at which the individual particles are injected becomes very important. Reducing the injection size from 250 nm to 100 nm, which is typically still large enough for cloud activation in marine boundary layer, increases the global mean RFP in the run of optimized regions to -2.1 Wm^{-2}. On the other hand, injection at 500 nm has only very minor effects on CDNC due to the low number flux (13% of the baseline flux) and produces roughly the same direct forcing as the baseline simulation.

The presented work is part of an interdisciplinary project "Aerosol intervention technologies to cool the climate: costs, benefits, side effects and governance" funded by the Academy of Finland. In addition to cloud seeding with artificial sea spray emissions, the project focuses on the climate and other environmental effects stratospheric particle injections and reduction of black carbon (BC) emissions. We investigate also how the introduction of geoengineering alternatives may lead to reframing of global and national climate policies as well as how the existing legal and political frameworks will affect the pace and direction of the package of admissible alternatives.

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Biochar for Climate Change Mitigation: Prospects and Limitations

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Biochar has received significant attention as a rapid climate-change mitigation strategy. Biochar is a charcoal-type substance that shares properties with biomass-derived pyrogenic carbon which is ubiquitous in soils (E. Krull et al., 2008; Johannes Lehmann et al., 2008). In a biochar system, biomass of a wide variety of feedstocks, including wood, grass, animal manures, crop residues, and other appropriate byproducts, is pyrolysed to biochar, which is added to soil. In many applications, this conversion is used to generate usable energy from the volatile liquids and gases, such as hydrogen, bio-oil, ethanol, electricity or heat. Several anthropogenic and natural analogs can be found that allow some evaluation of biochar amendments to soils for the long term. Notably, so-called Terra Preta soils in the Amazon have provided incentive to evaluate biochar for soil improvement as these soils received biochar-type materials several thousand years ago and retained their fertility.

However, dedicated biochar research and development only started to any significant extent in 2006. The stability of biochar has been calculated to mean residence times of several hundred to a few thousand years (Johannes Lehmann et al., 2009; Zimmerman, 2010; Spokas, 2010). While the greater stability of biochar relative to the uncharred biomass is the basis for the emission reductions through utilization of biochar as a soil amendment rather than combusting it for energy to offset fossil fuels, it is not always sufficient for achieving net emission reductions. Life-cycle assessment demonstrates that projects can have positive or negative net emission balances primarily depending on the source of the feedstock (Roberts et al., 2010). In bioenergy systems, using the biochar as a soil amendment shows greater emission reductions compared to the use of combustion only if the soil productivity increases or if other greenhouse gas emissions are either offset or reduced (Roberts et al., 2010; Woolf et al., 2010; Hammond et al., 2011).

On a global scale, this may result in greater emission reductions through biochar systems than combustion for bioenergy (Figure A.4.4). The proportion of stable carbon in biochar provides about 50% of the total emission reductions of a biochar system if it is integrated in a bioenergy project. If either no bioenergy is generated or bioenergy from cookstoves with low burning efficiencies are replaced by biochar-cookstoves, the importance of biochar stability may increase to over 80% or fall below 30% (Whitman et al., 2011). The emission reductions using waste materials or crop residues as feedstocks vary between 0.7-3.8 t CO_2e t-1 feedstock (JL Gaunt and J. Lehmann, 2008; J Gaunt and Cowie, 2009; Roberts et al., 2010; Hammond et al., 2011). In a modeled cookstove system, an improved combustion stove provided similar emission reductions of 3.5 t CO_2e yr-1 per household compared to 3.69-4.3 t CO_2e yr-1 per household for an improved pyrolytic stove with biochar additions to soil (Whitman et al., 2011). Hammond et al. (2011) report life-cycle emissions abatement of 1.4-1.9 t CO_2e MWh-1 for a variety of biochar-bioenergy systems in the UK in comparison to a generation of additional emissions of 0.05-0.3 t CO_2e MWh-1 for other bioenergy systems.

The global technical potential is likely not much greater than 1 Pg CO_2-Ce yr-1 if only biomass resources are used that do not compete with food crops and other existing uses of biomass, do not require land use change or clearing of natural vegetation, and do not remove crop residues to an extent that would negatively impact soil health (Woolf et al., 2010). The economic viability largely depends on the price for the biomass feedstock, and can vary significantly between projects. In many current projects, the costs may be offset by the value of increased crop yields due to biochar, but adoption may still benefit from financial support through a price on carbon.

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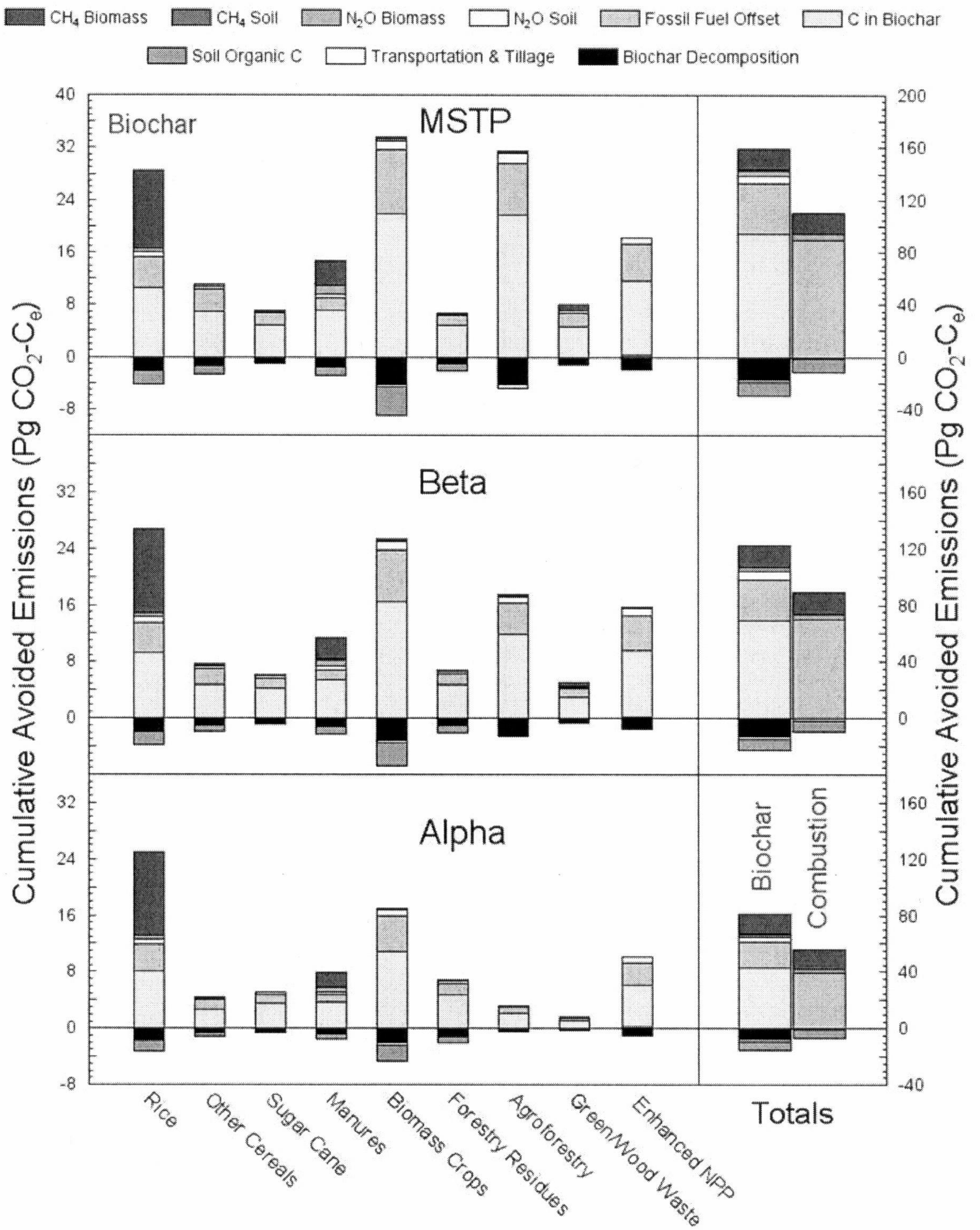

Figure A.4.4: *Cumulative avoided GHG emissions (Pg CO_2-Ce) from sustainable biochar production (Woolf et al., 2010).*

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Potential Applications of Climate Engineering Technologies to Moderation of Critical Climate Change Impacts

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Although pre-geoengineering proponents in the mid-20th century argued for application of early climate engineering technologies to 'improve' what was then the prevailing climate, the more we have learned about the climate, the more we have come to understand the hubris involved in contemplating upsetting its many valuable and beneficial intercouplings. Nonetheless, society continues with little restraint to combust more and more fossil fuels, releasing many billions of tonnes of carbon dioxide (CO_2) and other greenhouse gases that are, even if unintentionally, on track to cause changes in climate far larger than what had been proposed and then dismissed as overly audacious and dangerous.

With disappointing progress in international efforts to limit global emissions and with observations indicating that climate change was intensifying more rapidly than the seemingly dire consequences that model simulations were projecting, Crutzen (2006) suggested that geoengineering might be an essential complement to mitigation and adaptation for preventing 'dangerous anthropogenic interference' with the climate system. In this context, the purpose of geoengineering, or more descriptively, climate engineering, becomes to moderate the unintended changes in climate being caused primarily by the emissions of greenhouse gases (GHGs), primarily CO_2. Thus, its intent is to keep the climate as nearly the same as it has been rather than to transform it to some supposedly 'better' state. Under this formulation, the hubris is more properly associated primarily with those who are allowing high greenhouse gas emissions to continue with little effort to reduce them than to those suggesting potential use of climate engineering technologies and approaches to maintain the current climate. While there are very likely to be unintended consequences of counterbalancing the greenhouse-gas induced changes in climate, that the climate will be nearer to the conditions that science has been carefully investigating over the past several decades may well mean that we will be able to better estimate them than the unintended consequences being created as GHG emissions carry the climate to conditions the Earth has not experienced in many millions, even tens of millions, of years. Basically, the question that needs to be considered is not whether climate engineering on its own would be beneficial or detrimental for the environment and society, but whether society and the environment would be better off working through the consequences of eventually controlling greenhouse gas emissions with or without the partial counter-balancing of at least some of the consequences using climate engineering technologies.

In addressing this question, the role of the scientific community is to, in a responsible way, come up with options, with the public and governmental decision-makers responsible for making any decision about potential application. In identifying solar radiation management options meriting investigation of the strengths and weaknesses, there has been a nearly complete jump from doing nothing to attempting to completely offset the full warming influence of a CO_2 doubling. My research has focused on conceptual exploration of the many possibilities lying between these two extremes, believing that there is a much greater likelihood that climate engineering can play an important positive role if started up on a limited scale than if there is an immediate jump to the global scale.

Recognizing that global scale climate engineering is also likely to have some noticeable unintended consequences, the proposed justification has primarily focused on its use in response to a climate emergency; that is, to invoke climate engineering only when there is clear evidence of an impending or immediately past exceedance of a threshold that would lead to runaway warming or other very significant consequence. The most discussed of the possible emergencies have been a methane burst as a result of the rapid thawing of permafrost and/or clathrates trapped in the sediments of the continental shelves, the rapid loss of ice mass from the Greenland and/or Antarctic ice sheets, collapse of the Amazon rainforest, or greatly accelerated, runaway warming. The proposed invocation of climate engineering would be rapid and strong, taking the global average temperature, for example, back to much lower levels. It seems to me there are several problems with this formulation of, essentially, holding back climate engineering until it may be too late to reverse the disastrous changes. An implicit assumption in this approach is that climate is reversible, and this is not at all clear. In addition, adaptation is likely to have spread out the range of optimal temperatures for various societal and environmental systems, such that a sudden, sharp cooling might be very disruptive.

If the goal is to keep the climate near its present value, then it seems to me it would make much more sense to initiate climate engineering as early as possible, with the intent of slowing, stopping, and then perhaps reversing the climate change that the world has experienced. With governance issues likely to take an extended period to work through before taking actions to bring global climate under control, especially as there is the possibility, or at least the fear, that actual implementation might lead to a sloughing off (or further sloughing off) of efforts to cut emissions, global-scale climate engineering seems to me unlikely to be implementable for a decade or, more likely, more. At the same time, while much of the world is not yet experiencing sufficiently severe impacts to prompt rapidly implemented sharp cuts in emissions, there are regions of the world where climate change is already exerting very disruptive impacts; these regions merit consideration of the potential for climate engineering to moderate their impacts. In addition, even if CO_2 emissions could be significantly cut immediately, warming would very likely result due to the sudden drop of the sulfate cooling offset; quite clearly, a climate engineering approach to replacing the sulfate cooling offset needs to be sought. Within this framing, a number of potentially high priority applications of climate engineering technologies appear to be worthy of aggressive research and investigation (MacCracken, 2009):

1. Reversing Arctic warming: Limiting solar absorption in the region by injection of aerosols (or aerosol precursors) into the lower stratosphere or the troposphere (brightening both clear and cloudy skies) has the potential to reduce warming in the Arctic region and down into mid-latitudes while also promoting build-up of the region's mountain glaciers and ice sheets (Caldeira and Wood, 2008; Shin et al., 2011). Increasing surface reflectivity or cloud brightening to limit heat flow into the region may also be a possibility. Limiting changes in precipitation at other latitudes may require an offsetting reduction in solar radiation over the Southern Ocean (Shin et al., 2011).

2. Moderating tropical cyclone intensification: Using cloud or ocean-bubble brightening to reduce warming in ocean and coastal water bodies would seem an approach to moderating intensification.

3. Storm track redirection: Observations indicate that storm tracks into western North America are steered, at least to some extent, by ocean temperature gradients of a few degrees, an amount that might well be achievable by region-specific cloud or ocean-bubble brightening.

4. Replacement of the sulfate offset: Loss of the sulfate offset resulting from SO_2 emissions from coal-fired power plants (so high SO_2 levels over relatively limited areas where populations are high) might be able to replaced by creation of a sulfate offset created by SO_2 emissions that would lead to a low loading of sulfate over large, low-latitude oceanic areas that are largely unoccupied.

5. Slowing of ice stream calving: If the heat promoting calving from the streams draining ice sheets is coming from warm waters entering fjords, cloud or ocean-bubble brightening and/or wave-powered vertical mixing might be useful in chilling those waters.

Given the specific beneficial and generally regional focus of these proposals, and that they may be readily terminated if problems arise, it might well be that governance issues would be easier. In my view, these much more practical and possibly near-term applications merit aggressive and early investigation.

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Cloud-resolving modeling of marine stratocumulus cloud brightening

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Marine Stratocumulus (Sc) clouds cover vast areas of the ocean surface. They play a prominent role affecting the Earth's albedo and energy budget. The possibility of mitigating some consequences of global warming by brightening these clouds (Latham, 2002) has been explored in various global modeling studies, providing important insight into some aspects of this idea. However, the inability of global models to adequately represent cloud-scale physics and dynamics due to low model resolution limits their usefulness for assessing the climate system response to cloud brightening. High-resolution cloud modeling has proven to be a useful tool for process-level understanding of aerosol-cloud-precipitation interactions. It can also provide a necessary and critical test to the assumptions and parameterizations employed by global models when exploring the geoengineering idea.

In this study (H. Wang et al., 2011), we use the high-resolution Weather Research and Forecasting (WRF) model with explicit treatment of aerosol-cloud-precipitation interactions to perform cloud-system-resolving simulations of cloud brightening. The same model configuration has been used by Wang and Feingold (2009a) to examine the transition from closed-cell Sc to open cells. The two distinct cellular structures that have starkly different reflectance patterns (also revealed by satellite imagery; e.g.,Garay et al., 2004; Wood and Hartmann, 2006), have been shown to be associated with aerosol effects on rain-production processes and dynamical feedbacks in a self-organizing system (Stevens et al., 2005; H. Wang and Feingold, 2009a; Feingold et al., 2010). More relevant to cloud brightening, however, is that once the open cells are established, they appear to be resilient to aerosol perturbations. Another key result is that gradients in aerosols and precipitation can generate mesoscale circulations that impact clouds well beyond the conventional "aerosol indirect effects" (H. Wang and Feingold, 2009b).

Based on these prior studies, we conducted experiments with four combinations of different meteorological and aerosol background conditions observed in the Northeast Pacific Sc regime. Seawater particles are injected into the model atmosphere by single, multiple or numerous sprayers. In the first two cases, sprayers are allowed to move at a speed of 5 m s-1 in the domain approximately the size of a climate model grid box, while in the latter case sprayers are uniformly distributed over the model domain. The average surface injection rate of 1.45×106 m-2 s-1 is close to that suggested by Salter et al. (2008). The injection strategy is critical in influencing the spatial distribution of the additional aerosols. Both areal coverage and local number concentration are important players in cloud brightening but neither one always emerges as dominant. For a given amount of aerosols, the two aspects need to be balanced to optimize the enhancement of cloud amount and albedo. In the cases where clouds are susceptible to aerosol perturbations, injection from single or multiple sprayers can introduce a significant heterogeneous response in the domain. The study also suggests that mesoscale circulations induced by rain suppression associated with multi-sprayers can have unforeseen influence on cloud structures and brightness depending on the distance between the sprayers, and that diurnal variations of clouds and precipitation may be important for the effective timing of seeding.

Results show that the effectiveness of cloud brightening depends strongly on meteorological and background aerosol conditions and, sometimes, the injection strategy. Suppressing rain as a means of sustaining cloud water is the most efficient way to brighten clouds in the cases considered here. Hence, it is very effective in a weakly precipitating boundary layer in which the additional aerosols can substantially weaken the precipitation. Seeding the aerosol-limited cloud in conditions preceded by heavy and/or persistent rain that has significantly depleted existing aerosols is also effective. The same amount of injected material is less effective in either strongly precipitating clouds or aerosol-rich clouds. Cloud drops grow large enough to rain out in the former case even in the presence of additional aerosols. Cloud brightening is ineffective in a relatively dry boundary layer that supports clouds of low liquid water path. In the aerosol-rich case and the dry case, the aerosol injection increases drop number concentrations but lowers supersaturation and liquid water path. As a result, the cloud experiences very weak albedo enhancement, regardless of the injection method. Detailed results have been published in Wang et al. (2011), part of which is to be presented at the meeting.

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Groundwater temperature, an indicator of climate change?

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Groundwater temperature, GWT can be considered as a conservative parameter. Changes in GWT require large energy inputs. The thermal conductivity coefficient of water is 0.6 W/m K. consequently water is a bad heat conductor. Deviations from local steady state conditions can be associated to surface changes taking into account the local geological conditions; it means the presences of geothermal sources.

Since early 80´s GWT changes have been related to global warming (Beck, 1982; Lachenbruch and Marshall, 1986). Some authors have analyzed energy feedbacks across the local and regional hydrologic cycle to get correlations between GWT and climate changes (Allen et al., 2004; Maxwell and Kollet, 2008).

