Biocomplexity of Arctic Patterned Ground:



A tale of cracking, heaving, and smothering

Photos: Ina Timling and D.A. Walker

Biocomplexity of Arctic Patterned Ground:

A tale of cracking, heaving, and smothering

Photos: Ina Timling and D.A. Walker

Co-authors:

Donald Walker[1], Ronnie Daanen[1], Howard Epstein[2], William Gould[3], Grizelle Gonzalez[3] Anja Kade[1], Alexia Kelley[2], William Krantz[4], Patrick Kuss[1], Gary Michaelson[5], Corinne Munger[1], Dmitri Nickolsky[1], Rorik Peterson[1], Chien-Lu Ping[5], Martha Raynolds[1], Vladimir Romanovsky[1], Charles Tarnocai[6], and Corinne Vonlanthen[1]

[1]IAB, University of Alaska Fairbanks, [2] Univ.Virginia, [3]USDA Inst. Trop. Forest., San Juan, PR, [4]Dept. Chem. Mater. Eng., Univ. Cincinnati, [5]UAF Ag. And Forestry Exp. Sta., Palmer, AK, [6]Ag. and Agri-Food Canada, Ottawa, CAN

Funding:

NSF Biocomplexity in the Environment, OPP Grant #0120736

Central Questions

Howe Island, AK.
Photo; D.A. Walker

- How do biological and physical processes interact to form small patterned- ground ecosystems?
- How do these systems change across the Arctic climate gradient?

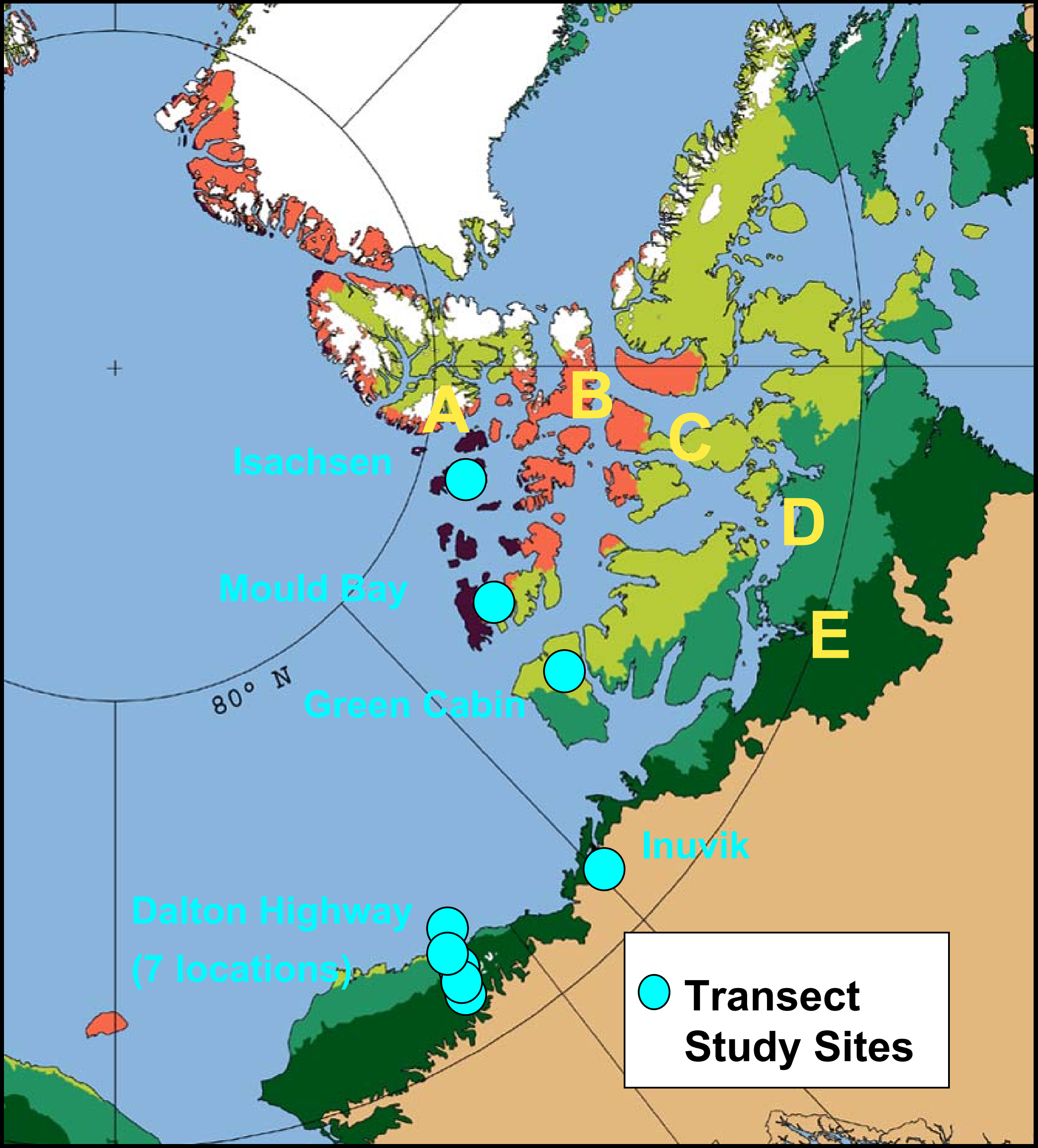
Why focus on small patterned-ground features?

- They are interesting.
- Formation processes not well understood.
- Important to biogeochemical cycling, and other ecosystem processes.
- Ideal system to study the effects of disturbance across the Arctic climate gradient.

