Detection and Attribution of Long-Term Vegetation Changes in Northern Alaska

Thesis Defense – Biology Master's Candidate

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UKPEAĠVIK IÑUPIAT CORPORATION

NATIONAL SCIENCE FOUNDATION ARCTIC PROGRAM

ITEX

NSF

ARCTIC ECOLOGY

GRAND VALLEY STATE UNIVERSITY

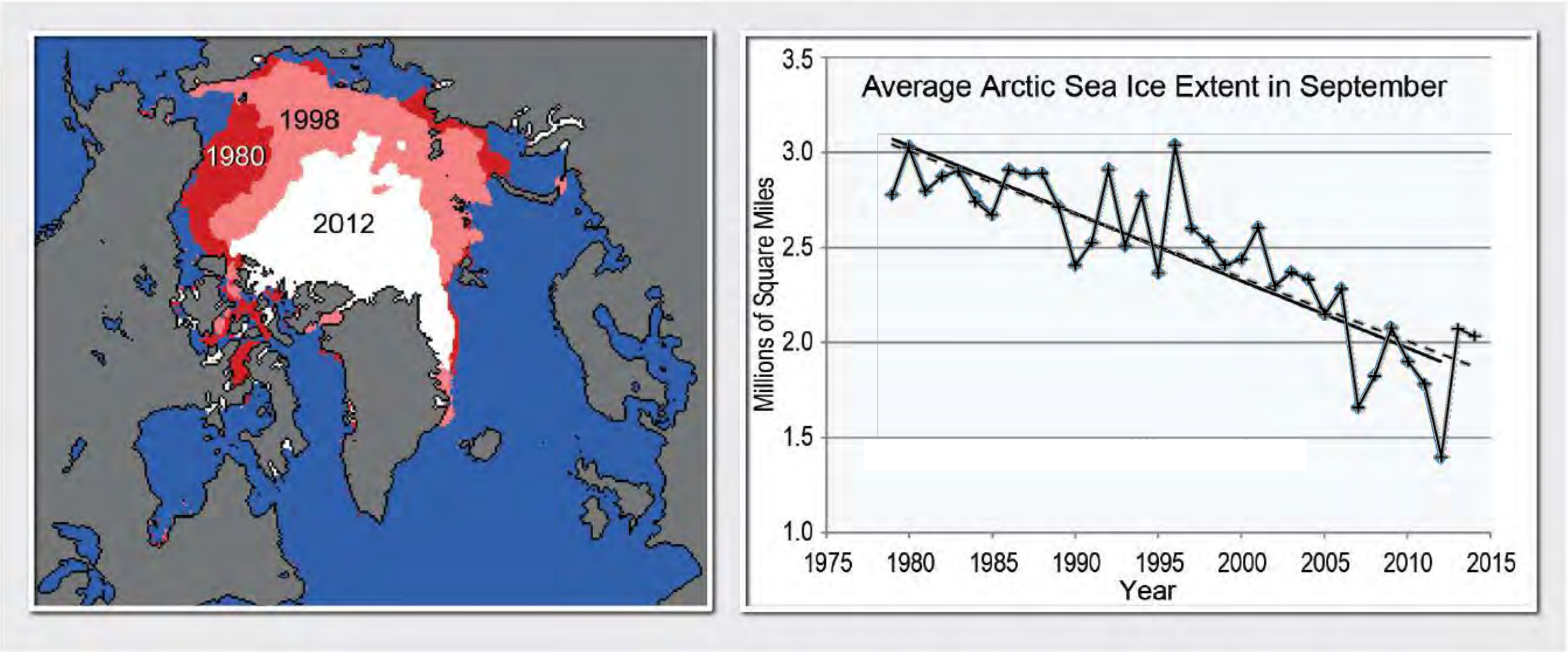
Presentation Outline

- Ch I: Introduction
- Ch II: Responses to long-term warming
- Ch III: Ambient change over time
- CH IV: Conclusions

Ch I: Introduction

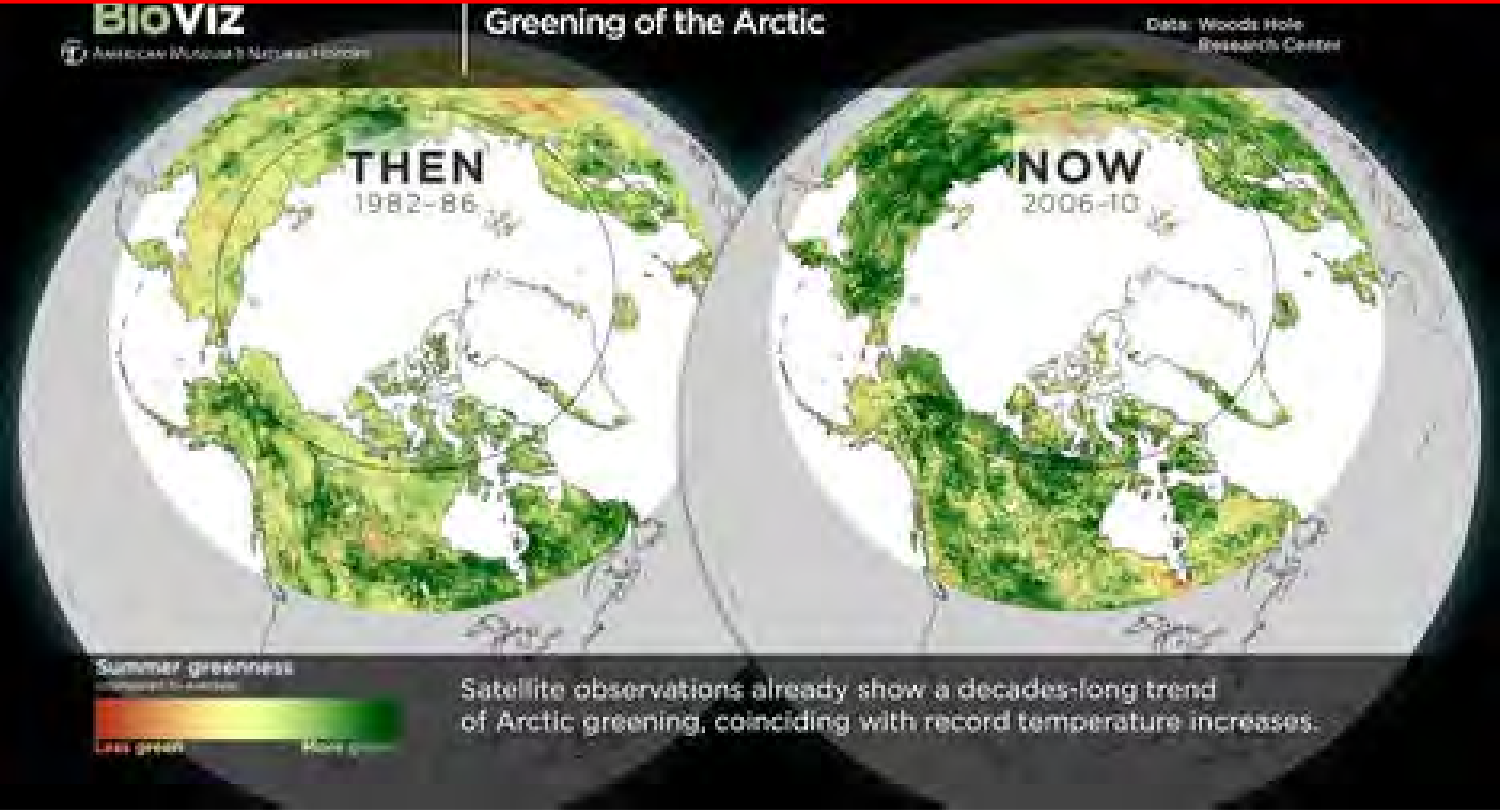
Observed change

Sea Ice (end of the summer)



NCADAC v. 11 Jan 2013

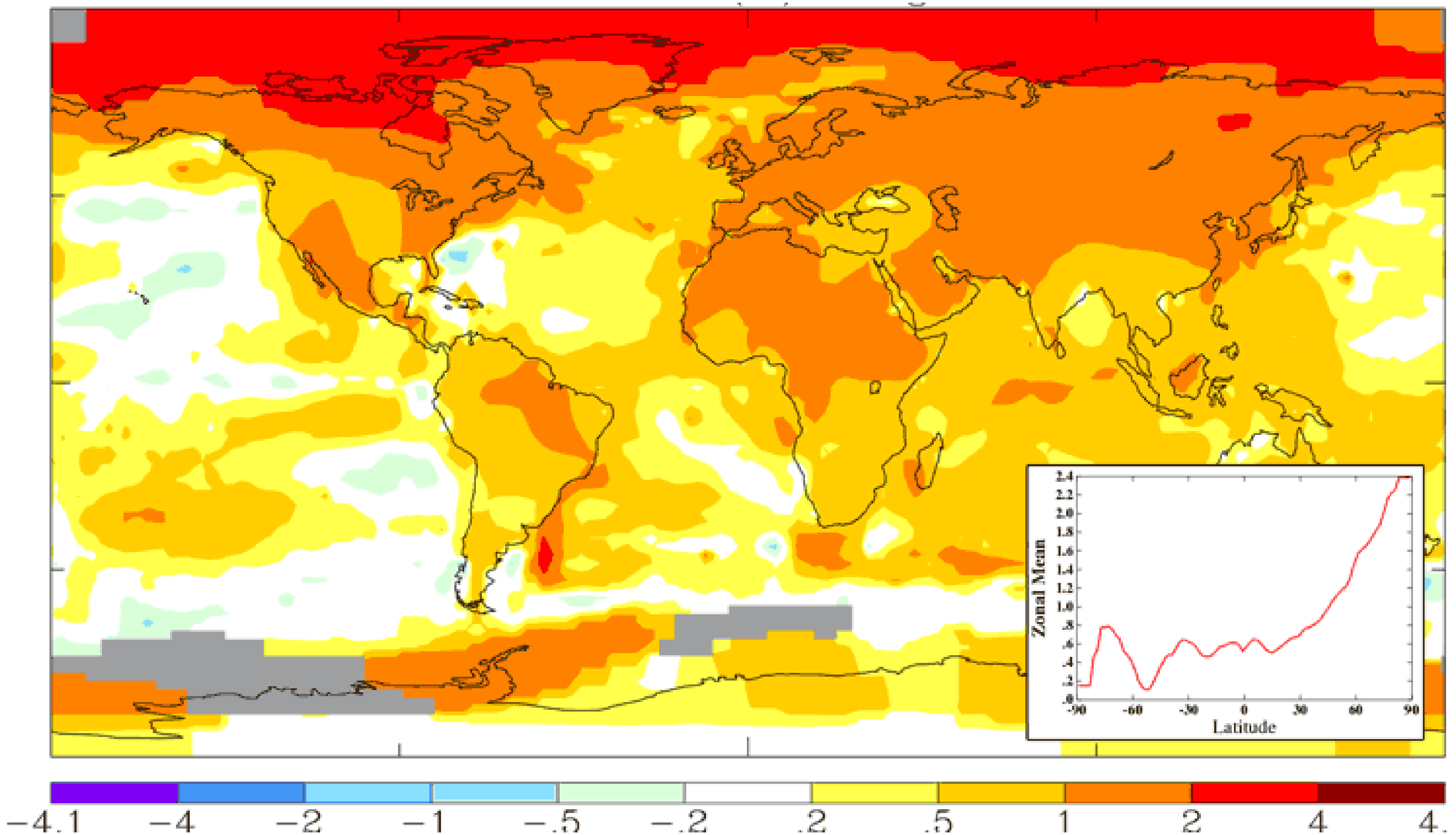
Observed change



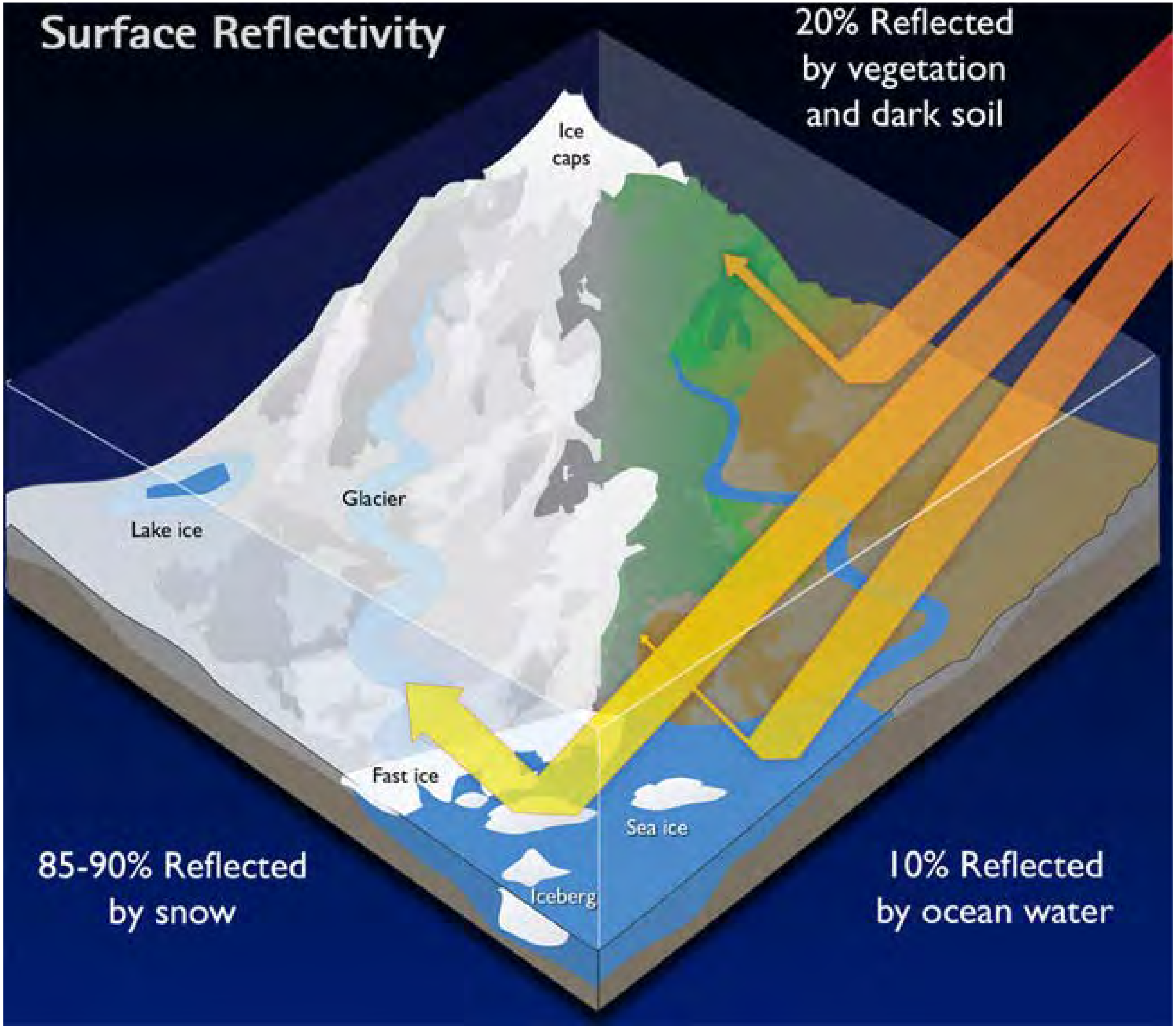
Greenness (NDVI) increasing (Woods Hole, MA)