There are some factors that must be taken into account when exists variations of GWT. If there are not geothermal sources or radioactive elements like Uranium that could increase temperature, then, any increase can be associated to surface temperature changes.

Soils and surface rocks can limit the heat penetration, even vegetation, making difficult a direct correlation between surface temperature and GWT, same situation can be found in urban areas (Taniguchi et al.). Rain infiltrations can decrease locally temperature of shallow aquifers. The type of aquifer rocks is one of the main factors that can facilitate heat penetration. Other aspect is the wind. Wind can cool terrain surface. Watertable variations intervene in GWT. In arid zones with limited recharge, extraction is almost greater than recharge and then watertable can go in depth some meters per year.

In Irapuato Salamanca Valley, Central Mexico, there are not feasible evidences of GWT changes (Rodriguez et al., 2006). There are not historical data records of GWT. We analyzed temperature data from 11 years that cannot be significant, not observing substantial changes. In the area there are meteorological stations with non continuous records.

It is necessary to instrument selected aquifers to have reliable data. Meteorological stations must be also recording without problems. This proposal implies a compromise from some federal institution responsible of environmental issues because it is necessary to have training personal, equipment, operation and maintenance programs and funds.

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Geoengineering and Emissions Mitigation: Policy Context

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The analysis presented in this poster considers the potential use of solar radiation management (SRM) techniques and the context in which this climate response option might be considered. As noted by others (Wigley, 2006), SRM is a viable option only if used in conjunction with emissions reductions. This is because SRM alone will not substantially reduce impacts due to ocean acidification, SRM itself will cause ancillary climate changes, and use of SRM without emissions mitigation would risk large climate changes if SRM were suddenly stopped. Only a long-term reduction in the net amount of fossil carbon dioxide entering the atmosphere can stabilize the climate system.

Scenario analysis is used to examine the context for the potential use of geoengineering. Several points are demonstrated.

- Emissions reductions, even under the most ambitious mitigation scenarios considered in the literature, cannot ensure that temperature is below a given threshold at all times if the climate sensitivity is high. Emissions reductions, however, can ultimately reduce long-term global temperature change below (or near) a 2 °C threshold value by some point in the 22nd century (or earlier if the climate sensitivity is not too high), although the scale of the necessary reductions may be large.

- The situation where the climate sensitivity is high (or, equivalently, the sensitivity of some key impact is high), is where forcing reduction through solar radiation management (SRM) techniques might be considered. SRM would need to be used in addition to emissions mitigation in order to meet stated policy goals (e.g., Cancun Agreements). SRM could potentially be used under these circumstances as a measure to reduce the magnitude of global temperature changes and associated impacts over an interim period.

- The primary determinant of the magnitude of potential SRM is the climate sensitivity. Delays in emissions reduction also increase the magnitude of the SRM that would be needed to keep global temperatures under a given threshold.

It is important to note that SRM will not exactly counter greenhouse gas forcing due to different spatial and spectral characteristics. SRM will, therefore, cause climate changes itself. The character of these changes would need to be much better understood before SRM could be deployed. It is important to examine the potential magnitude of these changes in an appropriate context. SRM used as an adjunct to emissions mitigation could be of much smaller magnitude than many of the scenarios considered in the literature (Wigley, 2006). Where scenarios in the literature have often considered SRM of sufficient magnitude to counter a CO_2 doubling, the magnitude of SRM needed if used in conjunction with emissions mitigation is generally much lower. SRM techniques are not understood well enough at present for application, and their potential use raises numerous ethical, technological, scientific, and policy issues that will need to be addressed. Because the goal of SRM is to reduce net impacts, the impacts due to the deployment of SRM measures would need to be smaller than the impacts that would have occurred without SRM. Because a deterministic understanding of all relevant impacts is unlikely to be realized, this comparison would need to be done on the basis of probabilistic and risk management paradigms. In summary, the possible use of SRM should be considered in the context of substantial, long-term emission reductions. The conditions under which SRM might be considered are the same conditions that require substantial emissions reductions in order to meet stated policy goals. SRM does not substitute for emissions reductions and it would be useful for analysis of SRM and its impacts to be done in this context. Policy measures to tie potential SRM use to long-term emission reductions could also be considered.

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Public perception of climate geoengineering in Japan as revealed in an online survey

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Public perceptions of emerging, controversial technologies play a vital role in public discourse on the path of technological development. For climate geoengineering, some studies examined the public perceptions, but efforts so far were focused only on the United Kingdom and the United States (The Royal Society, 2009; Ipsos MORI, 2010; Leiserowitz et al., 2010).

Here we present results on an online, national survey conducted in March 8-9, 2011, in Japan, to examine the public perception. Using a commercial service, we asked approximately 4000 respondents about their attitudes toward global warming and the stratospheric aerosol injection, arguably the most "promising" among various geoengineering options. Since respondents had little prior knowledge about this technology, respondents read short descriptions of climate geoengineering, which explained the basic mechanisms, possibilities of dangerous climate change as rationale for climate geoengineering, and potential side effects.

Majorities expressed cautious attitudes toward geoengineering, and show support for climate geoengineering research, although the survey questions did not distinguish between modeling, laboratory experiments, and field experiments. Survey participants chose the university researchers and international organizations as the most trusted sources for information about geoengineering, while the media and government ranked relatively low. We discuss the implications of the survey findings.

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Tropospheric sulfate burdens as a consequence of stratospheric sulfate geoengineering

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Stratospheric sulfur injection is a leading geoengineering idea to counteract climate change. Sulfate aerosols can cool the lower atmosphere by scattering and absorbing incoming shortwave radiation. The stratosphere is a more efficient location than the troposphere due to longer aerosol lifetime, but has unintended consequences such as changes to heterogeneous chemistry and ozone destruction.

Volcanoes act as natural tests to this idea; after major volcanic eruptions, reduced surface temperatures and reductions in the stratospheric ozone column are observed. However, little is known about the efficacy and consequences of continuous stratospheric sulfur injection. Simulations with prescribed size distributions have found a generally linear association between injection rate, sulfate burden, and temperature reduction (e.g. Rasch et al., 2008; Robock et al., 2008). The first microphysical aerosol simulations were conducted by Heckendorn et al. (2009) using a 2d aerosol model, and found geoengineered aerosols to grow much larger than previously assumed, resulting in a significantly lower lifetime and temperature change efficacy. All previous work has focused on the stratosphere and the earth's surface, while impacts in the middle and upper troposphere have not been well studied. We present geoengineering simulations using a 3d microphysical aerosol model fully coupled with a 3d general circulation model and full sulfur chemistry. We compare our stratospheric burden results to Heckendorn et al.(2009), and conduct a detailed analysis of the upper tropospheric sulfate burden.

We use the WACCM3/CARMA model that includes three-dimensional treatment of SO_2 and OCS surface emissions, 63-species chemistry, nucleation, growth, coagulation, and wet deposition (English et al., 2011). The model is run using 4 x 5 degrees horizontal resolution, 66 vertical levels, and 42 dry sulfuric acid aerosol bins. We use a numerically-efficient form of binary homogeneous nucleation (Zhao and Turco, 1995), and enhanced coagulation due to Van der Waal's forces (Chan and Mozurkewich, 2005). We specify four geoengineering scenarios (1, 2, 5, and 10 Tg sulfur annual injection) of SO_2 at the 50 mb level, between 4 degrees S and 4 degrees N, across all longitudes (similar to Heckendorn et al., 2009). Simulations are run for 5 years, with the 5th year analyzed.

We find the relationship between SO_2 injection rate and stratospheric mass burden is highly non-linear, with reduced efficacy at higher injection rates (Figure A.4.5). To achieve 6 Tg S burden, 10 Tg S/yr injection rate is required, which is five times more than simulations that assumed prescribed size distributions (Rasch et al., 2008), and very close to that predicted by the only other microphysical study done (Heckendorn et al., 2009). The burden discrepancy is attributed to the particles growing to larger sizes (1 micrometer radius) than previously assumed, which have faster fall velocities and shorter stratospheric lifetimes. (Additionally, larger particles are less effective at scattering shortwave radiation). Additionally, we find a significantly increased sulfate burden across large regions of the troposphere. Fully one-third of the sulfate burden is in the troposphere, with tropospheric enhancements observed in many regions, particularly the high latitude upper troposphere. For the 10 Tg simulation, we find the sulfate mass burden between the tropopause and 100 hPa below the tropopause is 30 times higher and the next 100 hPa region down is 10 times higher than the unperturbed scenario. The entire tropospheric burden is five times higher than normal. This enhancement of sulfate aerosols can have implications for tropospheric cloud properties, radiative forcing, and upper tropospheric chemistry. Additionally, increased acid deposition occurs in mid- and high- latitudes, as has been previously noted (e.g. Kravitz et al., 2009).

These results highlight numerous limitations and consequences of stratospheric sulfate geoengineering. In addition to limited efficacy, ozone destruction, and surface acid deposition that have been published previously, we find a significantly enhanced upper tropospheric sulfate burden which may alter tropospheric clouds, chemistry, and radiative forcing. We recommend geoengineering ideas to be studied in more detail before they are seriously considered as climate intervention options.

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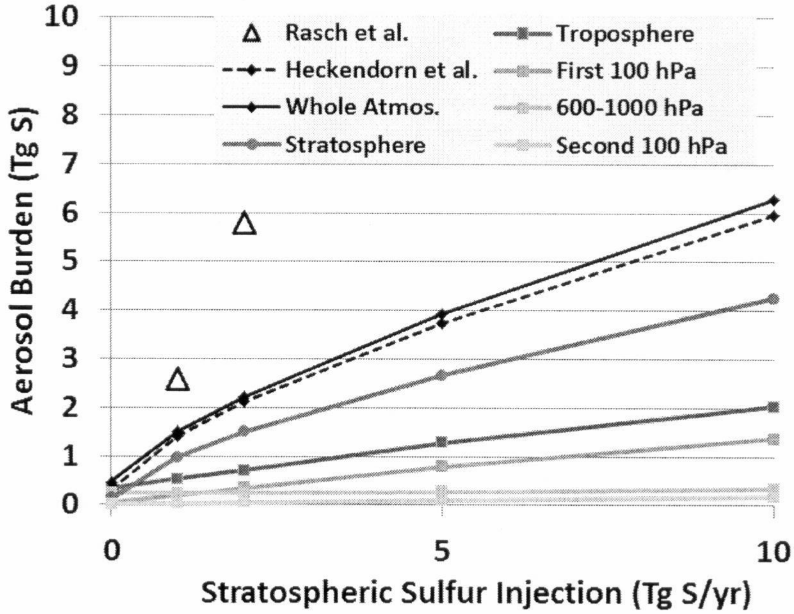

Figure A.4.5: *Aerosol burden as a function of stratospheric sulfur injection for the specified regions. "Whole Atmos." represents the whole atmosphere for a direct comparison to Heckendorn et al. and Rasch et al. Troposphere and Stratosphere burdens are found using the levels of the zonally averaged cold-point tropopause and warm-point stratopause. "First 100 hPa" represents the region spanning from the tropopause to 100 hPa below the tropopause. "Second 100 hPa" spans 100 hPa below the tropopause to 200 hPa below the tropopause. "600-1000 hPa" spans from 600 hPa to the surface.*

Understanding the potential of ocean iron fertilization to reduce atmospheric carbon dioxide.

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The reservoirs of carbon that interact on millennial time scales are those in the ocean, the atmosphere and over the top meter of the land. Of these millennial reservoirs, the ocean is by far the largest: 36 Tt as opposed to 0.7 Tt for the atmosphere and 2.3 Tt for land (Sarmiento and Gruber, 2002). By comparison, current estimates of the fossil hydrocarbon reservoir are of the order 4 Tt. Over tens of millennia, almost all of the CO_2 released into the atmosphere from fossil fuel use will enter the vast oceanic reservoir but before it does so, the enhanced atmospheric CO_2 concentrations will cause substantial environmental perturbation largely driven by greenhouse warming and ocean acidification.

Regardless of the strategy adopted for fossil fuel use over the coming decades, there will be an increase in atmospheric CO_2 followed by a much slower decrease, such that after 10,000 years, atmospheric CO_2 levels will still be substantially higher than pre-industrial levels (Archer, 2005; Solomon et al., 2009). In the context of geoengineering, the objectives of CO_2 reduction techniques are to reduce the rate of CO_2 increase and to reduce the ultimate height of the CO_2 peak so that human adaptation to environmental changes will be easier to achieve. From a carbon system perspective, because the oceans represent such a large reservoir of carbon, as well as roughly ¼ of the atmospheric CO_2 uptake, small perturbations of the system could potentially result in large changes to the carbon balance. From the oceanic geoengineering perspective, the objective of ocean carbon sequestration would be to develop ways in which the oceans can take up carbon at a faster rate than they currently do but with predictable and acceptable consequences.

The productivity of the oceans and hence their capacity to sequester CO_2 from the atmosphere is limited over large areas by the micronutrient iron. More than thirteen large scale open ocean addition experiments have been conducted to examine the effect of iron addition to the marine environment. There have also been several studies of ocean regions where there are natural supplies of iron (from islands or volcanic ash) in generally high nutrient, low chlorophyll (HNLC) regions. The conclusion from these experiments is that relief of iron stress does increase the biomass of marine phytoplankton. The effects of this biomass increase include a reduction in the concentration of CO_2 in the surface waters and potentially a local enhanced uptake of CO_2 from the atmosphere. Depending very much on the location, time of year of the experiments, and duration of the experiments, these iron additions have led to variable increases in the export of carbon from the upper ocean and sequestration of it into the deep ocean where it will be isolated from the atmosphere for decades to centuries (Boyd, 2008; Buesseler et al., 2008; Pollard et al., 2009; R. S Lampitt et al., 2010).

The experiments to date were not planned from the perspective of climate engineering and conclusions from them about the potential of this approach as a means of reducing atmospheric CO_2 concentrations have large uncertainties. The experiments have usually not been of adequate duration to determine whether sequestration occurred and have not been of sufficient areal coverage in order to reduce edge effects and to facilitate study of relationships between upper ocean processes and those at depth. In fact, few of the experiments measured carbon flux out of the surface water. Furthermore they have not been embedded in adequate coupled models of ocean physics and biogeochemistry to extrapolate results beyond the experimental area.

Few ocean iron addition experiments have addressed processes that would allow a better understanding of the unintended consequences of deliberate additions. This last point is of particular concern and has been a major feature during the recent discussion of a risk assessment framework for experimentation by the London Convention and London Protocol. There is no doubt that several consequences of ocean iron fertilization will occur beyond simply the uptake of CO_2. Some of these such as a decrease in deep water pH and in oxygen concentration are inevitable and relatively easy to predict. The potential of other unintended consequences -- such as the generation of nitrous oxide from organic matter degradation at depth, the generation of dimethyl sulfide and methane or the growth of phytoplankton which has the capability of releasing harmful toxins -- has much larger uncertainty at present. Some of these consequences are undesirable and on a large scale may be considered unacceptable.

Given the uncertainties, there is an urgent requirement to carry out more studies on ocean iron fertilization with three clear objectives

1. To develop coupled global scale computation models so that predictions can become more reliable and so that in situ experiments can be carried out efficiently and effectively

2. To carry out experiments on a sufficiently large scale and duration to determine the extent of carbon sequestration, including at what efficiencies, depths and hence time scales this would take place.

3. To explore in considerable detail the complete consequences of ocean iron fertilization, and not just the magnitude of carbon uptake from the atmosphere and sequestration in the deep ocean.

It is only when these activities have been completed that it will be possible to determine whether ocean iron fertilization has the potential to remove substantial amounts of atmospheric CO_2, whether there are harmful consequences and whether these consequences can be predicted with an uncertainty that is acceptably low.

The ISIS consortium (In Situ Iron Studies) of 13 institutions worldwide was formed in 2011 specifically to promote such studies so that informed decisions will be possible in the future. The mission statement is: "To resolve the impact of iron fertilization on marine ecosystems, to quantify its potential for removal of atmospheric carbon dioxide, and to improve our collective understanding of the changing ocean." http://isisconsortium.org/

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Annex 5: Breakout Group Reports

The program of the IPCC Expert Meeting on Geoengineering included three sets of BOG discussion sessions. In the discussions, expert participants broadly considered a range of geoengineering approaches and issues and identified both common understanding and divergent perspectives as background for author of the IPCC's Fifth Assessment Report (AR5). Three to four subgroups met in each BOG session, and the main points of each discussion are captured in the BOG reports included here. These individual BOG reports may not always be entirely consistent neither among themselves nor with respect to the overall meeting Summary of Synthesis Session (Boucher et al. 2012, this issue), instead providing snapshots of meeting discussions as context for the summary. The individual BOG reports also do not necessarily reflect the views of each BOG's Chair and Rapporteur.

Breakout Group I.1: Solar Radiation Management Options and Methods

Chair: Govindasamy Bala

Rapporteur: Piers Forster

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG I.1 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussion:

- What are the most important Solar Radiation Management approaches that IPCC authors might want to consider in the AR5?
- What are the most important aspects of these approaches to evaluate (e.g., physical impacts, time scales, system boundaries, spatial scales, direct/private costs)?
- Can the most important aspects of these issues be supported by reference to the peer-reviewed literature, ideally drawing from multiple lines of independent evidence? What is the available evidence and what are relevant references?

Introduction

This BOG discussed Solar Radiation Management (SRM) focusing on determining techniques IPCC authors might consider, overall framework and terminology that could be employed, and ways different impacts could be assessed.

Terminology

The group briefly discussed terminology. The group felt comfortable with "geoengineering" as a term describing a variety of mechanisms that deliberately affect climate at a large scale. The group discussed the boundaries of this term when impacts of a given technique are more regional than global. However, the group did not see the necessity of forcing an exact definition; a loose definition may serve the community.

As some proposed techniques, such as cirrus thinning, affect long wave radiation, the term SRM was discussed. The BOG suggested that the term "Radiation Management" may be more appropriate.

Scope

Much discussion focused on what was and was not in the scope of approaches that IPCC authors might want to consider in the AR5. Generally it was felt that the IPCC's AR5 reports should be as comprehensive as possible with regard to SRM, but focused on the most plausible schemes that are supported by the literature. Extensive discussion of speculative schemes or those with little potential of either deployment and/or impact would be less useful for policymakers.

Approaches supported by literature that the IPCC could consider are: space mirrors/generic total solar irradiance (TSI) experiments; stratospheric aerosol techniques via injection of gases, particles and/or special particles; cloud whitening, especially marine stratocumulus; direct tropospheric aerosol effects from sea-salt or sulphate; reducing cirrus amount or thickness; increasing crop albedo, land-surface albedo, or ocean surface albedo (e.g., ocean bubbles or painting roofs white). It was felt that within these techniques, stratospheric aerosol and cloud whitening had more extensive literature.

Some suggested assessment of ideas that, although small on the global scale, may be relevant for regional adaptation and mitigation, such as the possible role of urban surface albedo enhancement in urban heat island mitigation.

