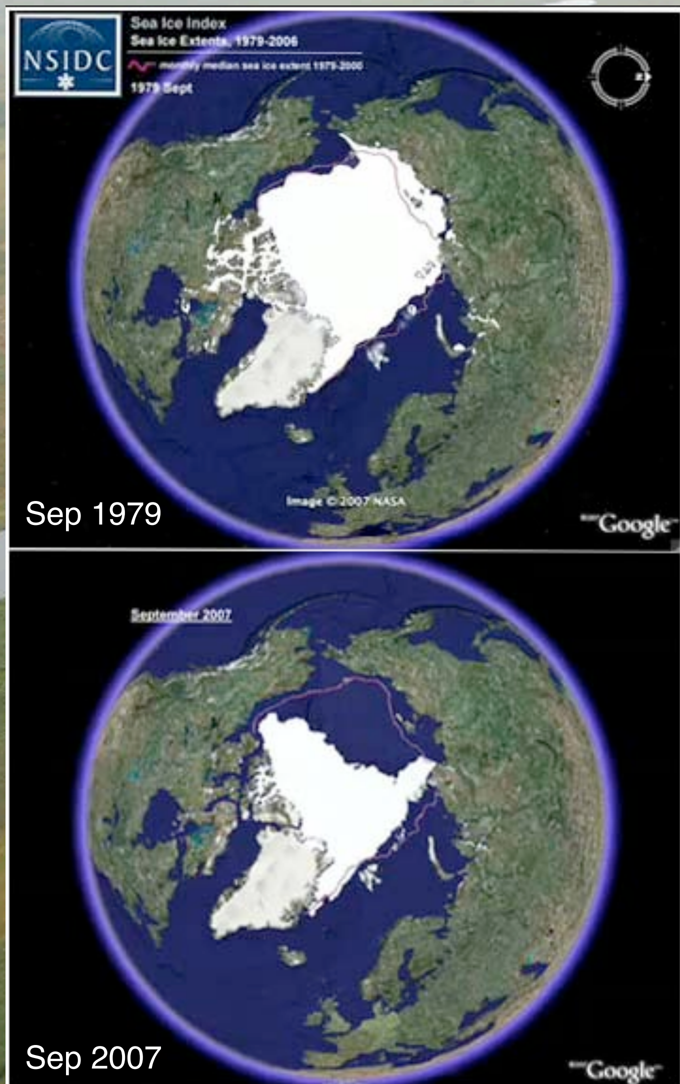
Greening of the Arctic: an IPY initiative



Does the the loss of sea ice affect the tundra and those who depend on it?

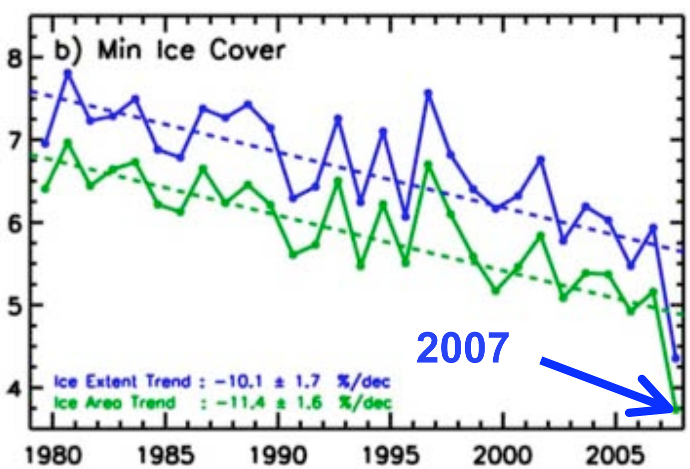
Skip Walker
University of Alaska Fairbanks
IAB Seminar, November 21, 2008

Outline of talk

- Rationale and overview of the GOA initiative.
- North American Arctic Transect.
- Yamal Russia Transect.
- Circumpolar analysis of 28-year trends of sea-ice concentration, land-surface temperatures and greening patterns.

Trend in Arctic sea-ice

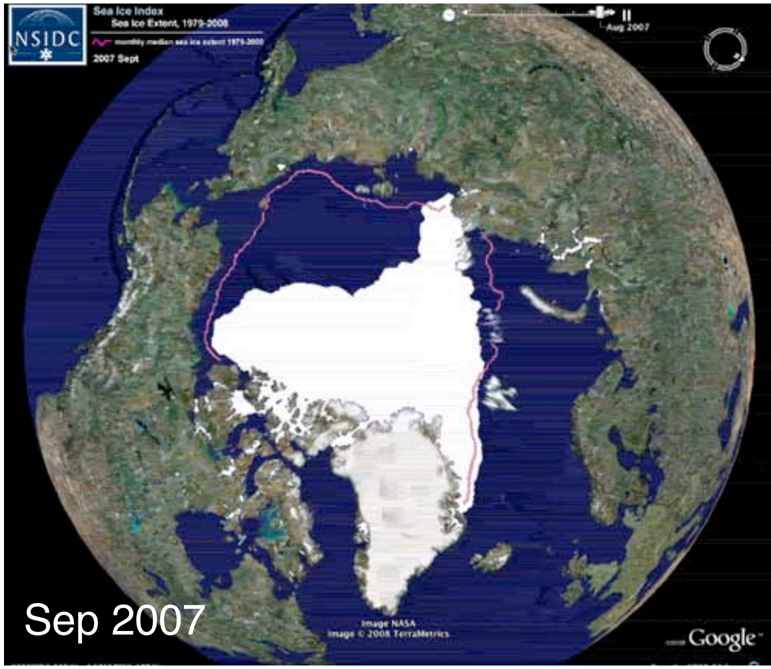
2007 minimum sea-ice extent, 4.5 million km^2.
NSIDC.

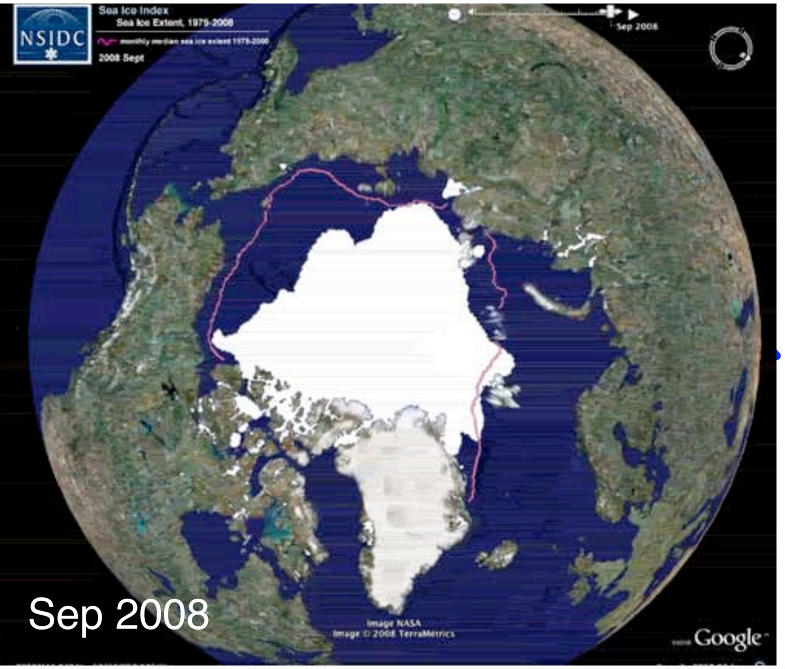


Since 1980, perennial sea ice extent in the Arctic has declined at the rate of 10.1% per decade, and area trend is -11.4% decade.

Comiso et al. 2008, *Geophysical Research Letters* 35: L01703.

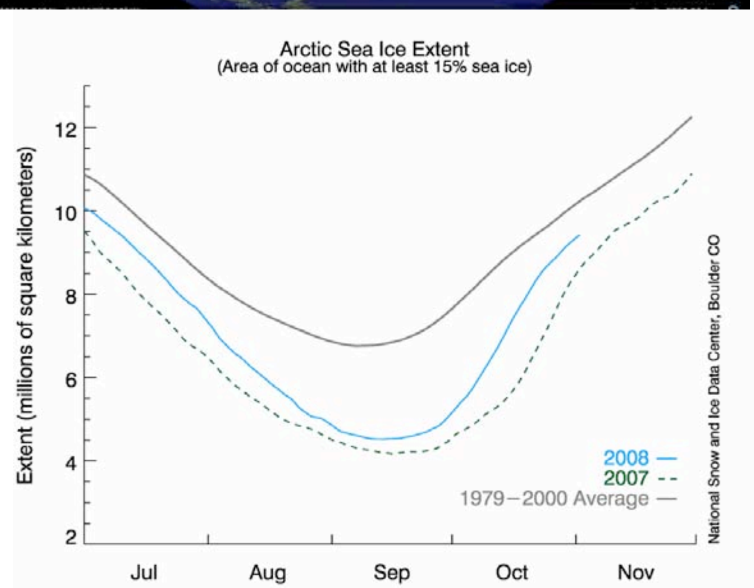
2008 sea-ice





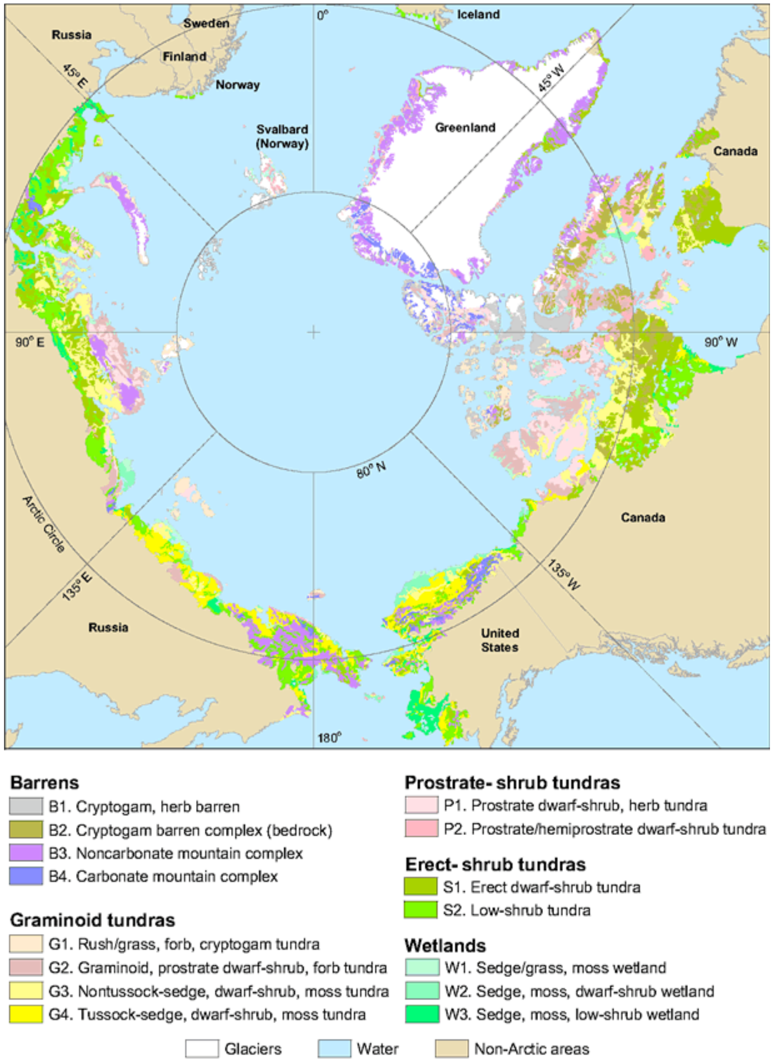
2008 was the second lowest minimum.

The Arctic coasts of North America and Asia were simultaneously ice free for the first time on record.

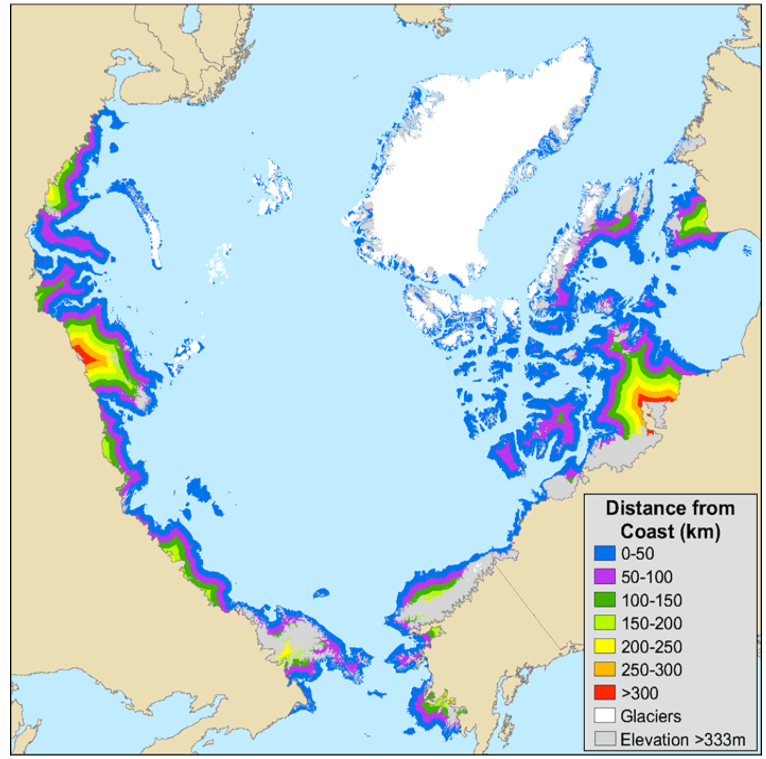


NSIDC: http://nsidc.org/data/virtual_globes/images/seaice_2008_climatology_lr.mov

The Arctic tundra is a maritime biome



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

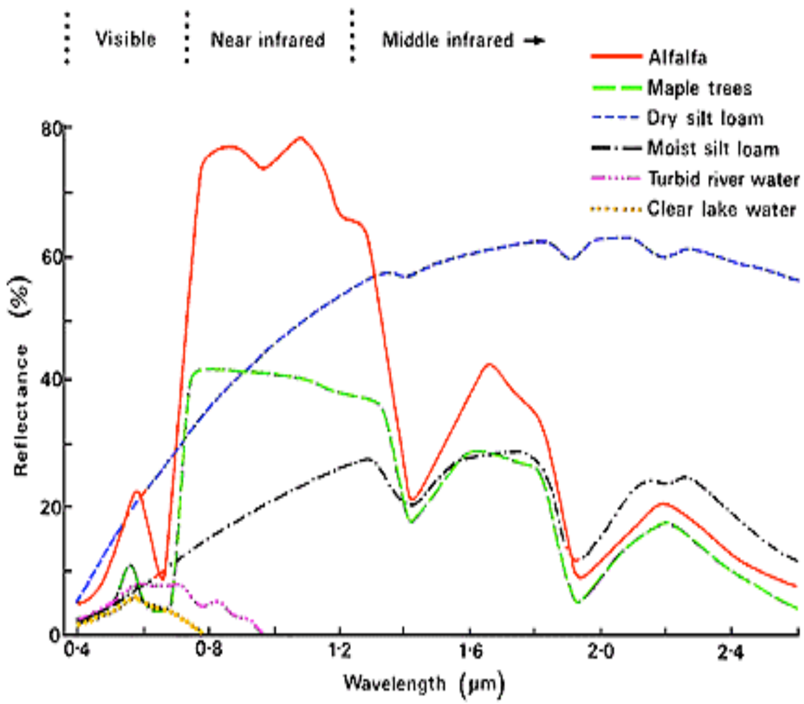


Map by Hilmar Maier.

- 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 (all colors).
- Changes in the Arctic ocean sea ice will very likely affect terrestrial ecosystems.

Normalized Difference Vegetation Index (NDVI): An index of greenness

Reflectance spectra of common ground-cover types



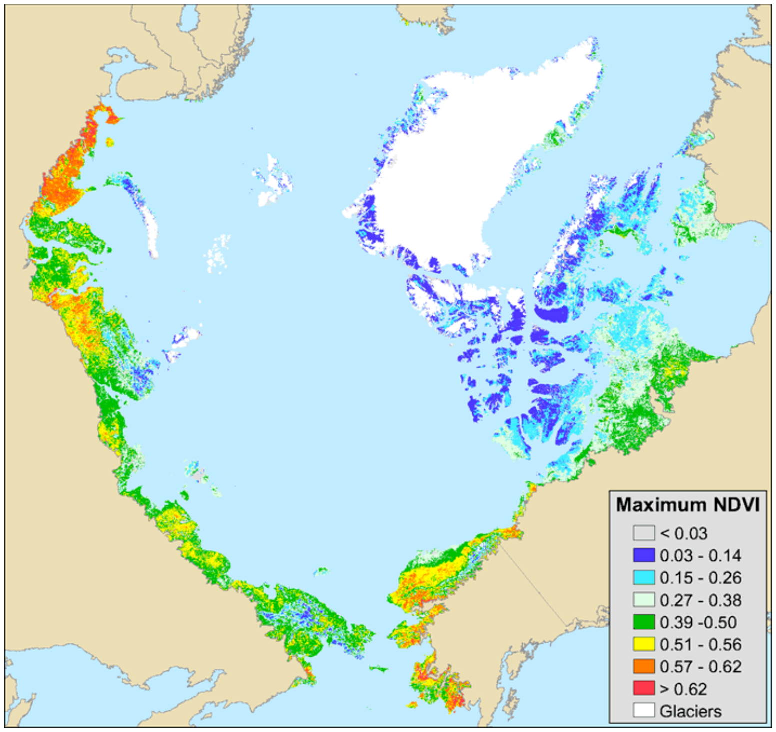
Normalized Difference Vegetation Index

NDVI = *(NIR – VIS) / (NIR + VIS)*

NIR = spectral reflectance in the near-infrared band (0.7 - 1.1μm), where light scattering from the cell-structure of the leaves dominates.

VIS = reflectance in the visible, chlorophyll-absorbing portion of the spectrum (0.4 to 0.7μm).

Circumpolar patterns of NDVI

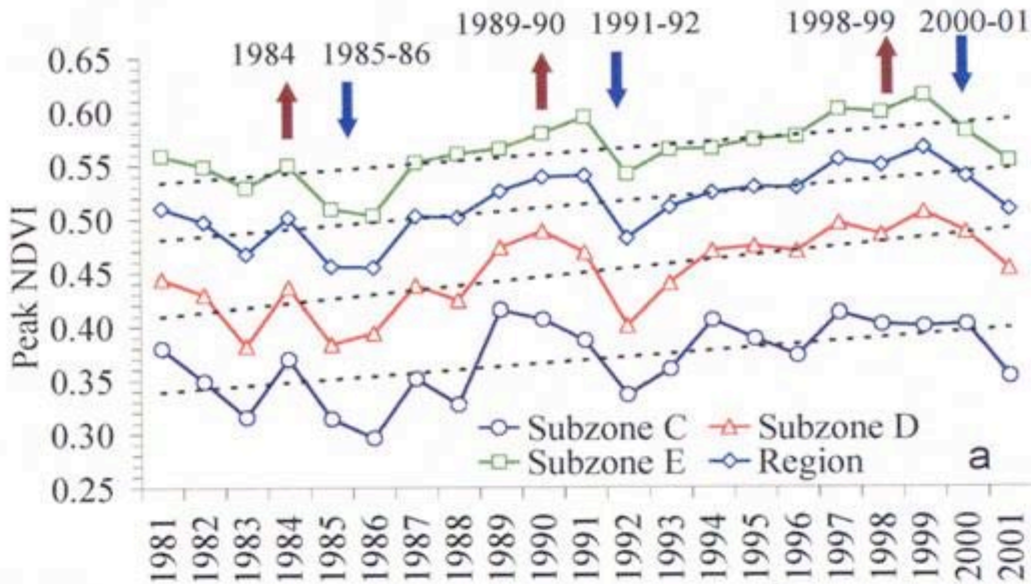


CAVM Team. 2003

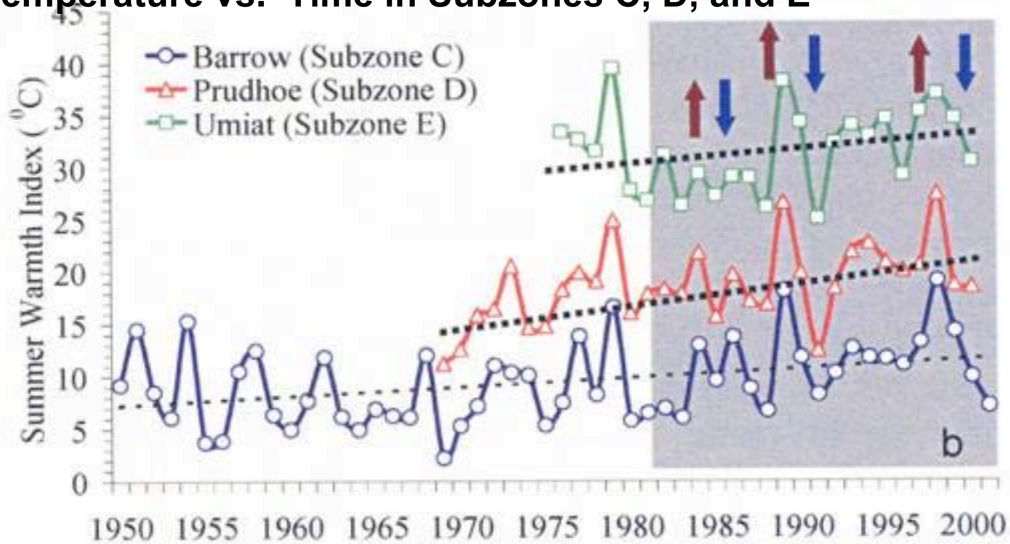
In general, land cover with high reflectance in the NIR and low reflectance in the visible portion of the spectrum has dense green vegetation.