North American Arctic Transect

Arctic Bioclimate Subzones

Sub-zone	Mean July Temperature (˚C)
A	<3
B	3-5
C	5-7
D	7-9
E	9-12
Forest	>12



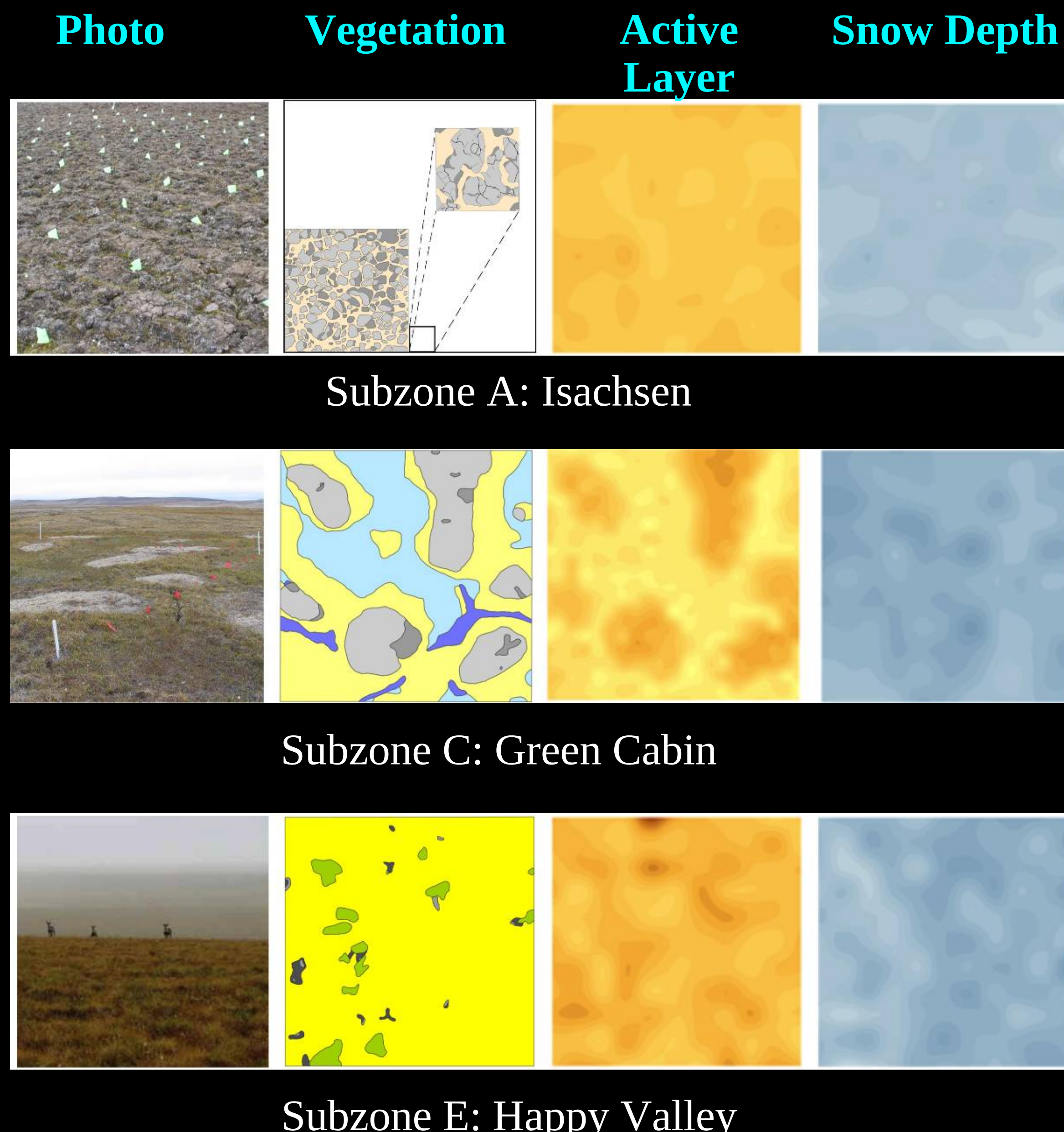
North American Arctic Transect

Measurements

- 21 Grids and maps
  - Active layer
  - Vegetation
  - Snow
- Climate /permafrost
  - Met station
  - Soil temperatures
  - Frost heave
- Soils
  - Characterization
  - Nitrogen mineralization
  - Decomposition
- Remote sensing
  - NDVI
  - Biomass

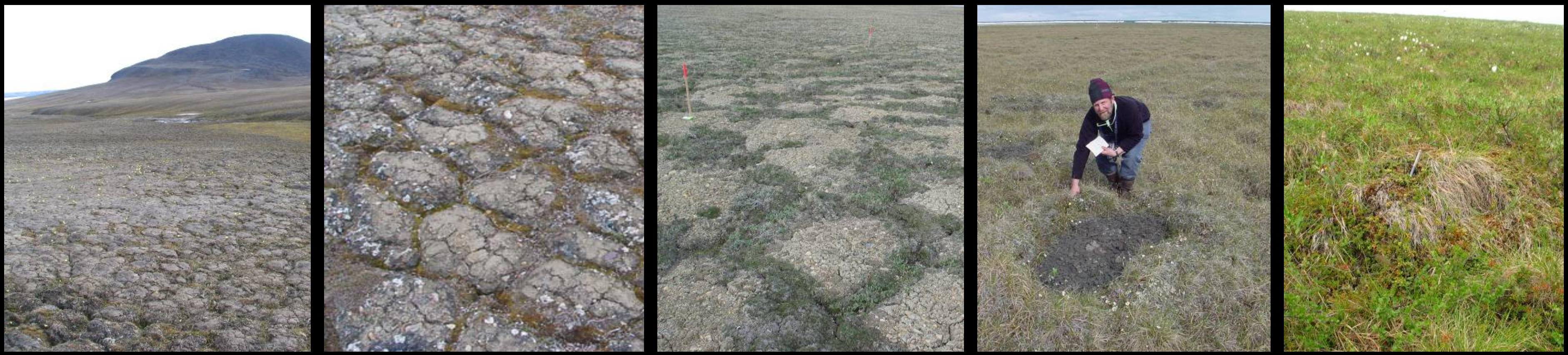
Maps of vegetation, active layer and snow

- Posters (Raynolds et al. and Munger et al.)

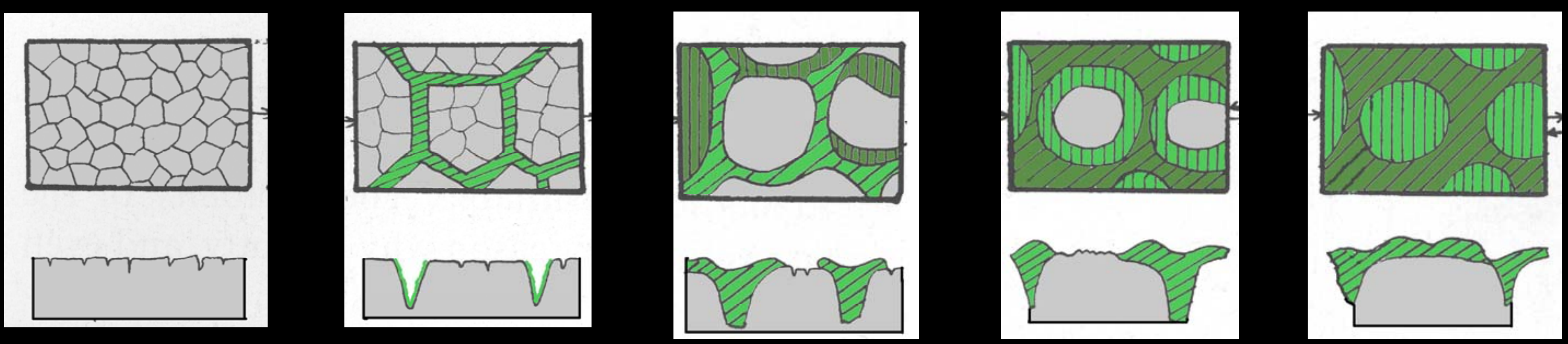


Munger et al. 2006

Conceptual model of patterned-ground trends along the Arctic bioclimate gradient



Sub-zone: A B C D E



Cracking *Heaving* *Smothering*

Drawings modified from Chernov and Matveyeva 1997

Cracking

Isachsen,

Mould Bay

Howe Island

- Small non-sorted polygons (Washburn 1980).
- Desiccation cracking or seasonal frost cracking (Washburn 1980).
- Very important in the High Arctic, but poorly understood.

Photos: D.A. Walker

Heaving

Earth mounds, Mould Bay, Nunavut.

Non-sorted circles, Howe Island, AK,

Earth mound, Inuvik, NWT

- Non-sorted circles and earth mounds
- Caused by differential frost heave.
- Most common in the Mid- and Low Arctic (subzones C and D).
- Several models.