Several other possible techniques such as hurricane suppression, modifying storm track position and protecting glaciers were also discussed. Some participants thought that these ideas were too small scale and may be better considered on the scale of adaptation, but they could also be assessed by the IPCC where literature is available.

Framing

The group felt that it was important to consider frameworks for assessing geoengineering, such as in the wider context of mitigation and climate change adaptation. Choice of baseline for comparing techniques was repeatedly discussed. The group acknowledged that publications have different baselines and this could make assessment of the literature difficult. Activities such as the Geoengineering Model Intercomparison Project (GEOMIP) could be useful as baselines are comparable (Kravitz u. a. 2011).

BOG participants discussed value judgments in assessing geoengineering techniques. Words such as "good" and "bad" or even "effectiveness" and "side-effects" can be awkward when there are winners and losers both from geoengineering and mitigation. Authors should try to be explicit when value judgments and/or assumptions are made.

The BOG discussed the advantages of the radiative forcing metric. It also considered the importance of assessing other aspects of the physical climate, as not all radiative forcings are created equal: there are regional effects and hydrological cycle effects, and radiative forcings can have different efficacies for even the globally averaged surface temperature.

Other framing issues considered were the timescale of deployment, the testability of techniques, their scalability, any termination effects from turning schemes off, and the timescales of such effects. How SRM could influence CO_2 was also considered, as were the costs that might be included in assessments.

Overall there was a general focus on Working Group I issues. Due to lack of time and the direction of the conversation several issues particularly surrounding Working Group II and III issues were not covered in detail.

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Breakout Group I.2: Solar Radiation Management Options and Methods

Chair: Olivier Boucher

Rapporteur: Michael Prather

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG I.2 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussion

- What are the most important Solar Radiation Management approaches that IPCC authors might want to consider in AR5?
- What are the most important aspects of these approaches to evaluate (e.g., physical impacts, time scales, system boundaries, spatial scales, direct/private costs)?
- Can the most important aspects of these issues be supported by reference to the peer-reviewed literature, ideally drawing from multiple lines of independent evidence? What is the available evidence and what are relevant references?

Introduction

The BOG's efforts to directly answer the above questions led to better defining an approach to answering such questions, an approach that could be shared by all three Working Groups. Participants in the discussion did not feel that this BOG could make the scientific assessment asked for in these questions, but recognized that AR5 authors must do so.

Terminology

Should IPCC authors change the terms? Probably not, but it would be beneficial to explain the limitations and multiple meanings of "geoengineering" as well as "Solar Radiation Management" (SRM). Also, authors may wish to be careful in the nomenclature regarding inadvertent or adverse effects; "indirect effects" can be used to cover both climate system issues (e.g., pertaining to the ozone, oceans, ecosystems) and socially related issues (e.g., costs, waste products, atmospheric visibility/astronomy).

Literature

The group discussed keeping the IPCC AR5 focused on assessment of the geoengineering literature, but also on scientific literature relating to processes invoked in SRM and on the scientific basis of the proposed geoengineering methodology.

Overall Approach:

AR5 authors may consider inclusion of the following topics:

- indirect, non-climate impacts
- energy inputs
- uncertainty in predicting aerosol-cloud response
- uncertainty in stratospheric aerosols' role in circulation and ozone

Regional SRM – regional climate change

There are limitations in current ability to predict regional climate change patterns from global mean forcing over several decades (e.g., from greenhouse gases), and hence the ability to project local, regional responses to local SRM (e.g., associated with roofs or agriculture) is also limited, with corresponding consequences for assessment possible at this time.

Verification

Verification of an SRM's impact on climate forcing may be through a set of simple metrics relating to reflectivity, rather than the much more difficult task of measuring a change in radiative forcing. Given surprises of non-linearity (e.g., as associated with Mt. Pinatubo) and indirect effects (e.g., as associated with anoxic oceans), there needs to be scientific verification that a geoengineering action actually has the pre-calculated results. The AR5 might assess the current state of scientific understanding regarding such verification.

Extent of AR5

Do IPCC authors focus on specific SRM topics or cover all equally? A table with similar format across all the Working Groups could help guarantee that all reasonable, published approaches are included, with assessments focused on approaches with more mature analyses and literature.

Proposal:

A table on geoengineering that cuts across the Working Groups and could be combined for the Synthesis Report. All Working Groups could use the same format, with the same rows (SRM and CDR proposals) but with different columns.

Approaches: (sectioned, with multiple rows, to include SRM and CDR)

Major SRM sections are:

- Space-based reduction in incident sunlight
- Stratospheric aerosols (e.g., sulfate, others, engineered)
- Cirrus modification (e.g., ice nuclei)
- Cloud brightening (e.g., marine stratus)
- Surface albedo change (e.g., no roofs, deserts, crops, ocean bubbles)

Columns: (columns specific to each Working Group)

- Realizable potential radiative forcing (possible global radiative forcing, also considering economic/social limitations)
- Scalability – in terms of climate and indirect environmental effects (Working Group 1 and 2), e.g., scalable from pilot to climate-effective implementation?; in terms of economic and social costs (Working Group 3)
- Indirect effects – in terms of the climate system (Working Group 1 and 2); in terms of social costs (Working Group 3)
- Potential for unpredictable effects
- Sustainability / Ability to be corrected (scientific or socio-economic)
- Affordability / Costs
- Verification of climate impacts
- Governance / Challenges (including ability to be invoked by individuals, impacts beyond boundaries, timescales of response)
- Subsections on scientific understanding and confidence level

Breakout Group I.3: Carbon Dioxide Removal Options and Methods

Chair: Peter Haugan

Rapporteur: Johannes Lehmann

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG I.3 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussion:

- What are the most important Carbon Dioxide Removal approaches that IPCC authors might want to consider in the AR5?
- What are the most important aspects of these approaches to evaluate (e.g., physical impacts, time scales, system boundaries, spatial scales, direct/private costs)?
- Can the most important aspects of these issues be supported by reference to the peer-reviewed literature, ideally drawing from multiple lines of independent evidence? What is the available evidence and what are relevant references?

Introduction

This BOG's discussion concentrated on identifying major Carbon Dioxide Removal (CDR) approaches that might be considered in the AR5, evaluating issues relevant to development and implementation of the approaches, and considering the peer-reviewed literature on development aspects. In addition, the group spent time discussing the terminology of geoengineering.

What are the most important Carbon Dioxide Removal approaches that IPCC authors might want to consider in the AR5?

The group wrestled with whether the terms "geoengineering" and even "Carbon Dioxide Removal" are appropriate organizing principles for associated technologies within the context of the IPCC or national debates. While the choice of terminology may at this juncture be unavoidable for multiple reasons (historical development, risk of "white-washing", etc.), the organizing principle may benefit from rethinking.

The unifying characteristic of currently grouped CDR approaches is creation of a storage issue. This can be used as a high-level organizing principle to distinguish with Solar Radiation Management (SRM). Other organizing principles worth considering include the following:

- Transboundary processes?
- Emissions reductions versus sink creation?
- Size of sink?
- Biological, physical, chemical?
- Local benefit as additional driver or control? (e.g., soil fertility in case of conservation agriculture, tillage, or biochar; or local energy needs in case of bioenergy in combination with Carbon Capture and Storage (CCS))

The group proposed a range of approaches without making a priority list:

- Afforestation/reforestation
- Improved forest management
- Sequestration in buildings
- Biomass burial
- No till agriculture
- Biochar
- Conservation agriculture
- Fertilization of land plants
- Creation of wetlands
- Bioenergy with CCS
- Ocean storage (biological, chemical, physical):
    - Fertilization
    - Algae farming and burial
    - Blue carbon (mangrove, kelp farming)
    - Modifying ocean upwelling
    - Direct CO_2 injection
    - Weathering
    - Ocean pipes
- Carbon absorbing cement
- Direct air capture of CO_2

Figure A.5.1 provides an example for applying the organizing principles discussed above to more appropriately shape the discussion about CDR:

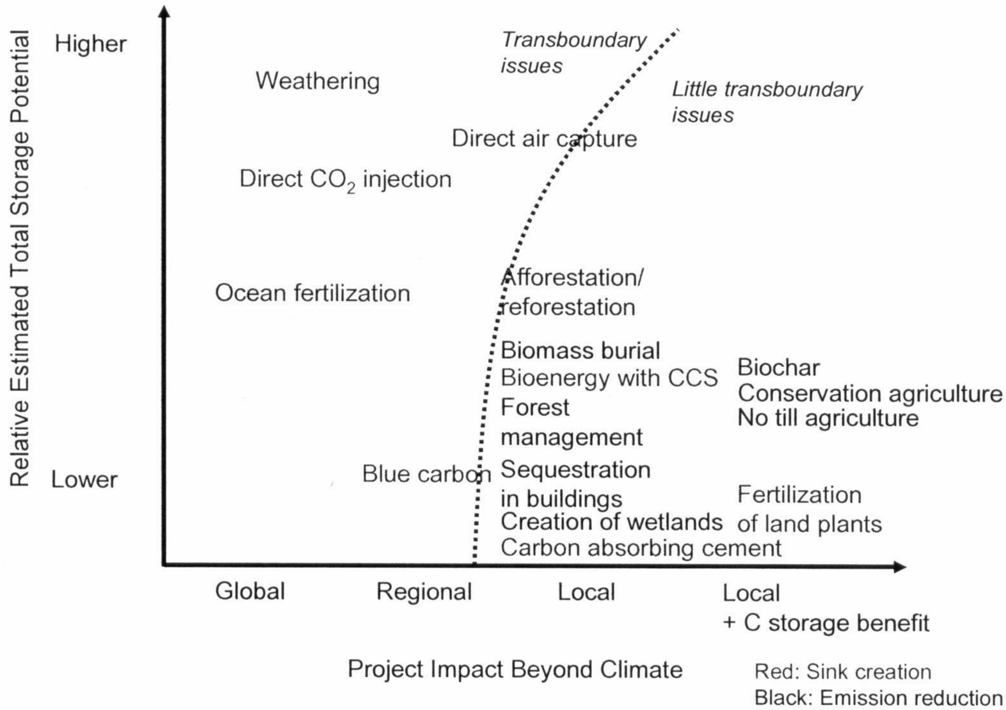

Figure A.5.1: *The relative estimated total storage potential for emission reduction and sink creation projects at different scales.*

What are the most important aspects of these approaches to evaluate?

The group's discussion included the following aspects:

- Feasibility (technical, risks)
- Effectiveness (time to maximum deployment, maximum rate of CDR (Gt C/yr); maximum integrated storage potential (Gt))
- Side effects (physical, biological, risks, local and global scale)
- Efficiency (direct cost, social costs, including side effects)
- Legal and social acceptability
- Regulation (economic incentives, command and control)
- Monitoring and Verification
- Ethics (long time scales)

The BOG noted that it is important to distinguish whether research or deployment is to be evaluated.

Can the most important aspects of these issues be supported by reference to the peer-reviewed literature?

The group discussed whether relevant criteria can be assessed using the available peer-reviewed literature (Y/N). The judgment is subjective rather than based on the number of publications in the peer-reviewed literature, also recognizing that publication activity is not necessarily an indicator of the ability to draw conclusion.

Table A.5.1: Criteria for Carbon Dioxide Removal Approaches

	Weathering (land and ocean)	Ocean fertilization, biological	Afforestation/ reforestation	No-tillage	Biochar	Direct capture
Feasibility	Y	Y	Y	Y	Y	Y
Effectiveness	N	Y	Y	Y	Y	Y
Side effects	N	N	Y	Y	N	Y
Efficiency	N	N	Y	Y	N	Y
Social/legal acceptability	N	N (Y for legal)	Y	Y	Y	Y
Regulation	N	N	Y	Y	N	N
Monitoring & Verification	N	N	Y	Y	Y	Y
Ethics	N	N	Y	Y	N	N

Breakout Group I.4: Carbon Dioxide Removal Options and Methods

Chair: Dieter Wolf-Gladrow

Rapporteur: Robert Scholes

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG I.4 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussion:

- What are the most important Carbon Dioxide Removal approaches that IPCC authors might want to consider in the AR5?
- What are the most important aspects of these approaches to evaluate (e.g., physical impacts, time scales, system boundaries, spatial scales, direct/private costs)?
- Can the most important aspects of these issues be supported by reference to the peer-reviewed literature, ideally drawing from multiple lines of independent evidence? What is the available evidence and what are relevant references?

Introduction

The BOG discussed the characteristic features of geoengineering in terms of Carbon Dioxide Removal (CDR) options and methods. Considerations also included direct and indirect consequences over a range of temporal and spatial scales, associated with economic considerations as well as risks and uncertainties. Important CDR approaches for land and ocean were listed. The group discussed criteria for assessing geoengineering methods and considered review papers, recent development papers and classical papers. The group was of the opinion that current knowledge and peer-reviewed literature is not sufficient to assess all important issues of geoengineering.

Definition of geoengineering

The BOG discussed that it could be useful to prioritize the IPCC AR5 geoengineering discussion by focusing on those actions with potentially large consequences and technologies that are relatively poorly understood. However, it was also recognized that the technologies fall on a continuum of scale and risk, and any delimitation is necessarily arbitrary. Rather than getting stuck in an endless debate about what is and is not geoengineering, the group suggested, for the purposes of the IPCC and in the immediate term, a core definition (based on Schneider (2001), Royal Society (2009) and the CBD definition):

'Geoengineering' consists of actions taken with the intent of controlling the global climate.

And then reducing the scope by specific exclusions. Some of the key criteria for including or excluding topics are:

1. ***Scale*** – this is 'climate scale' rather than 'geographical scale'
2. ***Consequence*** – are there potentially significant or poorly understood undesired impacts on either the climate system or on other issues of concern, such as biodiversity?
3. ***Reversibility*** – is it easy to return to the pre-action state, and will rapid climate change result from discontinuation of the activity?

4. ***International scope*** - Does the action take place and have its undesired impacts solely within the sovereign territory of the party taking the action, or does it unavoidably affect other countries or the global commons (e.g., atmosphere or open oceans)?

On one or more of these bases, some approaches (e.g., afforestation, energy technologies such as bioenergy) can be excluded from immediate global assessment (or relegated to a second tier, where they are noted but not assessed in depth), though they may need comprehensive local assessment (e.g., a national environmental impact assessment for action on Carbon Capture and Storage), potentially with global assessment at a later stage.

Technologies for potential consideration in the AR5

Predominantly land-based actions

1. Enhanced weathering of silicates. Mining and finely grinding silicate minerals and dispersing them widely over terrestrial or marine ecosystems or incorporating them into agricultural soils. Among the key impacts are the massive scale of mining and transport needed.
   a. Calcium silicates: $CaSiO_3 + CO_2 \rightarrow CaCO_3 + SiO_2$
   b. Olivine: $MgSiO_4 + 4\ CO_2 + 4\ H_2O \rightarrow Mg^{2+} + 4\ HCO_3^- + Si(OH)_4$
2. Biochar production through pyrolysis of biomass in a reduced-oxygen environment to the point where it becomes very resistant to decomposition (half life > 1000 years) and its subsequent incorporation in agricultural soils as an amendment
3. Bioenergy production coupled with Carbon Capture and Storage (CCS)
4. Direct Air Capture followed by CCS
5. Land use change and management, including but not restricted to afforestation and reforestation
6. Biomass harvest and burial in anoxic environments, such as deep oceans, lakes or bogs

Predominantly ocean-based actions

1. Deep or intermediate injection of CO_2 in oceans as CO_2 or as hydrates
2. Fertilisation of the oceans with iron or other nutrients
3. Addition of alkalinity to the ocean, alone or in conjunction with CO_2 injection
   a. Adding finely crushed $CaCO_3$ directly
   b. Converting $CaCO_3$ to CaO (added to ocean) and CO_2 (put into CCS)
   c. Actions involving silicates (see land discussion)
   d. Cooling and fertilising of surface ocean by pumping up deep water

Overview of possible criteria for assessment

1. Potential magnitude (Pg C) and rate (Pg C/yr) of removal associated with technology
   a. Technical (upper) vs realisable/realistic/market potentials
2. Timescales of
   a. deployment (technology readiness, time to build infrastructure),
   b. operation (for how long will this need to occur)
   c. reversion of atmospheric CO_2 if you stop doing it ('relaxation time')
   d. time-lag between doing it and seeing benefits (over what timescale do you assess the effects?)

3. Scale:
    a. Geographic extent of activity and its intended and unintended consequences
    b. What is the minimum unit size (not geographical, but in terms of Pg C/yr) to be viable and what is the potential for starting small and benefitting from learning curves?
    c. How does the technology scale? Is there a maximum size, a diminishing effectiveness with size or increasing effectiveness with size (economies/diseconomies of scale)?
    d. Where is the technology currently with respect to scale: laboratory-, pilot-, or full-scale?
4. Net consequences for the climate system
    a. temperature, precipitation, radiation (amount and the split between diffuse and direct radiation), CO_2^{atm}
    b. effects on climate variability (including diurnal and seasonal variation) and extremes
    c. regional differences in outcomes
    d. full Life Cycle Analysis including all relevant direct and indirect environmental impacts
5. Impacts, including benefits, on systems other than the climate system, whether intended or unintended
    a. Global to regional-scale impacts, e.g., on ocean acidification, food production (including fisheries), or biodiversity
    b. regional to local impacts, e.g., on ecosystem services, pollution, and land changes due to mining and infrastructure
6. Costs (including economic benefits)
    a. Include both financial (private) costs and full (public) costs.
    b. Differentiate between the entry cost versus the final costs for large-scale implementation.

The group noted the patchiness of the literature on costs, which is very sparse for some technologies.

7. Social acceptability
8. Risk of rapid leakage of CO_2, either by unforeseen failures or following discontinuation of action
9. Verification
    a. Can the claimed level of the activity be verified?
    b. Is it having the claimed and intended climate effect (attribution)?
    c. Can the associated impacts be monitored and attributed?
10. Legal issues
    a. conflict with existing treaties
    b. sovereignty
    c. equity
    d. Liability, responsibility
11. Current level of scientific knowledge/uncertainty, and what is it based on?
    a. Theory, simulation studies, small scale experimentation, or realistic-scale tests?

References

Schneider S.H., 2001: Earth systems engineering and management. *Nature* **409**, 417–421.

The Royal Society, 2009: *Geoengineering the climate: Science, governance and uncertainty*. Royal Society, London, UK. 82 pp., (ISBN: 9780854037735).

Breakout Group II.1: Solar Radiation Management Issues and Risks

Chair: Jason Blackstock

Rapporteur: Hannele Korhonen

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG II.1 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussions:

- What are the most important issues or dimensions related to Solar Radiation Management that IPCC authors might want to consider in the AR5 (e.g., governance issues, physical science issues, etc.)?
- What are the most important aspects of these issues to evaluate (e.g., unintended side effects, risks and uncertainties, indirect/social costs, legal and governance issues)?
- Can the most important aspects of these issues be supported by reference to the peer-reviewed literature, ideally drawing from multiple lines of independent evidence? What is the available evidence and what are relevant references?