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

NDVI vs. Time in Bioclimate Subzones C, D, and E



Temperature vs. Time in Subzones C, D, and E

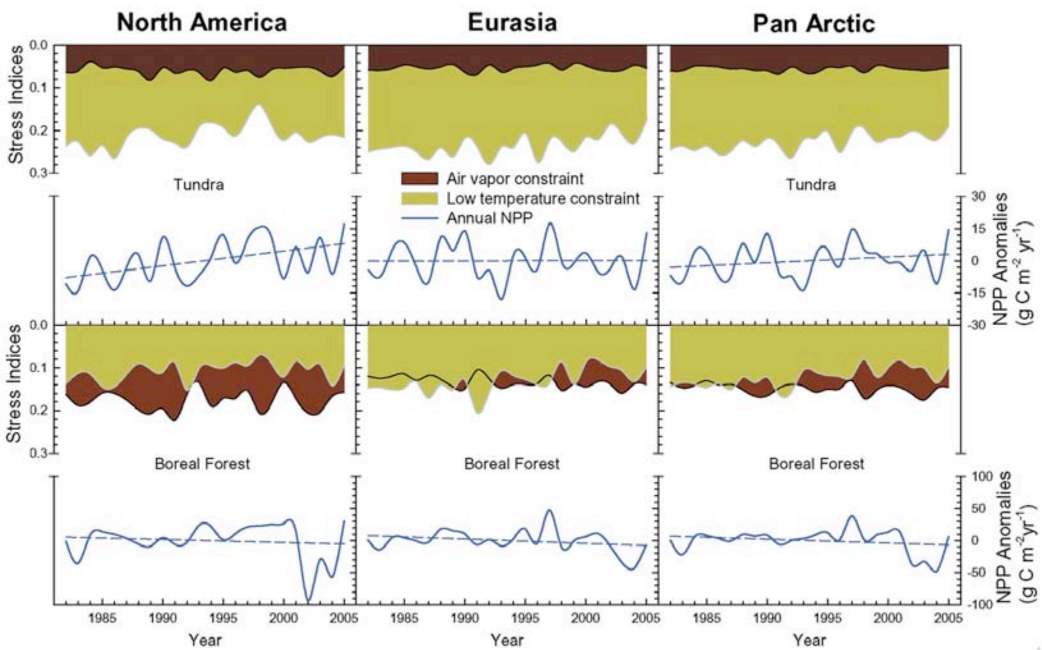


- 17 ± 6% increase in peak NDVI from 1981-2001.
- Available biomass data indicate that this increase in NDVI corresponds to about a 150 g m^{-2} increase in biomass.
- Changes in NDVI show a long term increase and also some correspondence to yearly fluctuations in temperature.

Jia et al. 2003 *Geophysical Research Letters.* 30: 2067.

Time series of peak NDVI anomalies in the tundra and boreal forest (1981-2005)

Green: increasing NDVI
Red: decreasing NDVI
White: no trend



- 88% of the region is shows no significant trends in NDVI. 3% have decreasing trends, and 9% have increasing trends.
- Most of the positive changes are in tundra areas, particularly in North America.
- Forest areas are showing an overall decline in NDVI.

Bunn et al. 2007. *EOS.* Northern high latitude ecosystems respond to climate change. 88: 333-335.

There is not a lot of direct evidence for change in Arctic vegetation.

Photo – M. K. Raynolds

- Mostly experimental evidence;
  - Green-house experiments (Chapin et al.)
  - ITEX experiments
- One long-term biomass study of Shaver at Toolik Lake that is suggestive of change but inconclusive.
- Photo record of shrub cover change in northern AK (Matthew Sturm, Ken Tape, and Chuck Racine):
  - Over 30% increase in alders on some stable valley slopes in the warmest parts of the Arctic.
  - Dramatic increase in shrub cover on river terraces.

Uncertainties and needed research

- There are virtually no long-term biomass data to support or dispute the trends shown by NDVI.

> *"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)

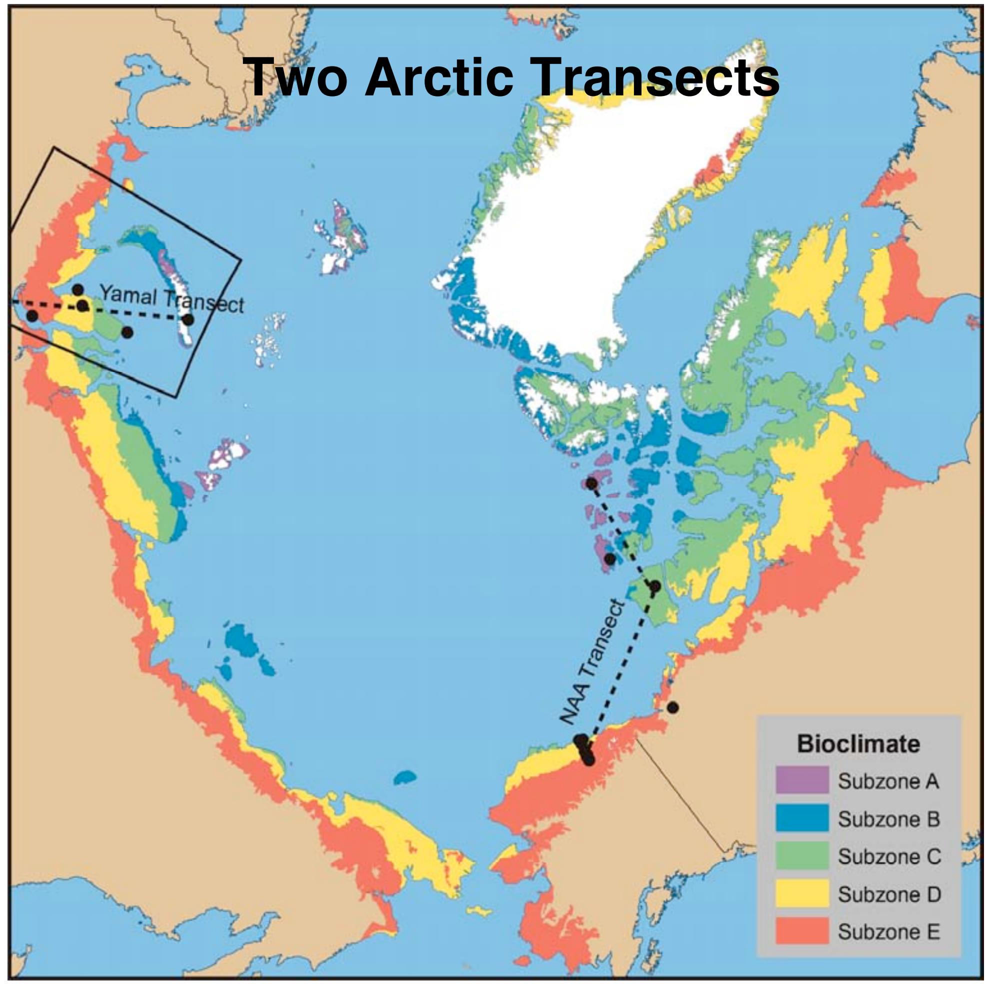
- Causes of variation of NDVI within the Arctic as well as seasonality of NDVI have not been examined. The relative roles of interacting factors (e.g., climate, sea-ice distribution, elevation, glacial history, substrate chemistry, water regimes) need to be better understood. Is the current trend still partially a long-term response from the last glaciation?

- Other NDVI issues:
  - –Variation with latitude and different sun angles in tundra.
  - –Calibration problems between different satellites.

- Greenness changes in the Arctic need to be more clearly linked to issues relevant to man (e.g., wildlife habitat, links to other elements of the Arctic system, feedbacks to global system).

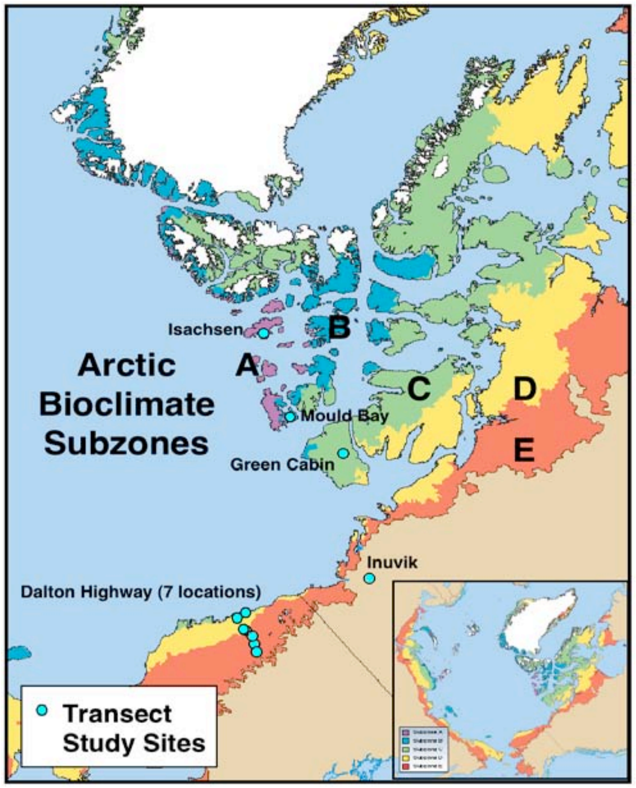
GOA studies are focused along two Arctic transects.

Transects in North America and Eurasia through all five bioclimate subzones as portrayed on the CAVM.



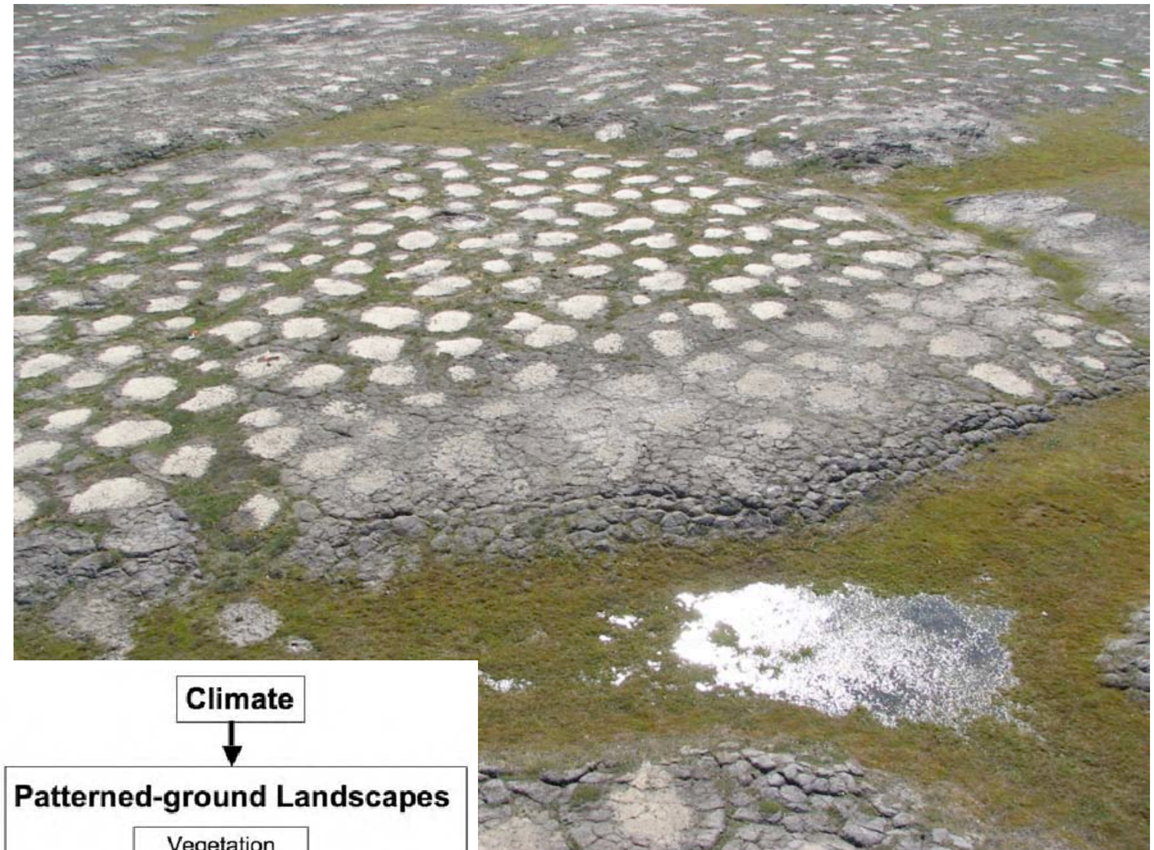
North American Arctic Transect (NAAT)

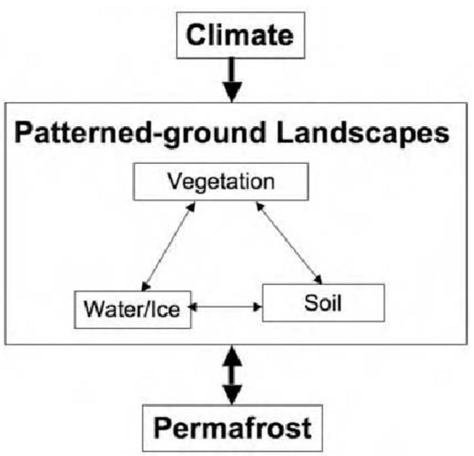
- 1800-km transect through five Arctic bioclimate subzones in North America.
- Initiated in 2002–06 as part of NSF Biocomplexity of Patterned-Ground Project.
- Numerous other IPY studies are coordinated with this effort (e.g. CALM, TSP, Lee Taylor's mycorrhizae transect).
- 7 sites in AK and 4 in Canada.



Subzone	Mean July Temp (˚C)	Circumpolar Area ($km^2 \times 10^6$)
A	1–3˚ C	0.114 (2%)
B	3–5˚ C	0.450 (6%)
C	5–7˚ C	1.179 (17%)
D	7–9˚ C	1.564 (22%)
E	9–12˚C	1.840 (26%)
Glaciers		1.975 (28%)
Total Arctic		**7.111 (100%)**

Central Questions of Biocomplexity project



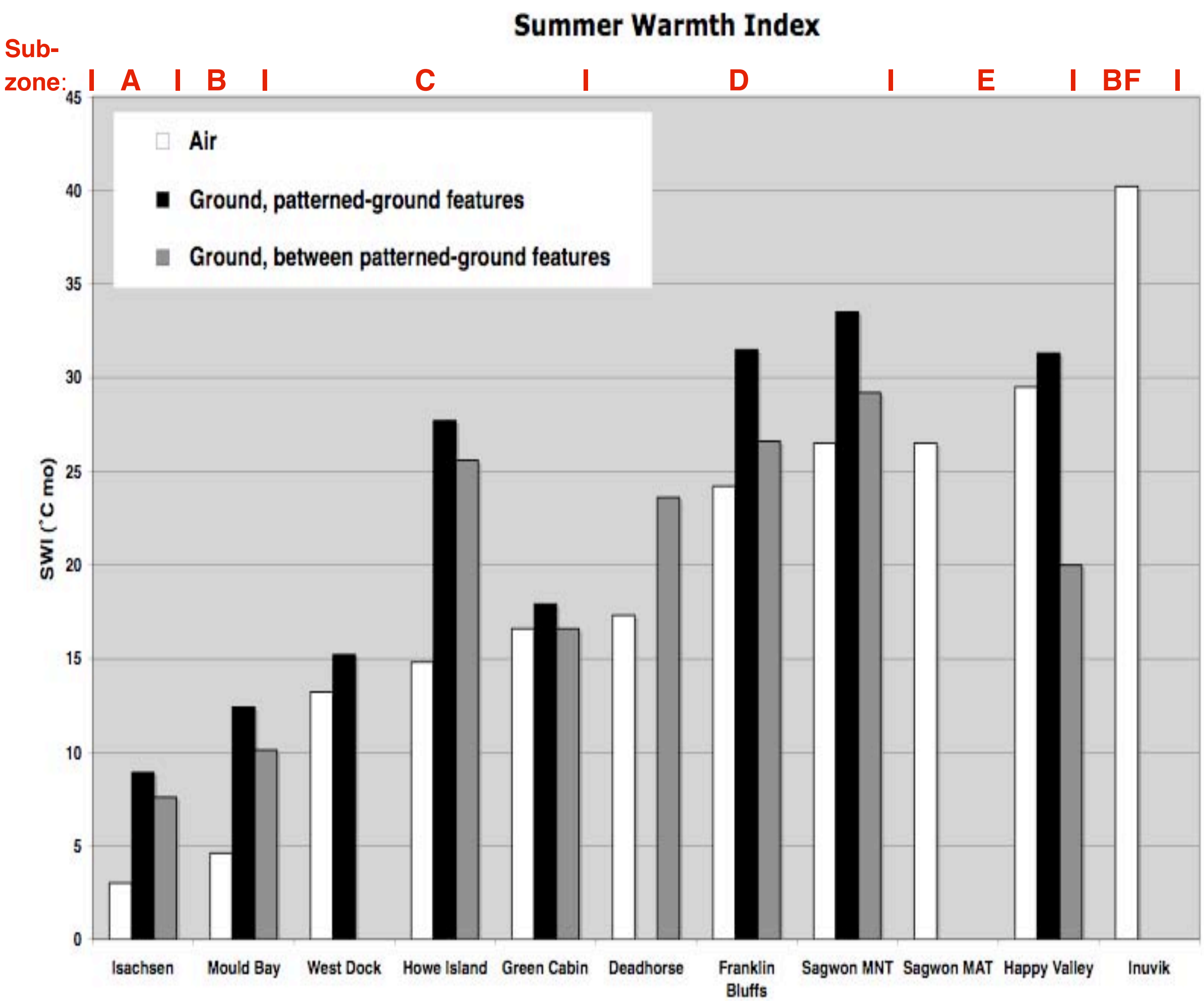


Howe Island, AK.
Photo; D.A. Walker

Walker et al. 2008, JGR

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

Summer warmth index along the NAAT



- > 10x increase in total air summer warmth (white bars).
- Surface temperatures are warmer than air temperatures (especially in High Arctic)
- Barren patterned ground features are warmer than the adjacent tundra.