Observed change

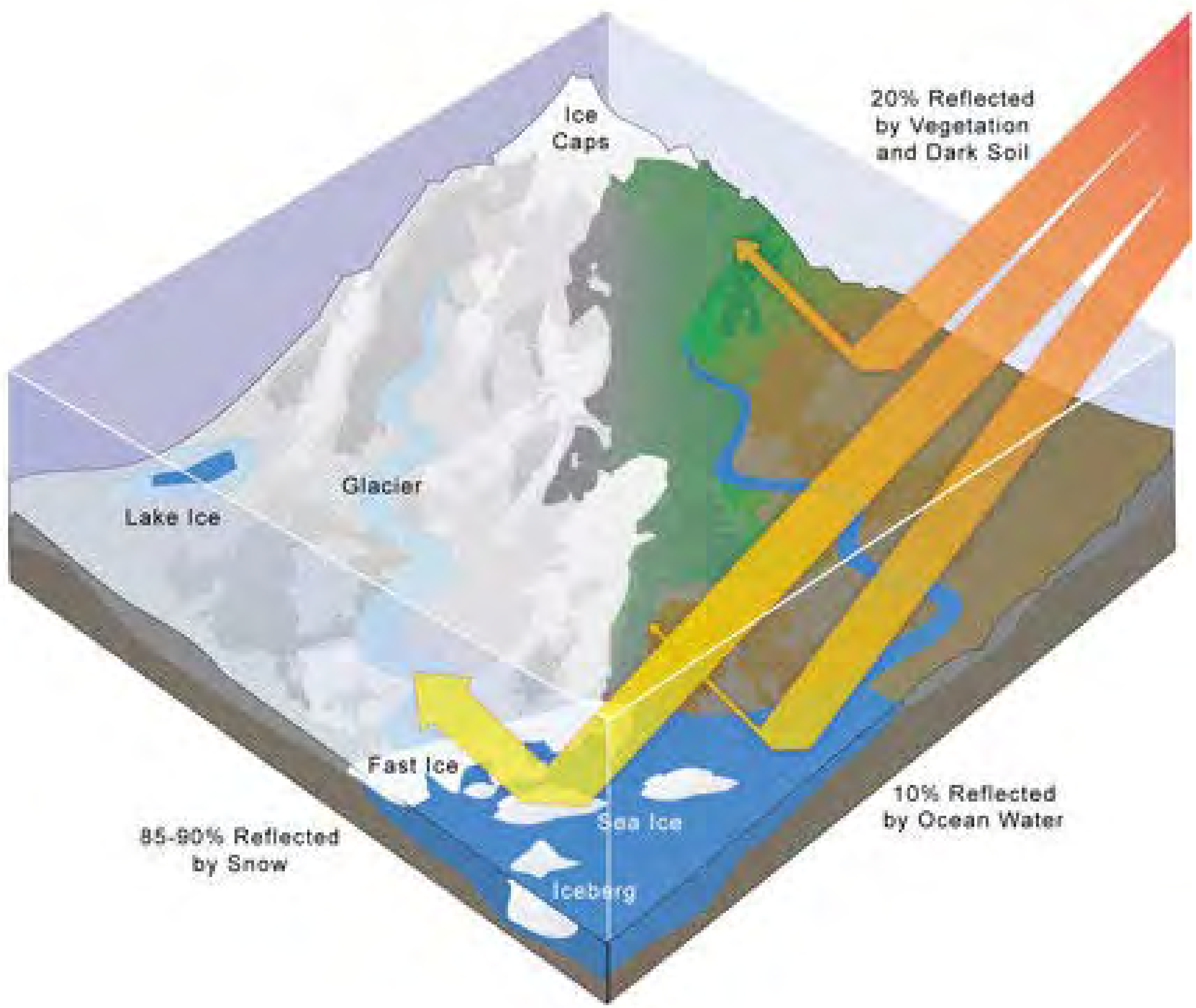
Variability is also higher



Main reason for polar amplification

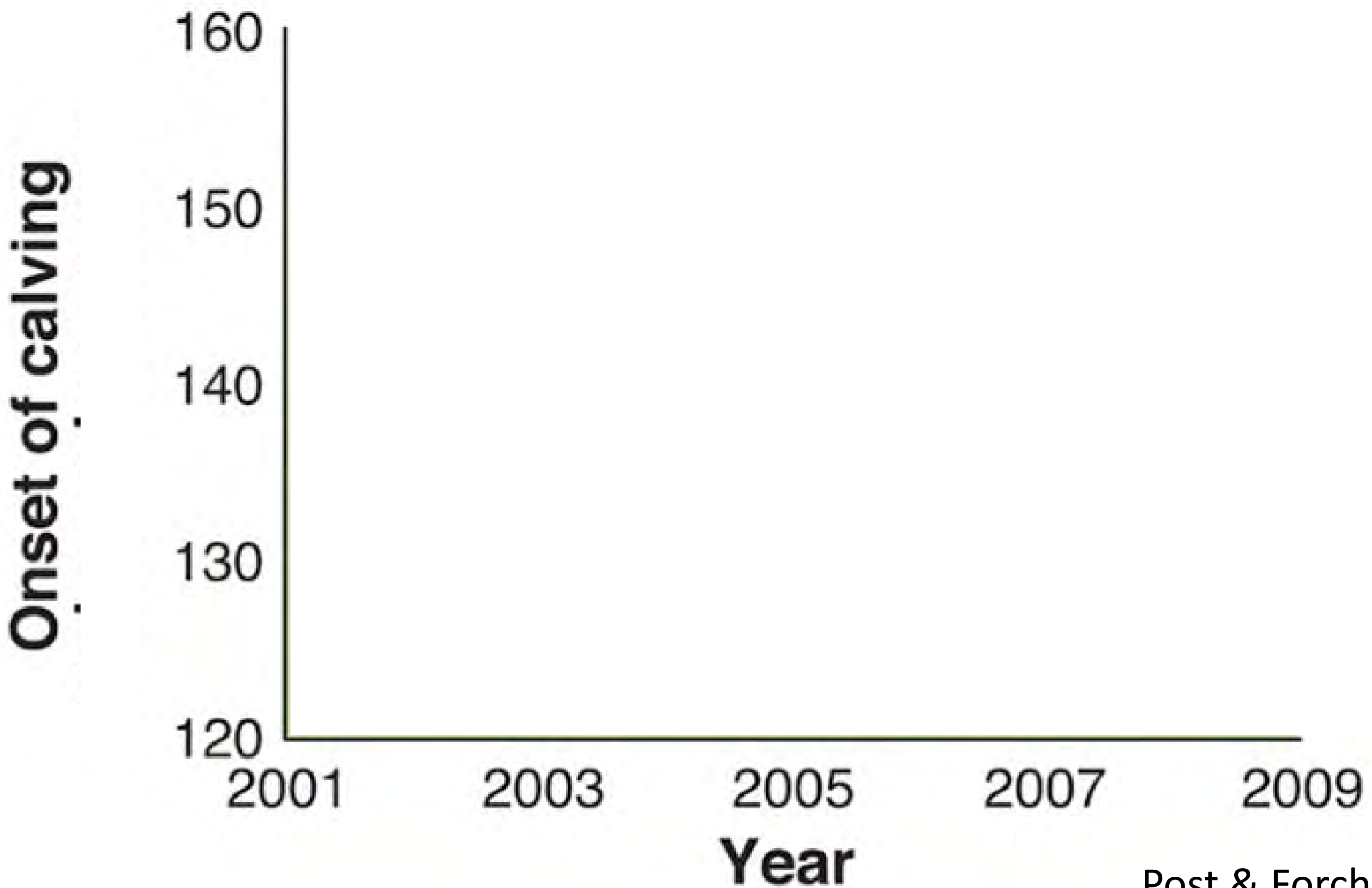


Reduced albedo (reflectiveness) will amplify warming



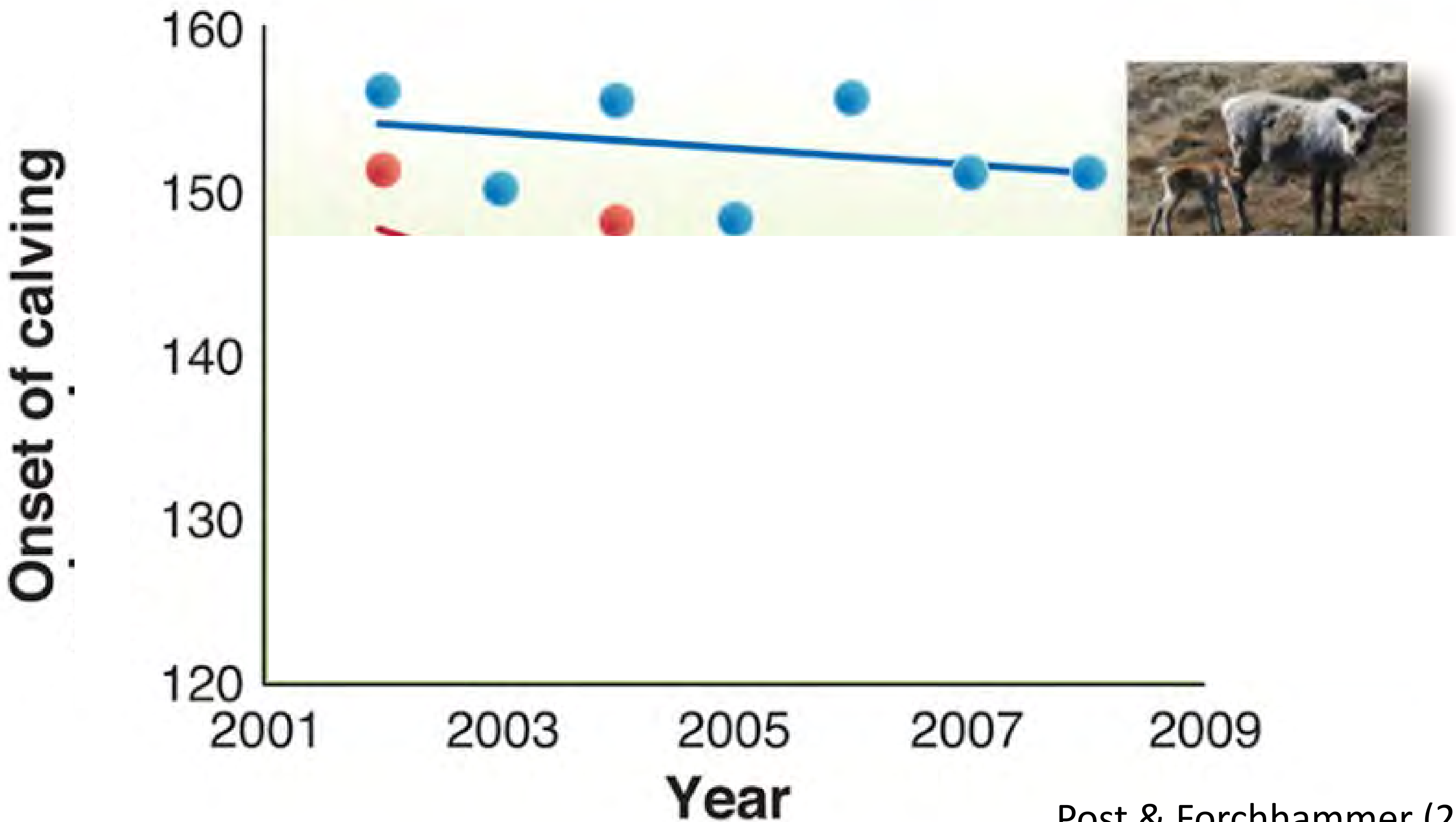
Observed change

Trophic mis match



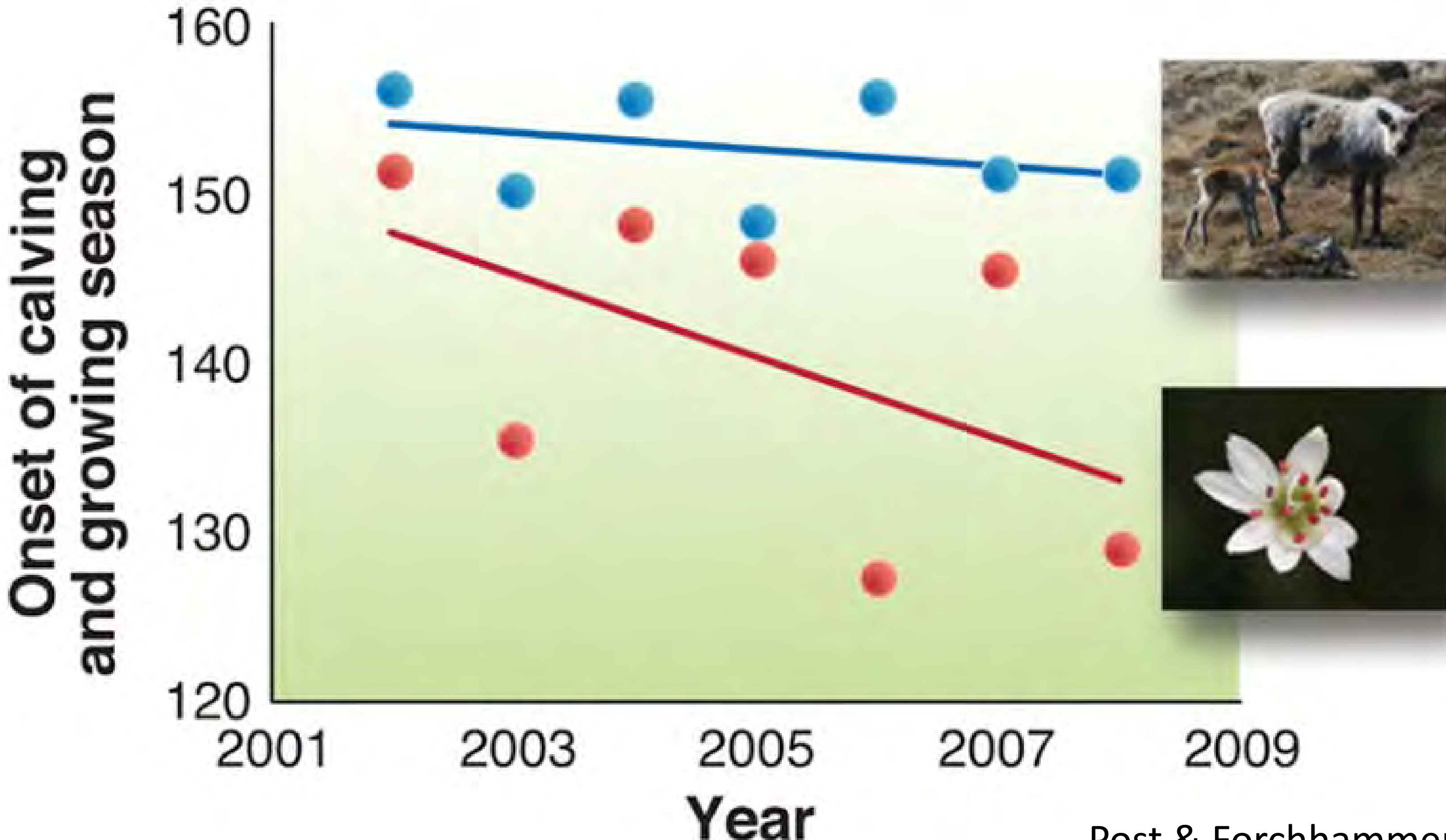
Post & Forchhammer (2008)

Vegetation changes will have local and world-wide effects on herbivores



Post & Forchhammer (2008)

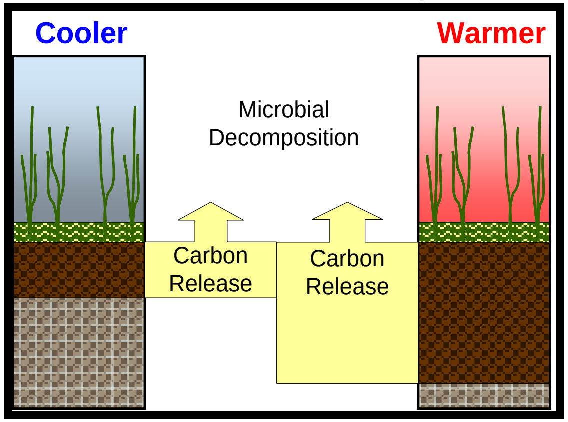
Vegetation changes will have local and world-wide effects on herbivores



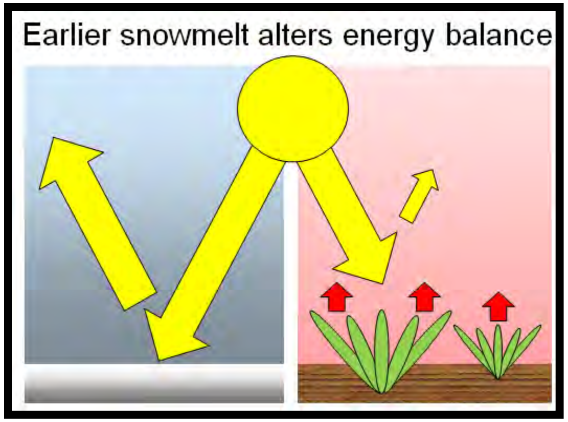
Post & Forchhammer (2008)

Why Plants are important

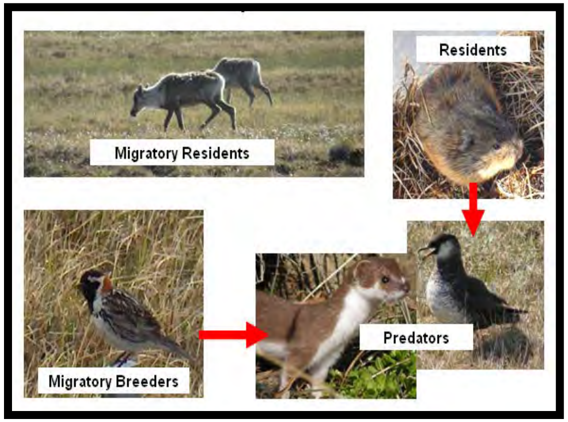
Carbon Budget



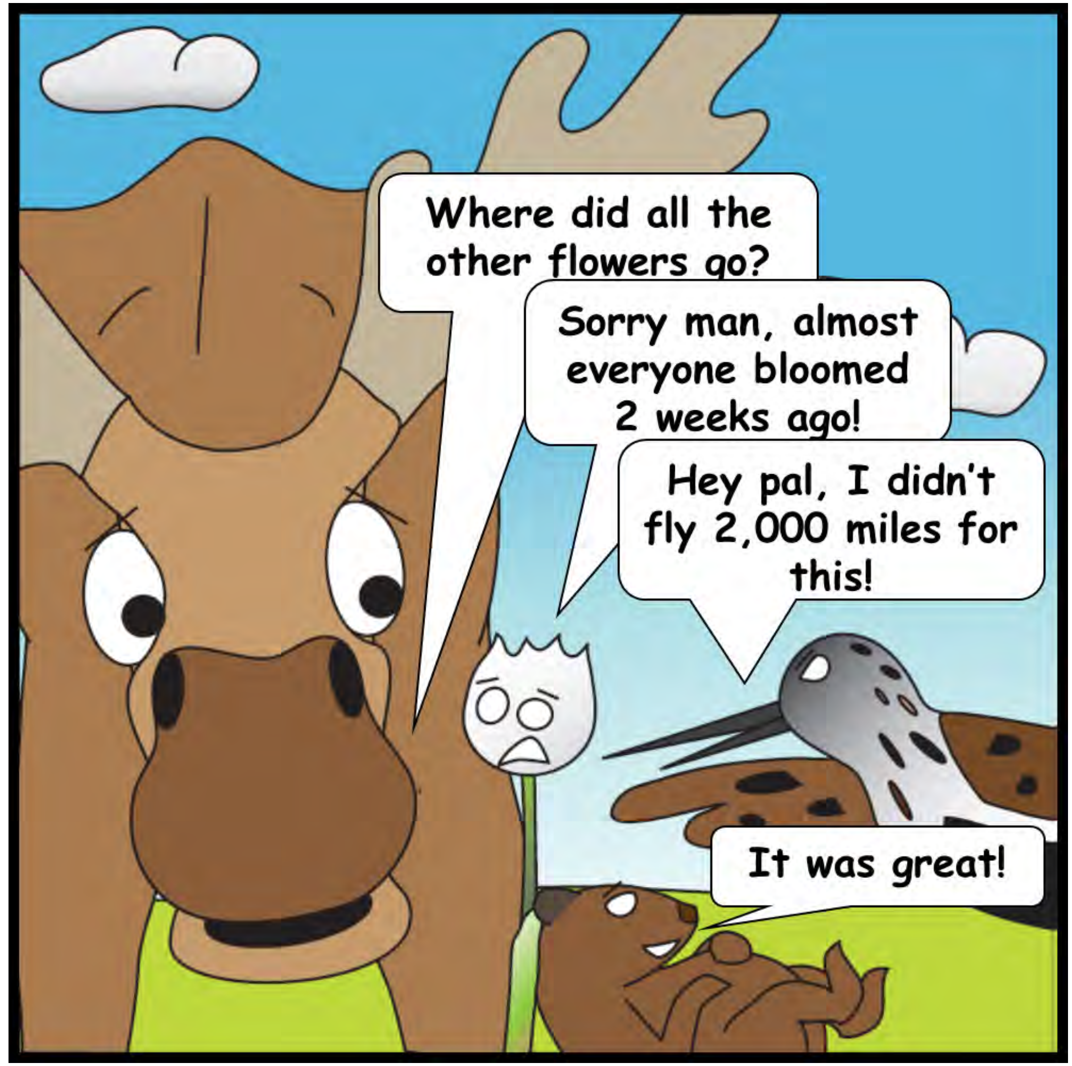
Energy Balance



Trophic Interactions

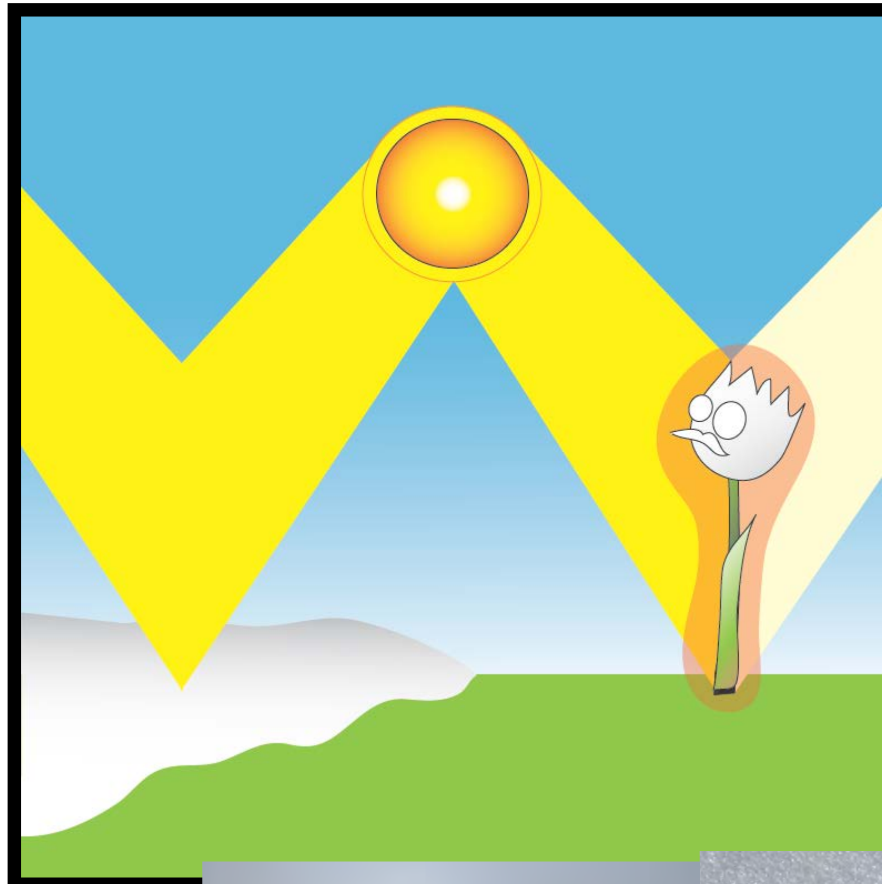


Arctic plants play critical roles in regulating global processes



Earlier growth & flowering → shift in herbivory → altered community

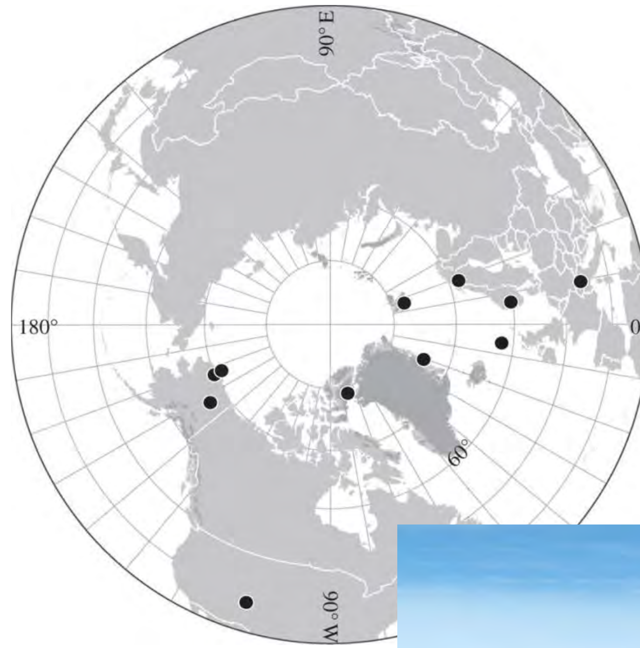
Arctic plants play critical roles in regulating global processes

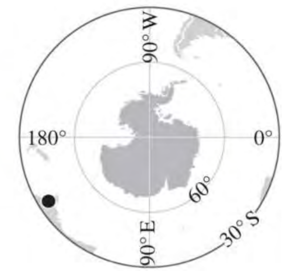


Less snow →
more energy trapped →
greater warming & faster melting

The International Tundra EXperiment (ITEX) has played a key role in understanding plant responses to warming by using…

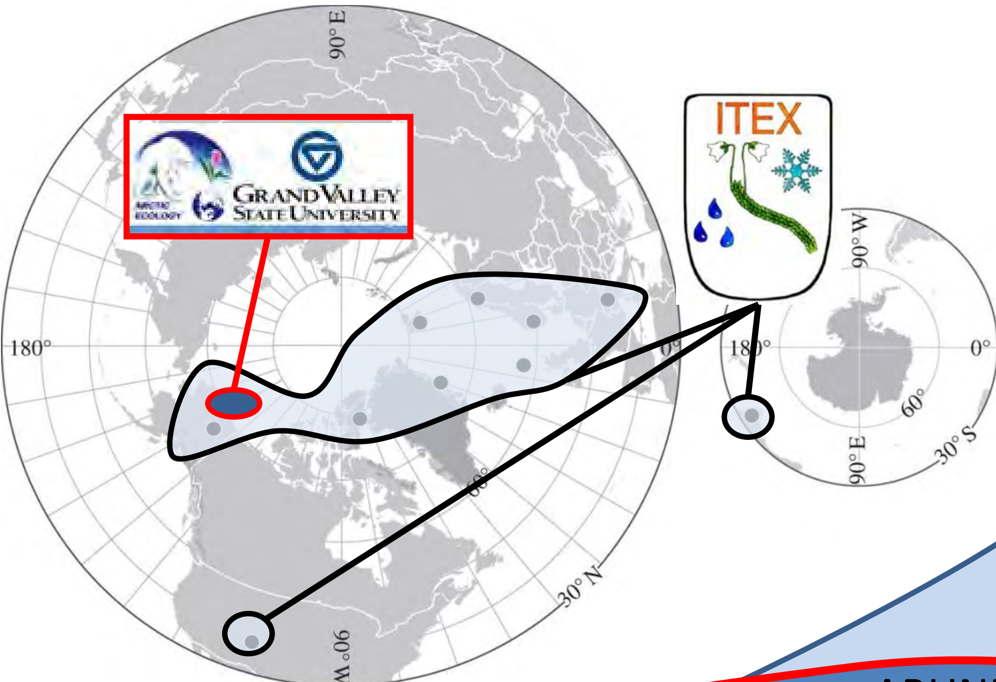
- Standardized protocols
- Simple & effective exp. design
- Collaborative data analysis
- Variety of backgrounds & experience
- Long-term datasets
- Variety of variables
- Variety of plants
- Variety of locations

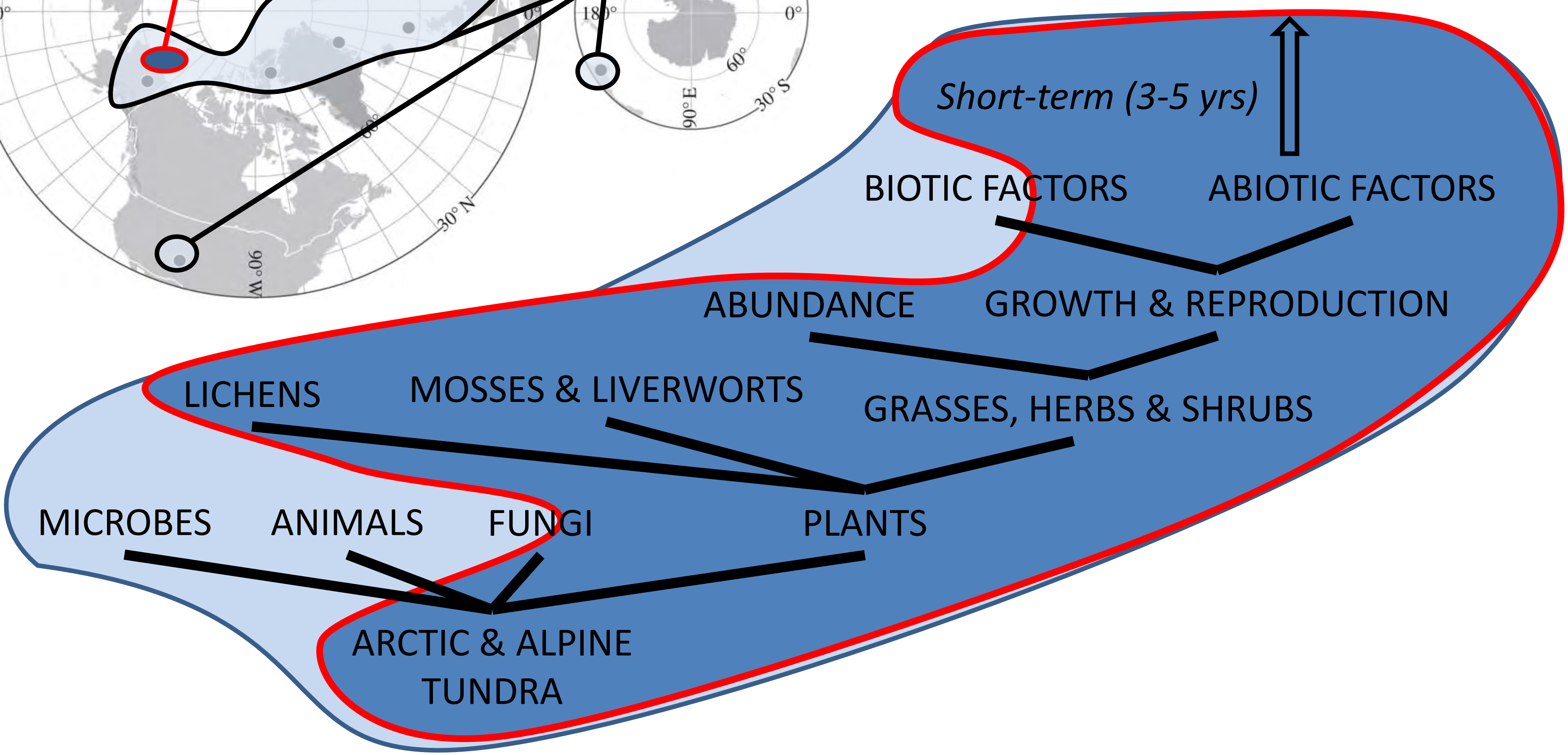




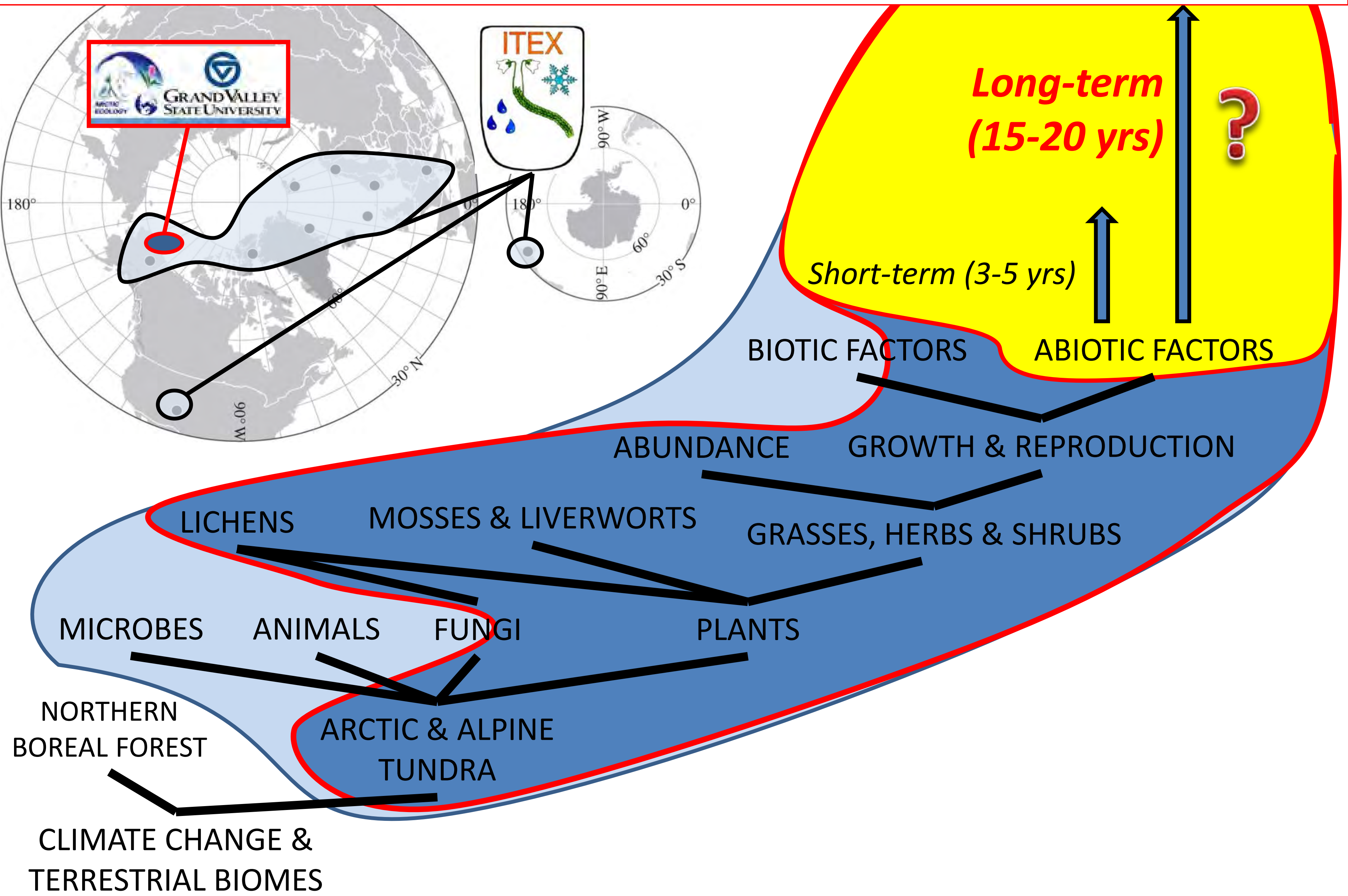
The study

The GVSU AEP & other ITEX members have played key roles in studying short-term tundra plant responses to experimental warming