Introduction

This BOG focused on the physical science related to Solar Radiation Management (SRM), governance and ethics issues that IPCC authors might wish to consider in the upcoming AR5. The group also discussed the extent of peer-reviewed literature available to evaluate each of these issues.

General points

It was stressed that all impacts of and uncertainties related to SRM should be evaluated in the context of not doing SRM. Even in a world without SRM, continuing greenhouse gas emissions mean that there is potential for new climatic conditions that could have severe or unexpected impacts on the environment and society.

The economics of SRM and the current knowledge on technological and engineering aspects were flagged as important issues that could be considered in the AR5, but questions were raised about which Working Groups and chapters this information would be assessed in. Concerns were raised that this information might fall between the cracks of existing Working Group and chapter outlines.

Physical science issues

The group noted that it may not be useful to make a distinction between intended and unintended consequences of SRM.

It was suggested that there is a reasonable amount of literature available from climate models related to global and regional precipitation and temperature effects from stratospheric aerosol injections and cloud whitening, as well as related to ozone loss from stratospheric injections. Constraining the physical effects can be done, for example, by looking at analogues (volcanic eruptions), model intercomparisons, etc.

For other SRM methods (e.g., cirrus clouds, space mirrors), the literature on physical impacts is very scarce.

There are a couple of publications available discussing sector-relevant issues, such as run-off, soil moisture, evaporation, diffuse radiation and UV flux. The group noted that these effects may be the most interesting to policy makers and the general public, although publications are limited.

There is no SRM-specific literature related to the potential for detection and attribution of SRM impacts against background climate change (signal-to-noise). However, some literature related to, for example, volcanic eruptions and "fingerprinting" climatic impacts can be relevant here.

Other important physical issues that might be discussed include ocean acidification, the termination problem, and the effect of SRM on atmospheric CO_2 concentration (e.g., by carbon uptake by vegetation in a cooler world with more diffuse radiation).

It was also mentioned that a thorough assessment of science in Working Group 1 will help the work of the authors of the other two Working Groups.

Social and governance issues

There is a range of peer-reviewed literature, in addition to the Royal Society report (Royal Society, 2009), that addresses the social and governance issues of SRM. However, most of this literature discusses the issues on a global, not regional scale.

It was suggested that, overall, SRM might be further discussed as a part of the IPCC AR5[2]. Legal and governance considerations and needs may evolve with new research and knowledge as well as with future climate conditions.

The group felt that IPCC authors might include both the governance of research and governance of implementation. It was also acknowledged that it can often be difficult to draw a line between research and deployment of SRM. However, it might be helpful to distinguish between the different levels of research (computer simulations, lab experiments, small scale tests with very little impacts, large scale tests). Although there is fear that successful small scale outdoor experiments could automatically lead to full scale deployment, many group members felt that this is unlikely without first going through a thorough investigation of large scale impacts.

The group also discussed the potential uses of SRM. Almost all the research thus far has focused on counteracting the effects of climate change that is, keeping the climate roughly where it is. However, SRM could also be used to meet more specific goals, for example, to optimize agricultural production or to preserve Arctic sea ice. There is currently no literature focusing specifically on this issue, although some papers address it to some extent.

It was also discussed that equity considerations need to be balanced. Also, an important governance issue is whether one country or a small coalition of countries can decide to implement SRM or whether a broader consensus is required.

Ethics

There is some literature either published or coming out soon on ethical questions of SRM. These issues may also be considered by IPCC authors.

References

The Royal Society, 2009: *Geoengineering the climate: Science, governance and uncertainty*. Royal Society, London, UK. 82 pp., (ISBN: 9780854037735).

[2] Note of the editors: No final attempt was made to place geoengineering within the range of human responses to climate change, including mitigation and adaption. This issue will need to be addressed in the context of the AR5.

Breakout Group II.2: Solar Radiation Management Issues and Risks

Chair: Catherine Redgwell

Rapporteur: Clarisse Kehler-Siebert

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG II.2 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussions:

- What are the most important issues or dimensions related to Solar Radiation Management that IPCC authors might want to consider in the AR5 (e.g., governance issues, physical science issues, etc.)?
- What are the most important aspects of these issues to evaluate (e.g., unintended side effects, risks and uncertainties, indirect/social costs, legal and governance issues)?
- Can the most important aspects of these issues be supported by reference to the peer-reviewed literature, ideally drawing from multiple lines of independent evidence? What is the available evidence and what are relevant references?

Introduction

This BOG discussion focused predominantly on Solar Radiation Management (SRM) issues that might be considered in the IPCC AR5 and their means of evaluation—that is, responding to the first two questions above. The final question regarding sources was addressed only cursorily.

What are the most important issues or dimensions related to Solar Radiation Management (SRM) that IPCC authors might want to consider in the AR5 (e.g., governance issues, physical science issues, etc.)?

The difficulty of assessing regional impact was identified as an issue that might be considered by AR5 authors. BOG participants proposed that assessing regional impacts of SRM is a governance issue (as opposed to a (purely) physical science issue). Work published today that *does* provide insight on regional impacts of global scale SRM is tentative. BOG participants proposed that while it would not be imprudent to trust extant predictions, there is also significant agreement that optimal forcing for one region would not be optimal for another region. It was proposed that the regional issues could be dealt with in various parts of AR5, including within Working Group I, and/or in the Working Group III chapter on national-international linkage (Chapter 13).

The detection and attribution of cause and effect was also identified by the BOG as a complex issue. From a scientific standpoint, it is difficult to attribute cause and effect in context of SRM. Thus, AR5 authors might consider the question of how well are we able to detect and attribute cause and effect for SRM. Furthermore, legal dimensions are also germane and complex. The question was also raised, but unanswered, as to whether IPCC AR5 authors should address liability and compensation. Finally, it was proposed that AR5 authors might question the increased complexity black carbon causes for this question of cause and effect.

IPCC AR5 authors may wish to consider how SRM is linked to current metrics in climate change. There is no metric to put these in the same framework—this was considered by some BOG participants as a gap in the literature. Still considering SRM and climate change, another issue for AR5 authors to consider is the flagging of risk (climate change) v. risk (SRM) to the 'external' world. Furthermore, the question of parallel treatment of issues was discussed: if looking at ethics and SRM, for example, parallel treatment might be considered for ethics of climate change generally. This led to several questions about IPCC assessment of questions of ethics.

The BOG also suggested that AR5 authors might pose the question, 'What are the governance gaps?' When considering governance, a distinction can be made between research and deployment. Some BOG participants believe that this distinction requires defining 'small scale'. The linkages to other processes might also be considered, for instance linking SRM and mitigation, or linking SRM to adaptation and development. Equity in governance is another consideration.

IPCC AR5 authors might also consider noting the outcome of a workshop of the Solar Radiation Management Governance Initiative (SRMGI), which articulated a need for an independent overseeing advisory board or committee which is independent and not purely scientific (SRGMI, 2011). A final question discussed by the BOG which might be considered by AR5 authors is whether there is something special about SRM that makes it 'international'. This may depend on the motivation of the actor. A need to assess technical impacts of SRM was also contemplated.

What are the most important aspects of these issues to evaluate (e.g., unintended side effects, risks and uncertainties, indirect/social costs, legal and governance issues)?

This question was to some extent addressed in the discussion summarized above. In addition, BOG participants emphasized that governance may not be 'one size fits all'. This is particularly true as concerns scale—it is important to be able to distinguish *de minimis* up to full-scale deployment. Another important distinction is between indirect and direct social cost, and unintended side effects.

Can the most important aspects of these issues be supported by reference to the peer-reviewed literature, ideally drawing from multiple lines of independent evidence? What is the available evidence and what are relevant references?

It was acknowledged that only the broadest outlines of the aspects discussed above are supported by the literature. For this reason, it might be relevant for AR5 authors to consider pertinent, analogous literature, and not just geoengineering literature—e.g. ethics and governance, but also other physical sciences. Some issues raised are quite absent from the literature—e.g., the metrics of SRM and climate change, as mentioned above.

References

Solar Radiation Management Governance Initiative, 2011: Solar radiation management: the governance of research. Environmental Defense Fund, The Royal Society, TWAS.

Breakout Group II.3 and 4: Carbon Dioxide Removal Issues and Risks

Chair: Gernot Klepper

Rapporteur: Shreekant Gupta

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG II.3/4 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions that might be addressed in this BOG include:

- What are the most important issues or dimensions related to Carbon Dioxide Removal that IPCC authors might want to consider in the AR5 (e.g., governance issues, physical science issues, etc.)?
- What are the most important aspects of these issues to evaluate (e.g., unintended side effects, risks and uncertainties, indirect/social costs, legal and governance issues)?
- Can the most important aspects of these issues be supported by reference to the peer-reviewed literature, ideally drawing from multiple lines of independent evidence? What is the available evidence and what are relevant references?

Introduction

The BOG decided to take an integrated view on approaches that could be taken for assessing certain Carbon Dioxide Removal (CDR) technologies. It went on to discuss priorities within these assessments and made suggestions to the authors of AR5 regarding potential points of focus. The time did not permit discussion of whether currently available literature could provide support for the assessment of the many CDR-technologies.

Potential focus of CDR assessments

The group looked at the matrix below, which lists a number of criteria that could be applied when different CDR options are assessed. This matrix refers both to the evaluation of research on CDR and to its deployment. The CDR options listed are not complete and should be further disaggregated. The naming of the criteria also should be interpreted as an abbreviation for a more elaborate definition.

Table A.5.2: Criteria for Carbon Dioxide Removal Approaches

	Ocean uptake, biological	Ocean uptake, chemical	Afforestation; Reforestation	Biochar; Bio-Storage	Air Capture	Weathering on land
Ethical Arguments						
Feasibility						
Effectiveness						
Side-effects						
Efficiency ("Social cost", including side-effects)						
Regulation (legal aspects)						
Regulation (policies and instruments)						
Monitoring / Verification						
Social Acceptability						

The group discussed the value of the criteria shown in the matrix in evaluating CDR technologies. There was also a suggestion not only to consider the economic efficiency of CDR options but also to recognize explicitly the distributional impacts of certain CDR options, across societal groups as well as across nations or regions.

Suggestions for AR5

It was agreed to discuss the evaluation criteria in a generic manner (CDR broadly rather than specific approaches) and to focus on the societal aspects (e.g., regulation, acceptability, etc.). Points raised include the following:

- AR5 authors may wish to note that published papers almost always refer to operating costs. They often ignore investment and research and development costs. Often, the market effects of rising prices for large-scale purchases for geoengineering activities are neglected, and in addition, the external costs of side-effects are not taken into account. It was highlighted that an assessment of CDR (and also of Solar Radiation Management (SRM)) may need to go beyond operating costs and look at the 'full' economic cost (a term that should be well defined) for each of the CDR approaches.
- One of the important aspects of an assessment of CDR is the choice of a reference case. There are many possible reference scenarios against which a certain CDR option can be evaluated. It was emphasized that the choice of a reference scenario by itself is a normative decision and has an important influence on the evaluation of a CDR option. It was suggested that several scenarios be used as a reference and that the difference in the results communicated.
- The issue of vulnerability or resilience in the context of implementing CDR options was raised. This is an important issue when certain vulnerable social groups might be affected by CDR. The evaluation of CDR might be considered within the particular external conditions of the region in which it will be applied. The example of afforestation was given.

- AR5 authors might also wish to consider assessment of research on the social acceptability of CDR, in terms of research on CDR and later deployment).

Breakout Group III.1: Solar Radiation Management in the Working Group Contributions to the IPCC AR5

Chair: Scott Barrett

Rapporteur: Naomi Vaughan

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG III.1 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussion:

- Where might each of the important Solar Radiation Management approaches and issues be evaluated within the IPCC AR5 (i.e., in which Working Group contribution and in which chapters)?
- Where might it be best to cover cross-cutting issues that do not neatly fall within one chapter or one Working Group's contribution?
- Are there some aspects of SRM that require expertise that is missing from the author teams of Working Group I, II and III? Are there other things the author teams can do to improve their ability to develop a high quality assessment?
- What geoengineering-related glossary terms might the AR5 include? For those terms, what might the corresponding entries be?

Introduction

The discussions in this BOG focused on where important Solar Radiation Management (SRM) approaches and issues might be evaluated within the IPCC's AR5 and where certain cross-cutting issues might be best covered. The discussions addressed the first two questions listed above but did not cover the last two questions.

Where should SRM be covered in the AR5?

BOG participants suggested that SRM should be covered in all Working Groups and treated consistently across them. Participants thought that the flow chart presented in plenary by one of the keynote speakers could be a useful framework for all Working Groups to reference (see Figure A.5.2). However, it was noted that in the framework all SRM proposals were grouped together and had an influence on 'radiative forcing'; a possible alternative is to have an influence on 'impacts'.

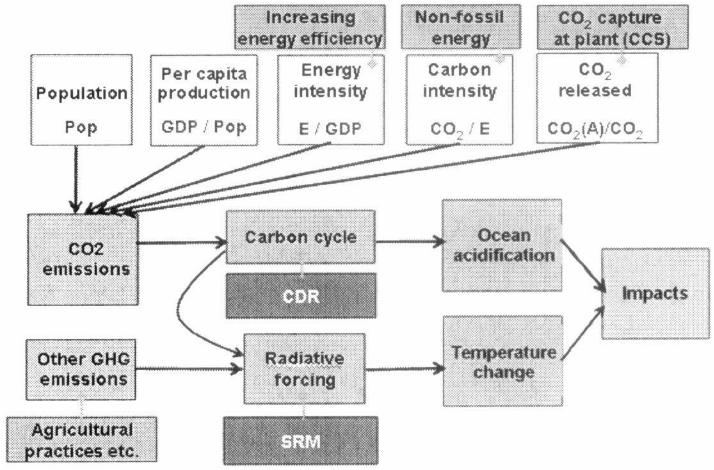

Figure A.5.2: *Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) methods in relation to the interconnected human, socio-economic and climatic systems and with respect to mitigation and adaptation. The Figure has been extracted from Figure 1.1.*

Working Group I - The Physical Science Basis

At the time of the expert meeting geoengineering was suggested as a topic in the following chapters of the Working Group I contribution to the AR5: Chapter 1: Introduction – Introduction to geoengineering (SRM and Carbon Dioxide Removal (CDR)); Chapter 6: Biogeochemistry – CDR; Chapter 7: Radiative forcing – SRM (cloud and aerosols), including sections on idealized experiments and one Frequently Asked Question on geoengineering; Chapter 11: Near term climate change projections and predictability including the outputs of the Geoengineering Model Intercomparison Project (GEOMIP) (see Kravitz et al., 2011).

Working Group II – Impacts, adaptation and vulnerabilities

The BOG suggested inclusion of SRM in Chapter 10: Key economic sectors and services. Suggestions of further possible chapters in which SRM may be considered include: Chapter 16: Adaptation opportunities, constraints and limits; Chapter 17: Economics of adaptation; Chapter 19: Emergent risks and key vulnerabilities; Chapter 20: Climate-resilient pathways: adaptation, mitigation and sustainable development. The impacts of SRM could be considered in the impact chapters (Chapter 3: Freshwater resources; Chapter 4: Terrestrial and inland water systems; Chapter 5: Coastal systems and low-lying areas; Chapter 6: Ocean systems; Chapter 7: Food production systems and food security. It was also suggested that Chapter 19 may be a suitable place to discuss the impacts of SRM, as SRM may be considered an emergent risk itself in addition to potential use to mitigate or lessen climate-change-related risks.

Working Group III Mitigation of climate change

According to the current plan for Working Group III, SRM is only suggested for inclusion in Chapter 5: Drivers, trends and mitigation, within the topic, 'Carbon and radiation management and other geoengineering options including environmental risks'. Suggestions for other chapters where SRM literature may be relevant were: Chapter 1: Introduction; Chapter 2: Integrated risk and uncertainty assessment of climate change response policies; Chapter 3: Social, economic and ethical concepts and methods; Chapter 4: Sustainable development and equity; Chapter 13: International cooperation: agreements and instruments; Chapter 14: Regional development and cooperation; and Chapter 16: cross-cutting investment and finance issues. Discussion then considered whether SRM fits into the Working Group III contribution to the AR5 given the title of the Working Group states 'mitigation' and the IPCC definition of mitigation does not include SRM activity (see Section 2 of this report).

Locally or regionally targeted SRM

It was suggested that localized and/or regionally focused impact remediation with targeted SRM may also be considered; for example, there is some literature on the use of SRM to cool the Arctic. It was unclear where in the AR5 this type of focused regional intervention could be covered, that is, would it require a separate category or fall under the definition of SRM? (N.B. geoengineering is usually defined as having large-scale or global impact).

Overlaps

There was a brief discussion about potential overlap of topics such as economics, between Working Groups II and III. It was suggested that ethical questions may be discussed in Working Group II as well as III.

Definitions of Mitigation and Adaptation

There was discussion about the IPCC definition of 'mitigation', whether it refers to emissions reductions or whether it is a more general term. The IPCC Working Group III AR4 definition is:

"Technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to Climate Change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks."

Although a dictionary definition of the word mitigation would generally mean reducing the impacts of something, it has come to be used by the IPCC to refer to emissions reductions and sink enhancement. Therefore CDR may fall under this definition but not SRM, even though ordinary usage of the word mitigation may include SRM. It was suggested that the IPCC definition of mitigation should not be changed to include SRM, not least because SRM does not affect atmospheric concentrations of greenhouse gases. This then led on to a discussion about whether SRM is a form of adaptation. The IPCC Working Group III AR4 definition of adaptation is:

"Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc."

Although SRM could be considered a type of adaptation (to climate change) it was suggested that SRM should be distinguished from adaptation in the AR5.

Baselines and reference scenarios

Identifying the baselines or reference cases used in SRM literature is important but can be difficult. For Working Group I, the GEOMIP modelling experiments are an example where consistent baselines are used. However, much of the modelling work on SRM uses a variety of baselines and reference scenarios (such as $2xCO_2$, $4xCO_2$, ramping up or not). For Working Group II it is likely to be difficult to find a consistent baseline or reference case across the literature. Similarly, for Working Group III (e.g., governance, economics, risk and ethics) the relevance of baselines may need to be discussed even if the literature is not entirely explicit or consistent. Across all Working Groups, analysis of SRM may need to compare scenarios, such as with or without SRM. A suggestion was made to consider the impacts of SRM with reference to different Representative Concentration Pathways (RCPs), that is, would SRM cause a shift from one set of RCP impacts to another, and what novel impacts would be caused by SRM? It was concluded that it is very important to be transparent about the reference cases and baseline assumptions.

References

Kravitz B., Alan Robock, O. Boucher, H. Schmidt, K.E. Taylor, G. Stenchikov, and M. Schulz, 2011: The Geoengineering Model Intercomparison Project (GeoMIP). *Atmospheric Science Letters* **12**, 162–167. (DOI: 10.1002/asl.316).

