Interactions of climate, sea-ice, land-temperatures carbon, and humans in the Arctic: an overview

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Photo courtesy of Bryan and Cherry Alexander

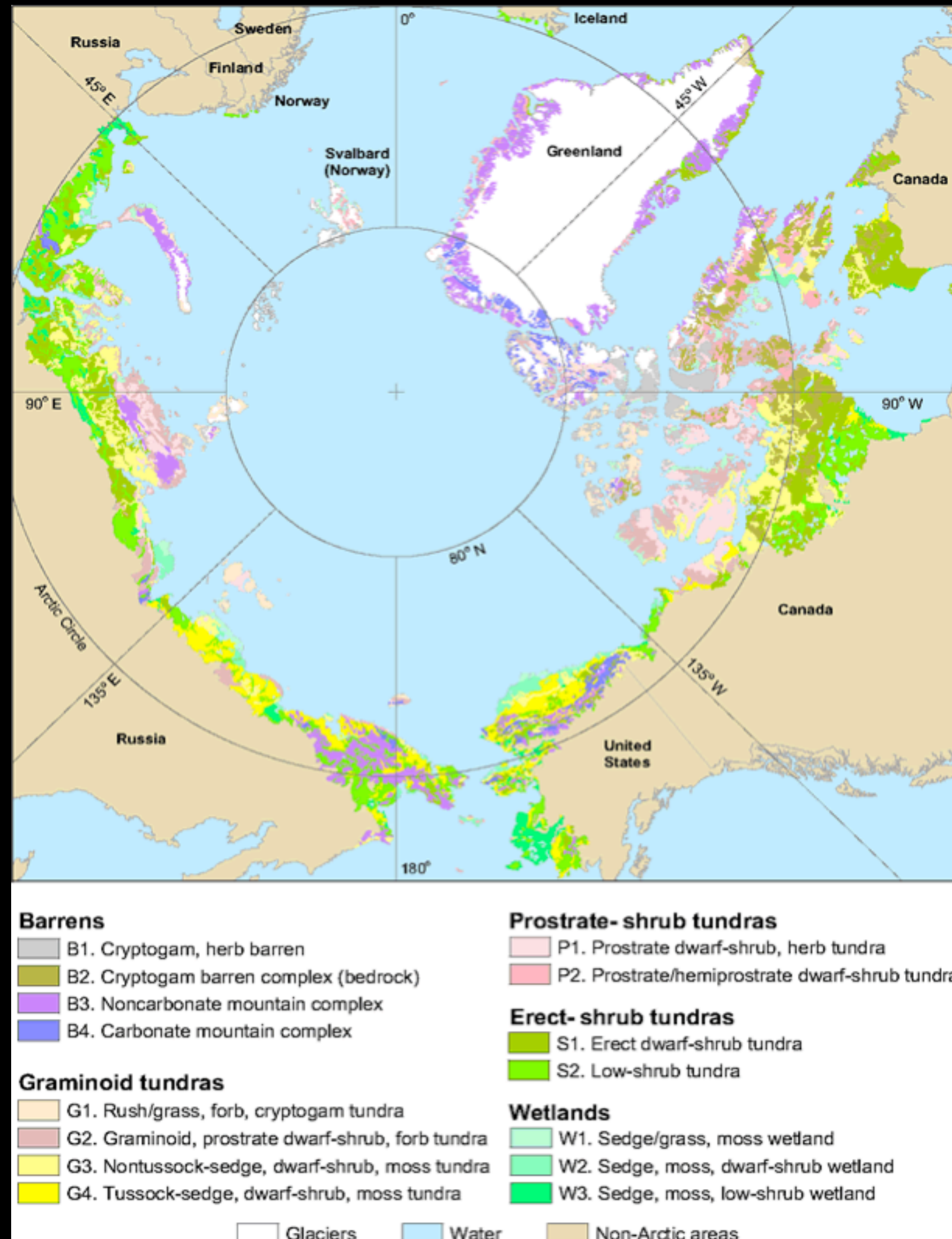
Outline

- The Arctic and LCLUC
  - The Arctic Bioclimate Zone.
  - Threat from global warming to the Arctic.
  - Carbon in the Arctic.
  - Sea-ice LST trends in the Arctic.
  - Evidence for vegetation change.
  - Threats of vegetation change to northern people.
  -
- Overview of the Greening of the Arctic initiative.
  - Science questions.
  - Approach.

- Overview of NASA-funded GOA project.
  - Northern Eurasia Earth Science Partnership Initiative (NEESPI)
  - The Yamal Peninsula.
  - Progress during Year 1.
  - Early results.
  - Plan for 2008 and 2009.

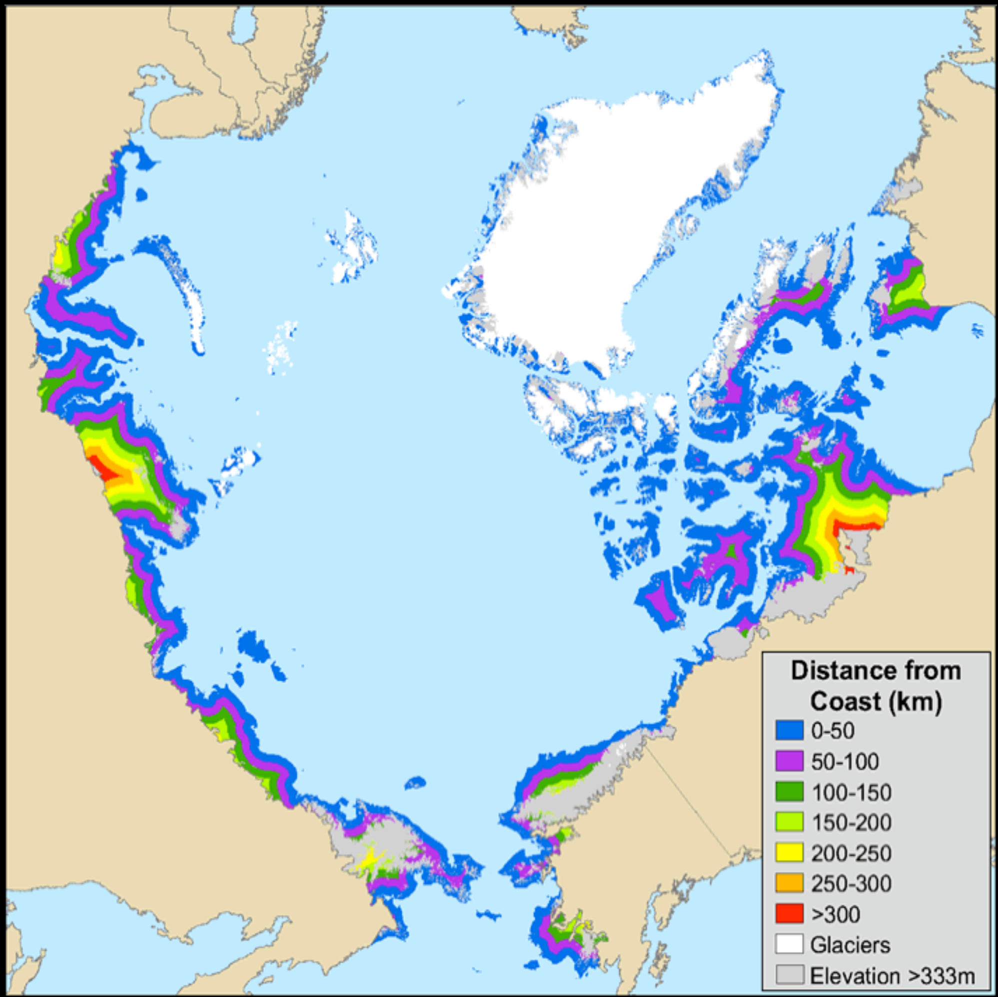
The Arctic tundra is a maritime biome

- Arctic tundra is defined as the area that has an Arctic Climate an Arctic flora, and contains tundra vegetation.
- Southern boundary of the mapped area is tree line.
- Note the close proximity of all parts of the biome to perennially or seasonally frozen seawaters.
- Tundra regions are defined by the cool summer temperatures caused by the proximity of the region to sea ice.



Changes in sea-ice concentrations could strongly affect the tundra

- 61% of the tundra is within 50 km of sea ice (blue buffer),
- 80% is within 100 km (magenta and blue buffers),
- 100% is within 350 km.
- Changes in the Arctic ocean sea ice will very likely affect terrestrial ecosystems by affecting summer-time land-surface temperatures.



Tree-line is advancing from the south and from low elevations

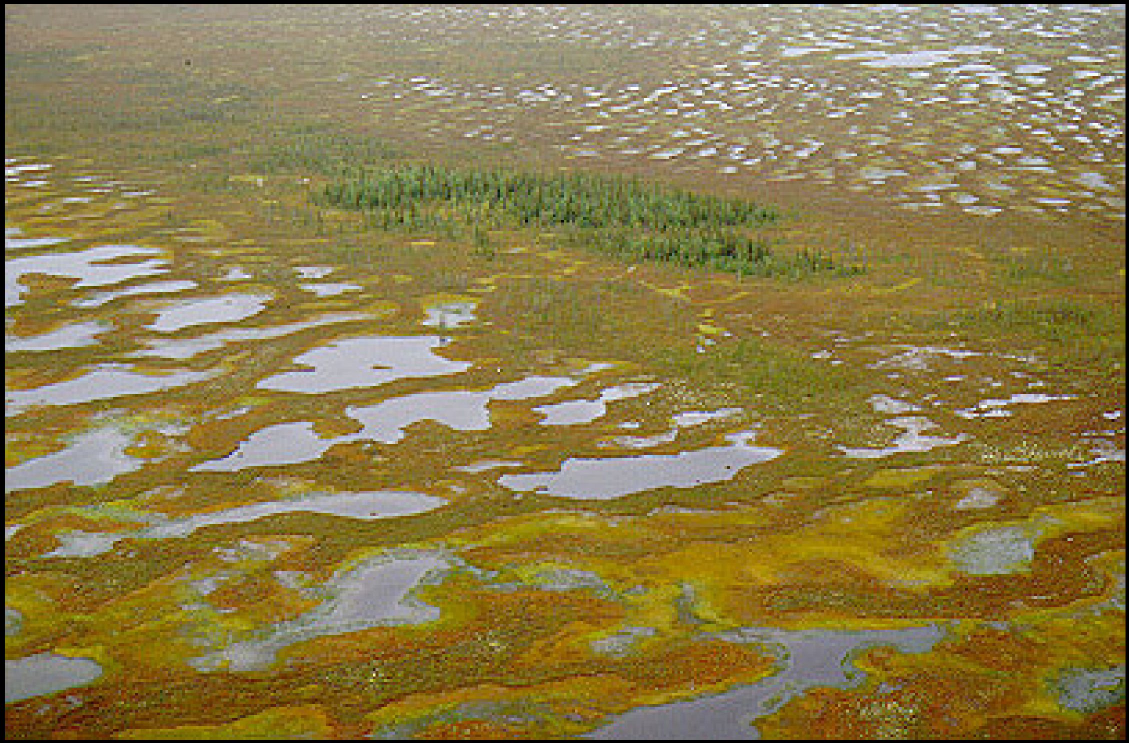
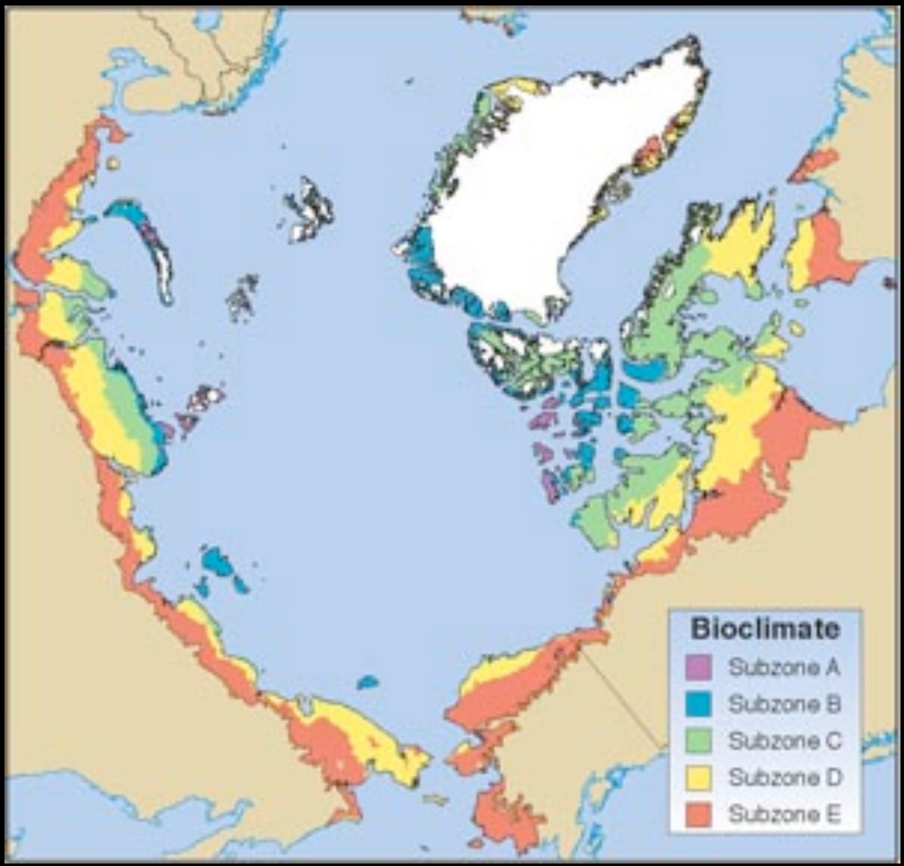


Photo P. Kuhry, http://www.ulapland.fi/home/arktinen/tundra/tu-taig.htm

- Treeline advance is not a matter of gradual response to temperature.
- Threshold responses suggest that pattern and timing of change is contingent on local, landscape, and regional-scale factors, as well as species' biology (Danby and Hik 2007).
- Response in Arctic is strongly related to permafrost and local hydrology.