Climate data: V.E. Romanovsky

North American Arctic Transect Activities

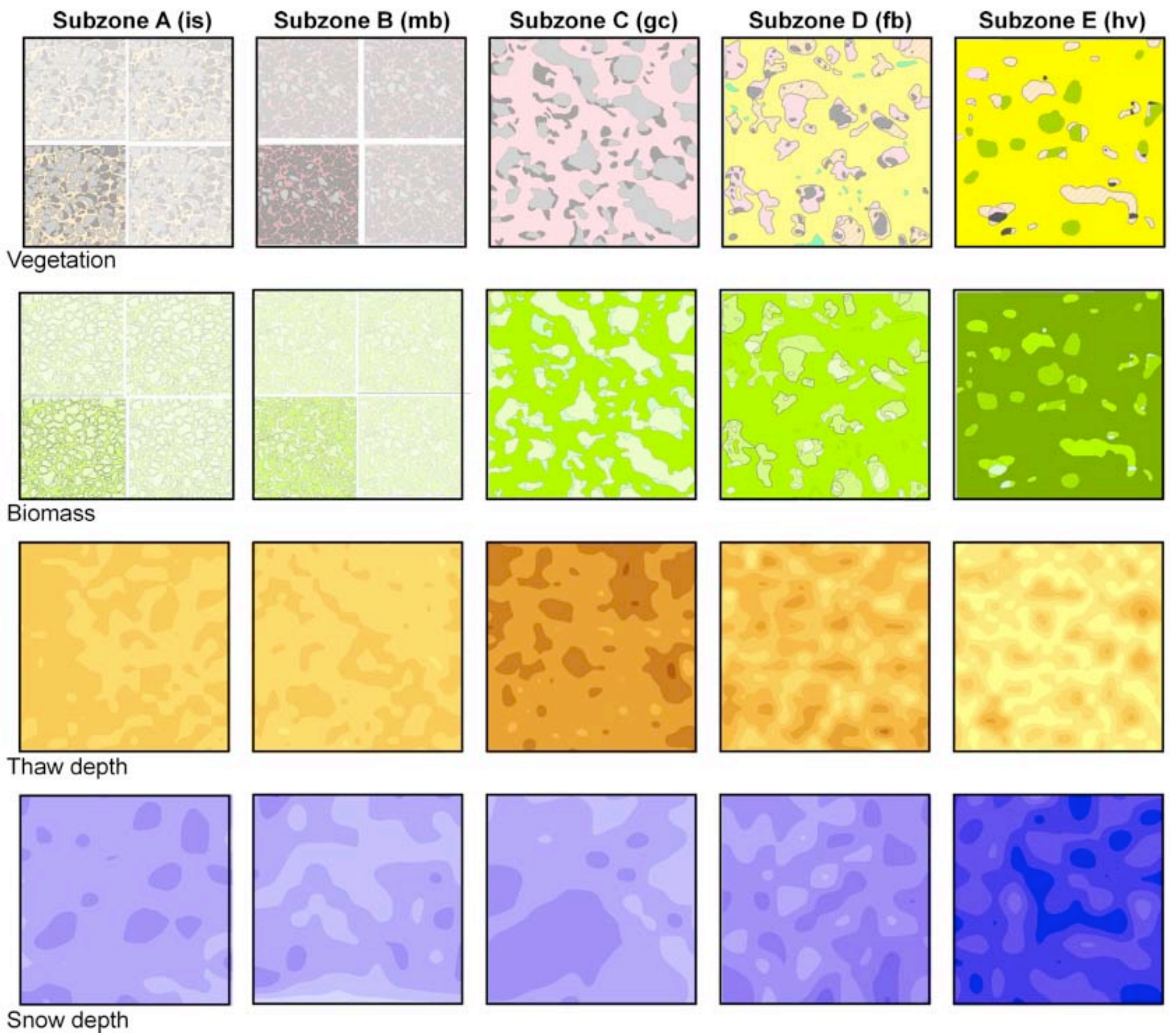
- CALM Grids
  - Active layer
  - Vegetation
  - Snow
- Climate /permafrost
  - Met station
  - Soil temperatures
  - Frost heave
- Soils
  - Characterization
  - Nitrogen mineralization
  - Decomposition
- Vegetation
  - Classification
  - Biomass
  - Mapping
- Remote sensing
  - NDVI
  - Mapping
- Modeling
- Education

Isachsen Grid, Subzone A
Photo D.A. Walker

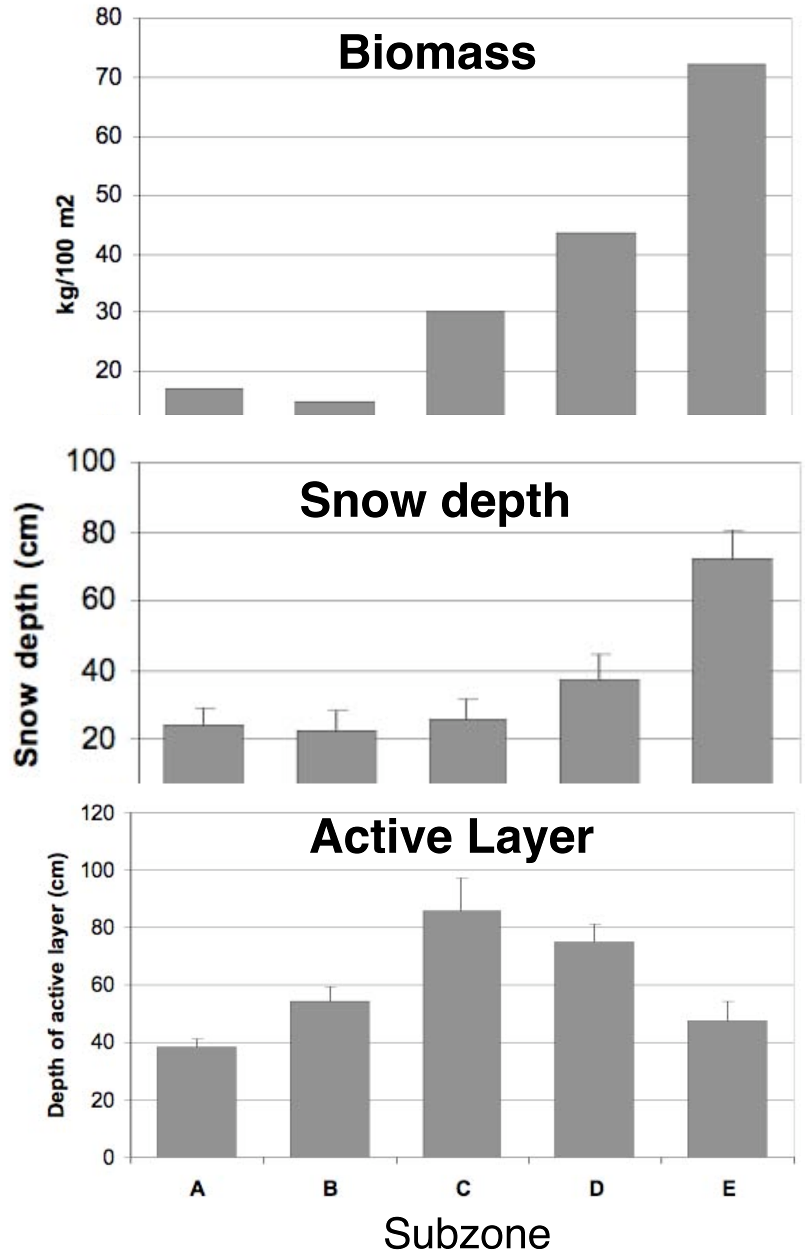
Maps of vegetation, biomass, active layer and snow depth

- Raynolds et al. 2008 *JGR - Biogeosciences*

- Maps are from representative zonal sites in each bioclimate subzone.



Trends in biomass, snow depth, and thaw on zonal grids

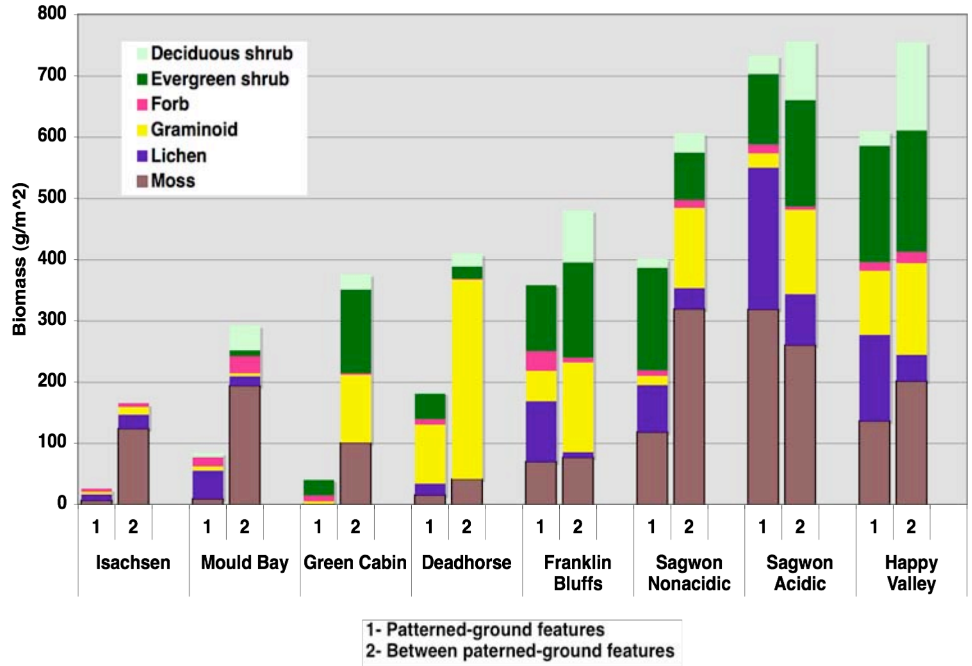


- Both biomass and snow depth depth increase toward the south and both have major effects on soil temperature regimes.

Raynolds et al. 2008, *JGR-Biogeosciences*

Biomass along the NAAT

Biomass on patterned-ground features and zonal areas

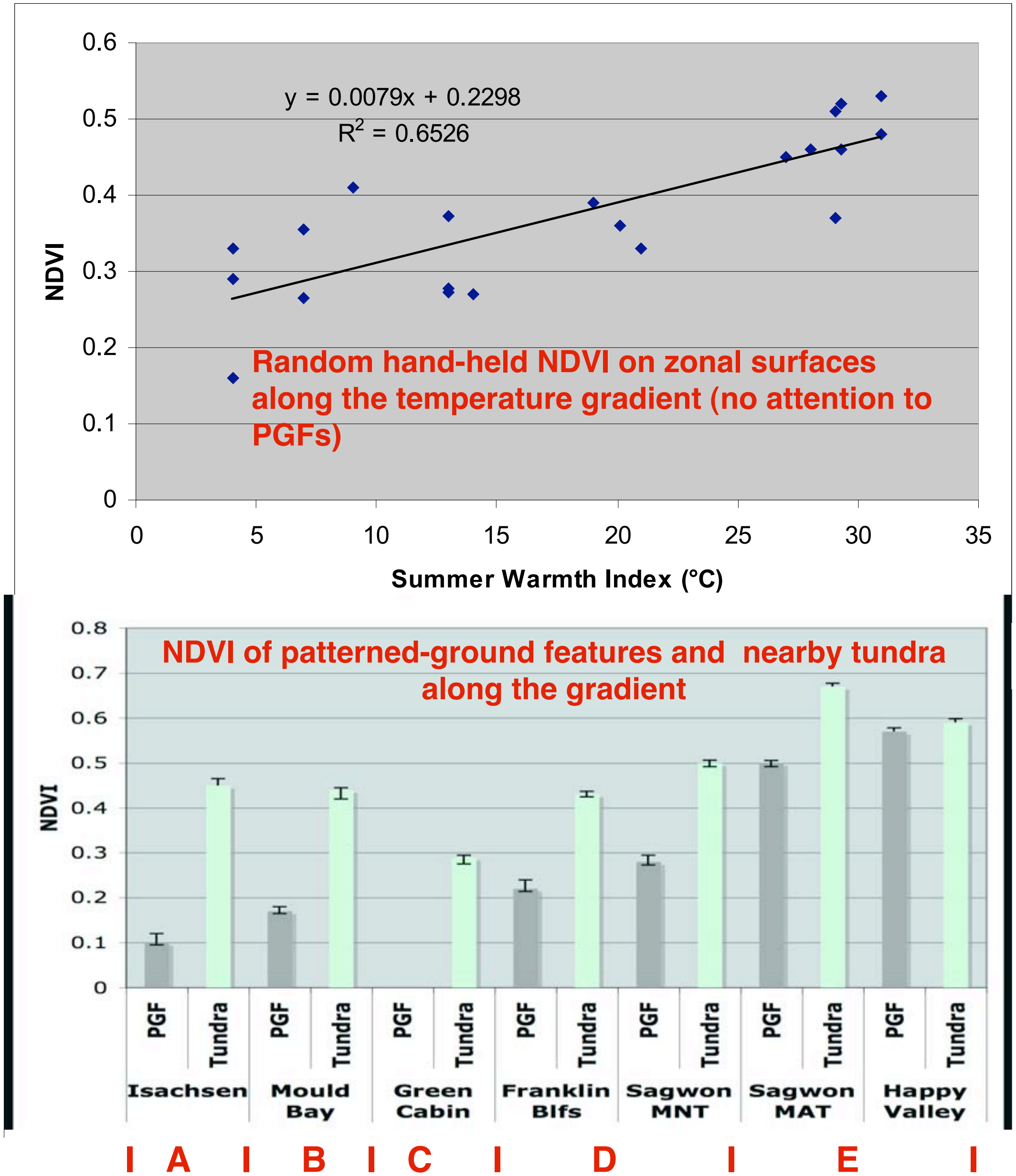


Sub-zone: I A I B I C I D I E I

Walker et al. 2008, *JGR-Biogeosciences*

- 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.

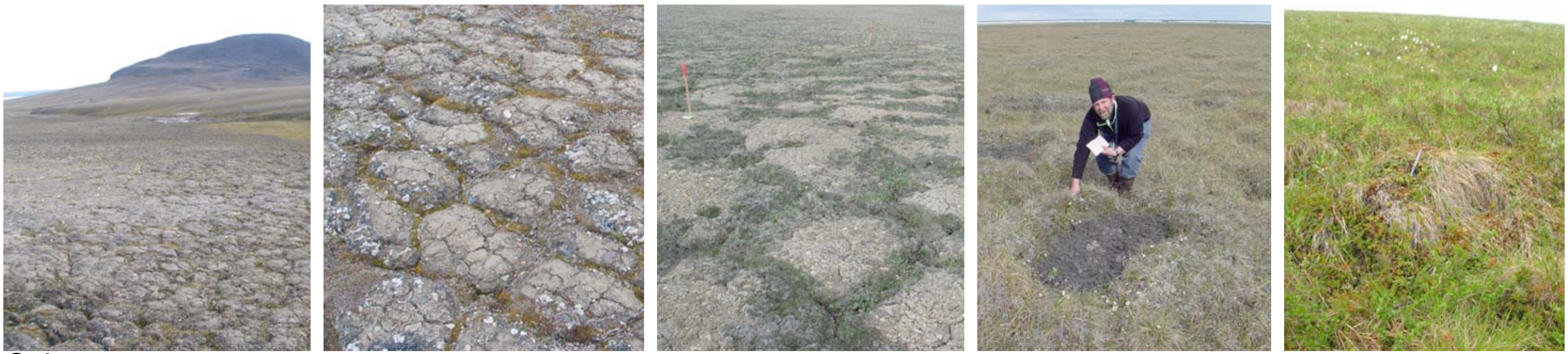
NDVI along the NAAT



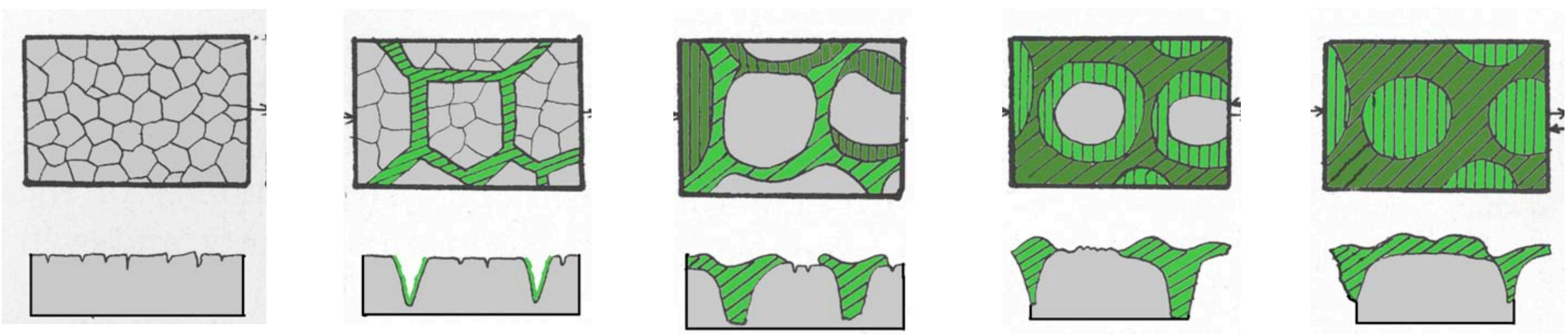
Courtesy of Howie Epstein and Alexia Kelley

- 2-fold increase of the NDVI on zonal surfaces.
- 6-fold difference in NDVI on PGFs.
- 2-fold difference in NDVI between PGFs.

Trend in patterned-ground along the Arctic bioclimate gradient



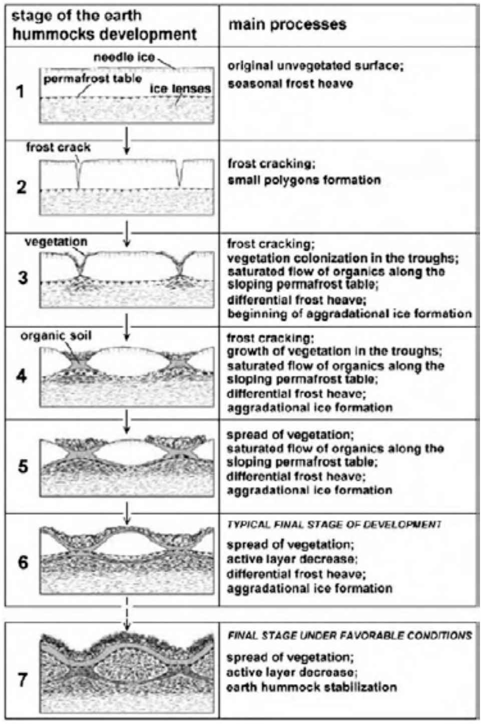
Sub-zone: A B C D E



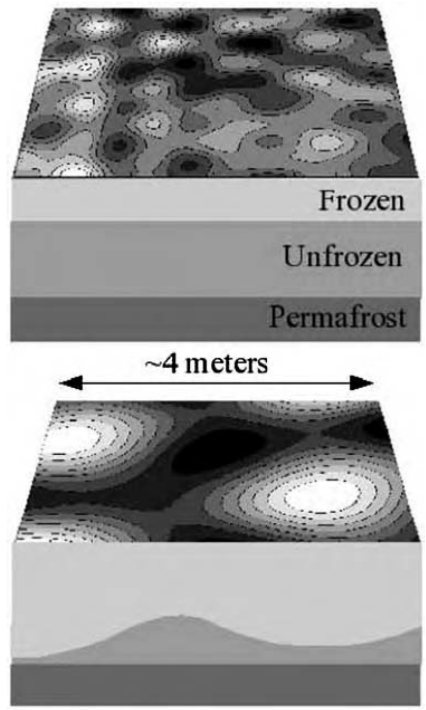
Small non-sorted polygons → *Non-sorted circles* → *Earth hummocks*

Drawings modified from Chernov and Matveyeva 1997

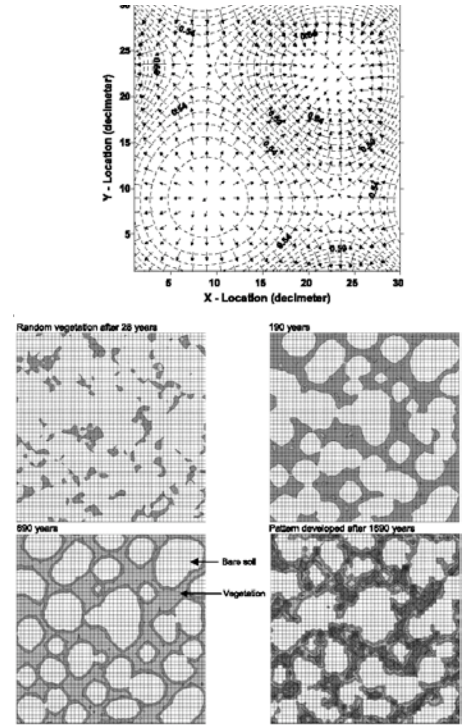
Four models of patterned ground formation



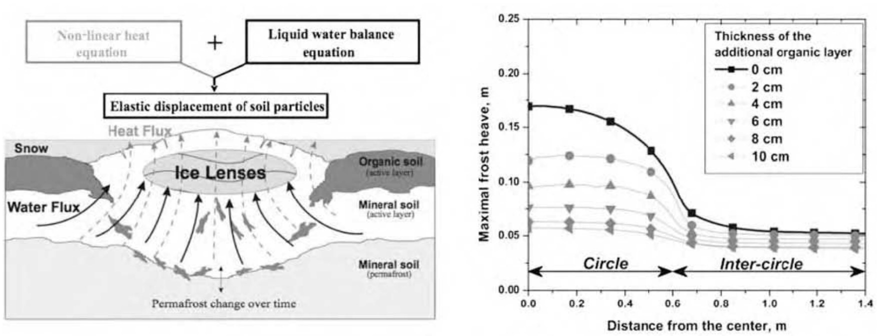
Conceptual model of frost-boil and hummock formation,
Shur et al. 2008, NICOP proceedings



Differential frost-heave model
Peterson and Krantz, JGR 2008



Coupled Water-Ice-Temperature / ArcVeg model,
Daanen et al. 2008 JGR



Thermo-mechanical model, Nicolsky et al., JGR 2008

Each provides a unique perspective:

- Conceptual nonnumeric approach that incorporates cracking and frost heave (Shur et al 2008).
- Self-organization model for initinvolving linear instability of top-down freezing in soils (Peterson and Krantz 2008).
- Linked hydrology-vegetation succession model at a landscape scale (Daanen et al. 2008).
- Detailed physical processes model of thermal, hydrology, and heave processes within a single non-sorted circle (Nickolsy, Romanovsky et al. 2008).