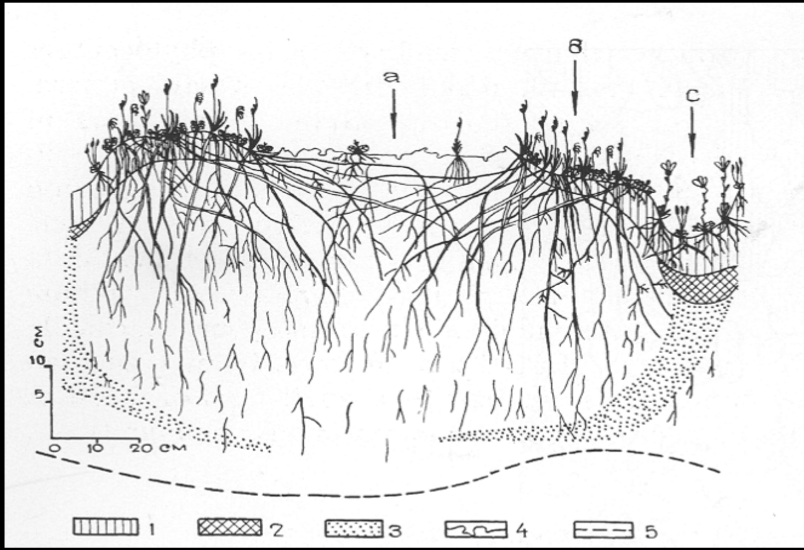
Photos: D.A. Walker

Vegetation succession

Vegetation and organic soils:

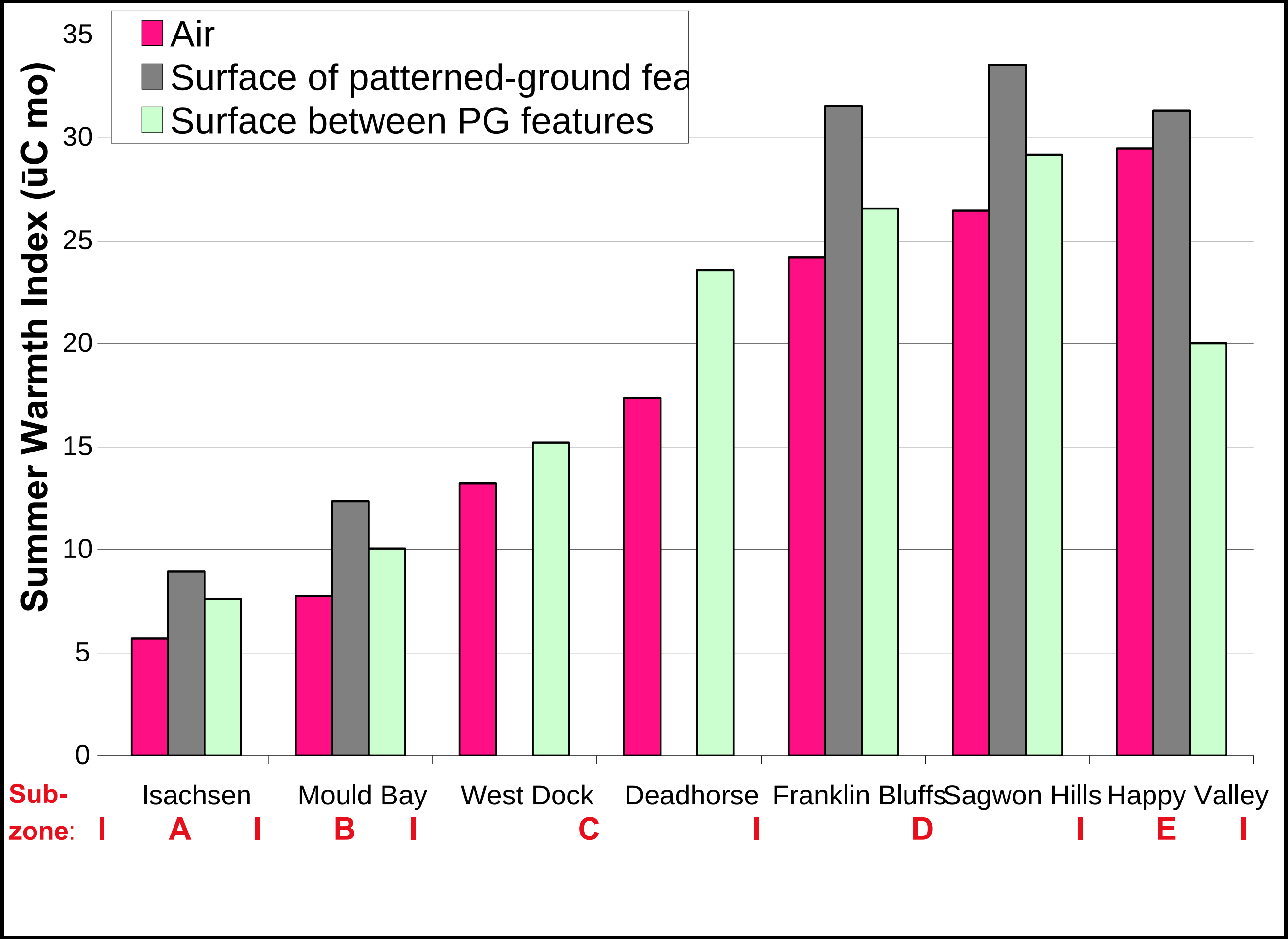
- Insulate the surface.
- Stabilize the soil.
- Mask cracking and heaving.

The effects increase toward the south.



