Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia

Skip Walker

NEESPI CLAC meeting, Fairbanks, AK, April 6-8 2006

Outline

- Rationale for the Greening of the Arctic studies
- Recent changes in sea-ice distribution and land-surface temperatures
- Distribution of tundra
- Evidence for vegetation change in the Arctic
- Review of NDVI
- Overview of the components of the Greening of the Arctic IPY initiative

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.

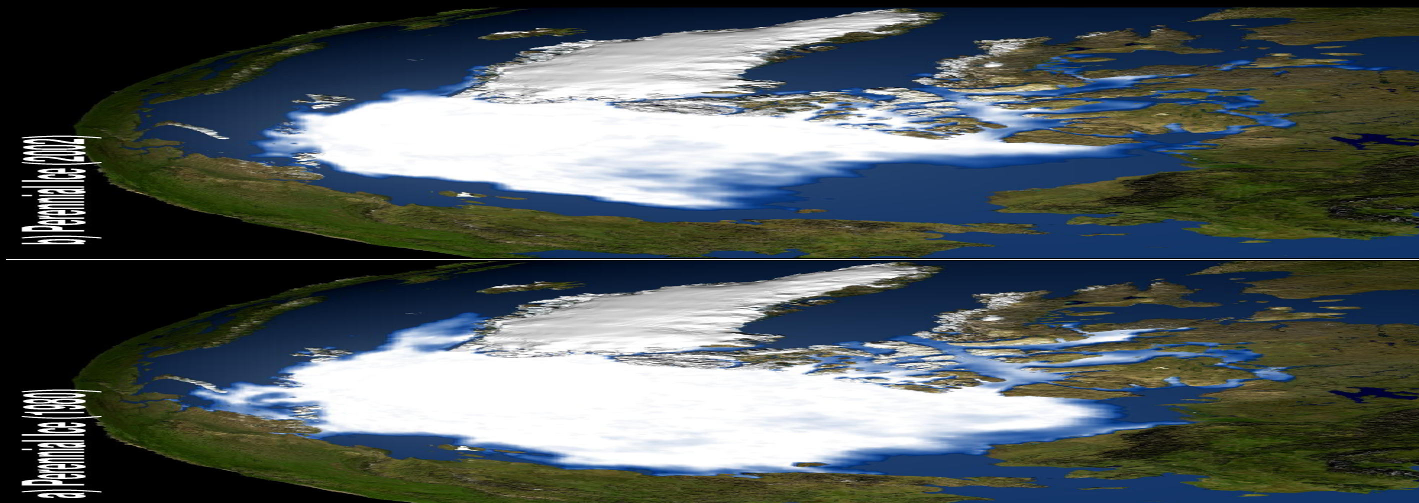
- Changes in green biomass can be expected across the entire bioclimate gradient from tree line to the coldest parts of the Arctic.

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

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

Trend in sea ice

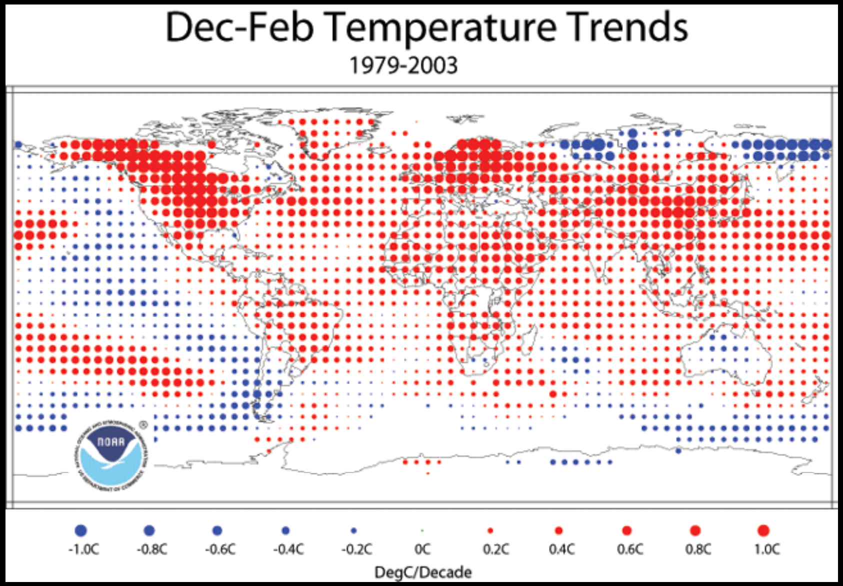


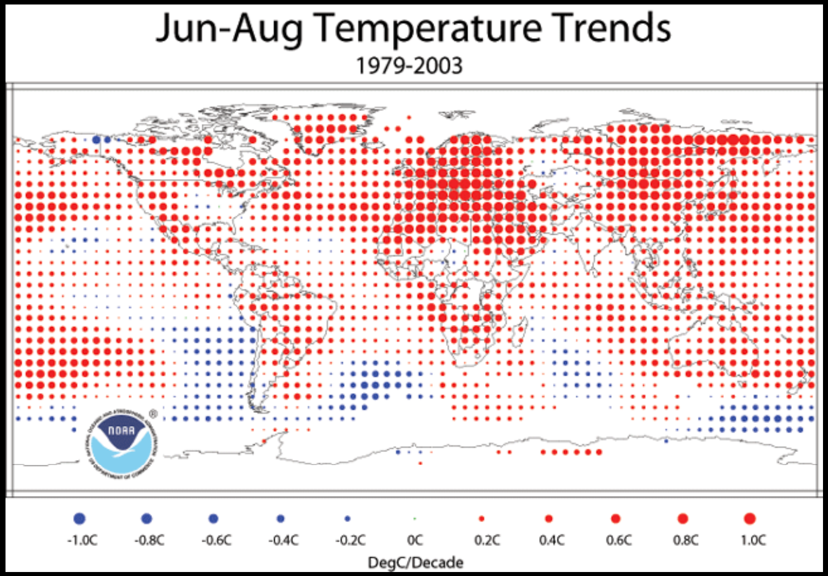
Since 1980, perennial sea ice in the Arctic has declined at rate of 9.8% per decade (Comiso 2006).

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

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).

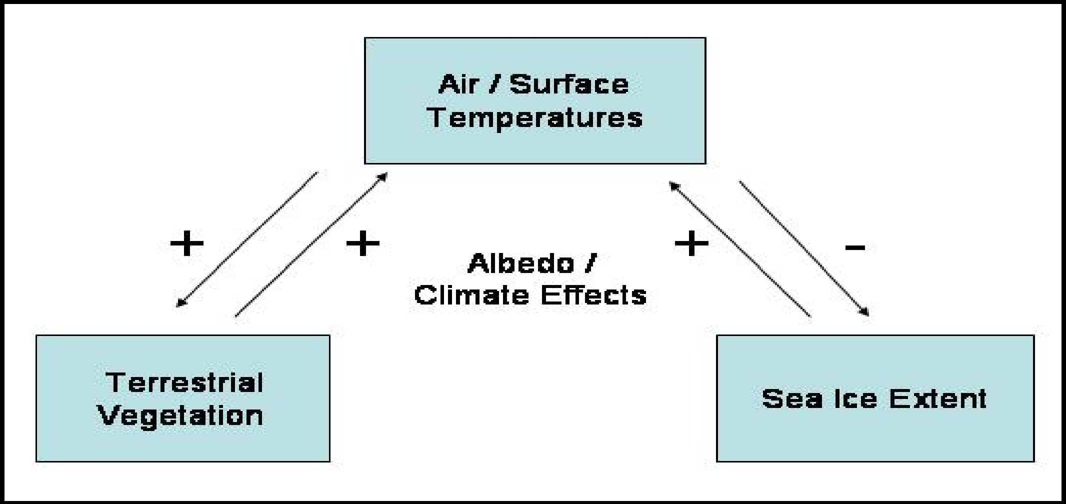
Arctic plant biomass and diversity are strongly related to total amount of available summer warmth, so changes in surface temperatures will likely result in increased biomass over much of the Arctic.

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



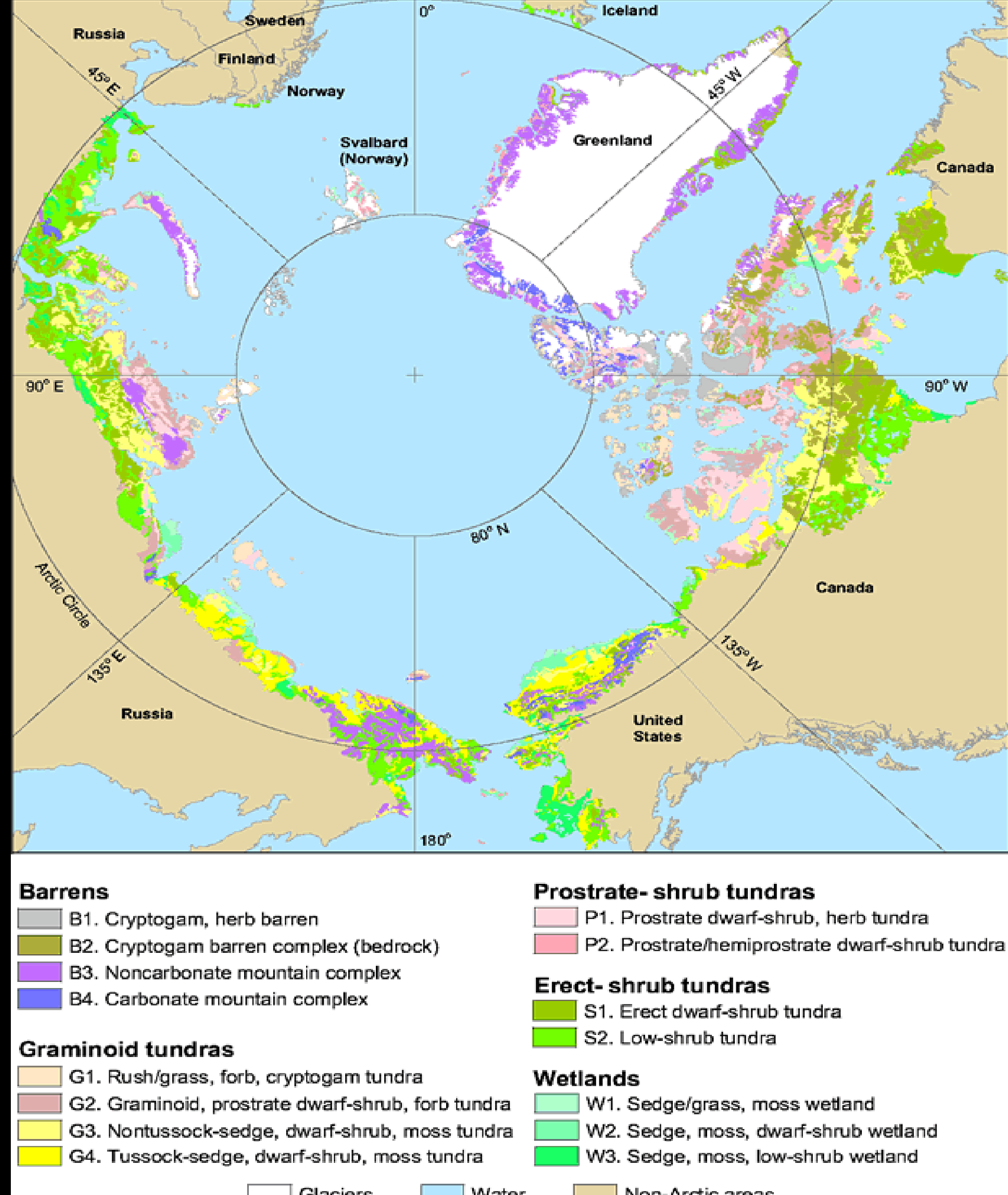
Linkages between sea ice and terrestrial vegetation are indirect – through albedo/climate feedbacks to the atmosphere.

The Arctic tundra is a maritime biome

Arctic tundra is defined as the area that has an Arctic Climate and an Arctic flora, and contains tundra vegetation.