Special significance of the Subzone A site at Isachsen

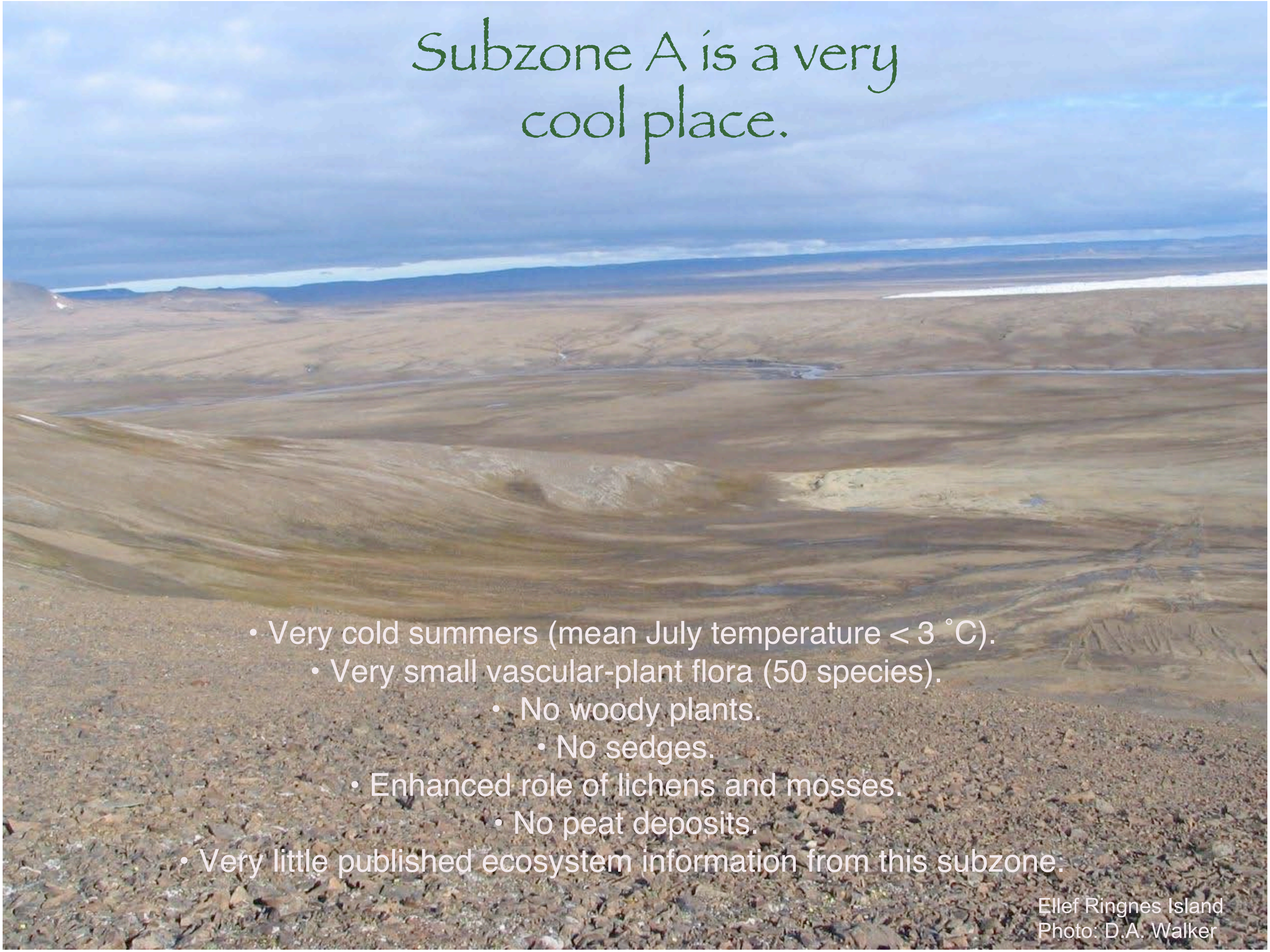
In the Russian literature, subzone A is treated as an entirely separate bioclimate "Zone" — the true "polar desert" of Gorodkov, Alexandrova and others.

If the Tundra Zone is defined by its proximity to the Arctic Ocean, subzone A is defined by its proximity to perennial sea ice.

Isachsen, Nunuvut, Canada

Barren sea cliffs at Isachsen coast

Subzone A is a very cool place.



- Very cold summers (mean July temperature < 3 ˚C).
- Very small vascular-plant flora (50 species).
- No woody plants.
- No sedges.
- Enhanced role of lichens and mosses.
- No peat deposits.
- Very little published ecosystem information from this subzone.

Ellef Ringnes Island
Photo: D.A. Walker

Subzone A: “the Poppy zone”

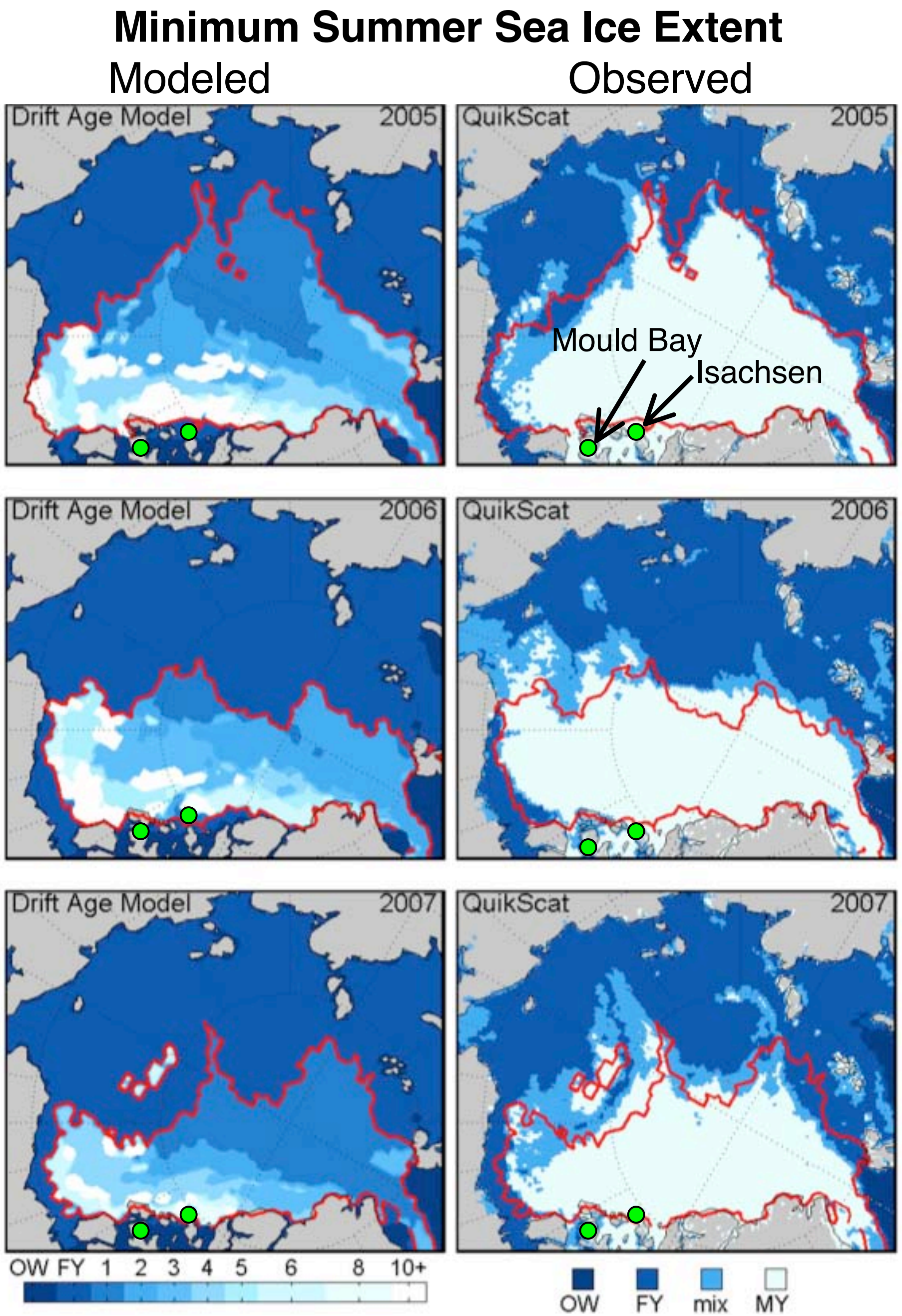
Small differences in microclimate or moisture make a huge difference in vegetation production.

A warming of only 2 ˚C will convert this to Subzone B climate with a potential doubling of the vascular-plant species that could colonize the area.

Vegetation on warmer mesic site, Isachsen

Papaver polare on dry zonal sites

Vegetation at base of snow bed, Isachsen



Modified from Nghiem et al. 2008.

Lessons from 2007 minimum sea-ice event:

Modeled predictions of sea-ice ages in Arctic Basin indicate that the oldest ice is in the vicinity of the western Canadian Archipelago and will be the last to melt in the Arctic. This is also the region of bioclimate subzone A.

The terrestrial ecosystems in this region are dependent on the summer sea ice to maintain the cold temperatures.

If summer arctic ice vanishes, so does Subzone A. Subzone A is a rare and endangered bioclimate subzone!

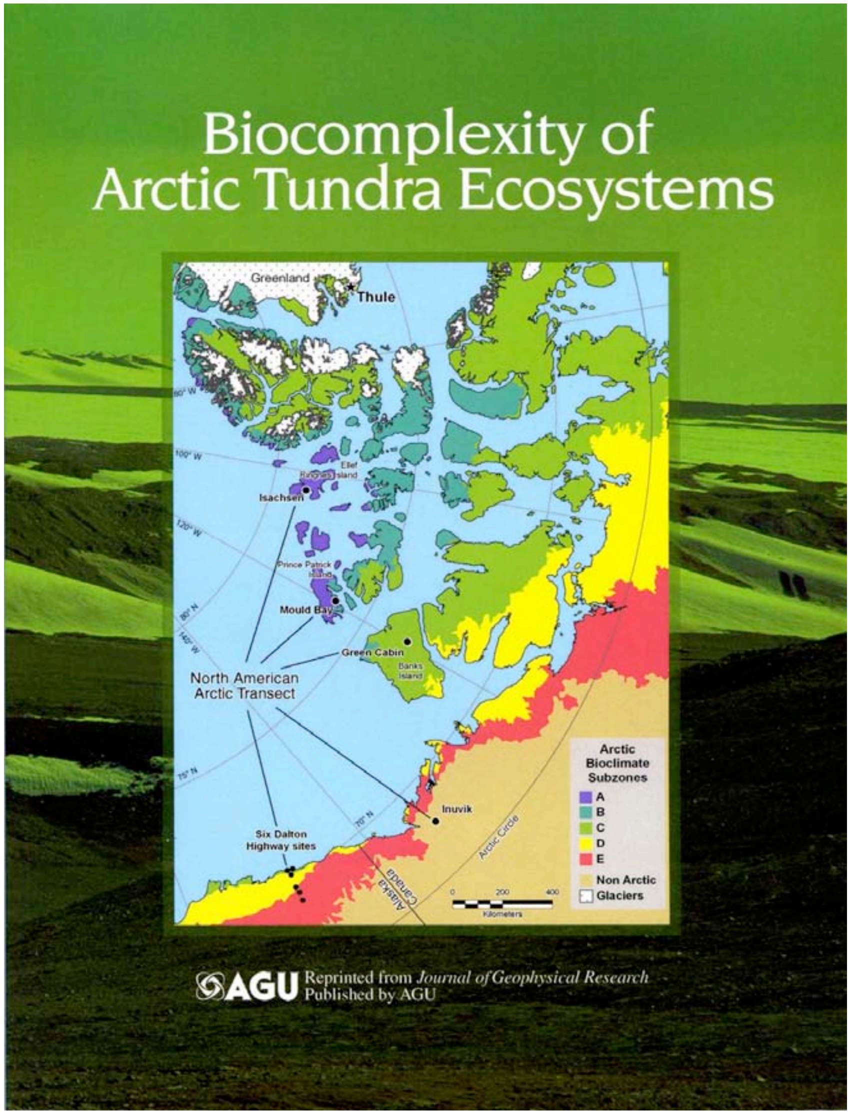
Legacy from the Biocomplexity Project

Datasets from the NAAT provide an important baseline of information for future climate change studies across the complete Arctic climate gradient.

Multi-scale Databases from the NAAT

	Macroscale (panArctic)	Mesoscale (Regional to toposequence)	Microscale (plots)
Climate	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)
Geology/ Geomorph.	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) Thermo-mechanical model of differential frost heave (Nickolsky, Romanovsky) DFH model of heave initiation (Peterson, Krantz)
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).
Microflora/ fauna	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, Daniëls). 1 x 1-m vegetation maps (Kade) Handheld LAI and NDVI of patterned-ground elements. Biomass of plant communities (Walker et al., Epstein). Buried seed bank within patterned ground elements (Kelley)

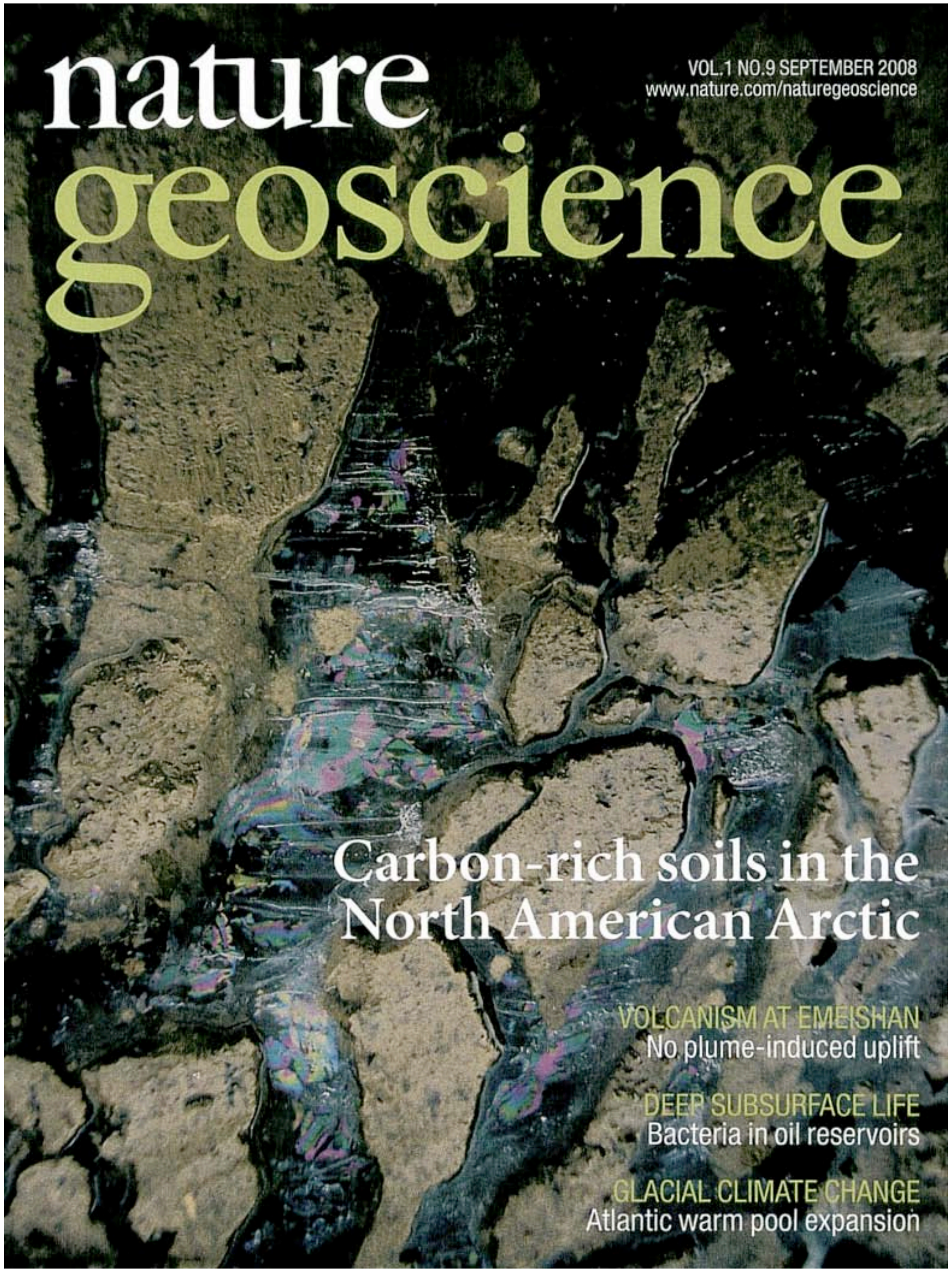
Synthesis of information from the North American Arctic Transect



- Synthesis of the project recently published in special issue of *Journal of Geophysical Research – Biogeosciences:*
    - 9 papers from the North American Arctic Transect.
    - 5 papers from the Thule, Greenland biocomplexity project (Welker et al).

- 21 collaborators including the following from UAF: Ronnie Daanen, Anja Kade, Patrick Kuss, Gary Michaelson, Corinne Munger, Dmitri Nickolski, Rorik Peterson, Chien-Lu Ping, Martha Raynolds, Vladimir Romanovsky, Ina Timling, Yuri Shur, Corinne Vonlanthen, Skip Walker

Walker, D. A. et al. 2008. Arctic patterned-ground ecosystems: a synthesis of field studies and models along a North American Arctic Transect. *Journal of Geophysical Research - Biogeosciences* 113:G03S01, doi10.1029/2007JG000504.



Other publications

Carbon is sequestered by patterned-ground formation processes deep in the active layer and permafrost, contributing to the high carbon stocks in Arctic soils.

High stocks of soil organic carbon in the North American Arctic region

CHIEN-LU PING[1]*, GARY J. MICHAELSON[1], MARK T. JORGENSON[2], JOHN M. KIMBLE[3], HOWARD EPSTEIN[4], VLADIMIR E. ROMANOVSKY[5] AND DONALD A. WALKER[6]

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Published online: 24 August 2008; doi 10.1038/ngeo284

The Arctic soil organic-carbon pool is a significant, but poorly constrained, carbon store. The most cited pool size estimates are based on a study that severely undersamples Arctic soils, with only five out of the 48 soils examined actually from the Arctic region. Furthermore, previous measurements have been confined to the top 40 cm of soil. Here, we present 1-m-deep measurements of soil organic carbon obtained at 117 locations in the North American Arctic region. To this dataset we add previously published measurements to generate a total sample size of 139 North American Arctic soils. We show that soil organic-carbon stores are highly dependent on landscape type, being highest in lowland and hilly upland soils, where values average 55.1 and 40.6 kg soil organic carbon m^{-2} respectively, and lowest in rubbleland and mountain soils, where values average 3.4 and 3.8 kg soil organic carbon m^{-2} respectively. Extrapolating our measurements using known distributions of landscape types we estimate that the total organic carbon pool in North American Arctic soils, together with the average amount of carbon per unit area, is considerably higher than previously thought. Our estimates of the depth distribution and total amount of organic carbon in North American Arctic soils will form an important basis for studies examining the impact of climate warming on CO_2 release in the region.

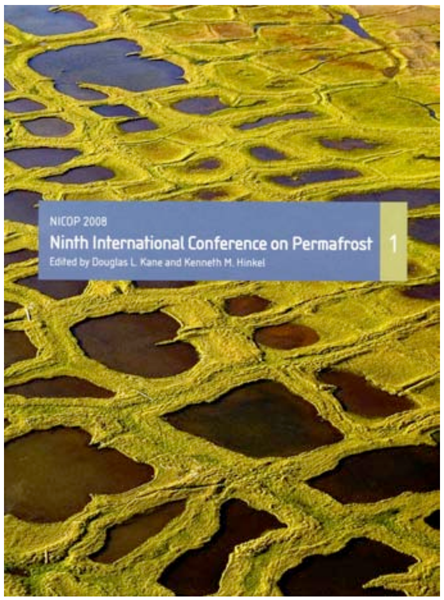
Patterned ground features, caused by frost cracking and heave, are prominent on the circumarctic landscape[1,2]. These features include sorted and non-sorted circles, stripes, desiccation polygons and ice wedge polygons[1]. Associated with these features, Arctic tundra soils show strong evidence of cryoturbation. The soils are characterized by warped, broken and distorted soil horizons, and surface organic matter is churned down to the lower active layers and upper permafrost[3,4]. The presence, form and abundance of patterned ground plays a key role in determining tundra vegetation[5,6], the morphology and properties of cryogenic soils[4,7] and the dynamics and sequestration of carbon[2,8,9]. In the Arctic, much of the movement of soil organic carbon (SOC) from the surface to depth is accomplished through cryoturbation[9]. This movement is caused by cracking due to soil freeze–thaw cycles and by soil hydrothermal gradients that produce differential frost heave[10]. Non-sorted circles are a common form of patterned ground in the hilly uplands and lowlands of the Middle and Low Arctic, whereas polygonal cracking and striping patterns are common in the hilly uplands of the High Arctic[5,7]. Based on surface observations, the influence of non-sorted circles seems to decrease from the north to the south. Non-sorted circles are also common in the hilly uplands and lowlands of the Low Arctic, but their surface appearance is masked by vegetation[11]. The SOC in a typical soil profile under a non-sorted circle is unevenly mixed and distributed in recognizable masses within the active layer and upper permafrost[3,4] (cryoturbated soil horizons; see Supplementary Information, Fig. S1). Chunks of surface organic matter, even whole-plant tussocks, are commonly found subducted along the bowl-shaped depressions of the permafrost table surface under non-sorted circles.

Recently, there have been many studies assessing SOC in relation to global change. These have included assessments of the temperature sensitivity[12] and global distribution[13] of SOC, and model simulations of CO_2 release[14]. These regional and global SOC assessments continue to use the average value of 21.8 kg m^{-2} for Arctic tundra[15] SOC stores, an estimate that ignores a significant part of the cryoturbated SOC (ref. 4). However, current studies in the Arctic have pointed to the importance of this deeper-soil profile of organic carbon and its potential for effecting and being affected by climate change[16,17]. There are several lines of evidence pointing to the importance of these SOC stores as they are affected by warming temperatures, such as the widespread warming of the upper permafrost in the Arctic[18,19] and efflux of up to 80% of the seasonal C flux from tundra soils during the cold season when the organic-carbon-rich subsoils are the warmest in the soil profile[16,17].