Arctic Bioclimate Subzones



Sub-zone	Mean Jul Temp (˚C)
A	< 3
B	3-5
C	5-7
D	7-9
E	9-12

High, Middle and Low Arctic

Subzone A

Subzone C

Subzone E

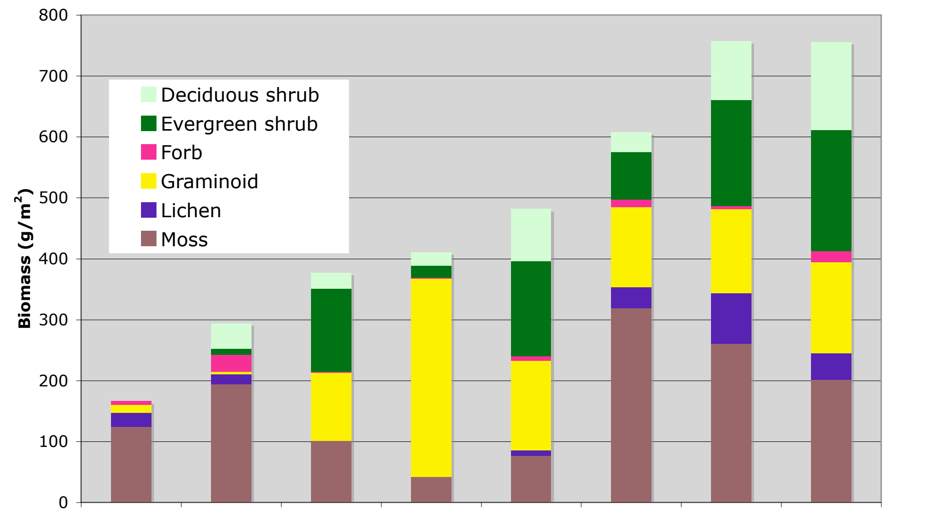
Across this narrow transition there is a 10-fold increase in biomass,

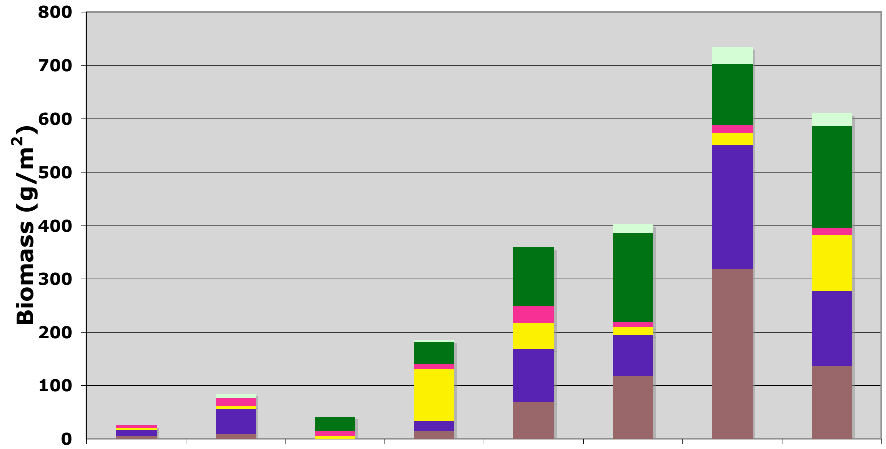
Carbon in the Arctic

- The average aboveground biomass per unit area of tundra (the standing crop) is estimated to be about 550 g m^{-2}. This compares to about 9500 g m^{-2} in the boreal forest and 7150 g m^{-2} for global terrestrial ecosystems.

- Within the Arctic, there is 5-30 fold increase in biomass from north to south (subzone A to E).

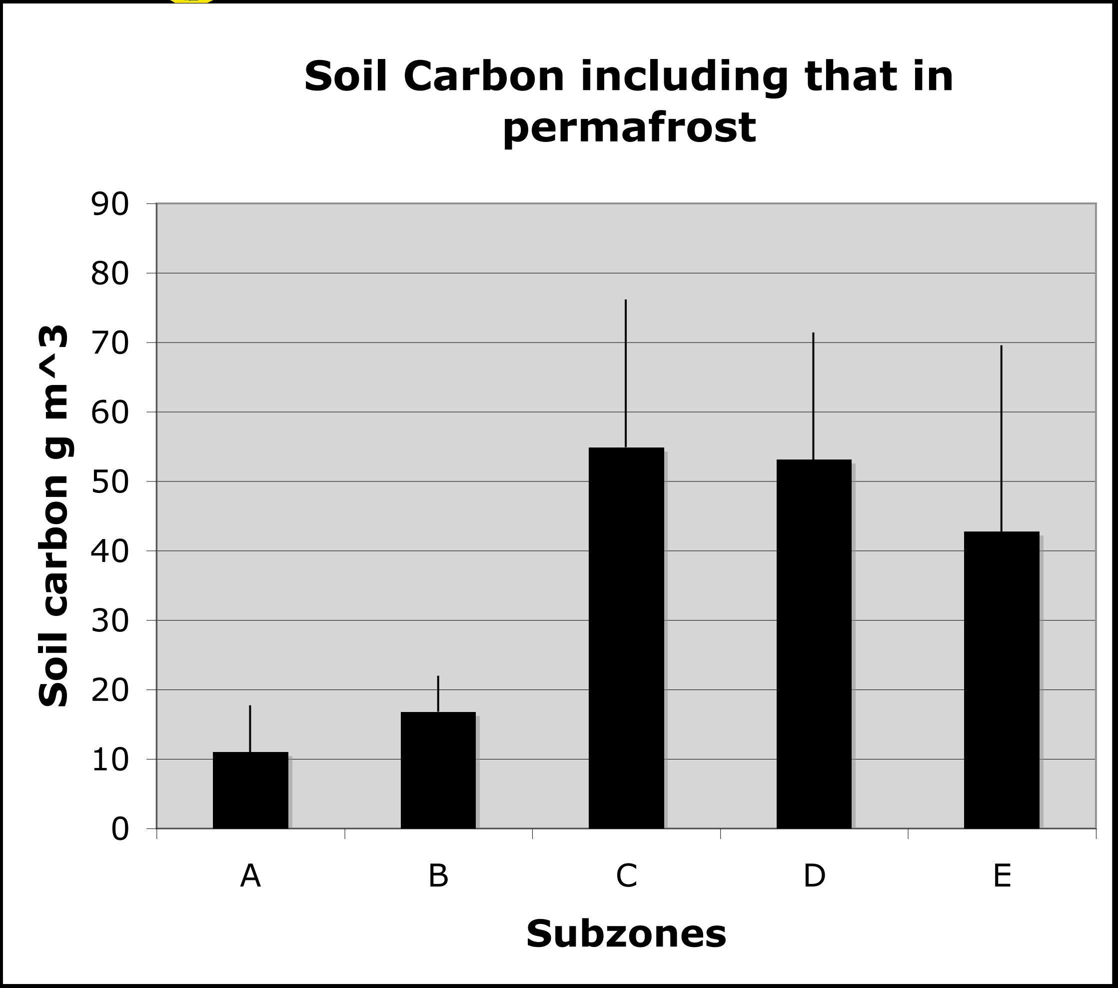
- Large variation in dominant plant growth forms. Much more moss in the Low Arctic (subzones D and E.)





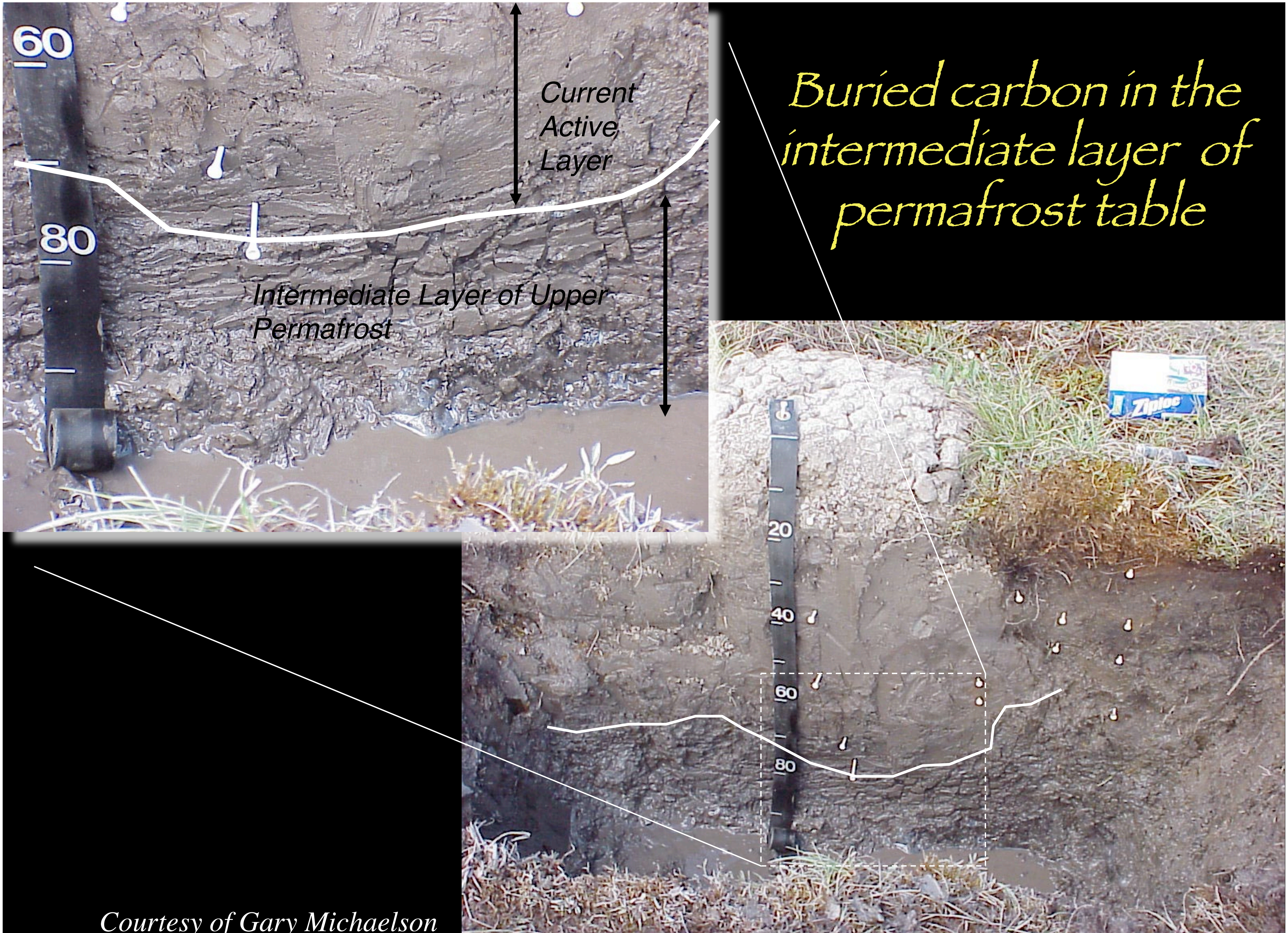
Below-ground Carbon

- A large amount of carbon accumulates in arctic soils due to slow decomposition rates.
- Published soil:vegetation C ratios are estimated to be 13:1 in the Arctic compared to 1.2 in the boreal forest and 0.8 globally.
- The combined total amount of carbon in the vegetation and soils in arctic and alpine tundras is estimated at about 9750 g m^{-2}, compared to the 13000 g m^{-2} for the global average .
- This is a conservative estimate because it is based only on the carbon in the active layer (see graph).



Courtesy of Chien Lu Ping 2007 in prep.

Buried carbon in the intermediate layer of permafrost table



Courtesy of Gary Michaelson

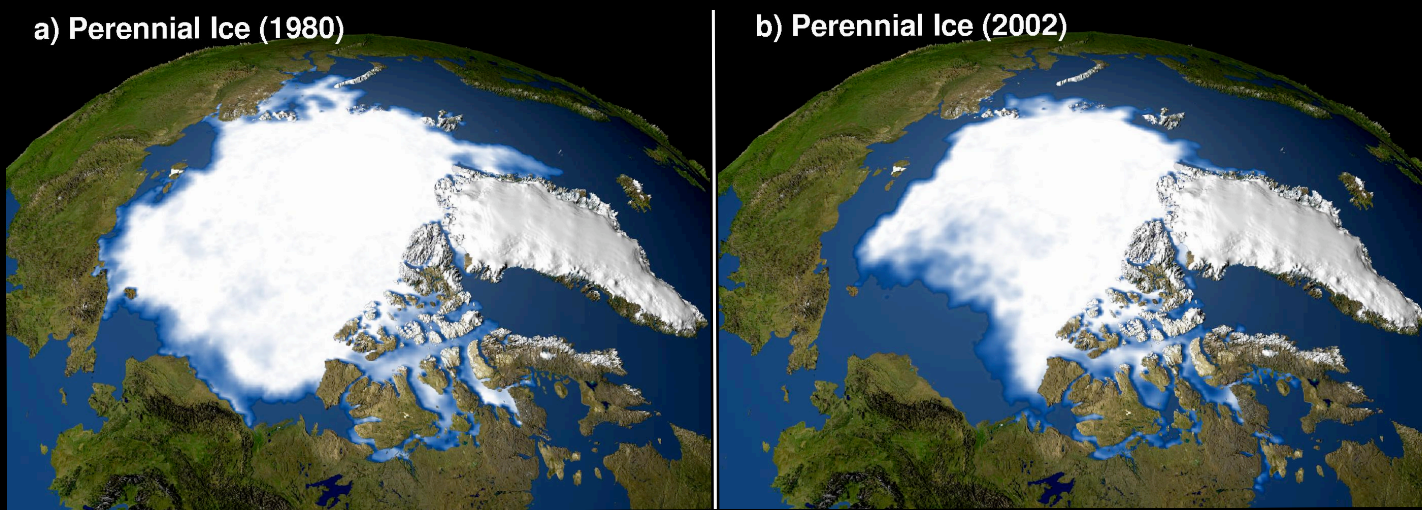
Changes to the above-ground carbon pool will have profound effects on nearly all Arctic system properties

Greater above-ground biomass will:

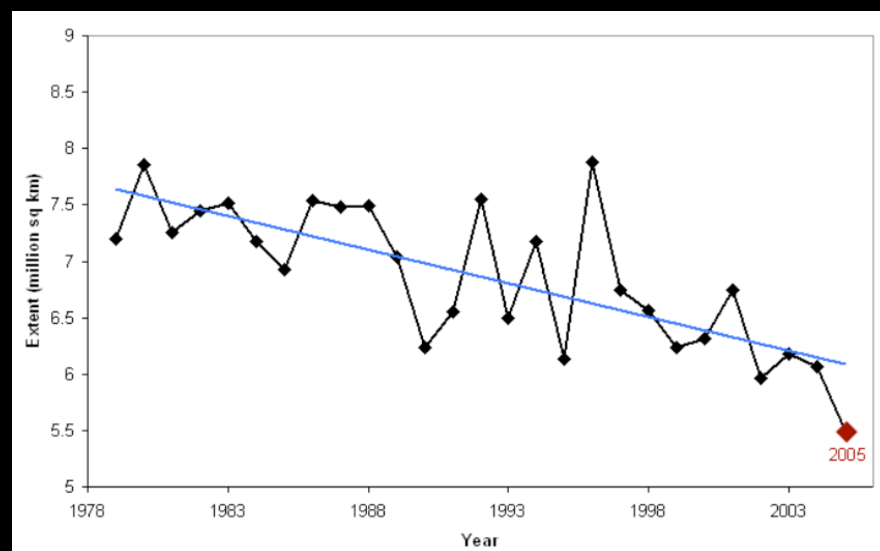
- Increase below-ground carbon reserves
- Trap more snow and water and affect
  - flux of moisture to the atmosphere
  - run-off of fresh water to the Arctic ocean
- Greater snow in winter and thicker vegetation mats will affect:
  - the insulation of the soils
  - soil temperatures and heat flux
  - active layer depths
  - permafrost temperatures

- Parts of the High Arctic will become more vegetated and function more like the Low Arctic.