Drawing: Nadya Matveyeva. Photo: D.A. Walker

Summer warmth index along the transect

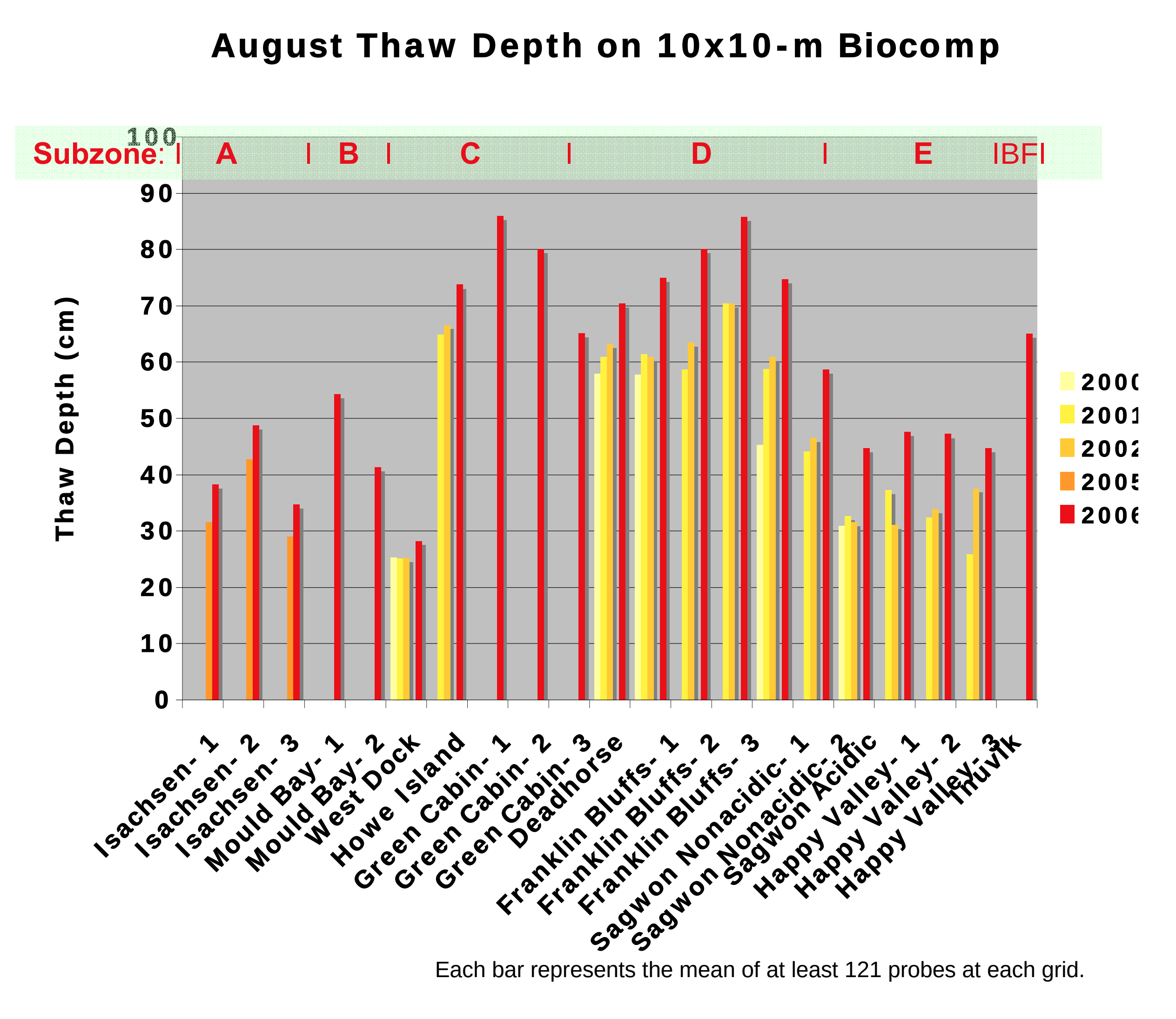


Courtesy V. Romanovsky and R. Daanen

- 5x increase in total summer warmth (red bars).
- Surface temperatures are generally warmer than air temperatures.
- Barren patterned ground features are warmer than the adjacent tundra.

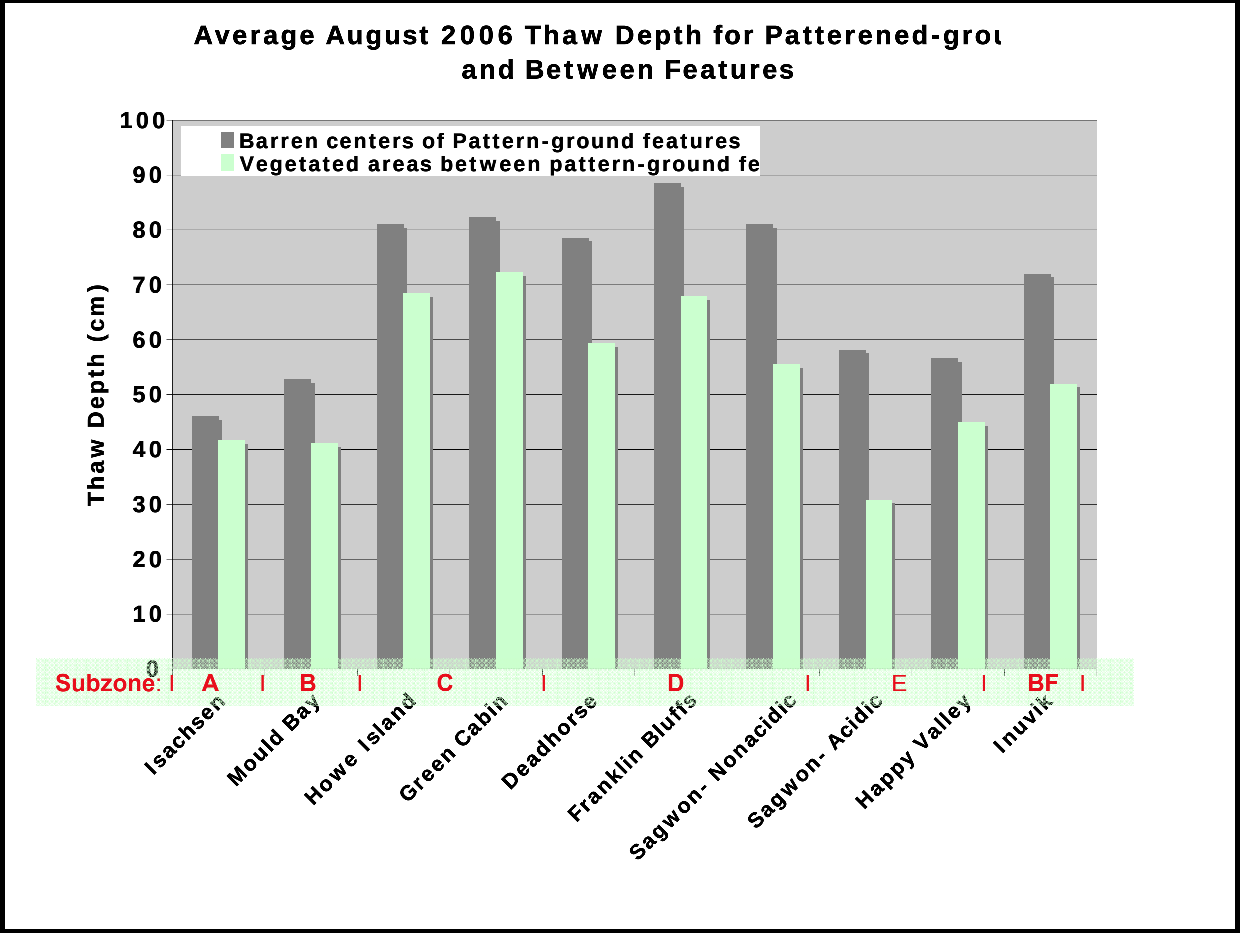
The active layer does not follow the air-temperature gradient.

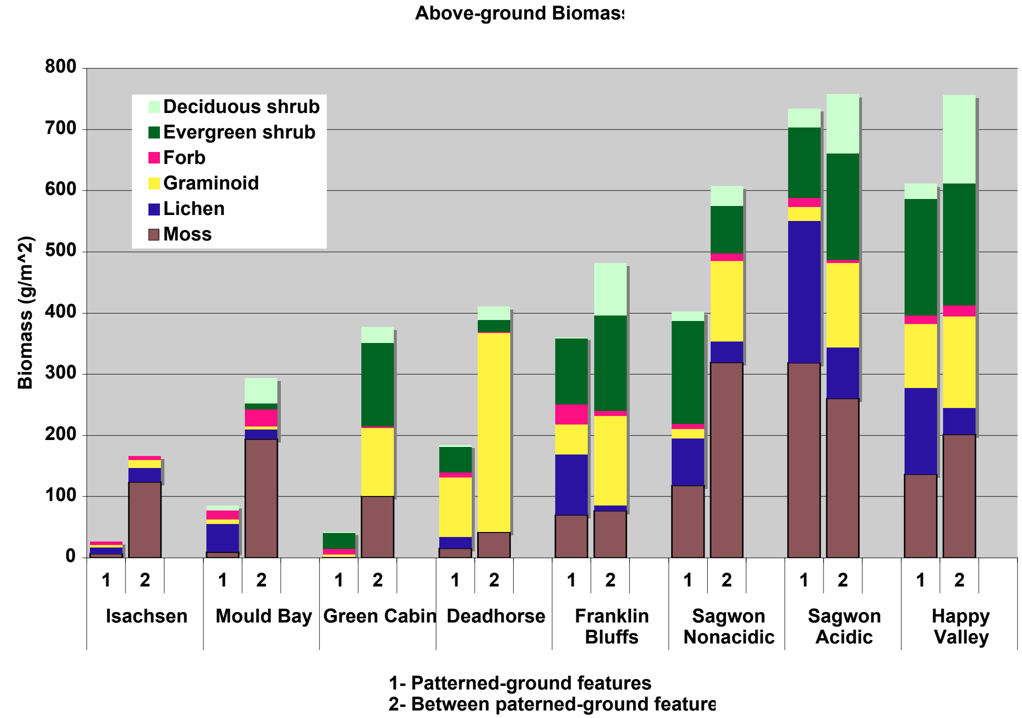
- Deepest thaw in subzones C and D.
- Thaw at Happy Valley (subzone E) was comparable to that at Isachsen (Subzone A).

