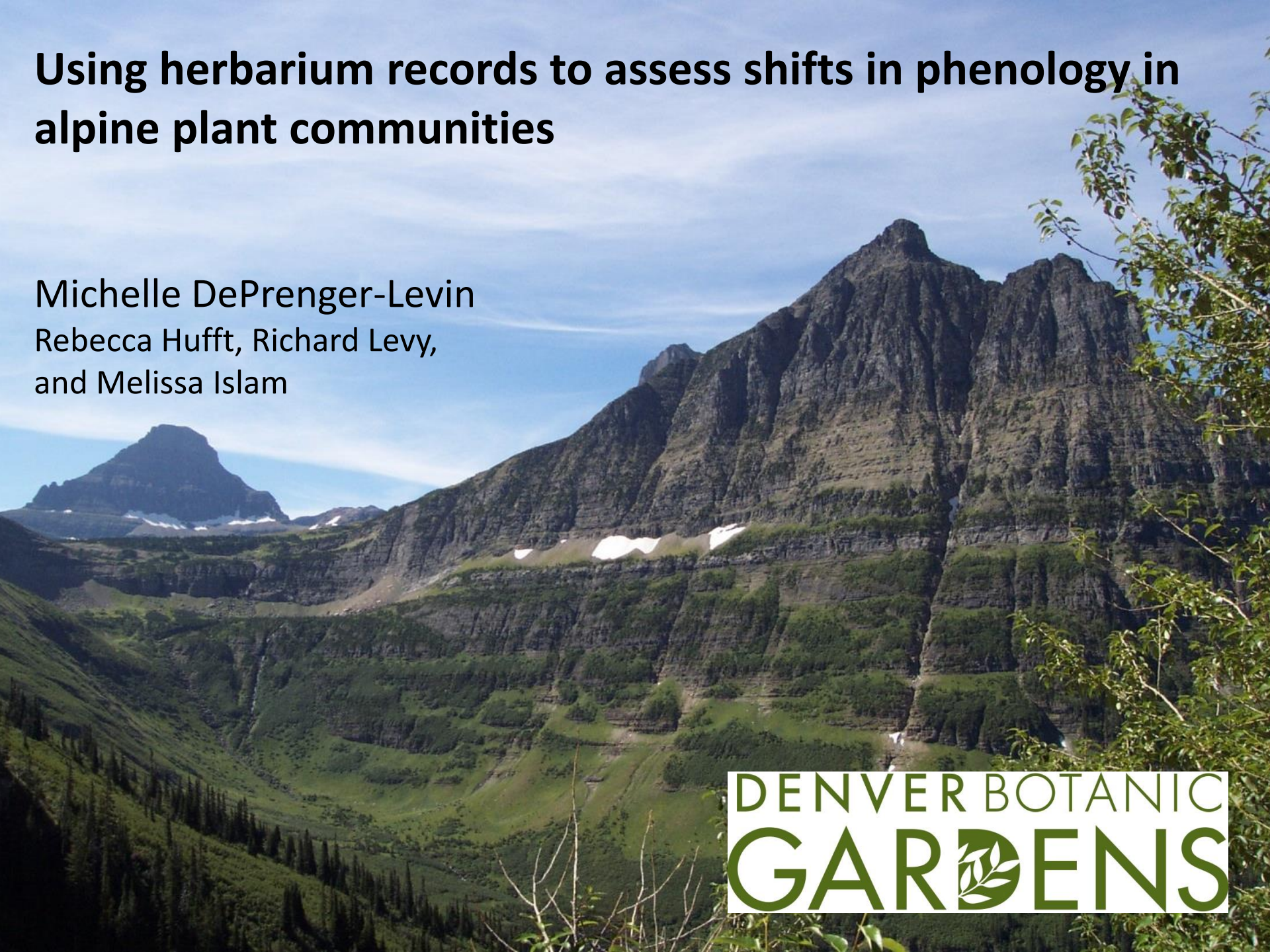


Using herbarium records to assess shifts in phenology in alpine plant communities

Michelle DePrenger-Levin
Rebecca Hufft, Richard Levy,
and Melissa Islam

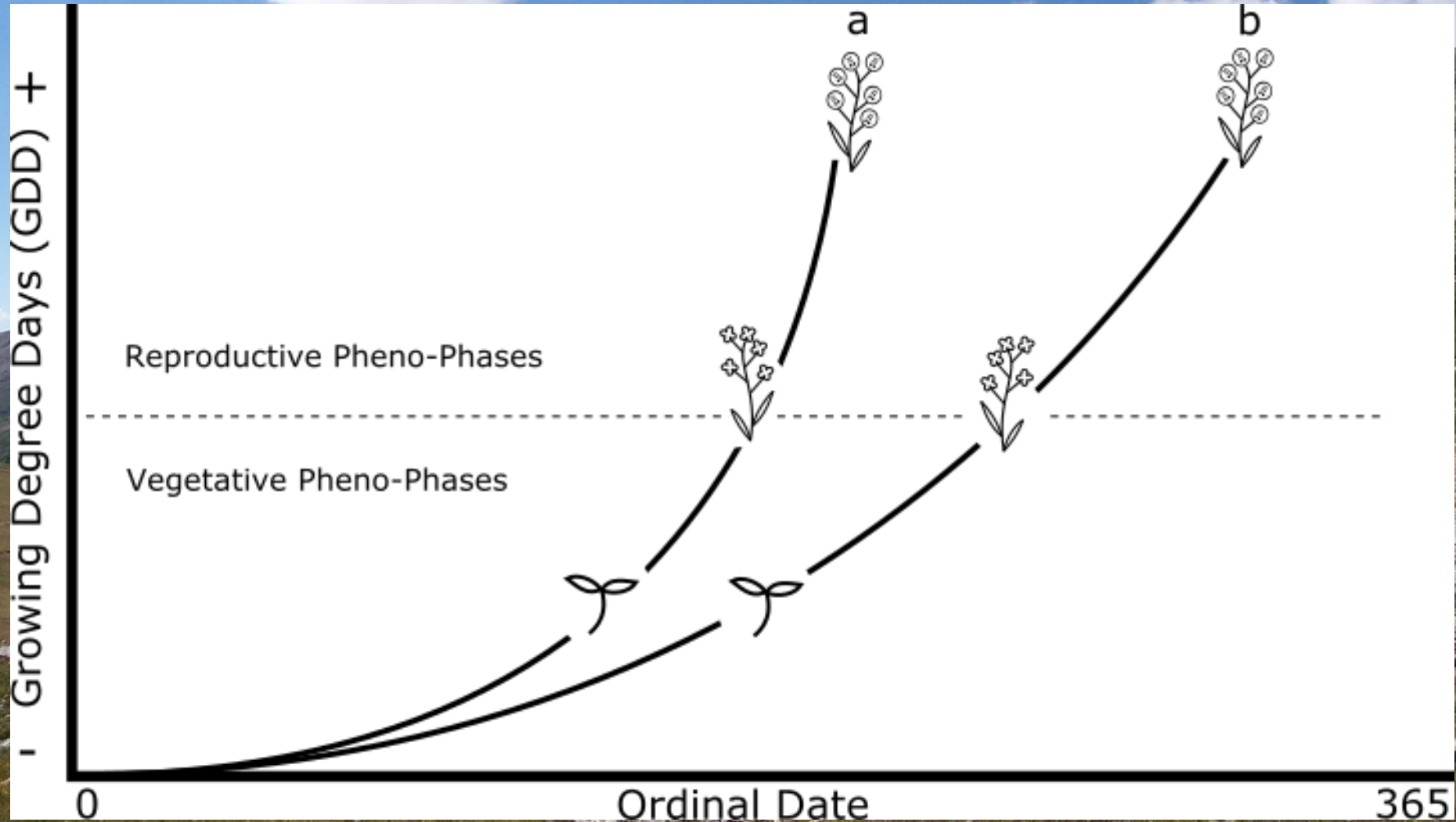


DENVER BOTANIC
GARDENS

Questions

- Can we detect community phenological changes through herbarium specimen data?
- Will alpine plant communities advance bloom date in response to climate change?
- Are widespread species used in phenology networks appropriate indicators for alpine habitats?

Alpine Environments





- Data portals and digitization
- Locality information: Georeferencing
- Phenology notes – lowest priority

Herbaria!

KATHRYN KALMBACH HERBARIUM
DENVER BOTANIC GARDENS
- 34832



Flora of the Buffalo Peaks Wilderness Area and
Vicinity, COLORADO, USA

Arnica rydbergii Greene AST
Rydberg's Arnica

CHAFFEE COUNTY: Mosquito Range. San Isabel National Forest. Buffalo Peaks Wilderness Area. S-end of pass between Buffalo Meadows and Fourmile Creek. USGS 7.5' Harvard Lakes Quad. T12S R78W SEC19 NE¼. Diverse meadow with sandy-gravelly soil; just above treeline. Flowers yellow. 11300 ft. Western North American distribution.

With *Eremogone fendleri*, *Pedicularis parryi*, *Artemisia scopulorum*, *Oreobroma pygmaea*, *Micranthes rhomboidea*, *Lidia obtusiloba*, *Bistort bistortoides*, *Packera cana*, *Rydbergia grandiflora*, *Antennaria corymbosa*, *A. rosea*, *A. pulcherrima*, *A. cf. media*, *Erigeron simplex*, *Astragalus alpinus*, *Phleum commutatum*, *Poa fendleriana*, *Amerosedum lanceolatum*, *Heterotheca pumila*, *Pulsatilla patens*, *Pentaphragmoides floribunda*, *Erythrocoma triflorum*, *Castilleja occidentalis*, *Stellaria longipes*, *Trifolium dasyphyllum*, *Polemonium viscosum*, *P. pulcherrimum*, *Pseudocymopterus montanus*, *Senecio pulcherrimum*, *Boechera drummondii*, *Anticlea elegans*, *Cerastium beeringianum*, *Achillea lanulosa*, *Vaccinium caespitosum*,

11 July 1998 Rea Orthner 588

Herbarium COLO (Boulder)

DENVER BOTANIC GARDENS
KHD0000044

Flora of the Buffalo Peaks Wilderness Area and Vicinity, COLORADO, USA

Arnica rydbergii Greene

AST

Rydberg's Arnica

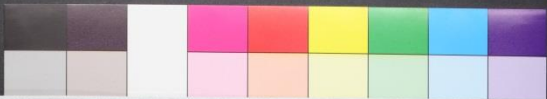
CHAFFEE COUNTY: Mosquito Range. San Isabel National Forest. Buffalo Peaks Wilderness Area. S-end of pass between Buffalo Meadows and Fourmile Creek. USGS 7.5' Harvard Lakes Quad. T12S R78W SEC19 NE¼. Diverse meadow with sandy-gravelly soil; just above treeline. Flowers yellow. 11300 ft. Western North American distribution.

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11 July 1998

Rea Orthner 588

Herbarium COLO (Boulder)



KATHRYN KALMBACH HERBARIUM
DENVER BOTANIC GARDENS
30952



Anisacanthus puberulus (Torr.) Henrickson & Lott
J. Wingate 4/16/1996

DENVER BOTANIC GARDENS
KHD00000005

HERBARIUM OF HENRIETTA L. ZOBEL
Family *Acanthaceae*
Genus and Species *Anisacanthus insignis*
Locality among acacia along Gray
Date June 10, 1937 Mts. area
Collected by B.H. Wernock Brewster County Texas

Anisacanthus puberulus (Torr.) Henrickson & Lott

J. Wingate 4/16/1996

HERBARIUM OF HENRIETTA L. ZOBEL

Family *Acanthaceae*

Genus and Species *Anisacanthus insignis*

Locality among acacia along Gray
Date creek bank at Painted Gap Chisos
Mts. area

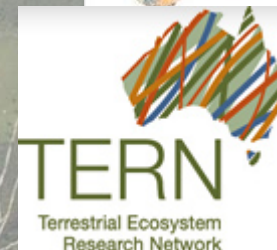
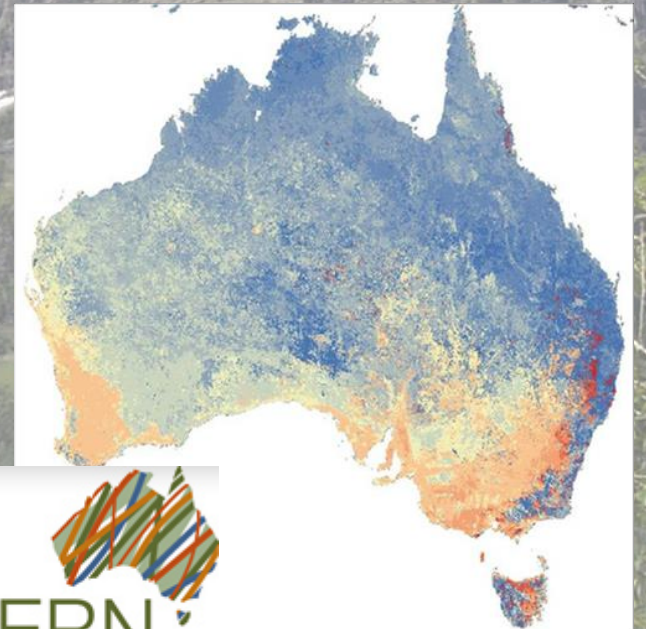
Collected by June 10, 1937
B.H. Wernock Brewster County Texas

Locality: Among acacia along
Oray Creek bank at Painted
Cap...