Southern boundary of the mapped area is tree line,

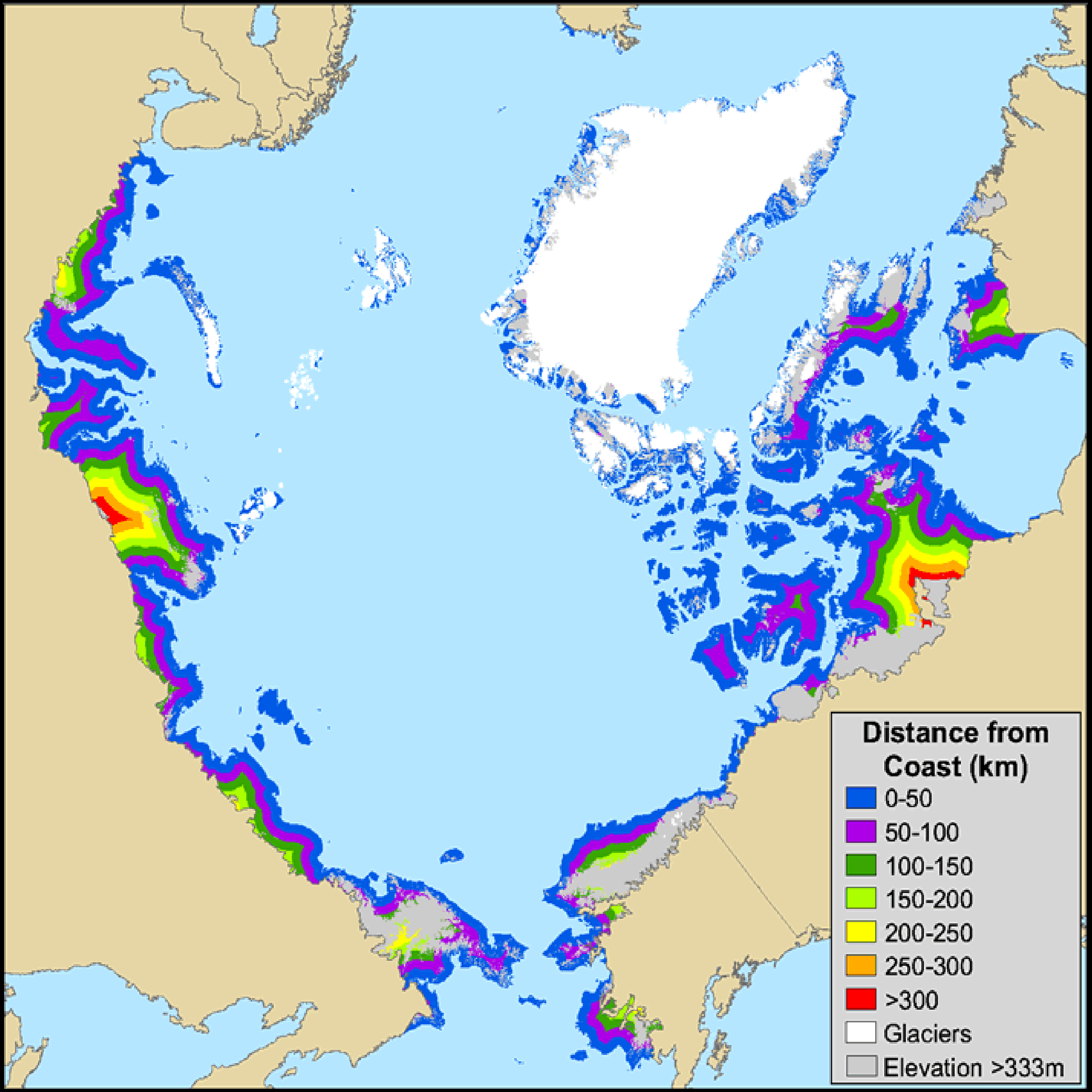
Note the close proximity of all parts of the biome to perennially or seasonally frozen seawaters.



Walker, D. A., 2005 in press. The Circumpolar Arctic Vegetation Map. Journal of Vegetation Science.

Proximity of lowland tundra areas to sea ice

- 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.



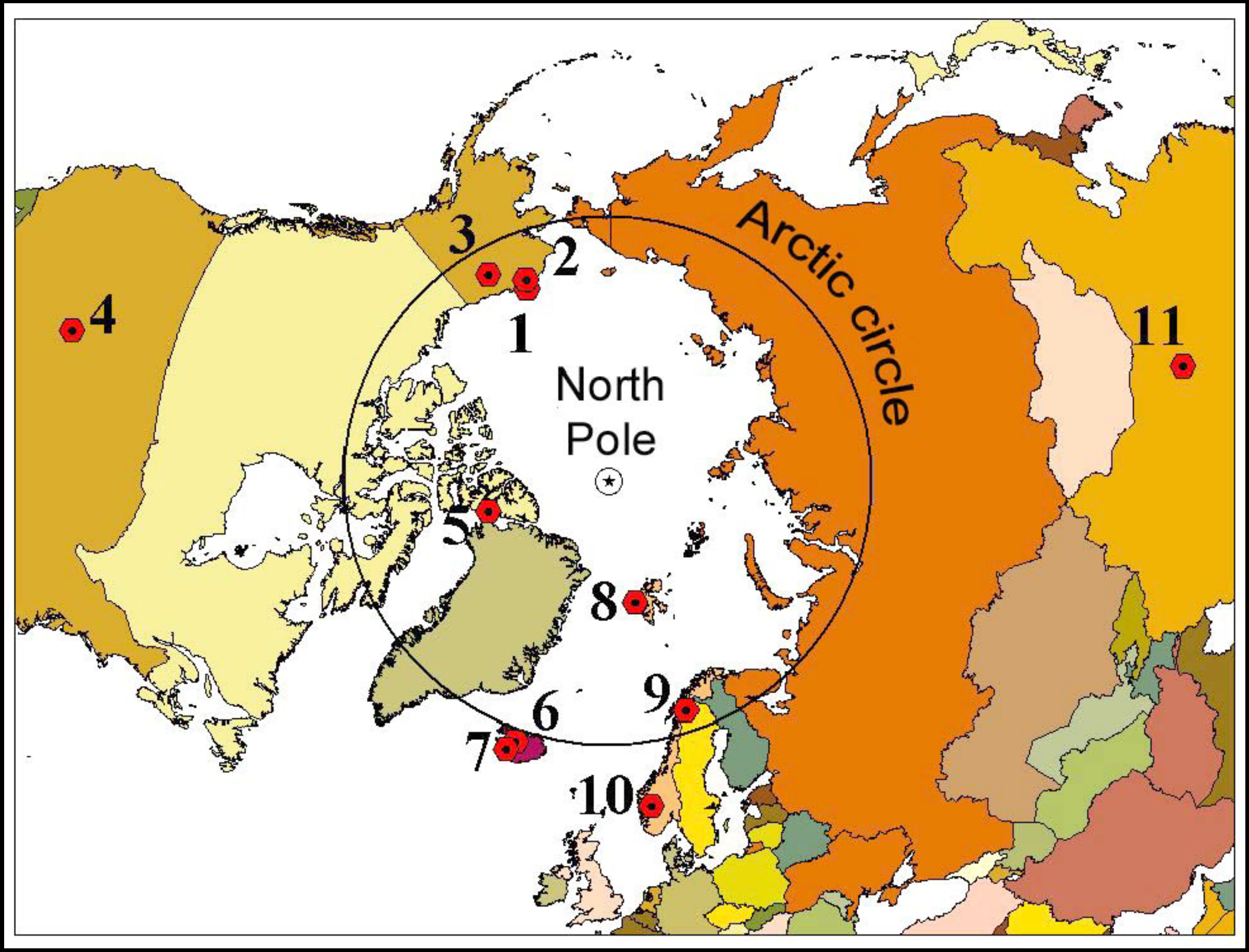
Evidence for Change in Arctic Vegetation

Photo – M. K. Raynolds

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

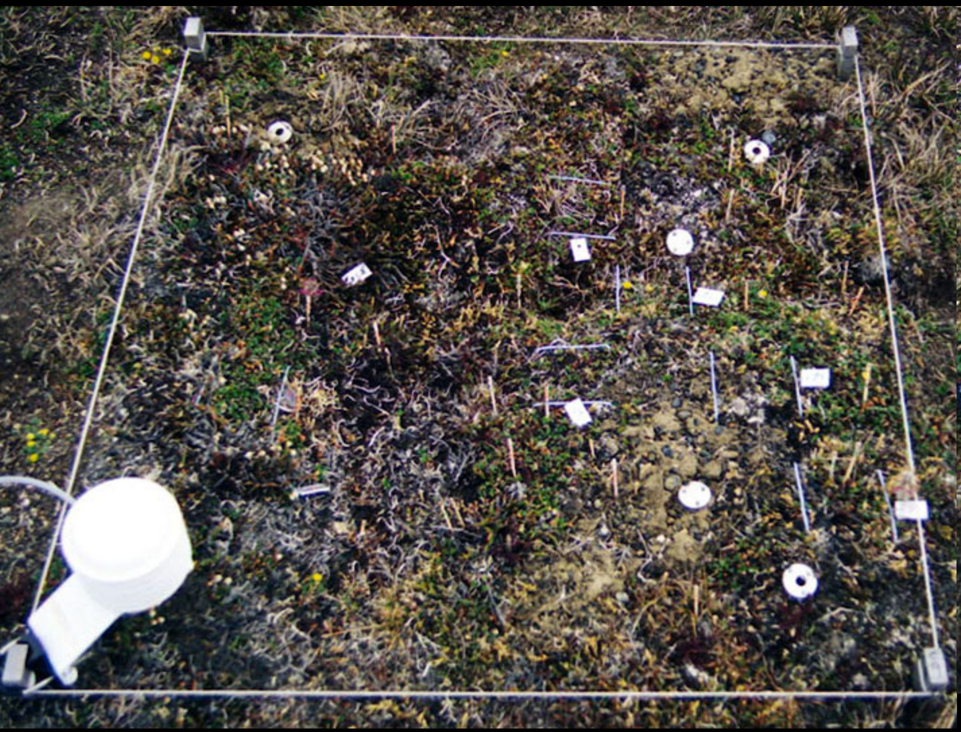
- Over 30% increase in alders on some stable valley slopes in Subzone E.
- Dramatic increase in shrub cover on river terraces.
- More vegetation and less sand and gravel in river floodplains.

International Tundra Experiment (ITEX) synthesis

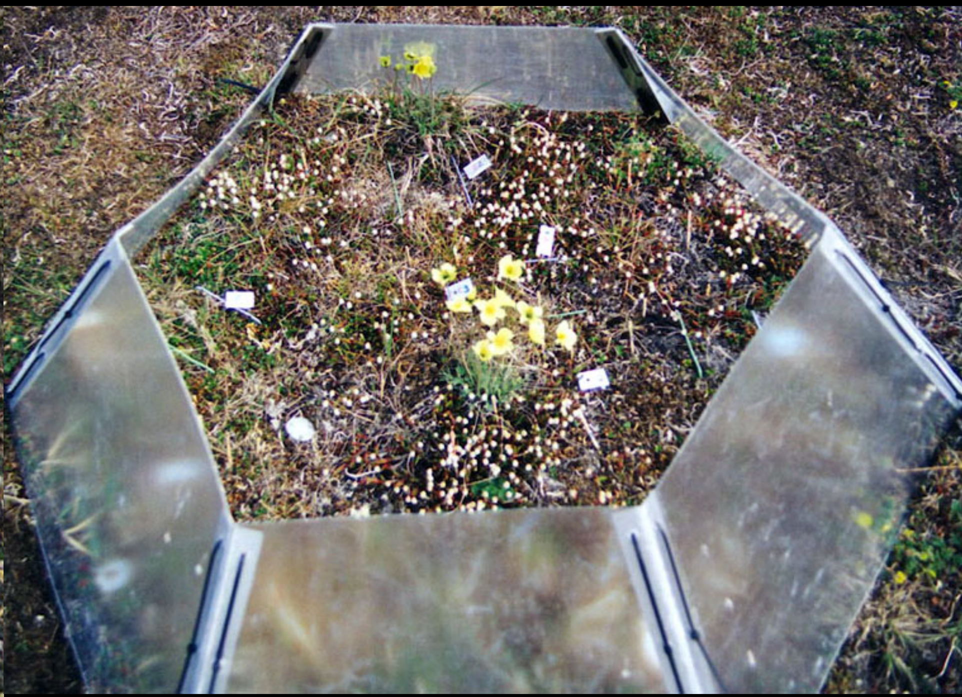


Walker, M. D., C. H. Wahren, R. D. Hollister, G. H. R. Henry, et al. 2005 in review. Plant community responses to experimental warming across the tundra biome. Proceedings of the National Academy of Science.