Trend in sea ice

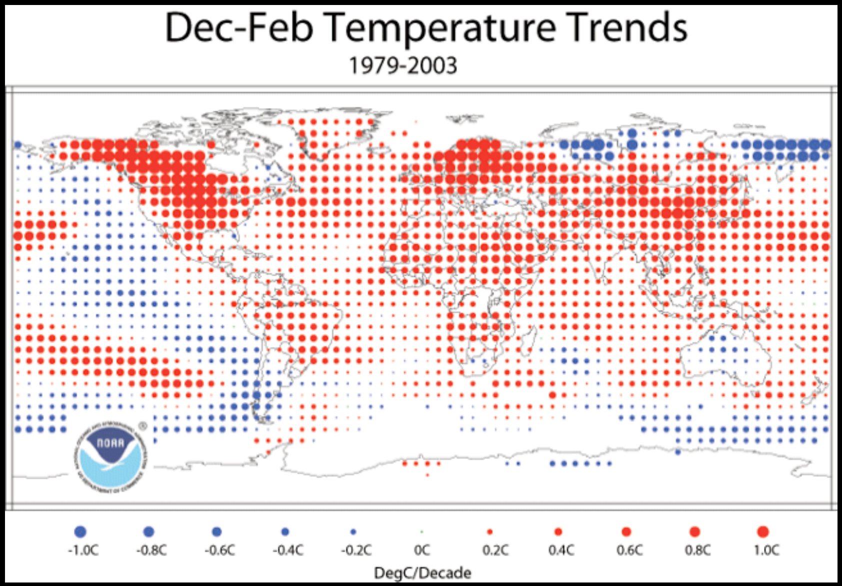


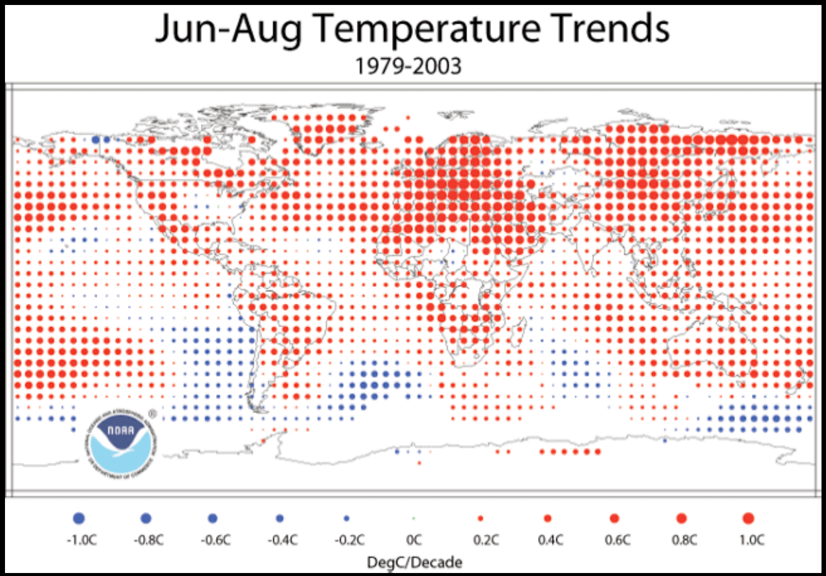
Since 1980, perennial sea ice in the Arctic has declined at rate of 9.8% per decade (Comiso 2006).



Courtesy of National Snow and Ice Data Center, http://nsidc.org/news/press/20050928_trendscontinue.html#fig1

Trend in surface temperatures



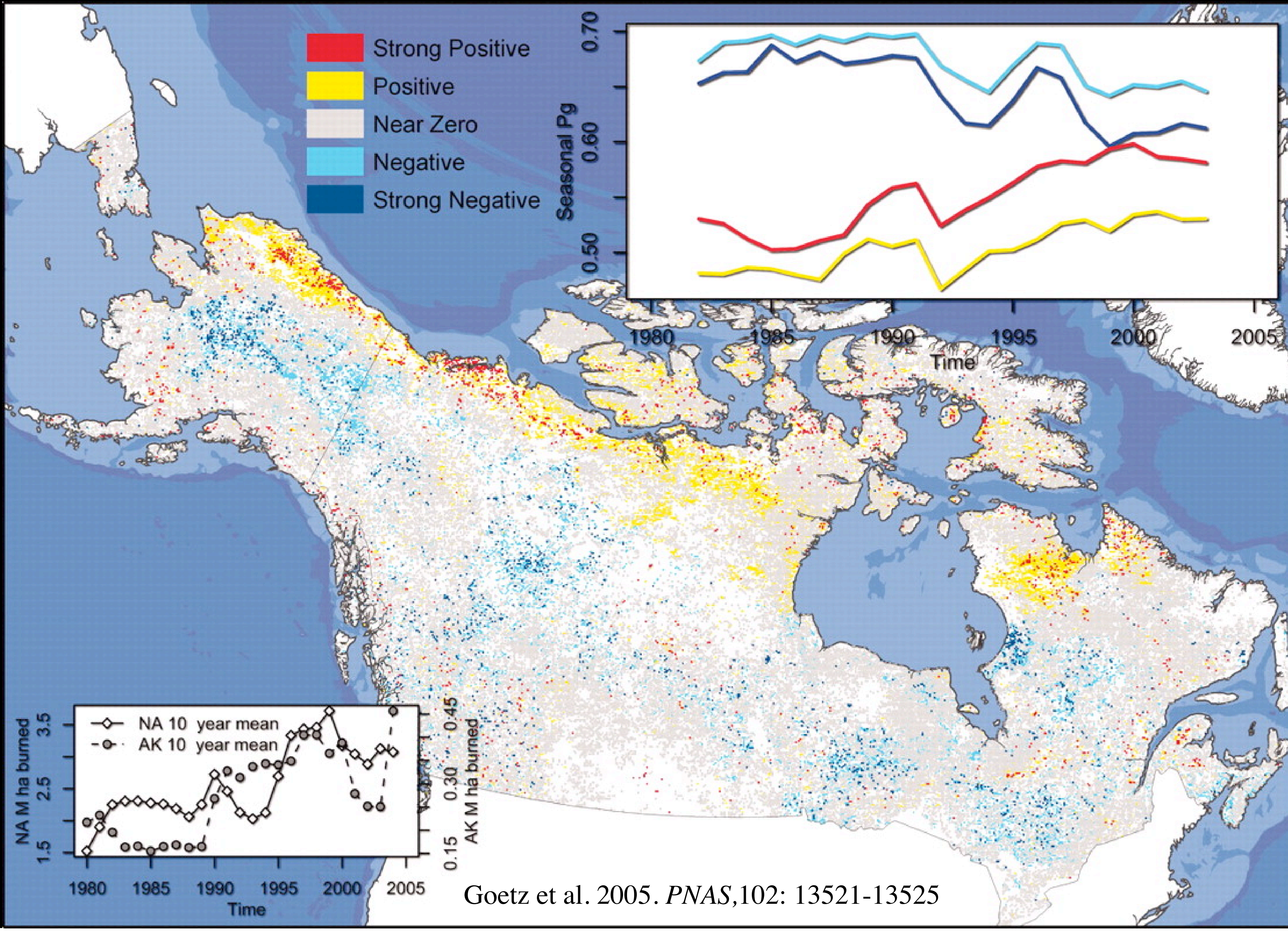


Courtesy of NOAA National Climate Center, http://www.ncdc.noaa.gov/oa/climate/research/trends.html

Land-surface temperatures of North America north of 60˚ N rose at rate of 0.84± 0.18 ˚ C per decade since 1978 (Comiso 2006).

Arctic plant biomass and diversity are strongly related to total amount of available summer warmth, so changes in surface temperatures will likely result in increased biomass over much of the Arctic.

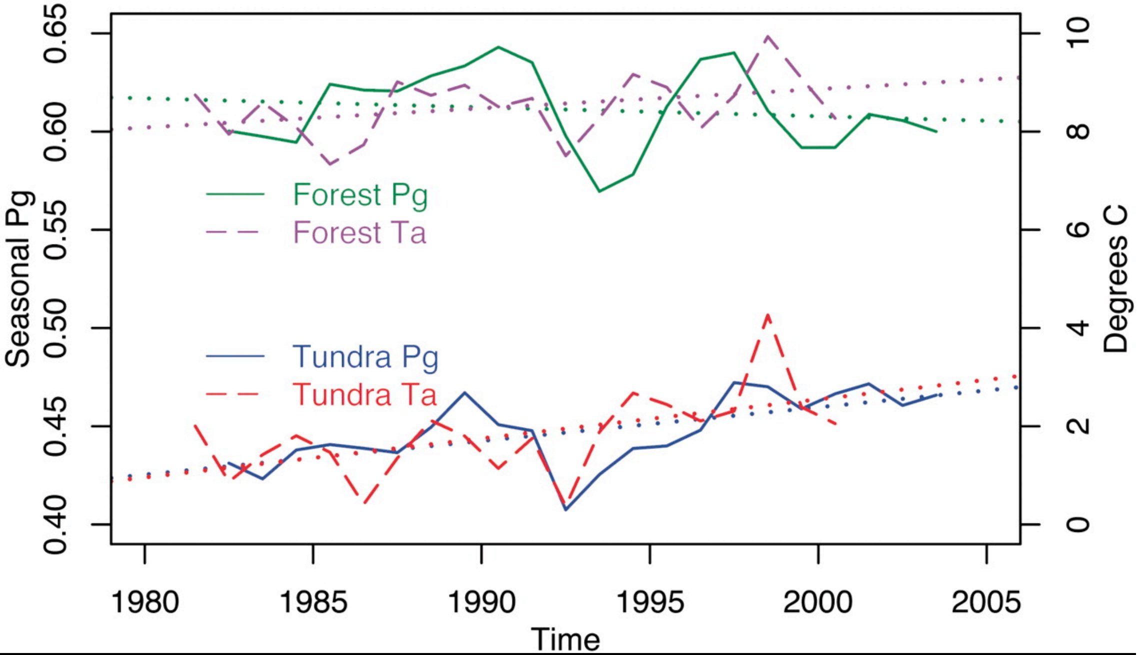
1981-2003 Trends in NDVI across Canada and Alaska



Goetz et al. 2005. *PNAS*,102: 13521-13525

Trends in temperature and NDVI in the forest and tundra

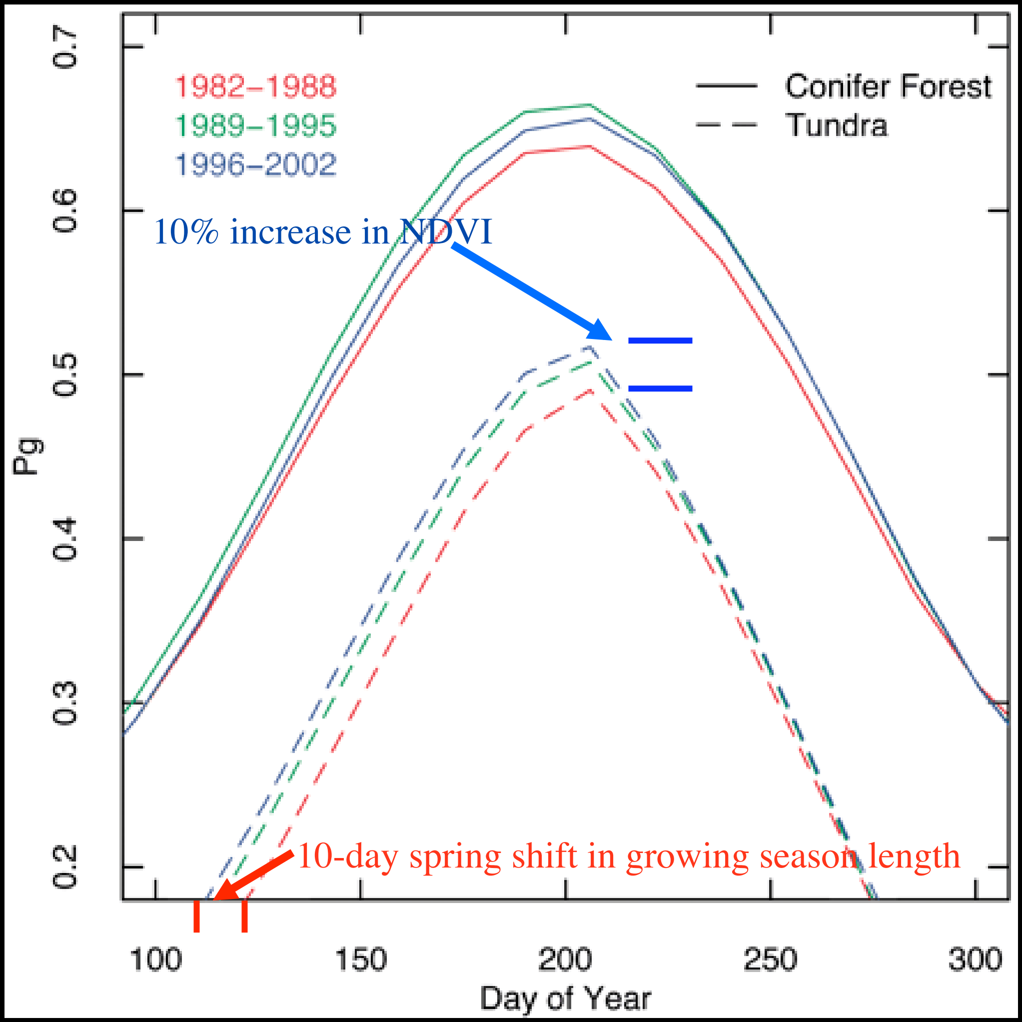
- Temperature has increased in both the forest areas and the tundra.
- NDVI has declined in the forest and increased in the tundra following the Pinatubo eruption in 1991.
- Decline in the forests may be due to drought stress.