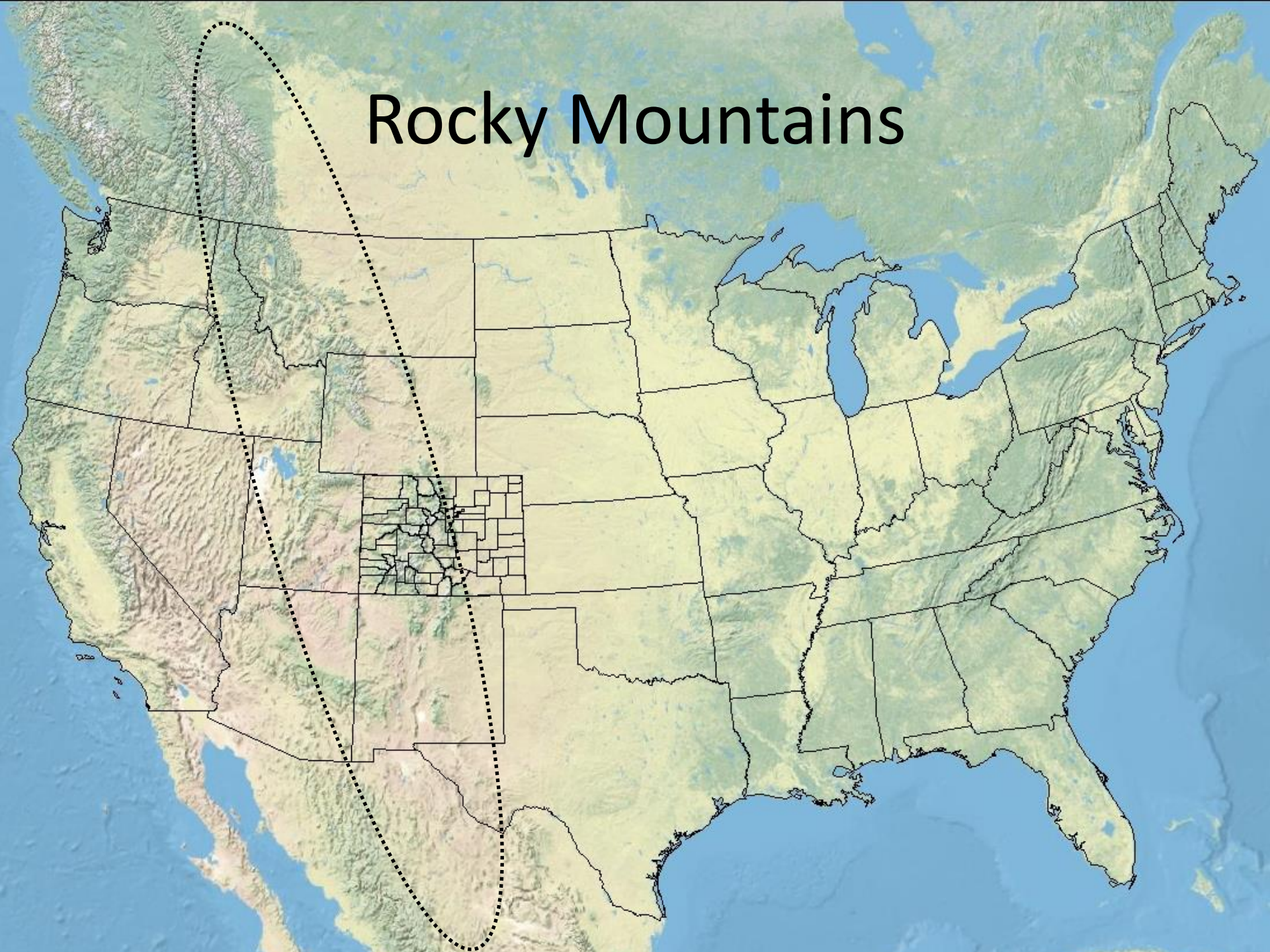
Date: June 10, 1937

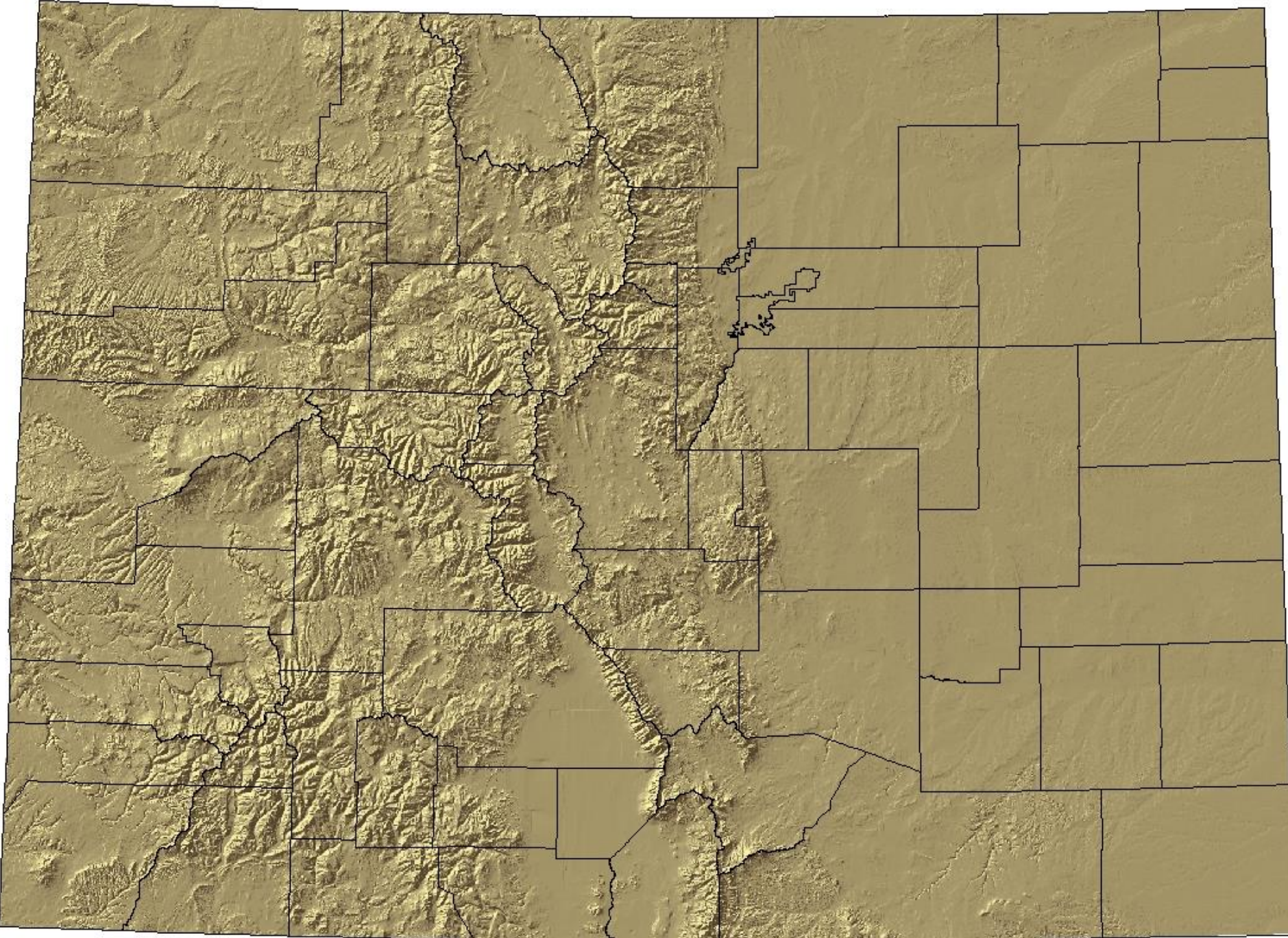
Climate Change

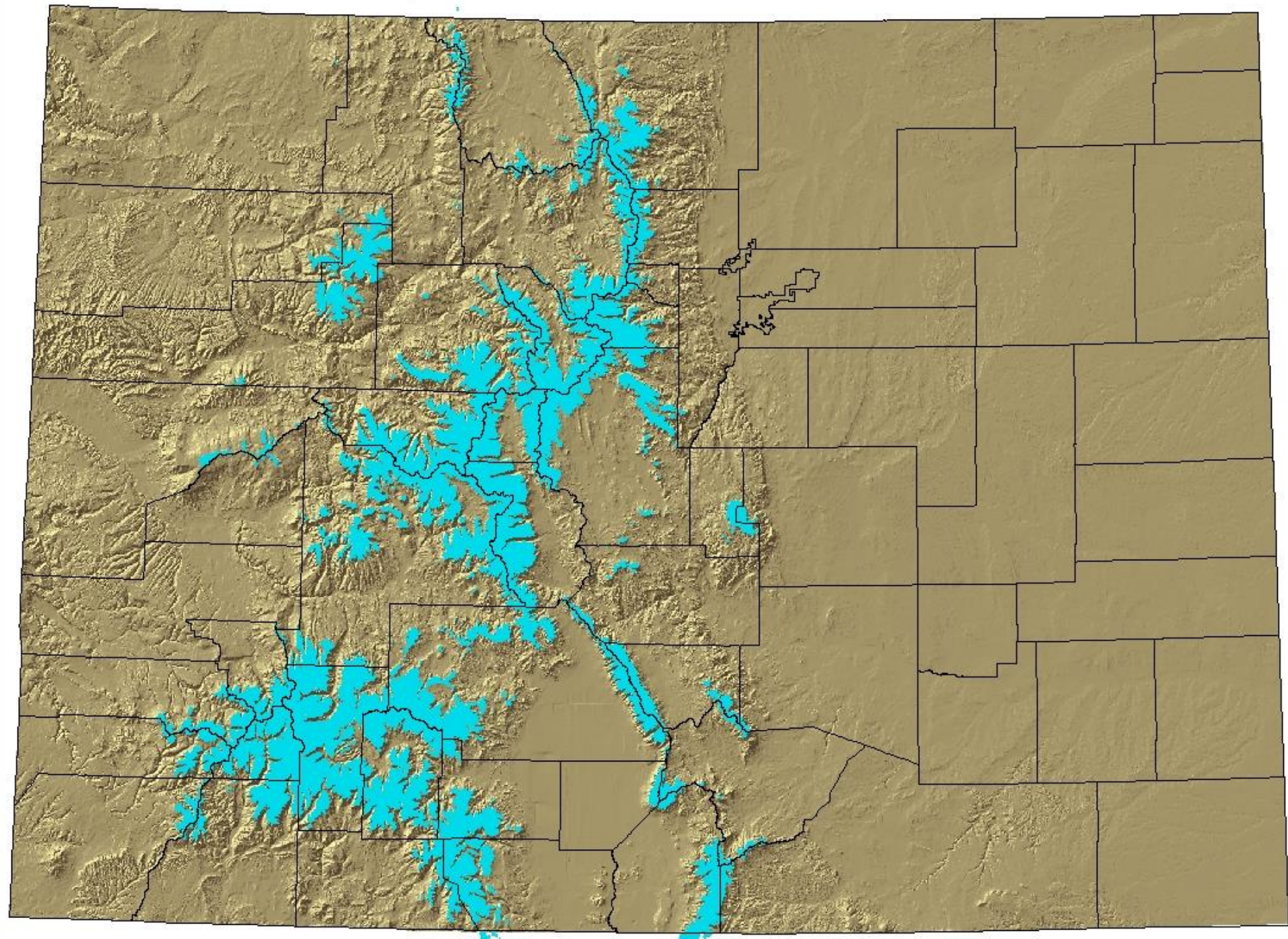
- USA National Phenology Network
- Satellite images
- Repeat photography
- Natural History Collections



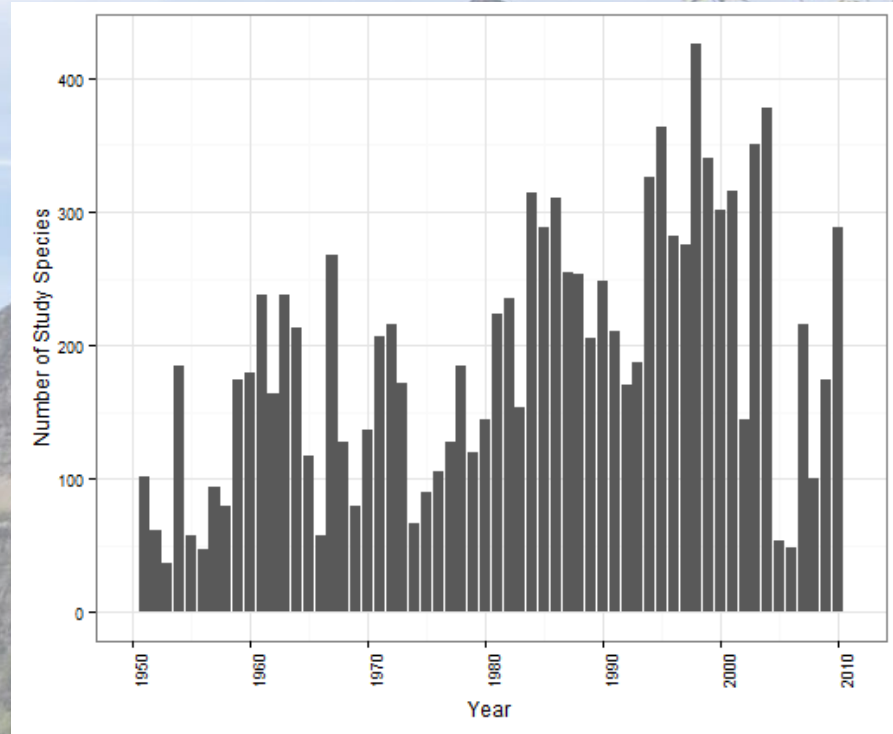
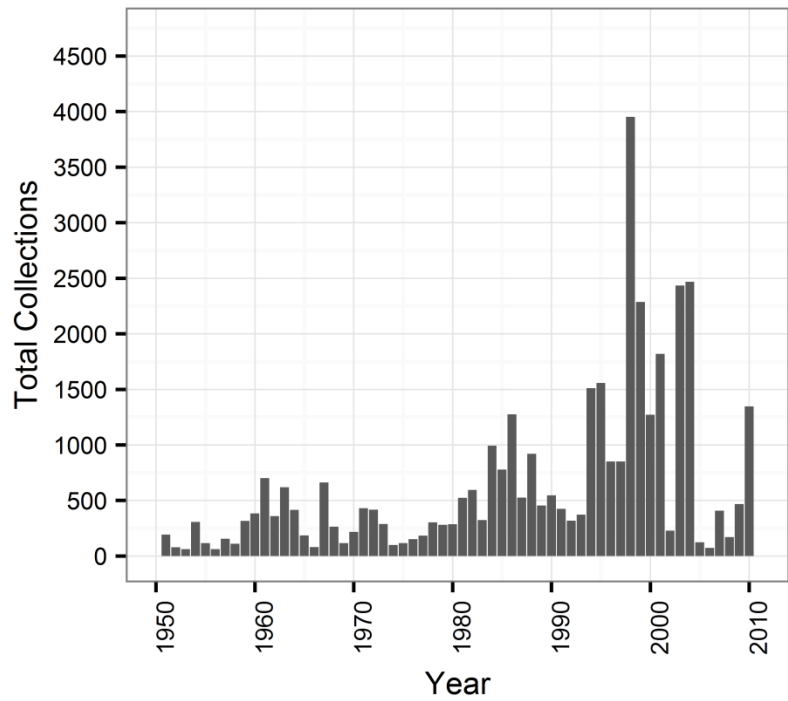
Rocky Mountains