Community changes in ITEX experiment after 6 years

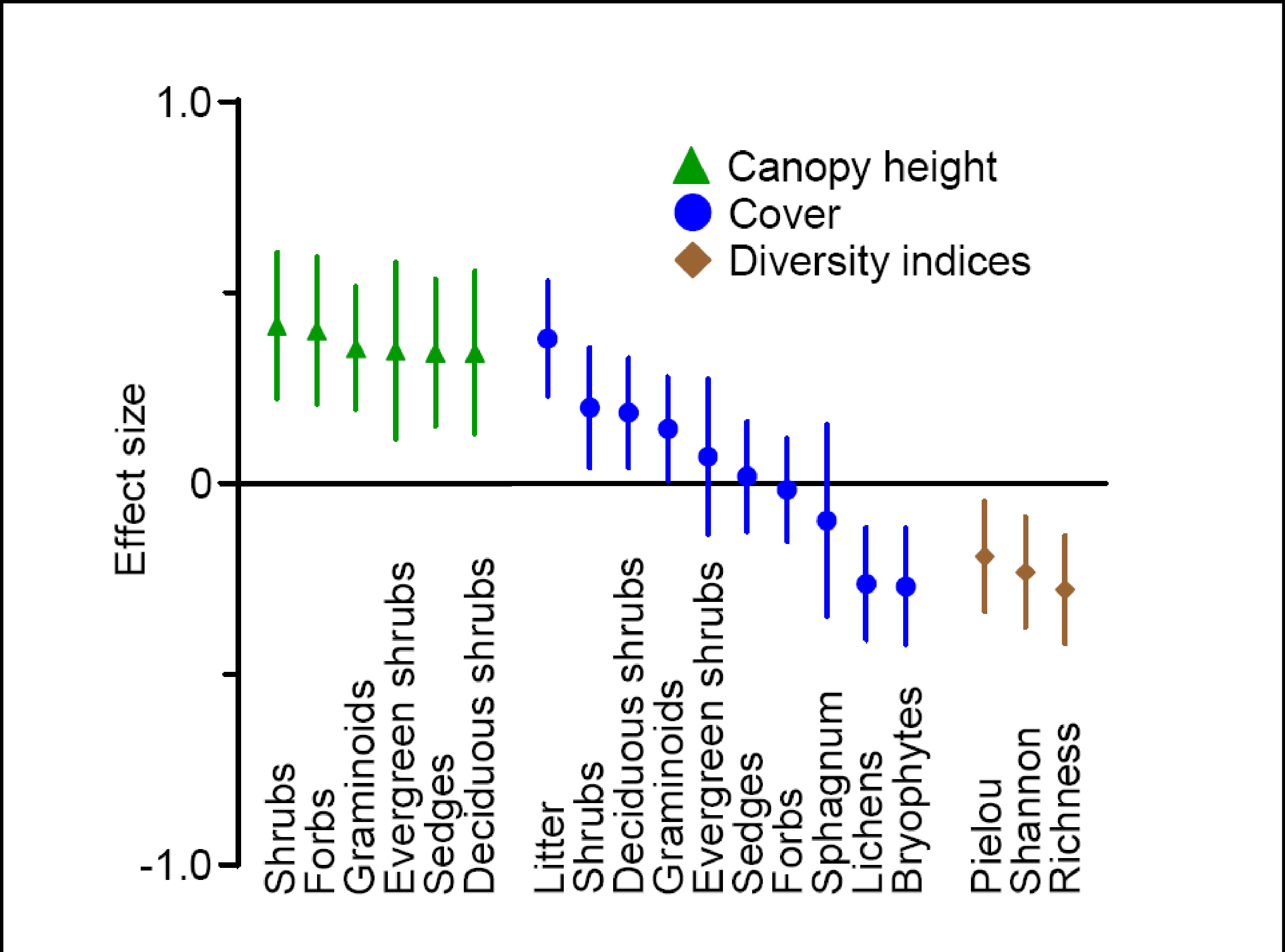


Control



Open-top chamber

ITEX meta-analysis of effects of warming experiment



Normalized Difference Vegetation Index: an index of greenness

$$\text{NDVI} = (NIR-R)/(NIR+R)$$

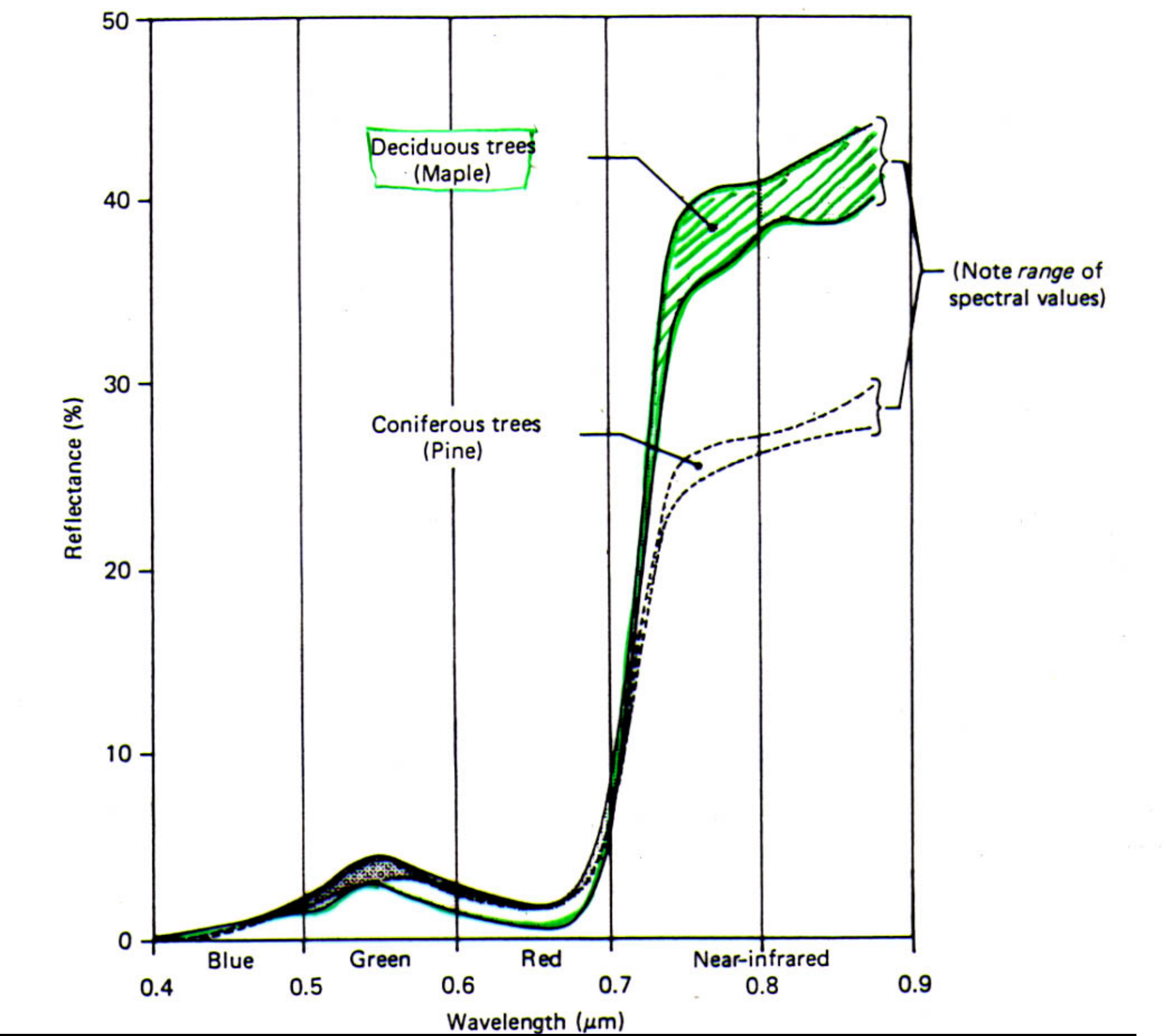
NIR = spectral reflectance in the near-infrared band (0.725 - 1.1µm), where light scattering from the canopy dominates,

R = reflectance in the red, chlorophyll-absorbing portion of the spectrum (0.58 to 0.68µm).

So called ‘greening index’ but it does not involve the green portion of the spectrum at all.

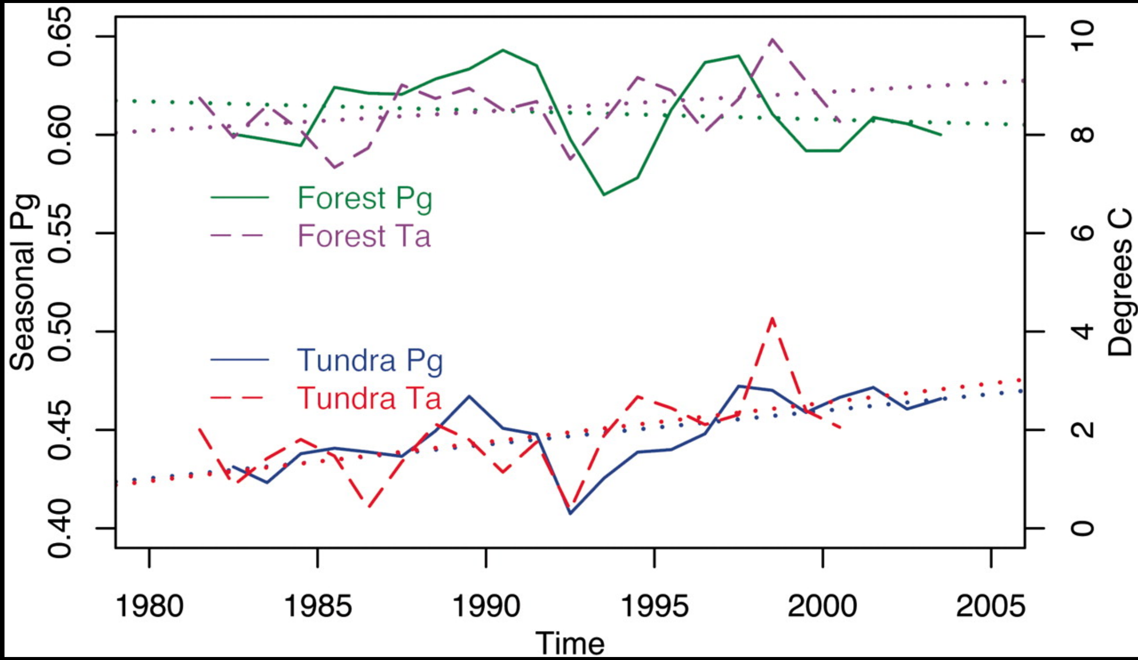
Reflectance spectra of vegetation

The greater the difference between the reflectance in the R and NIR portions of the spectrum the more chlorophyll is in the vegetation canopy.



Trends in temperature and NDVI in the forest and tundra

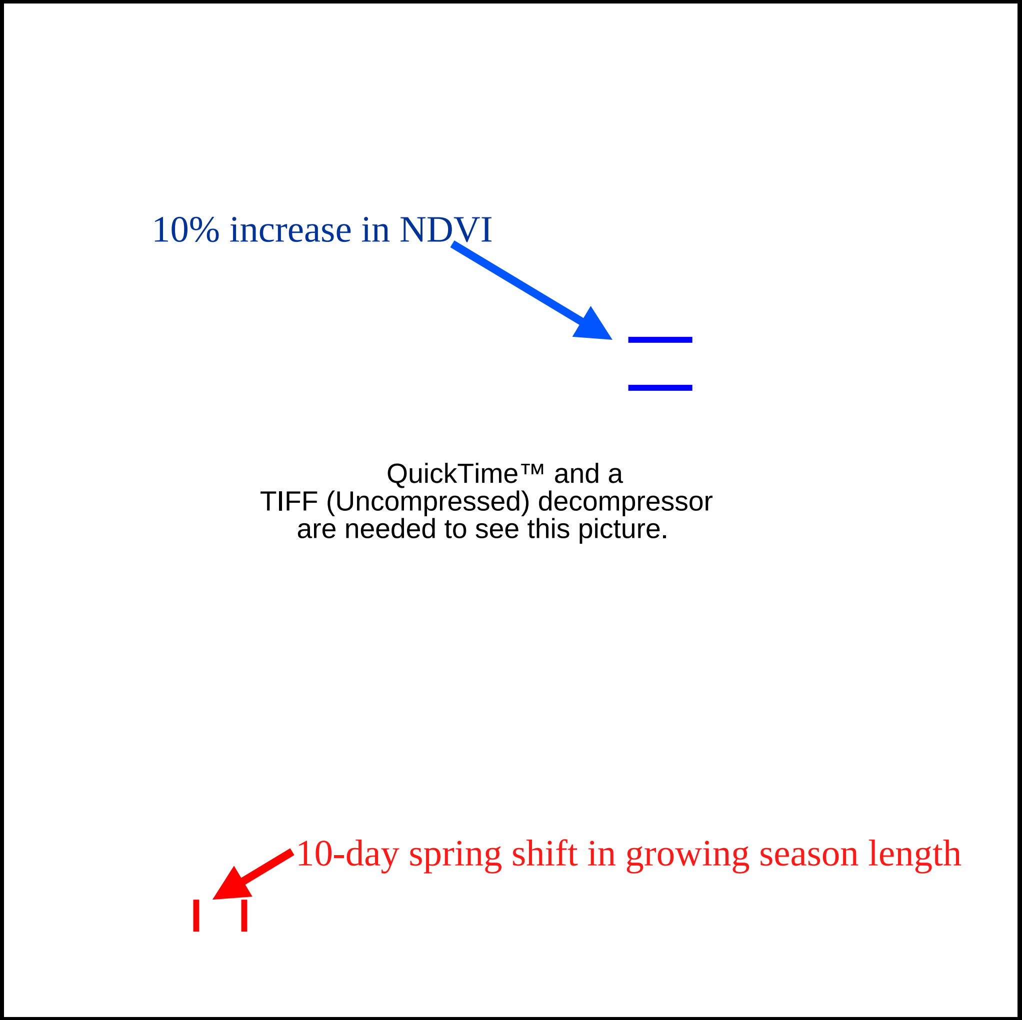
- Temperature has increased in both the forest areas and the tundra.
- NDVI has declined in the forest and increased in the tundra following the Pinatubo eruption in 1992.
- Decline in the forests may be due to drought stress.