The Arctic occupies about 13% of the land area and is estimated to hold about 14% of the SOC pool[15]. This widely cited estimate is from the 1982 study of SOC in the world's life zones[15] and is for the entire tundra life zone, but is commonly cited for the estimation of Arctic SOC pools. In this study the tundra regions were represented by an average value of 21.8 kg m^{-2} SOC for an

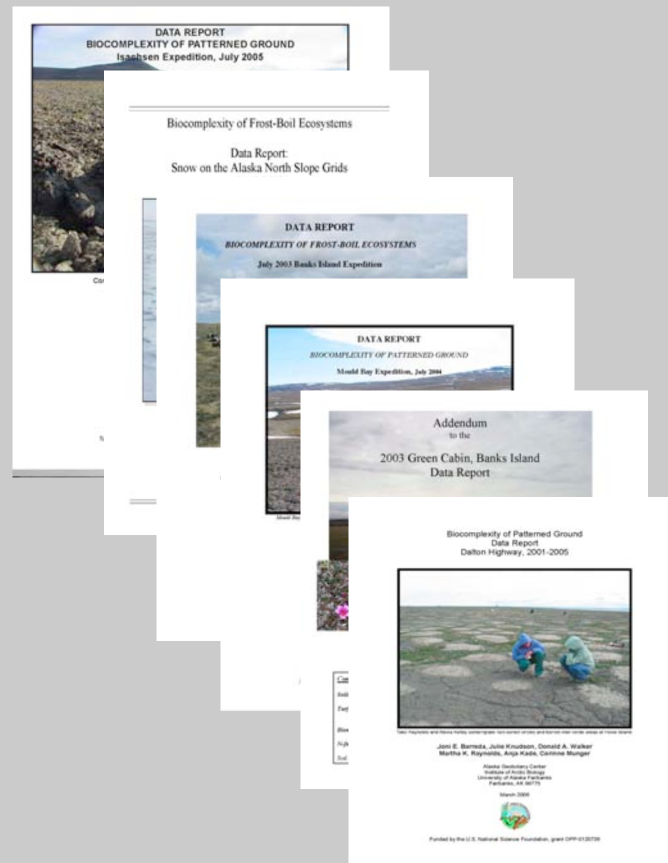
Other publications from the Biocomplexity project and North American Arctic Transect

Ninth International Permafrost Conference papers (6):



Other journal publications (30 + 2 in prep):

Data reports (9):



The Yamal Peninsula Transect:

Cumulative effects of resource development, reindeer herding, and climate change on the Yamal Peninsula, Russia

Funded by NASA

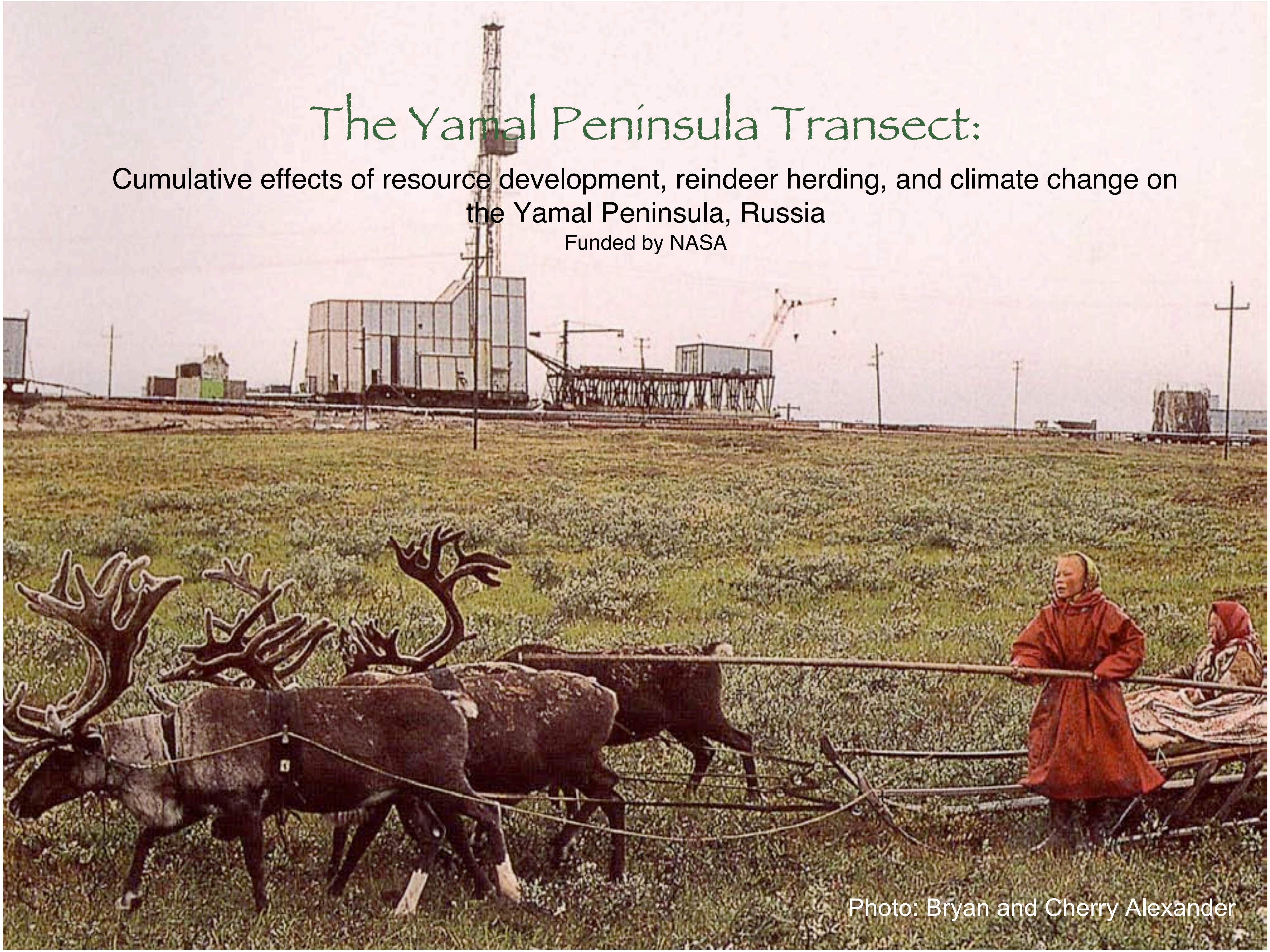


Photo: Bryan and Cherry Alexander

Yamal Transect

2007

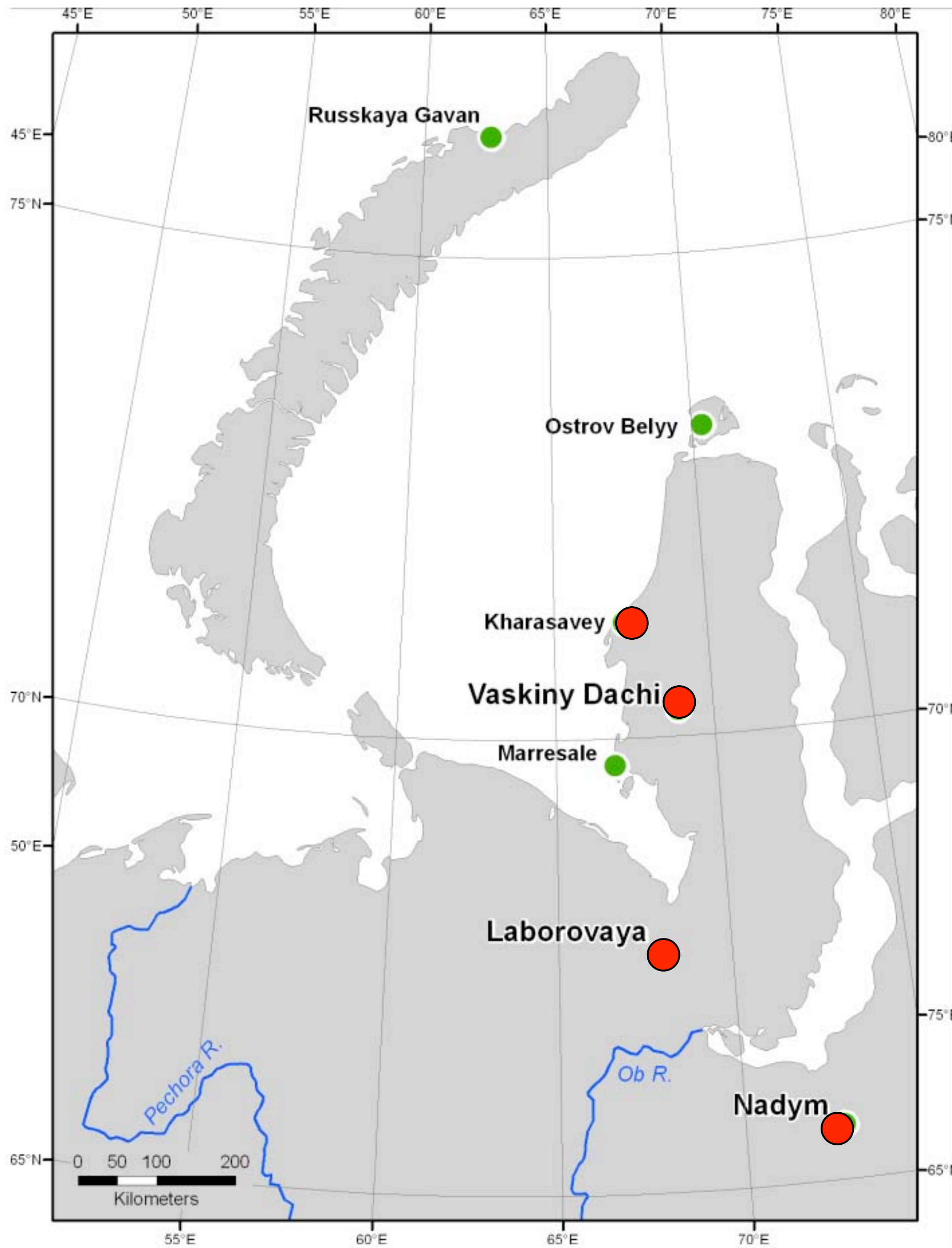
- Nadym
- Laborovaya
- Vaskiny Dachi

2008

- Kharasavey

2010 (proposed)

- Ostrov Belyy
- Russkaya Gavan (or Franz Josef Land)
- Marresale (or site in N. Yamal)



Collaborators

Uma Bhatt, Gary Kofinas, Jozsef Geml, Martha Raynolds, Vladimir Romanovsky, Lee Taylor, Skip Walker: *University of Alaska Fairbanks*

Marina Liebman, Nataliya Moskalenko, Pavel Orekov, Artem Khomotov, Anatoly Gubarkov: *Earth Cryosphere Laboratory, Moscow, Russia*

Bruce Forbes, Florian Stammler, Timo Kumpula, Elina Karlejaärvi: *Arctic Centre, Rovaniemi, Finland*

Howie Epstein: *University of Virginia*

Jiong Jia: *REC-TEA, Chinese Academy of Science*

Joey Comiso: *NASA Goddard*

- Examines the linkages between greening trend range and forage for the reindeer of the Nenets and the regional sea-ice conditions.
- Field research and modeling in all 5 arctic biocli subzones.
- Linked to the Circumpolar Arctic *Rangifer* Monit Assessment (CARMA) project, and the Cold La Process in NEESPI (CLPN), and the (Environm Social Impacts of Industrial Development in Nor Russia (ENSINOR). NEESPI = Northern Eurasia Science Partnership Initiative.

Working with permafrost experts, sociologists, biologists, and soil scientists with long experience on the Yamal Peninsula

Earth Cryosphere Institute, Russian Academy of Science, Moscow organized the expeditions. Led by Marina Liebman and Nataliya Moskalenko.

Elina Karlejaärvi (Arctic Centre, graduate student, botanist), Nataliya Moskalenko (ECI, ecologist), Howie Epstein (U Va Co-PI, ecosystem ecologist), Marina Leibman (ECI, Permafrost, geomorphologist), Patrick Kuss (UAF, Post Doc, botanist), Anatoly Gubarkov (ECI, graduate student, permafrost, industrial impacts), Artem Khumotov (ECI, graduate student, GIS), George Mateyshak (MSU, Soil Scientist)
Photo: D.A. Walker

Environmental and Social Impacts of Industrial Development in Northern Russia (ENSINOR)

Bruce Forbes, Arctic Centre, Rovaniemi, PI of the ENSINOR Project.

Florian Stammler interviewing members of Nenets brigade. Combining remote sensing and traditional knowledge.

Photo: Bruce Forbes

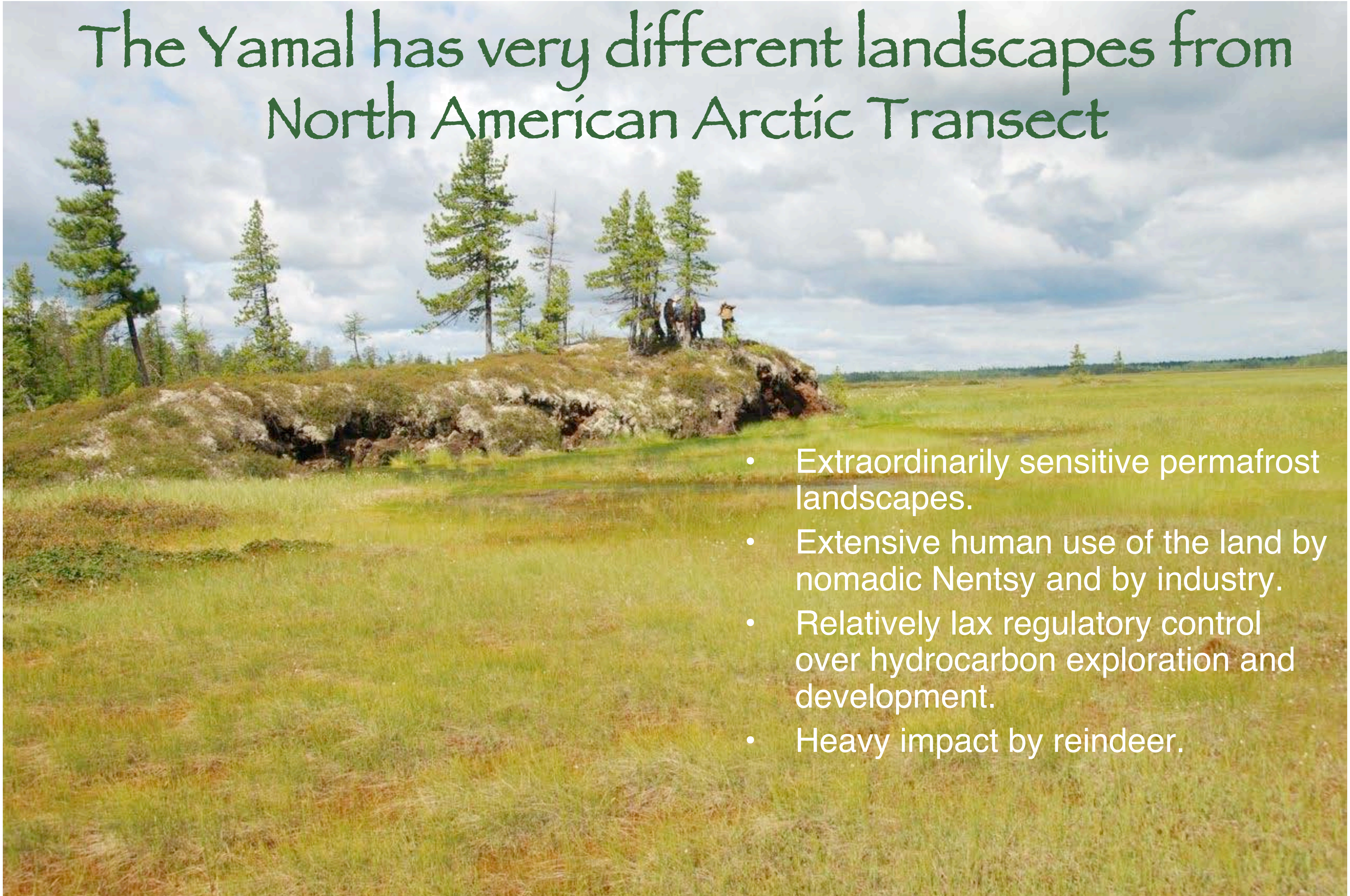
The Yamal

Typical of the sorts of changes that are likely to become much more common in tundra areas of Russia and the circumpolar region within the next decade.

- Currently, large areas of wilderness with no roads or development, but…
- large-scale gas and oil potential,
- extraordinarily sensitive permafrost environment
- traditional pasturelands for the nomadic Yamal Nenets people,
- rapid changes in climate.

Goal: Develop tools using remote sensing and modeling to better predict the cumulative effects of resource development, climate change, reindeer herding, and the role of terrain factors in affecting changes in tundra regions.

The Yamal has very different landscapes from North American Arctic Transect



- Extraordinarily sensitive permafrost landscapes.
- Extensive human use of the land by nomadic Nentsy and by industry.
- Relatively lax regulatory control over hydrocarbon exploration and development.
- Heavy impact by reindeer.

Extraordinarily Sensitive Permafrost Landscapes

Extensive nutrient-poor surface sands with lichens that are easily overgrazed by reindeer.

Underlain by permafrost with massive pure ice.

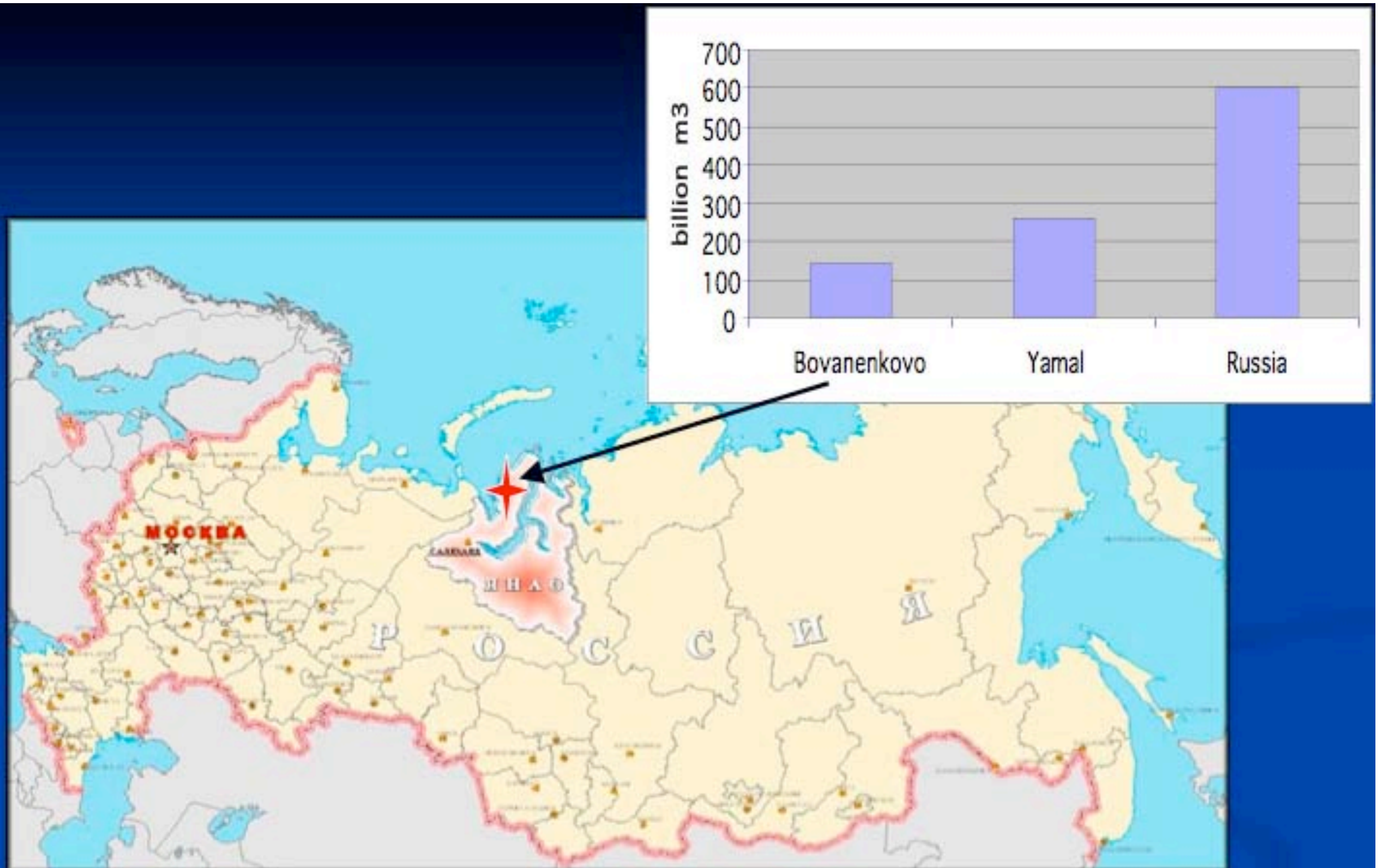
Extensive landslides are rapidly eroding the landscape.