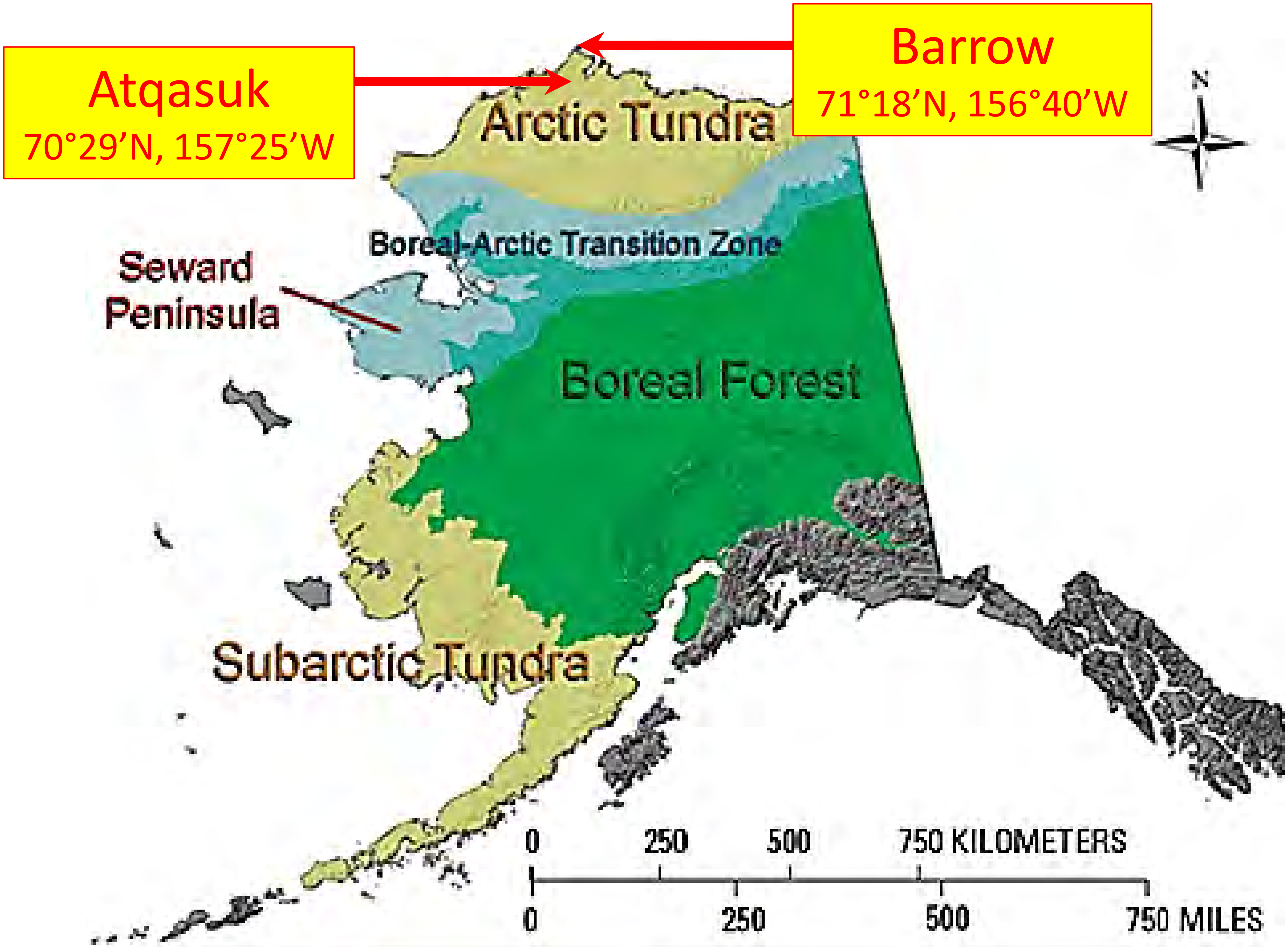




Problem: we don't know how plants will respond to long-term warming nor how to best predict their responses



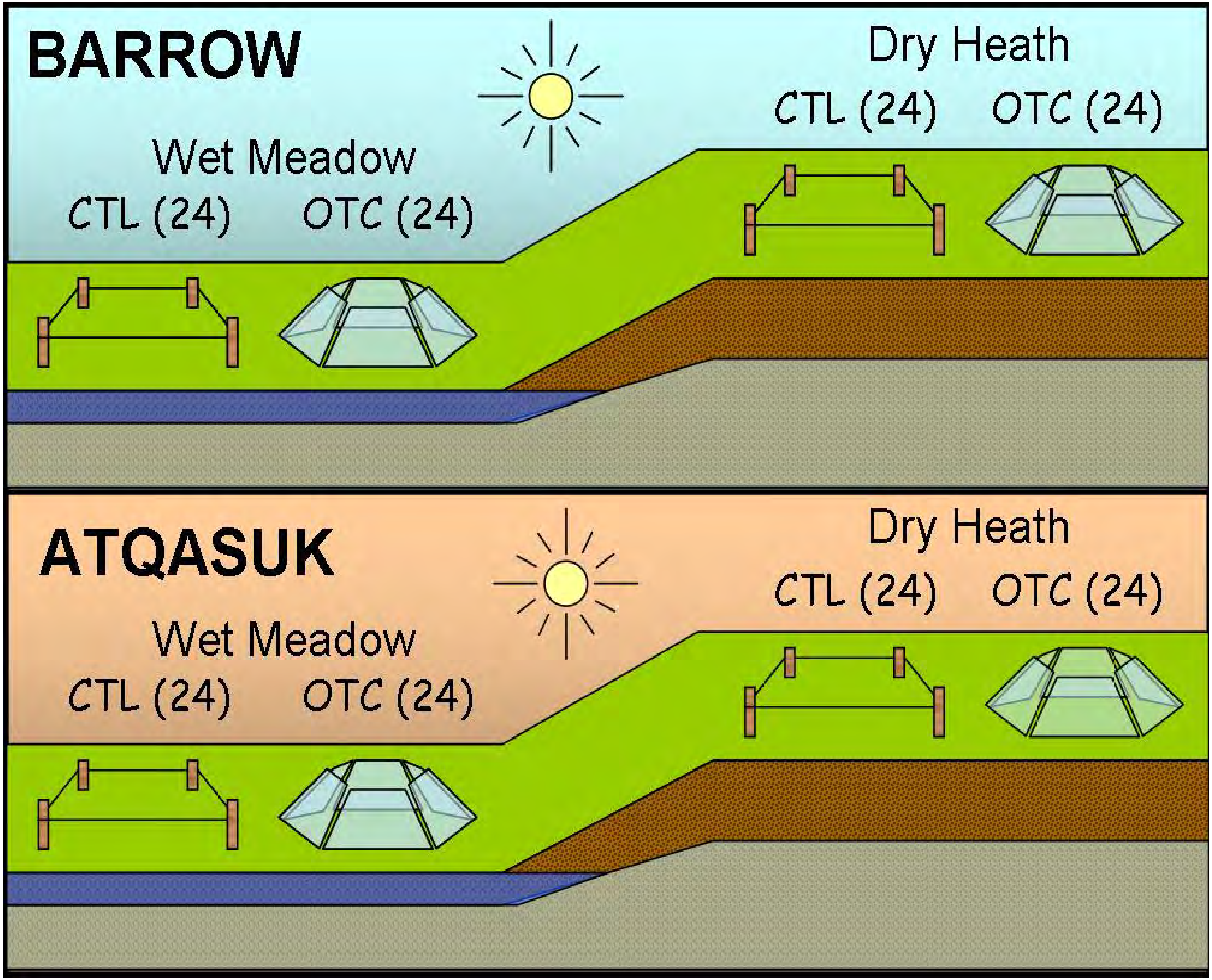
Study Sites


Atqasuk
70°29'N, 157°25'W
Barrow
71°18'N, 156°40'W
N
Arctic Tundra
Boreal-Arctic Transition Zone
Seward Peninsula
Boreal Forest
Subarctic Tundra
0 250 500 750 KILOMETERS
0 250 500 750 MILES

Open Top Chambers (OTC's) effectively warm by ~2°C

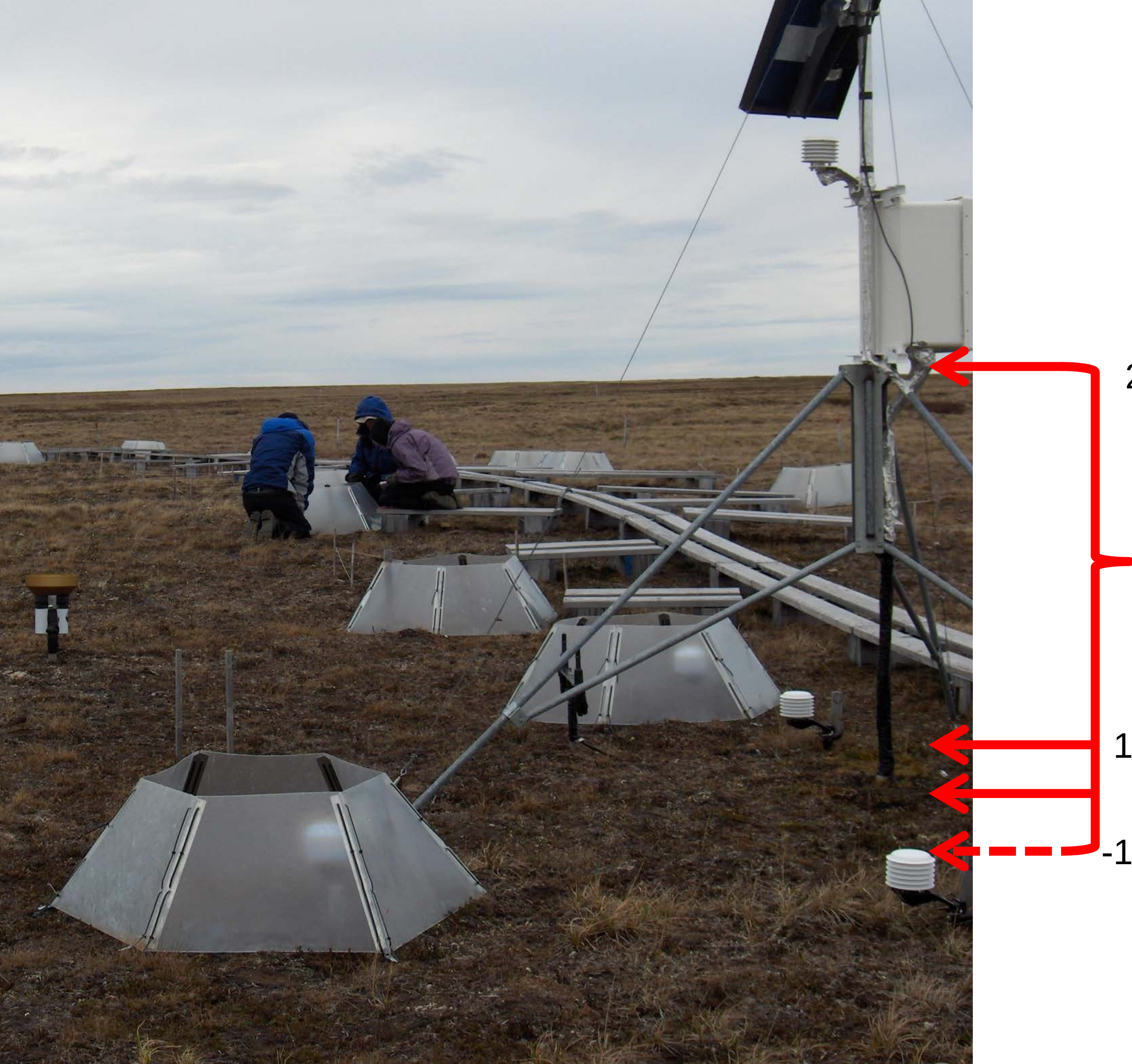
Hollister MS Thesis

Experimental Design

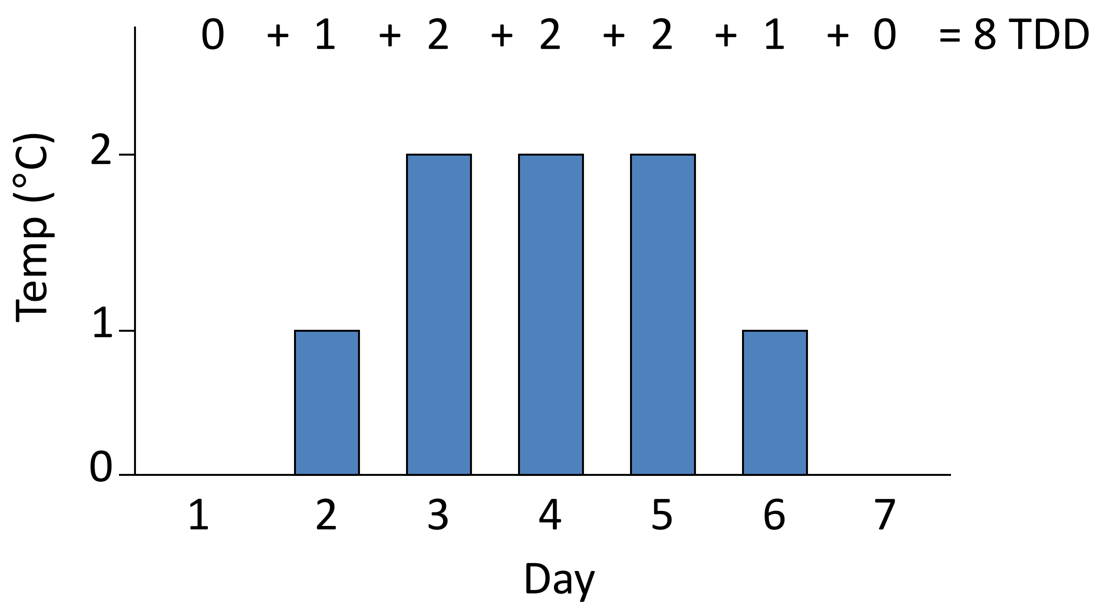


Abiotic Factors

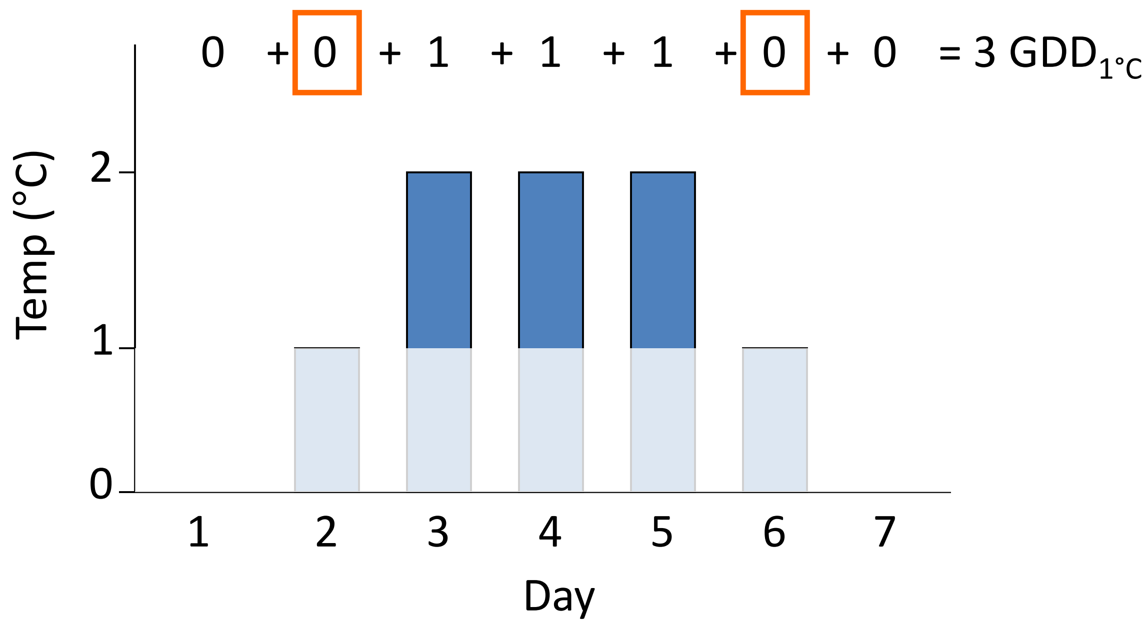
Temps.

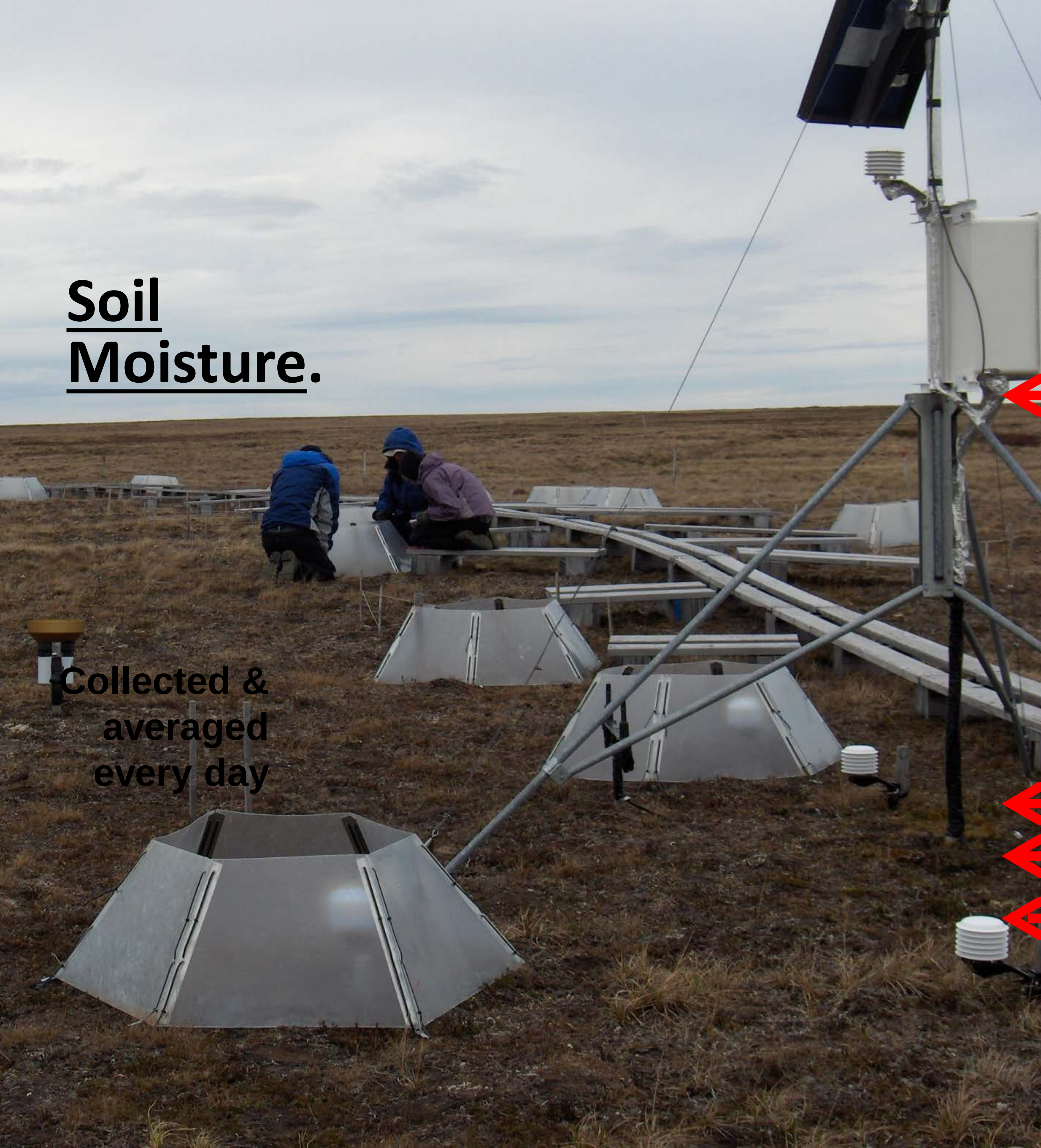


Better predictor if plant's minimal growing temp is 0 °C



Better if it's minimum is 1 °C





Temps.

2 m

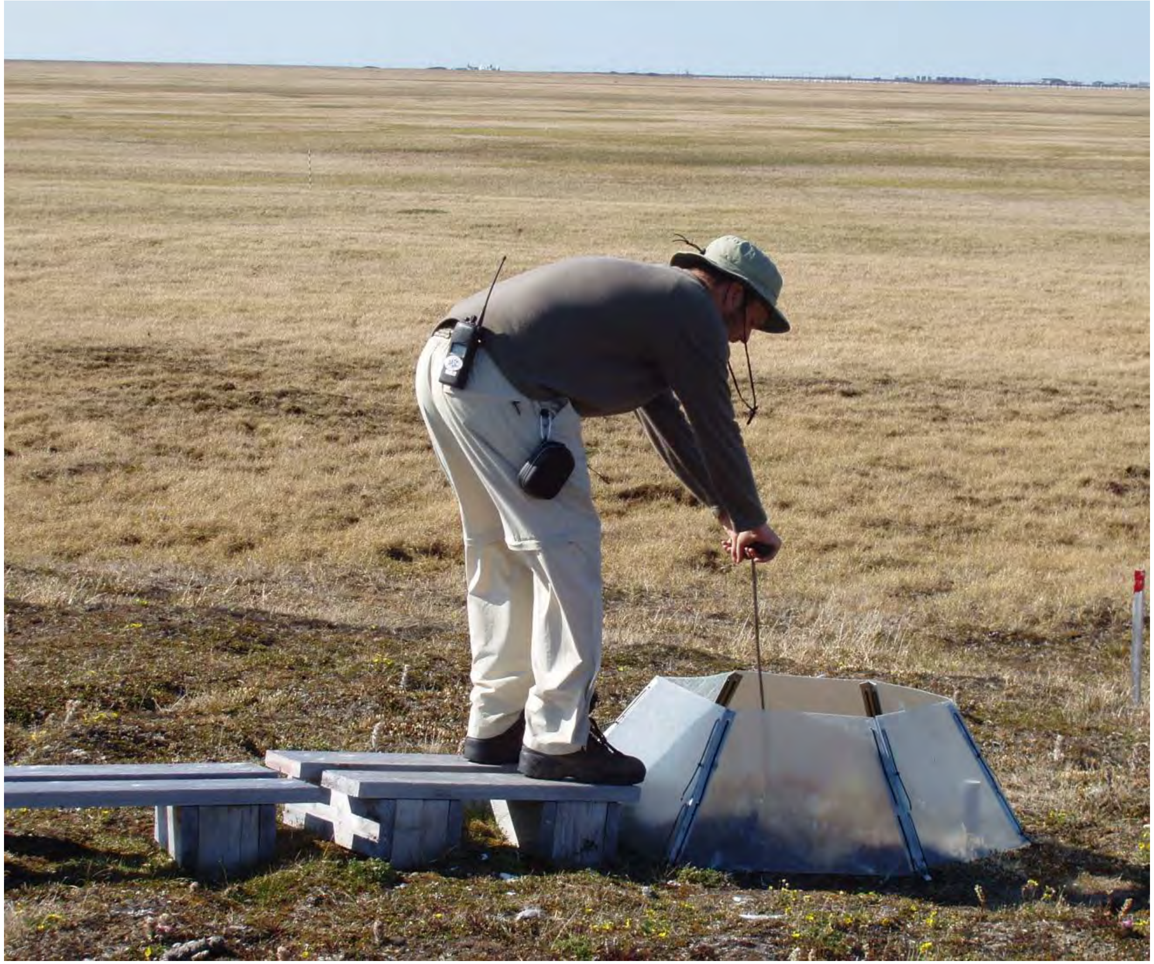
Collected & averaged every hour

10 cm

0 cm (ground)

-10 cm

Thaw depth



- Measured once at end of season

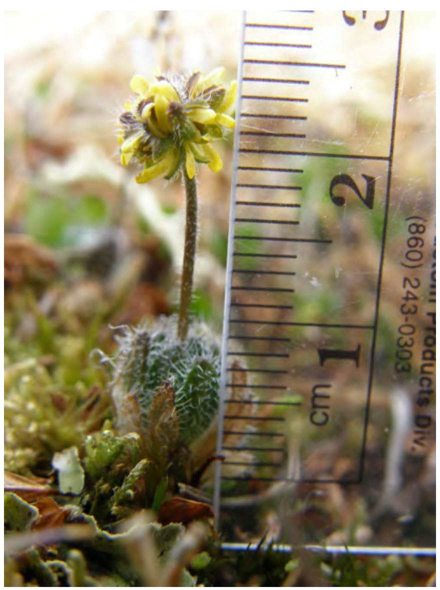
Snow-free date

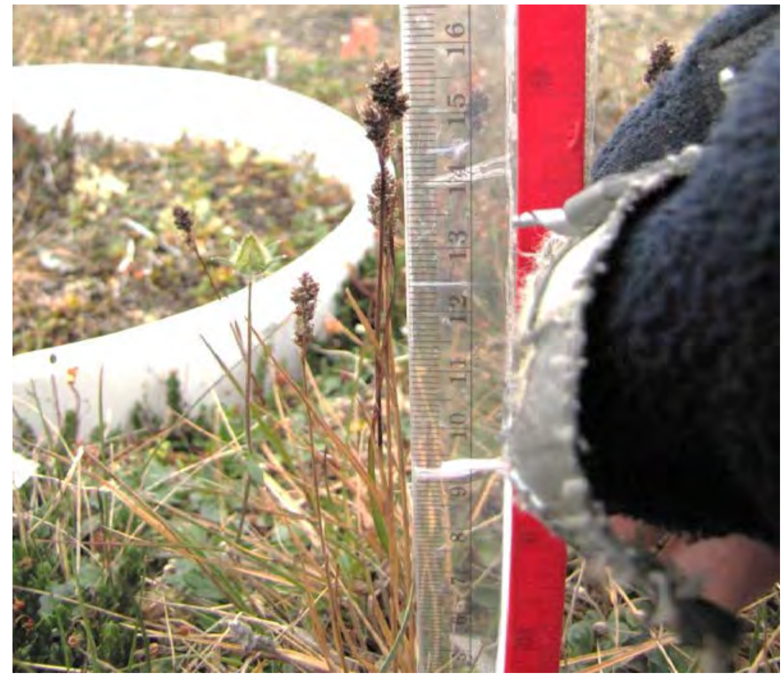
- Recorded date for each plot
- Used correlation with ground temp. when not directly observed

Plant Traits

Inflorescence Height

- 3-6 individuals per plot
- Tallest height by end of season





Leaf Length

- 3-6 individuals per plot
- Max length by end of season

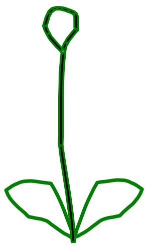
Flower number

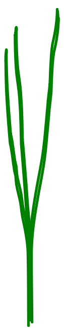
- Max. per plot per season

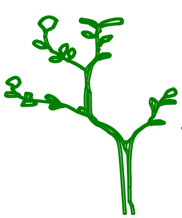
Flowering phenology

- Earliest inf. or flower burst per plot

	Atqasuk Dry Site	Atqasuk Wet Site	Barrow Dry Site	Barrow Wet Site
Forb	*Polygonum bistorta*	*Pedicularis sudetica*	*Papaver hultenii*	*Cardamine pratensis*
			Potentilla hyparctica	*Draba lactaea*
			Senecio atropurpureus	*Saxifraga cernua*
			Stellaria laeta	*Saxifraga foliolosa*
			Saxifraga punctata	*Saxifraga hieracifolia*
				Saxifraga hirculis
				Stellaria laeta
Graminoid	*Carex bigelowii*	*Carex aquatilis*	*Arctagrostis latifolia*	*Carex stans*
	Hierachloe alpina	*Eriophorum angustifolium*	*Luzula arctica*	*Dupontia fisheri*
	Luzula arctica	*Eriophorum russeolum*	*Luzula confusa*	*Eriophorum triste*
	Luzula confusa		*Poa arctica*	*Heirachloe pauciflora*
	Trisetum spicatum			*Juncus biglumis*
				Luzula arctica
				Luzula confusa
				Poa arctica
E. shrub	*Cassiope tetragona*			*Cassiope tetragona*
	Diapensia lapponica			
	Ledum palustre			
	Vaccinium vitis-idaea			
D. Shrub				*Salix rotundifolia* ♀
				Salix rotundifolia ♂