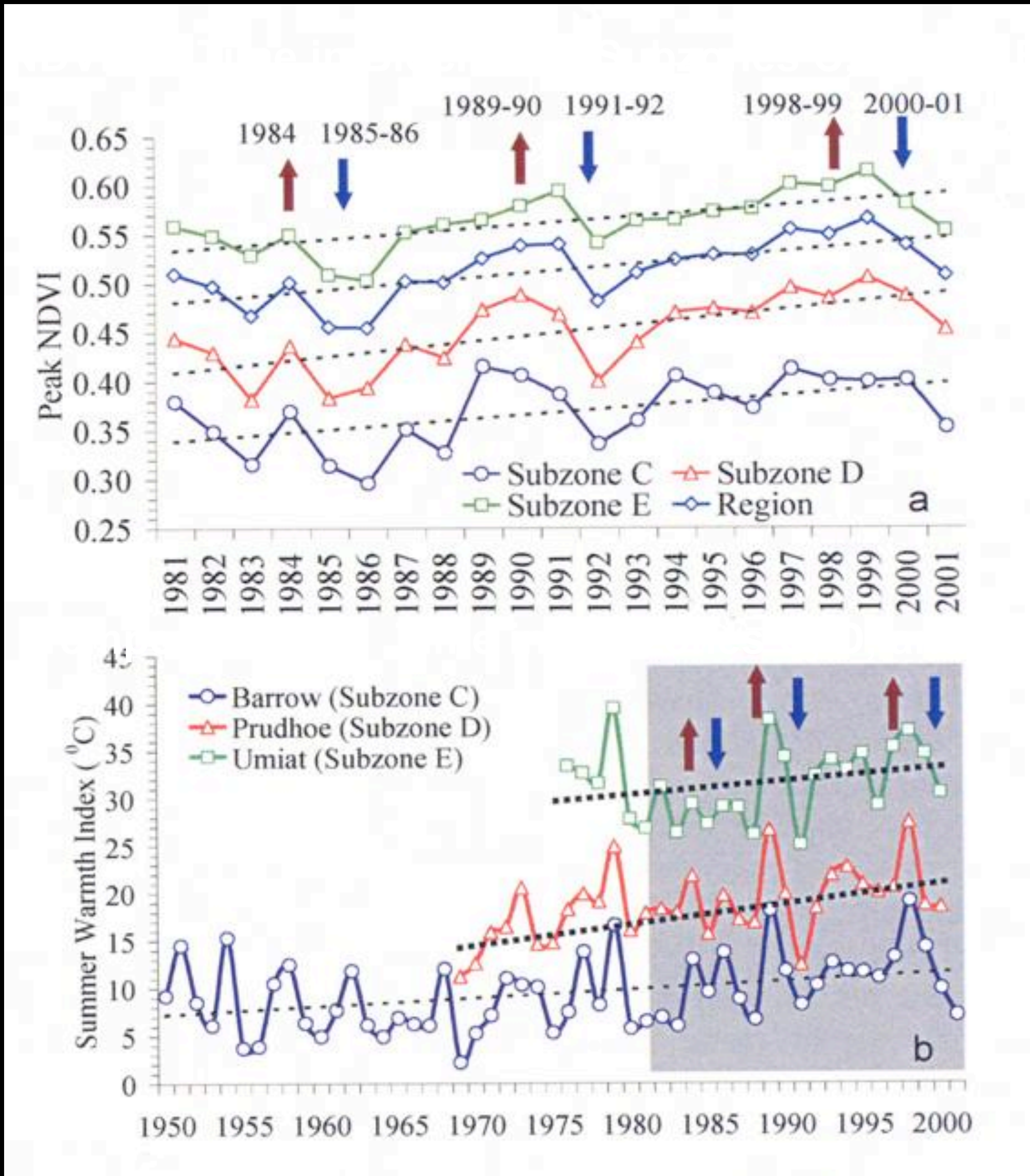
Goetz et al. 2005. *PNAS,*102: 13521-13525

The spring season has started earlier and max NDVI has increased

- NDVI trends for the forested and tundra regions, broken down by six-year intervals.
- The forested areas show a recent decline in the maximum Pg.
- Tundra regions have shown a continued increase in Pg and a marked 10-day shift toward earlier onset of greening.
- There is no corresponding shift in the cessation of the greening period.



Goetz et al. 2005. *PNAS*,102: 13521-13525



Time series of peak NDVI for northern Alaska (1981-2001)

- 17 ± 6% increase in peak NDVI from 1981-2001.
- Corresponds to about an 170 g m^{-2} average increase in biomass.
- Changes in NDVI follow yearly changes in temperature and long term increase.
- Currently unknown if similar changes have occurred across the entire Arctic bioclimate gradient.

Scepticism regarding magnitude of greening trends

"Should we believe in the NDVI trend? There are no "ground truth" measurements of photosynthesis at northern high latitudes over the same period, and so the accuracy of the trend cannot be established unambiguously…. It will be a challenge for ecologists to explain how photosynthesis could possibly have increased by approximately 10% from 1981 to 1991."

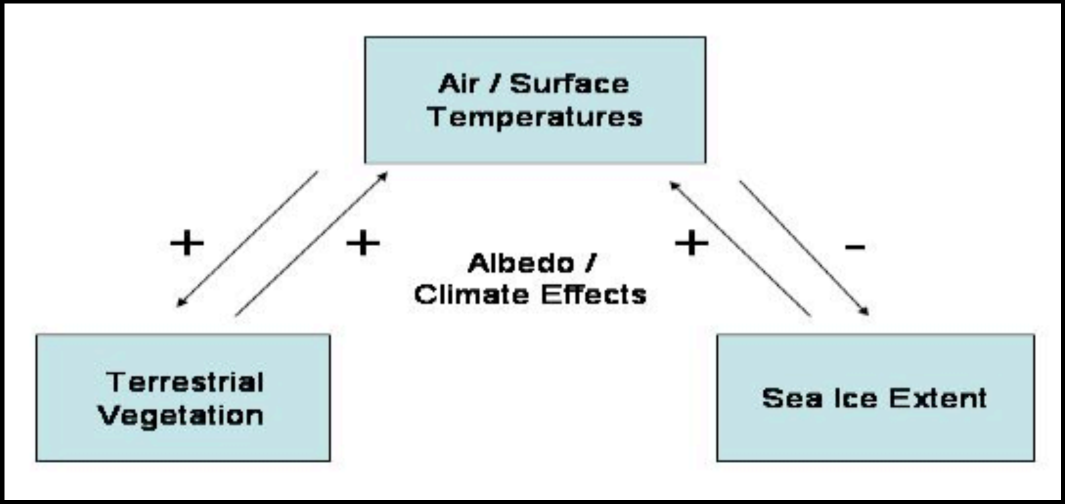
(Inez Fung 1997.)

Why changes to the vegetation are important

- Vegetation changes have major implications for the
  - carbon cycle (McGuire et al. 2000, Shaver et al. 2000, 2001; Oechel et al. 2000)
  - active layer (Nelson et al. 1987, Walker et al. 2003),
  - snow distribution (Sturm et al. 2001, 2005),
  - hydrology (Hinzman et al. 2005),
  - soils (Ping et al. 2004),
  - wildlife (Griffith et al. 2003),
  - trace-gases (Oechel et al, 2000, 2001; Reeburg et al. 1998; Eugster et al. 2005).
  - and albedo feedbacks to the climate system (Chapin et al. 2005),
  - …ultimately to people living in the Arctic and to the planet as a whole (ACIA, 2004, Sturm et al. 2003; Serreze et al. 2000; Overland et al. 2004, Overpeck et al. 2005, Hinzman et al, 2005).

There are many complex feedbacks between vegetation and all of these factors.

Land – Sea-ice Linkages



Linkages between sea ice and terrestrial vegetation are indirect – through albedo/climate feedbacks to the atmosphere.

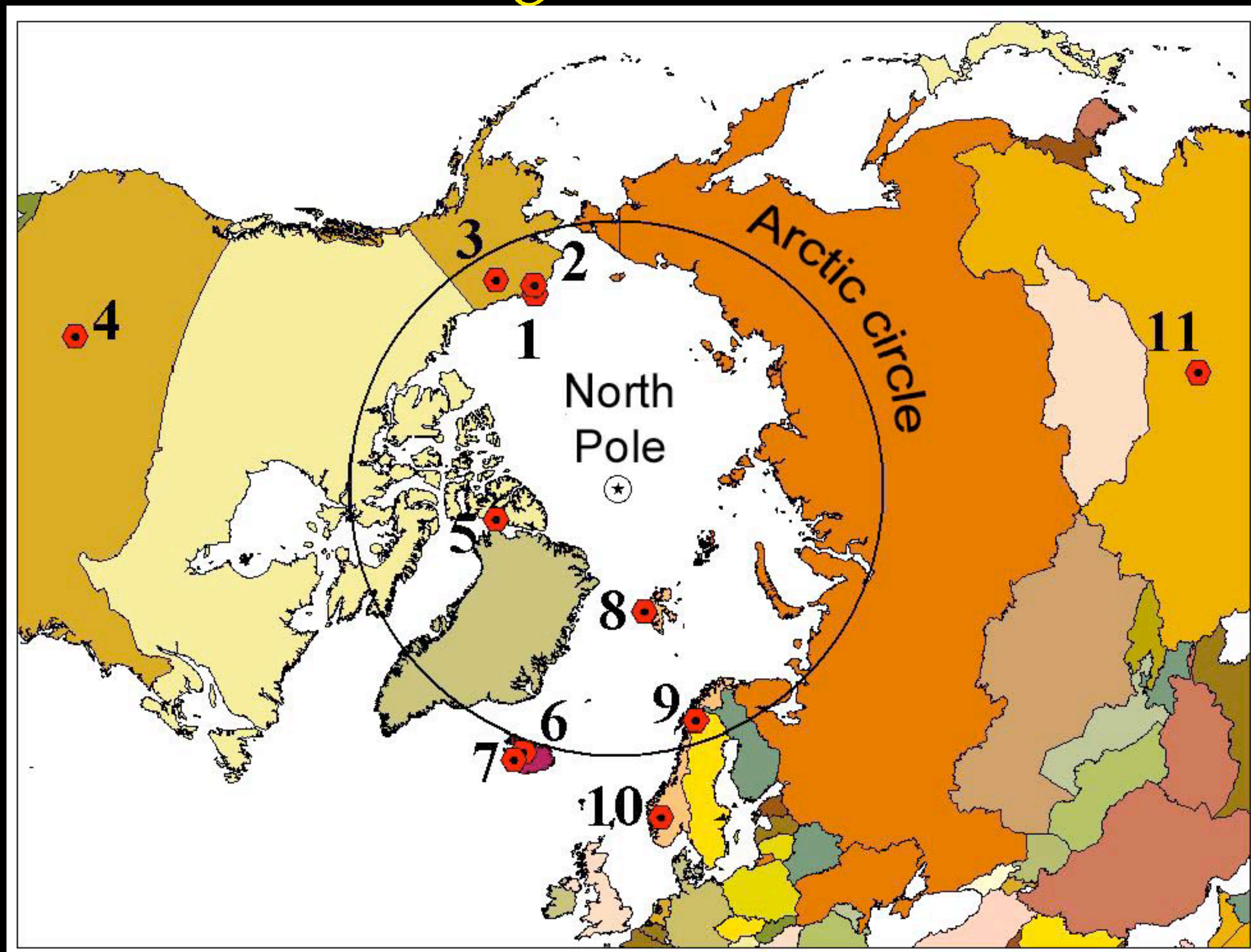
Evidence for Change in Arctic Vegetation

Photo – M. K. Raynolds

Photo record of shrub cover change
(Matthew Sturm, Ken Tape, and Chuck Racine):

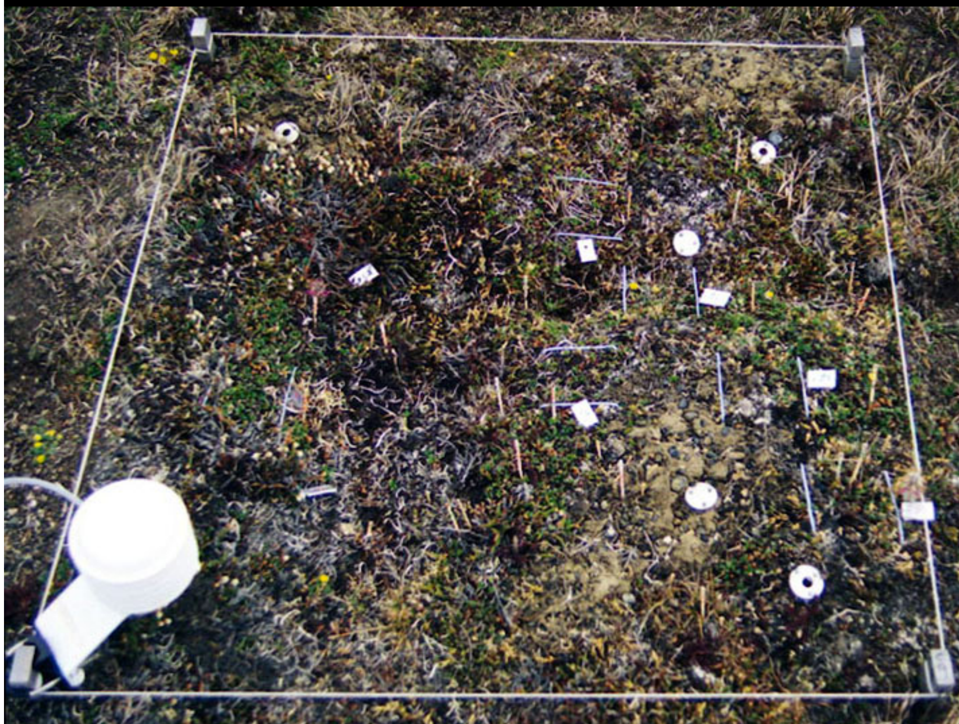
- Over 30% increase in alders on some stable valley slopes in Subzone E.
- Dramatic increase in shrub cover on river terraces.
- More vegetation and less sand and gravel in river floodplains.

International Tundra Experiment (ITEX) synthesis

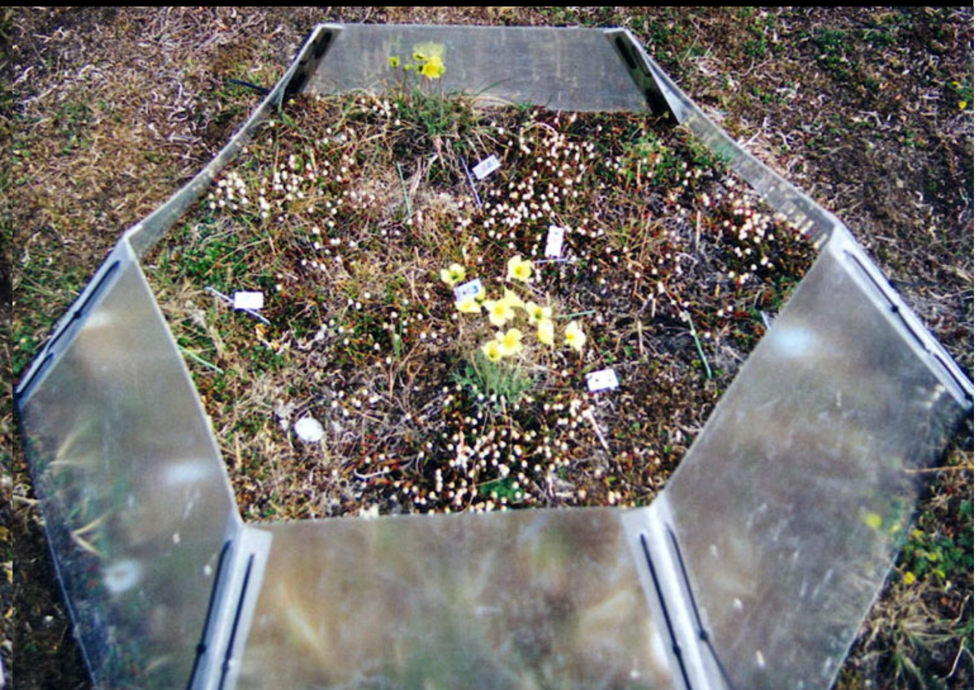


Walker, M. D., C. H. Wahren, R. D. Hollister, G. H. R. Henry, et al. 2005 in review. Plant community responses to experimental warming across the tundra biome. Proceedings of the National Academy of Science.