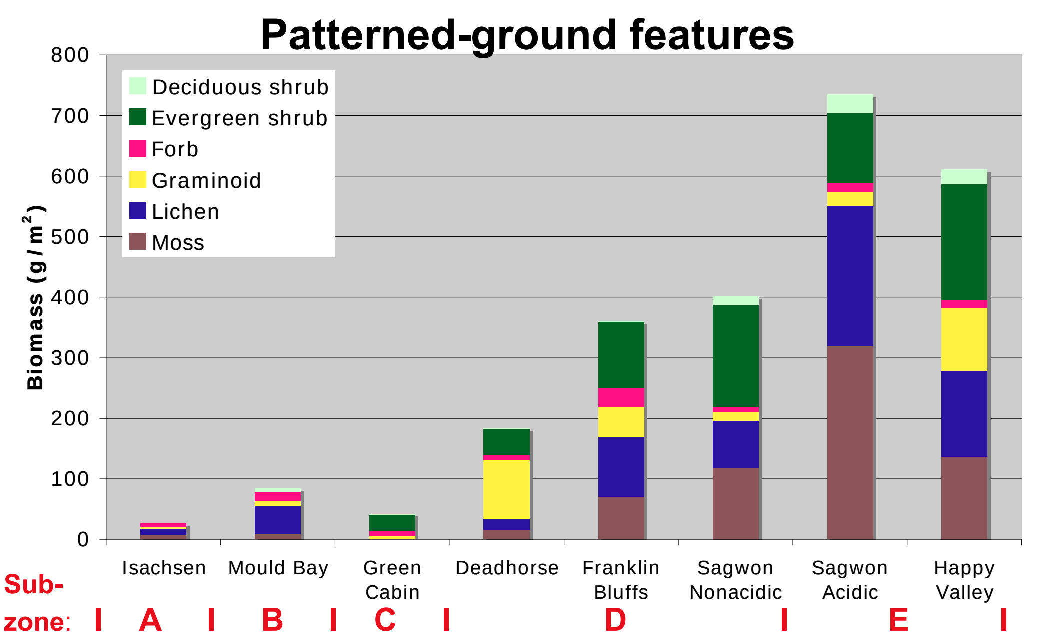


Plant cover strongly affects the thaw layer.

- End of Aug thaw is about 10-20 cm deeper on barren patterned ground features than in the adjacent tundra areas.
- Contrast much greater at the beginning of the thaw season (not shown).



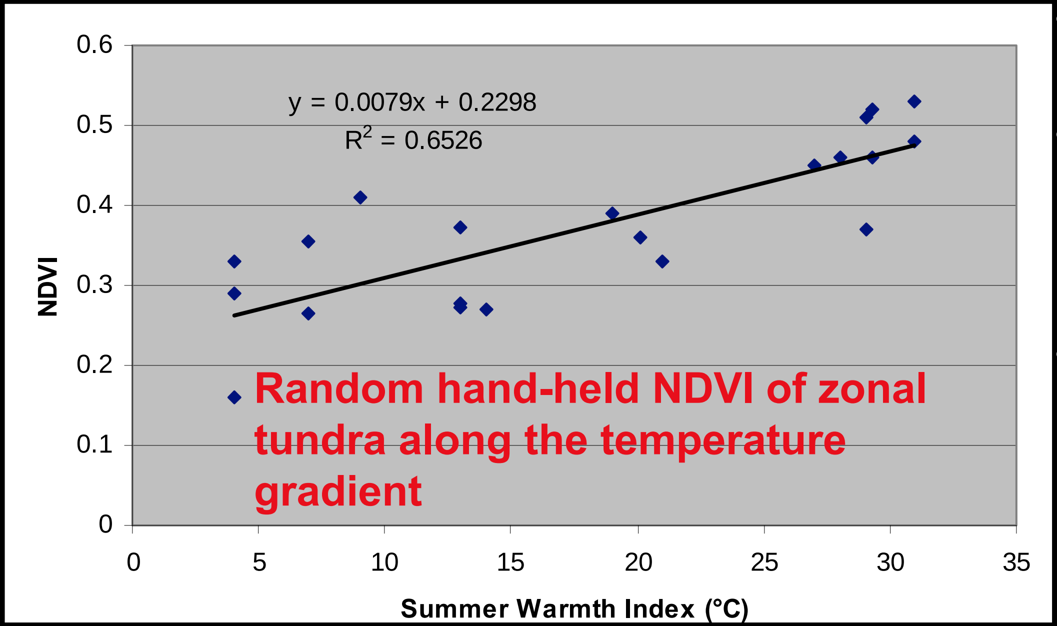




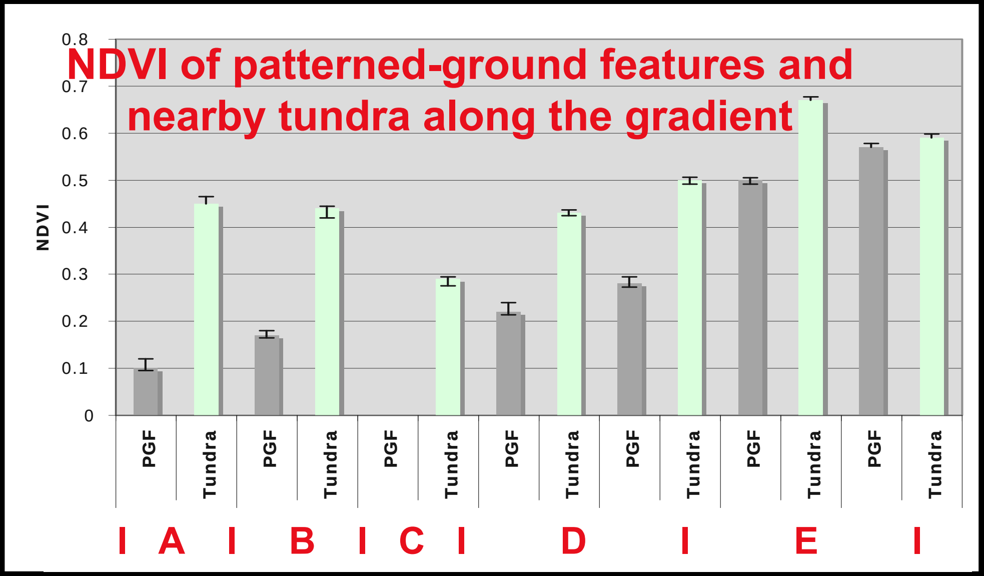
Biomass responds dramatically to warmer temperatures.