Chapter II:

1. How do arctic plants respond to long-term warming?

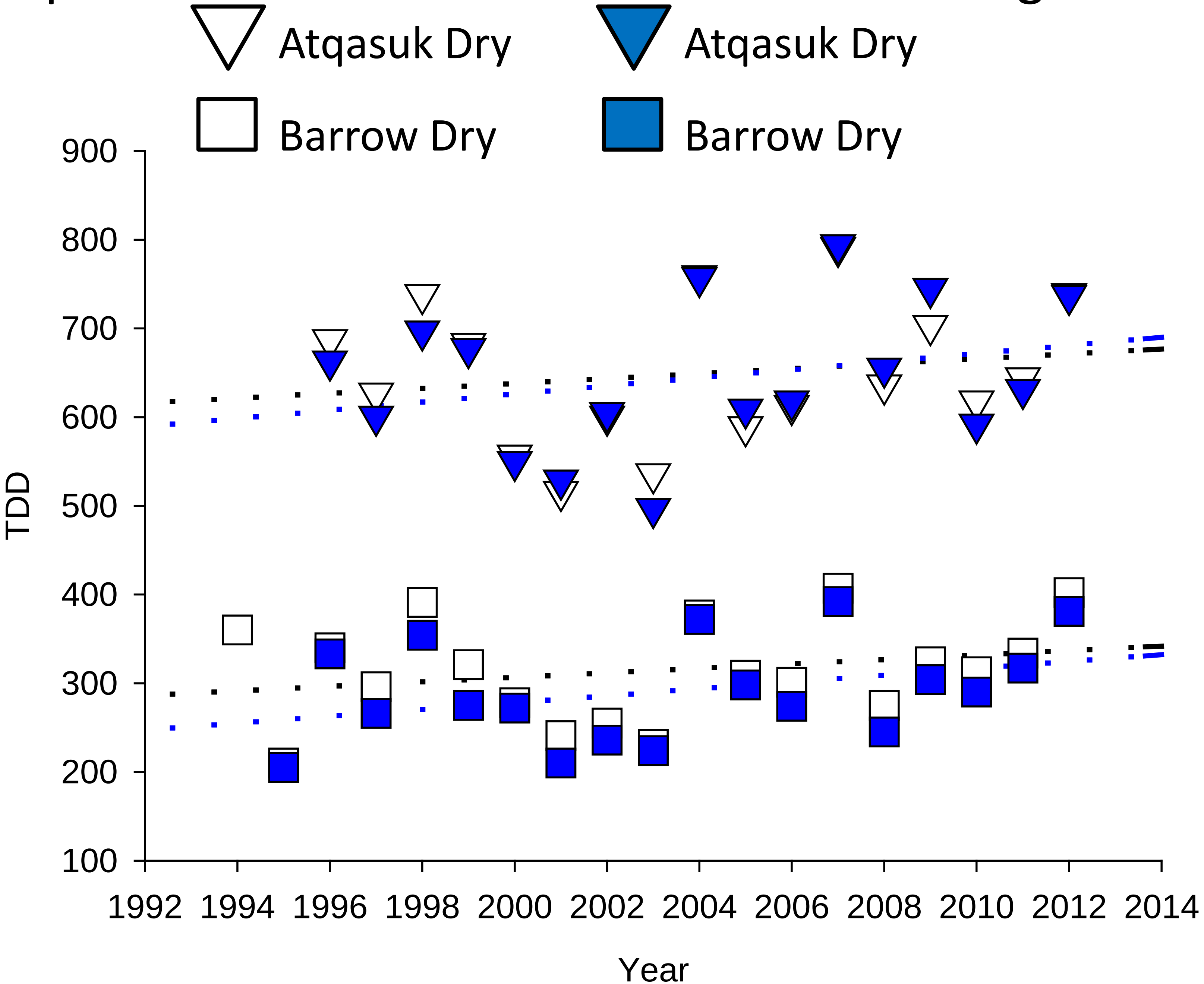
2. How consistent are these responses over time?

Statistical Methods

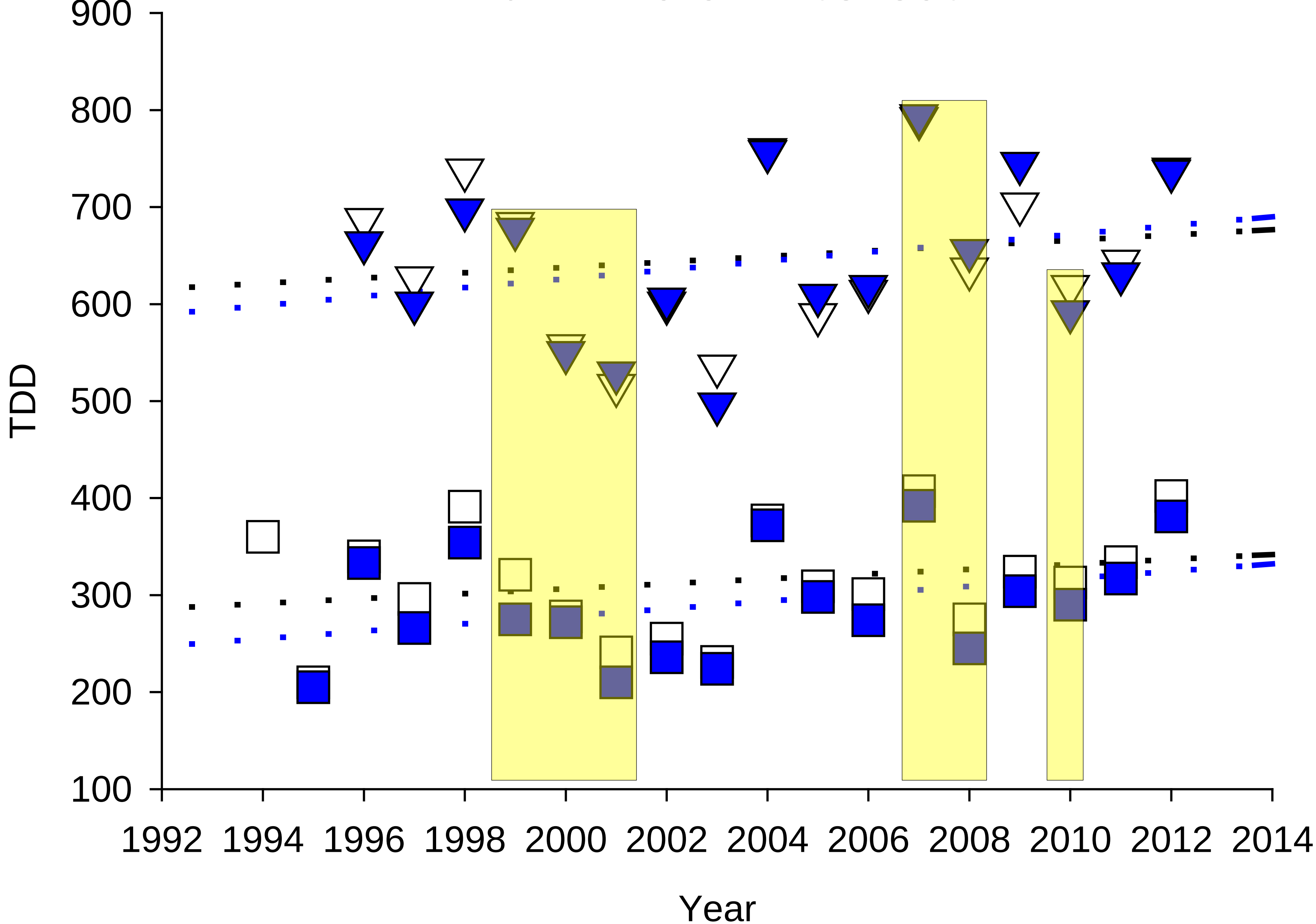
- Warming effect on plants
  - Used meta-analysis to calculate effect size of warming for each species (*Hedges’ d*)
  - Examined trends in effect sizes using weighted linear regressions (*MetaWin*)

- Temperature trends at sites
  - Used simple linear regressions to look for temperature trends over time (*Program R*)

Temperature shows NS trends toward warming at all 4 sites



Used data subset: years with all plant traits AND all AF's of interest



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- Temperature trends at sites
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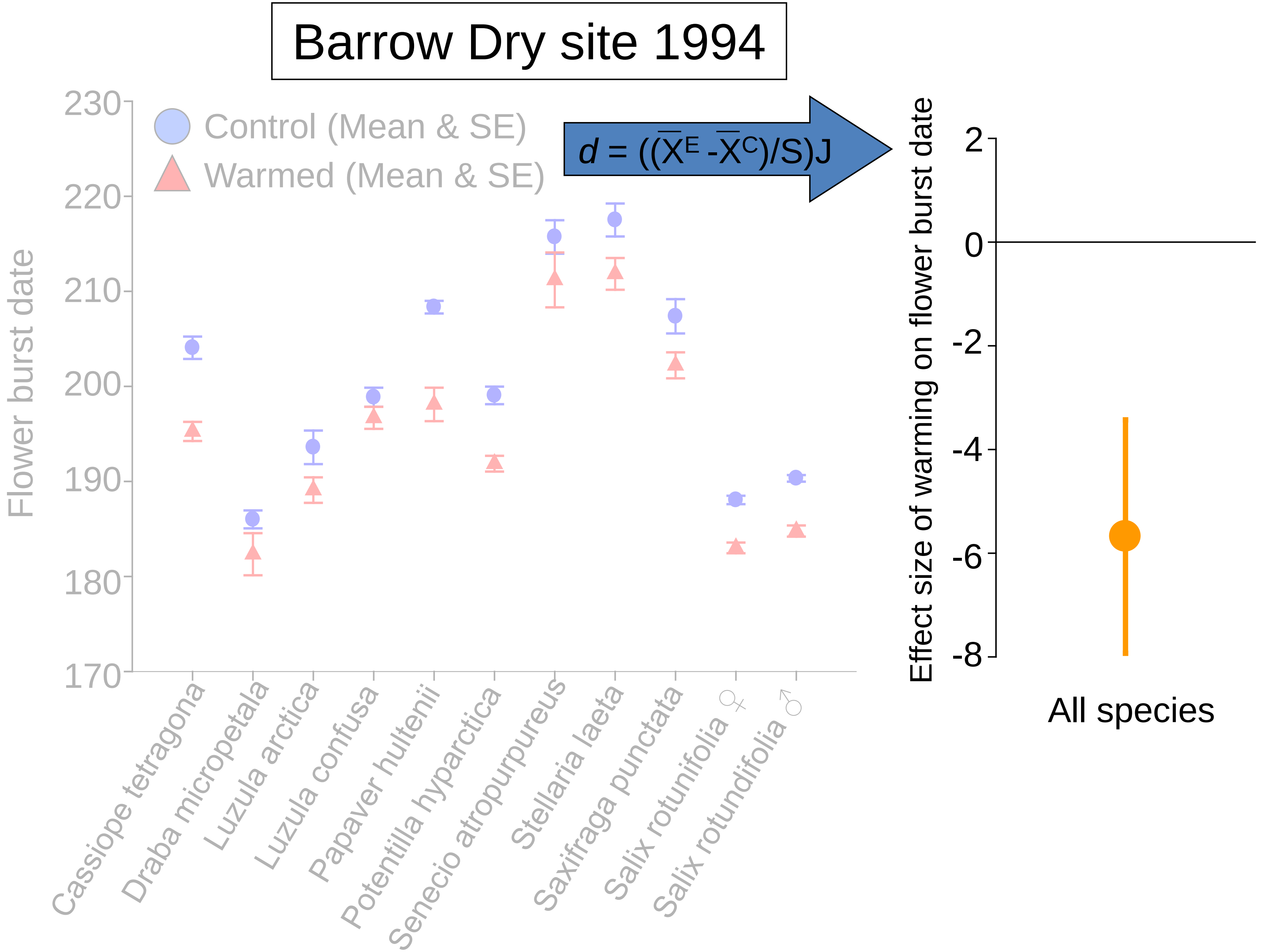
Meta-analysis: Calculating effect sizes



1. How do arctic plants respond to long-term warming?

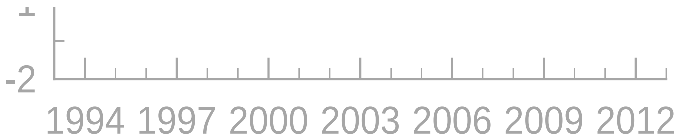
Warming responses over time (17-19 years warming)

= significant weighted linear regression   = non-significant weighted linear regression

Earlier flowering dates
(13/35 species)

ES = 0.39

Sig Trend: reduced ES over time



ncreased inflorescence heights
24/37 species)

ES = 0.89

NS trend: reduced ES over time

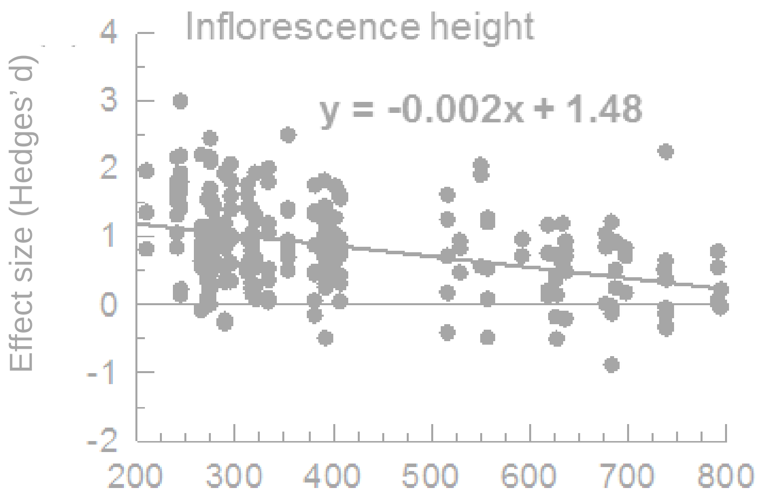
Increased leaf lengths
(19/36 species)

ES = 0.39

NS trend: reduced ES over time

Warming ES decrease in warmer conditions (all traits)

= significant weighted linear regression   = non-significant weighted linear regression



Ch III - Study Questions:

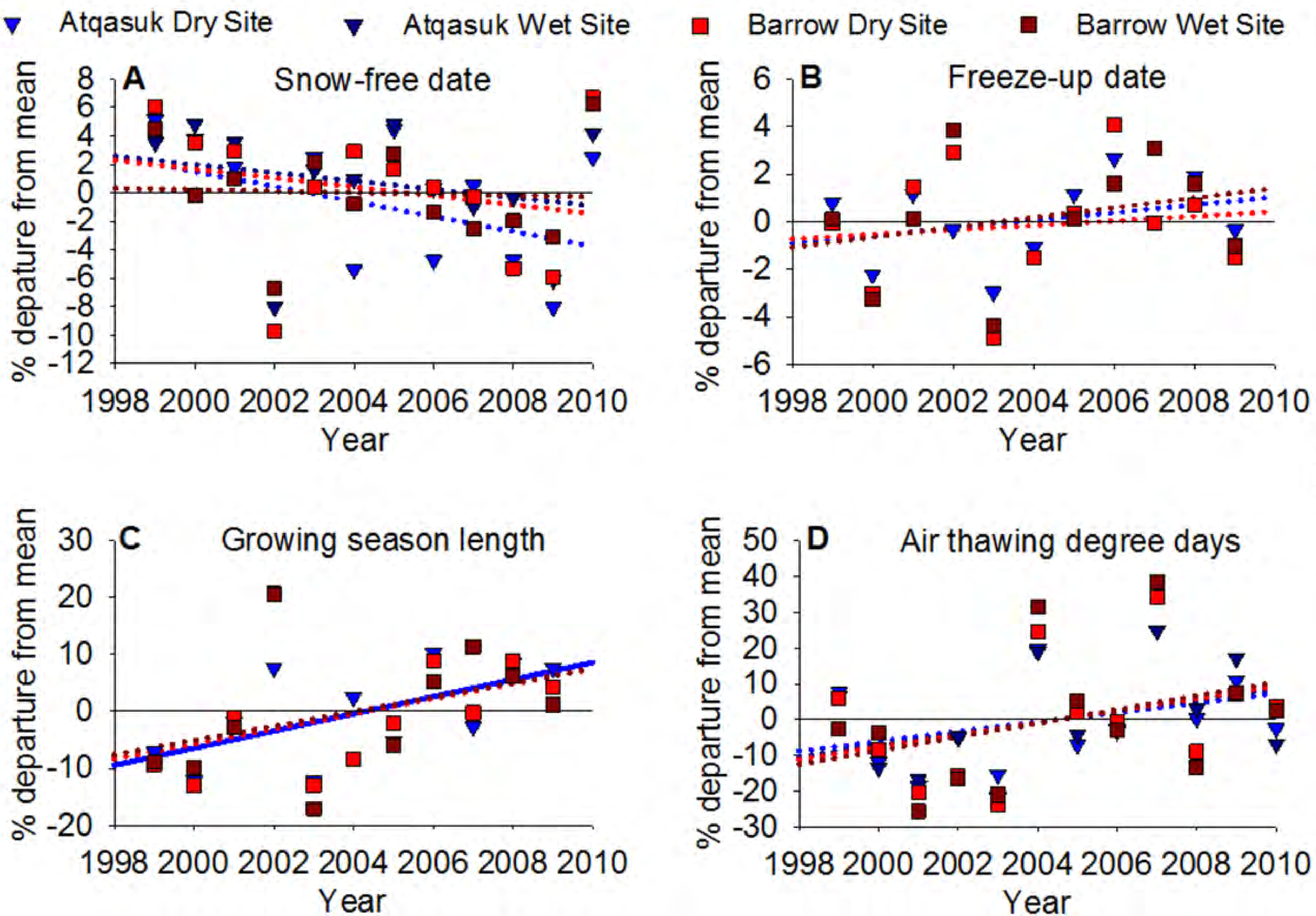
1. How have abiotic factors and plant traits changed over time at these sites?

2. Is there evidence that shifts in abiotic factors could be driving changes in plant traits?

Stats: Abiotic factors over time

- Simple linear regressions
- Program R

Abiotic factors consistently showed non-significant patterns across sites
Only significant trend was toward deeper thaw at AD Site



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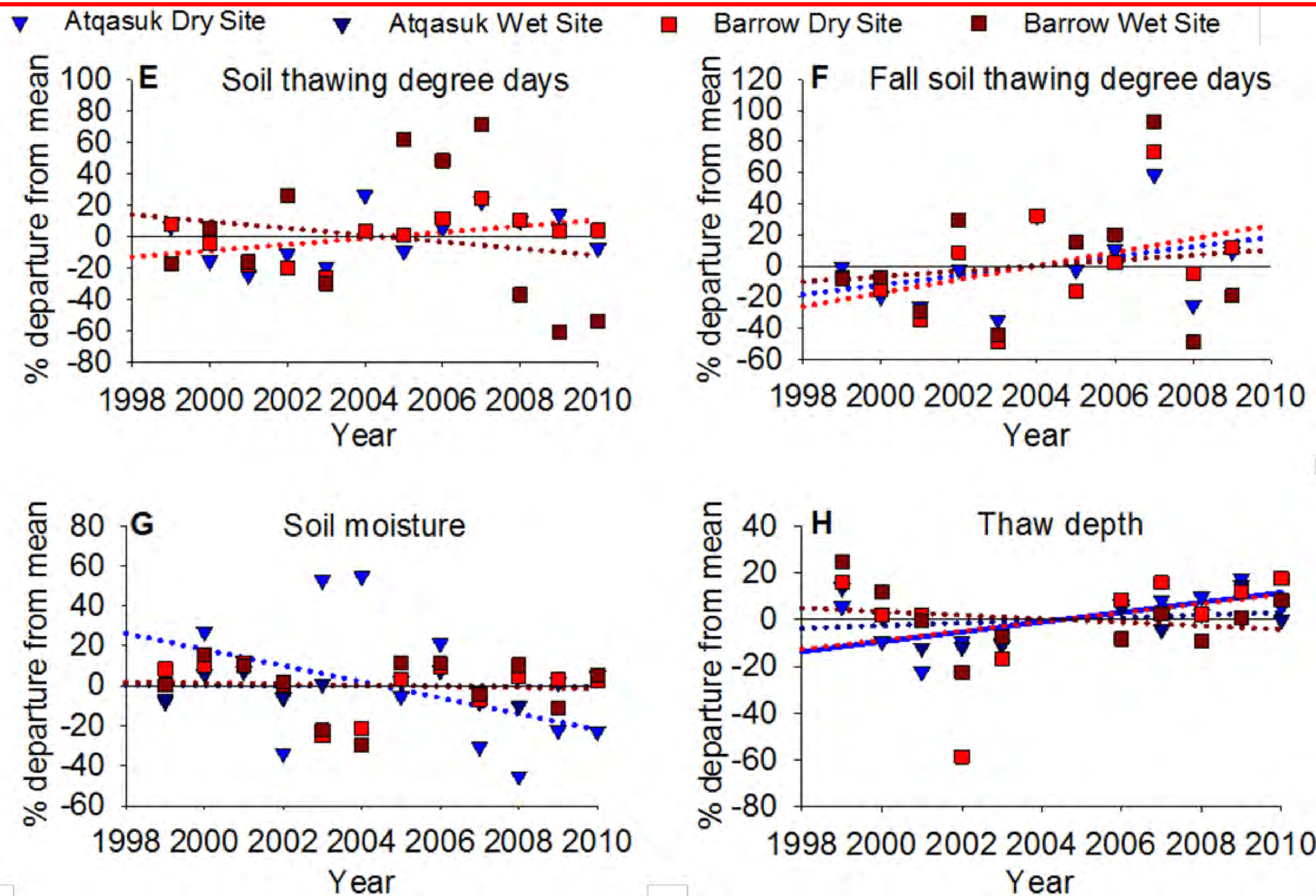
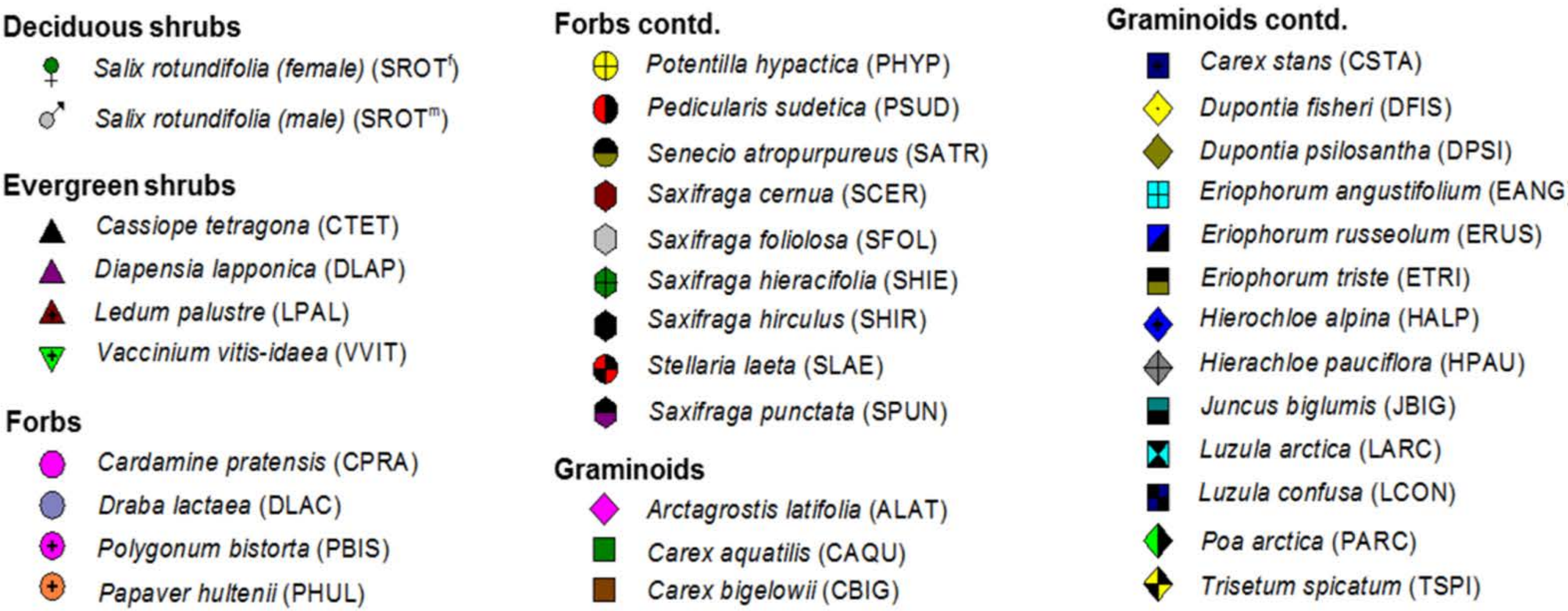