This exposes salt-rich and nutrient-rich clays.

Complex vegetation succession process that results in willow-shrub tundra in the interior parts of the peninsula.

Photos: D.A. Walker
and M. Liebman (upper right)

Yamal: Center of future gas production in Russia



- Contemporary Russia's gas production is more than 600 billions m^3 of gas which makes up 20% of the world consumption.
- In 2030 gas production on Yamal will be as high as 250 – 260 billions m^3/yr.

Courtesy of A. Gubarkov

Large-scale development will occur once road, railroad and pipeline links to the south are built.

Existing and designed pipelines

- "Gazprom" has accepted the Yamal hydrocarbons transportation scheme of main pipeline across the Baidarata Bay of the Kara Sea. Four pipelines will transport 50–60 billions m^3 of gas each.

Courtesy of A. Gubarkov

Relaxed Regulatory Environment

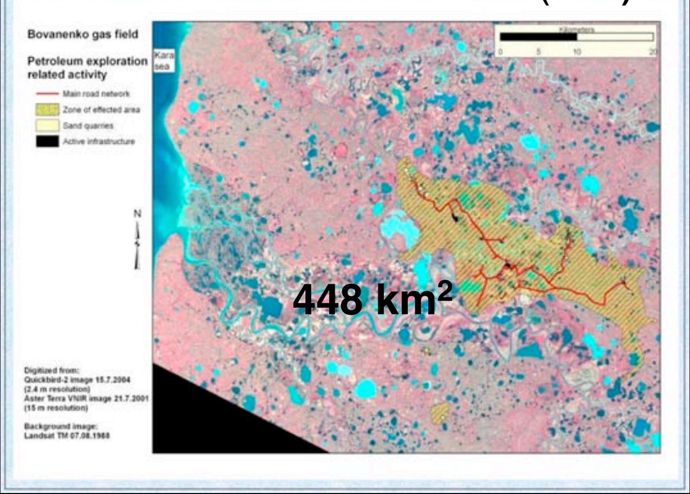
Photos: D.A. Walker

Extent of infrastructure of Bovanenkova Field compared to Prudhoe Bay

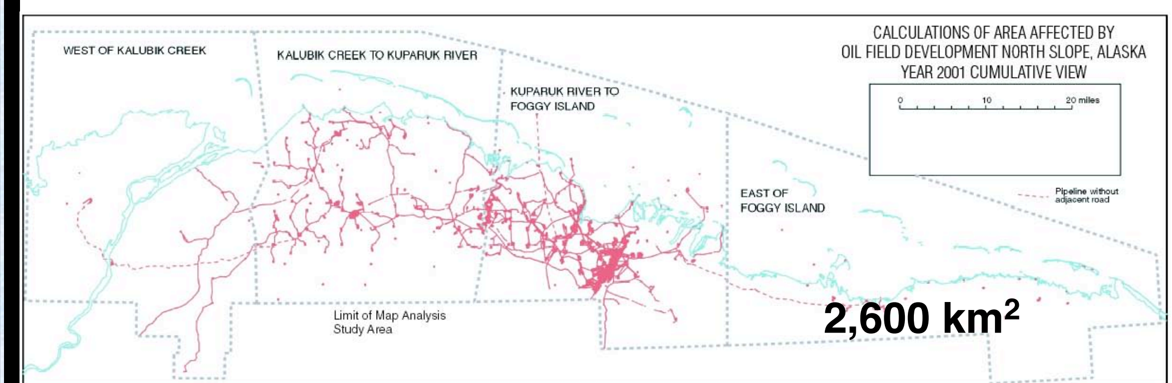
Area of infrastructure (km²)

	Bovanenkovo, RU (Kumpula 2007)	North Slope, AK (NRC, 2003)
Construction pads	2.1	24.2
Quarries	4.3	25.8
Roads (all types)	2.9 (79 km)	12.2 (954 km)
Air strips	0	1.2
Total infrastructure	9.3 km^2	63.4 km^2
Other affected areas (major ORV trails, debris)	24 km^2	7.14 km^2
TOTAL DETECTIBLE CHANGED AREA	33.3 km^2	70.5 km^2
Approximate total extent of infrastructure (perimeter, including currently enclosed unimpacted areas no longer accessible to herders)	448 km^2	2,600 km^2

Extent of Bovanenkovo Gas Field (2001)



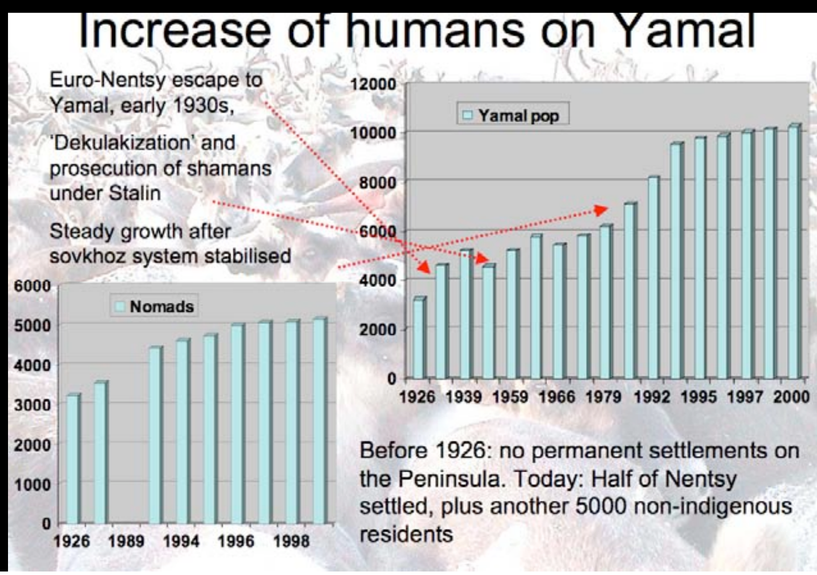
Extent of the North Slope, AK development (2001)

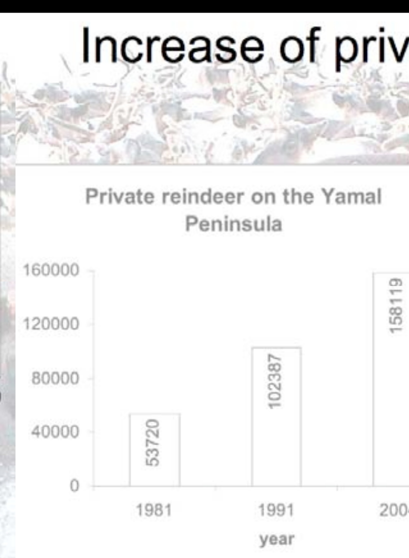


T. Kumpula: Yamal LCLUC Workshop, Moscow, 28–30 Jan 2008.

NRC, 2003. *Cumulative Environmental Effects of the Oil and Gas Development on the Alaska North Slope.*

The Nentsy and their reindeer





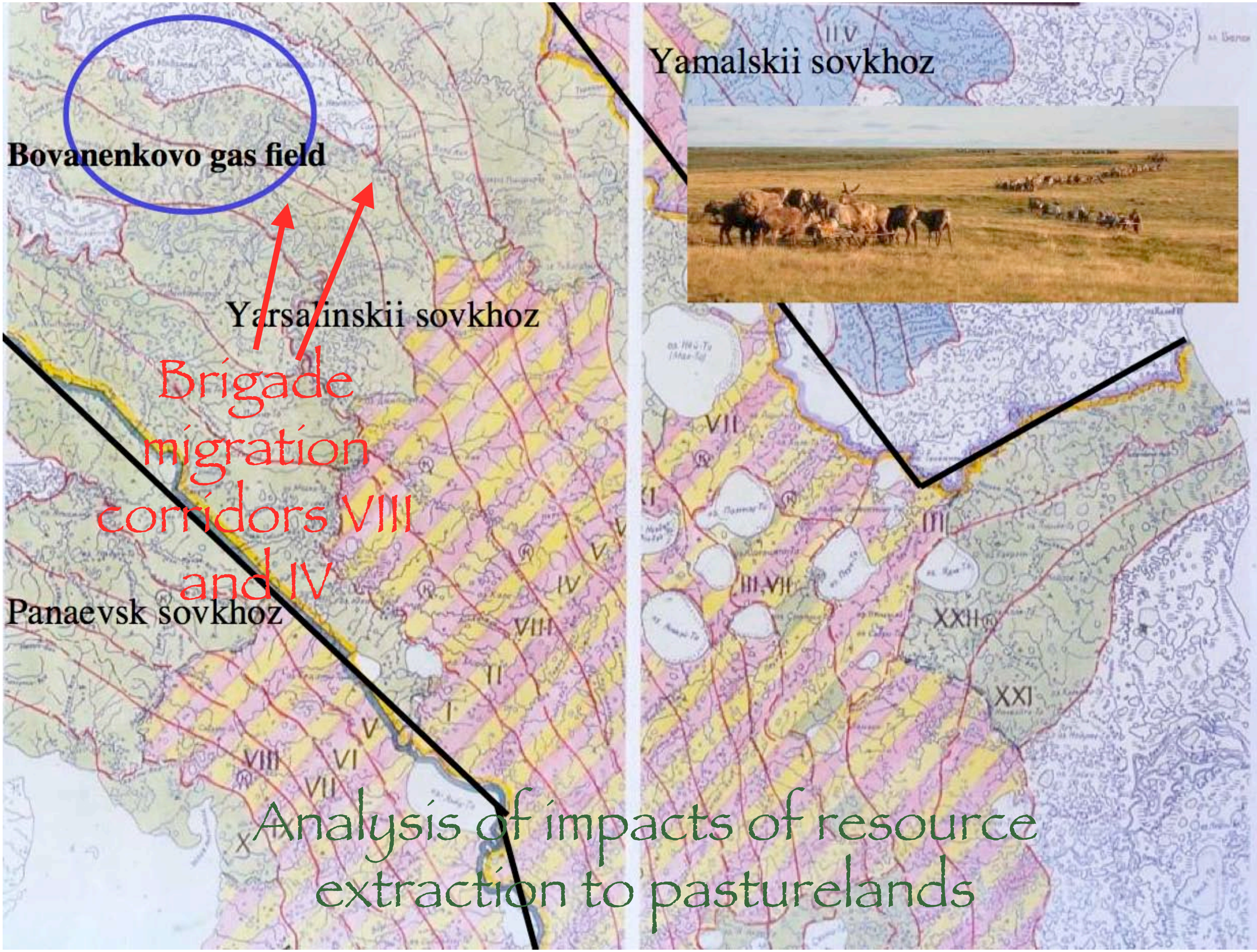
Graphics: Florian Stammler: Yamal LCLUC Workshop, Moscow, 28–30 Jan 2008.
Photos: D.A. Walker

Effects of reindeer herding

Photos: Bruce Forbes

The Nentsy use the entire Yamal Peninsula.

Photos: D.A. Walker

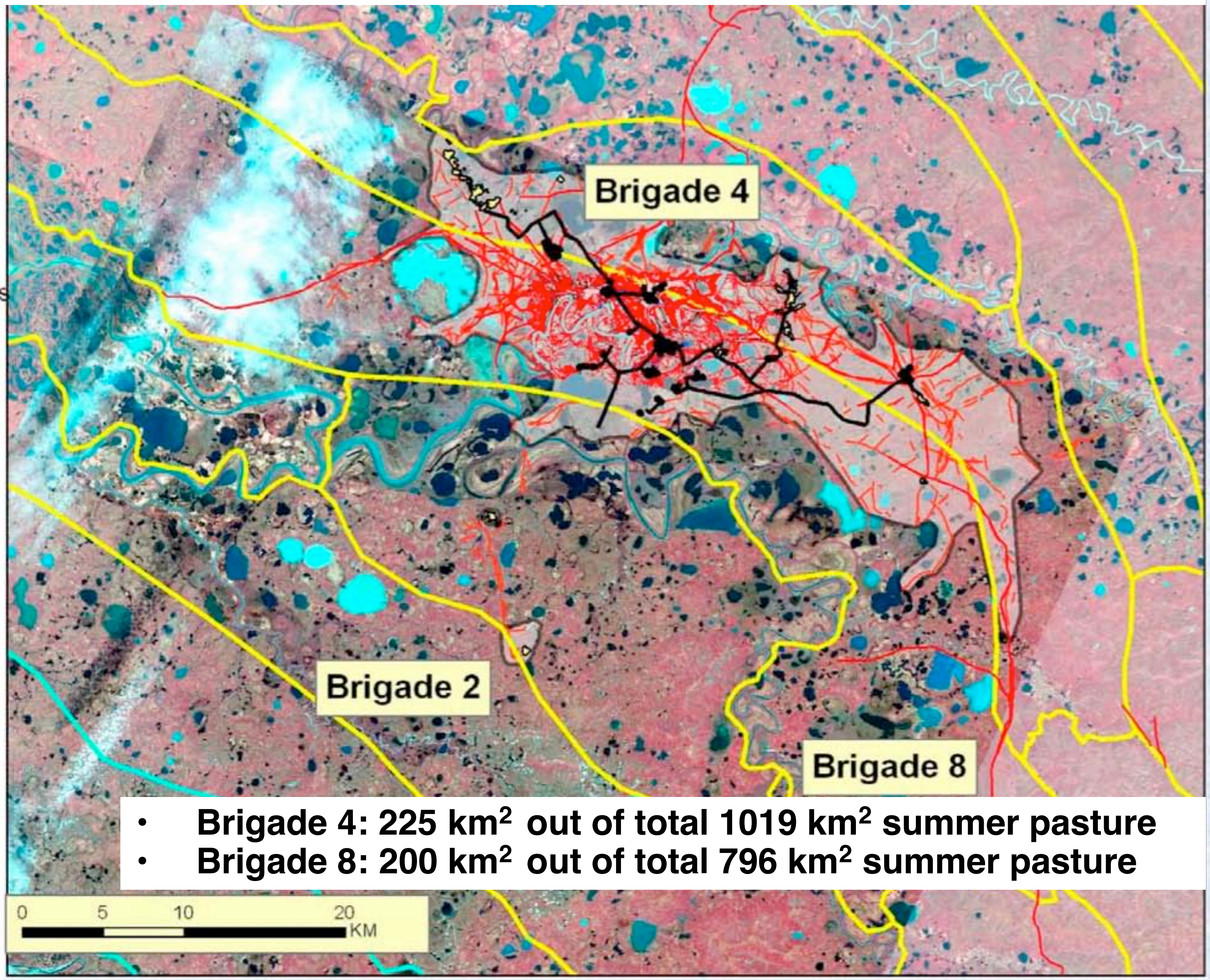


Analysis of impacts of resource extraction to pasturelands

Impacts of Bovanenkovo gas field to summer pasture of Brigades 4 and 8

Legend

- Infrastructure
- Quarries
- Road network
- Brigade borders
- Offroad vehicle tracks
- Affected area



- **Brigade 4: 225 km^2 out of total 1019 km^2 summer pasture**
- **Brigade 8: 200 km^2 out of total 796 km^2 summer pasture**

Datasource:
ASTER TERRA VNIR image 21.7.2001 (15 m resolution)

Quickbird-2 image 15.7.2004 (2.4 m resolution)

Herders view:

Photo: D.A. Walker

- Threats from industrial development much greater than threats from climate change.
- However, they currently generally view the gas development positively because of increased economic opportunities (e.g. markets for reindeer, some perks from the industry).
- Moderate demands:
  1. Complete and timely reclamation of lands used during the technical work that are not industrial and have no facilities on them.
  2. Establishing and protecting corridors for movement between camps by people and reindeer herders.

  (Zen’ko 2004, Stammler 2005).

Stammler, F. 2005. Reindeer Nomads Meet the Market: Culture, Property and Globalisation at the End of the Land. Litverlag-Halle Studies in the Antrhopology of Eurasia, Muenster.

Zen'ko, M. A. 2004. Contemporary Yamal: ethnoecological and ethnosocial problems. Anthropology & Archeology of Eurasia 42:7-63.

However, there is a lack of equity in discussions regarding land-use.

Pavel Orekhov and Nenets herder.
Photo: D.A. Walker

- Despite an amazing ability to adapt to past climate, social, economic, and political upheavals in Russia, the Nentsy face difficult challenges with respect to adapting to industrial change because they lack title to their land.
- In Alaska and Canada, indigenous groups gained legal land claims. No such legal land rights exist for the Nentsy.

Bruce Forbes. 2008. Equity, vulnerability and resilience in social-ecological systems: A contemporary example from the Russian Arctic. *Research in Social Problems and Public Policy,* 15: 203–236.

Effects of climate change: Analysis of biomass and NDVI trends across the climate gradient

Field data collected:

Soils

Plant Cover

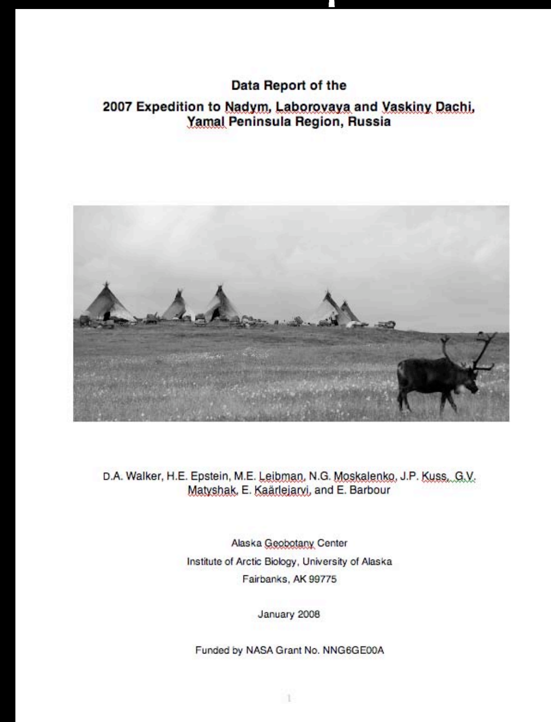
NDVI & LAI

Ground temperatures

Active layer

Plant Biomass

Data Report



Data Report of the
2007 Expedition to Nadym, Laborovaya and Vaskiny Dachi, Yamal Peninsula Region, Russia

D.A. Walker, H.E. Epstein, M.E. Leibman, N.G. Moskalenko, J.P. Kuss, G.V. Matyshak, E. Kaärlejarvi, and E. Barbour

Alaska Geobotany Center
Institute of Arctic Biology, University of Alaska
Fairbanks, AK 99775