Breakout Group III.2: Solar Radiation Management in the Working Group Contributions to the IPCC AR5

Chair: Don Wuebbles

Rapporteur: Thomas Leisner

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG III.2 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussion:

- Where might each of the important Solar Radiation Management approaches and issues be evaluated within the IPCC AR5 (i.e., in which Working Group contribution and in which chapters)?
- Where might it be best to cover cross-cutting issues that do not neatly fall within one chapter or one Working Group's contribution?
- Are there some aspects of Solar Radiation Management that require expertise that is missing from the author teams of Working Group I, II and III? Are there other things the author teams can do to improve their ability to develop a high quality assessment?
- What geoengineering-related glossary terms might the AR5 include? For those terms, what might the corresponding entries be?

Introduction

The group felt that it will be important to ensure a coherent coverage of geoengineering throughout the AR5 and that the crosscutting issues would benefit from consistent treatment in the respective chapters. This includes terminology as well as specific examples or measures of Solar Radiation Management (SRM) that might be discussed. Therefore, the group focussed mainly on questions one and two and to a lesser extent on questions three and four.

Where might each of the most important SRM approaches and issues be evaluated within the IPCC AR5 (i.e., in which Working Group contribution and in which chapters)?

The AR5 chapters where geoengineering should be mentioned have been considered by authors already, particularly in Working Group I, and the group highlighted the importance of mentioning SRM in all relevant chapters. The BOG suggested that a common table template could be used throughout the chapters, with the columns reflecting the various SRM approaches and the rows corresponding to the issues being addressed (see BOG Report I.2). The columns could be the same throughout AR5, but the rows could be specific to the relevant IPCC Working Group or chapter. Some suggestions for approaches and issues to be considered were worked out in a previous BOG and are summarized below. For in depth discussion of specific issues, the AR5 lead authors might want to concentrate some discussion especially on the same specific SRM approach (e.g., some variant of stratospheric aerosol injection) to achieve consistency throughout the report.

Where might it be best to cover cross-cutting issues that do not neatly fall within one chapter or one Working Group's contribution?

Crosscutting issues such as geoengineering benefit from consideration throughout the three Working Groups and in the synthesis report. The group discussed that a crosscutting committee could be formed to establish continuous communication among the IPCC Working Groups on geoengineering issues.

In the BOG, several specific issues that need a special emphasis in cross-cutting coverage were discussed more in detail. Key suggestions were:

- Cost issues: Authors could analyse, potentially with an integrated approach, cost estimates, including even for direct costs the time scale dimension to cost. Scalability: Are effects and side effects linear? Many aspects may be nonlinear (for example, feedbacks on stratospheric dynamics from sulphate injections need to be better represented).

- Technology: Working Group 1 may address the requirements for the technology to be effective, while Working Group 3 may discuss specific technologies and the costs (there is no obvious chapter for that in Working Group 3 – maybe Chapter 5?). It was an unresolved question in the BOG whether SRM approaches should be considered under adaptation technologies or technologies for adaptation in Working Group 2.

Are there some aspects of SRM that require expertise that is missing from the author teams of Working Group I, II and III? Are there other things the author teams can do to improve their ability to develop a high quality assessment?

The BOG felt that there is no obvious missing expertise amongst the lead authors. For specific questions that may need further consideration, it is advisable to involve others as contributing authors.

What geoengineering-related glossary terms might the AR5 include? For those terms, what might the corresponding entries be?

The BOG suggested that the major row and column items of the overarching table be present in the AR5 glossaries. The BOG also thought that the glossaries should be made as early as possible, with an emphasis on consistency throughout the Working Groups. The group discussed that, where possible and appropriate, the glossary should reflect definitions made in earlier reports.

Breakout Group III.3 and 4: Carbon Dioxide Removal in the Working Group Contributions to the IPCC AR5

Chair: Peter Cox

Rapporteur: Masahiro Sugiyama

The summary that follows, written by the Chair and Rapporteur, characterizes the main points of the BOG III.3/4 discussion. It may not reflect the personal views of the BOG's Chair and Rapporteur. The summary is intended for consideration by IPCC authors of the Fifth Assessment Report (AR5), but is neither endorsed nor approved by the IPCC or its Working Groups. Participants in the BOG considered a series of questions related to geoengineering research, developed by the meeting's Scientific Steering Group.

Questions suggested for discussion:

- Where might each of the most important Carbon Dioxide Removal approaches and issues be evaluated within the IPCC Fifth Assessment Report (i.e., in which Working Group contribution and in which chapters)?
- Where might it be best to cover cross-cutting issues that do not neatly fall within one chapter or one Working Group's contribution?
- Are there some aspects of Carbon Dioxide Removal that require expertise that is missing from the author teams of Working Group I, II and III? Are there other things the author teams can do to improve their ability to develop a high quality assessment?
- What geoengineering-related glossary terms might the AR5 include? For those terms, what might the corresponding entries be?

Introduction

This BOG first discussed issues surrounding terminology and the definition of "geoengineering", and spent most of the remaining time addressing the first two questions above, that is, where and how Carbon Dioxide Removal (CDR) geoengineering approaches should be covered in the IPCC AR5. The group did not have sufficient time to address expertise missing from the IPCC lead-author teams.

Terminology and definition of geoengineering

There was a good deal of discussion concerning the use of the term "geoengineering" for CDR techniques. Some members of the group felt that relabeling existing climate mitigation techniques, such as reforestation, as "geoengineering" could create confusion. Others felt suggested small-scale local actions (e.g., biochar) may be less relevant in the context of the IPCC. The group made the following suggestions for consideration by AR5 authors:

- Authors could mention geoengineering early in the AR5 Working Group contributions in order to guide policymakers, but then avoid the term "geoengineering" as much as possible afterwards, instead referring to specific techniques or "Solar Radiation Management" (SRM) and "Carbon Dioxide Removal" where necessary.
- It would be beneficial for authors to aim to use consistent terminology across the IPCC AR5. The group realized that some of the Working Group chapters have geoengineering in their section titles, and could use terminology that is consistent across the IPCC AR5.
- Authors may wish to avoid over-generalizations such as "SRM is cheap, fast, and imperfect", and instead refer to the characteristics of specific proposals, as these differ markedly even within the broad SRM and CDR categories.

- Authors may also want to avoid singling out geoengineering by imposing special criteria that are not equally applied to conventional mitigation. For example, it has been noted that CDR has a rebound effect (decreasing atmospheric CO_2 would reduce ocean CO_2 uptake), but this also applies to conventional mitigation.

With regard to consideration of CDR techniques in the IPCC AR5, the group then considered tightening the definition of CDR. Elements suggested for consideration by authors in the IPCC AR5 were the potential for techniques to:

1. significantly cool global climate (e.g., by removing greater than 1 GtC/yr of CO_2)

and/or

2. lead to significant trans-boundary impacts, other than the intended impacts of lowering global atmospheric CO_2.

A refined CDR definition might exclude some techniques from consideration as geoengineering in the IPCC AR5 on the basis of scale (e.g., ocean pipes), or the relative absence of non-CO_2 trans-boundary effects (e.g., no-tillage agriculture).

The figure proposed by BOG I.3 (Figure A.5.1) was thought to be useful to conceptualize these aspects of CDR approaches. On the basis of these criteria, CDR techniques that are on the left side of the dotted line could be the priorities for assessment in the IPCC AR5.

Treatment of various aspects of CDR across IPCC AR5 Working Groups

The BOG discussed which chapter/section of the IPCC AR5 might treat each aspect of CDR, with Table 1 produced as a first attempt at suggestions. The BOG also suggested that the following chapters may cover CDR in a broad sense: for Working Group 1, Chapter 6 (carbon and other biogeochemical cycles); for Working Group 2, Chapter 20 (climate-resilient pathways); for Working Group 3, Chapter 2 (risk, framework), Chapter 13 (international governance), Chapter 14 (national policy).

As the table shows, the treatment of CDR (and geoengineering in general) could be distributed throughout the contributions of the three IPCC AR5 Working Groups. This implies a challenge to present a coherent analysis of CDR. The group felt that the IPCC could consider the following options to meet this challenge: (a) A Technical Report or Special Report (but this would entail significant work and could only be undertaken after the IPCC AR5 process had been completed); and (b) a topic or box in the synthesis report that brings together the assessment of CDR from across the three Working Group reports.

Other suggestions

The group recommended that the expert meeting participants should serve as reviewers of the relevant chapters of the IPCC AR5, to help ensure consistent treatment of geoengineering across the different IPCC Working Groups.

Table A.5.3: *A possible allocation of various aspects of CDR options across the IPCC AR5 Working Groups (WGs), as discussed in BOG III.3 and 4.*

	Weathering (land & ocean)	Ocean fertilization, biological	Afforestation/ reforestation	Biochar	Direct air capture	Direct CO_2 Injection into the ocean
Feasibility	WG1&3	WG1	WG1&3	WG3	WG3	WG1
Effectiveness	WG1	WG1	WG1	WG1	WG1	WG1
Side effects	WG1/2	WG1/2	WG1/2	WG1/2	WG1/2	WG1/2
Costs, including social cost	WG3	WG3	WG3	WG3	WG3	WG3
Legal issue	WG3	WG3	WG3	WG3	WG3	WG3
Social acceptability	WG3	WG3	WG3	WG3	WG3	WG3
Regulation	WG3 Ch13-15	WG3 Ch13-15	WG3 Ch13-15	WG3 Ch13-15	WG3 Ch13-15	WG3 Ch13-15
Monitoring & Verification (*)	WG1/3 Ch13-15	WG1/3 Ch13-15	WG3 Ch13-15	WG3 Ch13-15	WG1/3 Ch13-15	WG1/3 Ch13-15
Ethics	WG3	WG3	WG3	WG3	WG3	WG3

*As for monitoring and verification, detectability should be discussed in Working Group 1.

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Discussion Paper

Canadian Environmental Protection Act, 1999

Issues & Possible Approaches

Prepared by Environment and Climate Change Canada

May, 2016

Contents

Introduction

The *Canadian Environmental Protection Act, 1999* (CEPA) is an important federal law aimed at preventing pollution and protecting the environment and human health. The Minister of Environment and Climate Change (ECC) is responsible for administering most of CEPA. Some provisions are jointly administered with the Minister of Health. For more information on CEPA, please see the CEPA Environmental Registry: https://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=D44ED61E-1.

CEPA is a large, complex and powerful law. When CEPA was originally created in 1988, it consolidated selected provisions and laws administered by Environment Canada and other federal departments. For example, it replaced the *Environmental Contaminants Act* of 1975, and subsumed the *Clean Air Act*, the *Ocean Dumping Act*, the nutrient provisions of the *Canada Water Act* and certain provisions of the *Department of the Environment Act*. The 1988 version of the Act underwent an extensive Parliamentary review, which ultimately led to CEPA 1999 (referred to in this paper as CEPA).[1]

For the most part, CEPA is an enabling statute that authorizes action on a wide range of environmental and health risks – from chemicals to air and water pollution to wastes and emergencies. It provides a suite of tools that can be used to identify, assess and address these risks. In many cases, CEPA authorizes more than one possible approach to address a given risk. This ensures that the Government can choose the approach that is most effective. As such, CEPA has been used as the legislative basis for many of the federal government's environmental and health protection programs. As a result of these programs, considerable progress has been made towards preventing pollution and protecting human health and the environment.

Despite being a fundamentally sound and well-structured Act, there are numerous issues with CEPA that need to be addressed. These have been identified by ECCC and Health Canada in the course of implementing CEPA for sixteen years. The list of issues has been informed by the development and delivery of programs, discussions and work with other governments and Indigenous Peoples, recommendations from the Parliamentary committees that reviewed the Act in 2007[2] and 2008[3], and ideas generated through public consultations[4] held in 2004 and 2005 and through ongoing interactions with stakeholders.

Of the various issues associated with CEPA, this Discussion Paper identifies those issues that are important and meaningful to our partners and stakeholders, and provides possible approaches to address them.

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[1] *Note: CEPA was also reviewed by Parliament in 2007 and 2008, but has not been substantively updated since that time.*

[2] *Report by the House of Commons Standing Committee on Environment and Sustainable Development: http://www.parl.gc.ca/HousePublications/Publication.aspx?Language=e&Mode=1&Parl=39&Ses=1&DocId=2614246*

[3] *Report by the Standing Senate Committee on Energy, the Environment and Natural Resources: http://www.parl.gc.ca/Content/SEN/Committee/392/enrg/rep/rep06mar08-e.htm*

[4] *Summary report of comments received online: https://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=4F2CD9D2-1; Summary report of comments received through public workshops: https://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=AEC66284-1*

The issues noted in this paper are wide ranging – both in subject matter and in scope – reflecting the nature of CEPA itself and its programs. However, they are individually and collectively important to consider in ensuring a strong legislative basis for delivering existing programs and for addressing new priorities related to the protection of the environment and human health.

1. Reducing Air Pollution and Greenhouse Gas Emissions

Many sources of air pollutants and greenhouse gases arise from our current patterns of energy production and consumption, as well as from our manufacturing industries and the products we produce and use.

CEPA provides the federal government with a variety of tools to control air pollutants and greenhouse gas emissions.

Divisions 4 and 5 of Part 7 of the Act provide authorities to regulate the manufacture and import of specific products that contribute to air pollution and greenhouse gas emissions, such as vehicles, engines, equipment and fuels. These Divisions enable the making of regulations to control the composition of fuels as well as the emission performance of on-road and off-road vehicles and engines, including cars, trucks, recreational vehicles, and engines used in lawn and garden, agricultural, and construction machinery. Under these authorities, increasingly stringent standards for smog-forming emissions from on- and off-road vehicles and engines, as well as for greenhouse gas emissions from on-road vehicles and engines, have been adopted. This has helped reduce the level of air pollutants such as nitrogen oxides, hydrocarbons, particulate matter, and carbon monoxide, as well as the level of greenhouse gases such as carbon dioxide, emitted from these sources. There are also regulations to lower the concentration of harmful components in gasoline and diesel fuels, resulting in a significant reduction in air pollution from the combustion of fuels, as well as requiring the inclusion of renewable content in certain fuels. For more information on vehicle, engine and fuel regulations, visit: http://www.ec.gc.ca/Air/default.asp?Lang=En&n=DDBB166E-1

In addition, greenhouse gases and many air pollutants are on the List of Toxic Substances in Schedule 1 of CEPA (Schedule 1). This allows the government to use the broad regulatory powers in section 93 of Part 5 of the Act for those substances. Regulations under section 93 can control a wide range of activities. For example, the *Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations* set a stringent performance standard for new coal-fired electricity generation units and those that have reached the end of their useful life. In addition, the *Gasoline and Gasoline Blend Dispensing Flow Rate Regulations*, which reduce emissions of benzene and other volatile organic compounds (VOCs) during the refueling of on-road vehicles, were made using the 'toxic substance' regulation-making powers.

1.1 Clarify the scope of vehicles, engines and equipment for which standards can be set

Issue

Currently, Division 5 of Part 7 of CEPA authorizes the Governor in Council, on the recommendation of the Minister, to set "standards on the design, functioning, construction or marking of vehicles, engines and equipment for the purpose of monitoring or controlling their emissions". The majority of the vehicle and engine regulations under CEPA are aligned with the standards set out in rules established by the United States Environmental Protection Agency (US EPA).

The US EPA also sets standards for *machines* that are powered by engines. This allows them to address the design, function and construction of the machine itself, which contribute to the overall emissions of the machine. CEPA, on the other hand, only expressly allows standards to be set for engines that power the machines.

Additionally, while the *Marine Spark-Ignition Engine, Vessel and Off-Road Recreational Vehicle Emission Regulations* came into force in 2011, in part to set emission standards for some types of small engines and vessels, there is no explicit authority to regulate the full suite of small marine diesel engines found in Canada.

Possible Approach to Address the Issue

CEPA could be amended to expressly allow regulations that set standards for the following:

- machines that are powered by engines
- small marine diesel engines (i.e., per cylinder displacement of less than 7 litres), such as tugboats, small ferries, emergency rescue vessels, small fishing boats and yachts.

This would better enable the development of regulations to reduce the impact that machines powered by engines or small marine vessels have on emission levels. They would also further the government's goal of harmonizing ECCC regulations and standards with those of the US EPA.

1.2 Provide a more flexible framework for managing temporary importations

Issue

Section 155 of CEPA allows for the temporary importation of vehicles, engines or equipment for certain reasons, such as its exhibition or testing for a period of one year or a period specified by the Minister – even if it does not comply with regulatory standards. Section 155 further provides that an importer must remove the vehicle or engine from Canada before the expiry of the temporary importation period. To qualify for this exception, the importer must submit a declaration that sets out prescribed information. This provision is similar to one set out in the *Motor Vehicle Safety Act.*

CEPA does not expressly provide the authority to extend the temporary importation period or to allow vehicles to remain in Canada in certain situations. This may impact importers who wish to bring the product into compliance with the applicable standards within that period, or donate it to a museum or a research body. Finally, there may be a valid reason to request an extension of the temporary importation period, such as additional testing or evaluation before returning it to the country of origin.

Possible Approach to Address the Issue

CEPA could be amended to clarify options in addition to removing the vehicle, engine, or equipment from Canada, including:

- bringing the vehicle, engine or equipment into compliance with the regulations prior to the expiry of the temporary importation period, such that it meets the emissions standards of its prescribed class and the importer has complied with all prescribed reporting and testing requirements;
- donating the vehicle, engine or equipment prior to the expiry of the temporary importation period, subject to rules that would be set out in the regulations; and
- requesting an extension of the temporary importation period by submitting a request to the Minister justifying the extension (e.g., additional tests needed, close to bringing vehicle, engine, or equipment into compliance with regulations).

1.3 Strengthening the notices of defect provisions

Issue

Section 157 requires a company that sells, manufactures or imports a regulated vehicle, engine or piece of equipment to notify the Minister and any owners, of any defect in the design, construction or functioning of the vehicle, engine or equipment that is likely to affect compliance with prescribed standards. There is no explicit requirement for companies to notify the Minister and others of defects in labelling or marking of vehicles, engines or equipment or to undertake corrections at their expense. Also, there is no express authority for the Minister to order a company that was issued a notice of non-compliance to submit a notice of defect when it is in the best interest of protecting the environment and human health.

Possible Approach to Address the Issue

CEPA could be amended to expand the Notice of Defect provisions to expressly include:

- label deficiencies;
- a requirement for companies to cover the cost of corrections; and
- an authority for the Minister to order a company to submit a notice of defect.

1.4 Ensure consistency with the *Motor Vehicle Safety Act*

Issue

When CEPA 1999 was brought into force, it included authorities for regulating vehicle emissions that were previously in the *Motor Vehicle Safety Act* (MVSA), which is administered by Minister of Transport. As a result, these CEPA provisions largely mirror the safety-related provisions in the MVSA.