Big Data



Climate Data



<http://prism.oregonstate.edu/>

```
devtools::install_github("ropensci/prism")
```

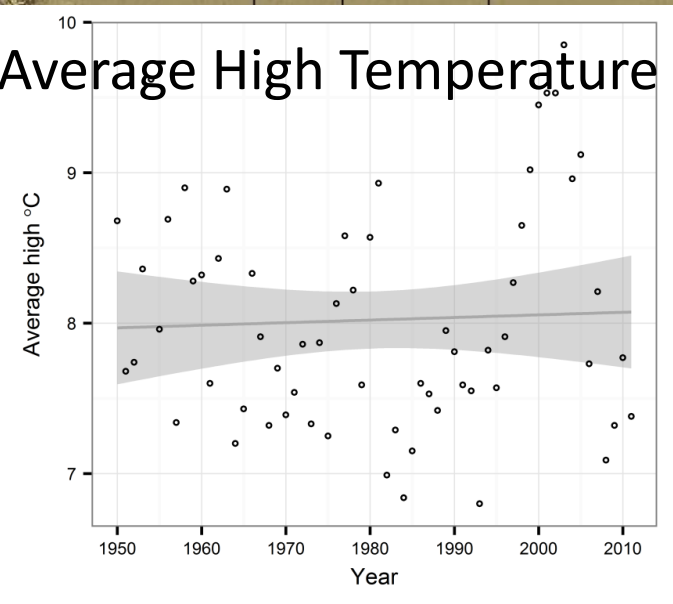
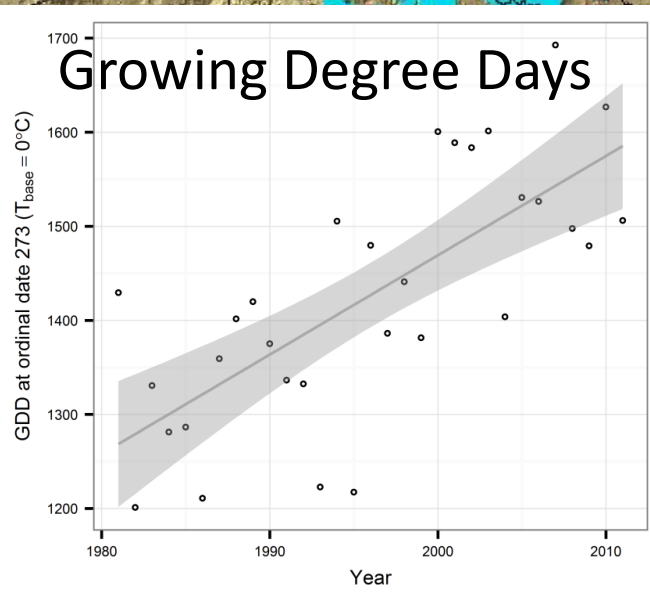
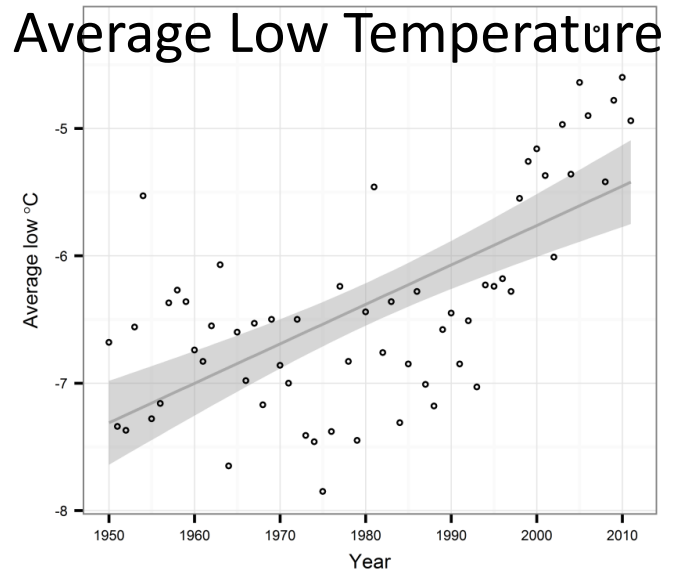
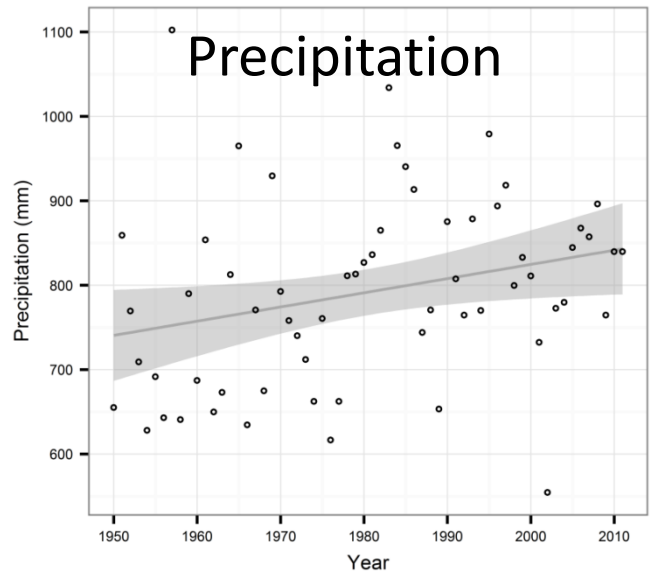
1950-2011

- Average annual maximum temperature
- Average annual minimum temperature
- Average monthly precipitation

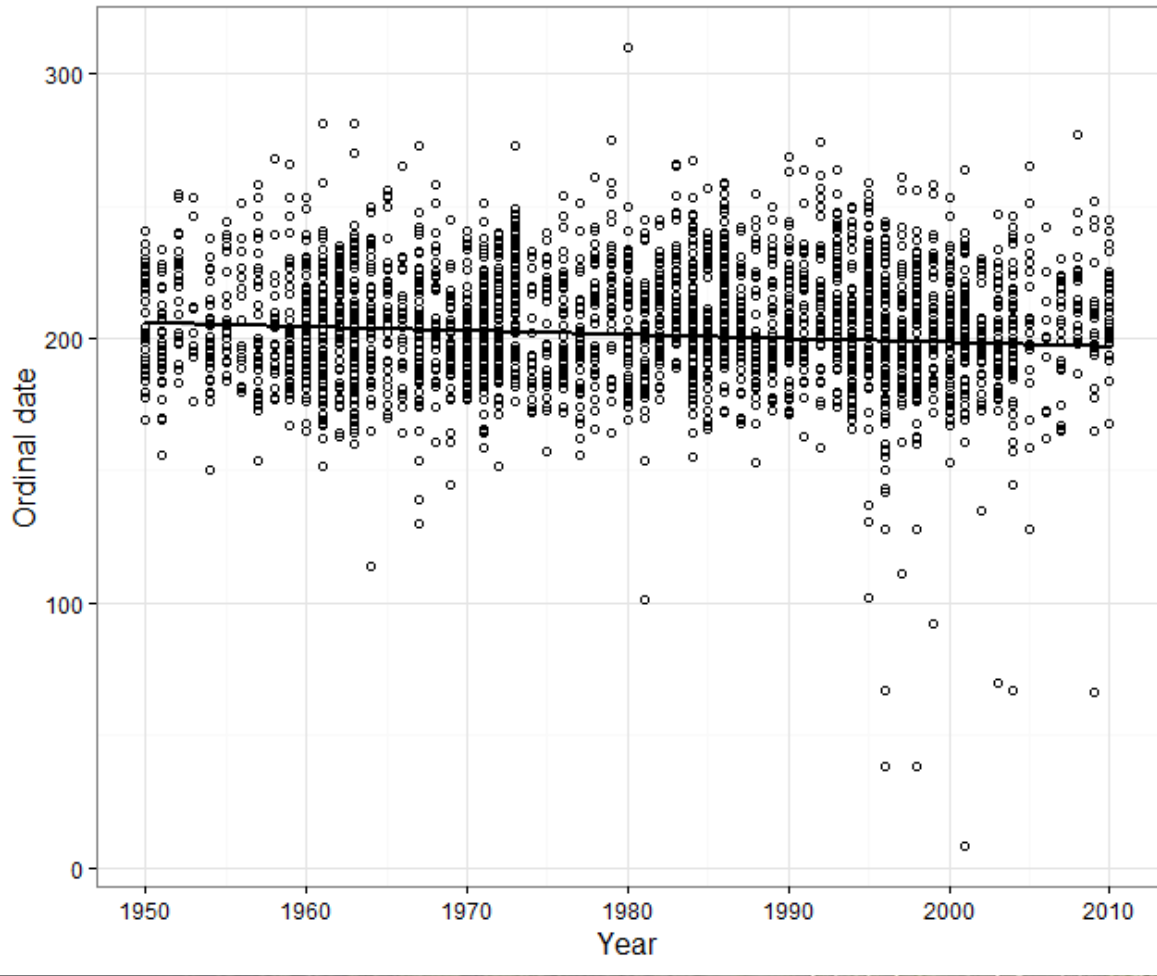
1981-2011

- Daily minimum and maximum temperatures

$$\text{GDD} = \sum_{k=1}^n \left(\frac{T_{max} + T_{min}}{2} \right) - T_{base}$$