January 2008

Funded by NASA Grant No. NNG6GE00A

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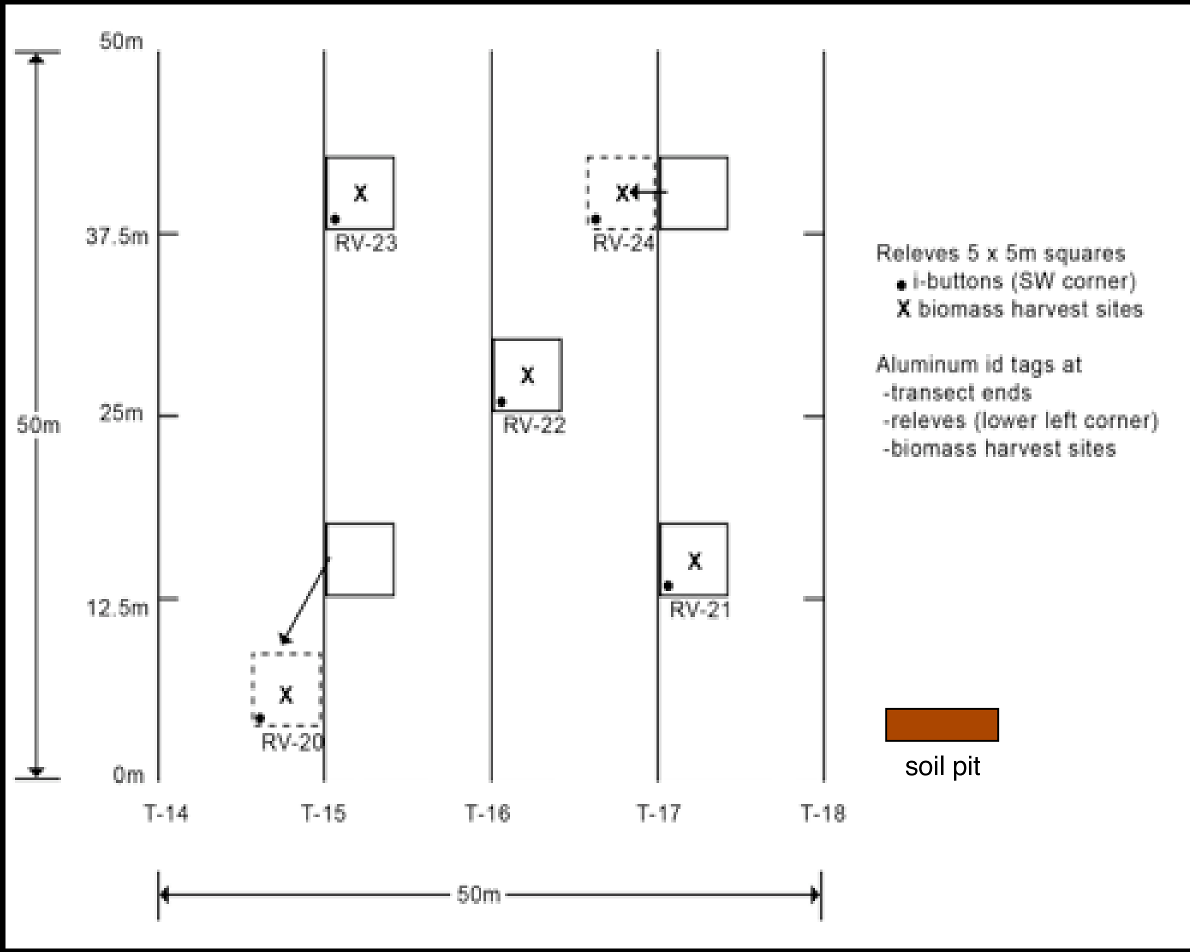
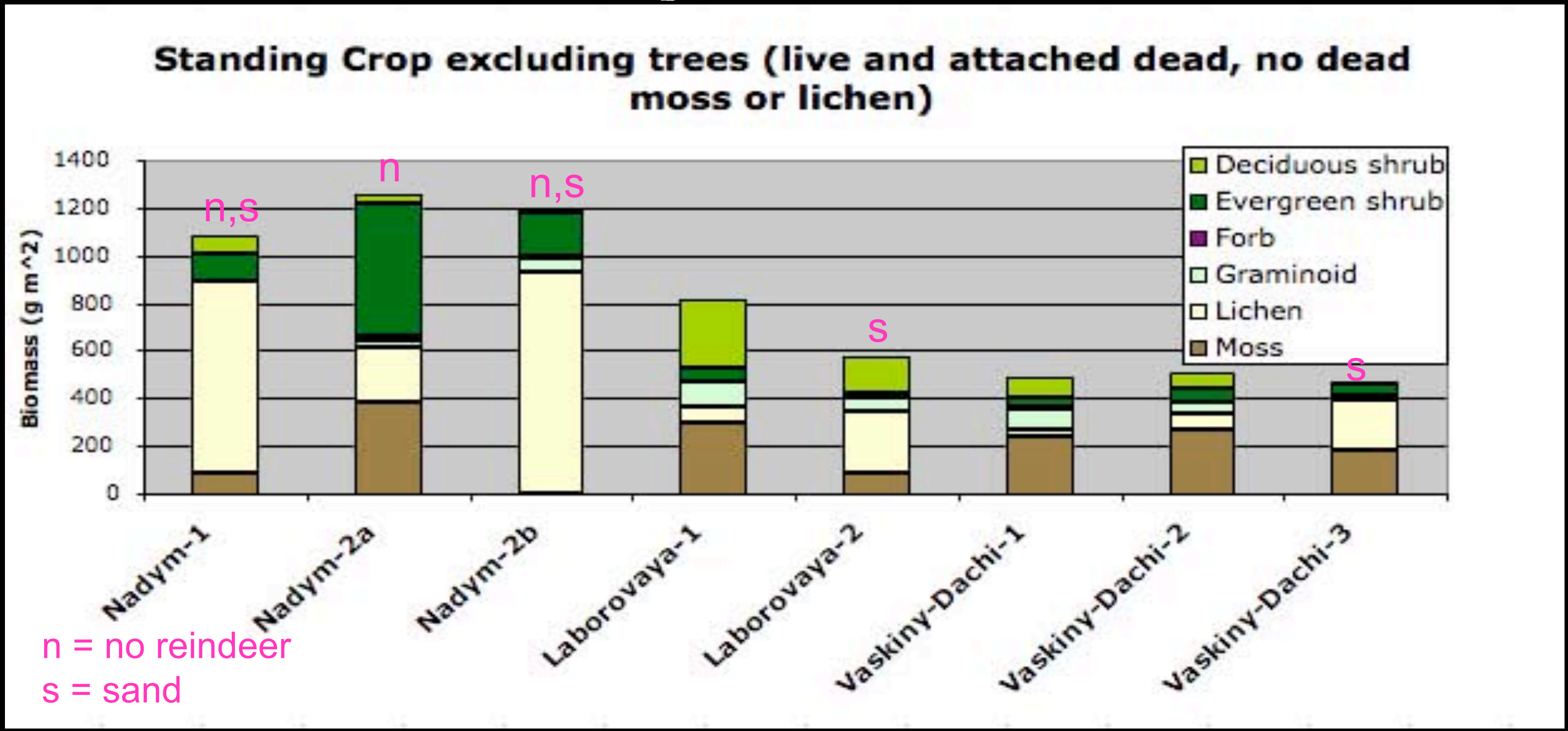
http://www.geobotany.uaf.edu/yamal/documents/yamal_2007_dr080211

Typical sampling strategy

- 5 50-m transects
- 5 5 x 5-m plots
- 1 x 3-m soil pit



Biomass along the Yamal transect

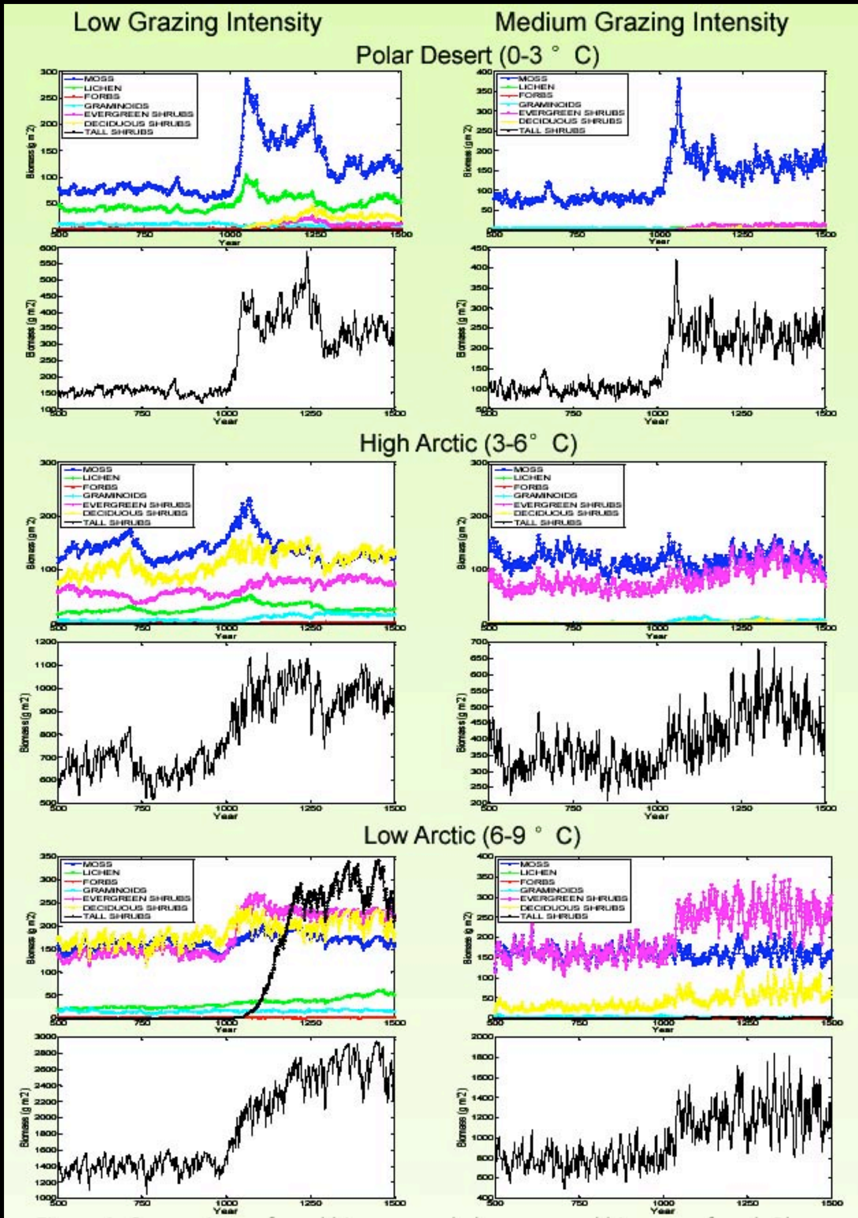


Climate trend:
2000–2300 g m^{-2} at Nadym to about 1000–1300 g m^{-2} at Vaskiny Dachi.

Effect of sandy soils:
- Sandy soils have 250–350 g m^{-2} less biomass than comparable clayey sites
- Much more lichen biomass and less mosses and graminoids.

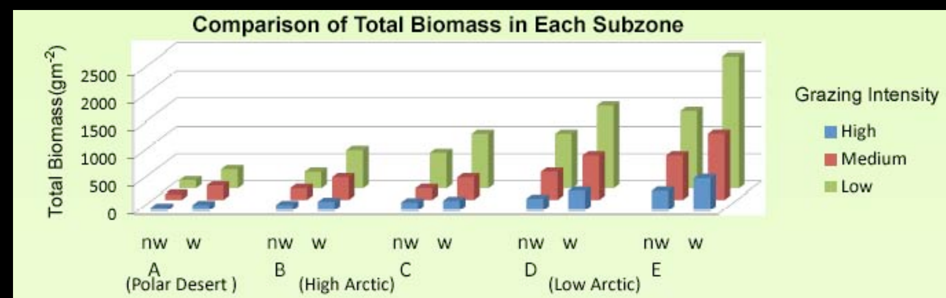
Effect of reindeer:
- Ungrazed sandy areas near Nadym – over 900 g m^{-2} of lichen
- Less than 200 g m^{-2} in sandy areas where reindeer grazing has occurred annually.

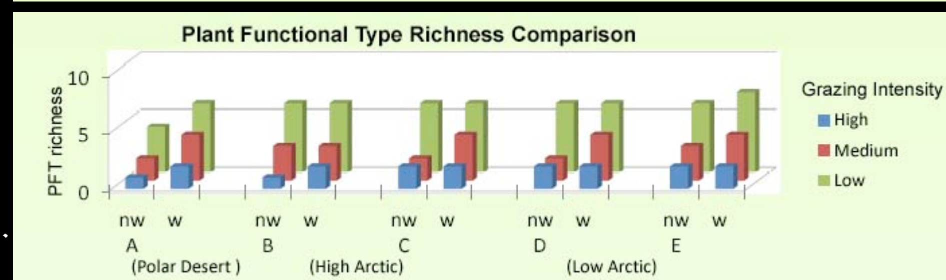
Epstein et al: NASALCLUC meeting 2008.



Modeled productivity of PFTs on the Yamal

- ArcVeg model (Epstein et al. 2002)
- Examines succession of biomass for seven Arctic plant functional types.
- Five climate scenarios.
- Warming vs. non-warming treatments.
- Three grazing intensities.
- Next steps will incorporate soil type and disturbance regimes (dust and complete removal of vegetation), relate to NDVI and develop regional extrapolations.





Yu and Epstein: 2008, NASA LCLUC conference.

Some problems with existing arctic biomass data in the literature

- Although trends in NDVI are clear, there are still no convincing ground-based studies of changes in Arctic plant biomass.
- Real vegetation type is often unknown.
- Soil and site factor information missing.
- Harvest methods not documented.
- Not georeferenced.
- Replication not documented.
- Not linked to NDVI, LAI, or other cover properties of the vegetation.
- Definitions of biomass components unclear.

"What is above-ground biomass?"

"What does NDVI really mean in tundra systems… particularly for reindeer and caribou?"

Some areas with low NDVI have high forage quality for reindeer.

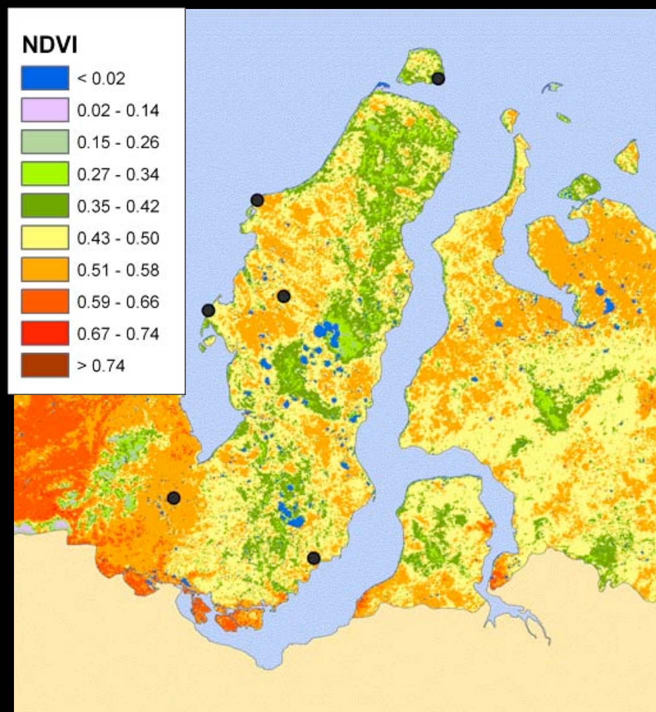
Lichen-woodland at Nadym

Bright green areas may be dominated by species such as alder or dwarf-birch, which have abundant toxic secondary plant compounds that protect them from grazing.

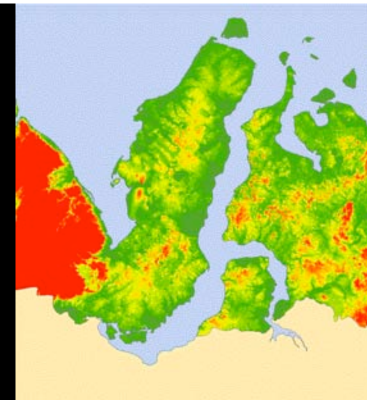
Shrub tundra at Laborovaya

Photos: D.A. Walker

Analysis of NDVI in relation to GIS databases



AVHRR-Derived NDVI of the Yamal Peninsula

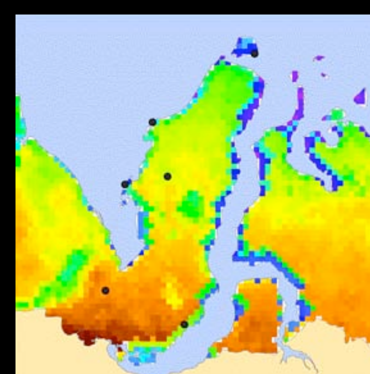


elevation

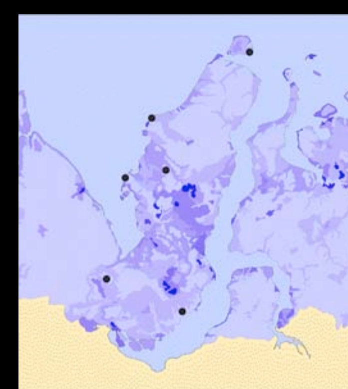
landschaft

lithology

veget-id

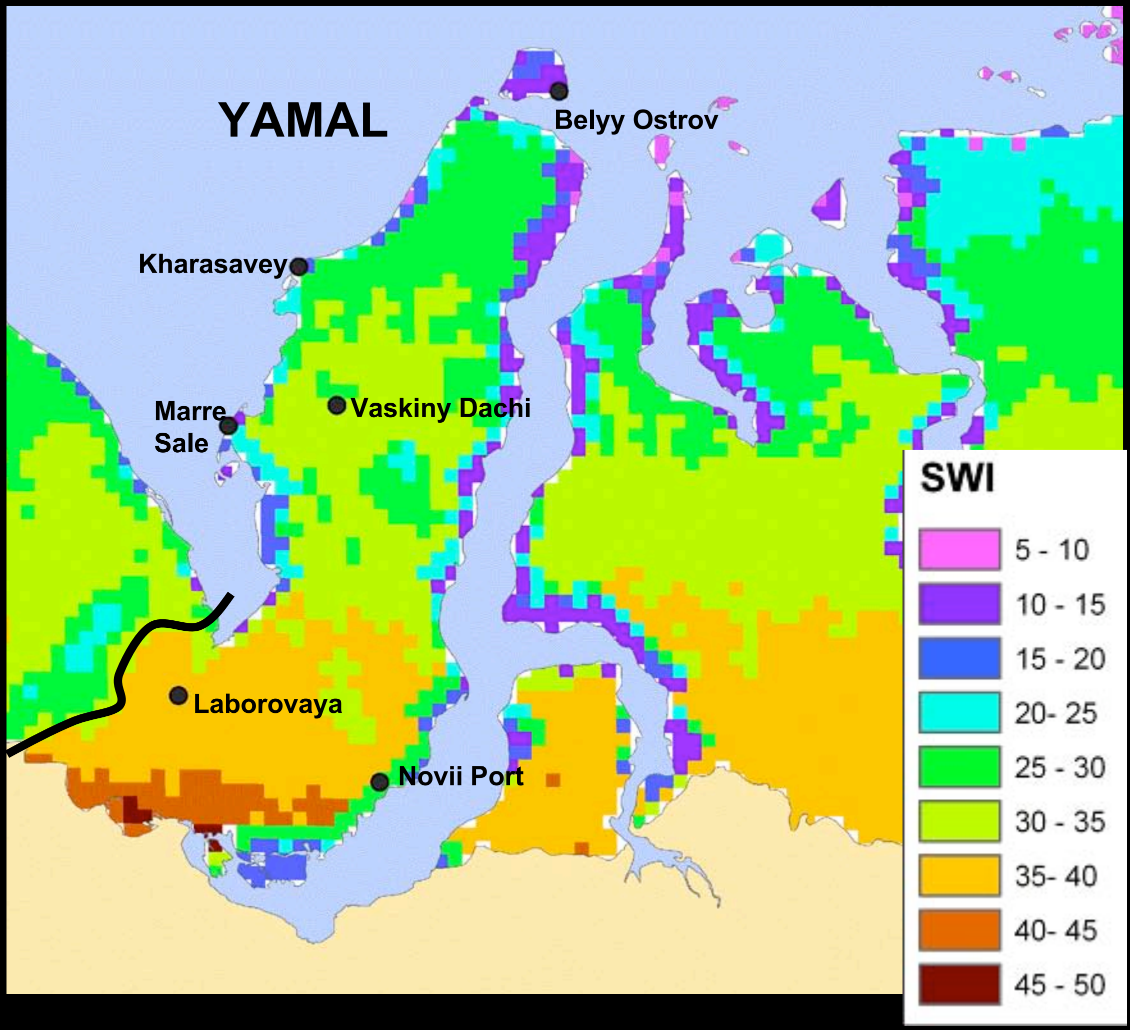


SWI



lake area

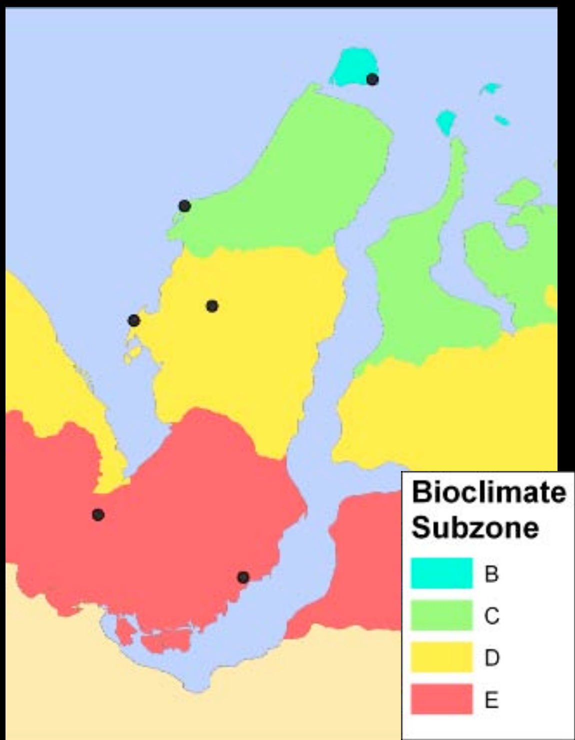
Land-surface summer warmth on the Yamal



Summer warmth index (SWI) of Yamal Peninsula, based on AVHRR satellite-derived land-surface temperatures (mean of 1982-2003, Comiso).