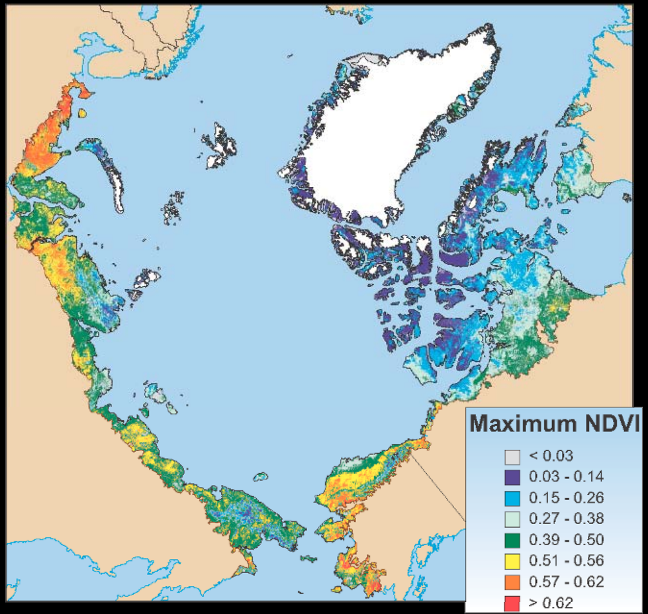
- 5-fold increase on zonal sites.
- 30-fold increase on patterned-ground features.
- Shift in dominant growth forms with temperature on zonal sites.
- Different suite of plant growth forms on the patterned-ground features.

Biomass affects NDVI along the transect.



- 2-fold increase of the NDVI on zonal surfaces.
- NDVI of patterned-ground features increase more rapidly than that of the adjacent tundra areas.
- Barren:zonal ratio decreases toward the south and affects circum-polar NDVI patterns.





Courtesy of Howie Epstein and Alexia Kelley

Vegetation removal and transplant experiment (Anja Kade)

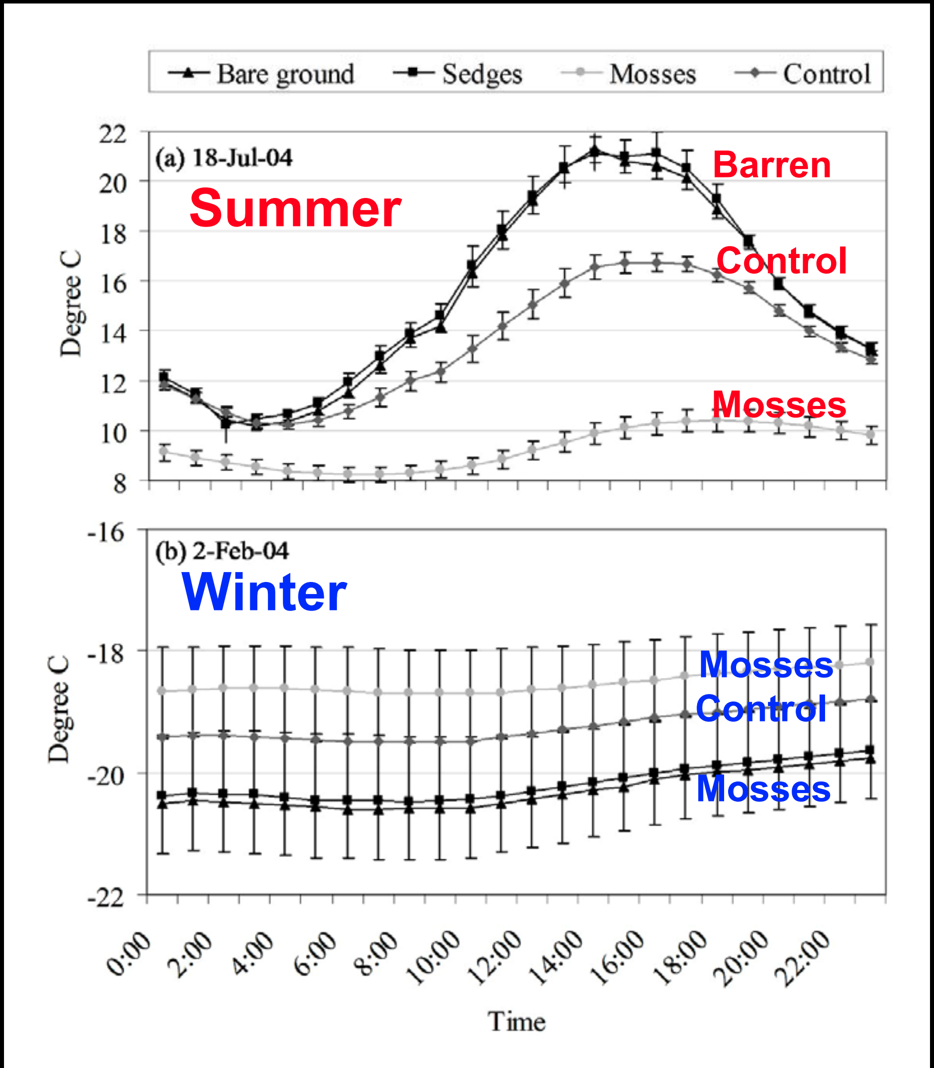
Control

Vegetation removal (barren)

Transplant sedges

Transplant moss carpet

Effects of vegetation on summer and winter soil surface temperatures.



Mean Summer Temperaure:

Vegetation removal: +1.5°C (+22%)

Moss addition: -2.8 °C (-42%)

Mean Winter Temperature:

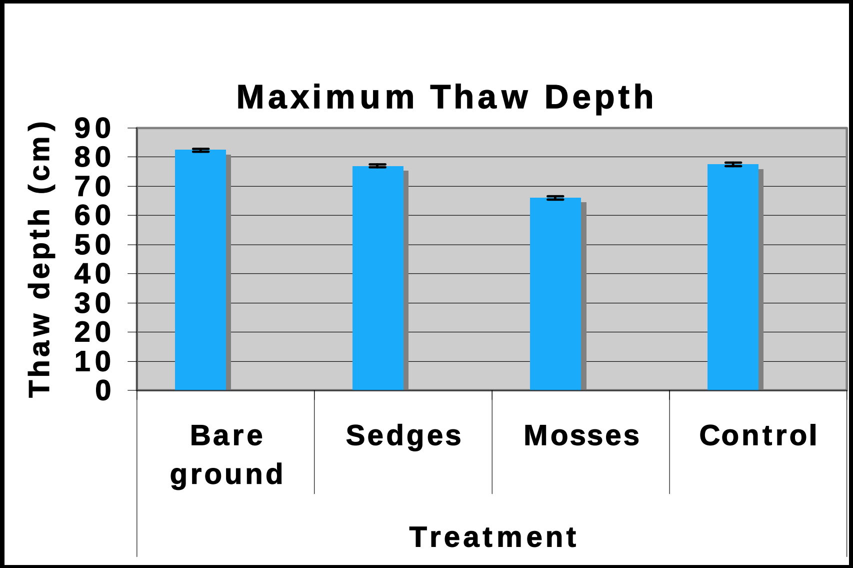
Vegetation removal: -0.9°C (-6%)

Moss addition: +1.3°C (+7%)

- The sedge treatment had a similar response as the barren treatment.