On June 19, 2014, *An Act to implement certain provisions of the budget tabled in Parliament on February 11, 2014 and other measures* received royal assent. It amended many federal Acts, including the *Motor Vehicle Safety Act*. It introduced measures for multiple purposes, including streamlining the regulatory process, reducing administrative burden, improving safety through revised oversight procedures, enhancing availability of vehicle safety information, etc. These changes created some inconsistencies between the MVSA and CEPA. In addition, some modifications made to the MVSA provided tools that could also be expressly specified under CEPA.

Possible Approach to Address the Issue
Where appropriate, CEPA could be modified to ensure consistency with the MVSA.

1.5 Help Canadians make environmentally informed choices about fuels

Several regulations made under CEPA regulate the composition and quality of fuels. For example, regulations limit the level of sulphur and benzene that can be present in gasoline and diesel fuels. Because those components are high contributors to air pollutants from the combustion of fuels, these regulations have significantly lowered the output of air pollutants from vehicles and engines that use gasoline and diesel.

Issue
Not all fuel components that impact potential emissions are covered by the regulations. Some companies voluntarily limit potential pollutants, or add additives that reduce emissions. As an alternative to regulating every aspect of fuel composition, if gasoline and diesel consumers were provided with sufficient information on the differences in fuel qualities, they would be able to make informed decisions and potentially choose to purchase fuels that have a lower impact on the environment. However, CEPA does not provide express authorities to require the labelling of fuel dispensing equipment.

Possible Approach to Address the Issue
CEPA could be amended to authorize expressly the making of regulations respecting labelling of fuel dispensers. Examples could include mandatory labelling to identify whether the fuels have particular additives that make them less harmful to the environment than others.

1.6 Facilitate use of the regulation-making power for fuel composition

Issue
The regulation-making authority in subsection 140(1) is constrained by subsection 140(2), which states that regulations under paragraphs 140(1)(*a*)-(*d*) may only be made if the Governor in Council is of the opinion that the regulation could make a "significant contribution to the prevention of, or reduction in, air pollution".

Possible Approach to Address the Issue
CEPA could be amended to change the pre-condition for section 140 regulations to "contribute to" rather than make a "significant contribution to the prevention of, or reduction in, air pollution".

1.7 Expressly allow efficient regulation of releases of substances from products

Issue

Parts 3 and 5 of CEPA allow information gathering and risk management actions to target products that contain a toxic substance. They do not expressly target products that do not contain the toxic substance, but release it during use. For example, portable fuel containers may not be made of toxic materials, but they can release VOCs while they are storing fuel if they are not designed with effective caps. As another example, woodstoves – while likely not constructed out of toxic materials – can emit air pollutants and greenhouse gases during use. Although CEPA would authorize regulations focused on users of those products, it would be much more efficient to regulate the product design to minimize the potential for release of toxic substances.

Possible Approach to Address the Issue

Parts 3 and 5 of CEPA could be amended to expressly allow information gathering and regulation making to target the design and functioning of products, and to apply to manufacturers, importers or distributors of the products, rather than only to the users of the products.

1.8 Allow for auctioning of tradeable units

Issue

Authorities exist under CEPA to develop systems of tradeable units. However, CEPA does not set out expressly all necessary authorities for the Government to operate a properly functioning auctioning system for those units.

Possible Approach to Address the Issue

CEPA could be amended to expressly provide for the tools necessary to operate a properly functioning auctioning system, such as the authority to sell tradeable units either at a fixed price or by competitive bidding.

2. Protecting Canadians from toxic substances and living organisms

The Chemicals Management Plan is a joint Environment and Climate Change Canada and Health Canada initiative that assesses risks from chemical substances and living organisms. It addresses chemicals and living organisms that are new to Canada as well as those that are already in commercial use in Canada (i.e., on the Domestic Substances List). In 2006, this program completed a triage (referred to in CEPA as "categorization") of the approximately 23,000 chemicals and living organisms on the Domestic Substances List at that time, and identified 4,300 existing substances for further attention by 2020. The program is generally viewed as functioning well.

Risk Assessment

2.1 Formally acknowledge vulnerable populations

Issue

Environmental exposure to certain substances may pose greater health risks for certain more vulnerable members of society, such as children, expectant mothers and elderly persons, than for the general population, owing to physiological differences such as body size, weight, metabolism and growth rate. Assessments of risks to human health, conducted under CEPA, consider the specific vulnerabilities of these groups, including appropriate safety factors, according to available hazard, use and exposure data. However, CEPA does not formally recognize the importance of considering the vulnerabilities of certain populations as an important matter of principle when determining whether a substance is toxic or capable of becoming toxic.

Possible Approach to Address the Issue

CEPA could be amended to mention in the preamble, the importance of considering vulnerable populations in risk assessments.

New Substances and Activities

CEPA required the Minister of ECC to create a Domestic Substances List that specified all substances that were, between 1984 and 1986: manufactured or imported in quantities of 100 kg or more, or in commerce. Any substance not on the Domestic Substances List is prohibited from being manufactured in or imported into Canada, until prescribed information is provided and the Ministers of ECC and of Health have had an opportunity to assess the substance to determine whether it is toxic, as defined in section 64 of the Act. Following this pre-market notification and assessment process, if certain criteria are met, the Minister of ECC must add the substance to the Domestic Substances List. As such, the list continues to grow over time. In addition, risk management actions can be taken if the substance is determined, or suspected, to be toxic. Similar obligations and authorities exist related to new activities associated with substances, if the Minister of ECC suspects that those activities could result in the substance becoming toxic.

This regime relies mainly on the provisions found in the first half of Part 5 of CEPA. A parallel regime exists for new living organisms, and is found in Part 6 of the Act. The issues identified below also apply to Part 6, in addition to the specific issues related to living organisms, which are noted in items 2.12 – 2.14.

2.2 Formally expand the authority to update the Domestic Substances List

Issue

Although CEPA requires the Minister of ECC to maintain the Domestic Substances List, it does not expressly authorize the removal of a substance from the List unless it was added by error. In addition, although CEPA authorizes the Minister to collect the information necessary to determine whether a substance should be removed, it does not oblige her to do so.

Possible Approach to Address the Issue

CEPA could be amended to add an explicit authority to remove a substance from the Domestic Substances List when it is not in commerce. This would result in the substance becoming subject to the new substance pre-market notification and assessment requirements, should someone wish to manufacture or import it into Canada following deletion from the List. As such, the removal should involve a transparent process, with opportunity for public comment. An obligation could also be put on the Minister to collect the information necessary to periodically update the Domestic Substances List.

2.3 Enhance the transparency of the Domestic Substances List

Issue

To protect confidential business information, a notifier of a new substance or living organism can request that its name be kept confidential, and appear as a "masked name" on public documents, such as the Domestic Substances List. However, there are cases when disclosure of the name may be desirable, in particular, when compliance by the broader regulated community depends on knowledge of the substance or living organism being regulated.

Possible Approach to Address the Issue

CEPA could be amended to explicitly require the disclosure of names when risk management instruments are in place for the substance or living organism (e.g., when it is added to the Domestic Substances List with the requirement that the Government must be notified of new uses). The Ministers could also be formally authorized to release a name after five years, after proponents have had the opportunity to demonstrate that it should remain confidential.

2.4 Clarify timelines in the new substance regime

Issue

The new substances provisions in Part 5 of CEPA prohibit the manufacture or import of new substances unless information is provided to the Minister in order for that new substance to be assessed for potential health or environmental risks, and an assessment period has expired. During the assessment period, the Minister can formally request additional information, which "pauses" the assessment period. However, if the Minister requests clarifications of submitted information, the assessment period is not "paused". As a result, the assessment period could expire (allowing the substance to enter Canada) before the Minister receives the clarifications required to make an informed decision.

Possible Approach to Address the Issue

CEPA could be amended to expressly allow the assessment period to be "paused" if the Minister requests clarifications related to submitted information.

2.5 Tailor authorities to address substances in products that are subject to the *Food and Drugs Act*

Issue

Subsections 81(1) to 81(4) of CEPA require the notification and assessment of new substances and new uses of existing substances. CEPA recognizes that other Acts may provide equivalent pre-market notification and assessment regimes that are better suited for certain new substances. If such a regime is listed on Schedule 2 of CEPA, the substances subject to it are exempt from the above-noted requirements in CEPA. For example, new animal feeds and new pesticides are assessed and managed through the *Feeds Act* and *Pest Control Products Act* respectively. This allows the departments with the relevant expertise to determine whether these substances are safe for use in Canada.

However, in certain cases, the appropriate departments do not have legislation with equivalent pre-market notification, assessment and management regimes. For example, substances that are used or intended to be used in products regulated under the *Food and Drugs Act* (FDA) are subject to the new substance requirements in CEPA. This has resulted in a number of issues:

- CEPA does not always formally provide for the tailoring necessary for the new substance regime to apply to substances in products subject to the FDA. For example, certain foods and substances that originate in nature do not pose a risk to the environment, and should be exempted from pre-market notification and assessment. However, the regime in CEPA does not expressly allow for such exemptions.
- Section 83 of CEPA requires the Minister of ECC and the Minister of Health to both assess information to determine whether a new substance is toxic or capable of becoming toxic. However, for substances in certain products regulated under the FDA, the assessment process could be streamlined if the Minister of Health was solely responsible.

Another issue relates to the administrative "In-commerce List" which comprises substances in products subject to the FDA that entered Canada between January 1, 1987 and September 13, 2001. These substances were subject to an assessment of safety and efficacy under the FDA, and are currently being prioritized under the Chemicals Management Plan for risks which they may pose to human health and the environment. However, their status in relation to the New Substances provisions of CEPA remains an issue.

Possible Approach to Address the Issue

CEPA could be amended, in the following ways, to address these issues:

- Explicitly allow for exemptions related to notification and information provisions for certain classes of new substances, such as substances in FDA regulated products that are originating in nature.
- Provide an express authority to the Governor in Council to designate the Minister of Health as the minister solely responsible for section 83 assessments of new substances in specified products regulated under the FDA.

- Formally authorize the Minister of ECC to add substances on the "In-commerce list" to the Domestic Substances List, with any restrictions necessary to account for uses that have not yet been assessed. This would provide regulatory certainty for industry with respect to the status of these substances.

2.6 Expressly allow simultaneous use of instruments

Issue

During the assessment period, where the substance is suspected of being toxic, or capable of becoming toxic, paragraphs 84(1)(*a*)-(*c*) provide that the Minister may a) permit the manufacture or import of the substance, with conditions, b) prohibit the manufacture or import of the substance, or c) request additional information. Subsection 84(2) prohibits the manufacture or import of the substance when additional information has been requested. However, in certain cases, it may be beneficial to expressly allow the controlled manufacture/import of a substance while also requesting the notifier to provide additional information.

Possible Approach to Address the Issue

CEPA could be amended to formally allow additional information to be requested using paragraph 84(1)(*c*) at the same time as allowing controlled manufacture/import under paragraph 84(1)(*a*) (i.e., to allow an exception to the prohibition in subsection 84(2) if the manufacture or import is permitted under paragraph 84(1)(*a*)).

2.7 Strengthen the Significant New Activity Provisions

Issue

The Significant New Activity (SNAc) provisions prohibit new activities associated with a substance, unless information is provided to the Minister in order for that new activity to be assessed for potential health or environmental risks. A number of issues have been identified related to these provisions:

- When the Minister publishes a SNAc notice for substances or living organisms not on the Domestic Substance List, CEPA requires every person who transfers the substance or living organism to notify all persons to whom the substance or living organism is transferred of the obligation to comply with the SNAc notice. However, a similar downstream notification requirement is not explicitly provided for SNAc notices issued for substances that ***are on*** the Domestic Substance List.
- The Minister can vary the significant new activities identified in a significant new activity notice, but is not expressly authorized to vary other information such as data requirements and timeframes for submission.
- Some substances on the Domestic Substances List are subject to the CEPA requirements concerning significant new activities. CEPA does not expressly provide the authority to use interim risk management measures such as Ministerial conditions and prohibitions to

manage risks identified when a proponent notifies the Ministers of a proposed significant new activity with respect to these substances.

Possible Approach to Address the Issue

CEPA could be amended, in the following ways, to address these issues:

- To provide explicitly for a downstream notification requirement for significant new activities regarding substances that *are on* the Domestic Substance List, similar to that for substances *not on* the Domestic Substances List. This provision may need to be tailored to take into account the specific circumstances of substances on the Domestic Substances List.
- Explicitly allow Minister to vary any part of a significant new activity notice (not just the new activities). Such an amendment could clarify that any information in a notice may be modified.
- Expressly allow Ministerial conditions and prohibitions to be used for Domestic Substances List substances.

Risk management of Existing Substances

Substances on the Domestic Substances List are referred to as *existing* substances, to distinguish them from *new* substances that are not yet in commercial use in Canada. If the results of a risk assessment for a substance show that the substance is toxic under CEPA, risk management actions may be undertaken. In certain cases, this is an obligation for existing substances. Along with regulations, a variety of other instruments can be used to risk manage toxic substances. This is known as the risk management toolbox. Having a wide selection of tools allows the departments to select the risk management action that will be the most effective and efficient at controlling the risk. Provisions related to risk management instruments are found throughout CEPA. In certain cases, there are timeframes and requirements for action with respect to risk management, which are set out in Part 5.

Some substances may also be managed through controls on exports, administered through the Export Control List, which operates under Part 5 of CEPA, Schedule 3 and related regulations.

2.8 Enable a more functional virtual elimination regime

Issue

CEPA's virtual elimination regime – established to address substances that are persistent, bioaccumulative, and toxic (PBT) – requires that certain PBT substances be added to a Ministerial Virtual Elimination List (in addition to Schedule 1), and that a Ministerial release limit regulation and virtual elimination plans be developed for each substance. However, this largely duplicates the risk management requirements that already exist by virtue of adding the substance to Schedule 1.

In addition, the regime requires that a "level of quantification" be developed for each substance added to the Virtual Elimination List. However, this restricts the use of the current provisions to substances that can be measured while they are being released into the environment (e.g., point source releases), thereby preventing the Government from adding to the Virtual Elimination List those PBT substances that are released diffusely.

For these reasons, only two substances have been added to the Virtual Elimination List, even though about 20 meet the criteria.

Possible Approach to Address the Issue

CEPA could be amended to create a more functional virtual elimination regime for managing persistent, bioaccumulative and toxic substances, with the following elements:

- Schedule 1 is divided into 2 parts:
    - Part 1: Virtual Elimination List
    - Part 2: Other toxic substances
- Following an assessment, a substance may be added to either Part of Schedule 1 (not both)
- Substances added to Part 1 (the Virtual Elimination List) must be risk managed with one of two possible instruments:
    - A regulation under CEPA or another federal Act; or
    - Addition to the *Toxic Substances with Restricted Activities List* (see 2.9 below)
- Exemption for substances that are critical to human or animal health
- This would involve removal of the following elements: the definition of virtual elimination, the level of quantification, virtual elimination plans, Ministerial release limit regulations, and the Ministerial virtual elimination list.

2.9 Expand the risk management "toolbox"

Issue

For most existing substances that are found toxic, section 91 of CEPA requires a *preventive or control instrument or regulation* to be proposed by the Minister of ECC within 24 months, and section 92 requires that instrument or regulation to be finalized 18 months later. Although CEPA provides for the use of a wide range of preventive or control instruments and regulations to manage risks from toxic substances, additional express authorities would formally enable the government to manage each risk as effectively as possible.

- *Performance Agreements* are entered into according to the existing *Policy Framework for Environmental Performance Agreements*. They are flexible instruments with core design criteria negotiated among parties to achieve specified environmental results. They stipulate clear and measurable performance standards and include effective accountability mechanisms. However, as they are not expressly mentioned in CEPA, these agreements do not formally allow the Minister of ECC to discharge the obligations under sections 91 and 92.

- The obligation on the Minister of ECC is to publish a regulation or instrument under CEPA. In some cases, however, another federal act may be the *best placed act* to manage the risks associated with a toxic substance. For example, measures provided under the *Canada Consumer Product Safety Act* may be better suited than CEPA to manage the risks of some substances found in certain types of consumer products.
- In some situations, the current activities associated with a toxic substance do not pose a risk, but potential future activities might. The addition of a new instrument (*Toxic Substances with Restricted Activities List)* would explicitly allow risk management to focus on only these potential new uses.
- *All CEPA instruments and regulations* are currently formally limited in their ability to control risks arising from products that do not originally contain a toxic substance, but release it during use (as mentioned in item 1.7 above). For example, portable fuel containers may not be made of toxic materials, but they can release VOCs while they are storing fuel if they are not properly constructed.

Possible Approach to Address the Issue

CEPA could be amended to formally expand the toolbox in CEPA as follows:

- *Performance agreements:* Expressly allow performance agreements between either the Minister of Health or the Minister of ECC and another party, to fulfill the risk management obligation.
- *Best Placed Act:* Formally allow a regulation or instrument made under another Act to fulfill the risk management obligations under CEPA
- *Toxic Substances with Restricted Activities (TSRA) List:* Create a list under the Act, and expressly allow the Governor in Council to add a toxic substance to this list, and specify the activities associated with the substance that are prohibited. The Governor in Council would also have the authority to modify the list (remove substances, add and remove activities, etc.)
- *All instruments & regulations:* Ensure they can cover products that may release a substance (as mentioned in item 1.7 above).

2.10 Streamline roles for managing toxics

Issue

The obligation to propose a risk management regulation or instrument for certain toxic substances (described above), rests solely with the Minister of ECC. However when risk management of a substance is entirely led by the Minister of Health, the accountability to meet the legislated timeframes arguably should expressly rest with the Minister of Health.

In addition, section 93 regulations for toxic substances are made by the Governor in Council (GiC) upon recommendation of both the Minister of ECCC and of Health. However, in certain cases, this adds unnecessary administrative process.

Possible Approach to Address the Issue
CEPA could be amended to formally allow the Minister of Health to be responsible for the sections 91 and 92 obligations to develop a preventive or control instrument or regulation for a toxic substance, in the following two circumstances:

- when the risk management will be entirely led by the Minister of Health using a CEPA instrument that the Minister of Health has authority to develop unilaterally (i.e., section 55 guidelines or code of practice); and
- when the development of the preventive or control instrument or regulation will be entirely led by the Minister of Health under a Health Canada Act such as the *Canada Consumer Product Safety Act* or the *Food and Drugs Act* (see item 2.9 re: Best Placed Act proposal).

Consideration could also be given to amending CEPA to streamline the process for putting regulations in place to manage a substance.

2.11 Align the timing of the Minister's risk management obligation with the Governor in Council decision to add a substance to Schedule 1

Issue
Section 91 states that the Minister must propose a preventive or control instrument or regulation for certain toxic substances within 24 months of making a *recommendation* to the Governor in Council to add that substance to the List of Toxic Substances. Subsection 90(1) specifies that the Governor in Council may (or may not) choose to add the substance to Schedule 1. This creates a possible problem because some risk management regulations and instruments are only available for substances that are listed on Schedule 1, but the obligation to risk manage the substance applies, even if the Governor in Council decides not to list the substance on Schedule 1.