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

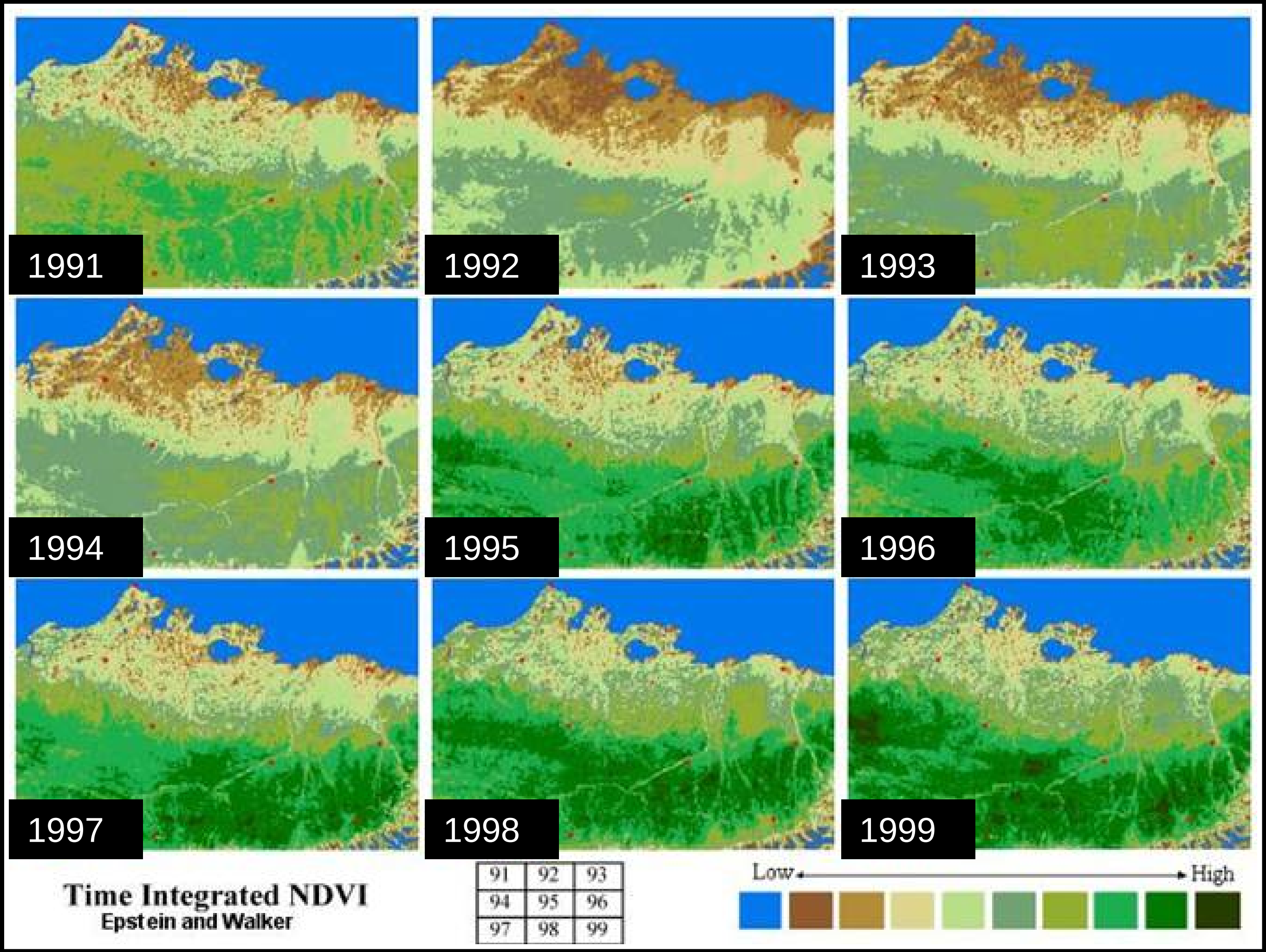
The spring season has started earlier and max NDVI has increased

- 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

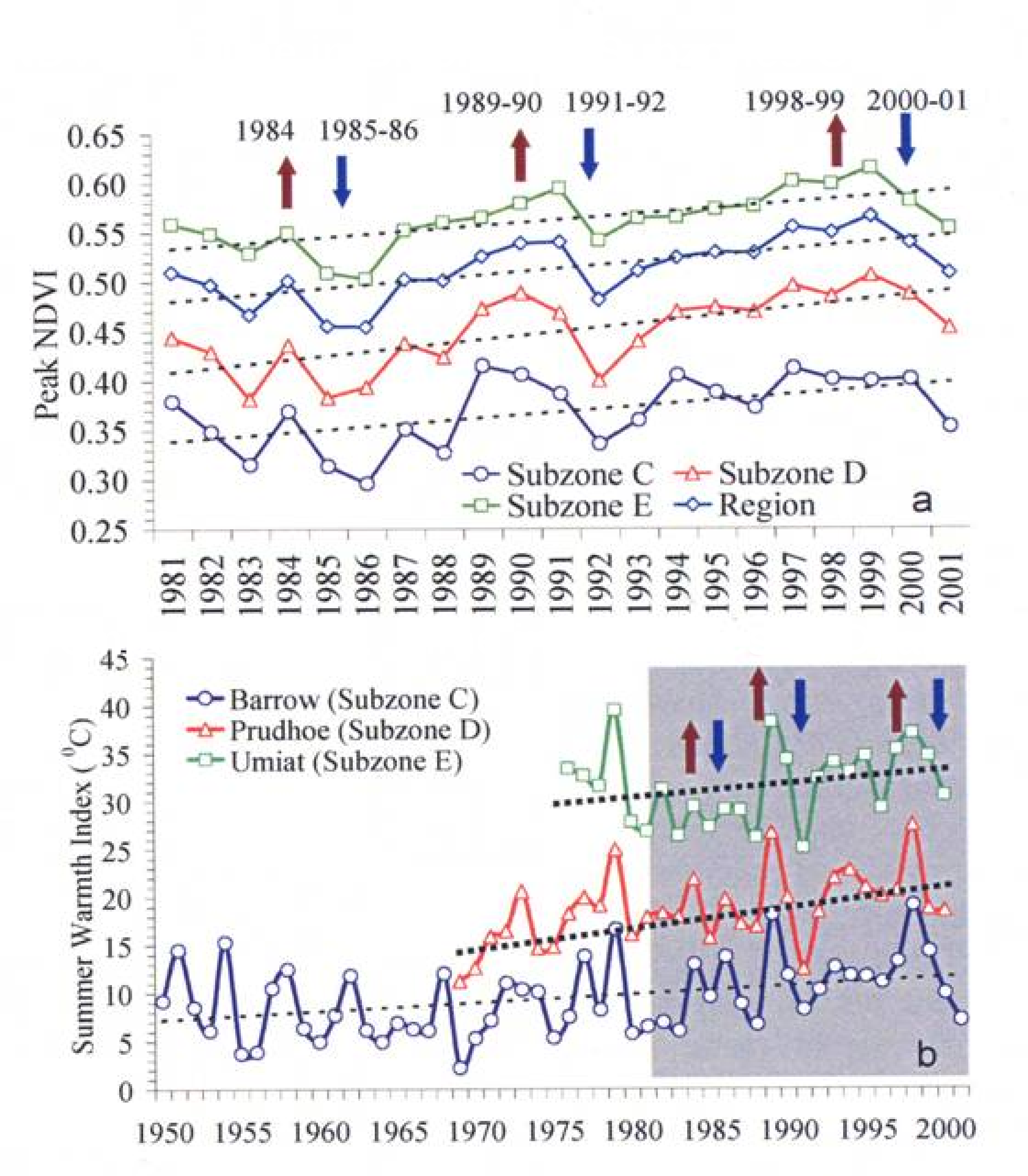
Trend of increased Maximum NDVI in northern Alaska 1981-1999



$$NDVI = \frac{NIR - R}{NIR + R}$$

From a series of papers by Jia, Epstein and Walker that document changes in the NDVI in Northern Alaska.

(Jia et al. 2003)



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.

Spring NDVI on the Porcupine Caribou Herd calving grounds

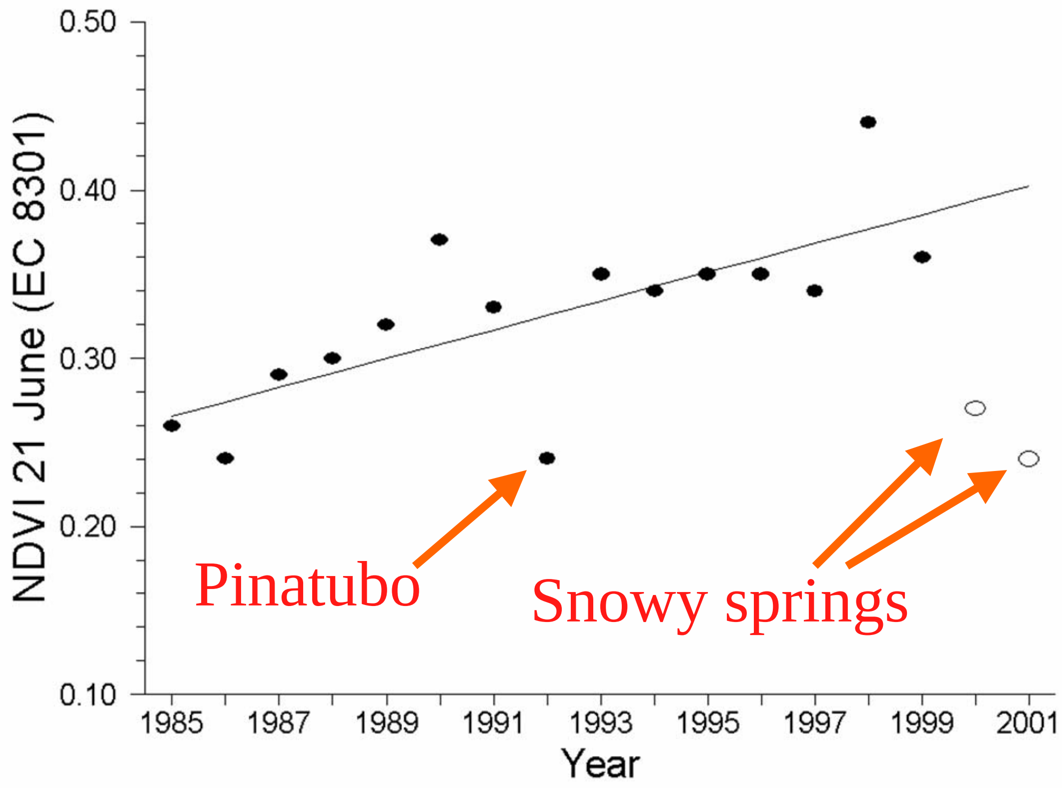


Fig. 3.4. Median Normalized Difference Vegetation Index (NDVI) on 21 June within the aggregate extent of calving for the Porcupine caribou herd, 1983-2001. Values for 2000 and 2001 were outliers (RStudent = -2.49, -2.86, respectively) and excluded from the displayed regression line, *r*2= 0.496, *P*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