Community changes in ITEX experiment after 6 years

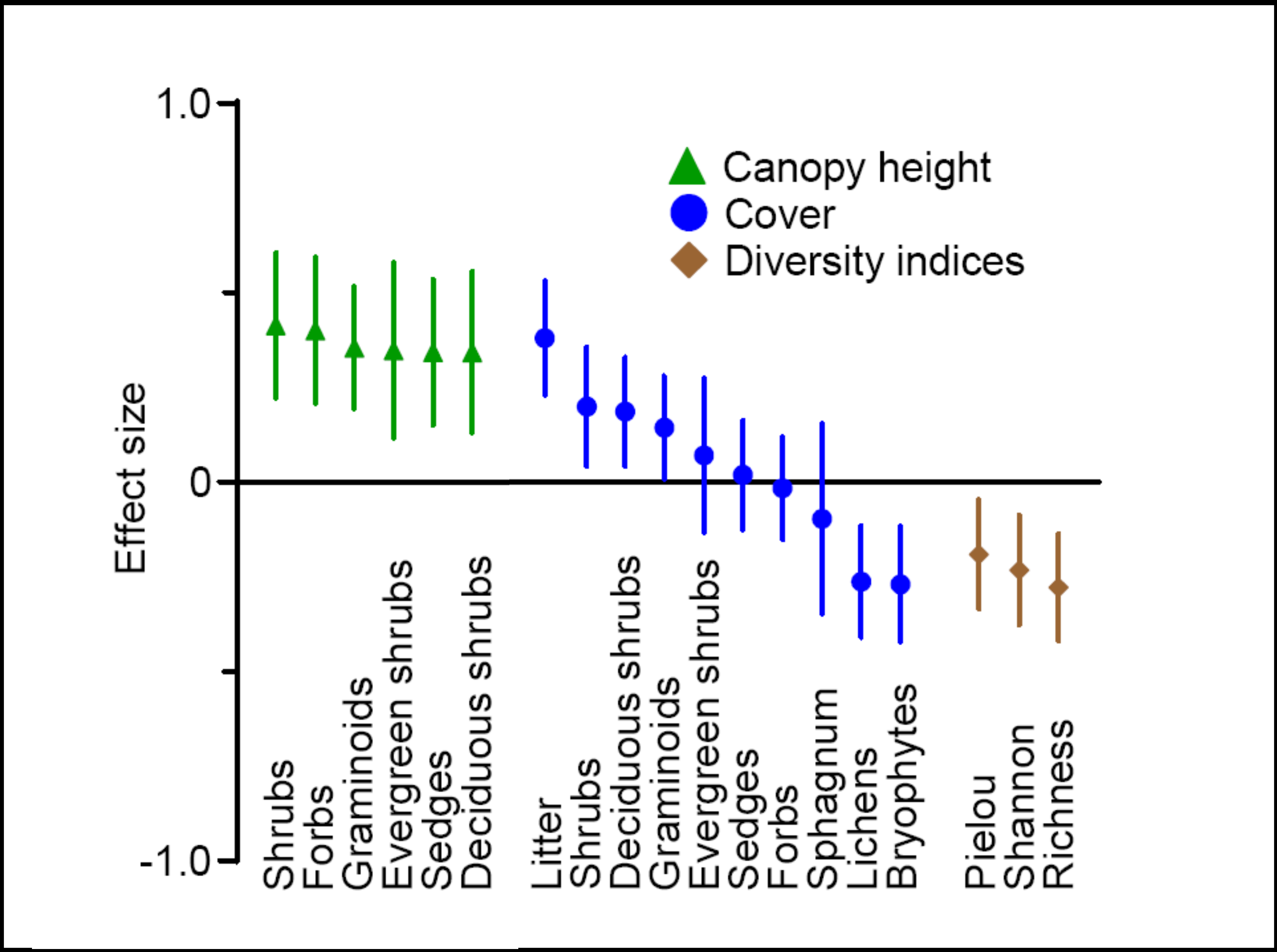


Control



Open-top chamber

ITEX meta-analysis of effects of warming experiment



Relevance to wildlife and people: Spring NDVI on the Porcupine Caribou Herd calving grounds

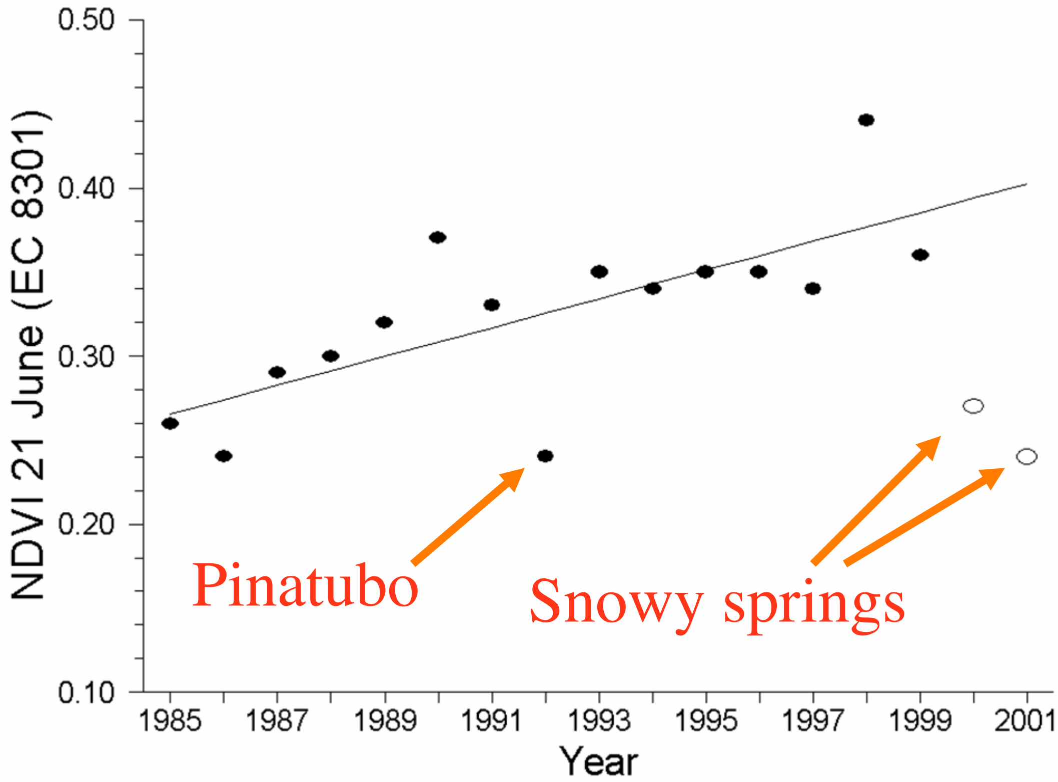


Fig. 3.4. Median Normalized Difference Vegetation Index (NDVI) on 21 June within the aggregate extent of calving for the Porcupine caribou herd, 1983-2001. Values for 2000 and 2001 were outliers (RStudent = -2.49, -2.86, respectively) and excluded from the displayed regression line, *r*2= 0.496, *P* = 0.0023. (USGS/BRD BSR-2002-0001).

Griffith et al. 2002. The Porcupine Caribou Herd. In Douglas et al. USGS BSR 2002-0001.

Caribou-NDVI-climate relationships

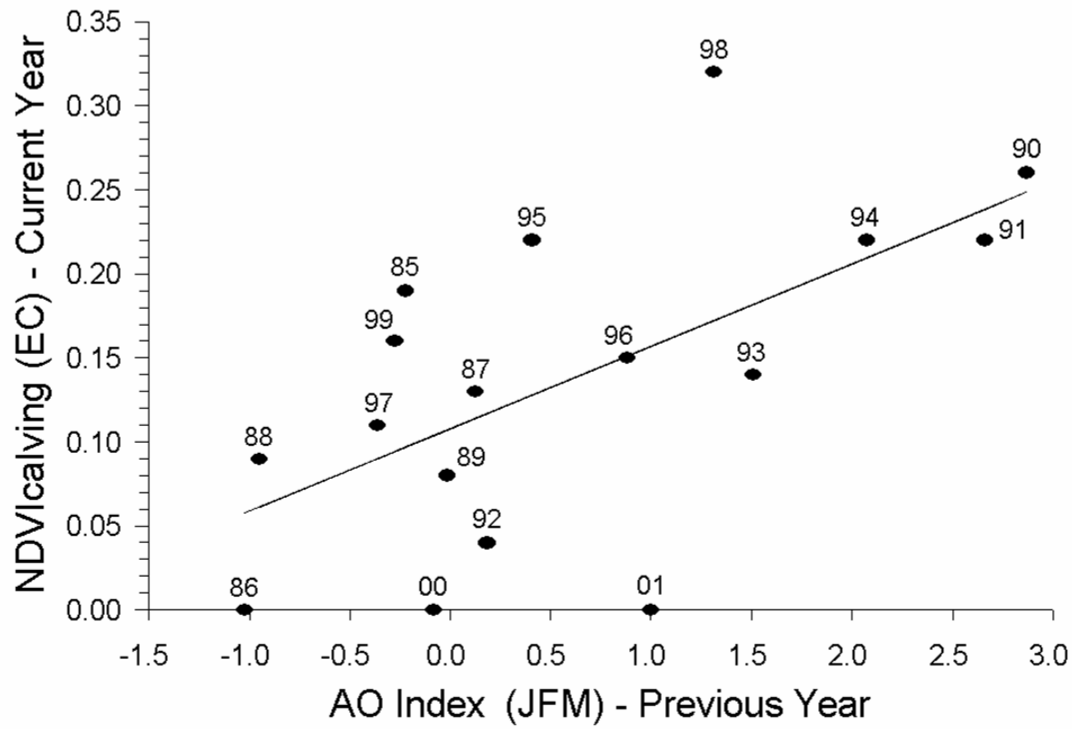


Fig. 3.6. Median Normalized Difference Vegetation Index (NDVI) at calving within the aggregate extent of calving of the Porcupine caribou herd for the current year, and winter Arctic Oscillation index (AO, January, February, March) for the previous calendar year, 1985-2001. (USGS/BRD BSR-2002-0001).

Griffith et al. 2002. The Porcupine Caribou Herd. In Douglas et al. USGS BSR 2002-0001.

PCH population during one cycle of the Arctic Oscillation

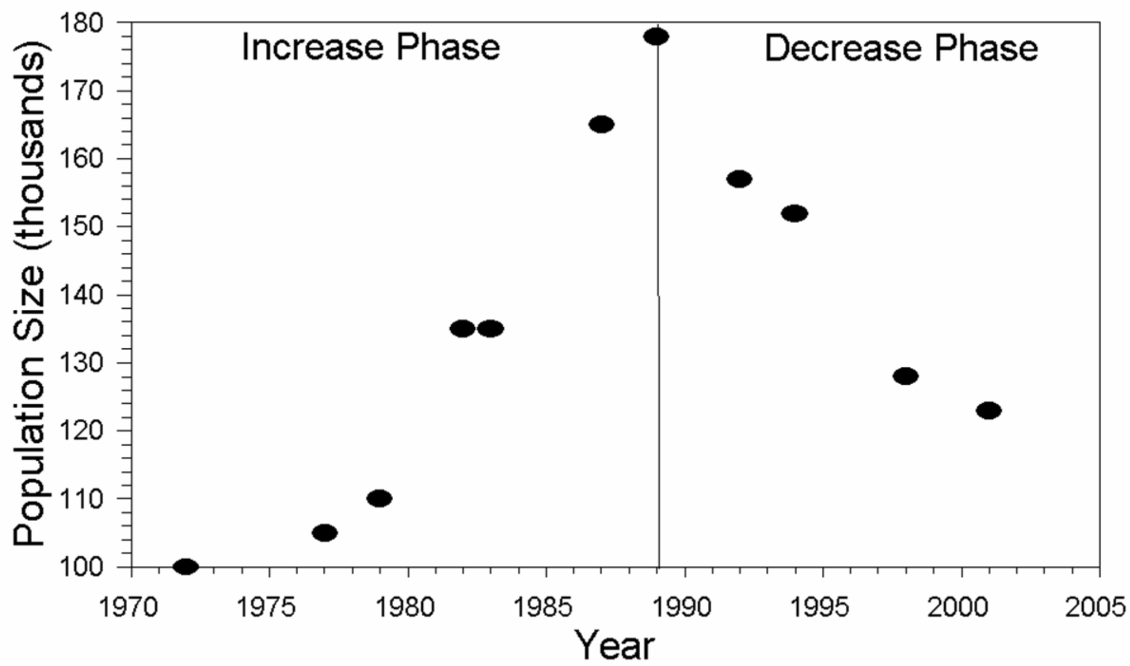


Fig. 3.8. Population size of the Porcupine caribou herd, 1972-2001, estimated from aerial photo-censuses by Alaska Department of Fish and Game. (USGS/BRD BSR-2002-0001).

USGS

Griffith et al. 2002. The Porcupine Caribou Herd. In Douglas et al. USGS BSR 2002-0001.

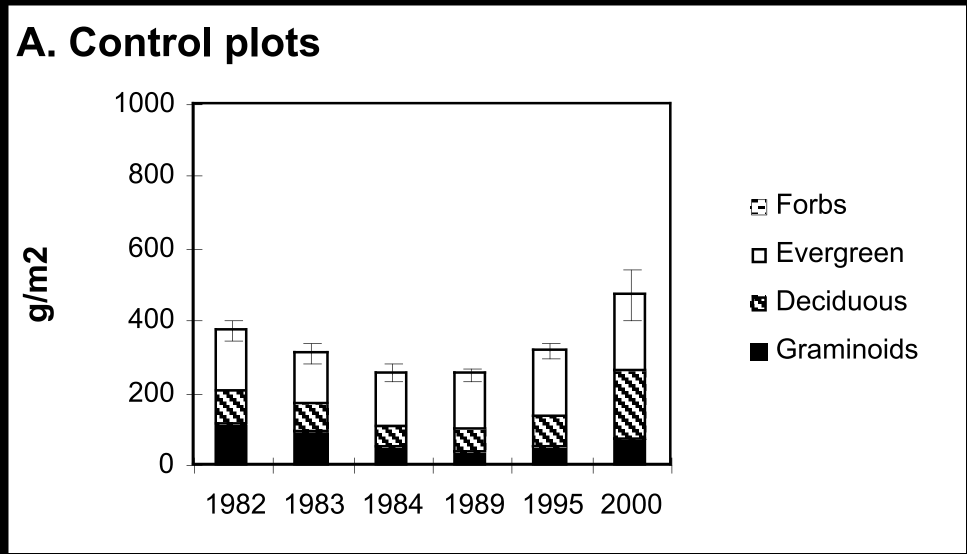
The Nentzy, reindeer and vegetation change

"The average brigadier is in his 50's and has lived his whole life on the tundra… they collect shrubs (mainly *Salix*)…all along the migration route for firewood. Of course, *Salix* is also one of the most important fodder species for the reindeer. So for these reasons they pay pretty close attention to the ecology of this particular genus in the landscape. In more southerly areas, they have noticed that some stands of Salix have gotten so big that the reindeer can now disappear into them. This is not good because if they lose sight of the animals during the migration when they are moving quickly, breaking camp once every 24 hours, the animals can get left behind. So, they have begun to make efforts to steer around the growing *Salix* patches to avoid losing animals.."