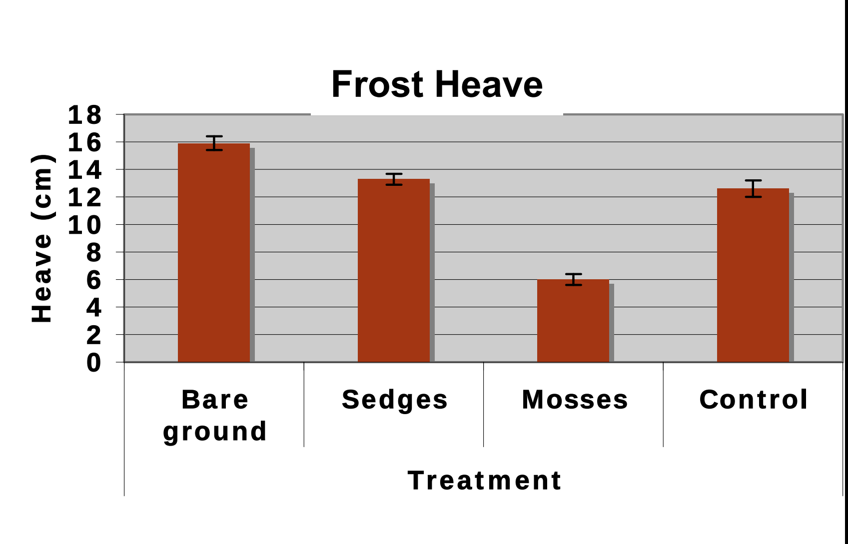
Kade and Walker in press

Effects on thaw depth and heave



Thaw:

Vegetation removal: +5 cm (+6%)
Moss addition: -11 cm (-14%)

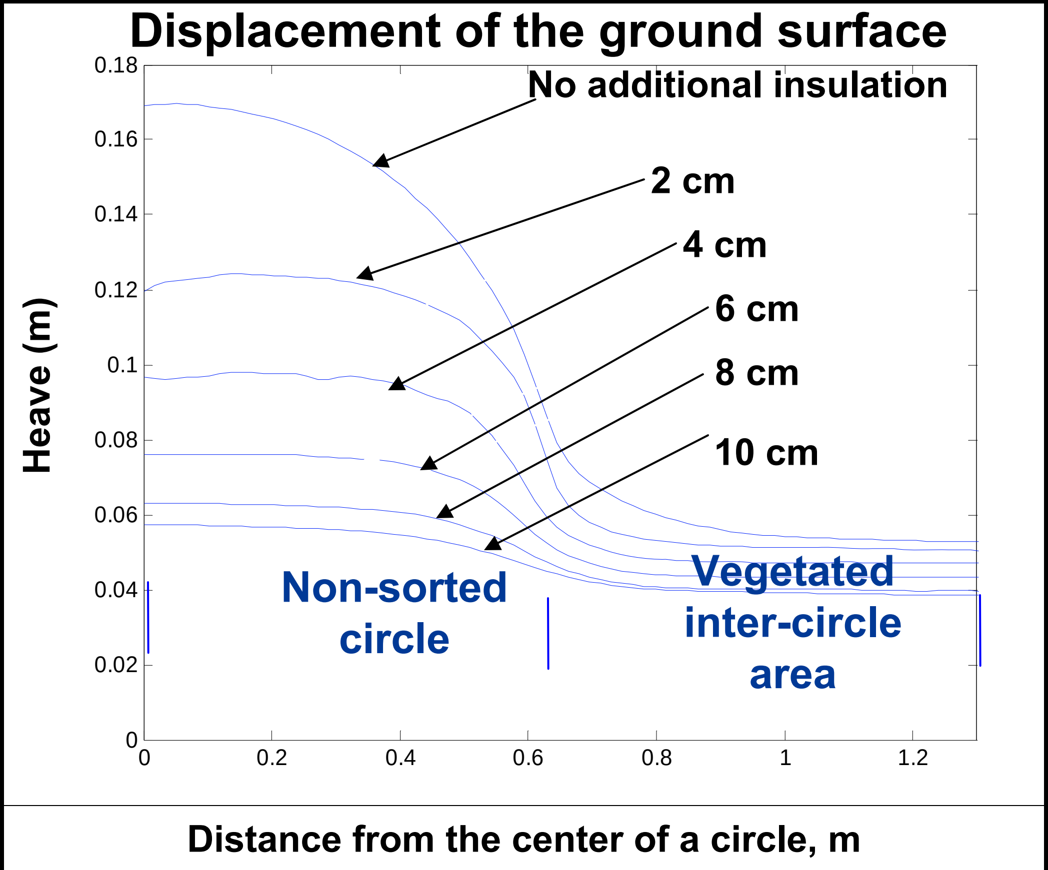


Heave:

Vegetation removal: +3 cm (+24%)
Moss addition: -5 cm (-40%)

Kade and Walker in press

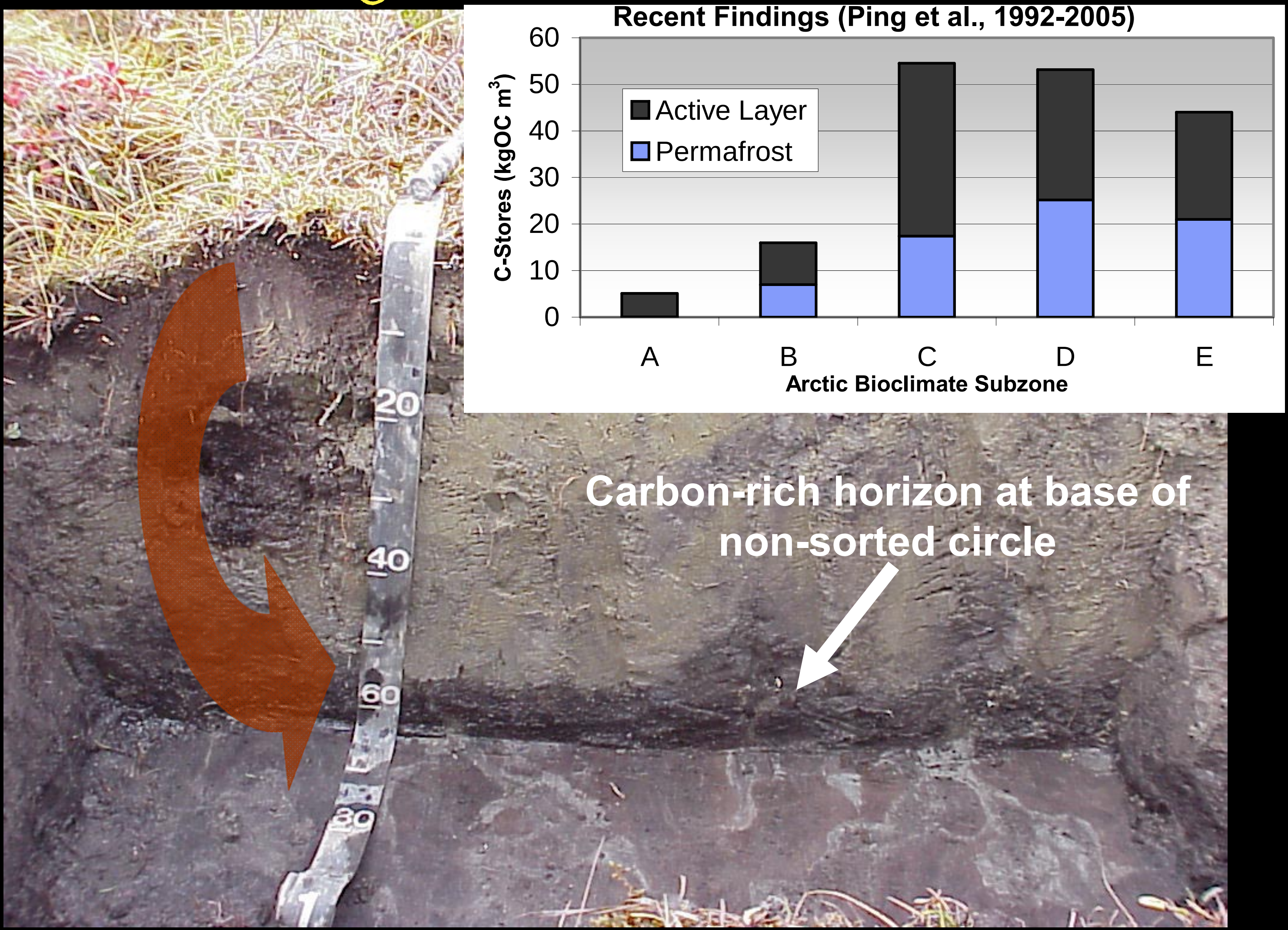
Thermo-mechanical model of frost-heave: vegetation interactions (D. Nickolsky et al.)