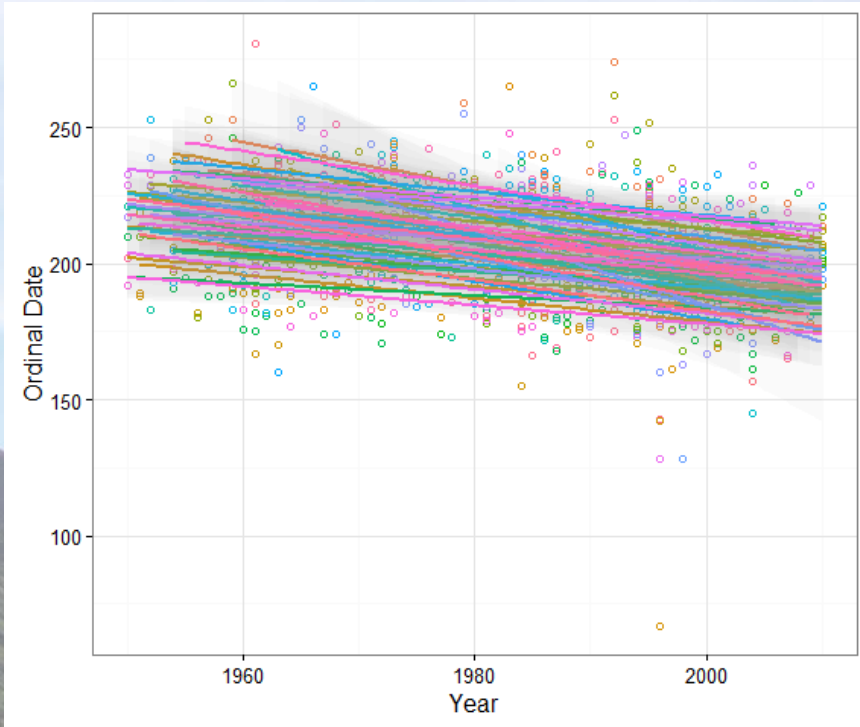


61 Years

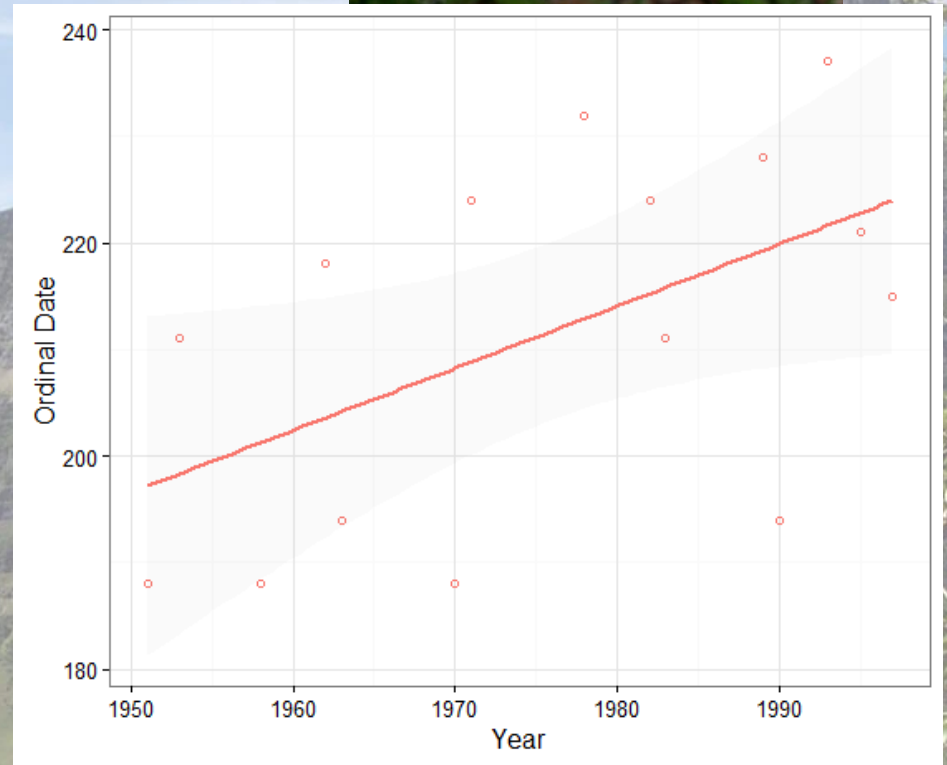


468 species:
Advancing 8.9 days

61 Years



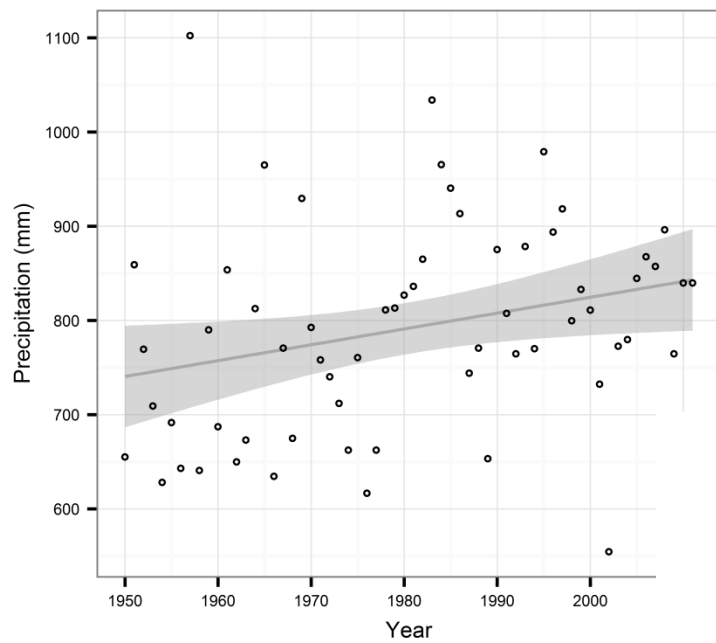
57 species:
Advancing average of 33 days



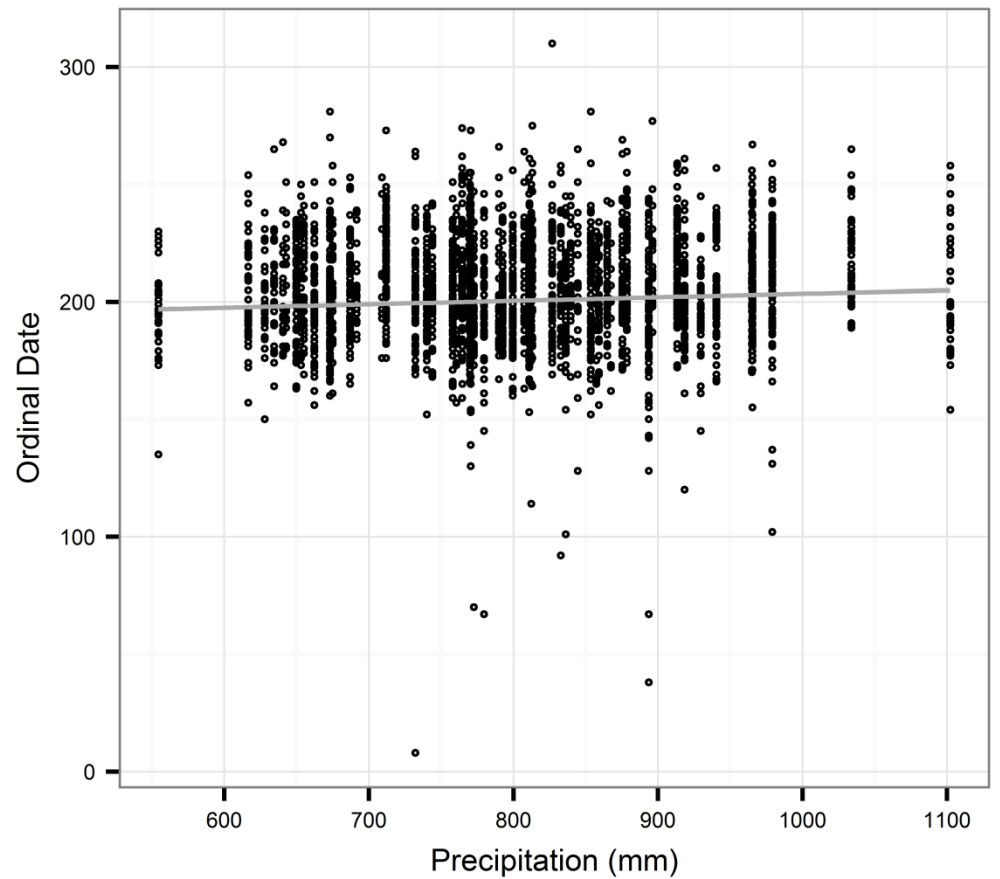
Achillea lanulosa Nutt.:
Delayed 53 days