Few significant trends in plant traits over time



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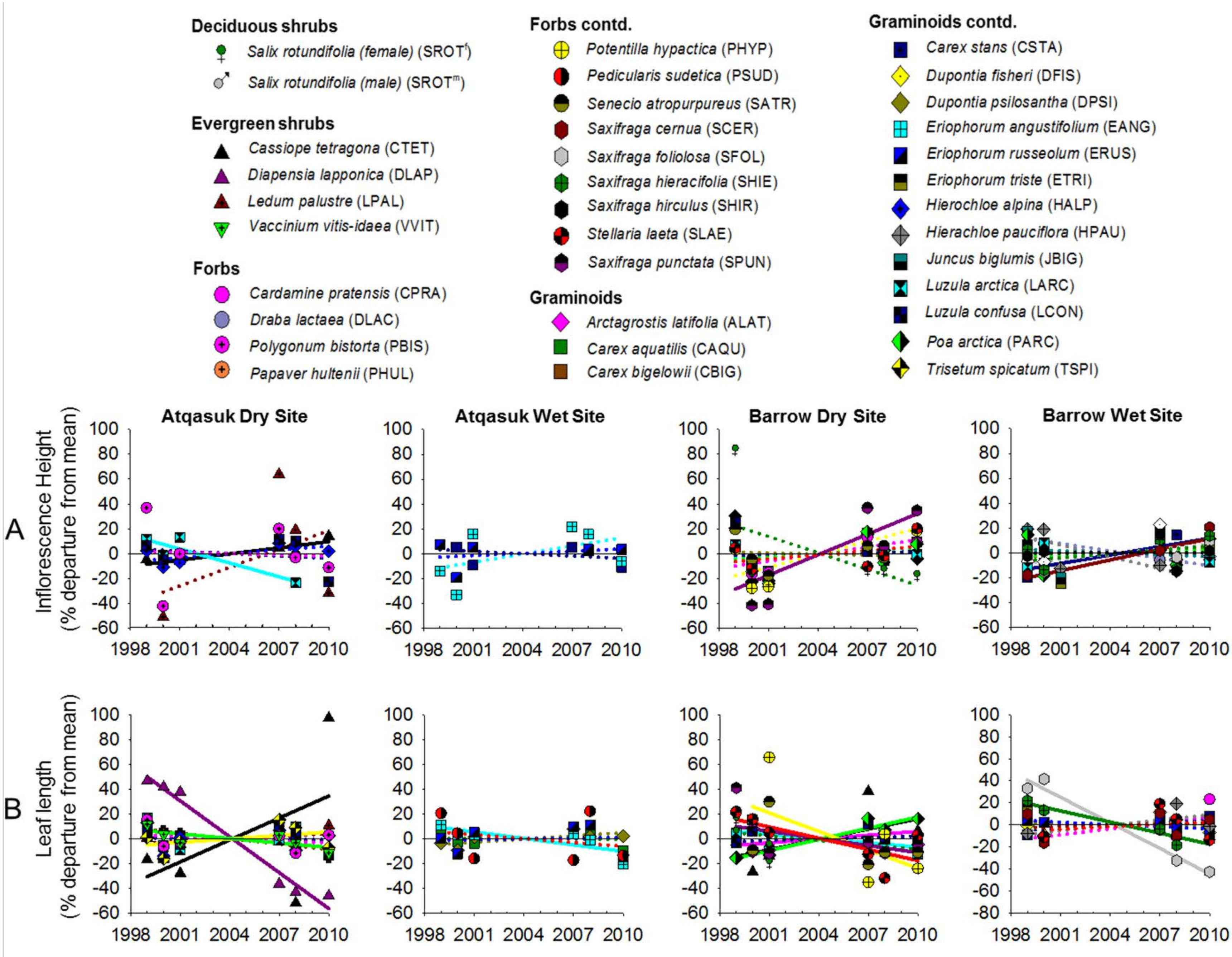

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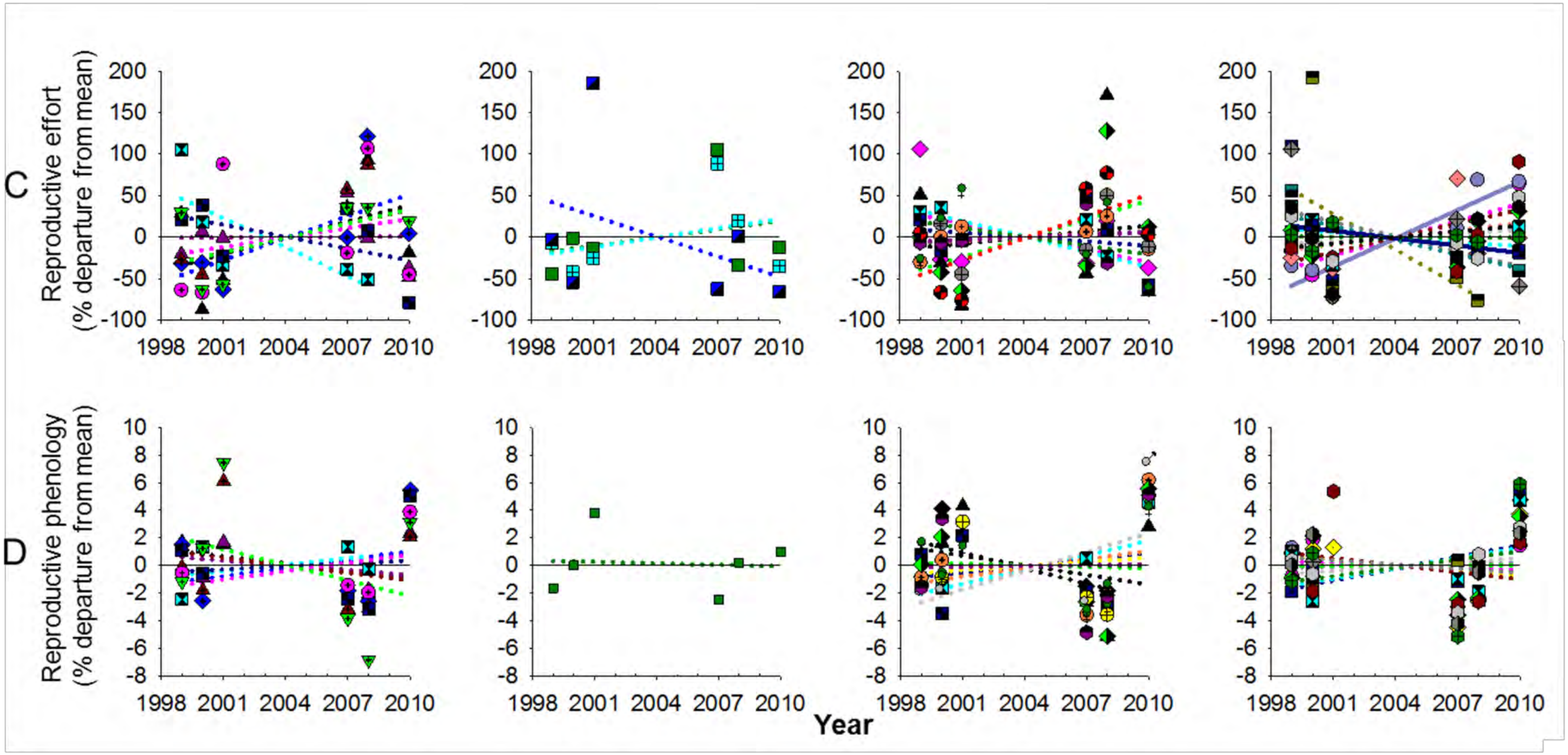


Is there evidence that shifts in abiotic factors could be driving changes in plant traits?

Specifically we ask what abiotic factor is most correlated with a given plant trait

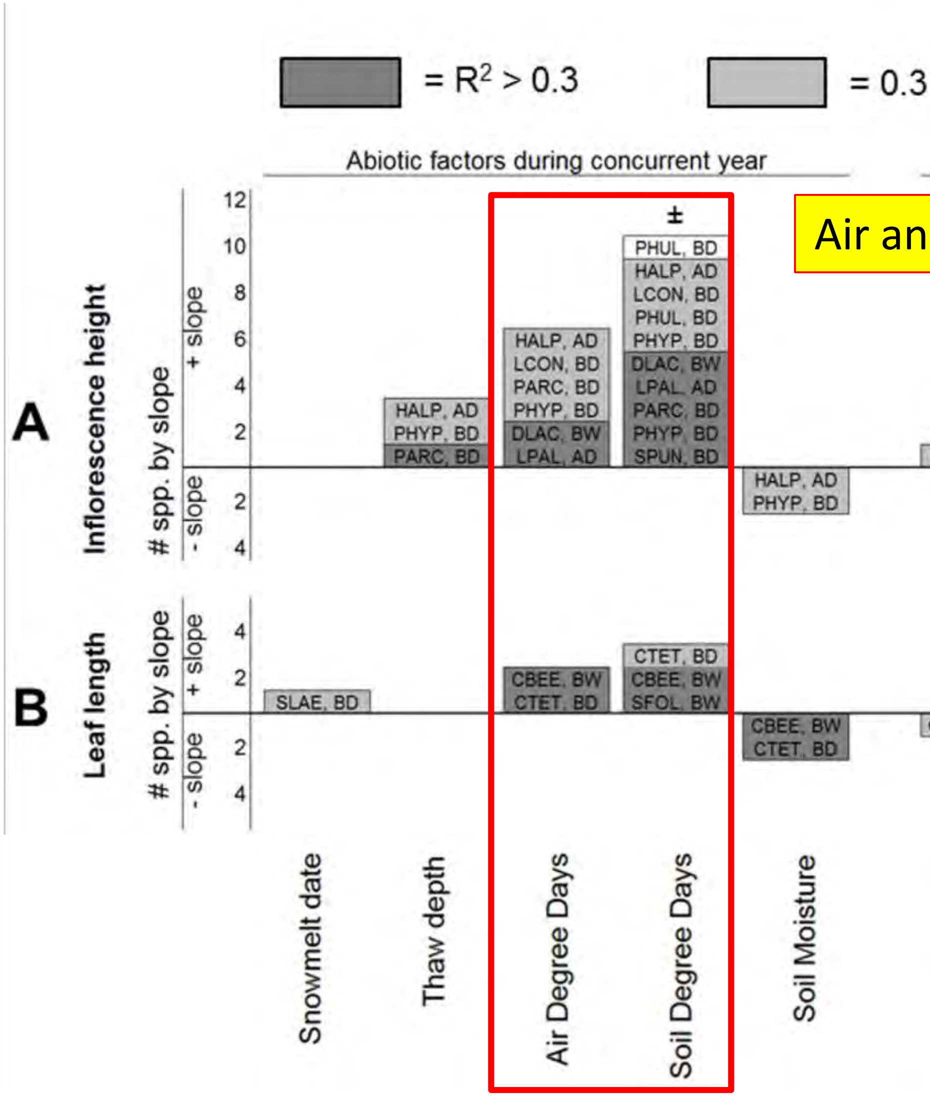
- Stats
- Transition of one graph poa arctica to next figure

Stats: Plant traits over time

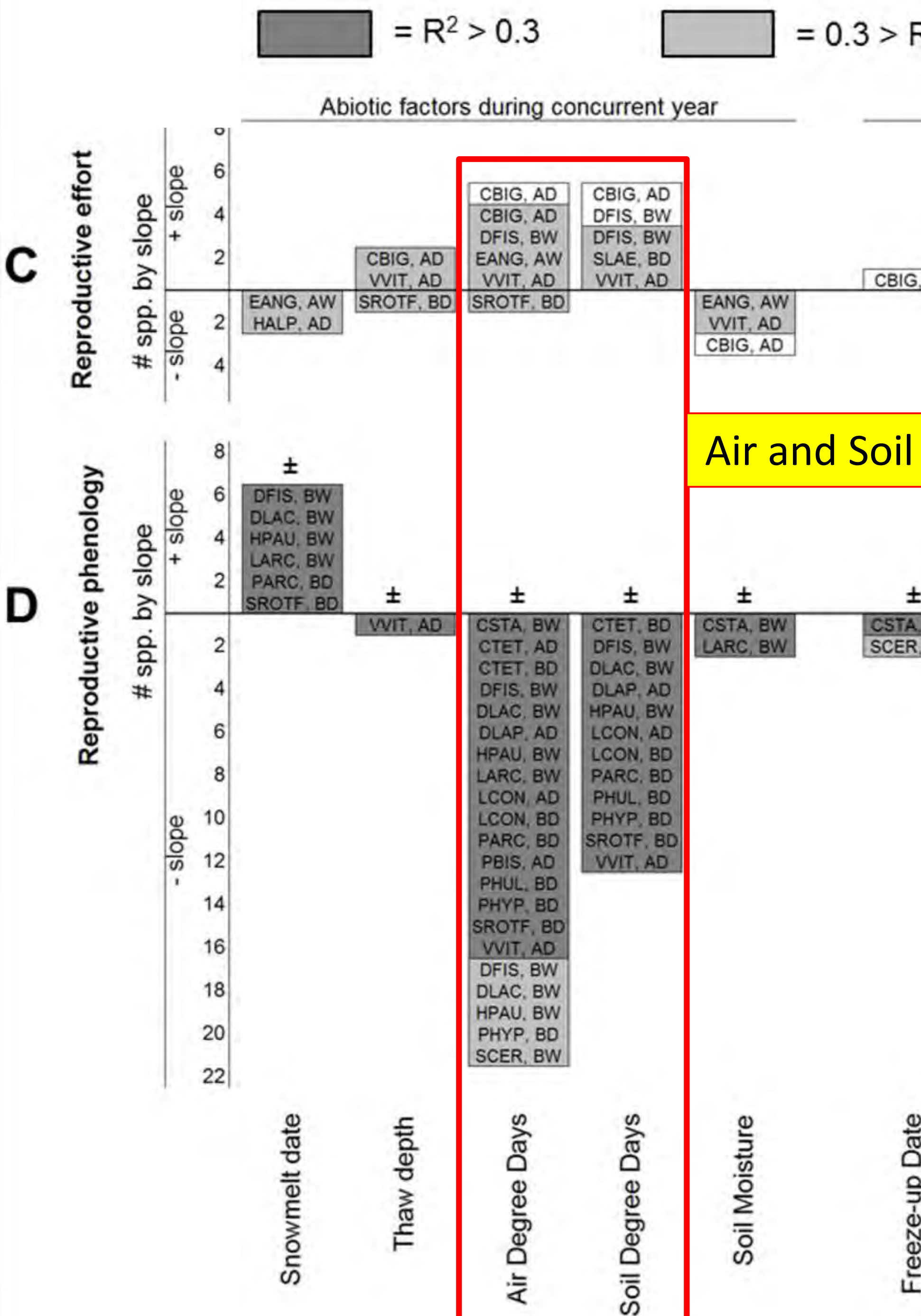
- Linear Mixed Models (LMM's)
  - Fixed effects: year
  - Random effects: year, plot
- Significance of results
  - Chi-squared likelihood ratio test with & without fixed effect
- Program R
  - lme4 package

Stats: Relationship between abiotic factors and plant traits

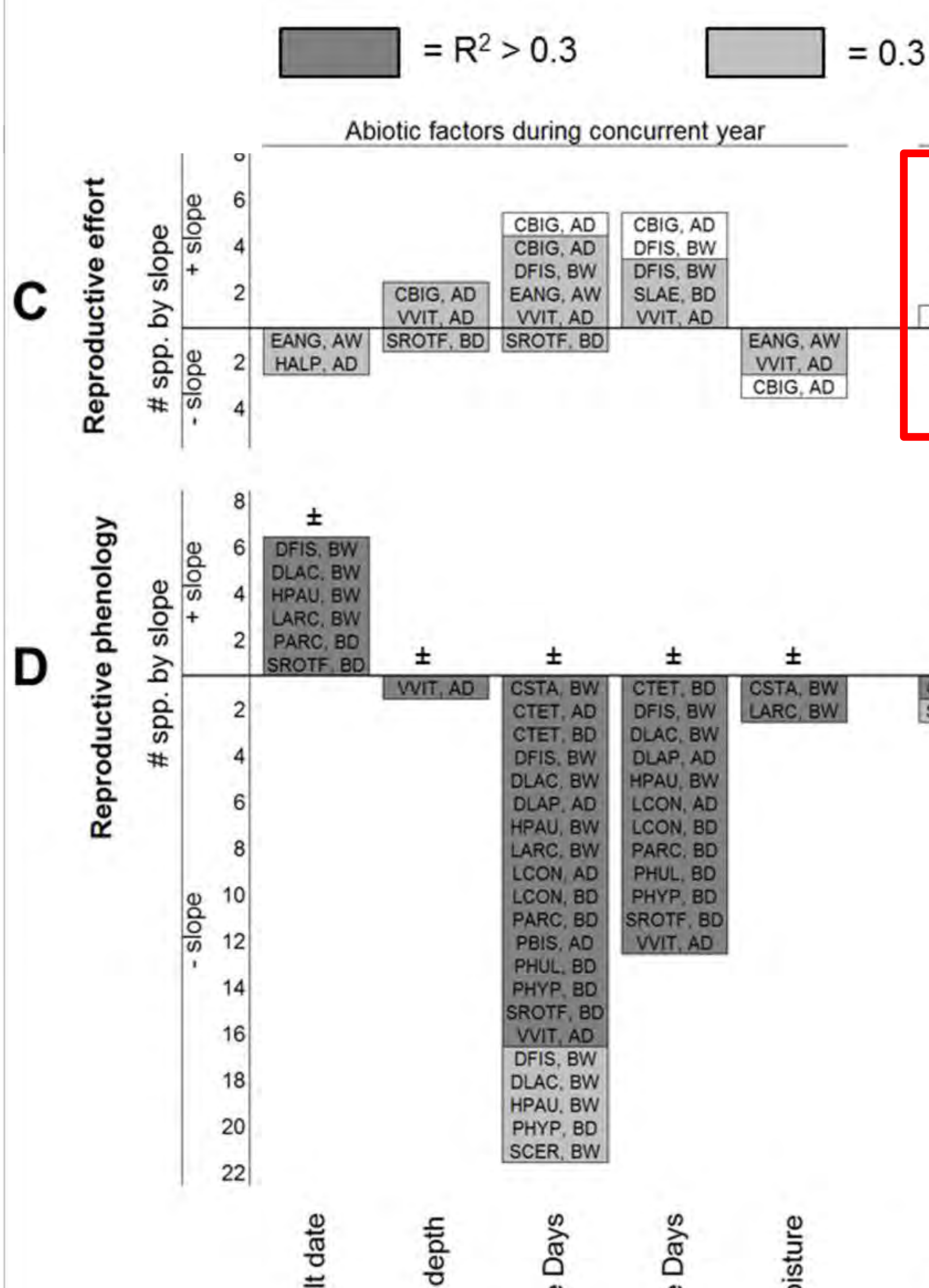
- Linear Mixed Models (LMM’s)
  - Fixed effects: year
  - Random effects: year, plot
- Significance of results
  - Chi-squared likelihood ratio test with & without fixed effect
  - Benjamini-Hochberg procedure (false discovery rate at 5%)
- Program R
  - lme4 package



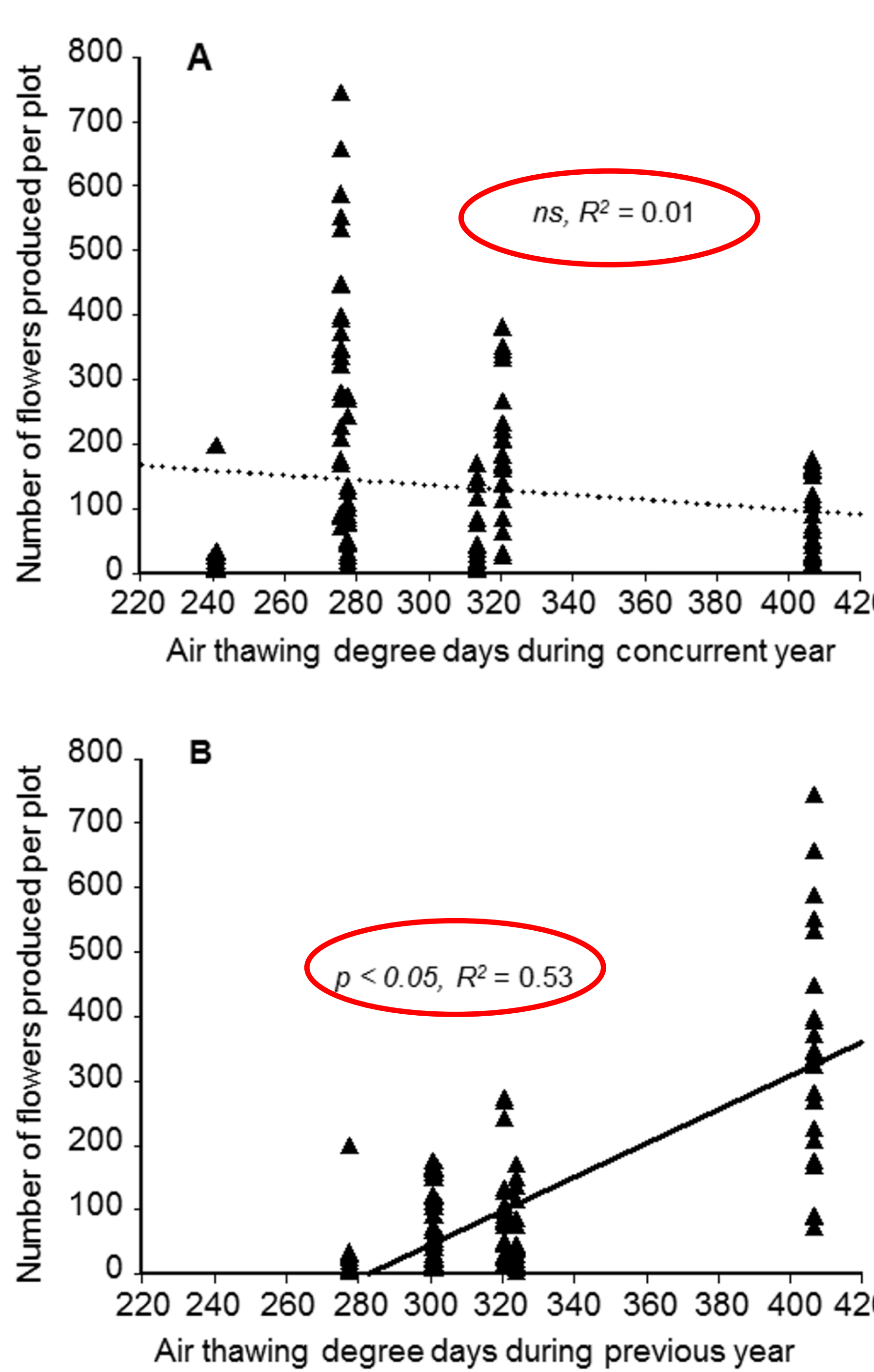
= R^2 > 0.3
= 0.3
Abiotic factors during concurrent year
Air and
A
Inflorescence height
spp. by slope
+ slope
- slope
12
10
8
6
4
2
±
HALP, AD
PHYP, BD
PARC, BD
LCON, BD
PARC, BD
DLAC, BW
LPAL, AD
PHUL, BD
PHYP, BD
SPUN, BD
B
Leaf length
SLAE, BD
CBEE, BW
CTET, BD
SFOL, BW
Snowmelt date
Thaw depth
Air Degree Days
Soil Degree Days
Soil Moisture


= R^2 > 0.3
= 0.3 > R
Abiotic factors during concurrent year
C
Reproductive effort
spp. by slope
+ slope
- slope
D
Reproductive phenology
±
EANG, AW
HALP, AD
CBIG, AD
VVIT, AD
SROTF, BD
CBIG, AD
CBIG, AD
DFIS, BW
EANG, AW
VVIT, AD
SROTF, BD
CBIG, AD
DFIS, BW
DFIS, BW
SLAE, BD
VVIT, AD
EANG, AW
VVIT, AD
CBIG, AD
DFIS, BW
DLAC, BW
HPAU, BW
LARC, BW
PARC, BD
SROTF, BD
VVIT, AD
CSTA, BW
CTET, AD
CTET, BD
DFIS, BW
DLAC, BW
DLAP, AD
HPAU, BW
LARC, BW
LCON, AD
LCON, BD
PARC, BD
PBIS, AD
PHUL, BD
PHYP, BD
SROTF, BD
VVIT, AD
DFIS, BW
DLAC, BW
HPAU, BW
PHYP, BD
SCER, BW
CTET, BD
DFIS, BW
DLAC, BW
DLAP, AD
HPAU, BW
LCON, AD
LCON, BD
PARC, BD
PHUL, BD
PHYP, BD
SROTF, BD
VVIT, AD
CSTA, BW
LARC, BW
Snowmelt date
Thaw depth
Air Degree Days
Soil Degree Days
Soil Moisture
Freeze-up Date
Air and Soil

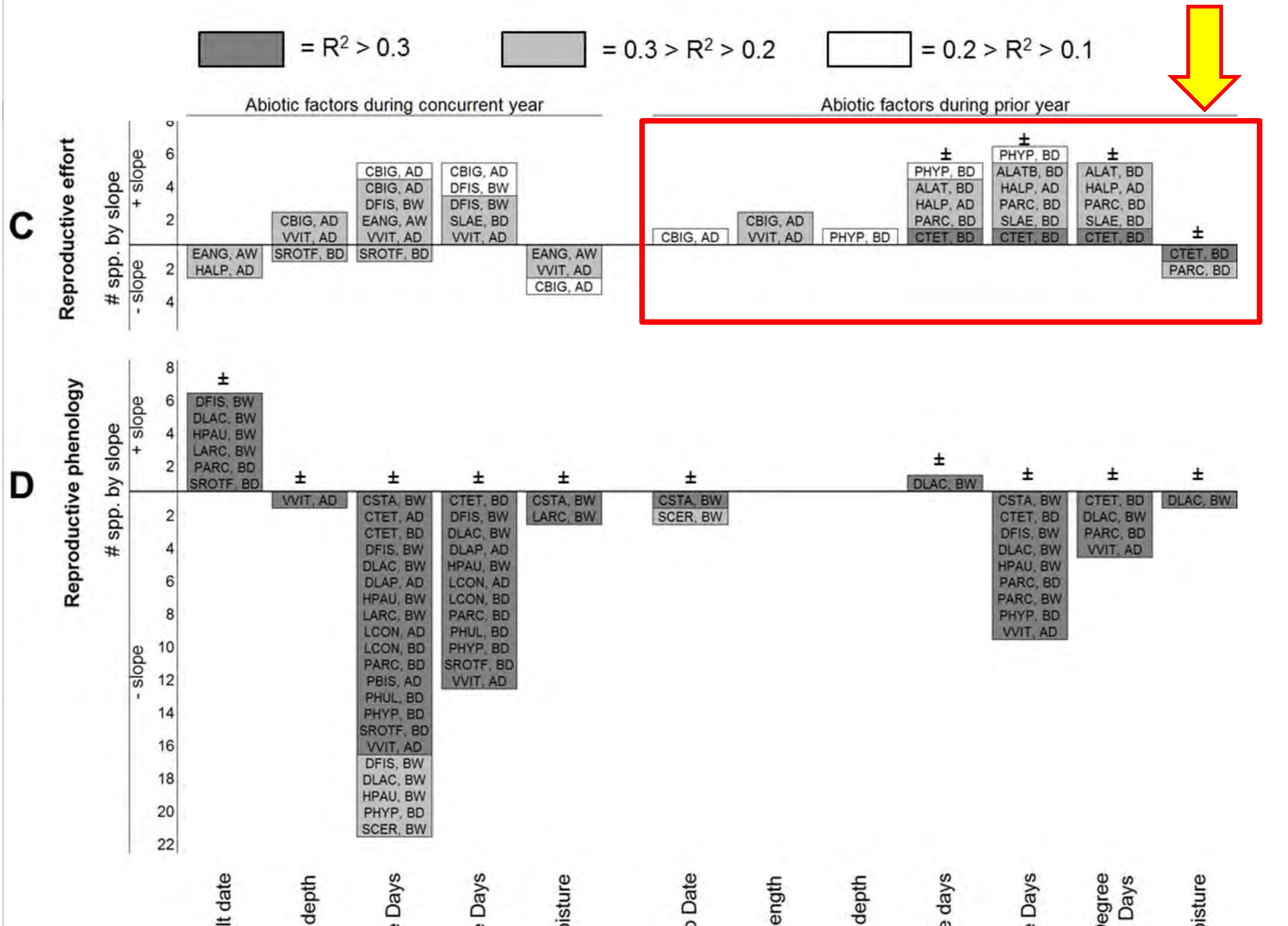
Conditions during year prior to plant trait meas