Possible Approach to Address the Issue
CEPA could be amended to trigger the obligation to develop the instrument or regulation for a substance when the Governor in Council decides to add the substance to Schedule 1.

Living Organisms

Living organisms, such as micro-organisms, are used in a growing range of products such as adhesives and detergents, and for purposes such as bioremediation and biomass conversion. New living organisms are subject to analogous pre-market notification and assessment requirements to chemicals. Existing living organisms can also be assessed, added to Schedule 1 if they are determined to be toxic, and risk managed if needed. This program relies mainly on Part 6 and Schedule 4, but could also use Part 5 for risk management.

2.12 Expand the definition of "biotechnology"

Issue

The current definition of "biotechnology" refers to the "application of science and engineering in the direct or indirect use of living organisms". This definition lacks clarity.

Possible Approach to Address the Issue

CEPA could be amended to clarify the definition of biotechnology.

2.13 Enable the appropriate department(s) to assess and manage new living organisms

Issue

The Government must assess the environmental and health risks of all new products of biotechnology before they are introduced into Canada. As for new substances, the default situation is for these assessments to be performed by ECCC and Health Canada under CEPA. Recognizing that other departments or agencies may be better placed to address certain living organisms, CEPA can stand-down in favour of other Acts that contain an equivalent assessment regime, if they are listed on Schedule 4. However, in certain cases, the departments with the relevant expertise do not have statutes with equivalent pre-market notification regimes.

Possible Approach to Address the Issue

CEPA could be amended to formally allow the Governor in Council to designate another Minister –whose department or agency has the appropriate mandate, expertise and stakeholder relationships for a given living organism– as responsible for, and having the authority under CEPA to assess and manage, specific products of biotechnology.

2.14 Miscellaneous amendments to the authorities related to living organisms in Part 6

Issues

There are a few issues that present challenges in the administration of Part 6 of CEPA:

- The Ministers of ECC and Health have authority to make guidelines on the interpretation and application of the provisions of Part 5 of CEPA, but this authority is missing for Part 6.
- A person must provide certain information to the Minister before manufacturing, importing or using a new living organism. The Minister can waive information requirements in certain circumstances, for example if the information is not required to determine toxicity, or if the living organism will be manufactured at a location where it will be contained in a way that protects the environment and human health. However, the provisions do not expressly allow for information requirements to be waived for a person

importing a living organism in a manner and to a location where it will be contained in a way that protects the environment and human health.

- Paragraph 115(1)(*b*) provides authority to make regulations dealing with the effective and safe of use of living organisms with respect to their use in pollution prevention, but this is narrower than it needs to be (i.e., living organisms are also often used in environmental remediation and protection).

Possible Approach to Address the Issue

CEPA could be amended to address these issues as follows:

- Ensuring that the section 69 authority to make interpretive guidelines explicitly applies to Part 6 (as well as Part 5)
- Updating waiver provisions to formally allow for waiving of information when a living organism is imported in a manner and to a location where it will be safely contained.
- Broaden language in paragraph 115(1)(b) to better reflect biotechnology uses in environmental protection applications.

3. Preventing water pollution from nutrients

Division 1 of Part 7 of CEPA provides the authority to regulate nutrients that degrade or have a negative impact on aquatic ecosystems, such as those contained in cleaning products and water conditioners. CEPA prohibits the manufacture or import of a cleaning product or water conditioner that contains a regulated nutrient in a concentration or quantity that exceeds the regulated limit.

3.1 Provide authority to regulate labelling of products containing nutrients

Issue

Regulation-making authorities in Division 1 of Part 7 of CEPA do not expressly provide the authority to specify packaging requirements, such as how a product should be labelled, or the type of information, including conditions of use and instructions for use, that the label needs to contain. The express ability to specify labelling requirements would facilitate the use of concentrated products, resulting in reduced shipping costs, emissions and packaging, but ensure that users of the products have the information needed to correctly dilute them to a safe level.

Possible Approach to Address the Issue

CEPA could be amended to explicitly provide the authority in Division 1 of Part 7 to specify labelling and packaging requirements.

4. Preventing marine pollution

Surrounded by the Arctic, Atlantic and Pacific Oceans, Canada has a 243,790 km long coastline - the longest coastline in the world – which also includes the coastline of the country's 52,455 islands. The oceans are an important part in our country's history and economy. Ports and harbours are used for shipping various commodities and regular dredging of waterways is necessary to keep these open and safe. The resulting dredged material is typically disposed of at sea. In addition, certain other low-risk materials are also routinely disposed of at sea.

Since 1975, Canada has prevented marine pollution from disposals at sea of waste and other matter by federally controlling them via a permitting system. This system is designed to ensure Canada's compliance with its obligations under two international treaties to which it is Party: the *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (London Protocol) and the *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972* (London Convention).

Consistent with the London Convention and its Protocol, Division 3 of Part 7 of CEPA prohibits the disposal of substances into waters or onto ice from a ship, aircraft platform or other structure, unless it is done in accordance with a permit issued by ECCC. Incineration at sea, and the import or export of a substance for its disposal at sea, are also prohibited.

Only a small list of wastes or other matter, which are listed in Schedule 5 of the Act, can be considered for permits. These are individually assessed to make sure that disposal at sea is the environmentally preferable management option and that there are no practicable uses for the material, that pollution is prevented, and that any conflicts with other legitimate uses of the sea are avoided. Permit conditions ensure the quantities, disposal sites and special precautions are well considered.

The program that manages the disposal at sea regime operates on a cost-recovery basis. ECCC recovers costs associated with permit processing and with monitoring of representative disposal sites. For further information on the disposal at sea regime, please visit: https://www.ec.gc.ca/iem-das/default.asp?lang=En&n=55A643AE-1#gp4.

The disposal at sea regime is sound and well-functioning. However, improvements to CEPA could be made to bring it up to date with recent changes to the London Protocol, to further protect the marine environment by changing the way specific activities are controlled, and to strengthen the regime's enforcement tools.

4.1 Permit storage of CO_2 in sub-seabed geological formations

Issue

Carbon capture and storage involves the extraction of CO_2 from gas streams typically emitted during electricity production, fuel processing and other industrial process, and the storage of that CO_2 in geological formations. CEPA prohibits the storage of CO_2 in sub-seabed geological formations. This was consistent with the London Protocol, until it was amended in 2006 and 2009 to authorize sequestration of CO_2 in sub-seabed geological formations and to transport CO_2 across international borders for the purpose of sequestration. With those amendments, the global community recognized the importance of mitigating the impacts of climate change and that the storage of CO_2 at sea could be done without causing marine pollution if appropriate safeguards are put in place.

Possible Approach to Address the Issue

CEPA could be amended to expressly authorize the Minister of ECC to issue permits for the storage of CO_2 in sub-seabed geological formations and to allow for import and export of CO_2 for the purpose of sequestration.

The permitted activity would occur in a way that protects the marine environment, as proposed projects would be subject to an assessment and permit conditions imposed by the Minister. This would reflect the amendments made to the London Protocol.

4.2 Prevent marine pollution from ocean fertilization and other marine geo-engineering activities

Issue

Amendments to the London Protocol were adopted on October 18, 2013 to create a mechanism to specifically address ocean fertilization[5] and other marine geo-engineering activities – defined as "a deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long lasting or severe". The amendments to the Protocol prohibit ocean fertilization, but allow the issuance of permits in cases where the activity is assessed as legitimate scientific research and not contrary to the aims of the Protocol. The amendment creates a mechanism such that additional marine geo-engineering activities can be controlled similarly in the future. The current ocean disposal provisions in CEPA prohibit ocean fertilization. However, the Act could be amended to be more explicit as to how it addresses this issue, to provide the necessary authorities

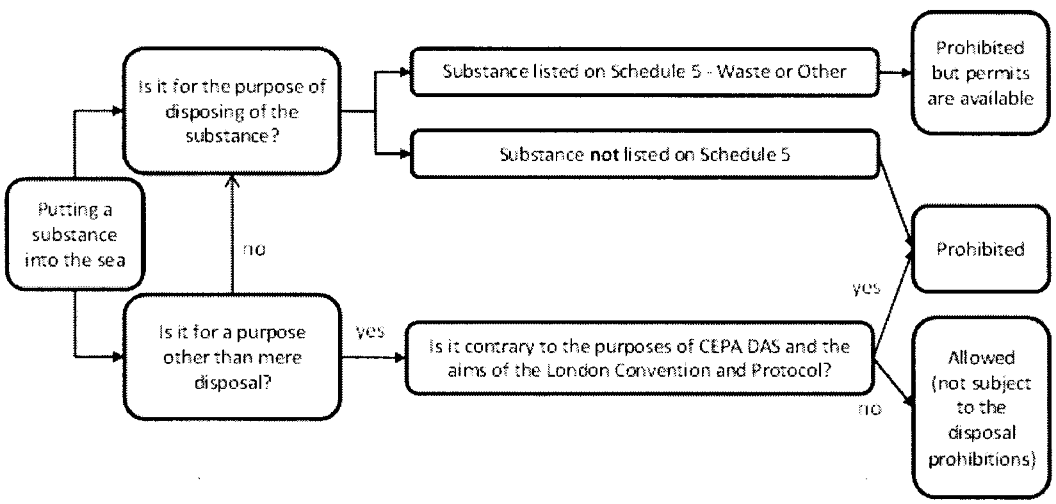
[5] Ocean fertilization is a type of marine geo-engineering activity which involves the addition of nutrient, such as iron filings, to the ocean with the goal of triggering of phytoplankton blooms. As these blooms grow, they convert carbon dioxide into "organic carbon", and in theory, sequester this carbon as they sink to the ocean floor. Global concern over the possible severe, ocean-scale and long-lasting environmental impacts of ocean fertilization activities prompted the international community to amend the London Protocol to clarify how it addresses this issue.

for the issuance of permits for legitimate scientific research and to include the other elements of the 2013 London Protocol amendments.

Possible Approach to Address the Issue
CEPA could be amended to expressly codify the recent changes to the London Protocol. This could be considered along with item 4.3 below.

4.3 Prevent marine pollution from other placement activities

Issue
CEPA's disposal at sea regime (CEPA DAS) mirrors the London Protocol by not subjecting specific activities to the disposal prohibitions, and therefore not requiring the issuance of permits in order for them to occur. This is the case for the "placement" of a substance for a purpose other than its mere disposal, if the placement is not contrary to the purpose of CEPA DAS and the aims of the London Protocol. This is illustrated below:



It is sometimes difficult for a potential proponent to determine whether the placement of a given substance is (or is not) contrary to the purpose of CEPA DAS and the aims of the London Protocol, and therefore whether it should be subject to the disposal prohibitions. In addition, the involvement of ECCC is necessary in certain cases, to ensure that a placement activity is performed in a way that minimizes impacts on the marine environment.

If a proponent determines that his or her activity is a placement that is not contrary to the purpose of CEPA DAS or the aims of the London Protocol, there is no explicit obligation to discuss that placement activity with ECCC, nor for the activity to be conducted subject to any conditions or mitigation measures that ECCC may suggest. In addition, CEPA does not expressly authorize the Department to require monitoring or request additional information related to that activity.

Possible Approach to Address the Issue

In addition to codifying the 2013 London Protocol amendments, which are limited to addressing marine geo-engineering activities, CEPA could be amended to create a regime that also resolves the lack of certainty in regards to specific placement activities that have proved problematic in the past, and that provides a framework to facilitate the control of additional placement activities in the future.

This could involve the following elements:

- Clarification of the delineation between "disposal" and "placement"
- Clarification of the status of specific placement activities that have proved to be problematic in the past by:
    - Expressly prohibiting certain placement activities that are contrary to the purposes of CEPA DAS and the London Protocol, such as ocean fertilization.
    - Prohibiting other placement activities that are contrary to the purposes of CEPA DAS and the London Protocol, unless done in accordance with a permit, such as:
        - legitimate scientific research on ocean fertilization;
        - the use of dredged material to create an artificial island.
    - Clarifying that specific placement activities that are not contrary to the purpose of CEPA DAS and the London Protocol – if they are done in accordance with specific criteria– can proceed without a permit, such as:
        - moving sediment when laying cable;
        - burial of human remains at sea;
        - using sampling equipment for scientific purposes.
- Creating a mechanism that could be easily updated to clarify the status of additional placement activities in the future.

4.4 Diversify CEPA's enforcement tools in the disposal at sea regime

Issue

Unlike other parts of the Act (e.g., sections 95 or 99 in Part 5), there is no express authority in Division 3 of Part 7 for the Minister to order a person who has contravened the division, or a permit issued under it, to take specific actions to remedy the damage caused by the contravention. There are also no express obligations on that person to take immediate remedial measures when such a contravention has occurred.

Possible Approach to Address the Issue

CEPA could be amended to add the express authorities to direct a person who has contravened Division 3 of Part 7 of CEPA or a disposal at sea permit to take specific measures to remedy the impacts of the offense,.and/or add specific requirements on such a person to take immediate remedial measures. This is related to the approach identified in item 6.3, related to remedial measures.

4.5 Improve the functioning of the disposal at sea regime

Issue

A number of minor issues impact the functioning of the regime:

- Under paragraph 127(2)(*d*) of the Act, a disposal at sea permit applicant is required to publish a notice of the application in a local newspaper circulating in the vicinity of the proposed site of the loading or disposal. Some Canadian communities do not have newspapers of local circulation.
- In order to dispose of a substance in Arctic waters, a proponent must seek both a disposal at sea permit under CEPA and an authorization under the *Arctic Waters Pollution Prevention Act*.
- CEPA does not explicitly provide that disposal at sea permits can be transferred in cases where, for example, a company is sold or restructured during the term of a valid permit. This creates unnecessary administrative burden.

Possible Approach to Address the Issue

CEPA could be amended to address these issues as follows:

- Formally allow the Minister to specify any manner for the publication of notices of application.
- Reduce duplication between CEPA DAS and the *Arctic Waters Pollution Prevention Act*.
- Expressly allow companies that have obtained permits to transfer them, subject to regulations.

4.6 Extend the authority to revoke or suspend permits

Issue

Subsection 129(3) of the Act authorizes the Minister to suspend or revoke a disposal at sea permit or vary its conditions, in very specific circumstances (consideration of Schedule 6 or in relation to the establishment of a board of review). In cases where the Minister suspects that a disposal at sea permit holder has contravened the permit or its conditions, there are no express authorities in the Act to suspend or revoke the permit. Express authority would be useful to stop a proponent from continuing with a disposal, allowing ECCC to assess if any damage to the marine environment resulted from the proponent's contravention.

Possible Approach to Address the Issue

CEPA could be amended to clarify that the Minister may suspend or revoke a permit when she suspects that a proponent has contravened the permit or its conditions.

5. Preventing pollution from the transboundary movement of hazardous waste and hazardous recyclable material

Through authorities provided under Division 8 of Part 7 of CEPA, Environment and Climate Change Canada is responsible for regulating transboundary movements of waste and recyclable material. Under this program, regulations were made to ensure that the hazardous waste and hazardous recyclable material (as defined in those regulations) that are transported across borders are managed in an environmentally sound manner that protects the environment and human health. This Division and its regulations were also enacted to contribute to Canada's ability to meet its obligations under various international agreements, including:

- The *Basel Convention on the Control of Transboundary Movements of Hazardous Waste and Hazardous Recyclable Materials and their Disposal*;
- The Decision C(2001)/107/Final of the Council of the Organization for Economic Co-operation (OECD) Concerning the Control of Transboundary Movements of Wastes Destined for Recovery Operations; and
- The *Canada-USA Agreement on the Transboundary Movement of Hazardous Wastes*.

Regulations under CEPA also prescribe conditions for inter-provincial/territorial and international movements of hazardous waste and hazardous recyclable material. With respect to international movements, ECCC issues over 2,300 permits per year to authorize more than 58,000 shipments of hazardous waste and hazardous recyclable materials.

5.1 Formally enable appropriate response to illegal imports or exports

Issue

Division 8 of Part 7 of CEPA prohibits the import, export or transit of hazardous waste and hazardous recyclable material, unless the Minister is notified, a permit is issued, and any prescribed conditions are met.

In circumstances where waste or recyclable material is illegally exported from Canada, CEPA lacks the express authority to order an exporter to return it back to a facility in Canada to manage it in an environmentally sound manner, or to manage it in an environmentally sound manner at a facility in the importing country or the country of transit.

Similarly, CEPA does not provide the express authority to order a person who has imported waste or recyclable material in contravention of Division 8 of Part 7 to either return it to the country of export or manage it in an environmentally sound manner in Canada.

In addition, if the government takes action itself (if the non-compliant importer or exporter fail to take the necessary corrective action), there are no express authorities in CEPA to allow for the recovery of the resulting costs.

Possible Approach to Address the Issue

CEPA could be amended to provide the express authority to allow the Minister to:

- require a person who has exported waste or recyclable material in contravention of Division 8 of Part 7 of CEPA or the associated regulations to return it to a facility in Canada for management in an environmentally sound manner or manage it an environmentally sound manner at a facility in the importing country or the country of transit;
- require a person who has imported waste or recyclable material in contravention of Division 8 of Part 7 of CEPA or the associated regulations to similarly manage it in an environmentally sound manner, either in Canada or after return to the country of export;
- recover the costs incurred by the Government of Canada for taking measures to take-back or return or manage the waste or material, if the exporter or importer fails to do so within the time required.

5.2 Expressly allow tailoring of conditions in permits

Issue

Division 8 of Part 7 of CEPA provides the authority to make regulations prescribing the conditions and duration of permits for the import, export or transit of hazardous waste, hazardous recyclable material and prescribed non-hazardous waste. However, this does not expressly provide the flexibility to tailor the permit conditions or duration of a permit to address specific circumstances on a case-by-case basis.

Possible Approach to Address the Issue

CEPA could be amended to address this issue by expressly allowing conditions and duration of the permit to be set out clearly in the permits themselves.

5.3 Extend the authority to revoke or suspend permits

Issue

There is currently no express authority in the Act to suspend or revoke a permit issued under subsection 185(1) for the import, export or transit of hazardous waste, hazardous recyclable material and prescribed non-hazardous waste. This could be an appropriate action to take in a number of situations, for example:

- if the Minister of ECC has reason to believe that the permit holder is in contravention of the terms or conditions of the permit;
- if the Minister has reason to believe that a person provided false or misleading information in his notification to obtain the permit;
- if the authorities of the country of destination or transit or of the jurisdiction of destination in Canada suspended or revoked their authorization.

Possible Approach to Address the Issue
CEPA could be amended to expressly provide the authorities to suspend or revoke permits issued under subsection 185(1), in certain circumstances, such as those listed above.

6. Preventing and responding to emergencies

CEPA contains various authorities related to emergency situations.

Part 8 of CEPA addresses environmental emergencies related to specific substances, defined as the uncontrolled, unplanned or accidental releases (or the likely releases) of those substances. Part 8 authorizes the government to make regulations and take non-regulatory measures, such as guidelines and codes of practice, to prevent, prepare for, respond to and recover from such environmental emergencies. The *Environmental Emergency Regulations* have been promulgated under this Part, and require the preparation of environmental emergency plans for the substances prescribed in the regulations.