Precipitation

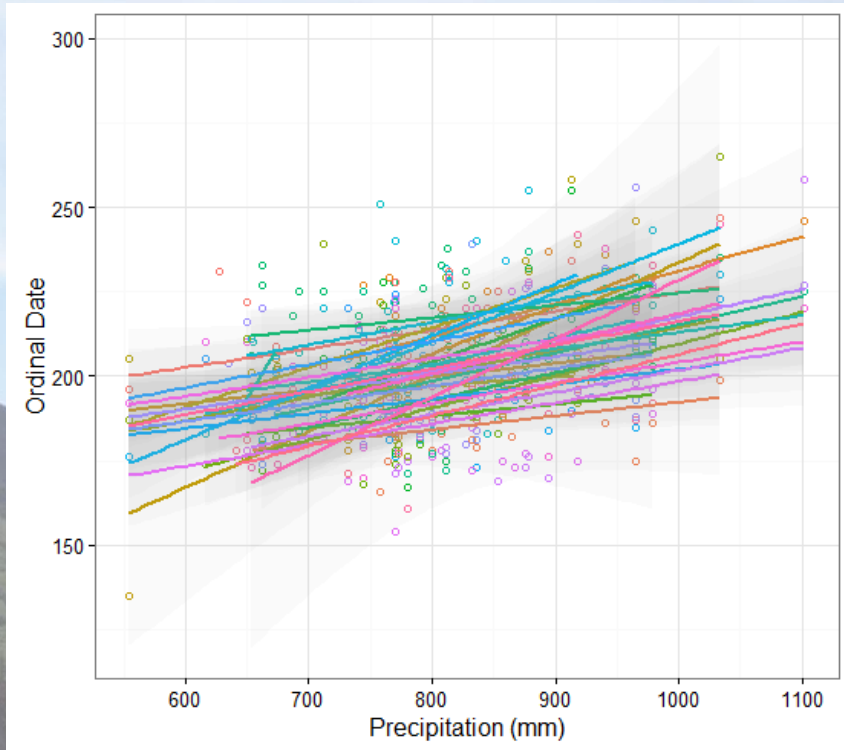
1.68 mm a year



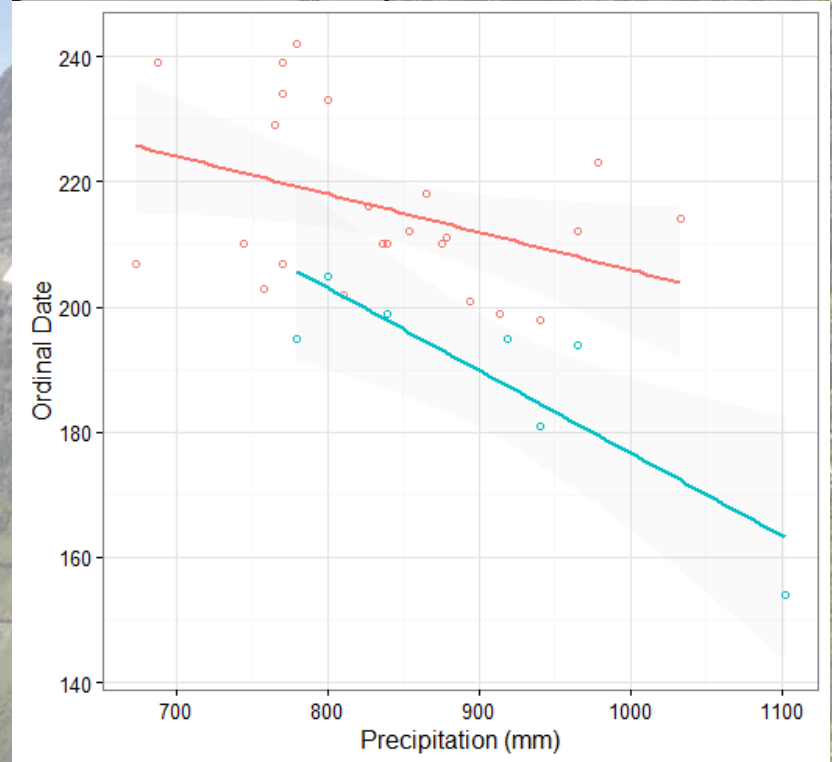
0.02 days per mm



Rain and Snow



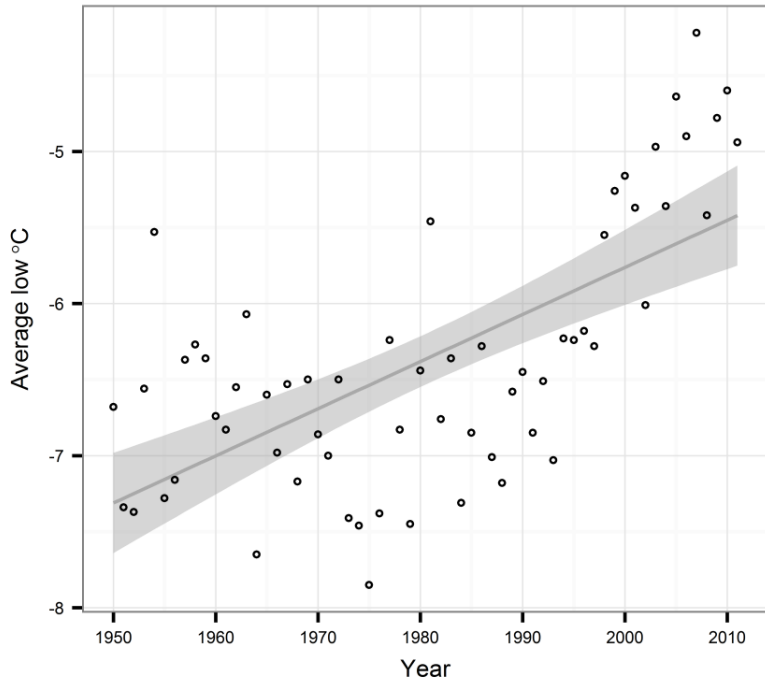
44 species:
0.09 days per millimeter



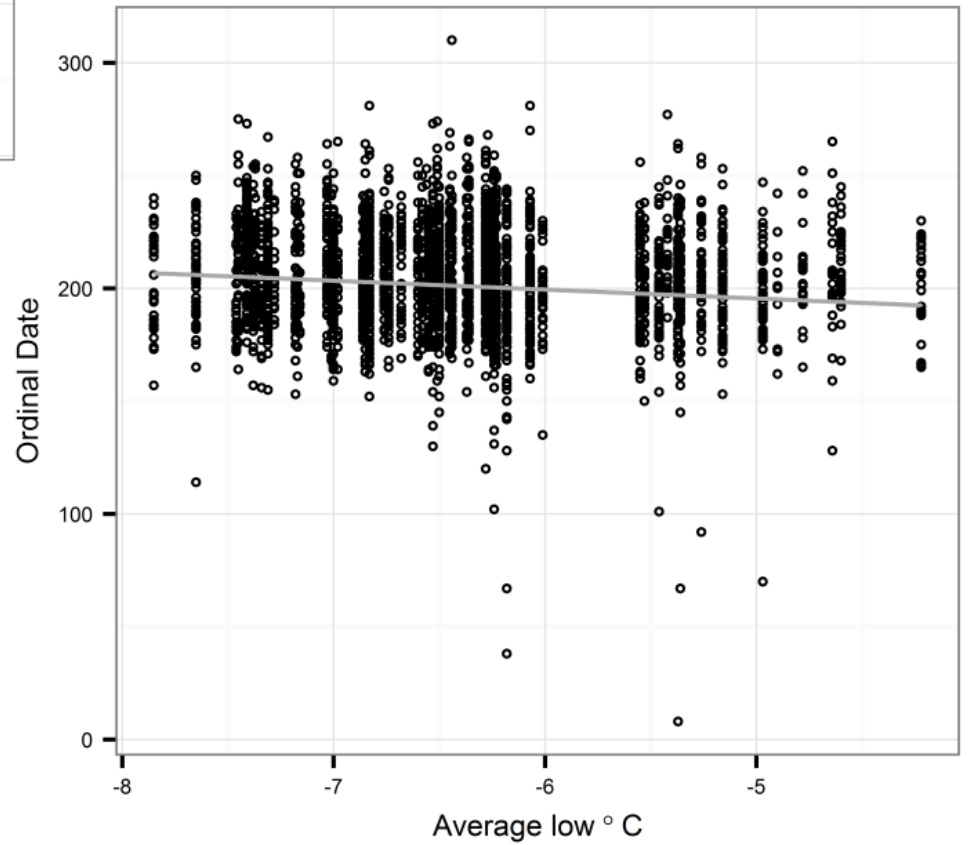
2 species: 0.06 days per millimeter

Low Temperature

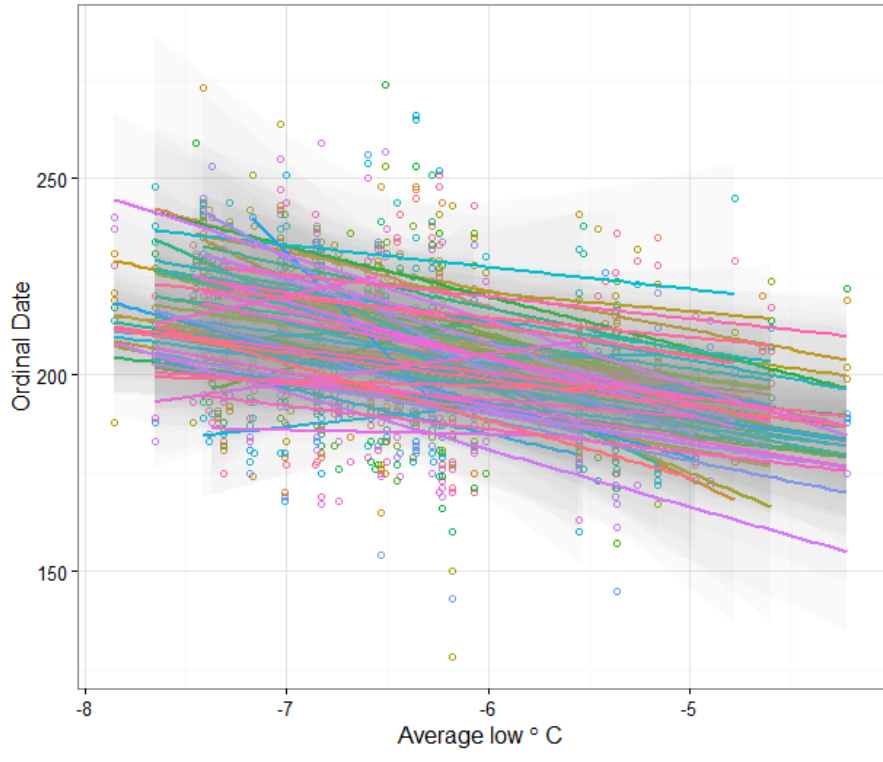
0.03°C a year



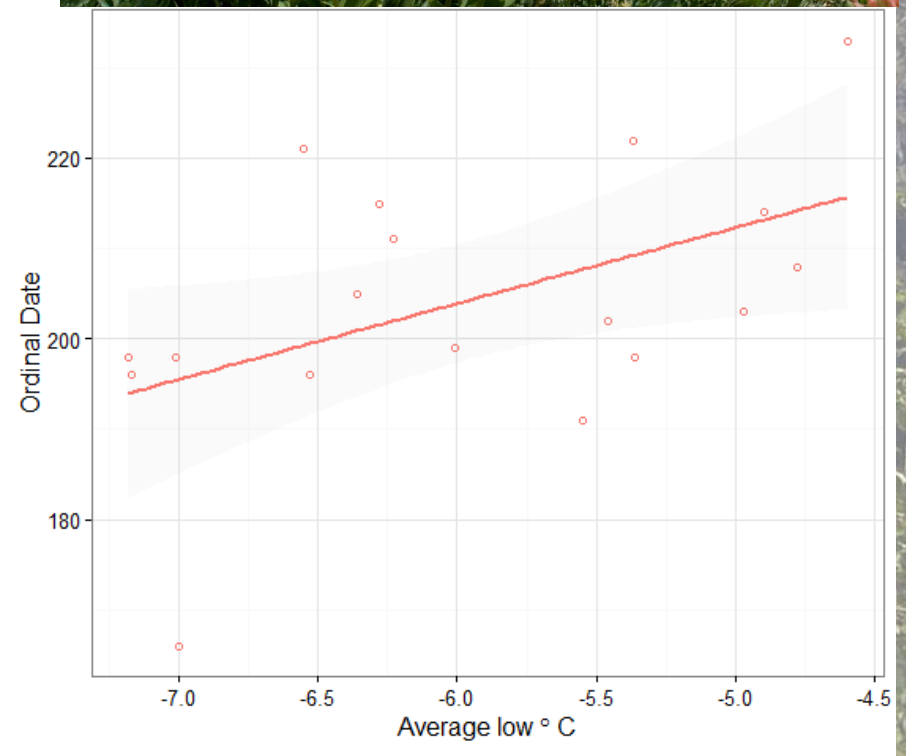
4.2 days per °C



Low Temperature



74 species:
9.6 days per °C

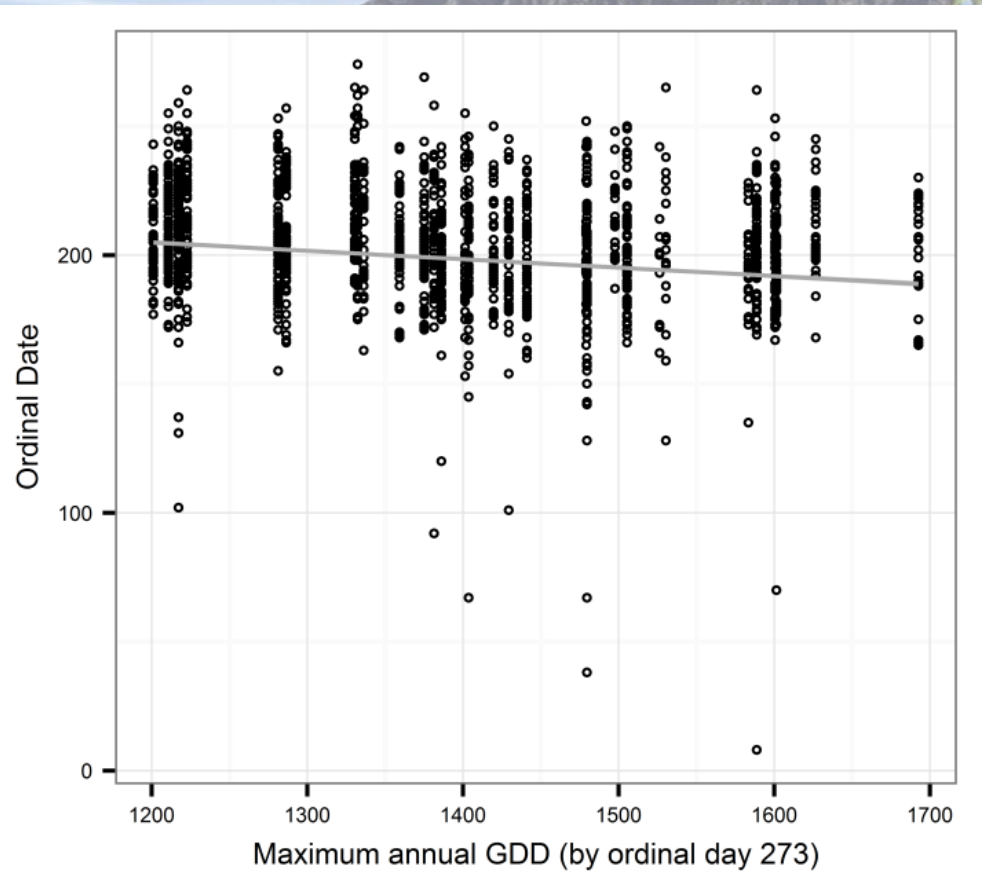
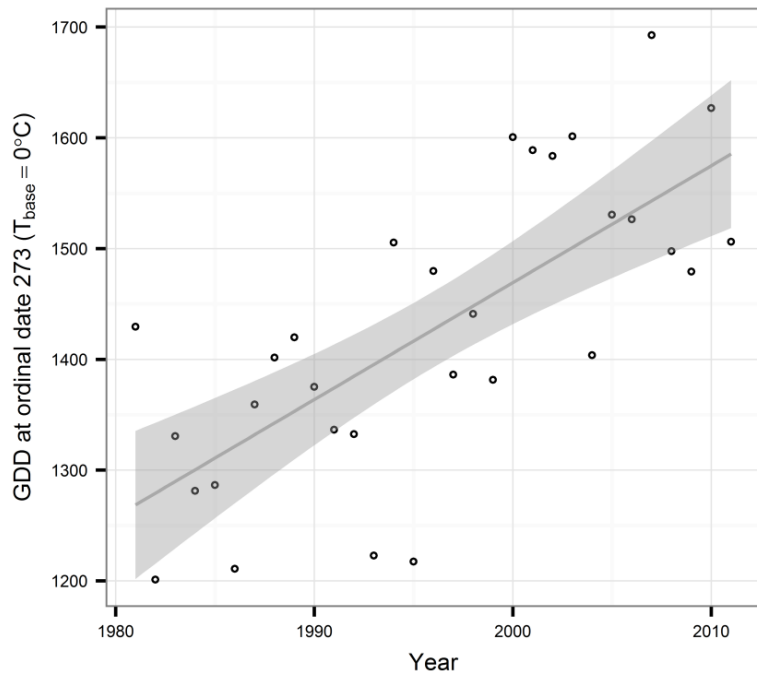