--Bruce Forbes

Very few long-term biomass studies

"…although the 2000 harvest occurred after 20 years of climate warming, we still cannot say for sure whether the greater total ANPP and the greater productivity of deciduous shrubs in 2000 is the result of warming or is within the "normal" range of ANPP." (Shaver et al. 2001. *Ecology* 82: 3163-3181).



For purposes of monitoring change to circum-Arctic vegetation, it is essential to have replicated sampling of biomass in conjunction with NDVI measurements using standard protocols for collecting and reporting biomass data.

Greening of the Arctic: an IPY initiative

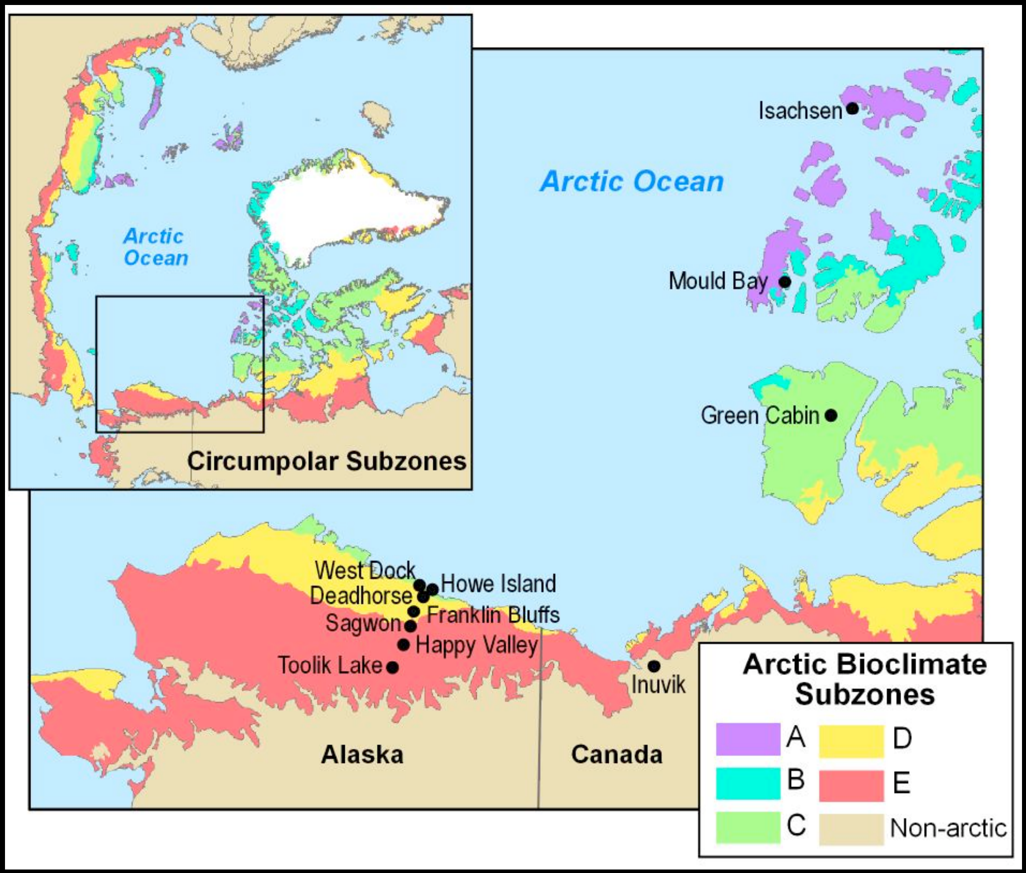
- One of the key goals of IPY will be to document the rapid and dramatic changes to terrestrial vegetation that are expected to occur across the circumpolar Arctic as a result of climate change.

- Changes in the biomass of terrestrial ecosystems will likely affect the carbon cycle, permafrost, active layer, trace-gas fluxes, hydrological systems, biodiversity, wildlife populations and the habitability of the Arctic.

- Changes in green biomass can be expected across the entire bioclimate gradient from tree line to the coldest parts of the Arctic.

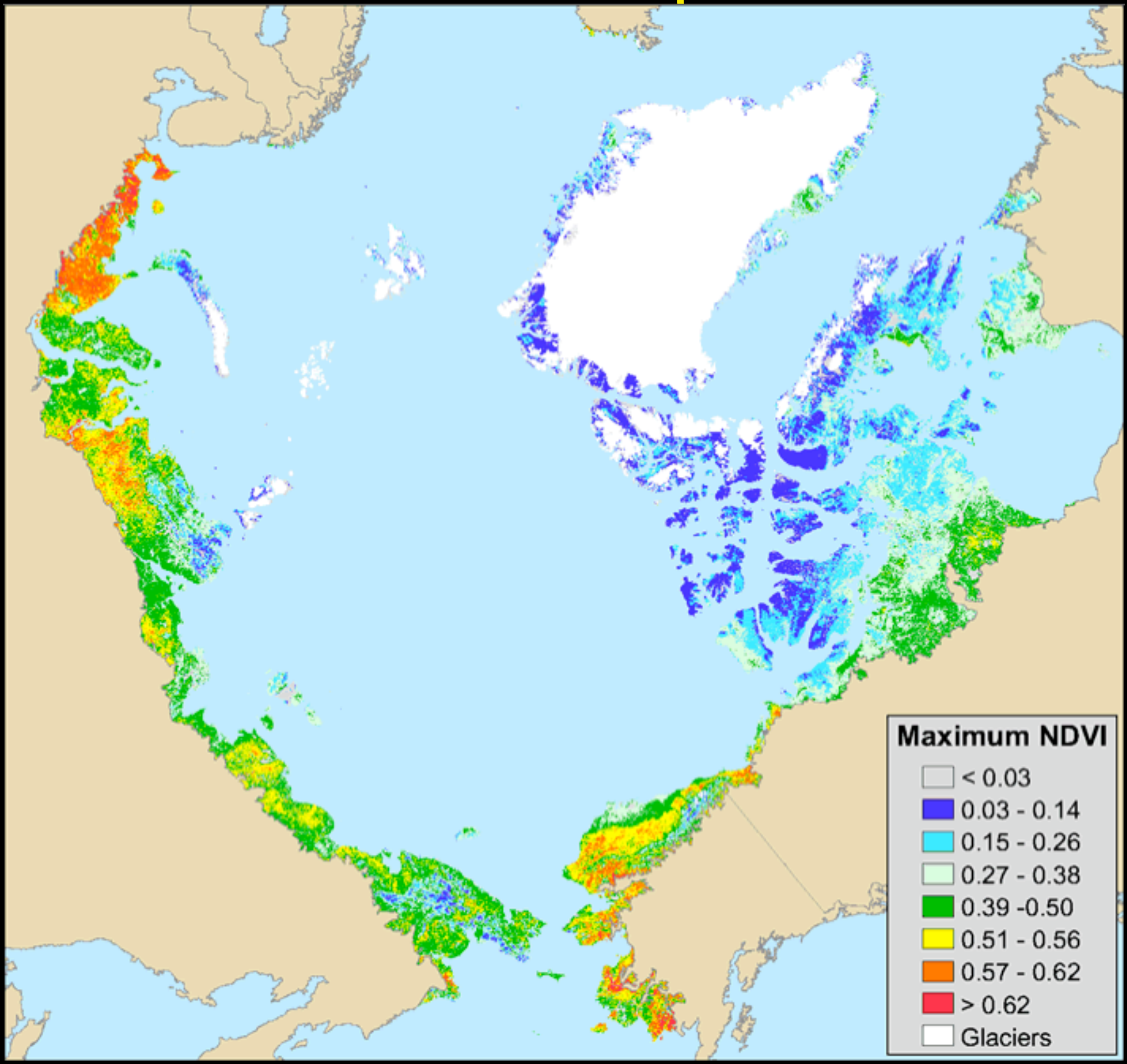
- The Greening of the Arctic (GOA) initiative consists of a group of scientists who are part of four components:

Arctic bioclimate zones and North American Arctic Transect



The Greening of the Arctic (GOA) initiative: a study of circumpolar NDVI and biomass patterns

- GOA study will extend the Jia et al. analysis to the circumpolar Arctic.
- Our umbrella question is,"How do different patterns of sea-ice distribution affect spatial and temporal patterns of the terrestrial NDVI patterns?"



CAVM Team. 2003

Four components of the GOA study

I. Spatial and temporal analysis of Sea Ice – Land-surface-temperature – Terrain – NDVI relationships: Funded by NSF.

II. Analysis of impacts of shrubification to reindeer and the Nenets people in Russia: GOA transect on the Yamal Peninsula: Funded by NASA

III. Web-based *Arctic Geobotanical* Atlas: Funded by NSF.

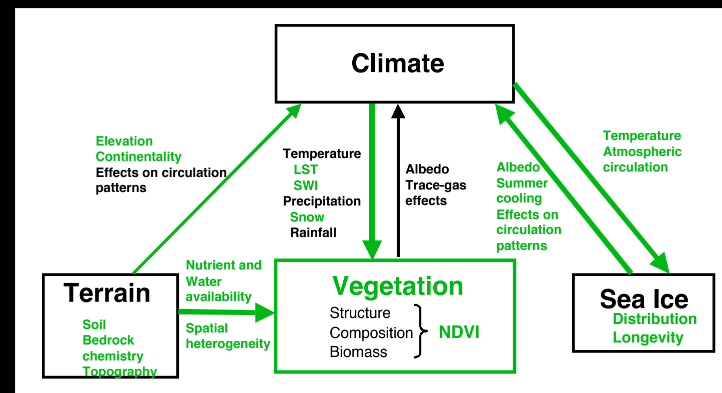
IV. North American Arctic Transect: Long-term study of biomass change in the Arctic: Proposal submitted to NSF.

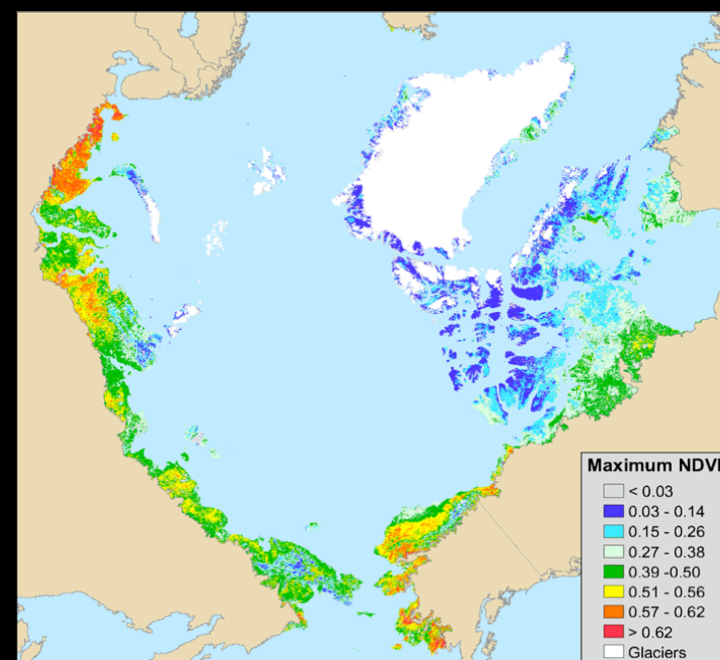
Component I: Sea Ice – Land-surface-temperature – Terrain–Greening relationships (The GOA SASS project)

- Detailed examination of the 24-year record of greenness across the entire circumpolar Arctic as measured by the normalized difference vegetation index (NDVI) using satellite imagery (AVHRR and MODIS).

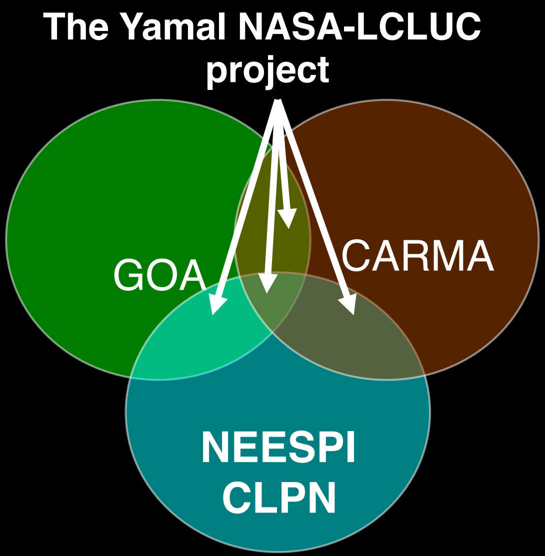
- Will document areas of major increases or decreases in the NDVI and link these trends to changes in sea-ice distribution, land-surface-temperatures (LSTs), snow-cover, bioclimate subzones, vegetation type, glacial history, and other variables in a circumpolar GIS database.

- Modeling studies will use the past trends in NDVI to predict future distribution of arctic vegetation using the BIOME4 model. Transient dynamics of the vegetation will be examined using the ArcVeg model.



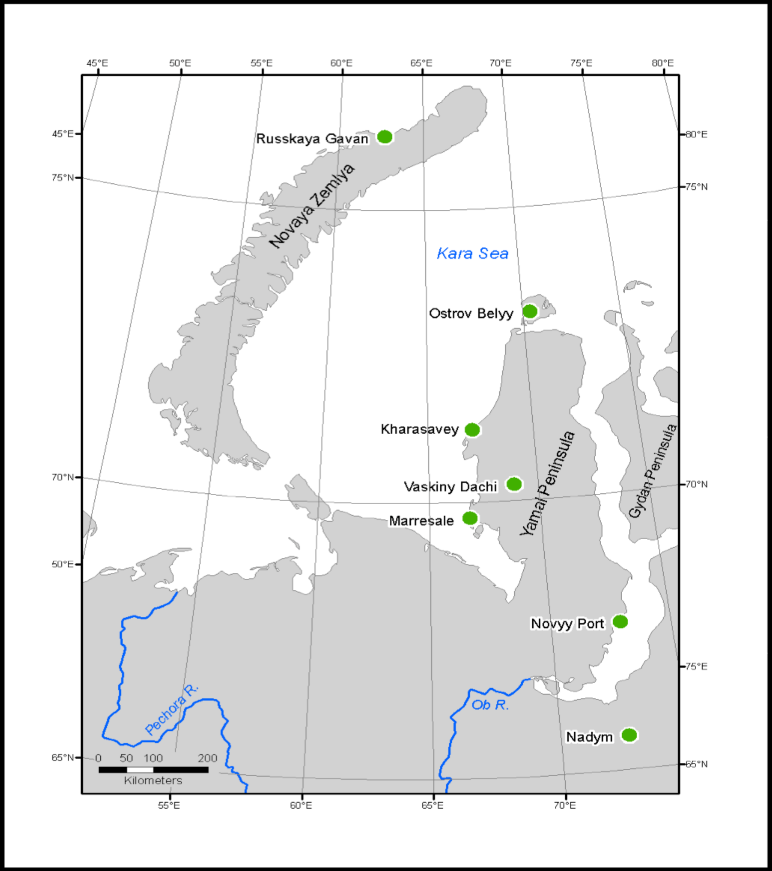


Component III: GOA transect on the Yamal Peninsula, Russia (Funded by NASA)



- Examines the linkages between greening trends, the range and forage for the reindeer of the Nenets people, and the regional sea-ice conditions.
- Field research and modeling in all 5 arctic bioclimate subzones on the Yamal Peninsula and Novaya Zemlya in Russia.
- Linked to the Circumpolar Arctic *Rangifer* Monitoring and Assessment (CARMA) project, and the Cold Land Process in NEESPI (CLPN). NEESPI = Northern Eurasia Earth Science Partnership Initiative.