USGS

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

Caribou-NDVI-climate relationships

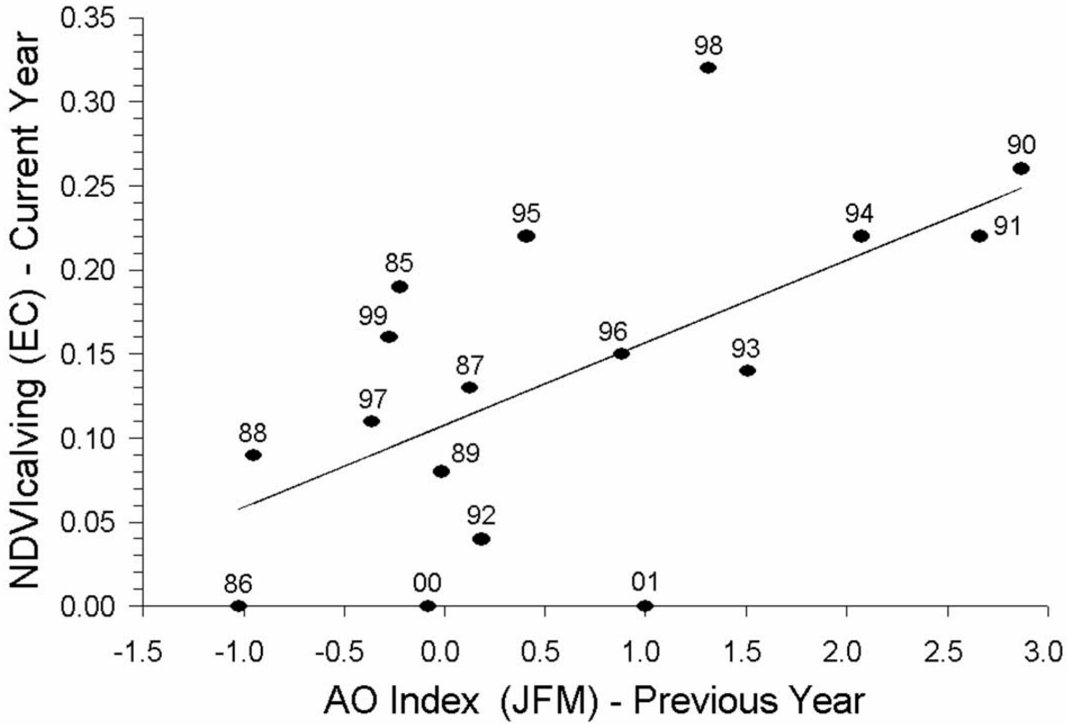


Fig. 3.6. Median Normalized Difference Vegetation Index (NDVI) at calving within the aggregate extent of calving of the Porcupine caribou herd for the current year, and winter Arctic Oscillation index (AO, January, February, March) for the previous calendar year, 1985-2001. (USGS/BRD BSR-2002-0001).

USGS

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

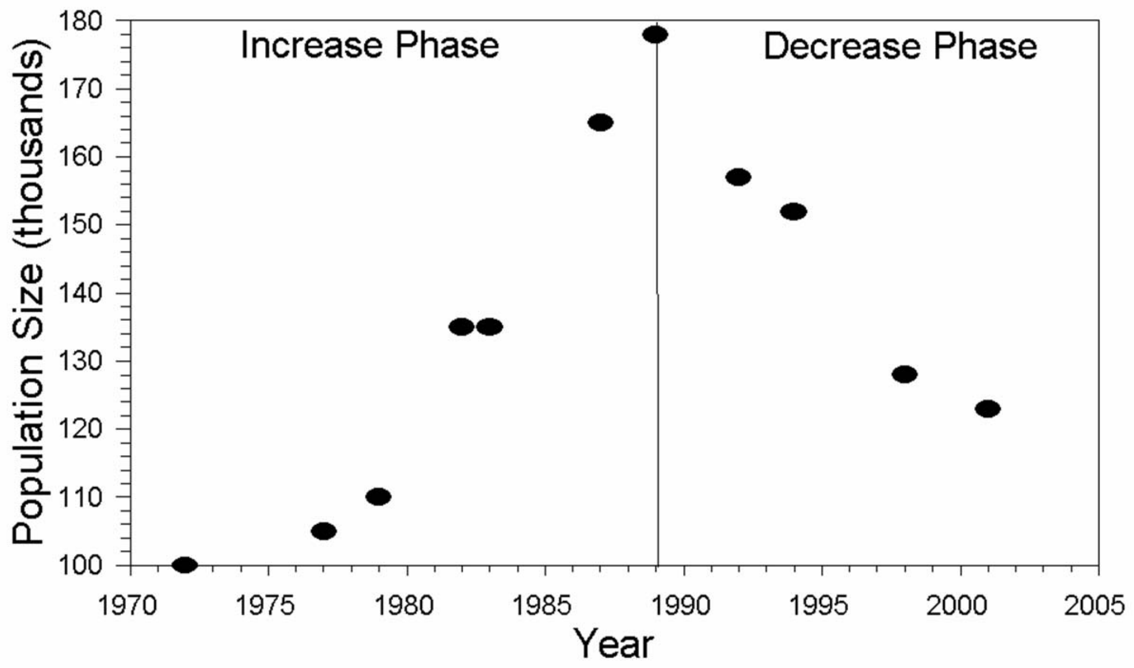
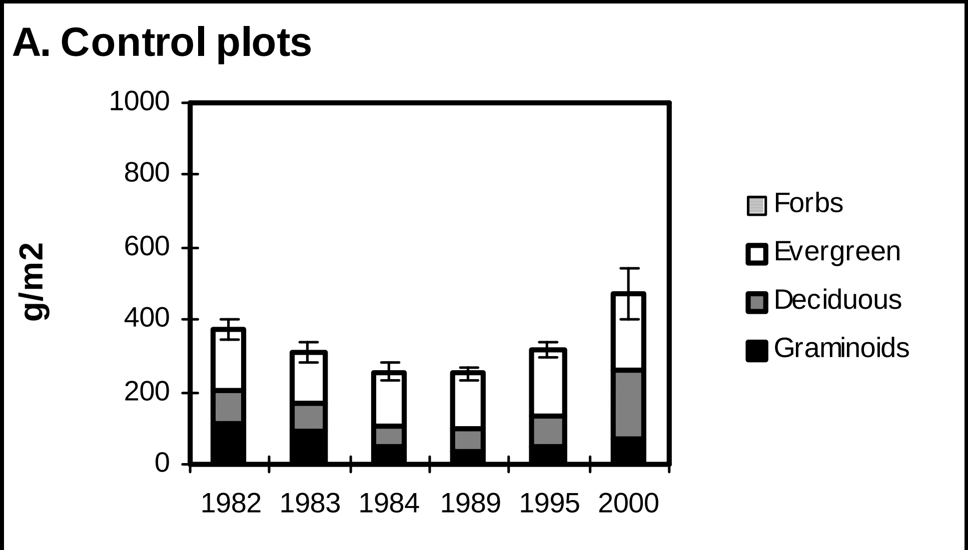


Fig. 3.8. Population size of the Porcupine caribou herd, 1972-2001, estimated from aerial photo-censuses by Alaska Department of Fish and Game. (USGS/BRD BSR-2002-0001).

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

Very few long-term biomass studies

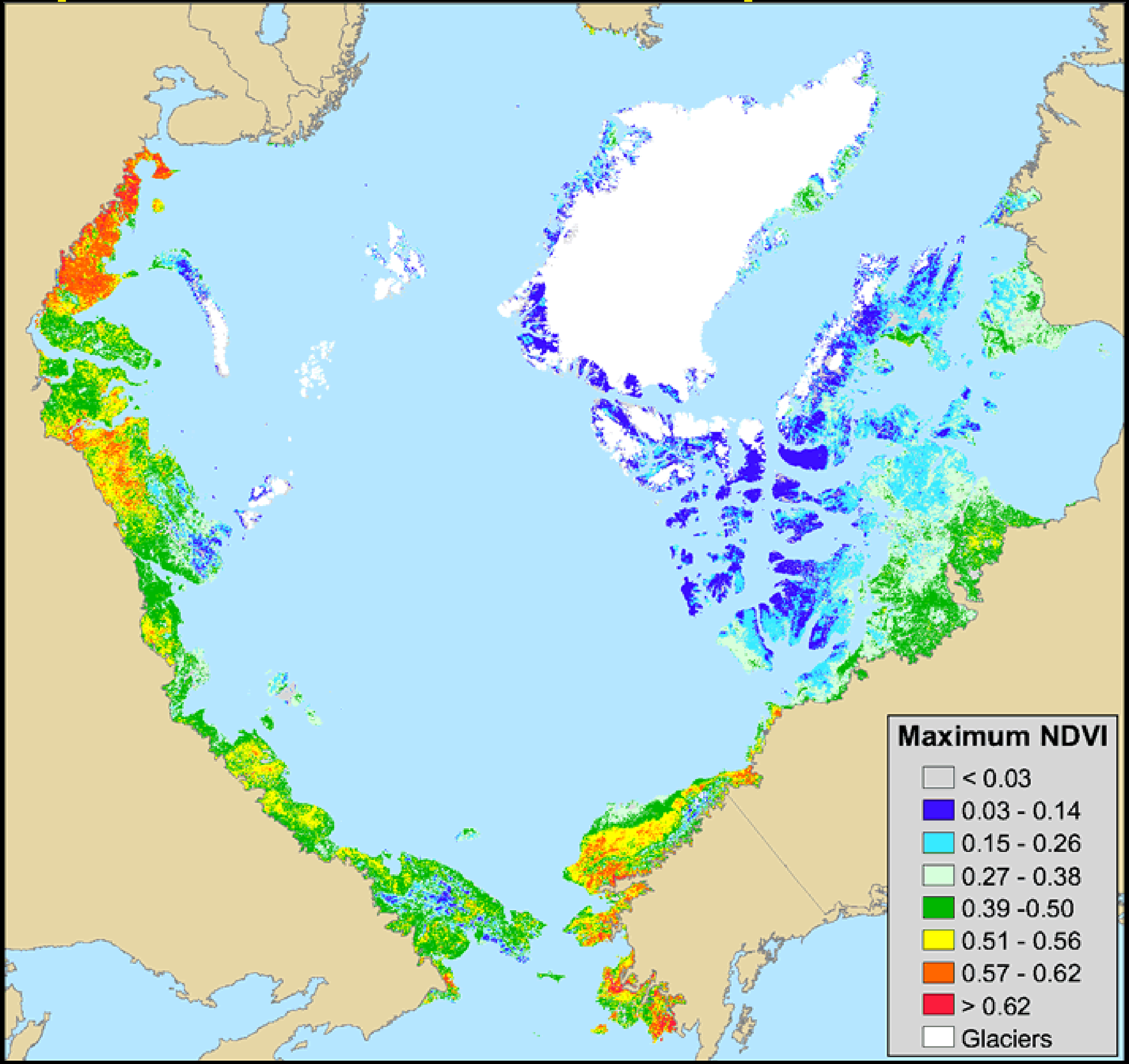
"…although the 2000 harvest occurred after 20 years of climate warming, we still cannot say for sure whether the greater total ANPP and the greater productivity of deciduous shrubs in 2000 is the result of warming or is within the "normal" range of ANPP." (Shaver et al. 2001. *Ecology* 82: 3163-3181).



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.