2 species: 9.5 days per °C

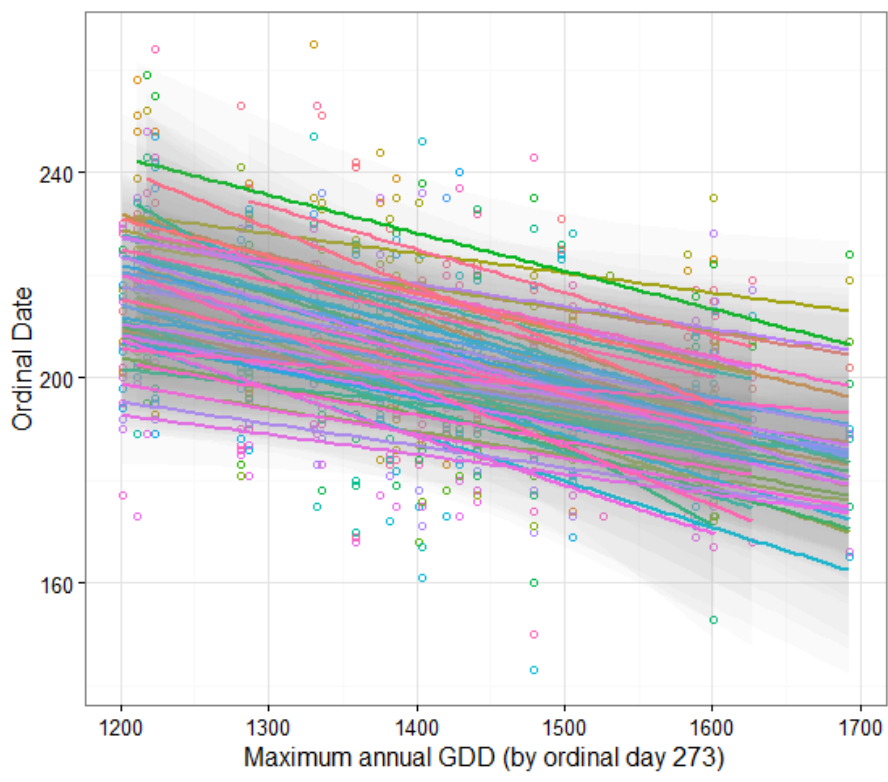
Growing Degree Days

10.6 heating units a year

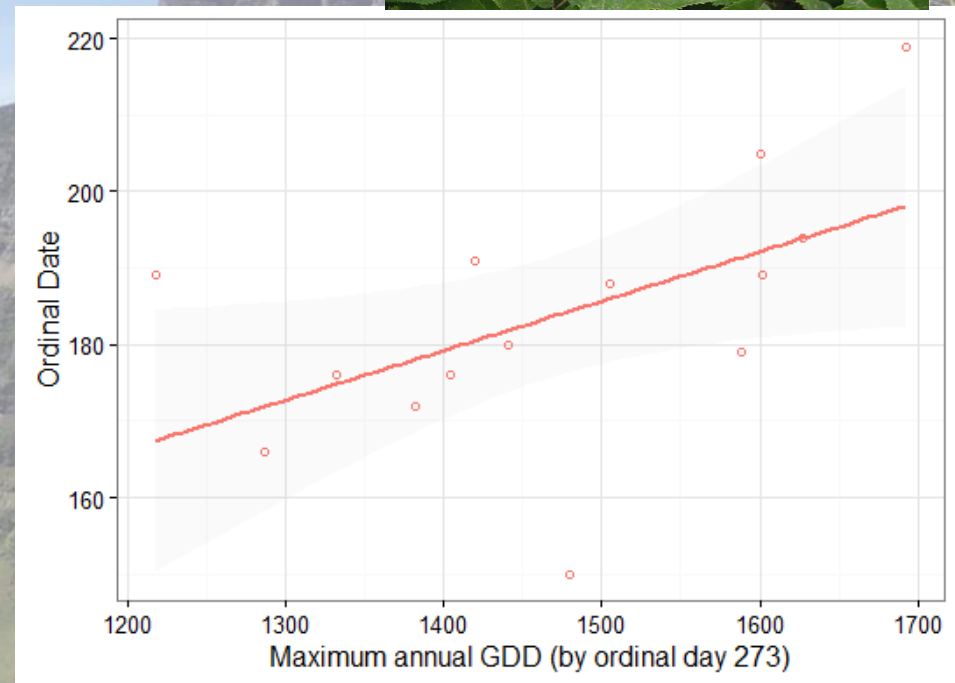
0.04 days per GDD
heating unit



GDD

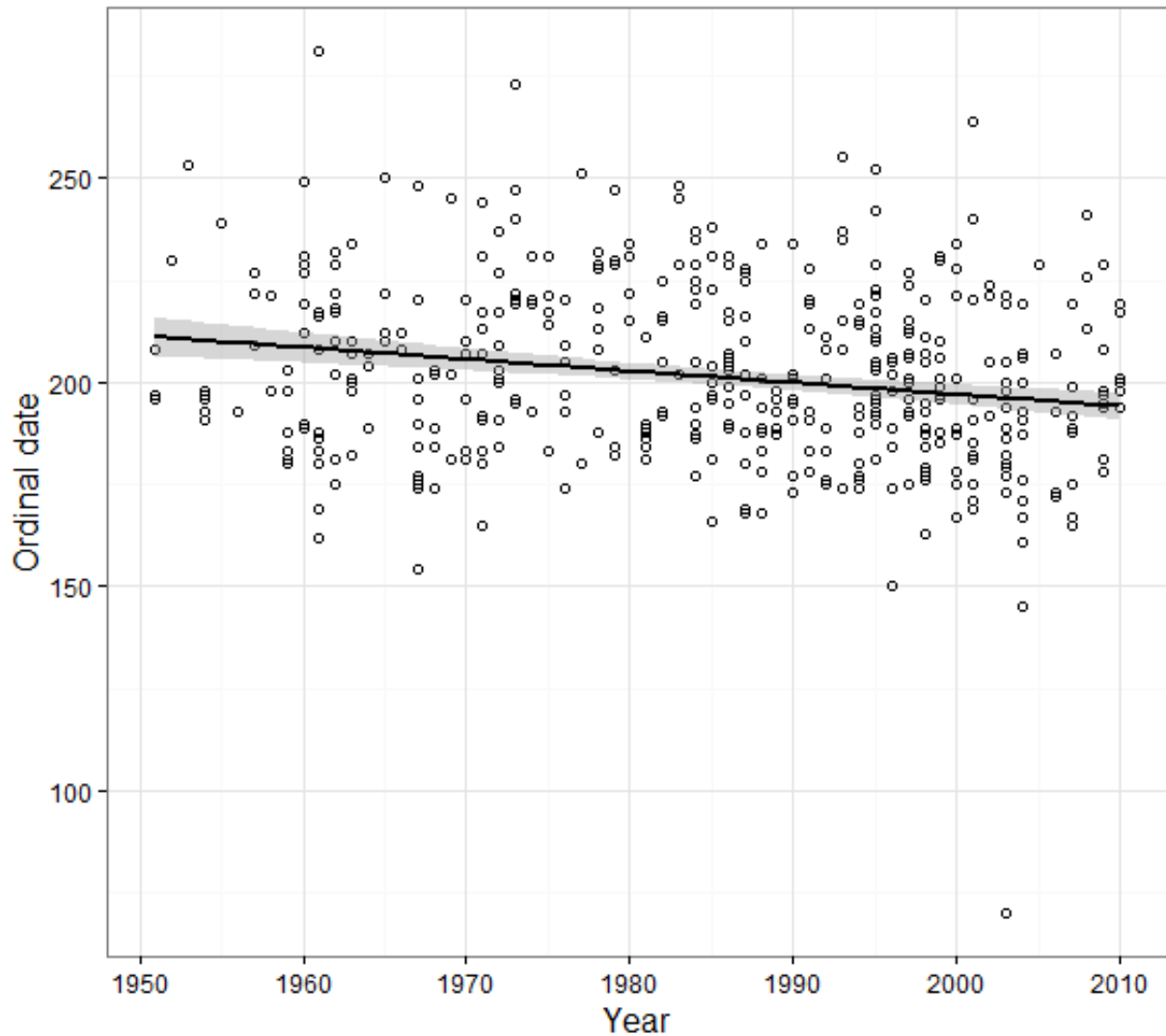


69 species:
0.06 days per heating unit



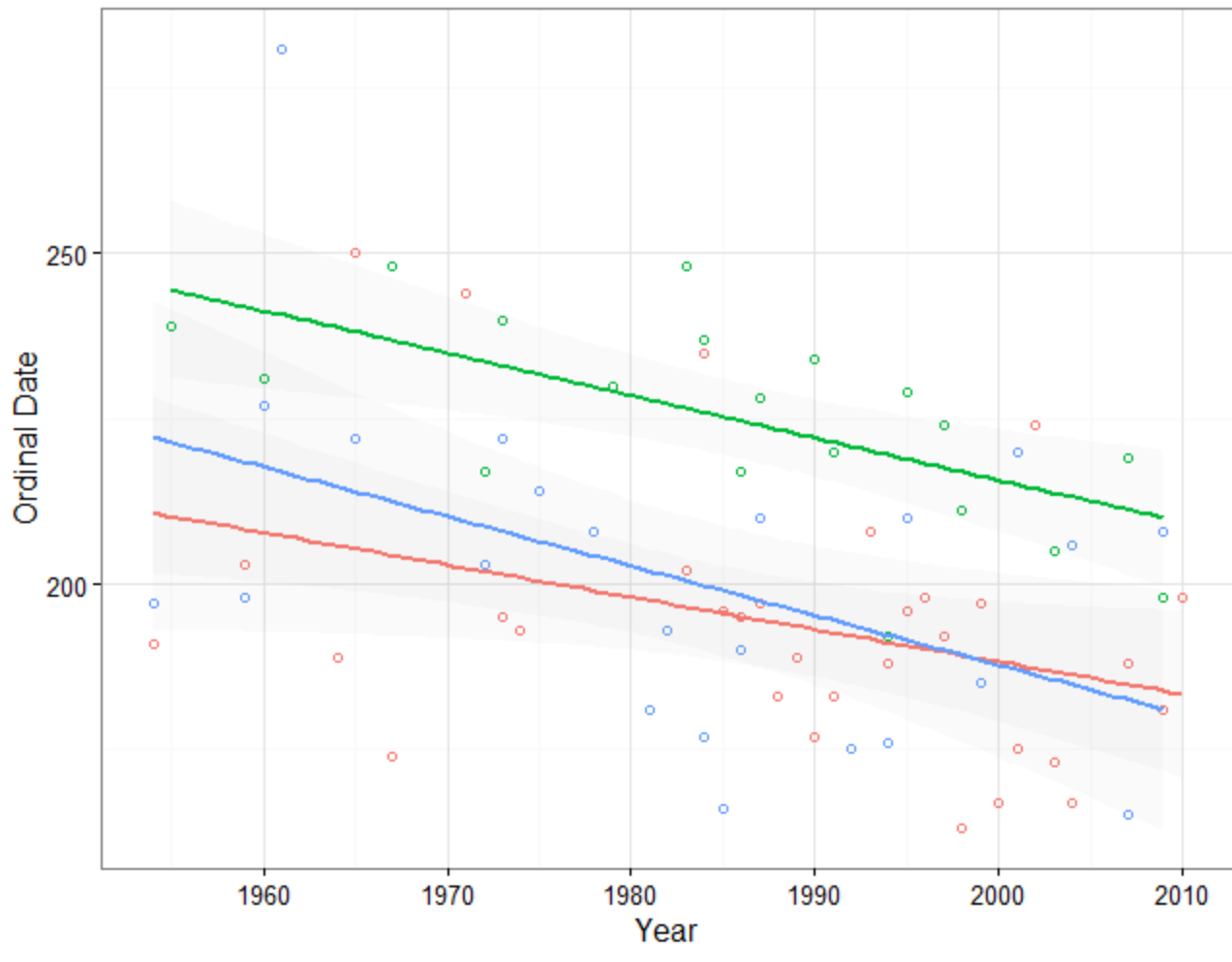
Sambucus racemosa var. *racemosa*:
0.06 days per heating unit