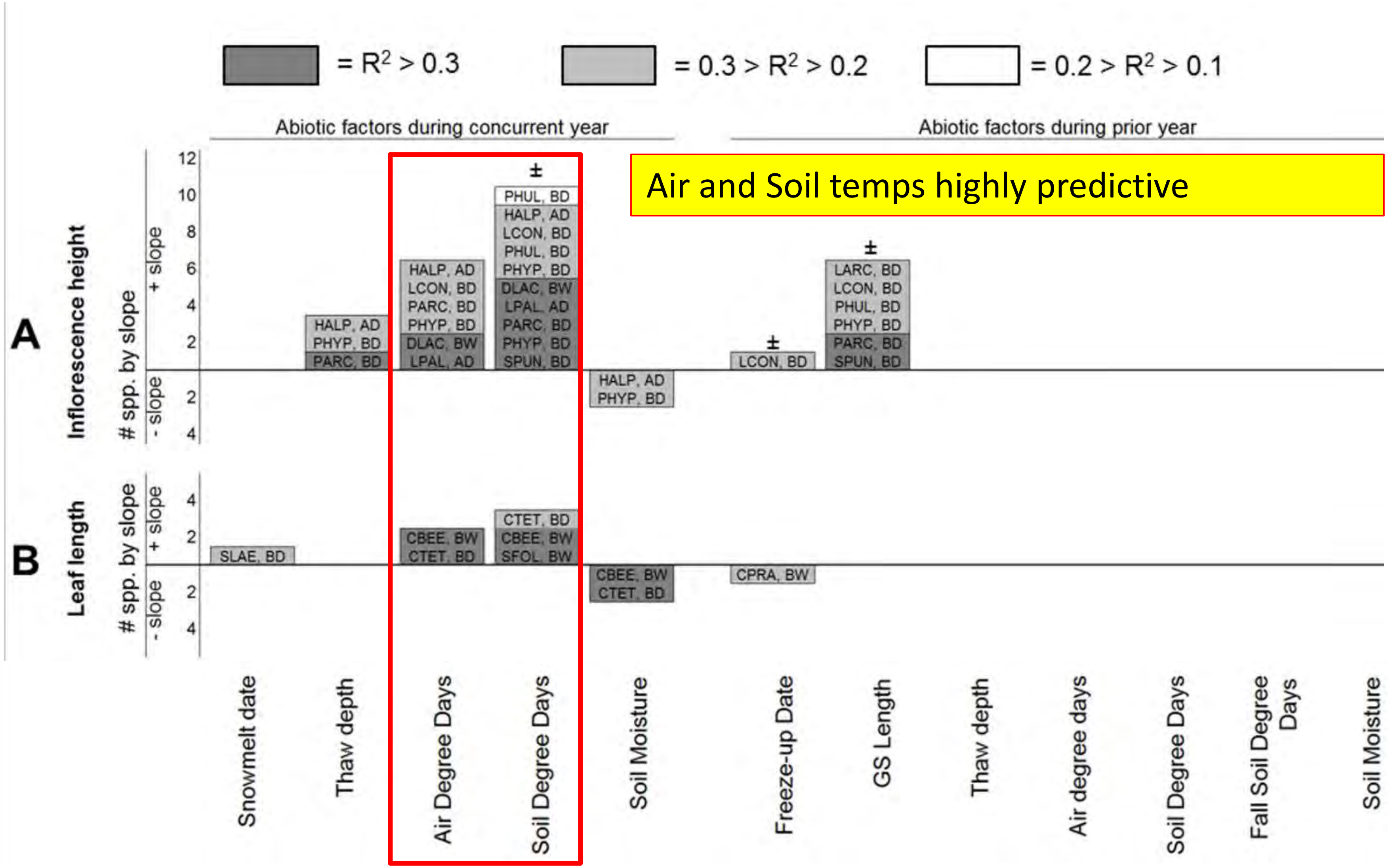


- Conditions during year prior to plant trait measure improve reproductive effort predictions



Conditions during year prior to plant trait measure improve reproductive effort predictions





= R^2 > 0.3
= 0.3 > R^2 > 0.2
= 0.2 > R^2 > 0.1
Abiotic factors during concurrent year
Abiotic factors during prior year
Air and Soil temps highly predictive
A
Inflorescence height
spp. by slope
+ slope
- slope
B
Leaf length
HALP, AD
PHYP, BD
PARC, BD
LCON, BD
DLAC, BW
LPAL, AD
PHUL, BD
SPUN, BD
LARC, BD
SLAE, BD
CBEE, BW
CTET, BD
SFOL, BW
CPRA, BW
±
Snowmelt date
Thaw depth
Air Degree Days
Soil Degree Days
Soil Moisture
Freeze-up Date
GS Length
Air degree days
Fall Soil Degree Days

Because of the interest in changing summer air temperatures

Trait & Site	Species	E (H	LMM Marginal R^2
Inflorescence height			
Barrow Dry			
	Luzula confusa		0.15
	Poa arctica		0.29
	Potentilla hyparctica		0.30
Reproductive effort			
Barrow Dry			
	Cassiope tetragona		0.53*
	Poa arctica		0.25*
Reproductive phenology			
Barrow Dry			
	Cassiope tetragona		0.55
	Luzula confusa		0.46
	Papaver hultenii		0.58
	Poa arctica		0.60
	Potentilla hyparctica		0.44
Barrow Wet			
	Luzula arctica		0.45

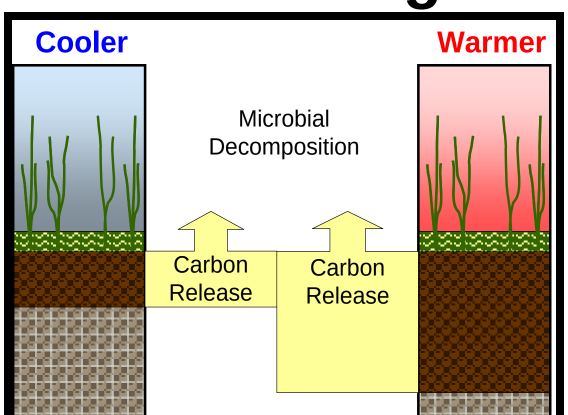
CH IV: Overall Conclusions

In Summary:

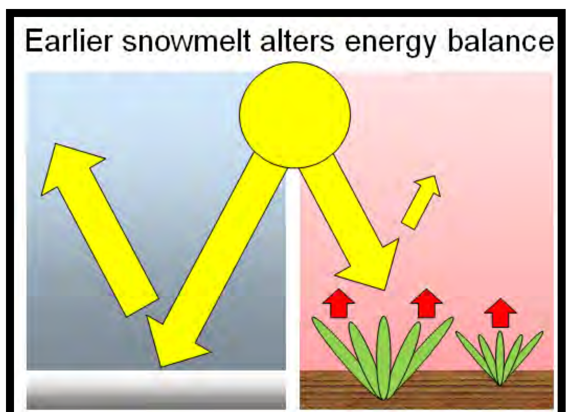
- As Arctic continues to warm, tundra plants will likely
  - Grow taller inflorescences
  - Grow longer leaves
  - Flower earlier in the years
- Long-term records of air temps and other AF's will be highly useful in predicting plant responses

How will s… to climate change affe… influence?

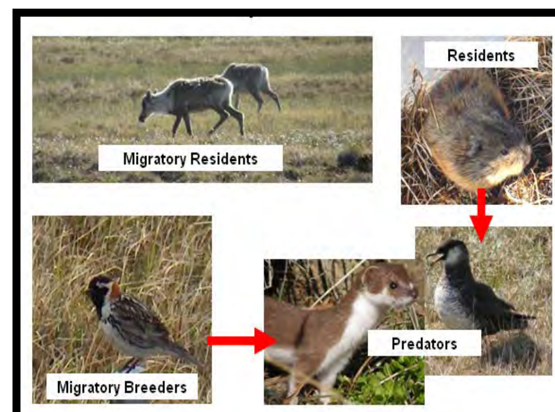
Carbon Budget



Energy Balance



Trophic Interactions

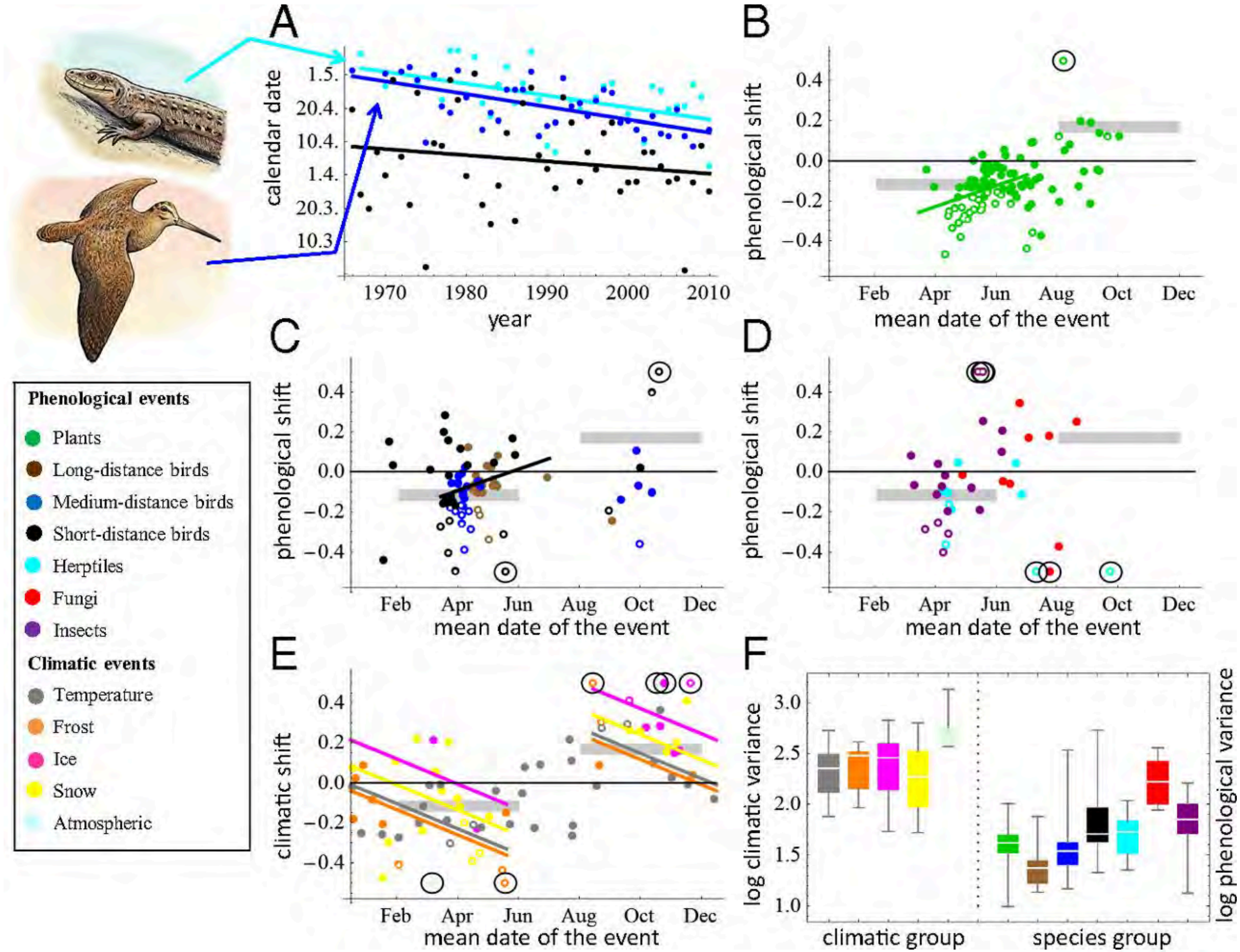


Acknowledgements

- Special thanks to Bob Hollister for all his guidance, training, support, and patience
- Thank you to the GVSU AEP, especially…
  - Bob Hollister, Tim Botting, Kelsey Wright, Jeremy May, Jenny Liebig, and Sarah Elmendorf!
- Thank you to WMAES!

Organizations
- National Science Foundation (NSF)
- Grand Valley State University (GVSU)
- Barrow Arctic Science Consortium (BASC)
- International Tundra Experiment (ITEX)

Phenology (timing) of life events are shifting

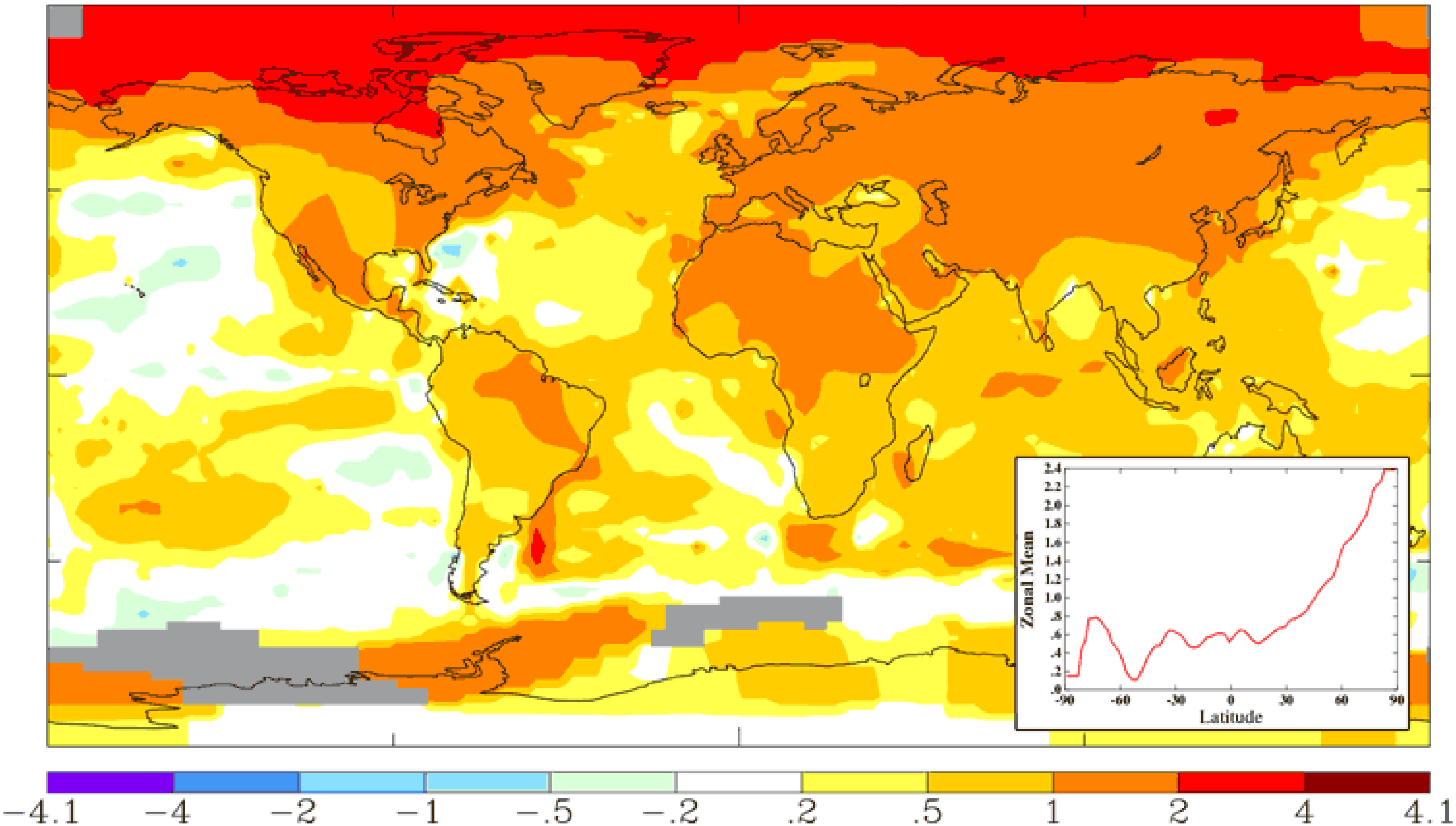


Otso Ovaskainen et al. PNAS 2013;110:13434-13439

Permafrost thaw has many negative implications

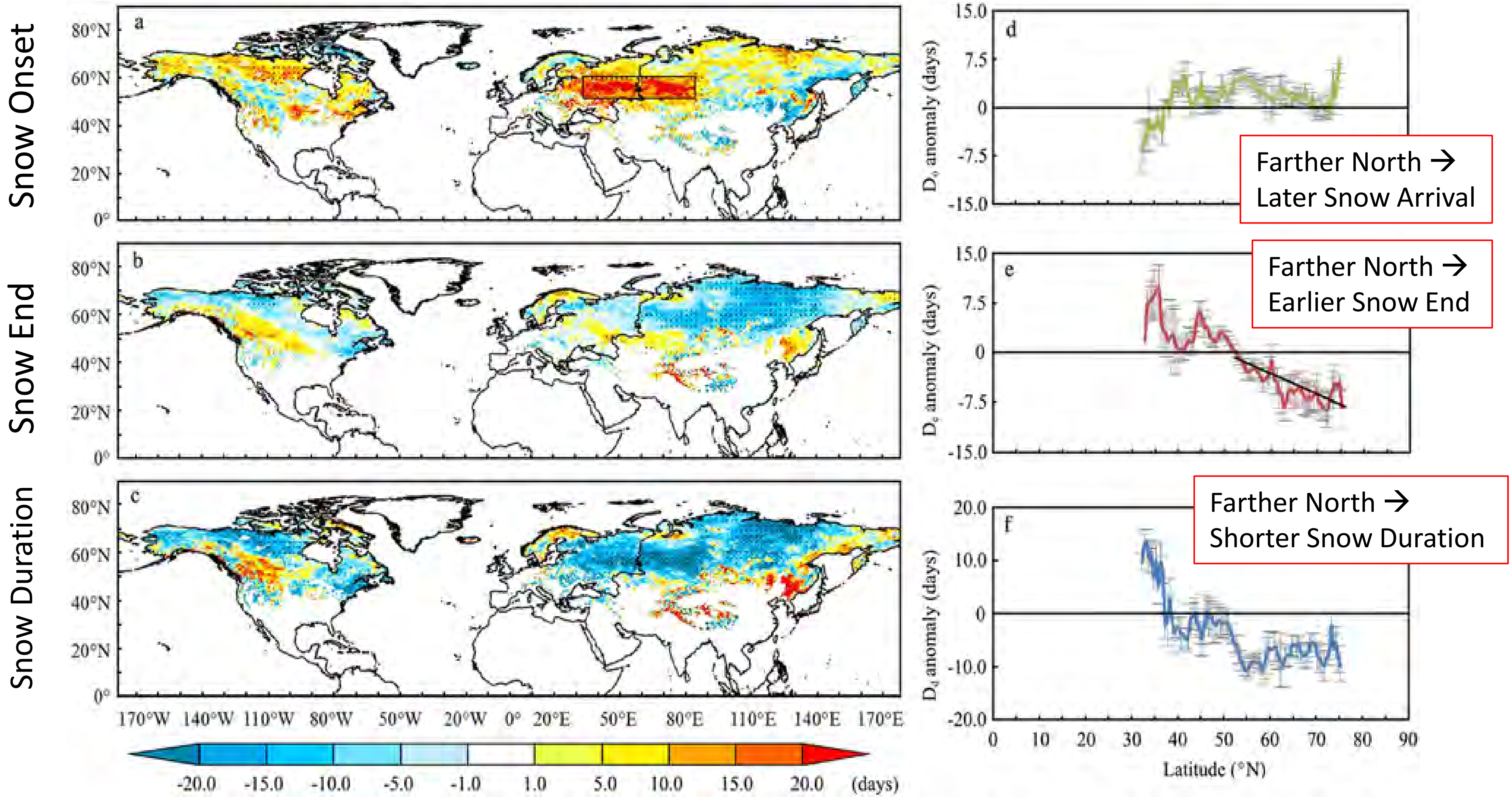
Thaw slumping
→ habitat disturbance

The Arctic is particularly vulnerable to climate change



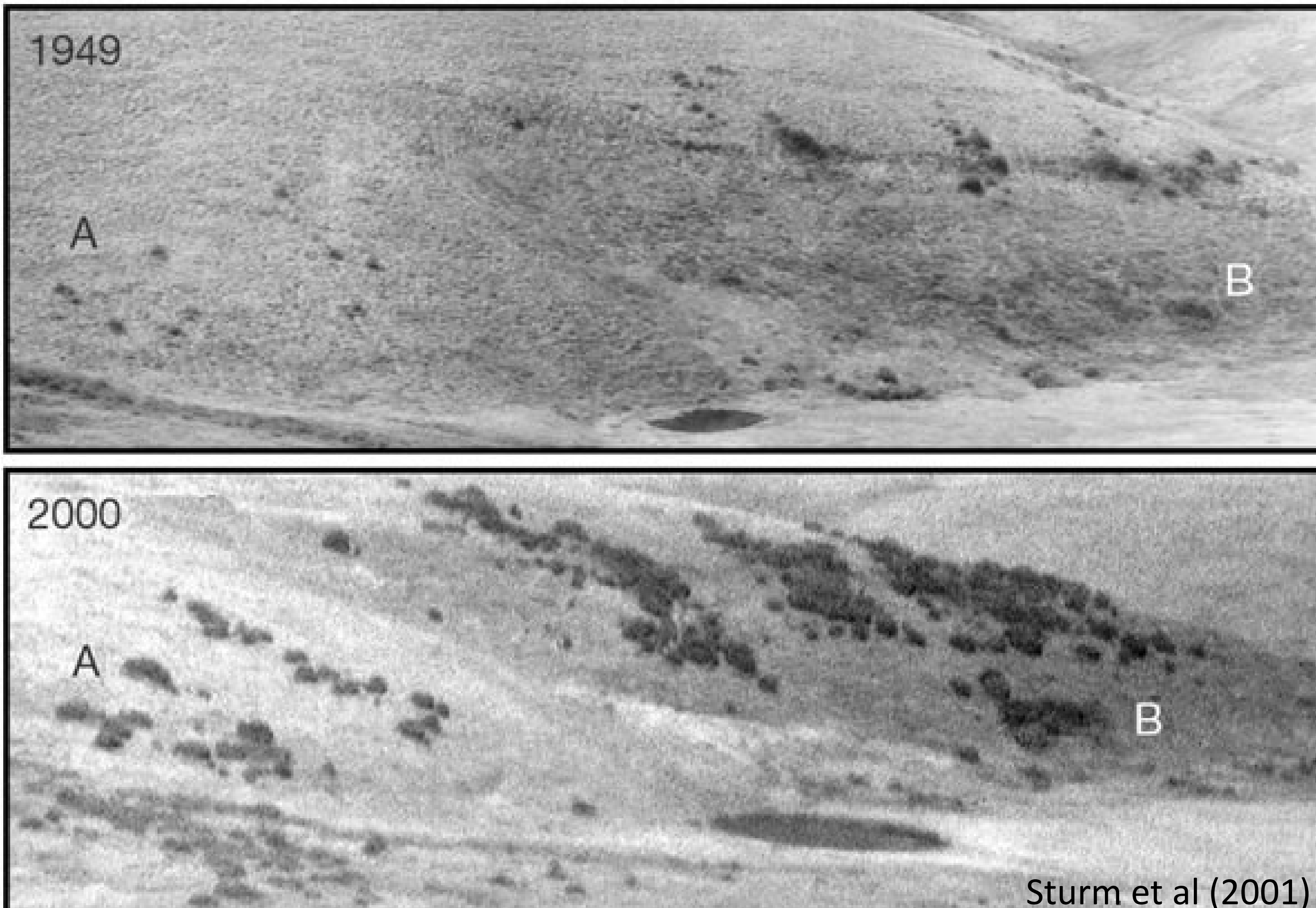
1960-2011, NASA

The Arctic growing season is getting longer

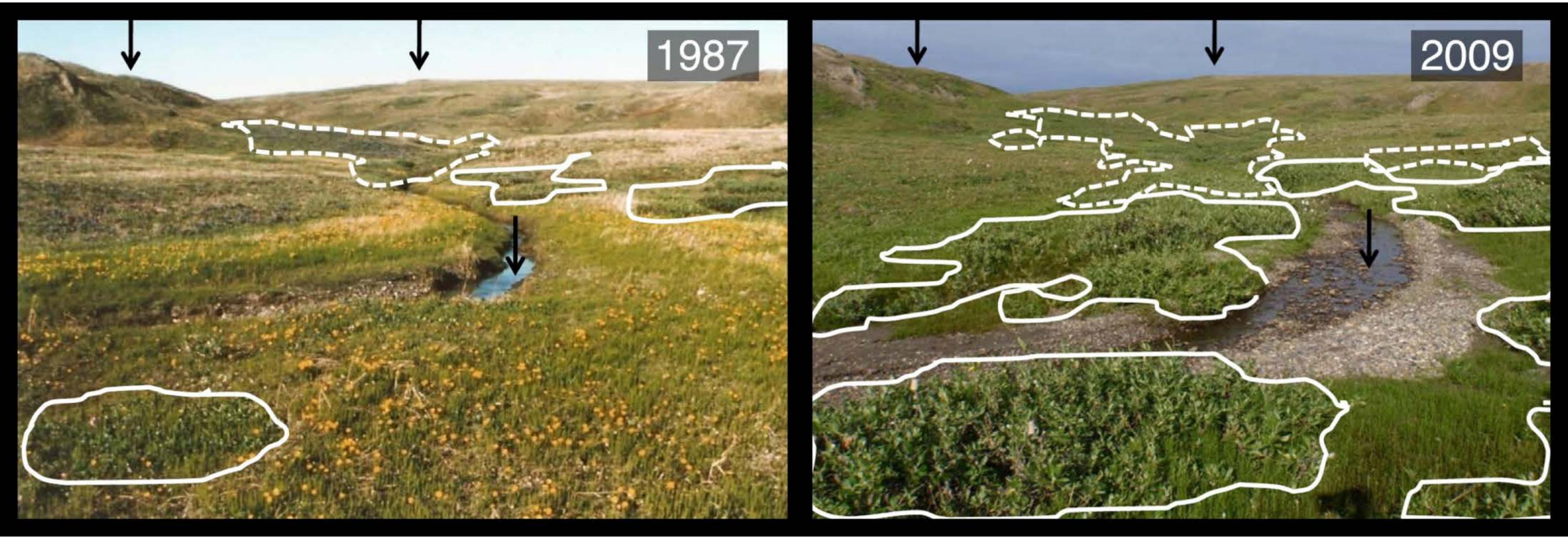


Chen et al (2015)