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 study

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

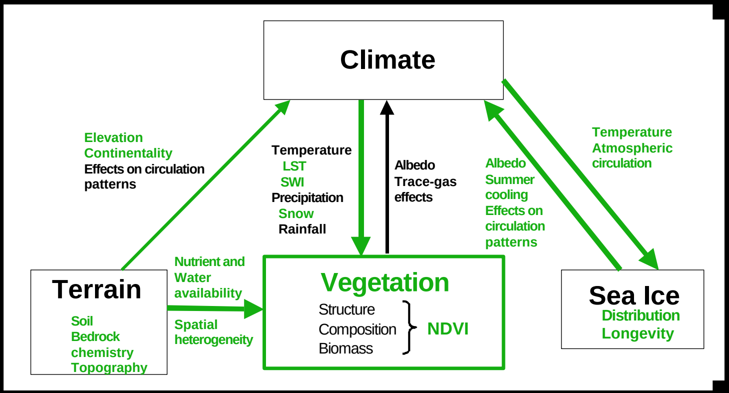
II. North American Arctic Transect: Long-term study of biomass change in the Arctic

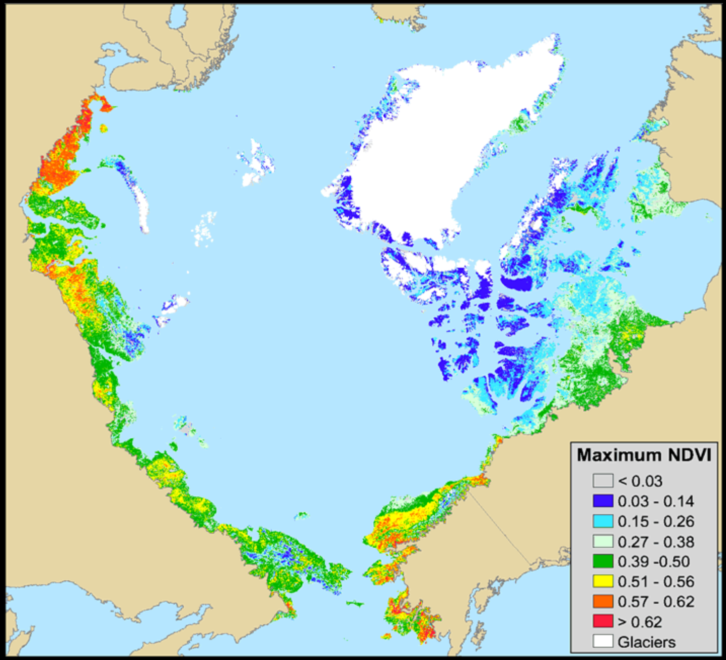
III. Analysis of impacts of shrubification to reindeer and the Nenets people in Russia: GOA transect on the Yamal Peninsula

IV. Education-Outreach component

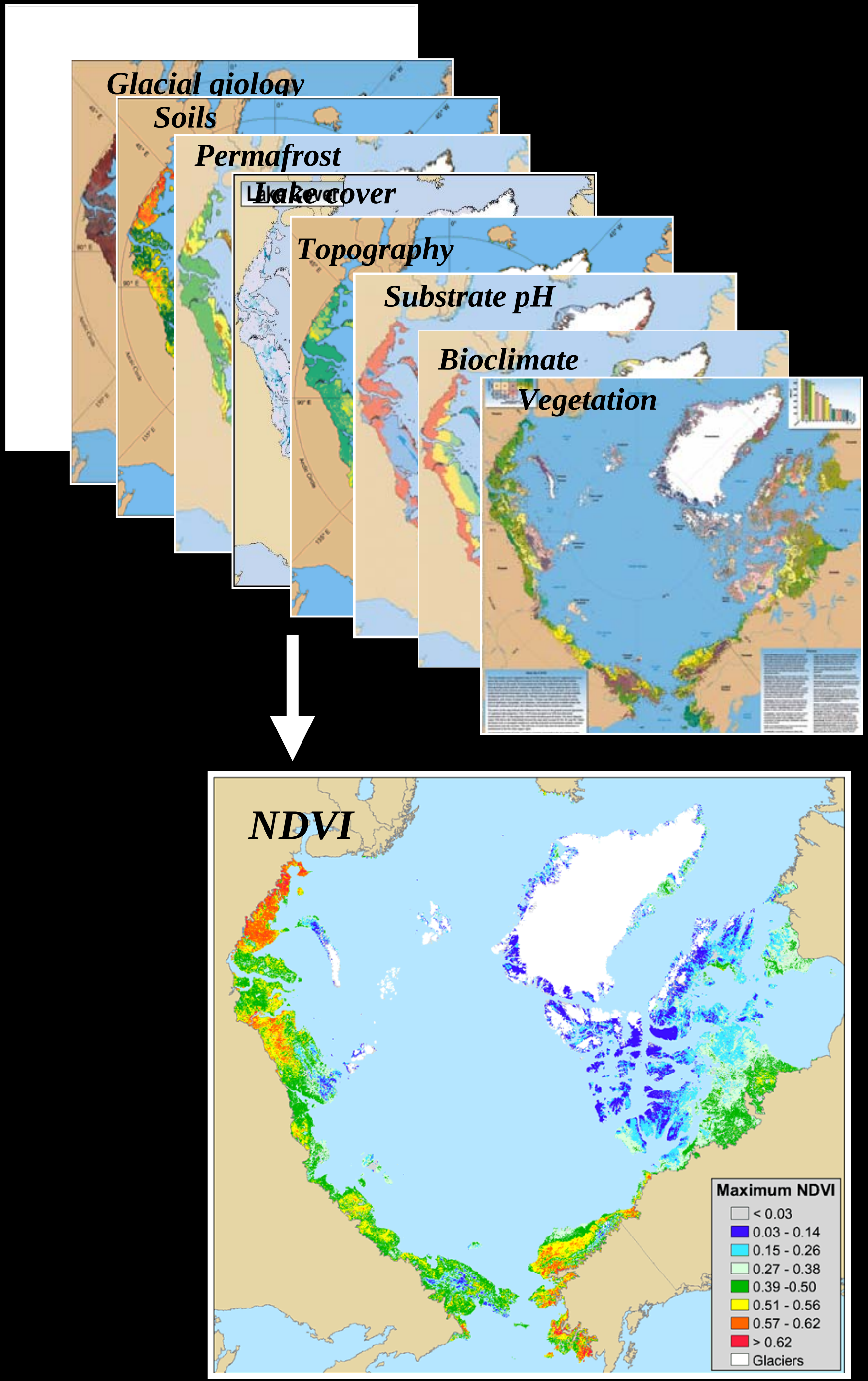
Component I: Sea Ice – Land-surface-temperature – Terrain–Greening relationships (The GOA SASS project)

- 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.





Spatial analysis of NDVI



- Will use the CAVM GIS to analyze the effects on NDVI of:
  - LST,
  - proximity to perennial ice,
  - snow distribution
  - elevation,
  - abundance of lakes,
  - glacial history,
  - permafrost regime,
  - bedrock type,
  - soils,
  - vegetation types.
- Ph.D. thesis of Martha Raynolds

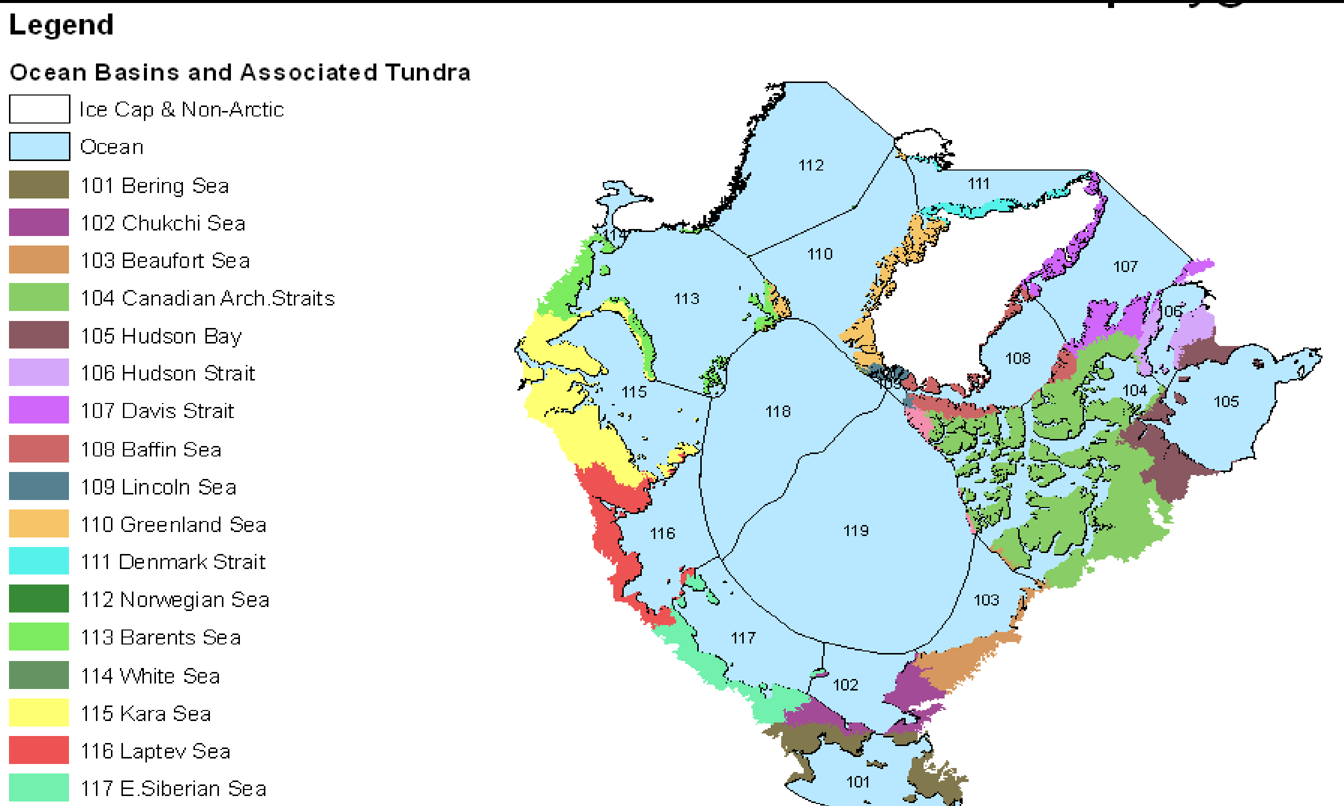
Annual temperature anomalies in the Arctic, 1981-2001

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

QuickTime™ and a
TIFF (Uncompressed) decompressor

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

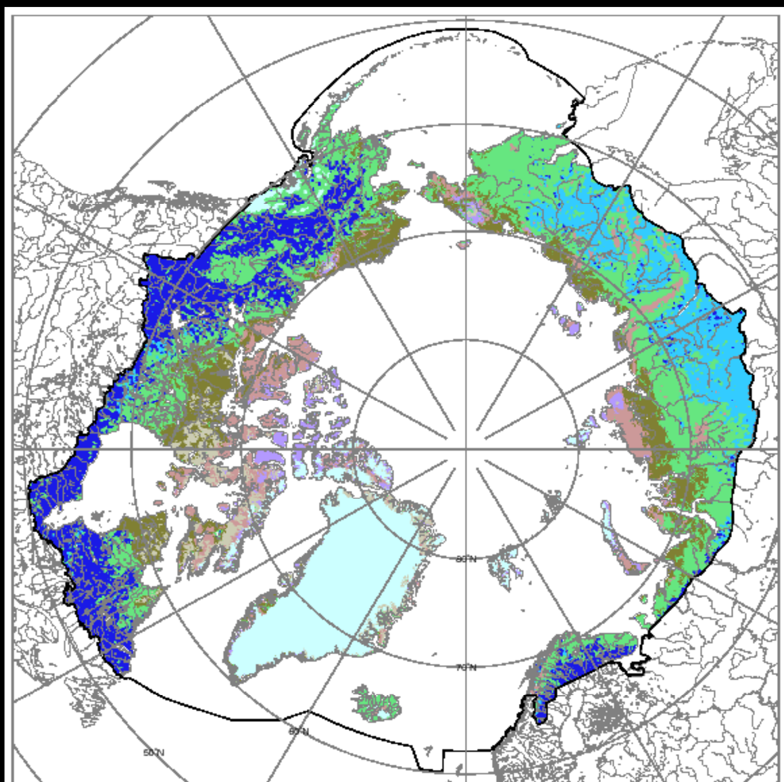
Treshnikov's subdivisions of the Arctic Basin and CAVM subdivisions on land

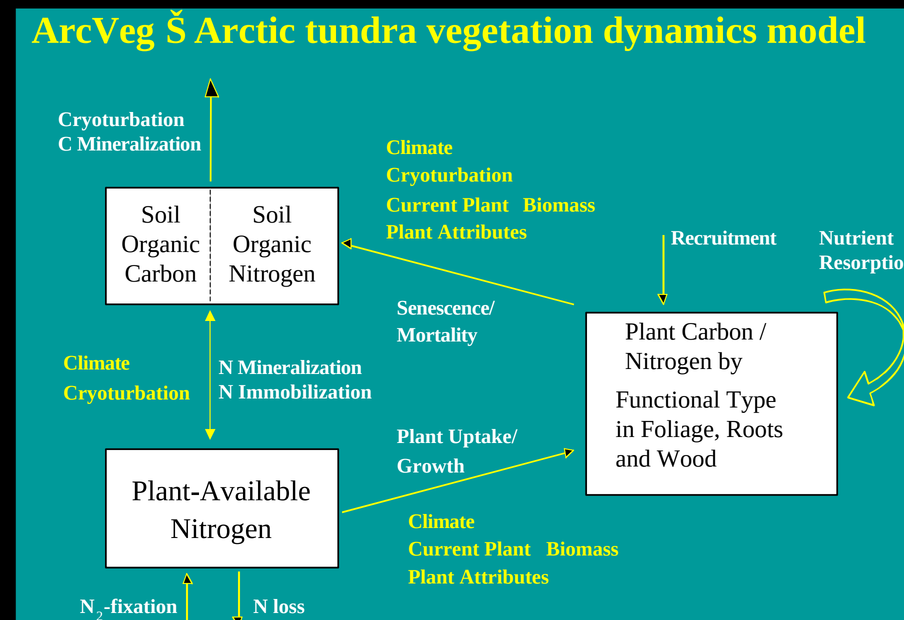


From the Treshnikov et al. (ed.) 1985. *Arctic Atlas*, Russian Academy of Science.