NPN species



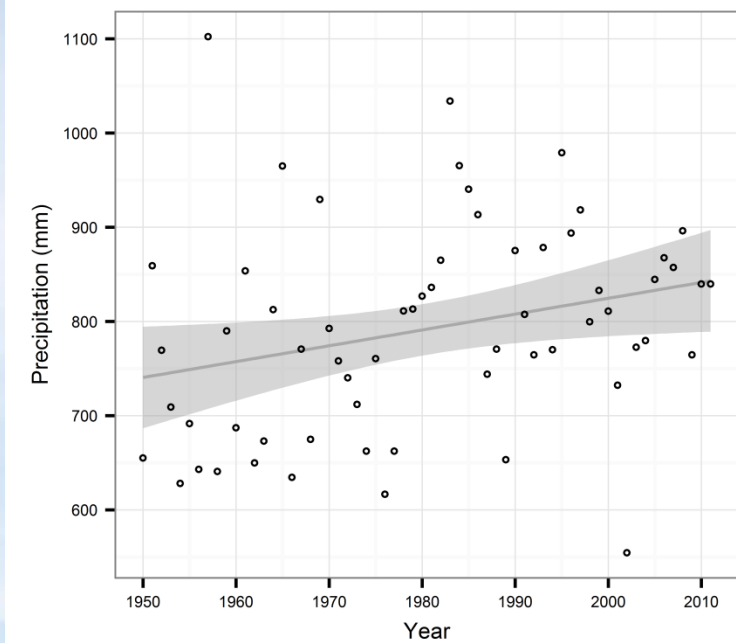
26 species:
Advancing 17.5 days





3 species:
Advancing average of 38 days

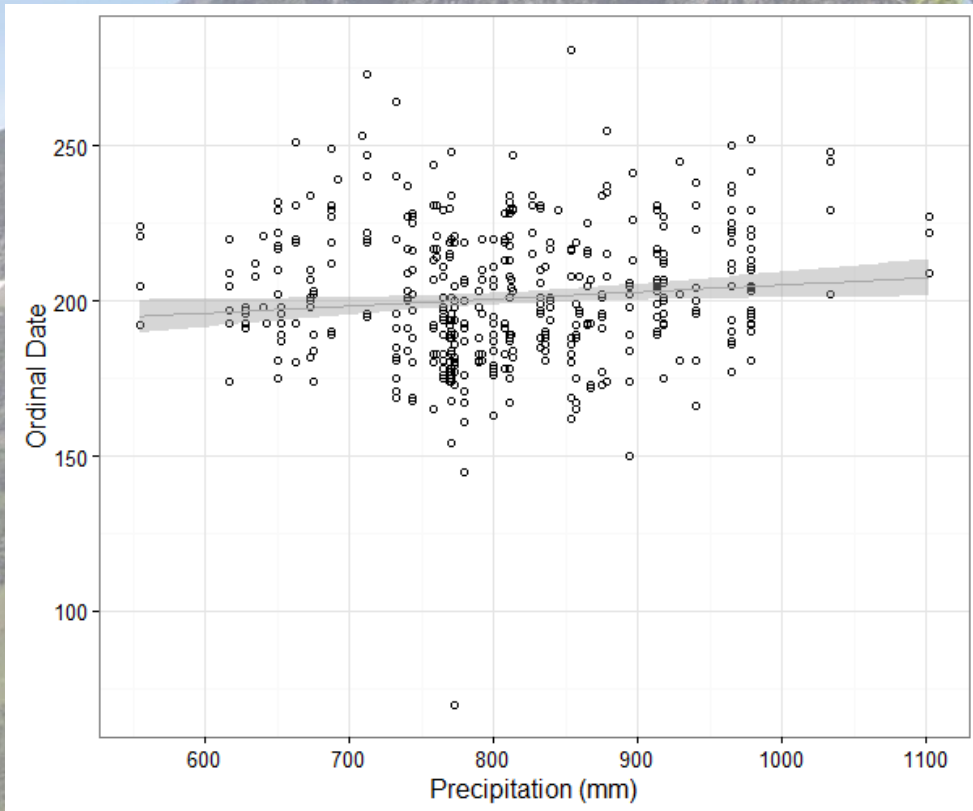




NPN Precipitation

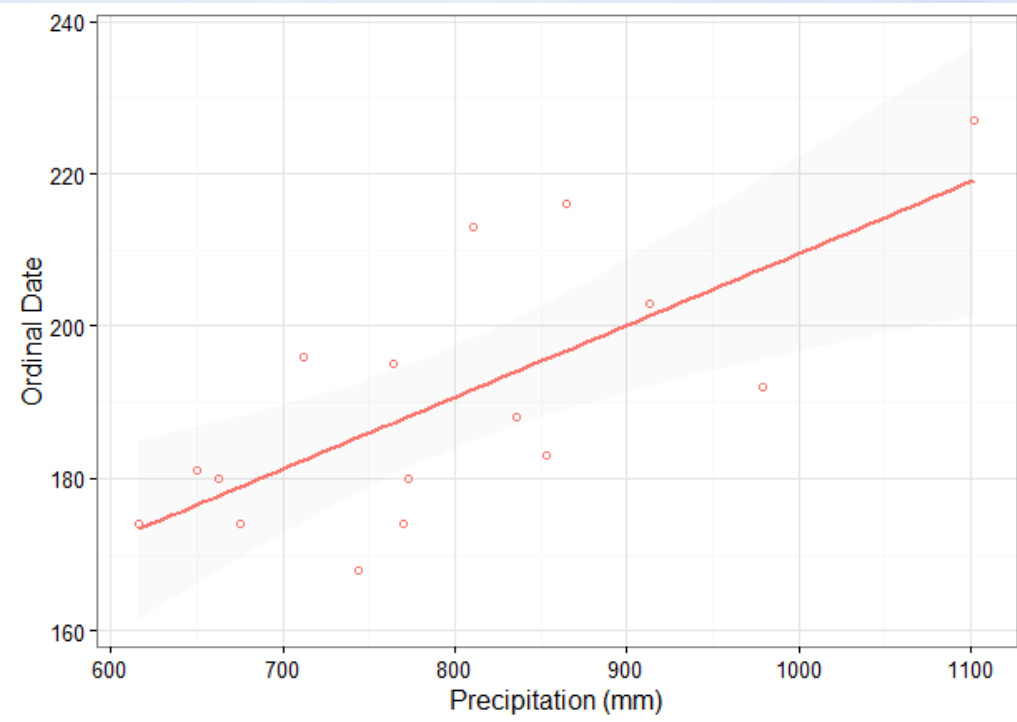
1.68 mm a year

0.02 days per mm

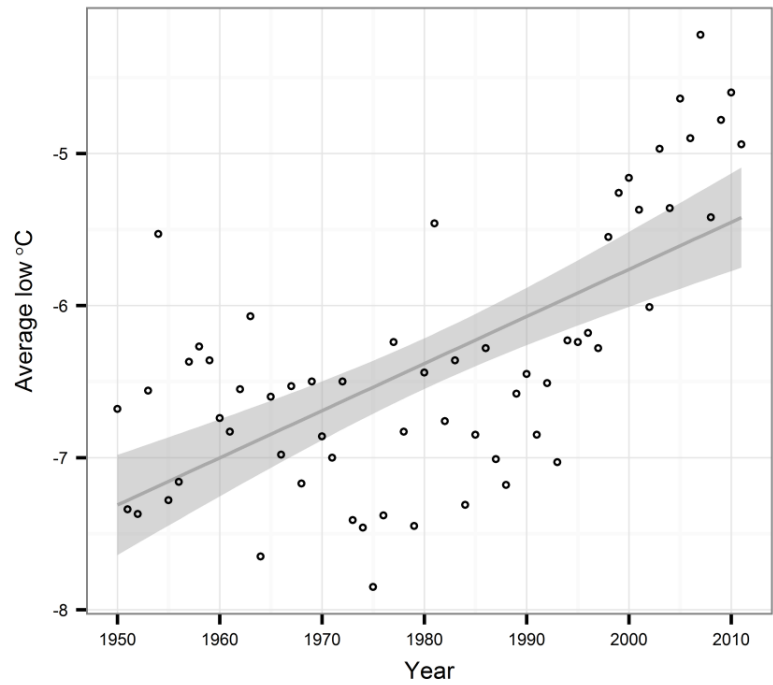


NPN

Rain and Snow



Erythronium grandiflorum:
0.09 days per millimeter

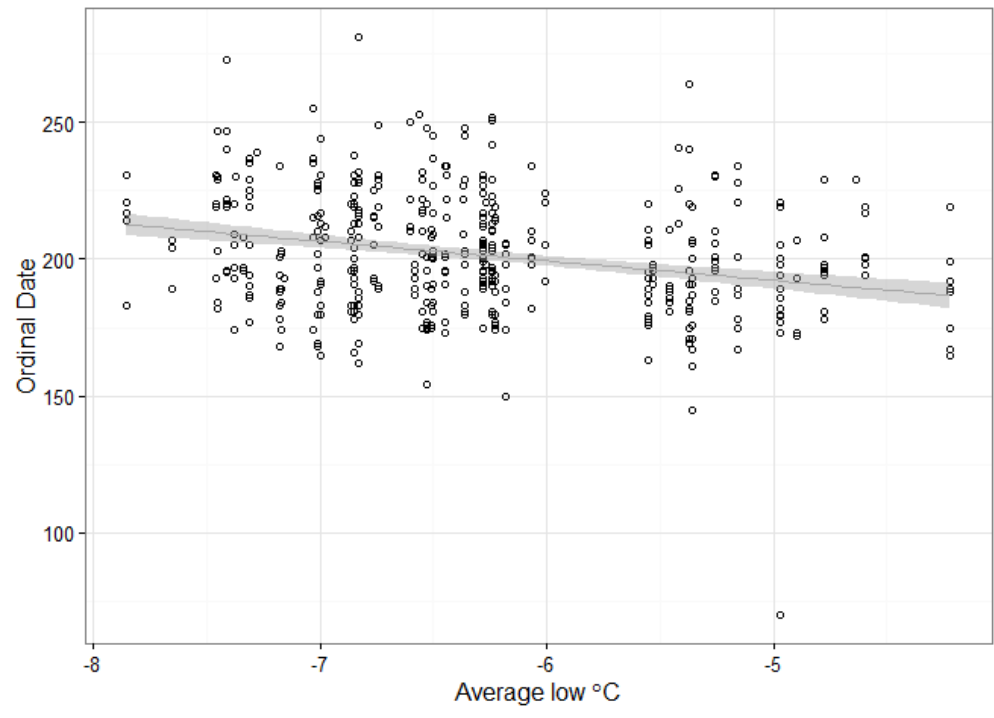


NPN

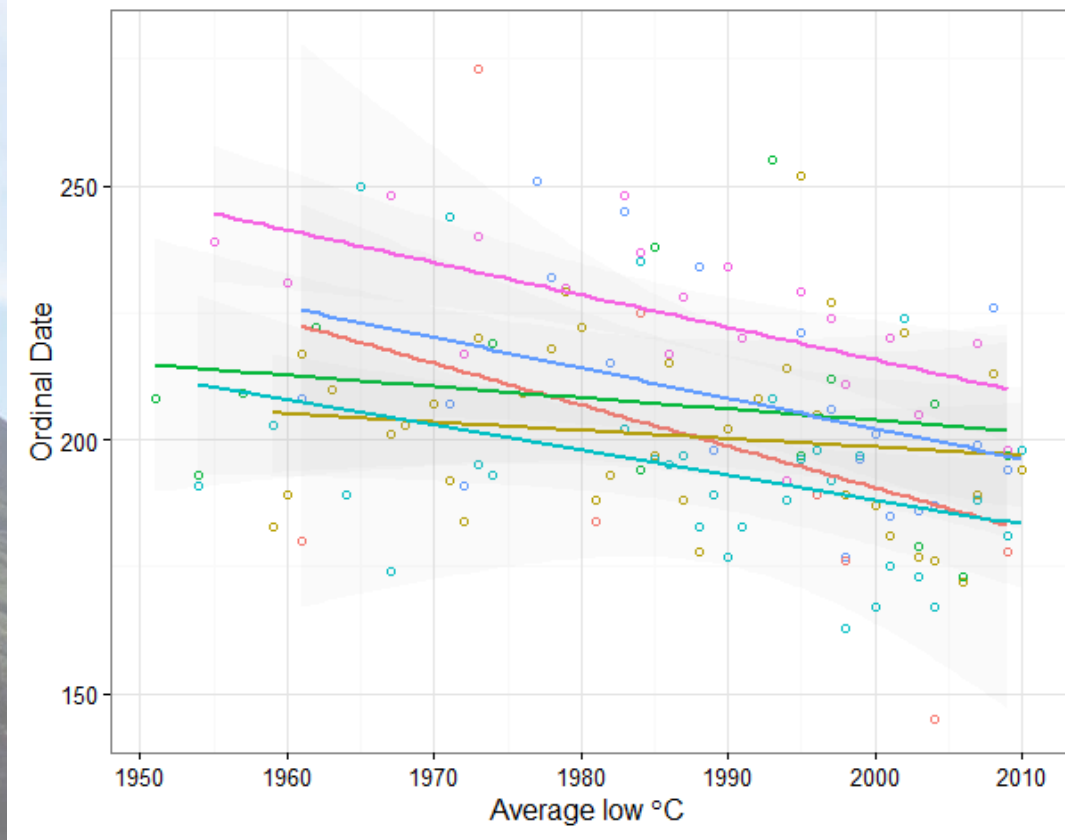
Low Temperature

0.03°C a year

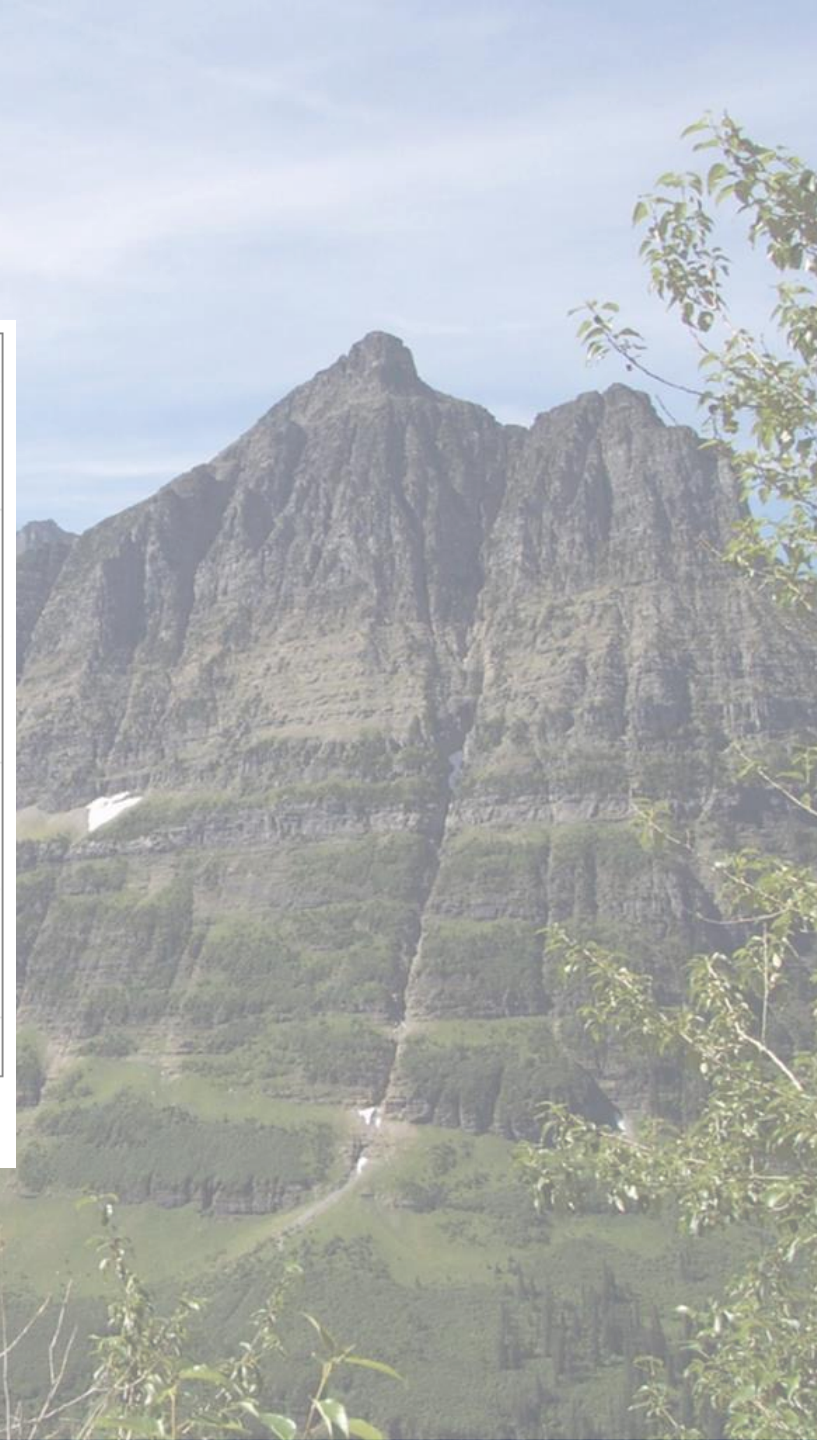
7.2 days per °C



NPN: Low Temperature

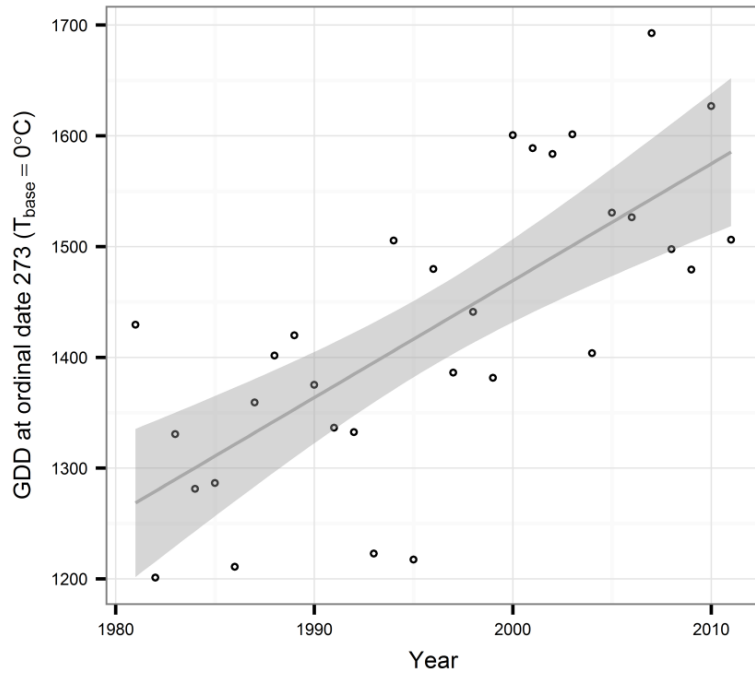


6 species:
12.9 days per °C

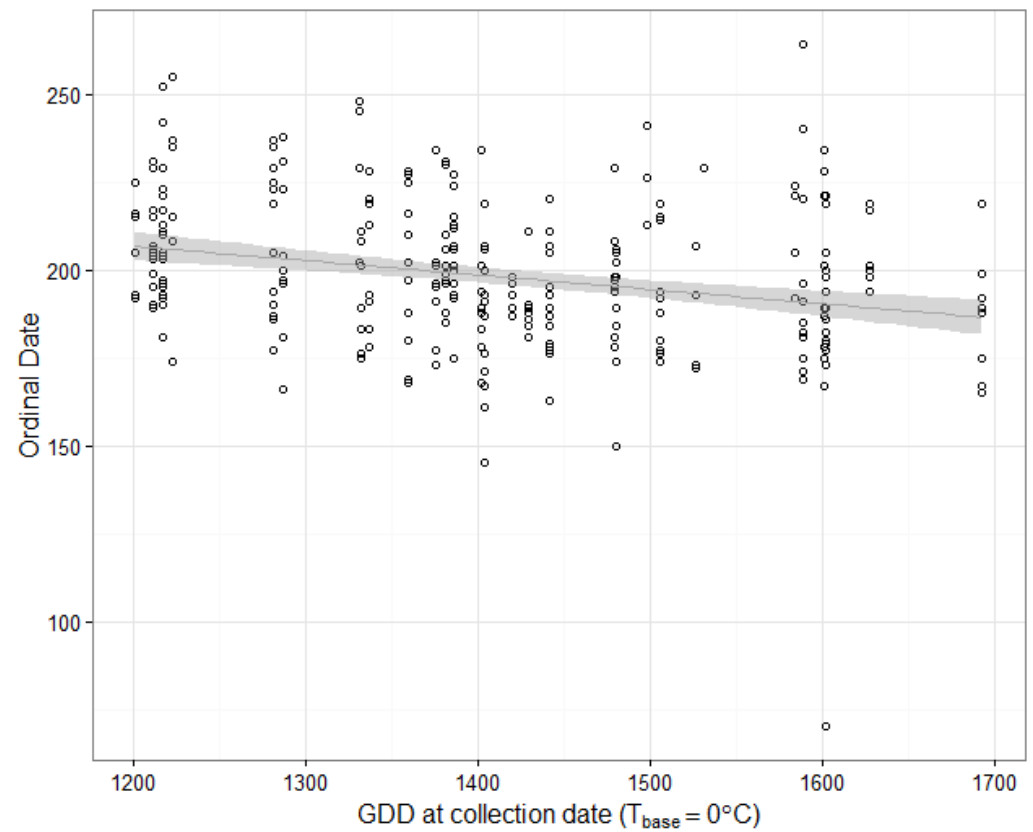


NPN: Growing Degree Days