Shrubs and trees moving northward

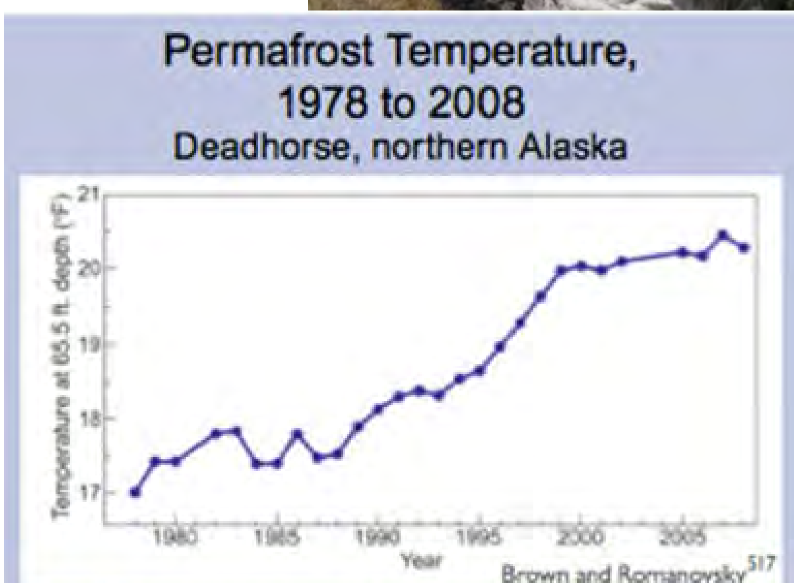


Shrubs and trees moving northward



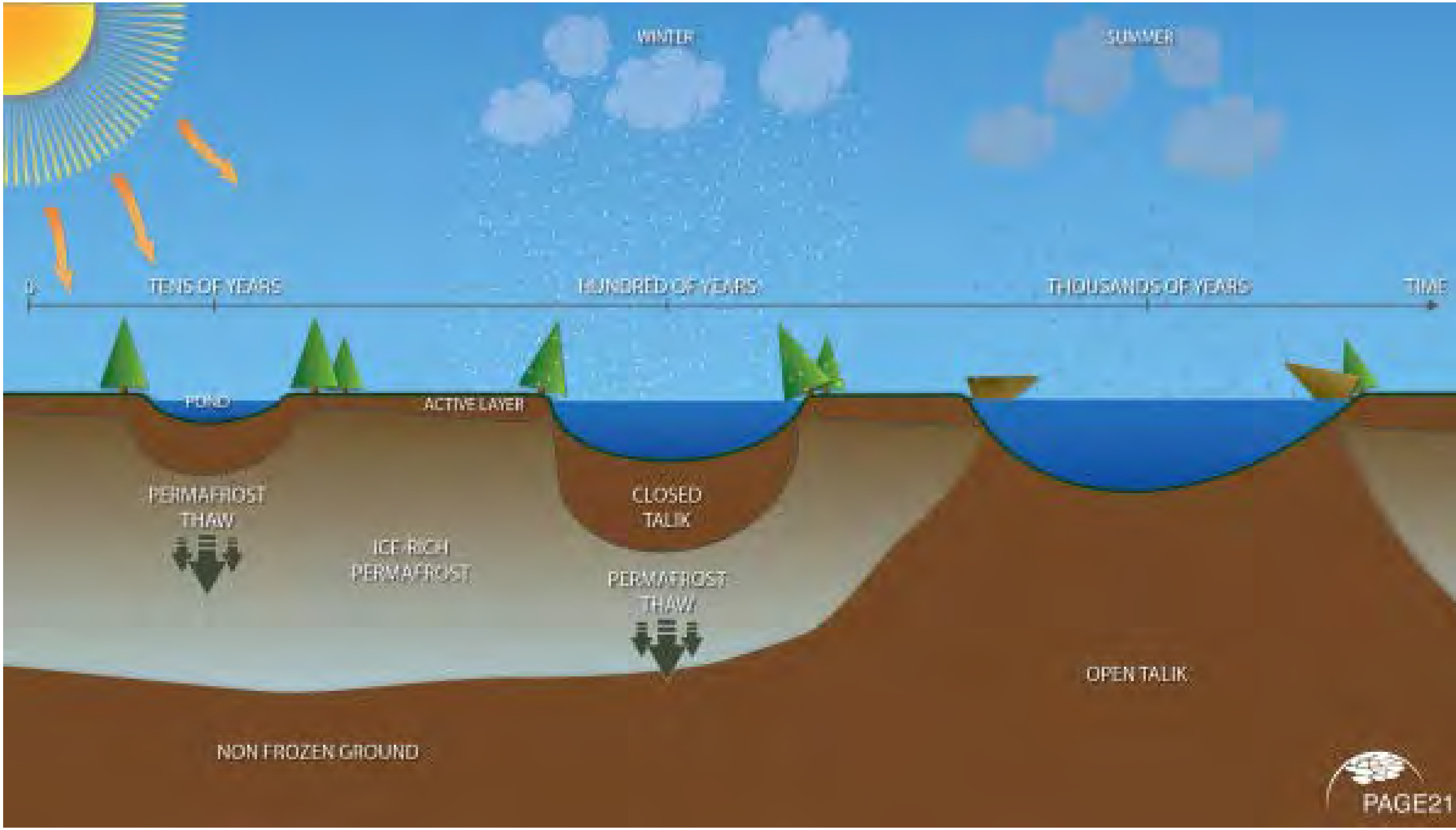
I. H. Myers-Smith *et al., AMBIO* **40** (2011)

Permafrost is thawing



Permafrost temperatures have risen throughout Alaska, with the largest increases in the northern part of the state.

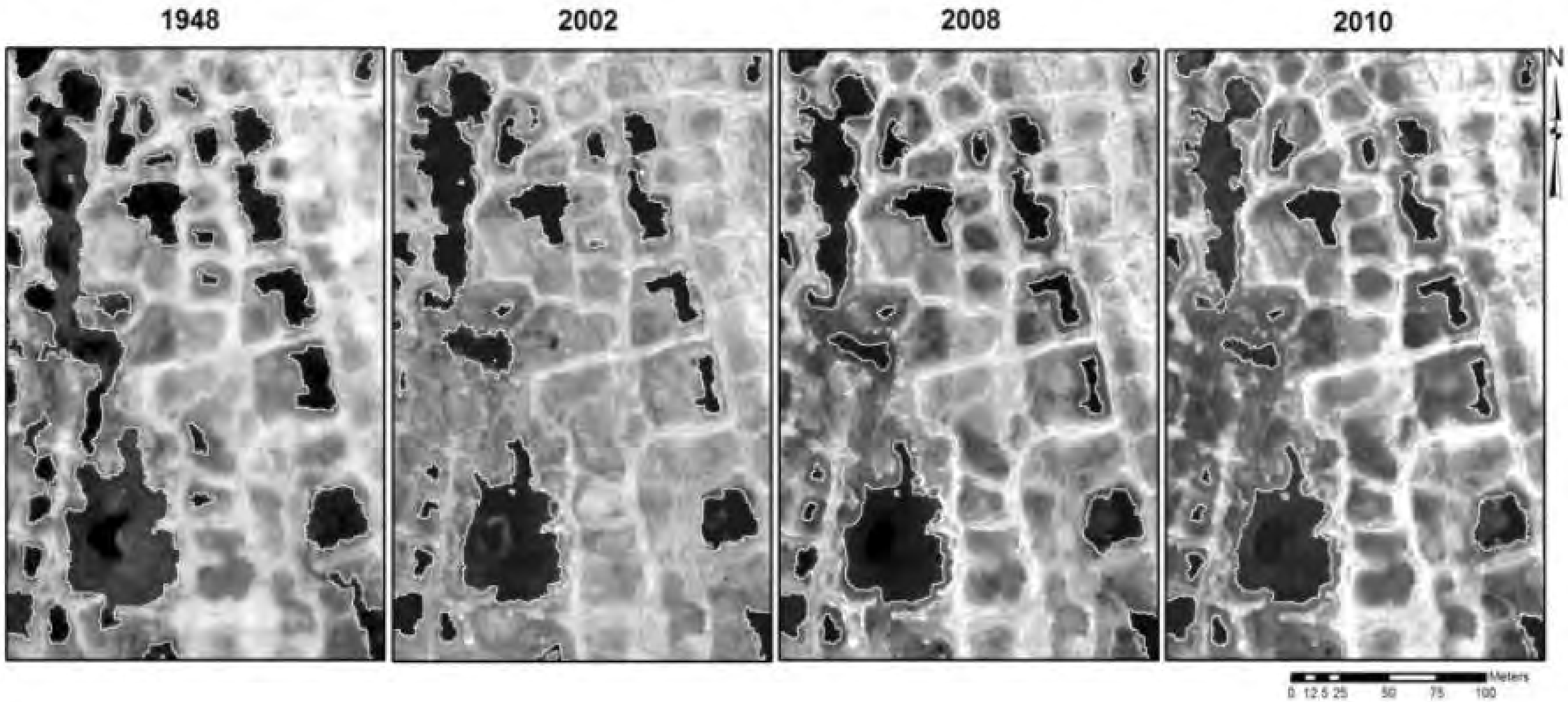
Permafrost thaw has many negative implications



Permafrost thaw has many negative implications

(V. Romanovsky)

Permafrost thaw has many negative implications



Thaw lakes → habitat disturbance

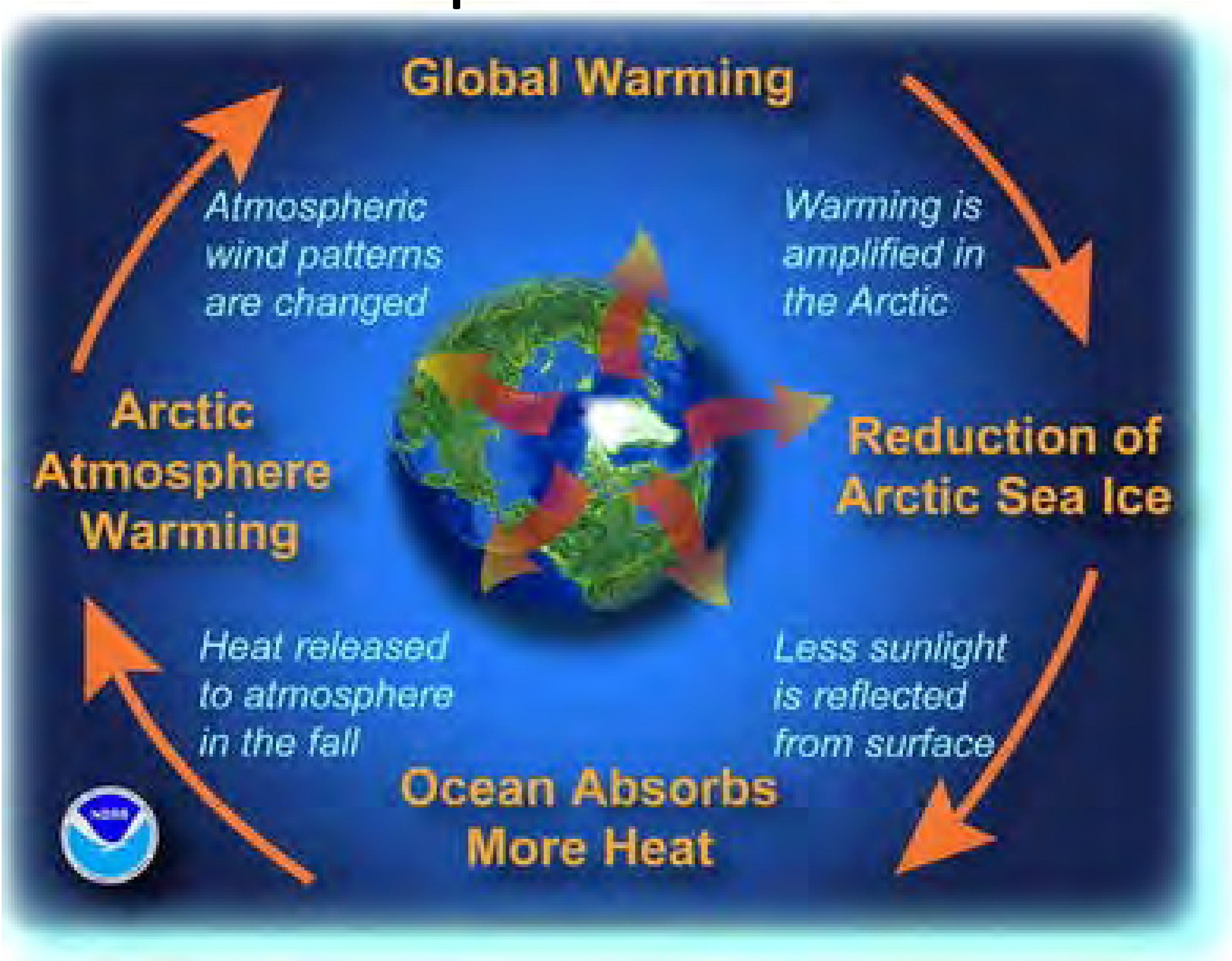
UTEP, 2015

Permafrost thaw has many negative implications

Methane
(Greenhouse gas)
release

Changes in the Arctic will have global repercussions

Changes in the Arctic will have global repercussions



Permafrost thaw will create massive amounts of further warming

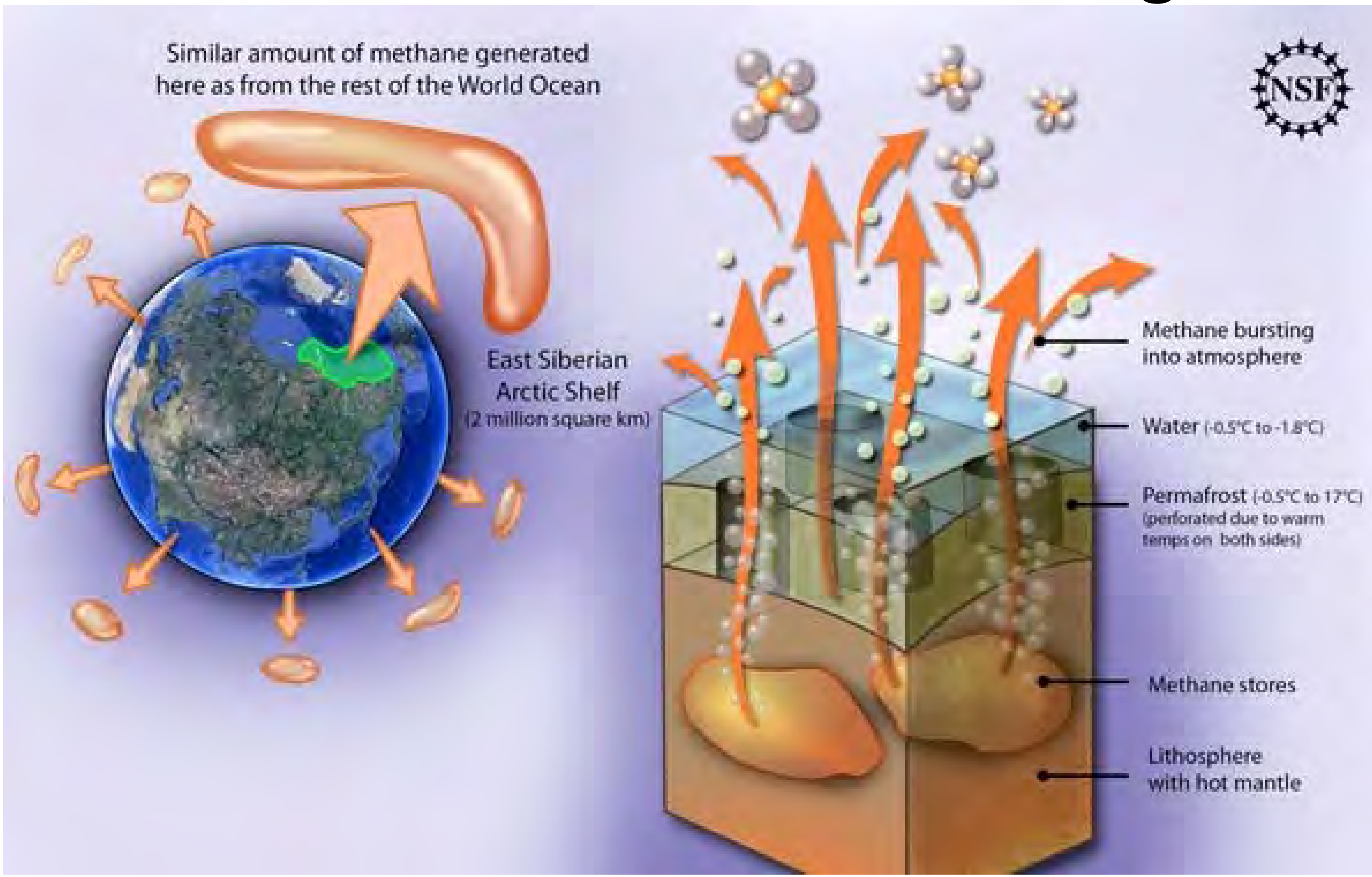
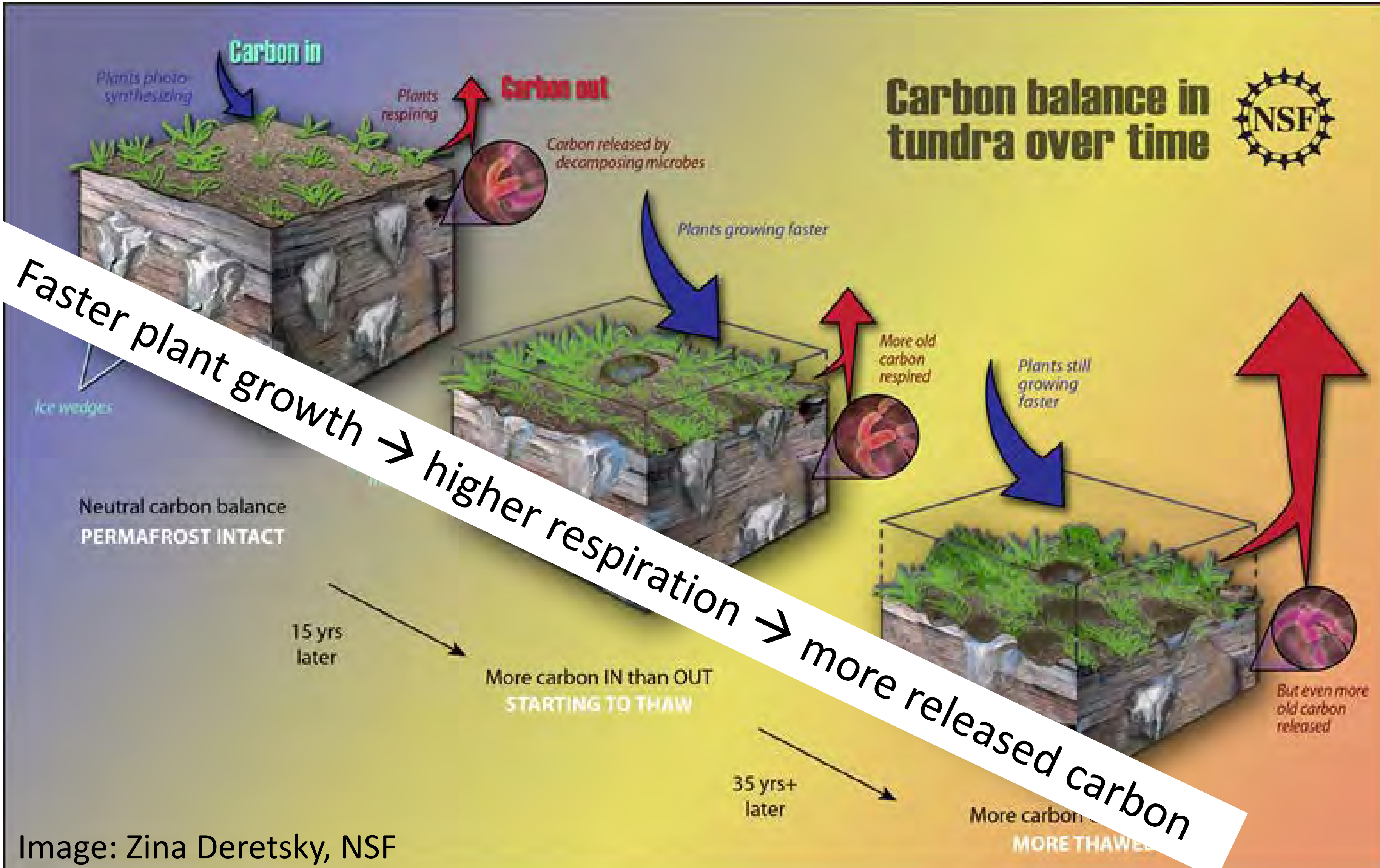


Image: National Science Foundation

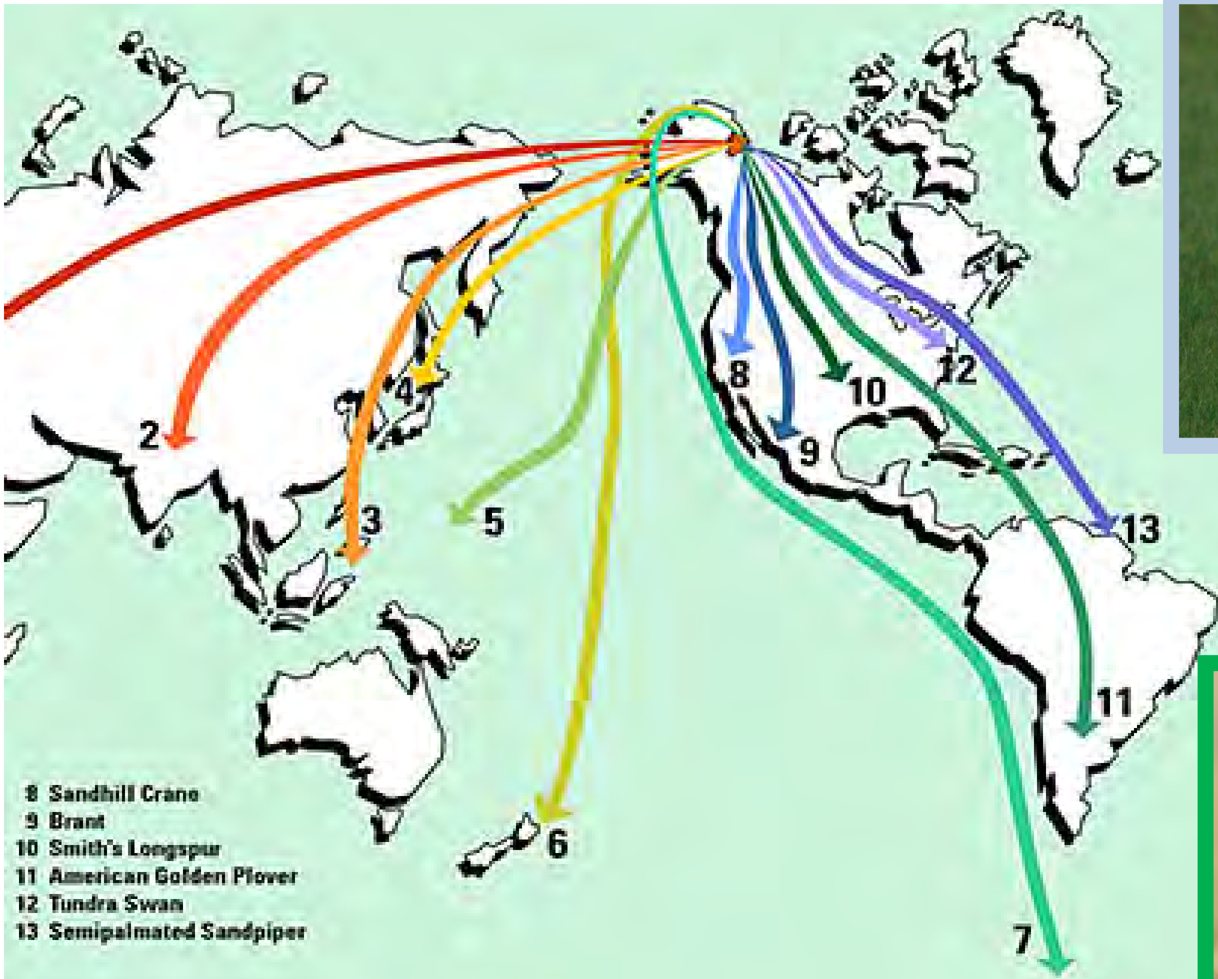
Arctic plants play critical roles in regulating global processes