Yamal transect



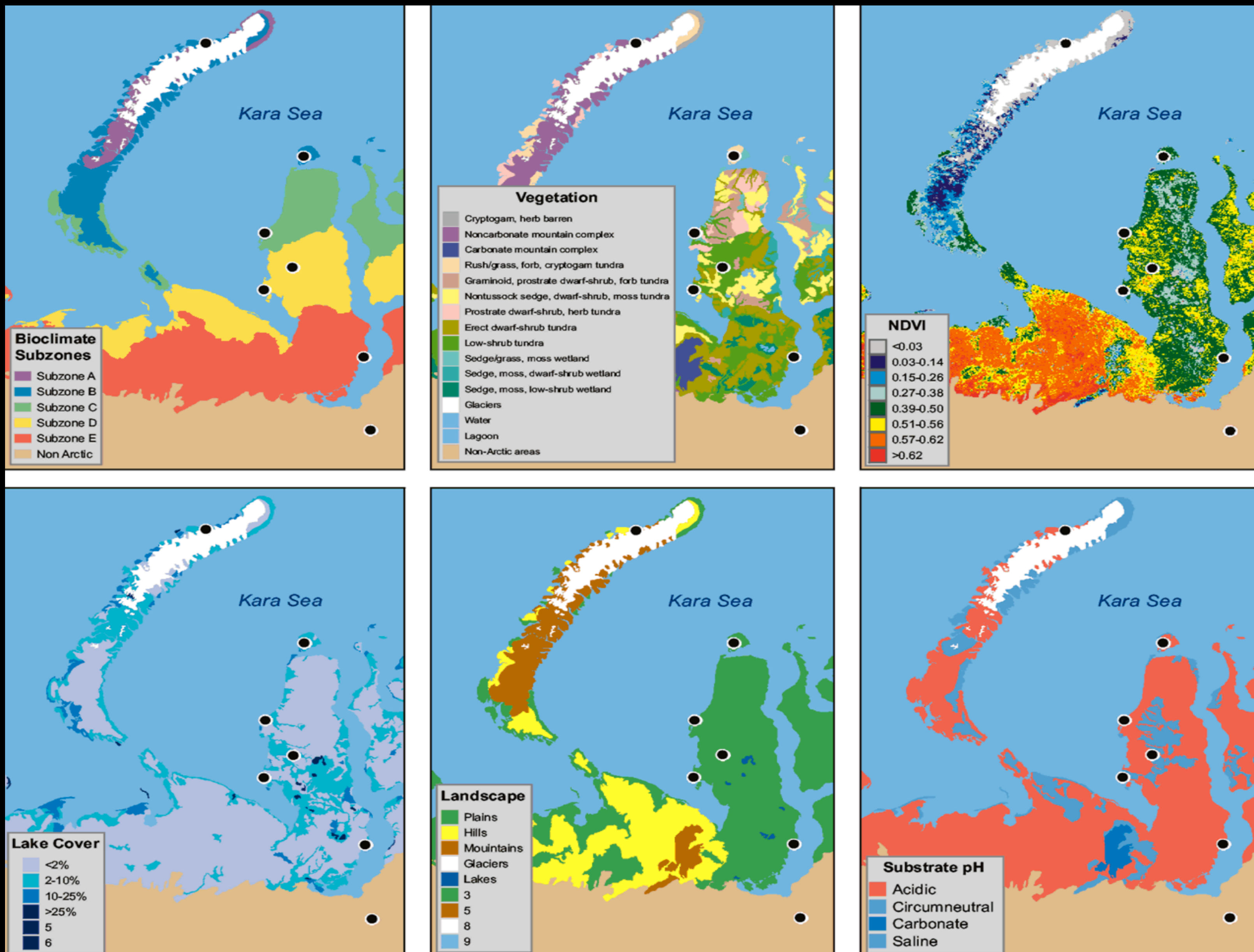
- Will follow the same protocols for climate, permafrost, active-layer biomass, and NDVI, monitoring as the North American Arctic Transect.
- Additional study of Nenets people will be conducted by researchers from Finland and Russia.

Central land-cover/land-use change questions in Northwest Siberia

- What will happen to the tundra regions as the global climate warms?
- What will happen as rapid industrial development and land-use changes related to the indigenous peoples proceed?

The Yamal region in northwest Siberia is a “hot spot” for both of these forces of change . Large-scale oil and gas development is interacting with a sensitive landscape and nomadic reindeer herds to produce extensive land-cover changes.

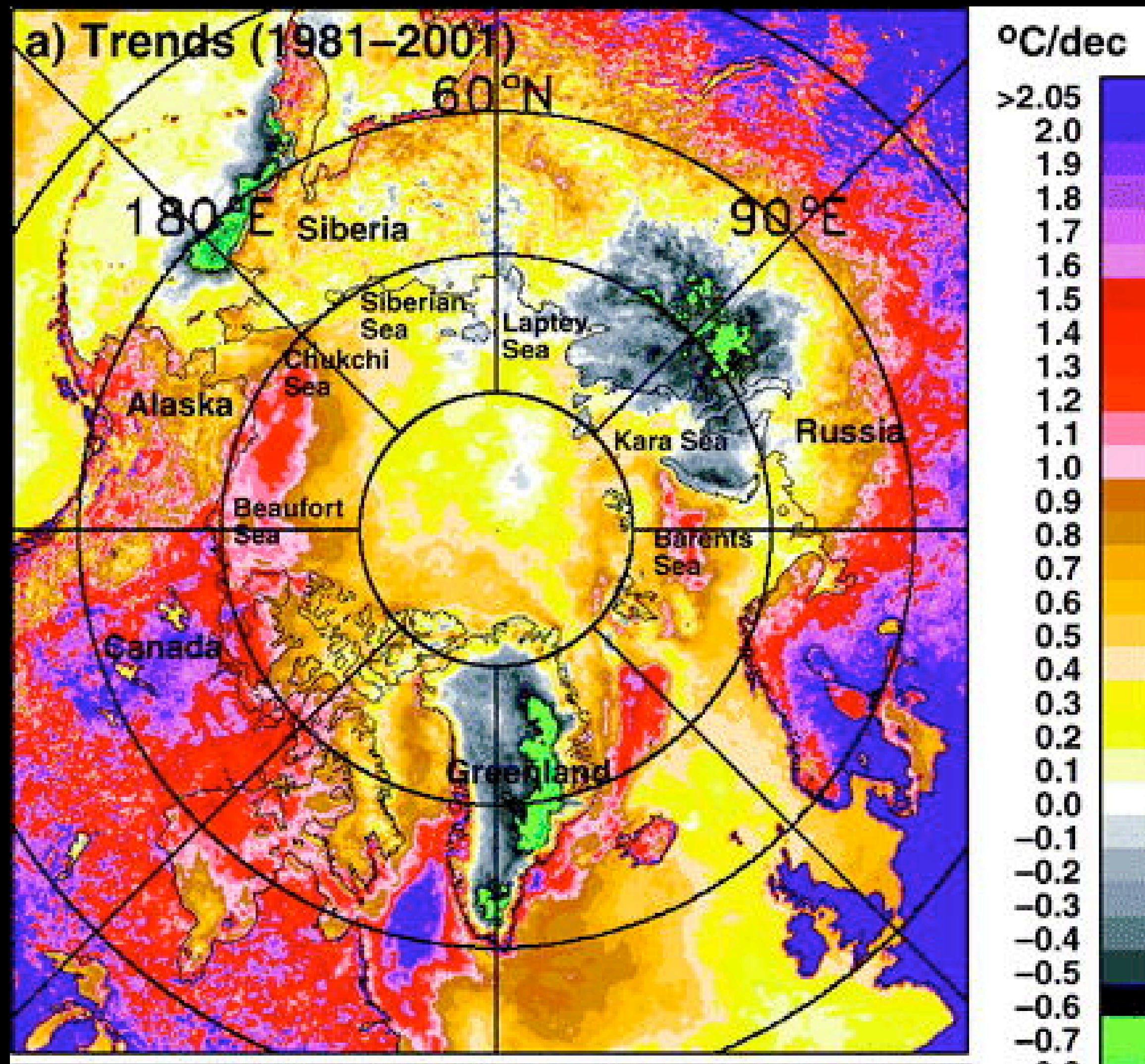
Geobotanical variation across the Yamal transect



Base Map: CAVM Team 2003, Alaska Geobotanical Center

Annual temperature anomalies in the Arctic, 1981-2001

We are using the Comiso (2006) ice cover and LST 12-km AVHRR data for the analyses.



Comiso, 2003. Warming trends in the Arctic from clear sky satellite observations, *Journal of Climate.* 16: 3498-3510,

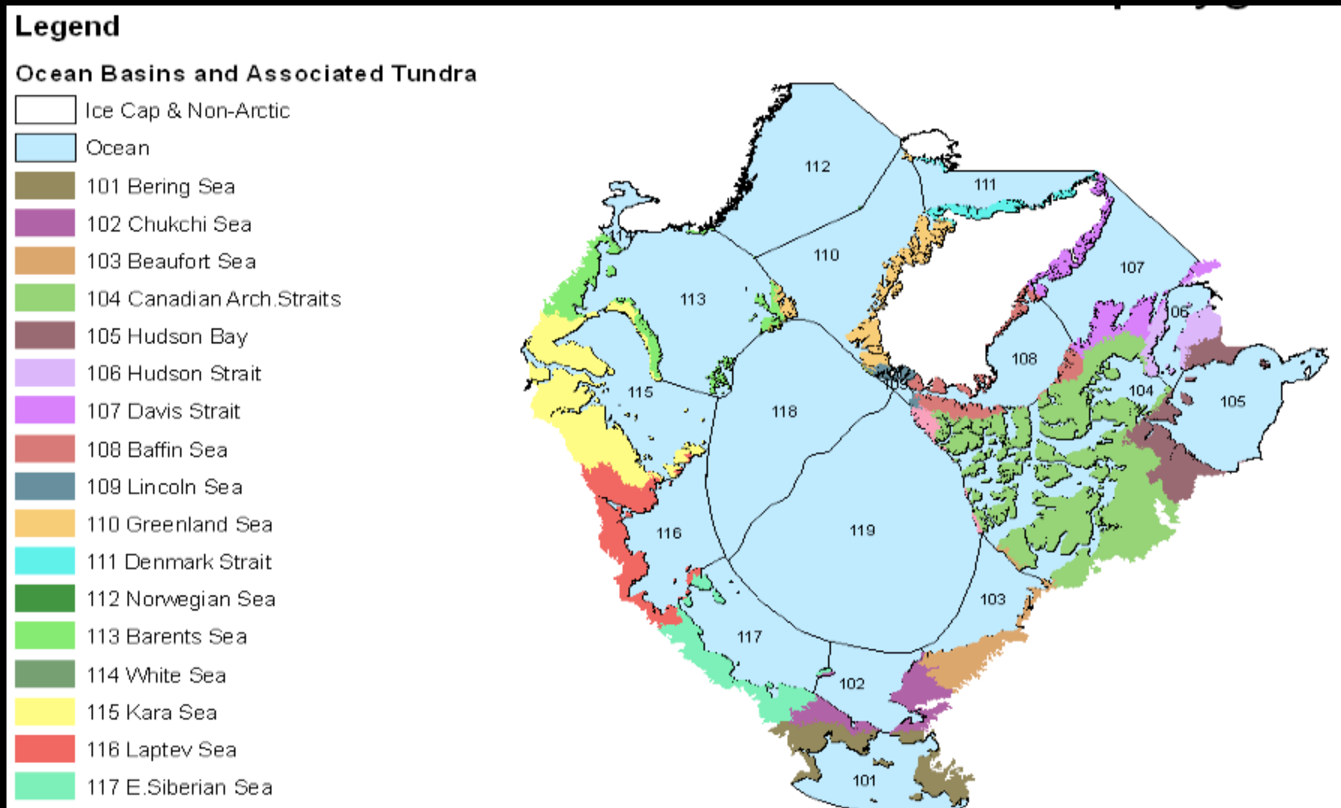
Using high-resolution satellite images during interviews with Nenets herders

Courtesy of Bruce Forbes

"…in addition to taking part in daily life and seeing with our own eyes exactly how the animals are managed we … do more formal semi-structured interviews. some of these are recorded on either digital tape or film, or both. in these cases we have medium or very high resolution satellite imagery of the areas we are discussing to focus on specific places and features that the herders can recognize easily."

--Bruce Forbes

Treshnikov's subdivisions of the Arctic Basin and CAVM subdivisions on land

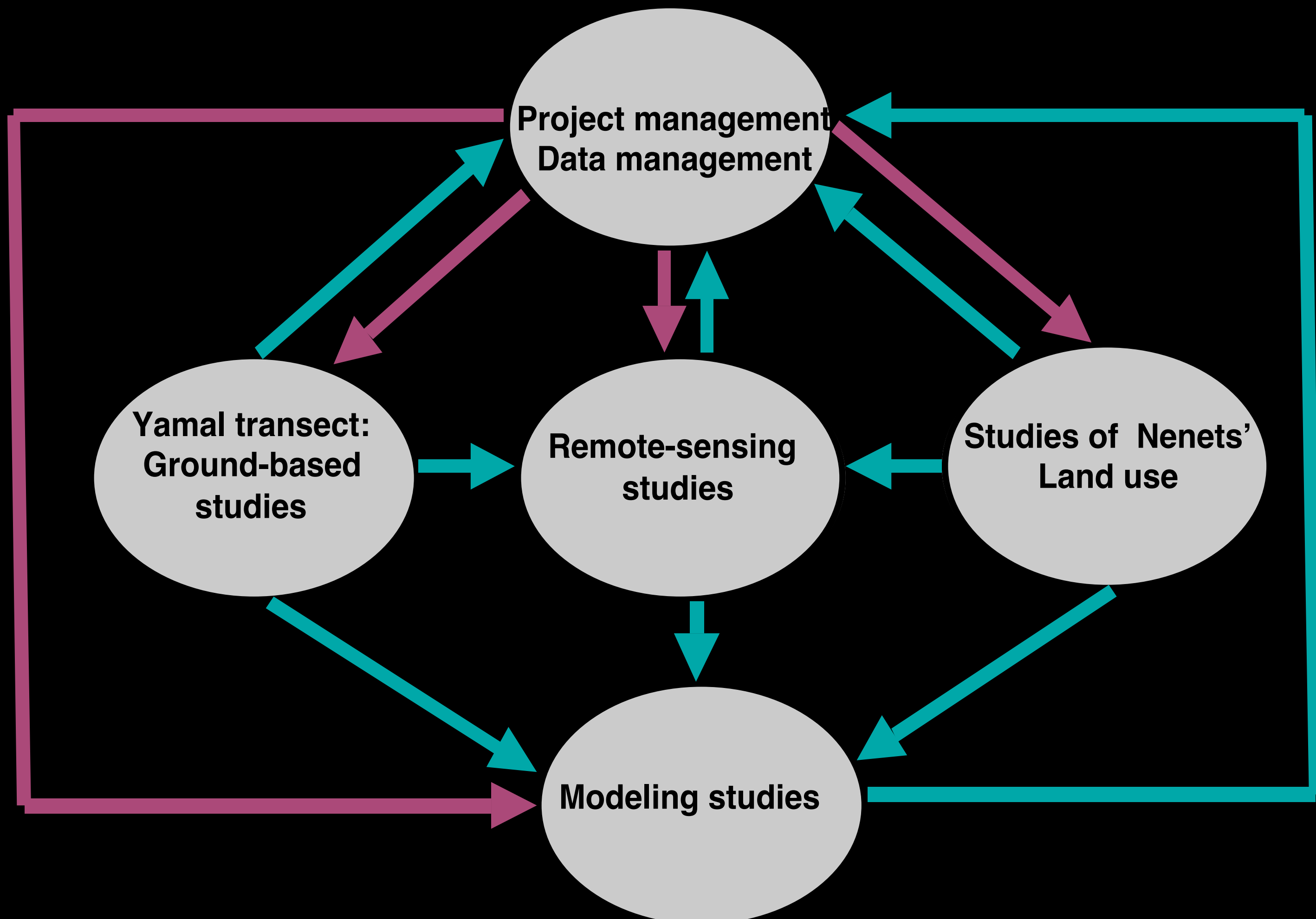


From the Treshnikov et al. (ed.) 1985. *Arctic Atlas,* Russian Academy of Science.