- *Differences in heat flux drive the movement of water necessary for differential heave.*
- Vegetation removal, as occurs with many types of disturbance, causes cryogenic activity to increase.
- Adding a thick vegetation mat, as occurs with vegetation succession, reduces frost heave and other cryogenic processes.

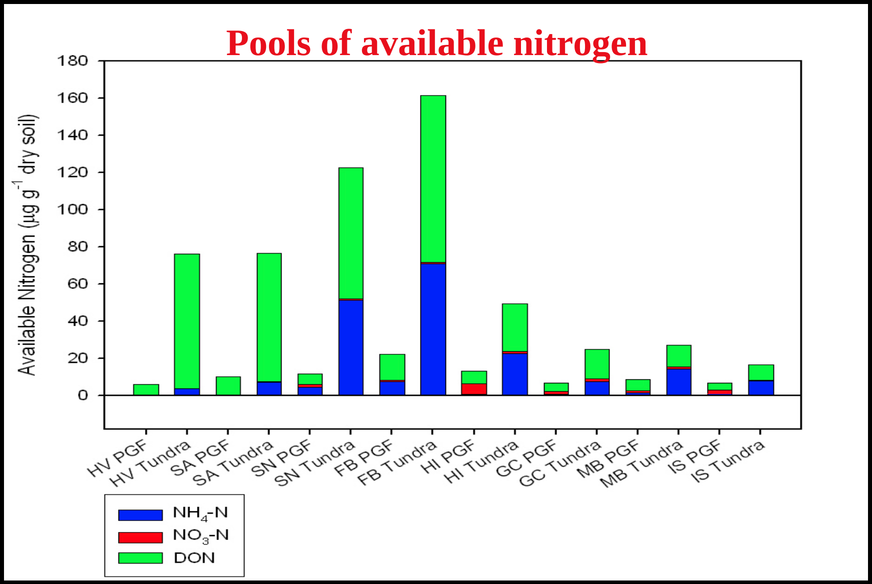
Sequestered carbon at depth caused by cryoturbation.

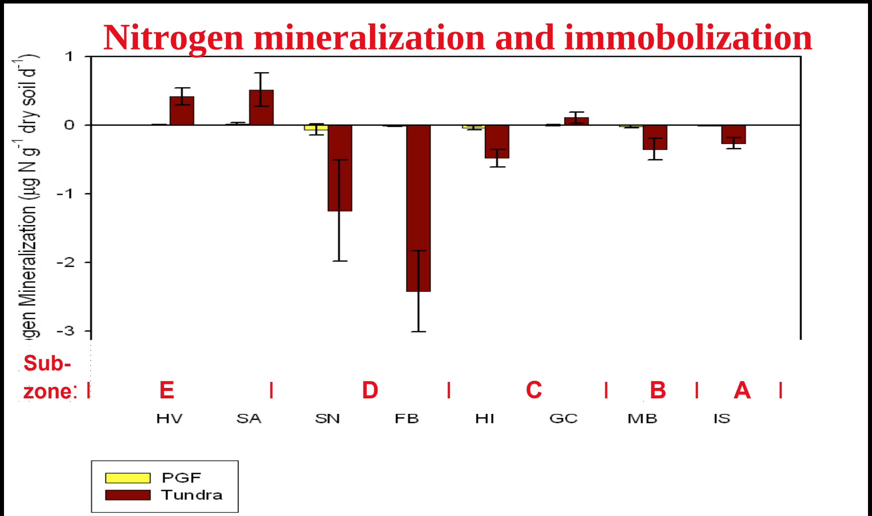
- Movement of carbon from margin of circle to the base of circle via cryoturbati on.
- 2x previous estimates of soil carbon in subzones D and E.



Photos courtesy of Gary Michaelson.

Effects on soil nitrogen



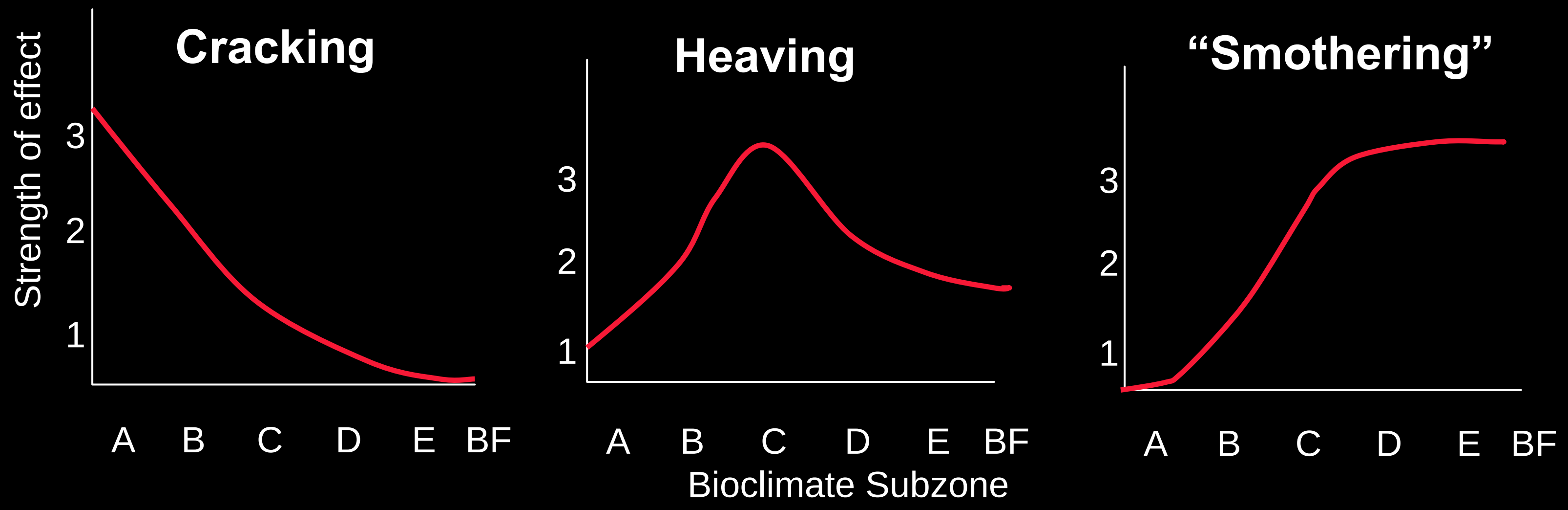


Courtesy of Alexia Kelley, in prep.

- Strong differences in nutrient pools between patterned ground features (short bars) and the surrounding tundra (long bars).
- Nutrient pools and N-immobilization are greatest in subzone D, the region with the warmest soil temperatures.

Conclusions:

1. Cracking, differential heave and vegetation succession all interact to affect pattern-ground morphology along the Arctic climate gradient. Each of these processes has its dominant effect in a different part of the climate gradient.



Conclusions

2. Our study and models focused on the combined effects of differential heave and vegetation succession. New models will be needed to incorporate cracking.
3. Strong thermal contrasts between the centers and margins of heave features drive the movement of water and the development of frost heave.
4. The presence of patterned ground affects most ecosystem processes at small spatial scales. How these small-scale processes scale up to large regions still needs to be described.
5. Experimental manipulation of small-patterned ground features, such as that of Anja Kade help elucidate the response of these features to disturbance.