In addition, various provisions throughout CEPA help the Department respond to environmental emergencies. For example, under sections 95, 169, 179, 201 and 212, a person who has contravened the Act is required to report to an enforcement officer on the contravention and to take all reasonable remedial measures to protect the environment and public safety. Sections 99, 119 and 148 provide the Minister the authority to direct an offender to take specific remedial measures. In all cases, the Government is able to take those measures if the person failed to take them and to recover the associated costs.

6.1 Expressly allow for field research related to environmental emergencies

Issue
Section 195 of CEPA authorizes the Minister to release substances in order to conduct field research on causes, effects and response to environmental emergencies. However, the provision does not explicitly exempt the Minister from all potentially applicable prohibitions that would otherwise prevent the research (e.g., section 5.1 of the *Migratory Birds Convention Act*, etc.), nor does it allow the Minister to authorize other individuals to conduct the research.

Additionally, the definition of environmental emergency is limited to research related to substances that are identified in regulations or interim orders made under Part 8 of CEPA.

Possible Approach to Address the Issue
CEPA could be amended to expand the scope of section 195 to allow for authorization of 3rd party field research related to environmental emergencies and for research on any substance, and to expand the list of provisions of federal laws from which authorized research on environmental emergencies will be exempt.

6.2 Formally allow for exemptions for urgent, time sensitive issues of national security

Issue

The regulatory process through which the Department of National Defense (DND) currently obtains exemptions from CEPA or its regulations may not be appropriate in time-sensitive situations.

Possible Approach to Address the Issue

This issue could be addressed by formally allowing the Governor in Council to issue an order exempting government activities from regulations or provisions of the Act on a case-by-case basis, for urgent, time sensitive issues of national security.

6.3 Expand reporting and remedial measure provisions

Issue

Sections 95 to 98 of CEPA require a person who releases a substance in contravention of section 92.1 or section 93 regulations, or a section 94 interim order, to notify an enforcement officer of the release and to take all reasonable measures to mitigate this release. These provisions also allow enforcement officers to take the measures him/herself or to require the person to take the measures if the person fails to do so. These provisions do not expressly capture all the situations where the release of a substance can pose a health or environmental risk.

In addition, there are some discrepancies between the remedial measures under sections 99, 119 and 148, and between those under sections 95 to 98, 169 and 170, 179 and 180, 201 to 203 and 212 to 215.

Possible Approach to Address the Issue

CEPA could be modified to expressly extend sections 95 to 98 to cover situations where a person has released a substance in contravention of a Ministerial condition or prohibition that restricts the use of a substance, such as under subsections 84(1) and 109(1). In addition, changes to the various remedial measures provisions could be made to ensure their consistency, where appropriate. This is related to the approach identified in item 4.4, which is also related to remedial measures.

7. Supporting environmental protection related to federal activities and on federal and Aboriginal lands

Under Canada's Constitution, provincial environmental laws do not necessarily apply to federal government operations or on federal lands (including water). This means that these federal operations and activities on federal lands, including activities on certain Aboriginal lands, may not be subject to provincial regulations or permit systems covering emissions, effluents, environmental emergencies, waste handling and other environmental matters. Part 9 of CEPA provides some enabling authorities to address this gap.

7.1 Facilitate incorporation by reference of provincial regimes

Issue

'Incorporation by reference' describes a mechanism by which a document or part of a document, as it exists on a particular date or as it is amended from time to time, may be included in a statute or regulation, without needing to reproduce the text of the document in the legislation itself. Once incorporated, the document is considered to be part of the legislation and acquires the force of law.

Incorporation by reference of provincial environmental legislation, or a part thereof, into federal regulations made under Part 9 of CEPA, could help address some of the gaps that exist due to provincial regulations not applying. However, some additional authorities would be needed in Part 9, in order for incorporation by reference of provincial legislation to function effectively.

Possible Approach to Address the Issue

CEPA could be amended to:

- Modify Part 9 regulation making powers to facilitate the incorporation by reference of provincial permitting regimes.
- Formally allow Part 9 regulations to incorporate provincial regimes by reference, on a jurisdiction-by-jurisdiction basis.
- Expressly allow Part 9 regulations to distinguish, not only on the basis of jurisdiction, but also on the basis of classes of entities or areas, or specific entities or areas.

8. Updating regulation-making provisions

8.1 Facilitate regulatory alignment

Issue

Unless warranted by different environmental or health protection objectives, regulatory differences among jurisdictions can impose unnecessary costs on citizens and businesses, particularly in relation to integrated markets such as those for vehicles, engines, and fuels, as well as other products. In order to maintain harmonized regulatory requirements with another country, it is advantageous for the Government to be able to respond quickly to changes the other government makes to its regulations. However, the Canadian regulatory process can take several years to finalize a regulatory amendment.

CEPA contains a tool that allows for a quick response for the purpose of maintaining alignment with another country's regulation. However, it only formally applies to one regulation-making authority. The interim order power in section 163 allows the Minister to modify or suspend any portion of vehicle, engine and equipment regulations under CEPA to the extent necessary to maintain alignment with foreign regulations, for a temporary period, to allow time for the regulation to be amended.

Possible Approach to Address the Issue
CEPA could be amended to expressly allow the Minister to issue an interim order (similar to that in section 163), to be used for any regulation under CEPA, to the extent necessary to maintain alignment with a foreign regulation. This would provide the Minister with a quick and efficient means of maintaining regulatory alignment while regulatory amendments are developed and finalized.

The effective period of the interim order could be set to reflect the fact that Canadian regulations typically take at least two years to finalize, and the deadline for obtaining the Governor in Council's approval of the interim order could be extended from the typical 14 day period found in CEPA to 30 days.

This authority would be limited in scope, and could only be exercised in respect of inconsistencies with foreign legislation, with which a CEPA regulation is intended to be harmonized.

8.2 Expand the authority to incorporate by reference

Issue
'Incorporation by reference' describes a mechanism by which a document or part of a document, as it exists on a particular date or as it is amended from time to time, may be included in a statute or regulation, without needing to reproduce the text of the document in the legislation itself. Once incorporated, the document is considered to be part of the legislation and acquires the force of law.

Incorporation by reference is a timely and effective means of responding to advances in areas such as science, technology, and any associated technical standards; it can help ensure that legislation remains current without requiring the full legislative amendment process.

Various authorities related to incorporation by reference were provided to the federal government through recent amendments to the *Statutory Instruments Act*. However, there remain some limitations with respect to incorporating by reference documents that Ministers produce themselves, or produce jointly with other another Minister or body in the federal public administration. While designed to ensure that the legislative process is not circumvented or sub-delegated to departmental officials, these limitations may impact on departments' ability to respond to scientific or technical advances in a timely and effective manner.

Possible Approach to Address the Issue

CEPA could be amended to expressly allow incorporation by reference of the following types of material, as amended from time to time:

- Formal instruments made under the Act, such as guidelines and codes of practice.
- Internally generated technical documents that specify: 1) how to quantify prescribed data to be reported, including factors to be used for quantification; and 2) how to conduct prescribed tests, measurements, sampling, monitoring, and analyses.
- Documents produced jointly by the Minister of ECC and/or the Minister of Health, with another Minister or body in the federal public administration.

When dealing with internally or jointly produced documents, CEPA could be amended to ensure that an appropriate framework is in place to provide accountability for these documents.

9. Improving information gathering provisions

Information gathering under CEPA relies on provisions in Parts 3, 5 and 6 of the Act, and information-related provisions found in the various regulations and instruments throughout the Act.

9.1 Enhance the transparency of collected information

Issue

Section 313 of CEPA allows persons who are required to report information under CEPA to request, in writing, that the information be treated as confidential. CEPA does not require the person to provide reasons why this information should be treated as confidential, unless it is required under a Governor in Council regulation issued under paragraph 319(*a*).

The Minister is unable to disclose any information for which a request for confidentiality has been submitted, except in certain situations specified in sections 315 to 317 of CEPA. For example, the Minister may disclose information for which a request for confidentiality has been made if the public interest in health, safety, or protection of the environment outweighs any material financial loss or prejudice to the competitive position of the person who provided the information, and any damage to the privacy, reputation or human dignity of any individual that may result from the disclosure. However, it is difficult for the Minister to assess these competing interests when no information has been provided to support the confidentiality request.

Possible Approach to Address the Issue

CEPA could be amended to require persons who submit a request for confidentiality under section 313 to provide the Minister with reasons to support the request. This could be tailored to allow the Minister to require information on request or to require that reasons be provided in certain situations.

9.2 Expand information gathering authorities

Issue

There are some limitations associated with CEPA's information gathering authorities.

Subsection 71(1) of CEPA authorizes the Minister to require persons, via a notice, to submit certain information related to a substance for the purpose of assessing whether a substance is toxic or capable of becoming toxic.

- When issuing a notice under paragraph 71(1)(*b*), CEPA does not expressly provide the authority for the Minister to request the submission of information such as the methodology, data or models used in developing information or collecting or processing samples. This limits the departments' ability to compare and properly interpret the information collected.
- When issuing a notice under paragraph 71(1)(*c*), CEPA does not expressly provide the authority for the Minister to request that samples of toxicological tests or other tests be submitted along with the results of the tests. This is needed in order to verify the information provided.

Possible Approach to Address the Issue

CEPA could be amended to:

- Provide the Minister with the express authority to request the following information under section 71 for the purpose of assessing whether a substance is toxic or capable of becoming toxic:
  - other information, such as methodology, data, models used, etc.
  - samples of the toxicological tests and/or the other tests.

9.3 Facilitate administration of information gathering authorities

Issue

Certain information gathering and information reporting authorities under CEPA are missing the express administrative tools needed to facilitate and modernize the information gathering process.

- The sections 46 and 71 information gathering provisions do not expressly require persons to update the information they provide. As a result, the Minister may be in possession of information that is not up to date.
- Most CEPA authorities related to making regulations or instruments or to gathering information can require the regulatee to maintain and retain records. The period of time during which these records will be maintained is not always clear.

Possible Approach to Address the Issue

CEPA could be amended to:

- Allow sections 46 and 71 notices to require some information to be updated if it changes

- Ensure that there are clear, consistent time frames (e.g. 7 years) for the maintenance and retention of records related to regulations, instruments and information gathering, but also allow these timeframes to be tailored if needed, in specific circumstances.

10. Strengthening the enforcement of CEPA

Environment and Climate Change Canada's Enforcement Branch is responsible for the enforcement of CEPA. Enforcement is an essential component of the regulatory-compliance continuum and plays a crucial role in ensuring that regulatory instruments enacted by the Government are implemented fairly, consistently, and predictably.

ECCC's Enforcement Branch relies on provisions throughout the Act, but mainly on Part 10.

10.1 Provide explicit authorities for illegal imports/exports of substances and living organisms

Issue

If a person *imports* a substance or living organism in contravention of the Act or its regulations, there are no express authorities for the government to order this person to either return it to its country of export or to manage it in Canada. In addition, if the government takes action itself (if the importer fails to do so), there are no express authorities in CEPA to allow for the recovery of the resulting costs. CEPA is also lacking similar authorities related to the illegal *export* of a substance or living organism (i.e., authorities to order a person who has exported a substance or living organism in contravention of the Act to bring it back to manage it in Canada and if the exporter fails to do so and the government takes action itself, allow for the recovery of the resulting costs).

Possible Approach to Address the Issue

CEPA could be amended to expressly provide the necessary authorities to ensure that:

- A person who has exported a substance or living organism in contravention of Parts 5 or 6 or the associated regulations is required to take the substance back and manage it in Canada in accordance with the Act and its regulations;
- A person who has imported a substance or living organism in contravention of Parts 5 or 6 or the associated regulations is required to either return it to its country of export or manage it in Canada in accordance with the Act and its regulations;
- The government may recover the costs of conducting the take-back/return/management of the substance or living organism, if the person fails to act.

10.2 Formally provide effective enforcement tools for illegally imported vehicles, engines and equipment

Issue

There is no express authority under CEPA to require the removal from Canada or the return to the country of origin of any vehicle, engine, or equipment that are reasonably believed to have been illegally imported.

Possible Approach to Address the Issue

CEPA could be amended to expressly allow the Minister to order the removal of illegally imported vehicles, engines, machines or equipment.

10.3 Expressly allow refusal and revoking of permits for unpaid fines

Issue

The *Environmental Violations Administrative Monetary Penalties Act* (EVAMPA) has limited means to recover unpaid penalties. In comparison, the *Contraventions Act*, a statute also used to enforce regulatory instruments under CEPA, contains provisions to refuse or revoke permits when an offender who is convicted in a proceeding does not pay its fine.

Possible Approach to Address the Issue

EVAMPA could be amended to allow persons responsible for issuing or revoking licenses or permits under environmental acts to which EVAMPA applies to refuse to issue or to revoke permits for unpaid administrative monetary penalties.

11. Facilitating intergovernmental cooperation

In Canada, protection of the environment is a shared responsibility among governments. This makes close cooperation among the federal, provincial, territorial and Indigenous governments important to Canada's environmental well-being. Intergovernmental cooperation is one of CEPA's guiding principles, and the Act includes provisions to help ensure that federal actions are complementary to, and avoid duplication with, other governments.

11.1 Facilitate the use of equivalency agreements

Issue

The equivalency regime, set out in section 10 of the Act, gives the Governor in Council the authority to "stand down" a CEPA regulation – i.e., to declare that the regulation does not apply – in a province, a territory or an area under the jurisdiction of an Indigenous government that has provisions in force that are equivalent to those of the CEPA regulation. This tool reduces federal-provincial overlap, and recognizes that other governments may be better placed to manage particular environmental issues in their jurisdictions.

It could be helpful to clarify that the test of "equivalent provisions" can be met by provisions that have similar environmental effect. Recent experience with equivalency agreements has also raised questions about the utility of requiring an agreement before the issuance of an order.

Possible Approach to Address the Issue

CEPA could be amended to:

- Mirror the language in the *Fisheries Act* by replacing the term "equivalent provisions" with "equivalent in effect".
- Remove the precondition of a written agreement between the federal government and the other jurisdiction, before the Governor in Council can stand down the federal regulation.

11.2 Expand list of parties that can formally enter into administrative agreements

Issue

Administrative agreements are work-sharing arrangements that can cover any matter related to the administration of the Act. Such matters can include inspections, investigations, information gathering, monitoring and reporting of collected data. These agreements do not release the federal government from any of its responsibilities under the law, nor do they delegate legislative power from one government to another.

Section 9 of CEPA explicitly authorizes the Minister to enter into an administrative agreement with a government or an aboriginal people. It does not list other entities. For example, offshore oil and gas is regulated by the National Energy Board and by two federal–provincial offshore petroleum boards in Newfoundland and Labrador and Nova Scotia through the Accord Acts. The boards are the primary regulators of these activities and, in certain circumstances, might be in the best position to administer a federal regulation that relates to them.

Possible Approach to Address the Issue

CEPA could be amended to expand the list of parties with whom the Minister may formally enter into administrative agreements under section 9. Parties added to the list could include bodies or entities responsible for the administration of another Act of Parliament or an Act of the Legislature of a province.

11.3 Expressly allow the expiry date of administrative agreements to be negotiated

Issue

CEPA requires that administrative agreements expire after five years. In some cases, this may impose an unnecessary obligation to negotiate a new agreement when a current arrangement is satisfactory.

Possible Approach to Address the Issue
CEPA could be amended to replace the automatic five-year termination date for administrative agreements with an authority that allows the parties to negotiate a longer agreement. The current ability for either party to terminate an agreement with reasonable notice could be retained to ensure that ineffective agreements can be dissolved.

12. Further encouraging public participation and removing administrative barriers

12.1 Lower the precondition for public to initiate Environmental Protection Actions

Issue
Under Part 2 of CEPA, members of the public can initiate a suit, known as Environmental Protection Actions, against someone whom they suspect has committed an offence under the Act. There are strict tests for using Environmental Protection Actions set out in section 22 of the Act, one of which being that the alleged offence must have caused significant harm to the environment. The Senate Committee, during the last review of CEPA, recommended that that the Act be amended by removing the need for a citizen to show that an action has caused *significant* harm to the environment before being able to proceed with an environmental protection action.

Possible Approach to Address the Issue
CEPA could be amended to lower the threshold for bringing an environmental protection action from an allegation that the offence caused "significant harm" to simply that it caused "harm" to the environment.

12.2 Improve board of review provisions

Issue
Only one Board of Review has been set up under the Act: the Board of Review for Decamethylcyclopentasiloxane (Siloxane D5). In implementing a Board of Review for the first time under CEPA, the Departments identified some possible improvements to the related provisions.

The Act states that when a Board of Review is *established*, the time period by which a final preventive or control regulation or instrument must be published is paused until the board has submitted its report to the Minister (subsection 92(2)). However, this period continues to run from the time the Minister makes a decision to constitute a Board of Review until the time that the Board is actually established, which ultimately reduces the Ministers' time to develop and propose a risk management instrument. In addition, there is currently no requirement for the Minister or Ministers to indicate their intention to proceed with a Board of Review following a notice of objection.

Possible Approach to Address the Issue

CEPA could be amended to ensure the Board of Review provisions function efficiently and result in the best possible risk management decisions. Amendments could include such things as:

- Requiring the Minister or Ministers to publish a notice indicating the intention to establish a Board of Review and
- Allowing the 18-month period in subsection 92(1) to be suspended by this notice, rather than the establishment of the Board.

12.3 Consider whether certain laws of general application should apply to CEPA

Issue

Some laws of general application, such as the provisions of the *User Fees Act*, impose onerous requirements that may not be appropriate for some environmental regulations. For instance, the *User Fees Act* imposes process requirements that largely duplicate requirements relating to notice and consultation that are part of the regulatory impact analysis process (per the *Cabinet Directive on Regulatory Management*) as well as requirements, under CEPA, for consultation on regulations respecting fees and charges. In addition, federal funding rules can limit the spending of funds in a fiscal year other than the one in which they were collected. This can impact the ability to conduct activities needed to properly administer regimes and ensure environmental protection – such as the monitoring performed related to disposal at sea activities.

Possible Approach to Address the Issue

Consider amendments to CEPA to exempt certain regulations made under it from the application of the *User Fees Act*. In addition, consideration could be given to a mechanism that would provide flexibility for funding activities such as monitoring, etc.

12.4 Provide for a more appropriate frequency of Parliamentary Reviews

Issue

Subsection 343(1) requires Parliamentary review of the Act every 5 years. However, both the Parliamentary review process and the development and finalization of legislation take a long time. A 5 year review period is not long enough to allow amendments based on a prior review to be enacted and assessed. A 10 year window would reflect more realistic review and legislative timelines.

Possible Approach to Address the Issue

CEPA could be amended to require a Parliamentary review every 10 years, rather than every 5 years.