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.

Projections of future vegetation using modeling approaches





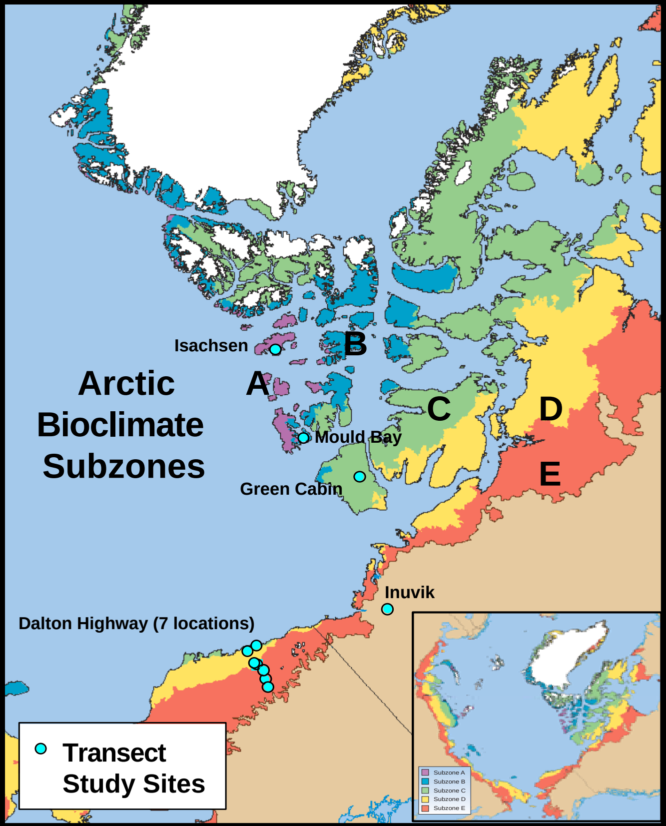
Epstein et al. 2001. Analyzing the functional type concept in arctic plants using a dynamic vegetation mode. *Oikos* 95: 239-252.

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

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

Component II: North American Arctic Transect
(Proposal in process for SEARCH)

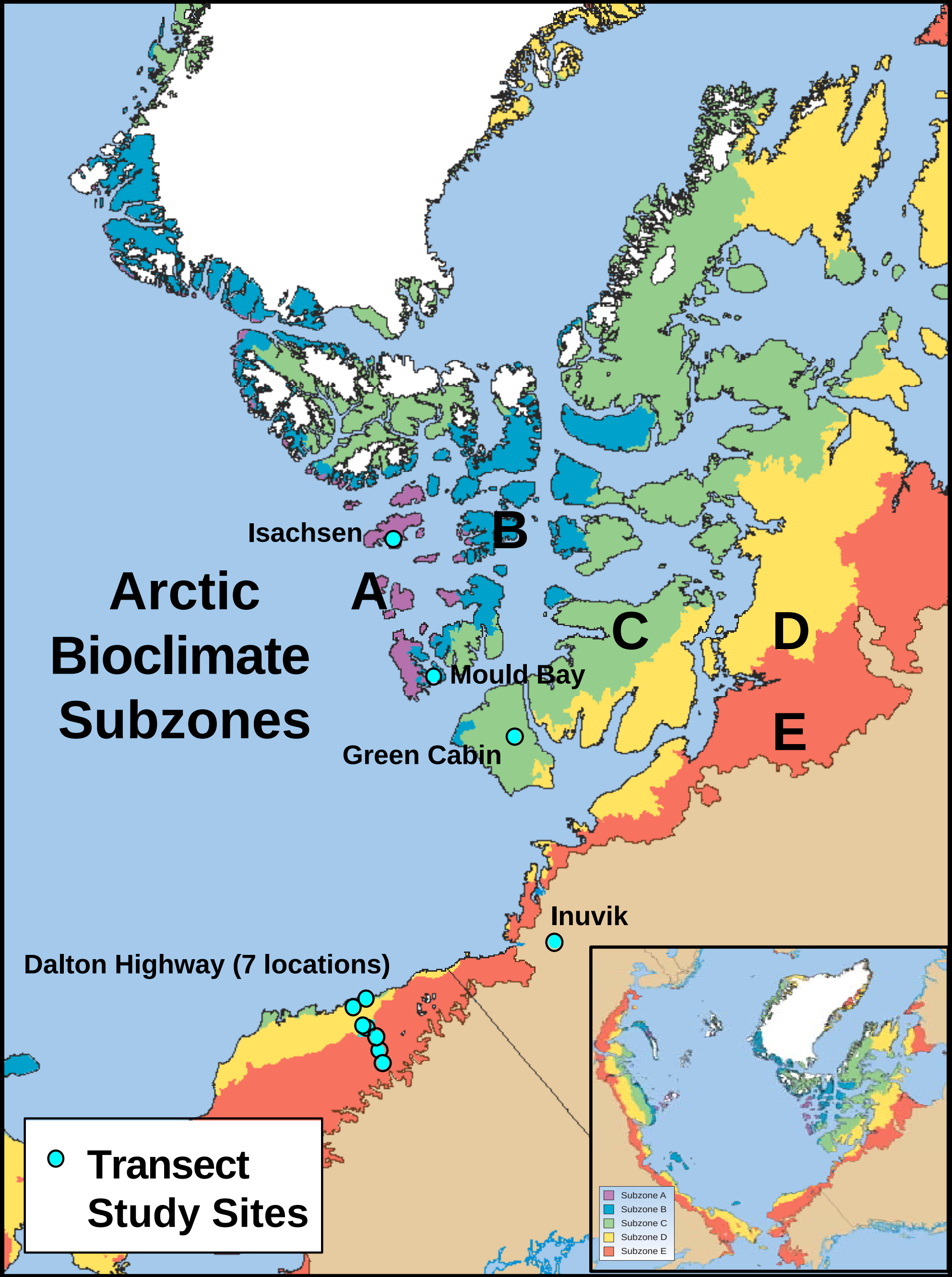
- Legacy IPY dataset of baseline biomass and NDVI measurements at three scales from 11 sites spanning the five Arctic bioclimate subzones.
- In collaboration with several other IPY projects examining climate, C-N relationships, snow, permafrost, sea-ice, active-layer depth, soil, invertebrate, contaminants, and vegetation information along the same transect.
- Complements the Yamal transect in Eurasia.
- Would be part of the Arctic Observing Network (AON) with an anchor at the Toolik Lake flagship environmental observatory.



7 sites in AK, 4 in Canada

Isachsen Camp

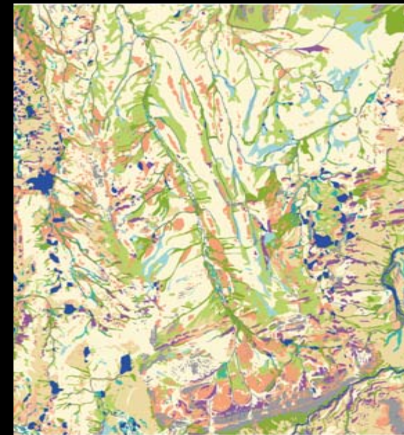
North American Arctic Transect



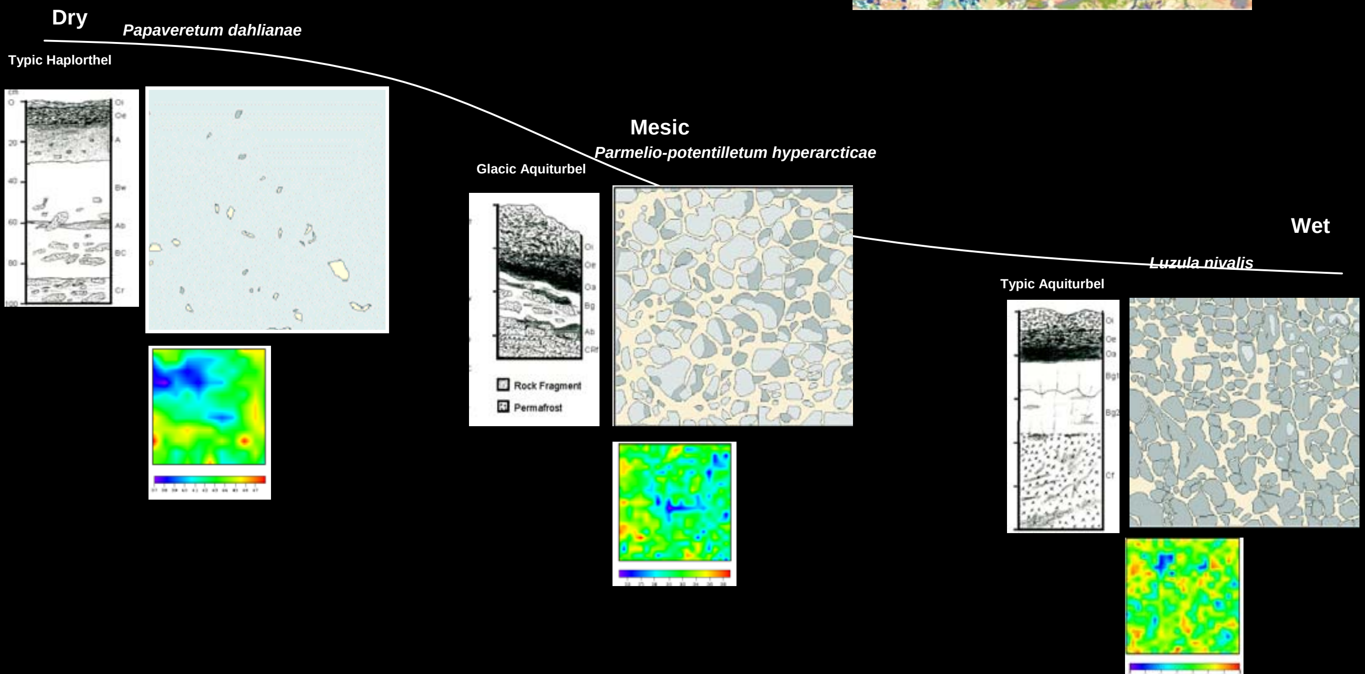
- Biomass workshop and manual in collaboration with the ITEX IPY and Arctic LTER projects.
- Clip harvest of biomass at all 11 sites in 2008.
- Hierarchical map analysis of biomass and NDVI patterns (10-m grids, 25-km areas surrounding the grids, circumpolar region) using geobotanical mapping methods and remote sensing.