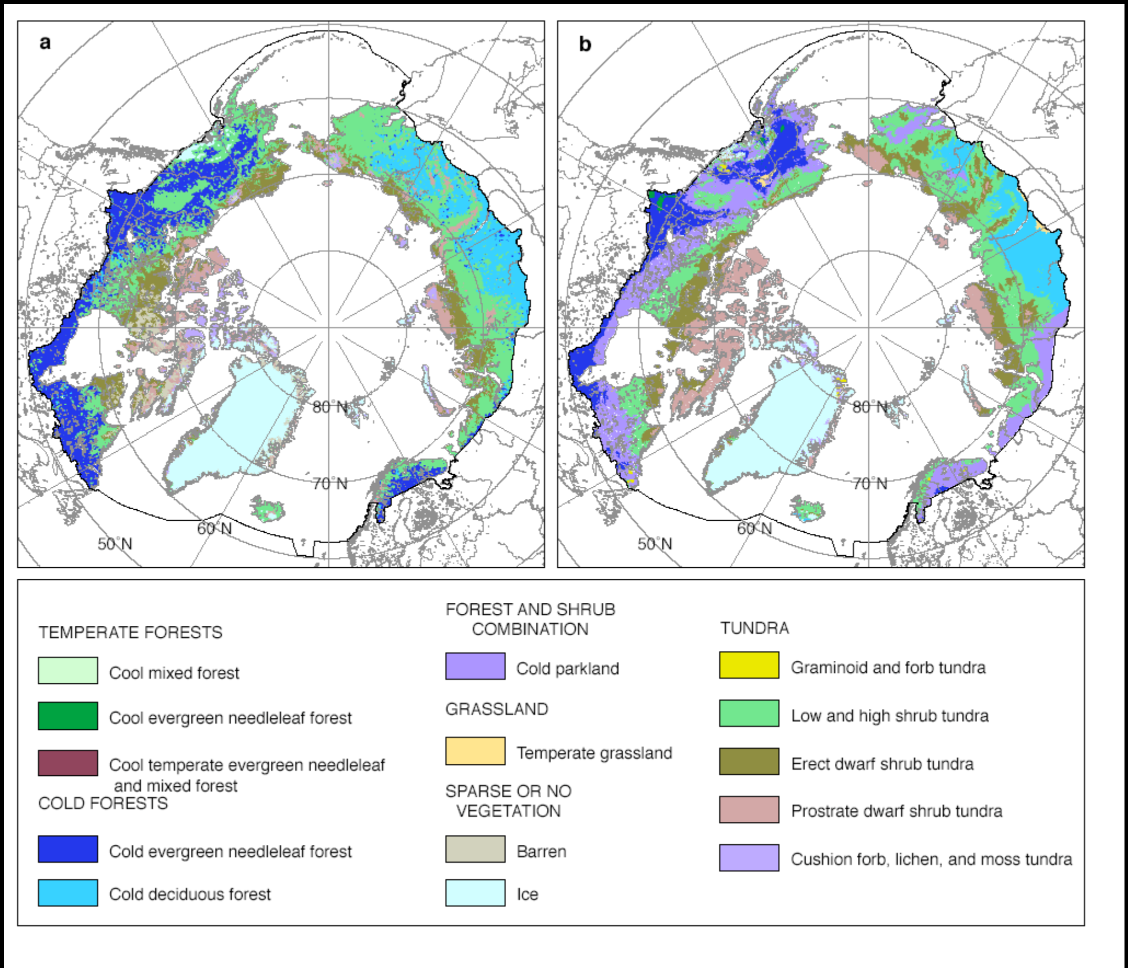
We will examine the historical ice conditions in each of the subdivisions of the Arctic ocean, determine climate drivers and the correlations with LST and NDVI on land.

Five project components

Coordination (red arrows) and data flow (blue arrows)



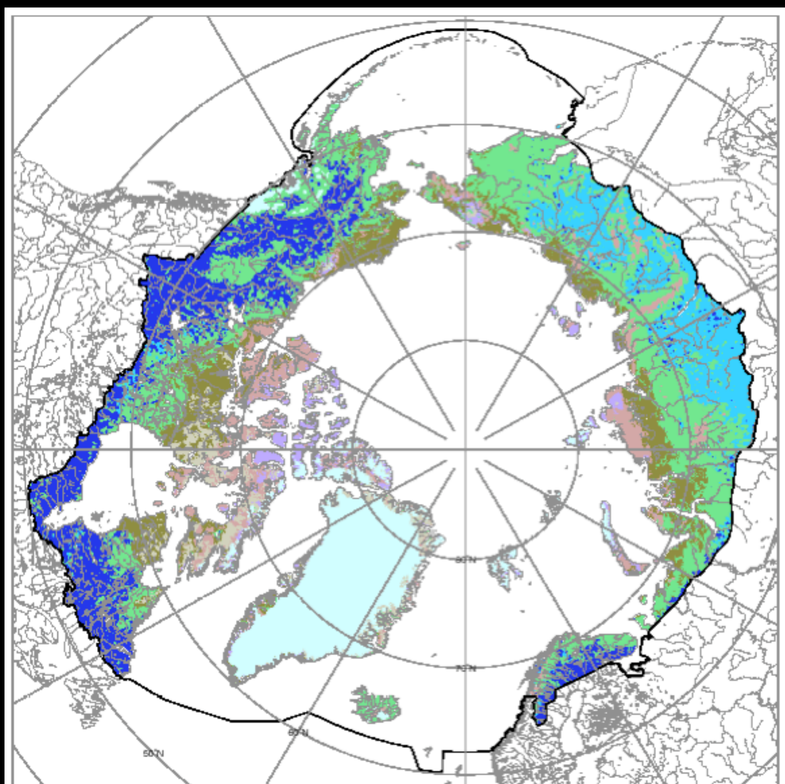
Simulation of tundra and boreal forest vegetation with BIOME4 model



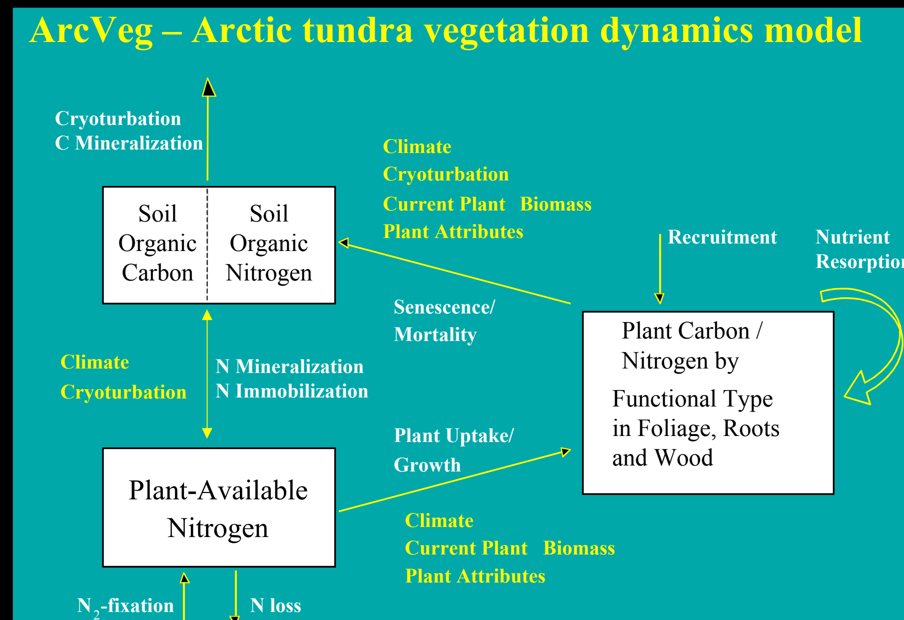
Arctic vegetation for the present day (a) Classified using satellite imagery and (b) simulated by BIOME4.

Epstein, Kaplan, et al. 2007

Projections of future vegetation using modeling approaches



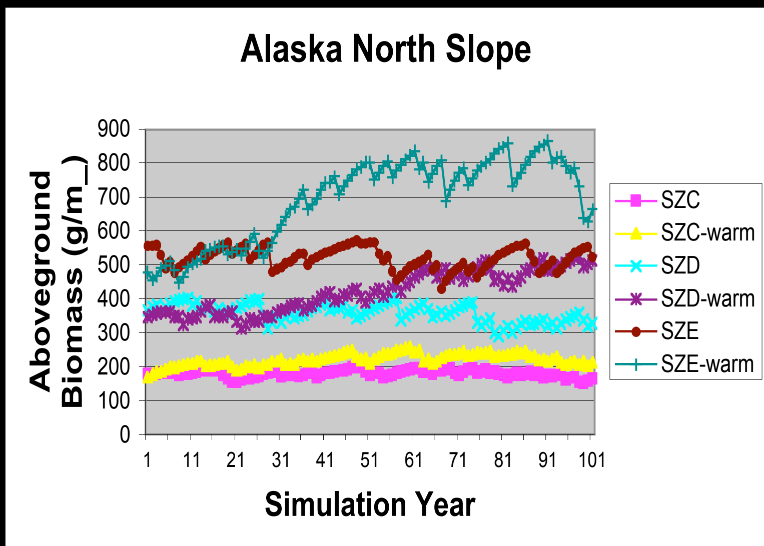
BIOME4 model:
Future vegetation patterns based on physiology and climate limits of plant functional types

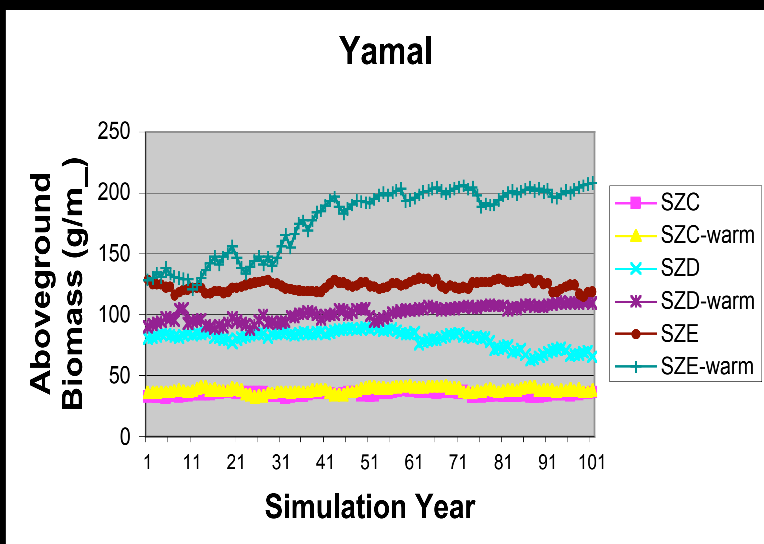


Epstein et al. 2001. Analyzing the functional type concept in arctic plants using a dynamic vegetation mode. *Oikos* 95: 239-252.

ArcVeg model:
Transient dynamics of individual plant types based on nutrient and climate limitations.

Modeling transient dynamics of the vegetation





- ArcVeg model (Epstein et al. 2001, 2004) examines soil nutrient effects on interannual changes in tundra.
- Simulates changes to plant functional types, with nitrogen being the key limiting nutrient, the availability of which is driven by climate.
- Preliminary simulation shows the differences in production expected on the nutrient-rich soils of the Alaskan North Slope, vs the nutrient-poor soils of the Yamal.

Courtesy of Howie Epstein

Plan for Yamal field work

2006:

- **This meeting: Letter of agreement between UAF and Russian colleagues, begin planning for 2007 field season.**
- **Another meeting in fall?**

2007:

- **Jun 30 to Jul 26 Field work at Nadym, Km 143, and Vaskiny Dacha.**

2008:

- **Field work at Marrasale, Kharasavey, and Ostrov Belyy**

2009:

- **Field work at either Svalbard, Franz Josef Land, or Novaya Zemlya**

Participants in the GOA project (all four components)

- ***Skip Walker, Howie Epstein:*** **PIs, Vegetation, NDVI, ArcVeg Model**
- ***Jiong Jia:*** **Temporal analysis of circumpolar NDVI**
- ***Martha Raynolds:*** **Spatial analysis of circumpolar NDVI**
- ***Uma Bhatt:*** **Climate dynamics**
- ***Joey Comiso:*** **Circumpolar sea-ice and LST**
- ***Vlad Romanovsky and Jerry Brown:*** **Permafrost and climate, Circumpolar, NAAT, and Yamal transects**
- ***Jed Kaplan:*** **BIOME4 modeling**
- ***Marina Liebman and Natalia Moskolenko:*** **Russian Yamal transect**
- ***Gary Kofinas and Bruce Forbes:*** **Human dimensions of Yamal transect**
- ***Charles Tarnocai and Chein-Lu Ping:*** **NAAT and circumpolar soils**
- ***Corinne Munger:*** **Meso-scale analysis of NDVI patterns at Toolik Lake**
- ***Bill Gould:*** **NAAT education component**
- ***Gus Shaver and Greg Henry:*** **Biomass and ITEX along NAAT**
- ***Hilmar Maier , Edie Barbour, Matt Nolan, Peter Prokein, Tom Heinrichs, Jason Grimes, Buck Sharpton, Andrew Balsar:*** **Arctic Geobotanical Atlas, EarthSLOT, web-site development**
- ***Brian Barnes:*** **Toolik Lake and LTER coordination and support**
- ***Carl Markon:*** **Alaska and global NDVI support**