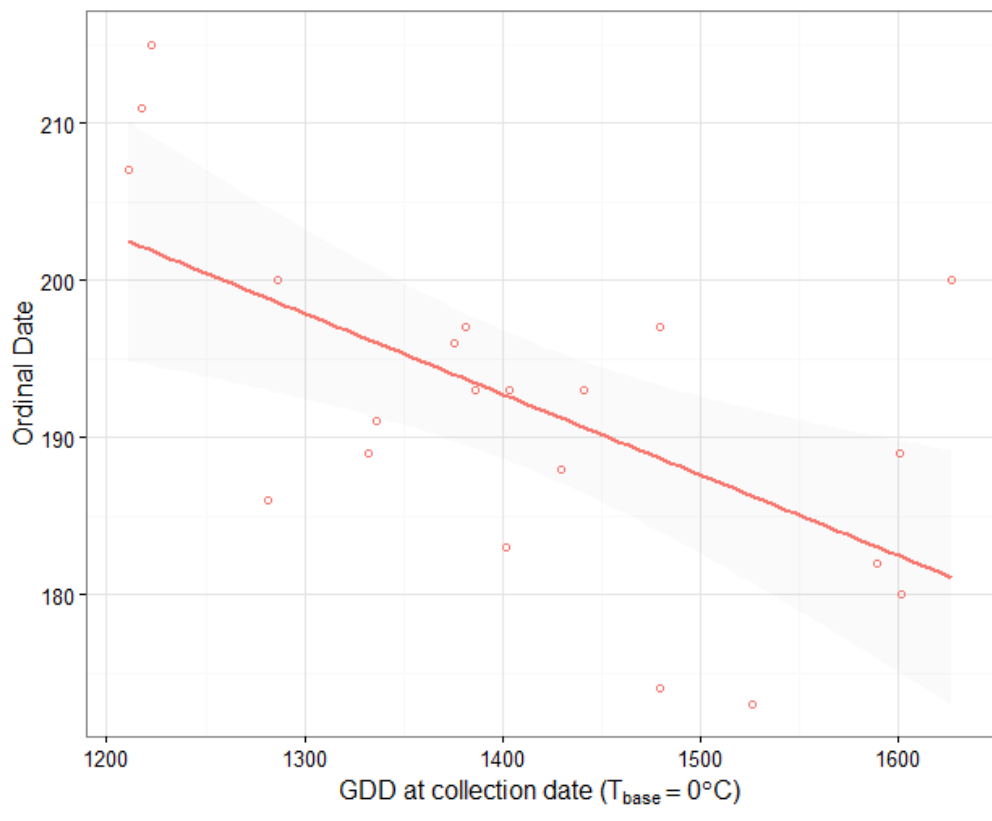
10.6 heating units a year



0.04 days per GDD
heating unit



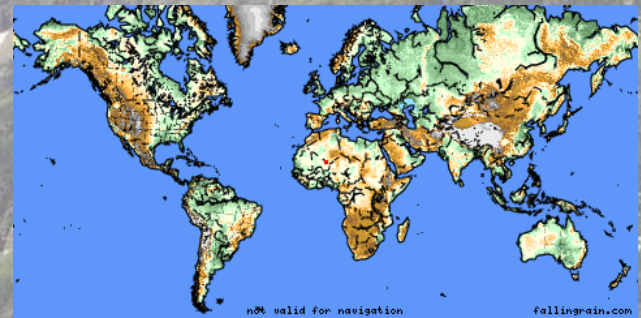
NPN: GDD



Zigadenus elegans Pursh:
0.05 days per heating unit

Herbaria data & Phenological monitoring

- Scale of interest
- Select monitoring species



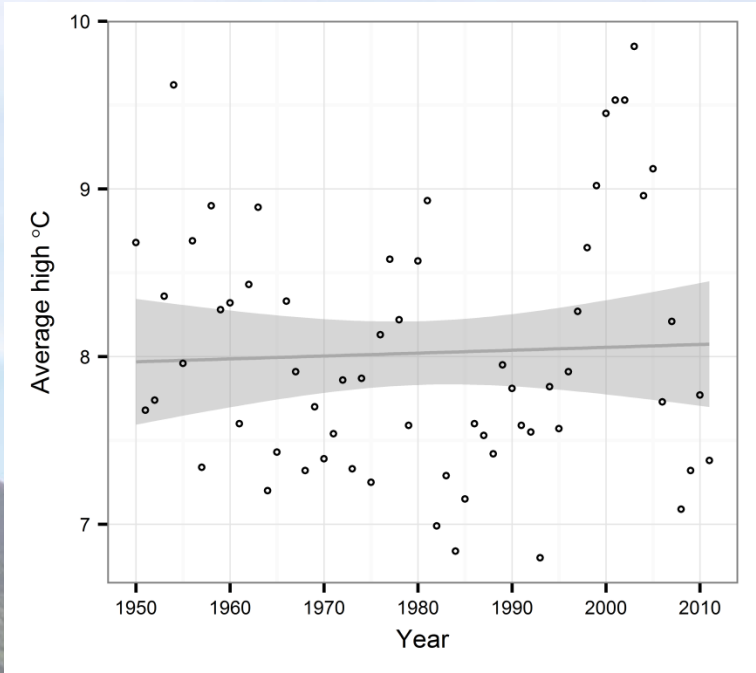
<http://www.fallingrain.com/world/index.html>



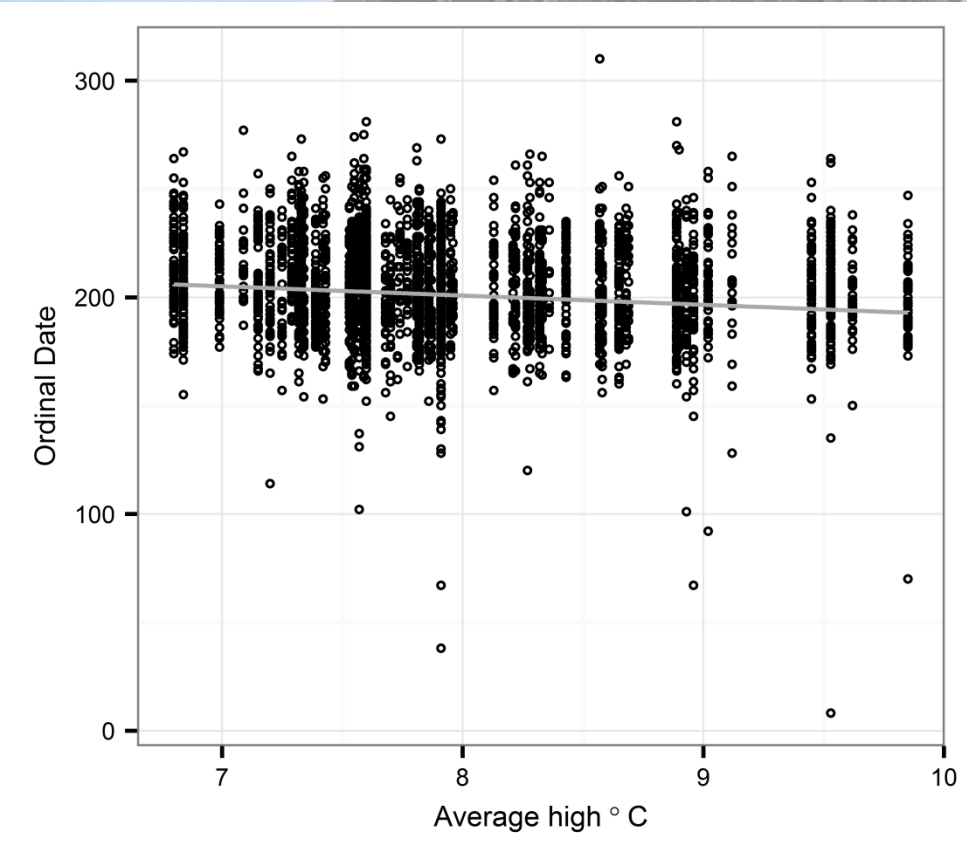
<http://www.museum.tulane.edu/geolocate/>



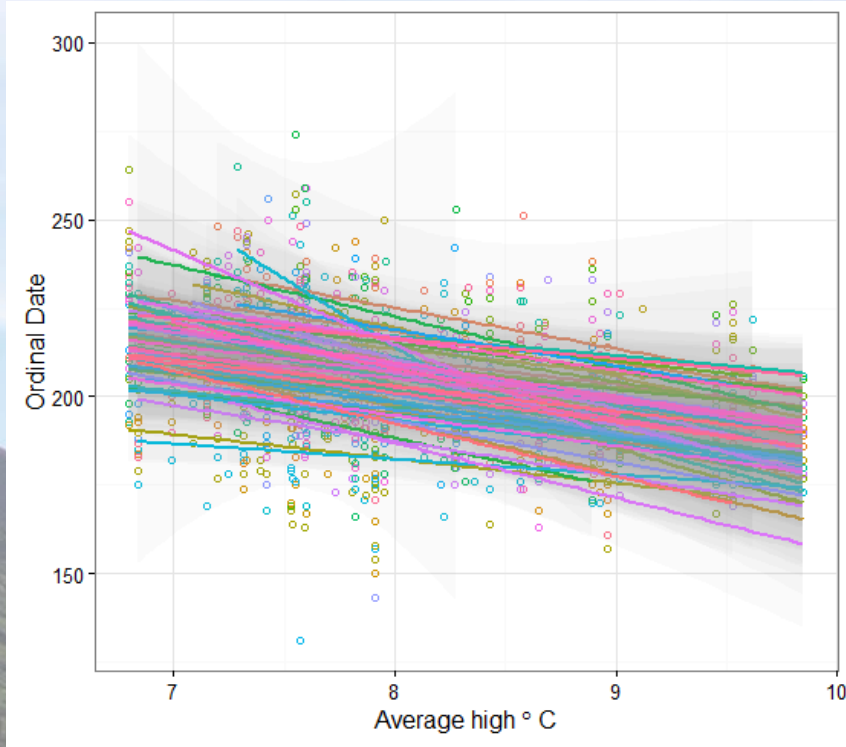
Annual Average High Temperature



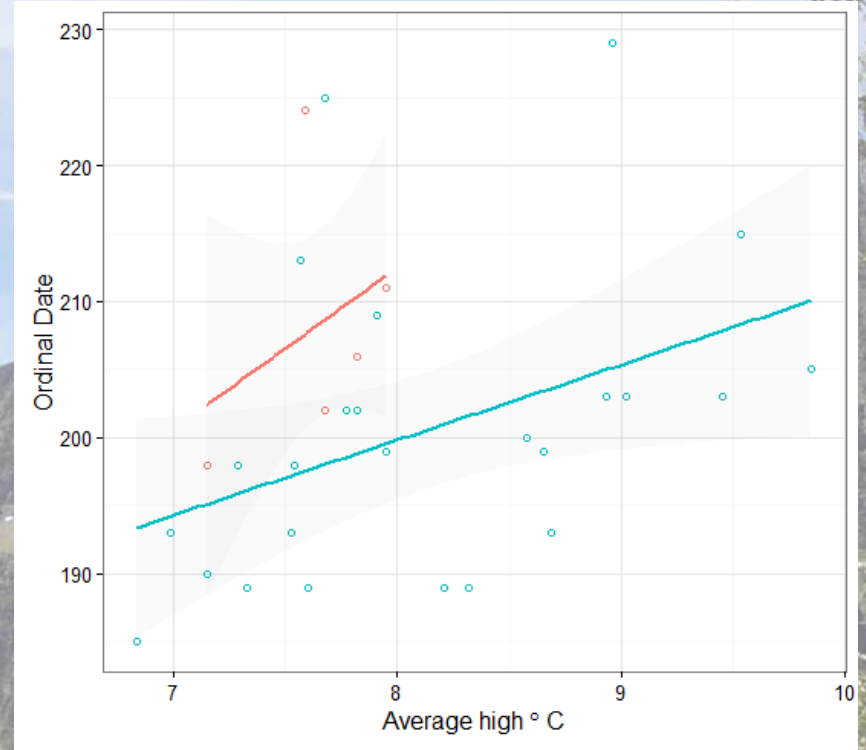
Advancing 4.3 days per degree



High Temperature



67 species:
10.6 days per degree increase



2 species:
8.9 days per degree increase