Faster plant growth → higher respiration → more released carbon

Image: Zina Deretsky, NSF

Vegetation changes will have local and world-wide effects on herbivores



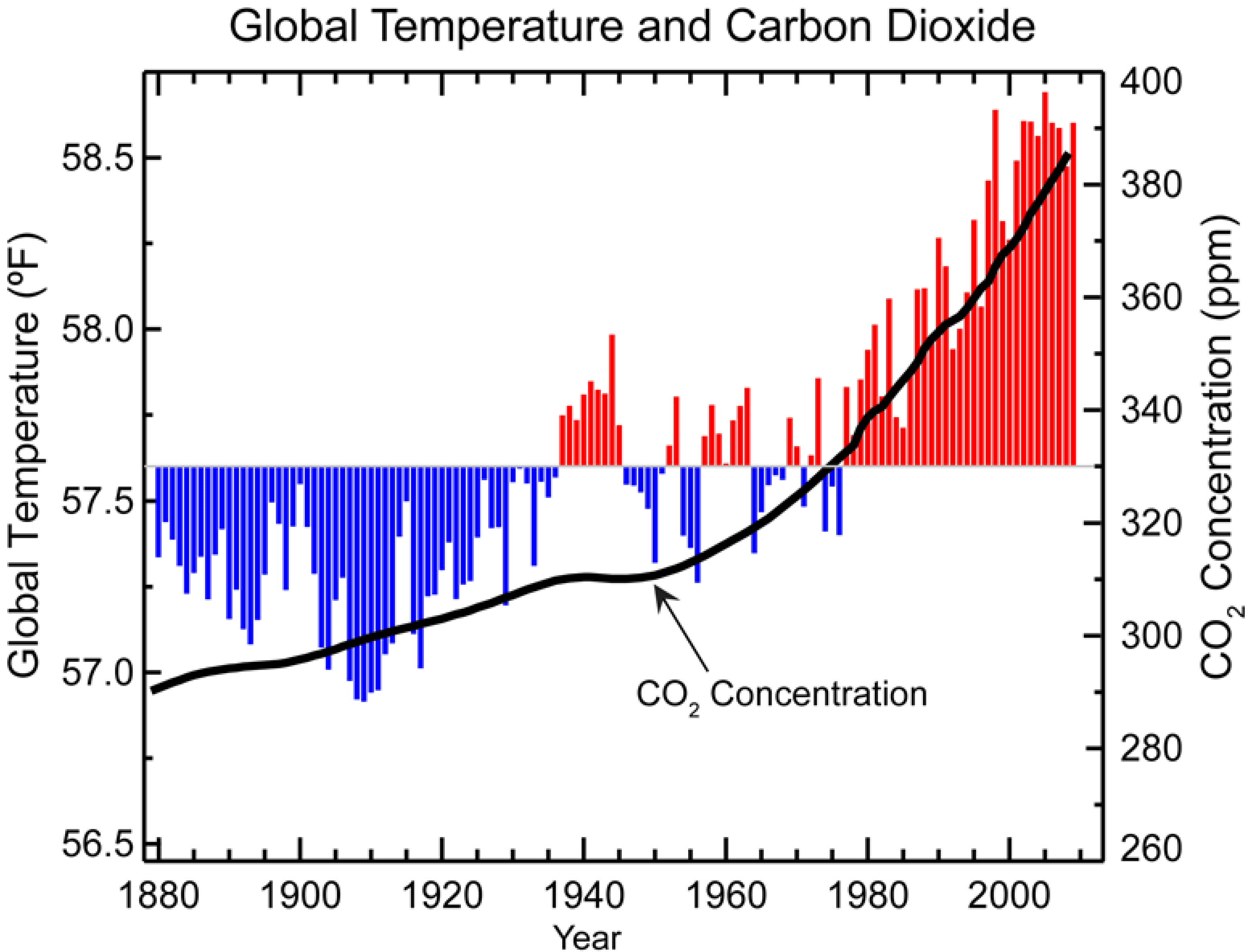
Arctic National Wildlife Refuge
US Fish & Wildlife Service

Permafrost thaw will have many negative implications

"Drunken forests" → habitat disturbance

Study Sites & Data Collection

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
BD Site														X	X		X	X	X				
BW Site														X	X		X	X	X				
AD Site														X	X		X	X	X				
AW Site														X	X		X	X	X				

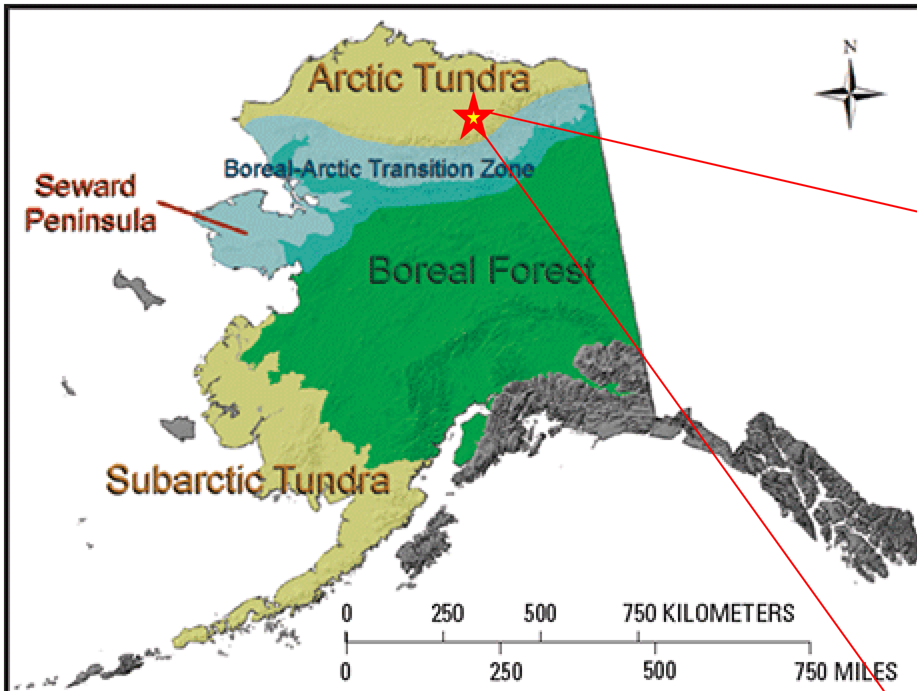

Global Temperature and Carbon Dioxide
Global Temperature (°F)
58.5
58.0
57.5
57.0
56.5
400
380
360
340
320
300
280
260
CO2 Concentration (ppm)
CO2 Concentration
1880
1900
1920
1940
1960
1980
2000
Year

NOAA

Arctic plant responses to warming are <u>highly</u> variable

Generally: warmed tundra plants grow longer leaves, taller flowers, flower earlier, and make more flowers

Other problems: Earlier studies were shorter in length & examined relatively warmer regions

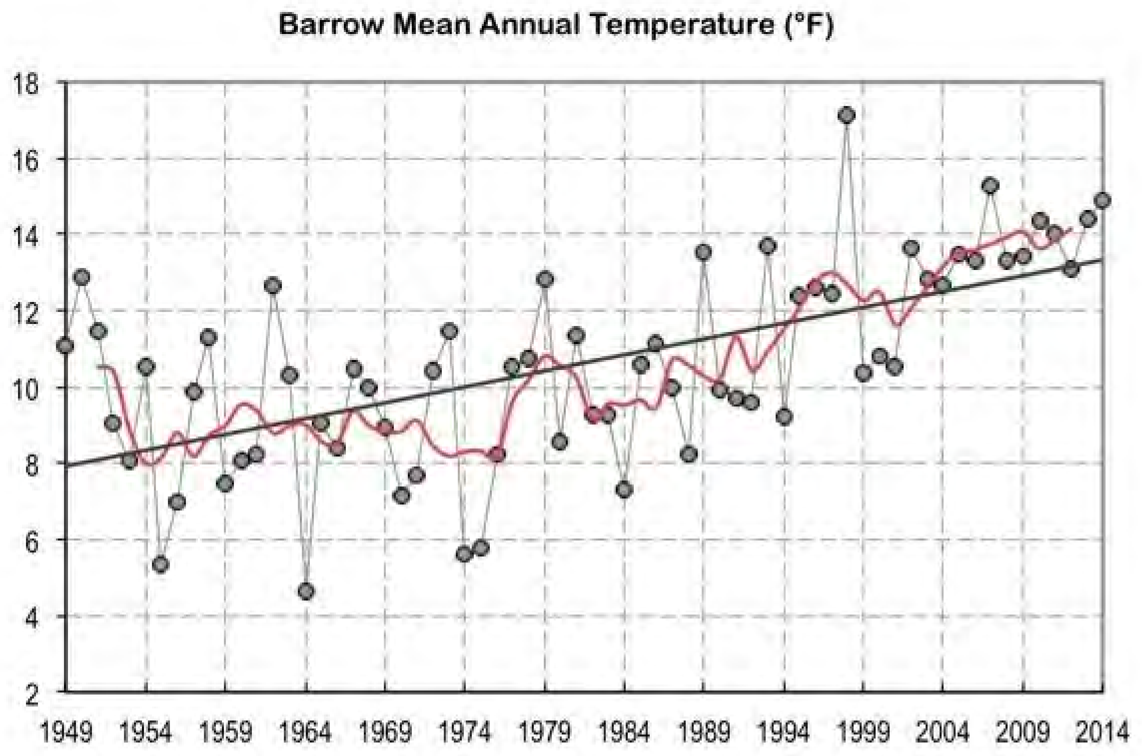


USGS (2013)

Toolik Lake Field Station
Chapin & Shaver (1985)

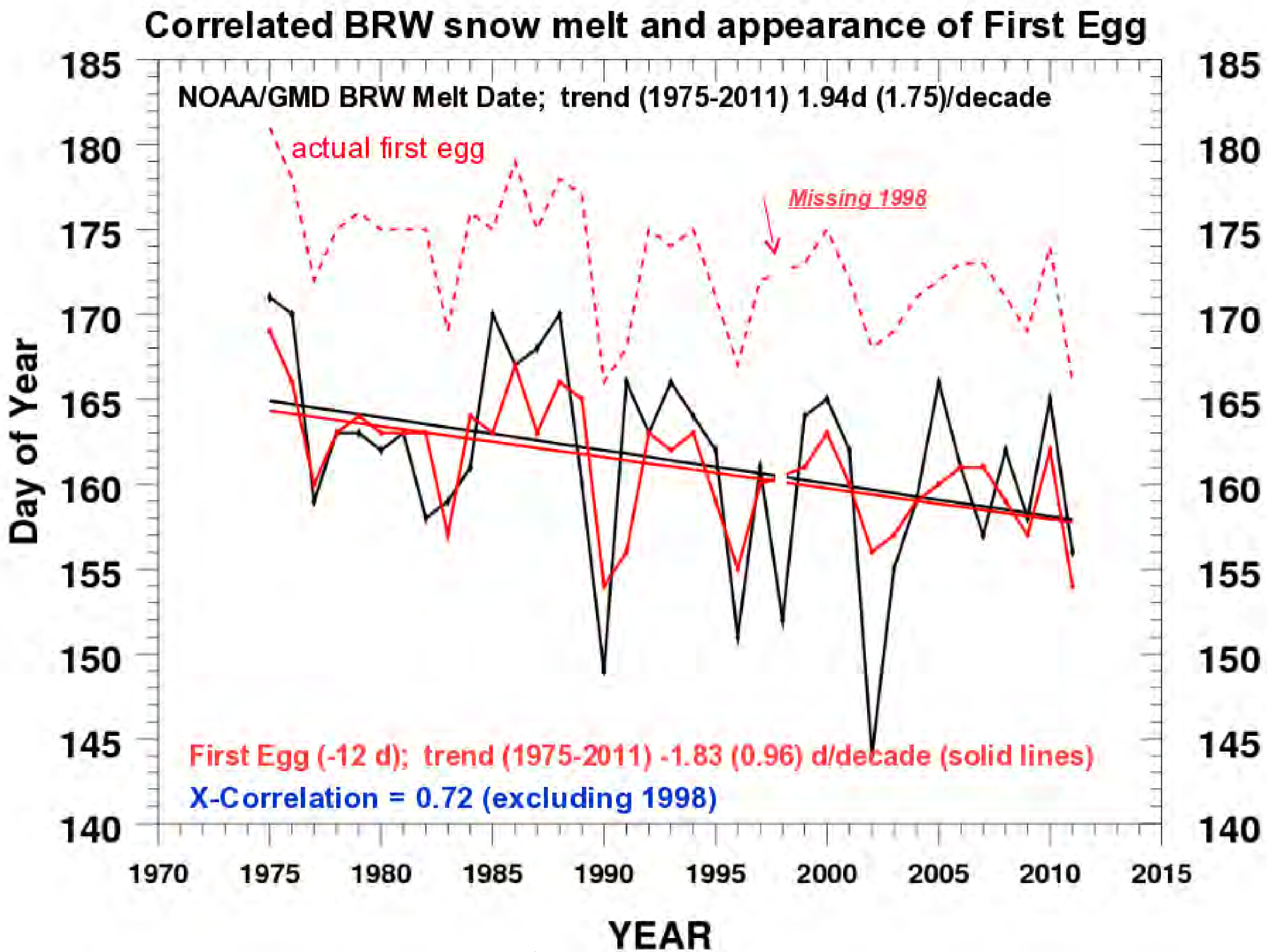
Brete-Harte et al (2002)

Barrow temps



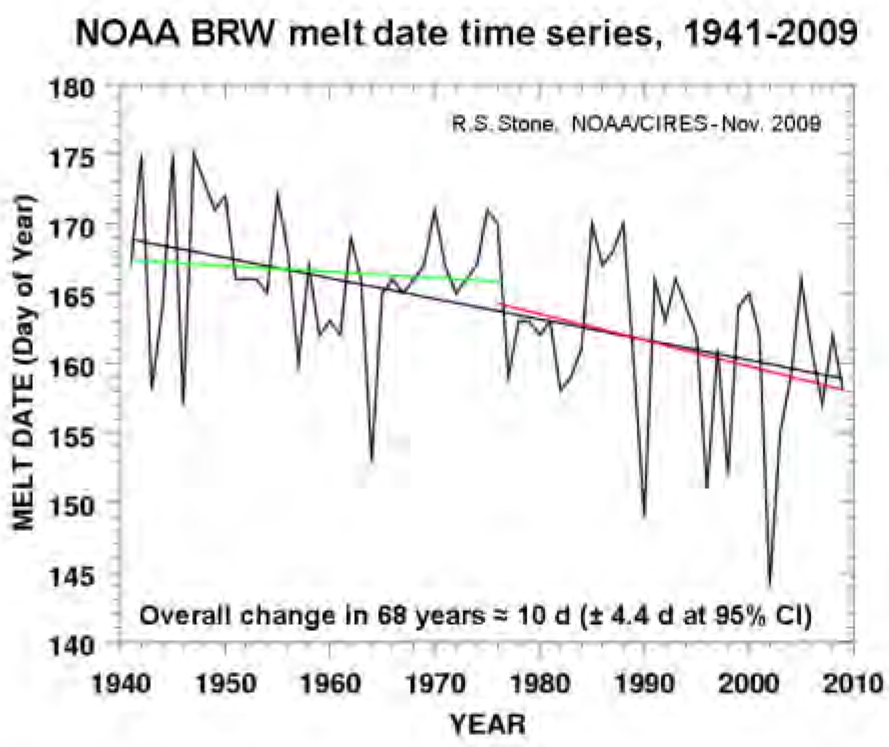
Source: [Alaska Climate Research Center]

Snowmelt date

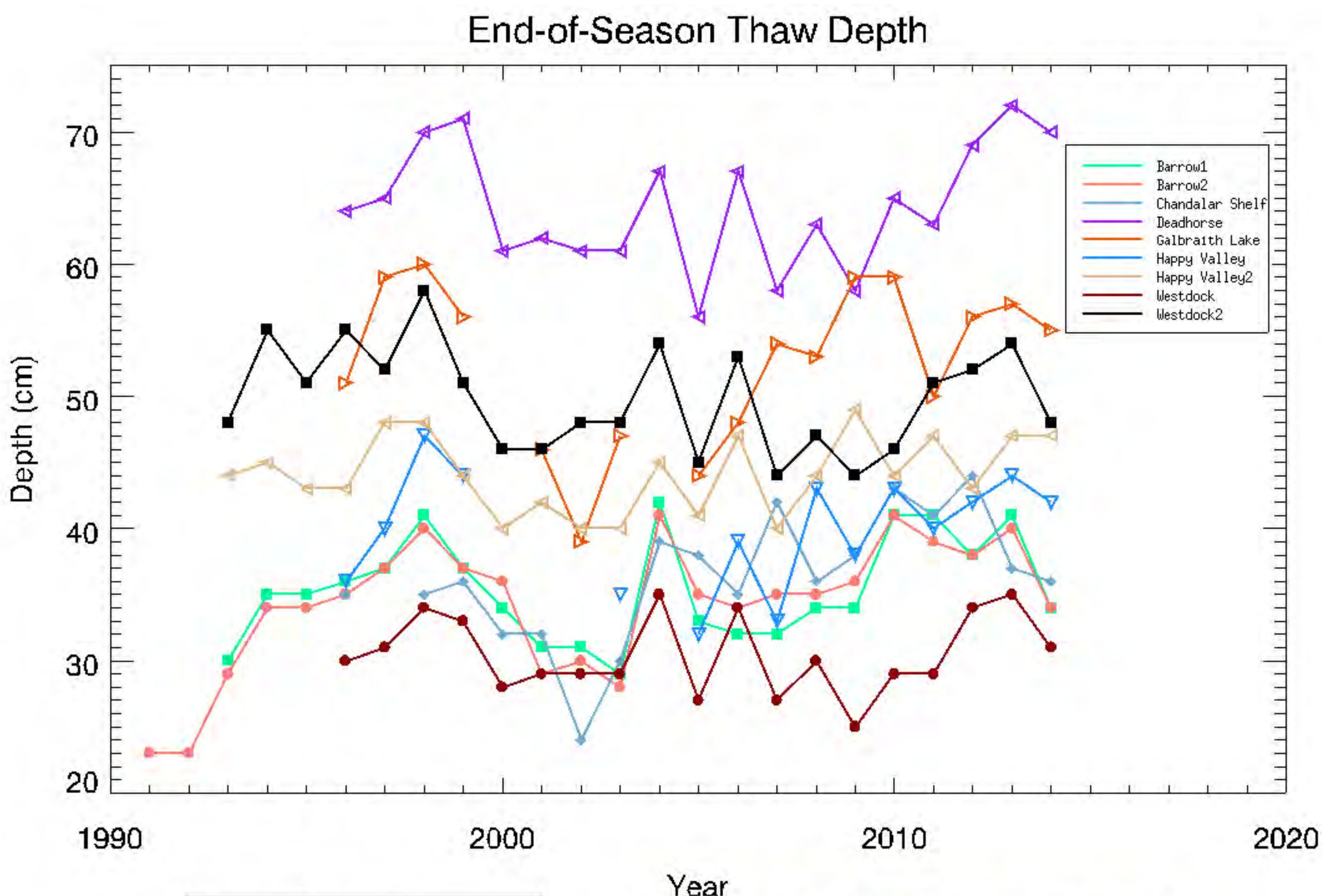


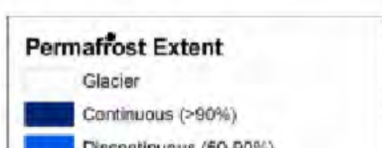
NOAA ESRL GMD Barrow Observatory (BRW) RS STone

Snowmelt date

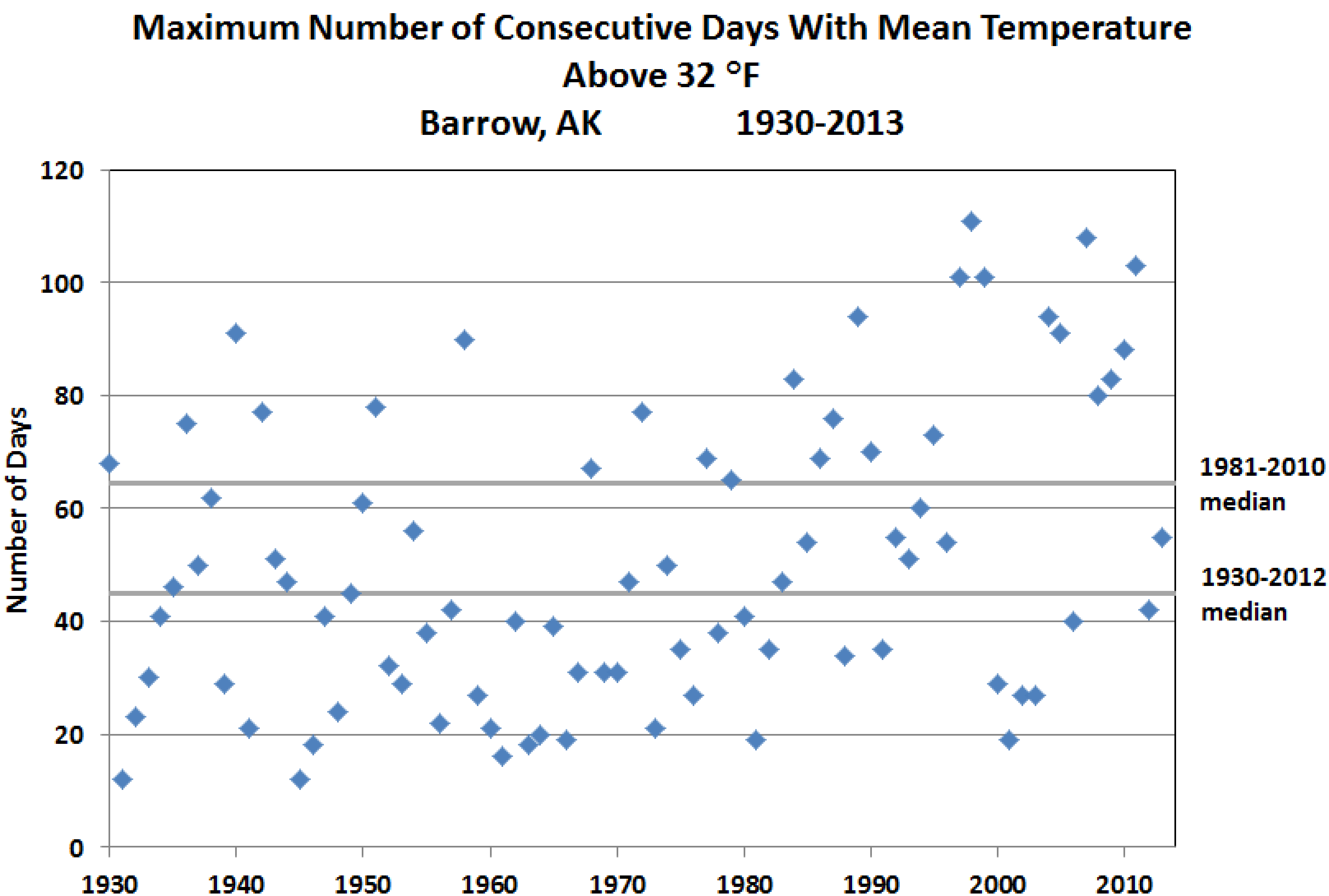


Thaw depth

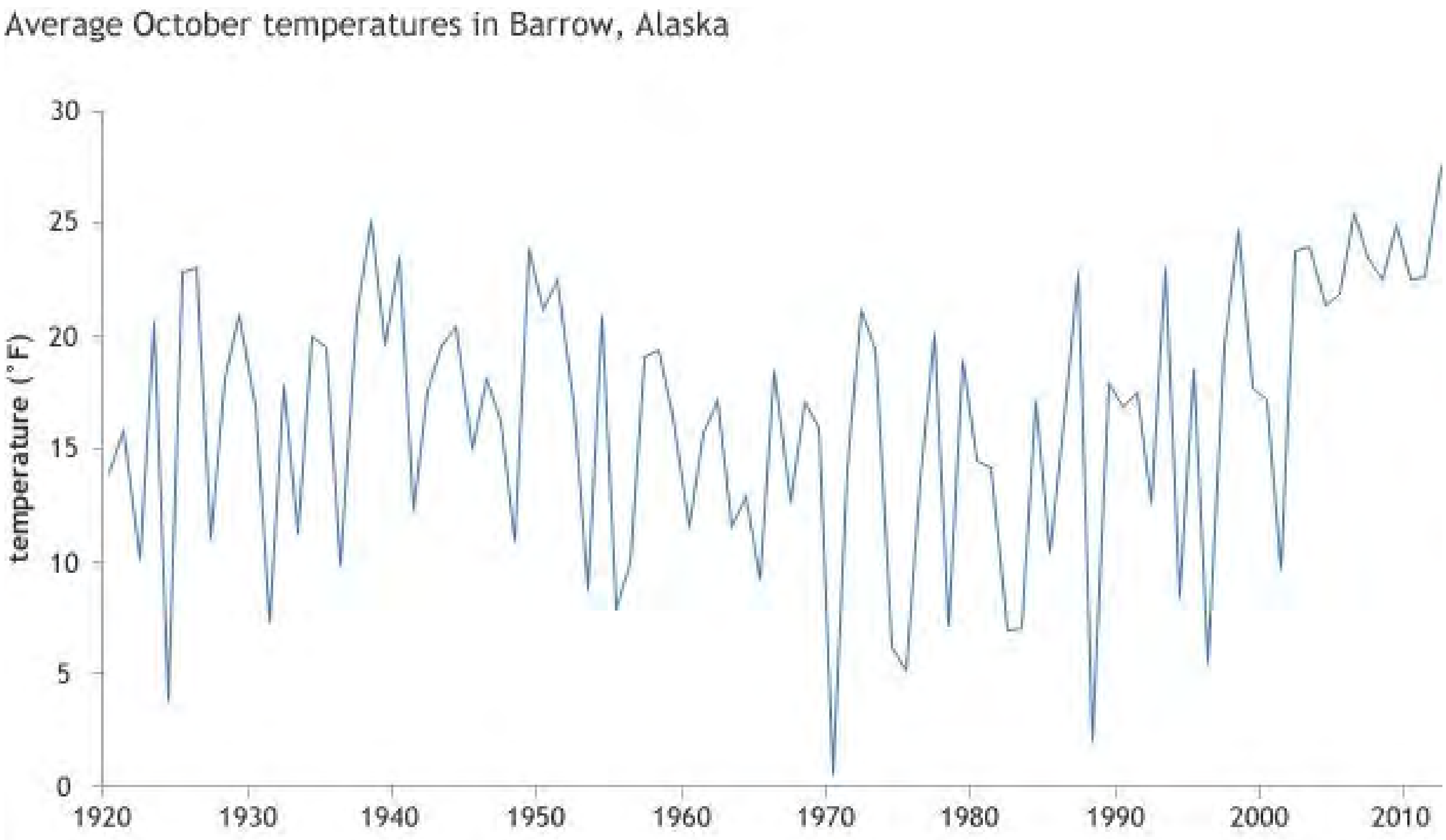




Permafrost Distribution in Alaska and
Permafrost Observatories Location


Maximum Number of Consecutive Days With Mean Temperature
Above 32 °F
Barrow, AK 1930-2013
Number of Days
0
20
40
60
80
100
120
1930
1940
1950
1960
1970
1980
1990
2000
2010
1981-2010 median
1930-2012 median

Fall temps


Average October temperatures in Barrow, Alaska
temperature (°F)
30
25
20
15
10
5
0
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010