Biomass mapping at multiple scales

Circumpolar



Regional
25-725 km^2



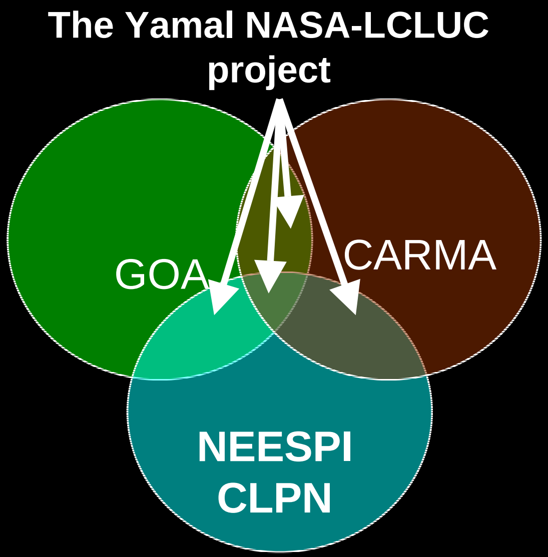
Toposequence
10-m grids

Patterned-ground elements
1-m plots

Biocomplexity studies along the NAAT at three scales

	Macroscale (Climate gradient to circumpolar)	Mesoscale (Toposequence to regional)	Microscale (Patterned-ground elements to 10-m grids)
Climate/Snow	Trends in air and ground temperature, snow depth along the climate gradient (Romanovsky, US Weather Service, Environment Canada). Circumpolar land-surface temperature (Comiso)	Trends in soil temperatures, and snow distribution along toposequences (Romanovsky).	Soil temperatures, and snow depth on patterned-ground elements. (Romanovsky) Snow profiles on patterned-ground elements (Walker et al.) Snow depth maps (10 x 10-m grids) (Raynolds, Munger).
Permafrost	Trends in permafrost temperature, n-factor unfrozen water content, active layer depth, and frost heave along the climate gradient. (Romanovsky, Kade). Circumpolar permafrost map (Brown et al.)	Trends in n-factor, active layer depth, and frost heave along the toposequences (Romanovsky, Kade) WIT/ArcVeg model of patterned-ground formation (Daanen, Misra, Epstein)	Heave, active layer depth, soil-water content, unfrozen water, and n-factor within patterned-ground elements (Romanovsky). Active-layer and snow-depth maps (10 x 10 m grids) (Raynolds, Munger) Thermo-mechanical model of differential frost heave (Nickolsky, Romanovsky) DFH model of heave initiation (Peterson, Krantz)
Geology/ geomor-phology	Circumpolar patterns of landscape age, glacial geology, bedrock,and physiography. (CAVM Team, Raynolds)	Surficial geomophology along toposequences. (Walker et al.)	Elements of patterned-ground features. (Walker et al., Tarnocai)
Soils	Circumpolar Soils Map (Tarnocai and Ping) Circumpolar Carbon Map (Tarnocai) Trends in soil C and N along the climate gradient (Ping and Michaelson)..	Soil associations along toposequences (Ping). Trends in soil chemical and physical characteristics along toposequences. (Ping and Michaelson)..	Pedon within each patterned ground element (Ping). Cryptogamic crusts in each patterned ground element. (Michaelson) Physical and chemical properties of soils in each patterned-ground element. (Ping and Michaelson).. N-cycling in each patterned-ground element (Kelley).
Soil biota	Trends in soil invertebrates, microbes, fungi/ mycorrhizae along the climate gradient. (Gonzalez, Timling)	Trends in soil invertebrates, microbes, fungi/ mycorrhizae along toposequences. (Gonzalez, Timling)	Soil invertebrates, microbes, fungi/ mycorrhizae in patterned-ground elements. (Gonzalez, Timling)
Vegetation	Circumpolar AVHRR NDVI, and vegetation(CAVM Team, Raynolds, Epstien, Jia) Trends in zonal vegetation biomass along the climate gradient (Walker et al., Epstein) Buried seed bank along the climate gradient (Kelley) ArcVeg succession models along the climate gradient (Epstein)	Plant communities along toposequences (Kade, Vonlanthen et al.). 10 x 10-m vegetation maps along toposequences (Raynolds, Munger)	Plant communities within patterned-ground elements (Kade, Vonlanthen et al., Matveyeva, Danels). 1 x 1-m vegetation maps (Kade) Handheld LAI and NDVI of patterned-ground elements (Epstein) Biomass of plant communities (Walker et al., Epstein). Buried seed bank within patterned ground elements (Kelley)

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



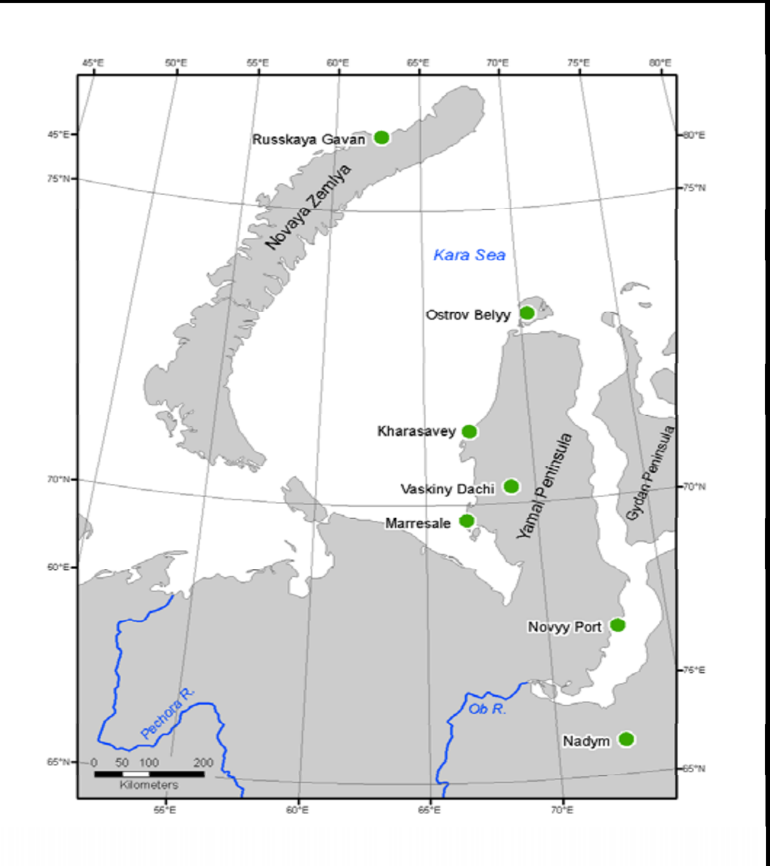
- Examines the linkages between greening trends, the range and forage for the reindeer of the Nenets people, and the regional sea-ice conditions.
- Field research and modeling in all 5 arctic bioclimate subzones on the Yamal Peninsula and Novaya Zemlya in Russia.
- Linked to the Circumpolar Arctic *Rangifer*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

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.

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.

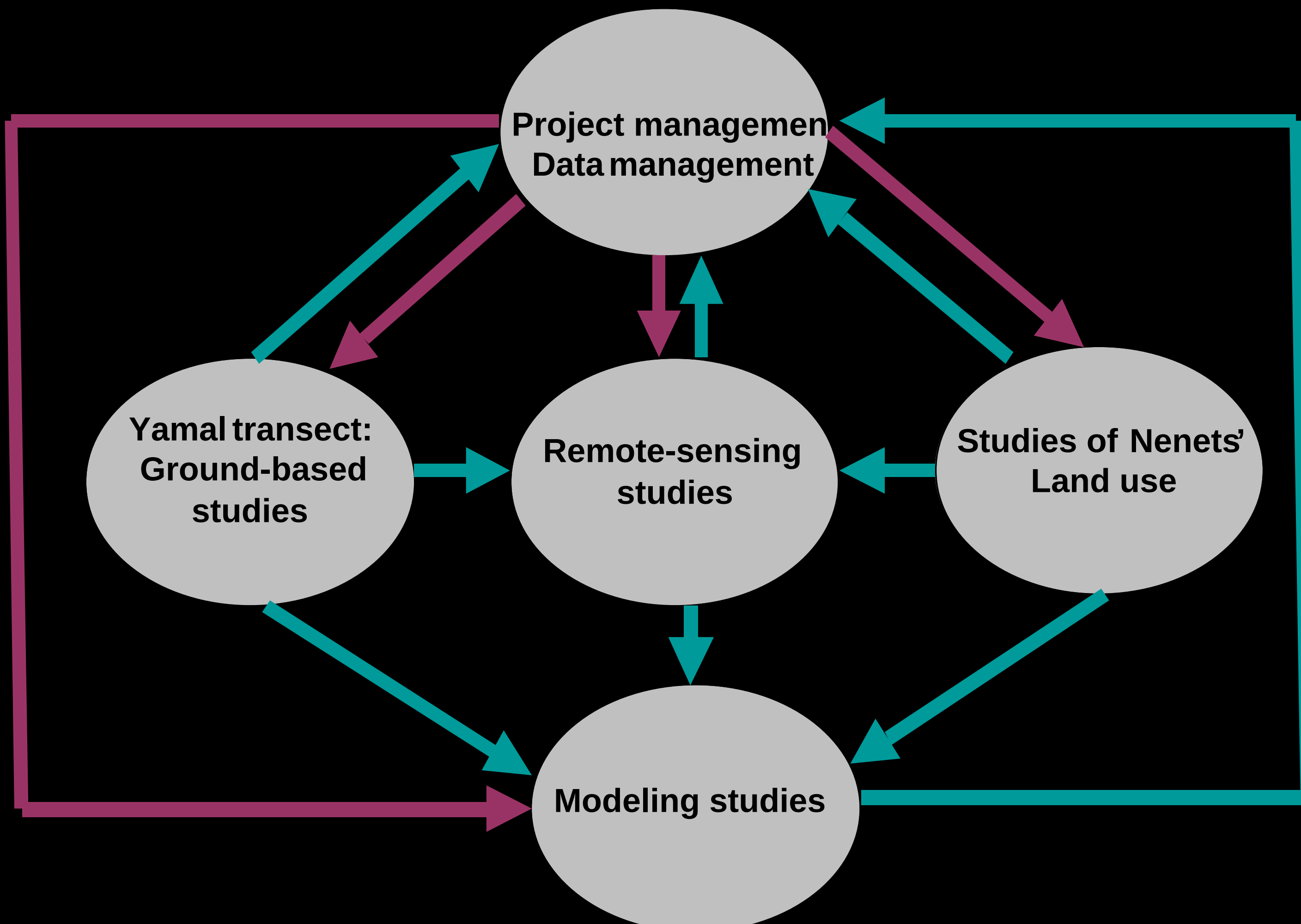
Geobotanical variation across the Yamal transect

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Base Map: CAVM Team 2003, Alaska Geobotanical Center

Five project components

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



The Nenets 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. We would like to get a better idea of specific sites where *Salix* growth has been observed by herders. we would then try to quantify the changes in growth using western science methods - repeat air photography and/or dendrochronology - on the very same sites. the region is too large and varied to just go out and randomly try to document recent changes. Besides shrubs, we will also be asking herders about general trends in vegetation cover, e.g. grassification, sandy erosion, etc. as with shrub growth, these things are relevant to any overall 'greening' signal and so of direct interest to GOA."

--Bruce Forbes

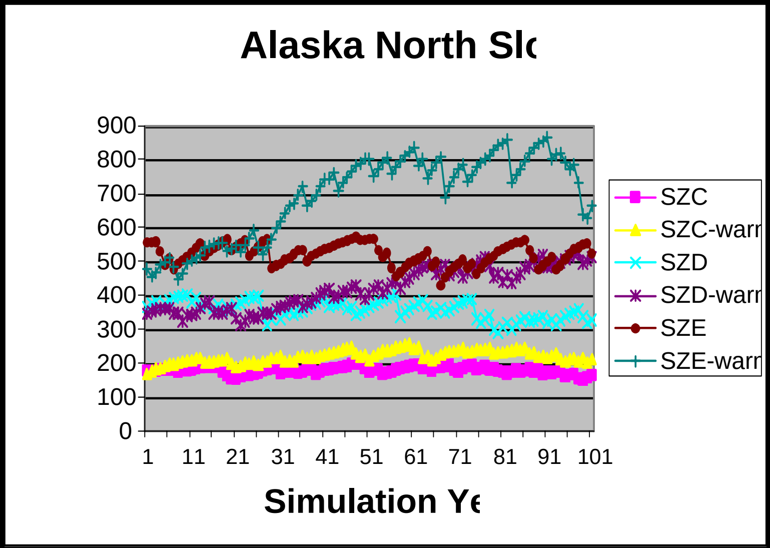
Using high-resolution satellite images during interviews with Nenets herders

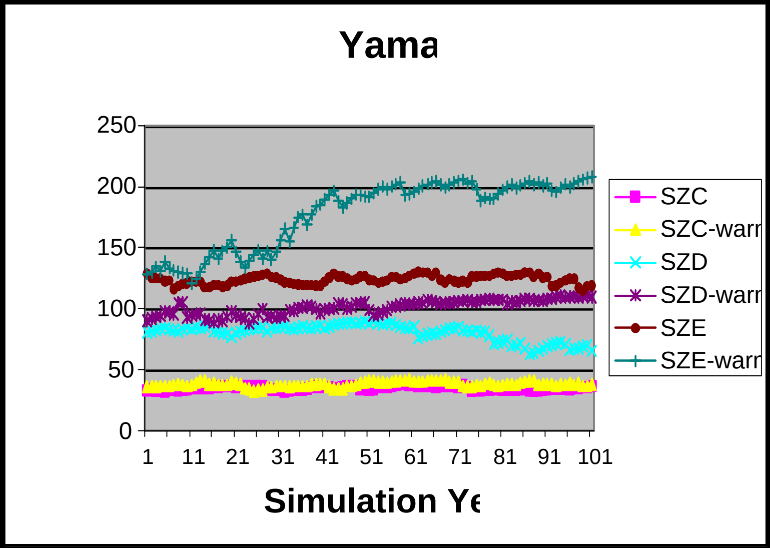
Courtesy of Bruce Forbes

"…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

Modeling transient dynamics of the vegetation





Courtesy of Howie Epstein

- 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.

Component IV: Education/Outreach

Arctic Geobotanical Atlas

"Plant to planet scale volume of maps and related information"

Maps and GIS information available on line via map-server software.

Arctic Field Ecology course

Bill Gould's course integrating research, arctic education, and involvement of Native communities along the NAAT.

9th International Conference on Permafrost field trip

Field trip along the NAAT in 2008.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

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