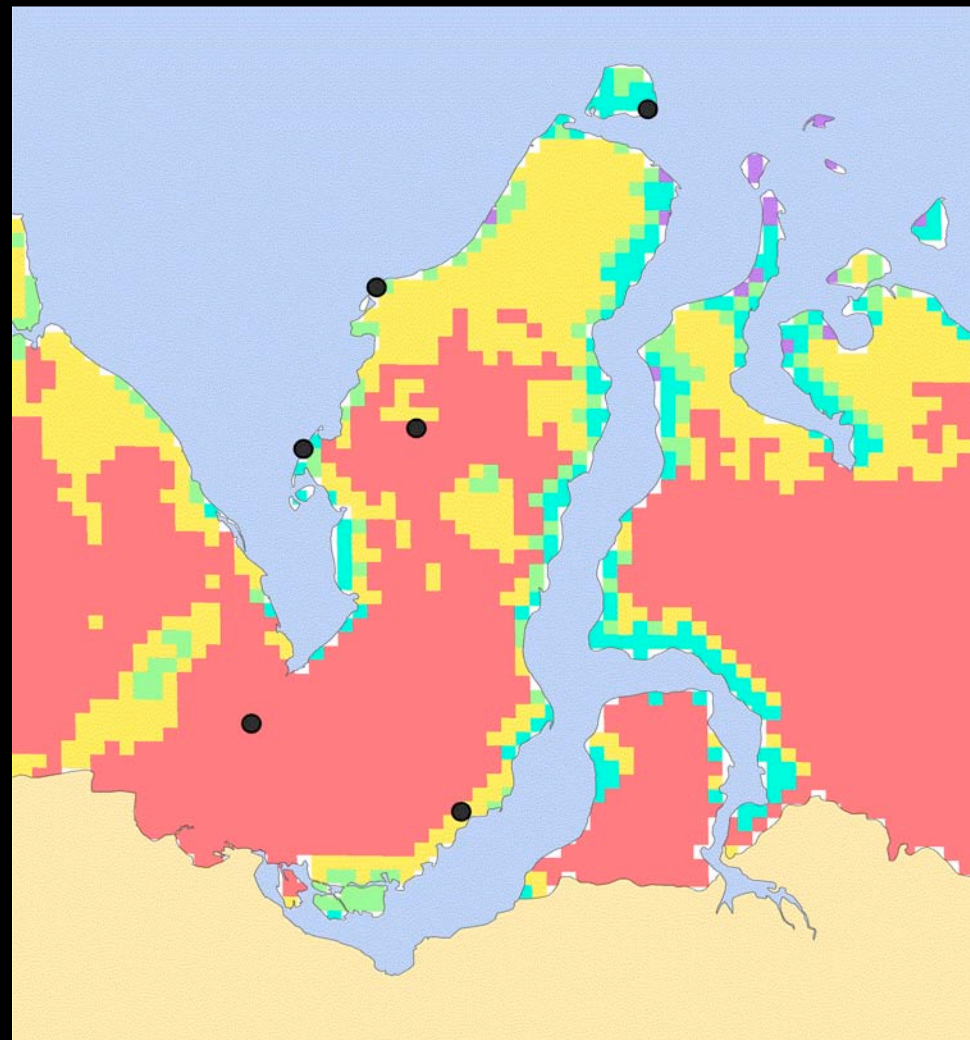
Martha Raynolds: Yamal LCLUC meeting, Moscow 28–31 Jan 2008.

Reevaluation of circumpolar zonal boundaries using AVHRR LST data



Bioclimate subzones as mapped on the Circumpolar Arctic Vegetation Map

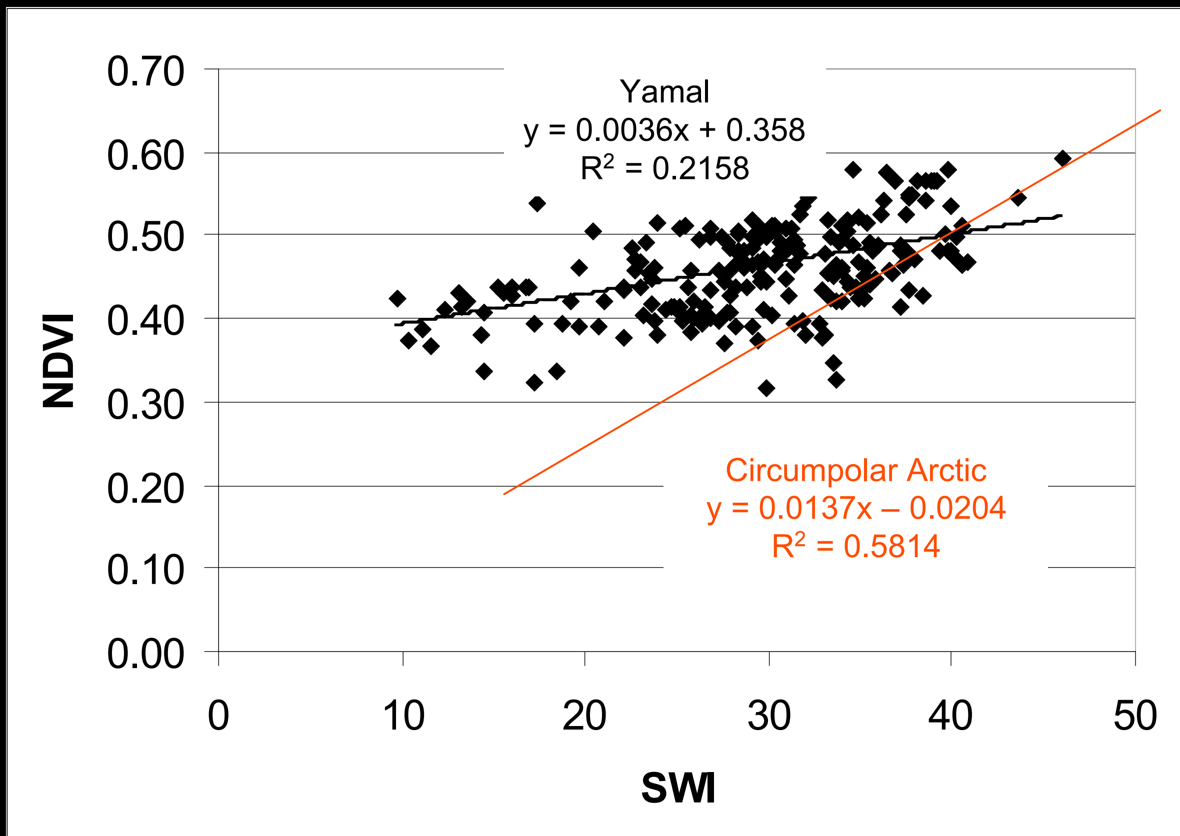
- Colder coastal strips
- Interior areas warmer
- Mountains colder



Bioclimate subzones as mapped by SWI

Martha Raynolds: Yamal LCLUC meeting, Moscow 28–31 Jan 2008.

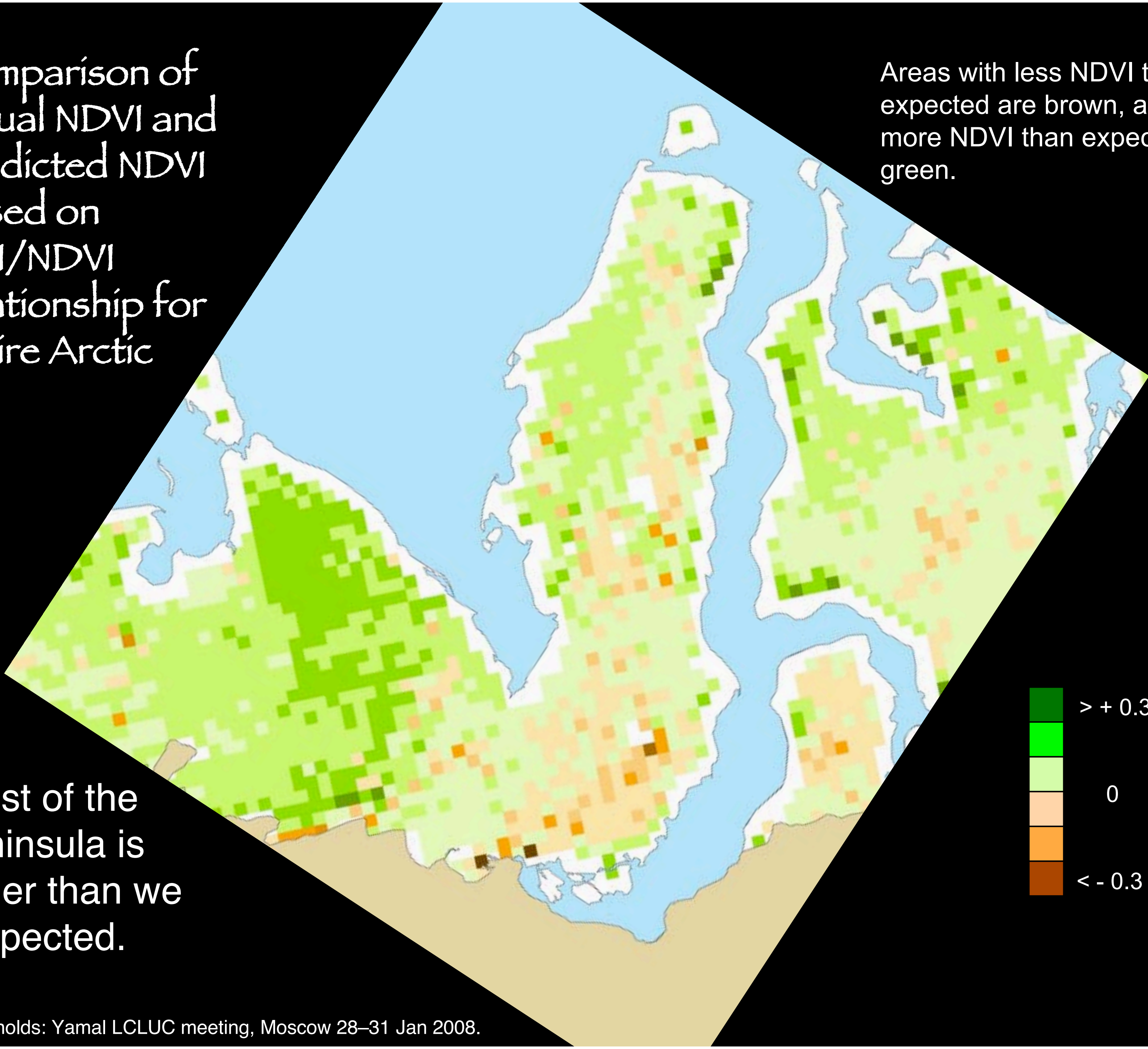
NDVI vs. Summer Warmth on the Yamal compared to the Circumpolar Arctic



- Arctic as a whole has much stronger correlations between NDVI and SWI.

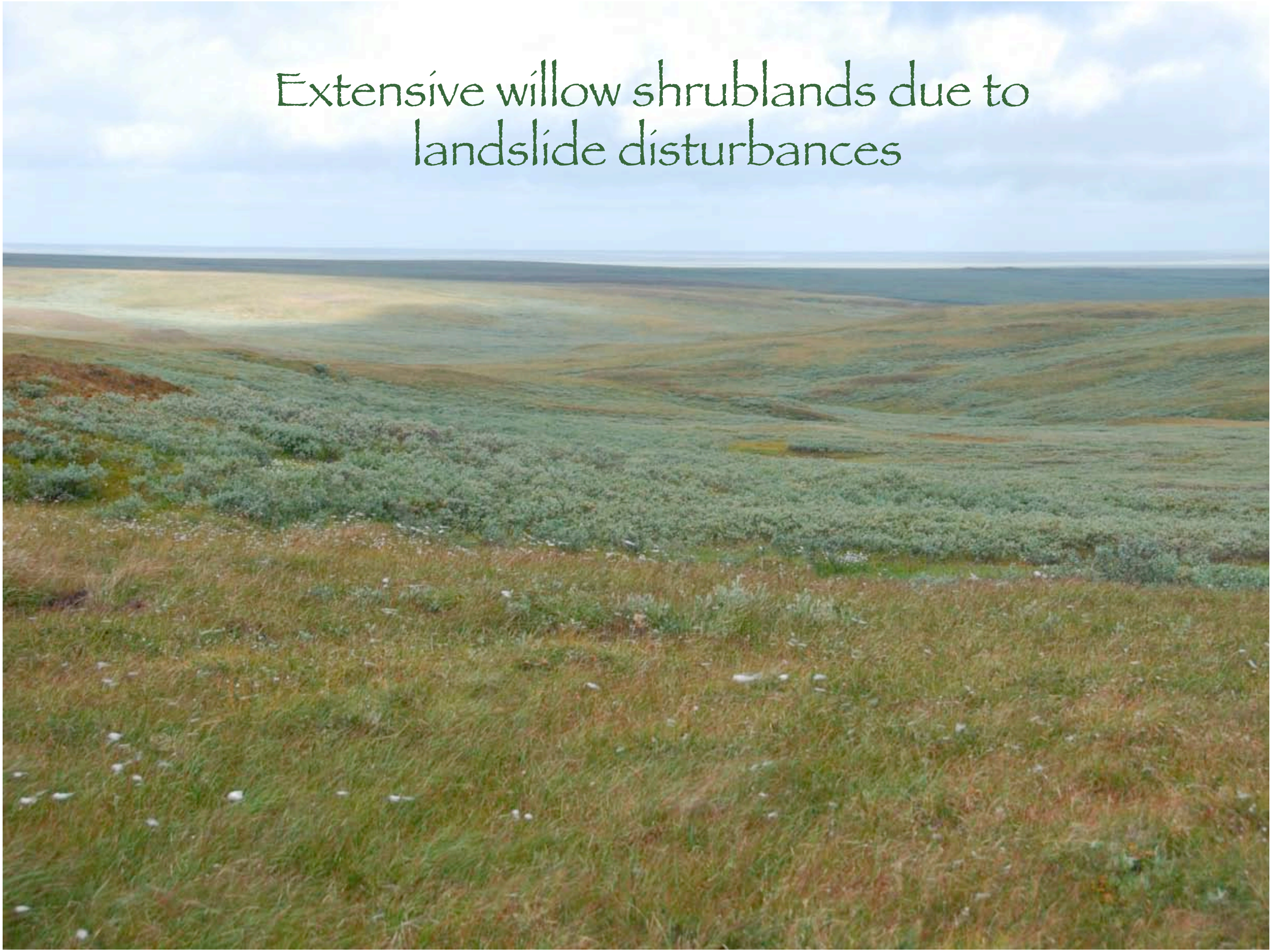
Comparison of actual NDVI and predicted NDVI based on SWI/NDVI relationship for entire Arctic

Areas with less NDVI than expected are brown, areas with more NDVI than expected are green.



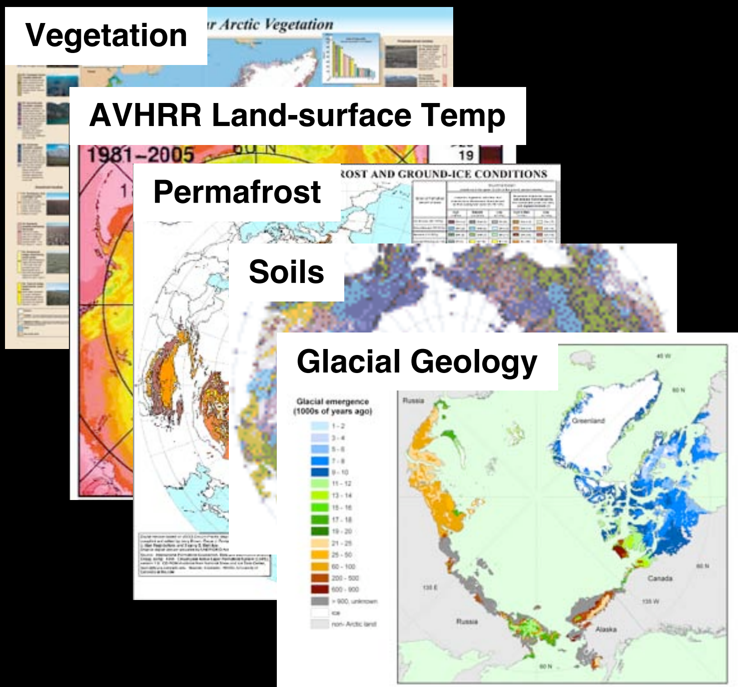
Most of the peninsula is greener than we expected.

Martha Raynolds: Yamal LCLUC meeting, Moscow 28–31 Jan 2008.

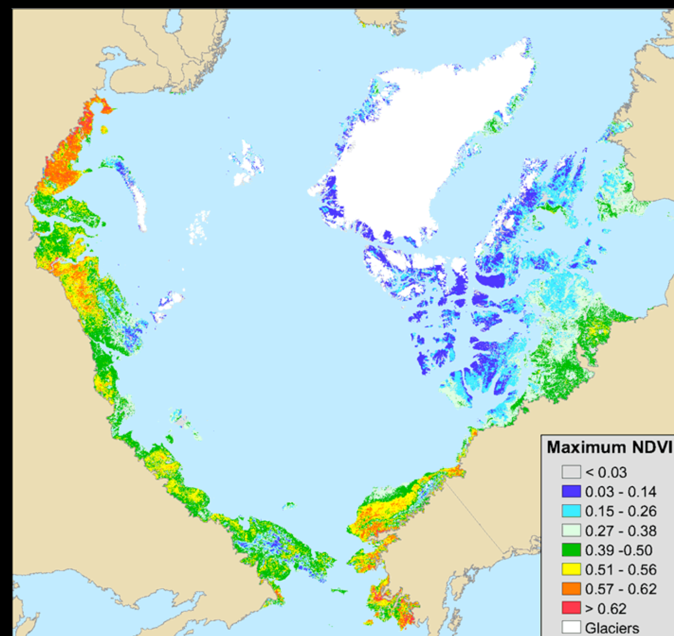

Extensive willow shrublands due to
landslide disturbances

Circumpolar Analysis of NDVI patterns: Martha Raynolds Ph.D. thesis

Circumpolar Data Sets



NDVI



Primary controls at pan-Arctic scale:

- Summer temp
- Lake cover
- Glacial history
- Soil type

Raynolds, M.K., D. A. Walker and H. A. Maier. 2006. NDVI patterns and phytomass distribution in the circumpolar Arctic. *Remote Sensing of Environment* 102:271–28 .

Raynolds, M. K., J. C. Comiso, D. A. Walker, D. Verbyla. 2008. Relationship between satellite-derived land surface temperatures, arctic vegetation types, and NDVI. *Remote Sensing of Environment* 112:1884–1894.

Raynolds, M. K. and Walker, D. A. 2008. Relationship of permafrost characteristics, NDVI, and arctic vegetation types. *Proceedings of the Ninth International Conference on Permafrost*: 1469–1474.

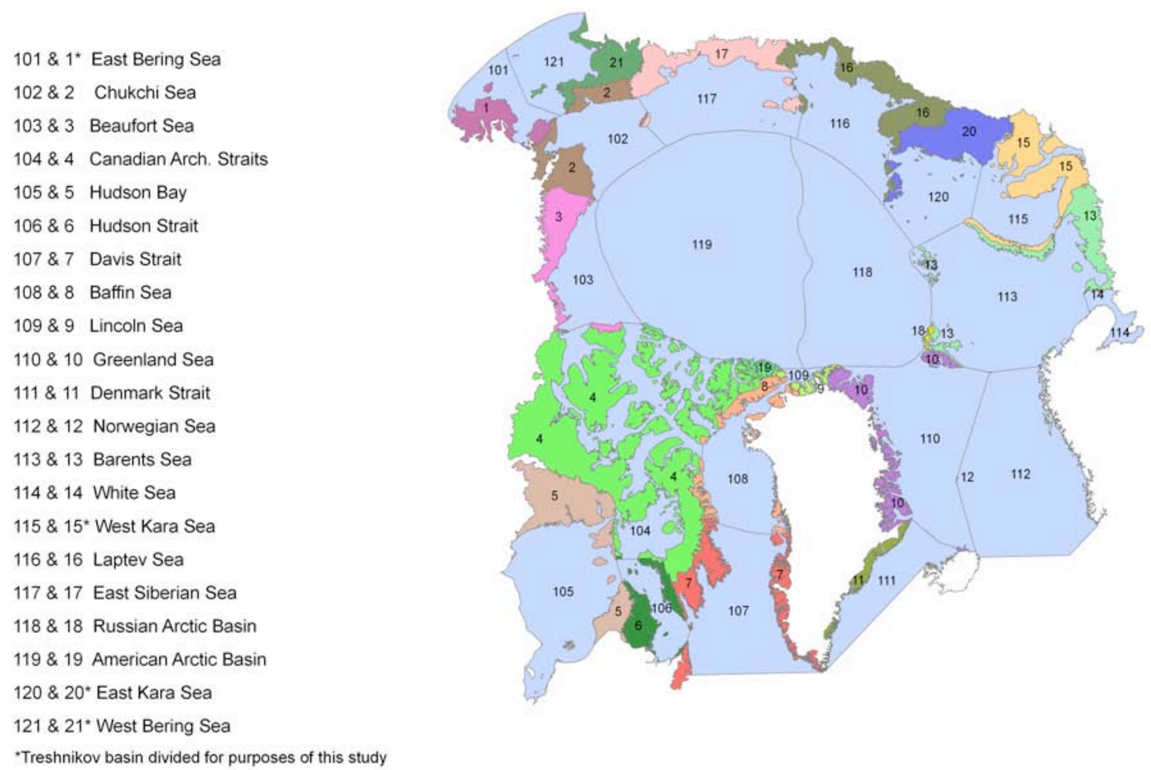
Raynolds, M. K. and Walker, D. A. 2008 (submitted): The effects of deglaciation on circumpolar distribution of arctic vegetation. *Canadian Journal of Remote Sensing.*

Raynolds, M.K. 2009 in prep. Synthesis of circumpolar controls on NDVI.

Analysis of sea-ice, land surface temperature and NDVI trends:

Uma Bhatt, D.A. Walker, M.K. Raynolds, J. Comiso

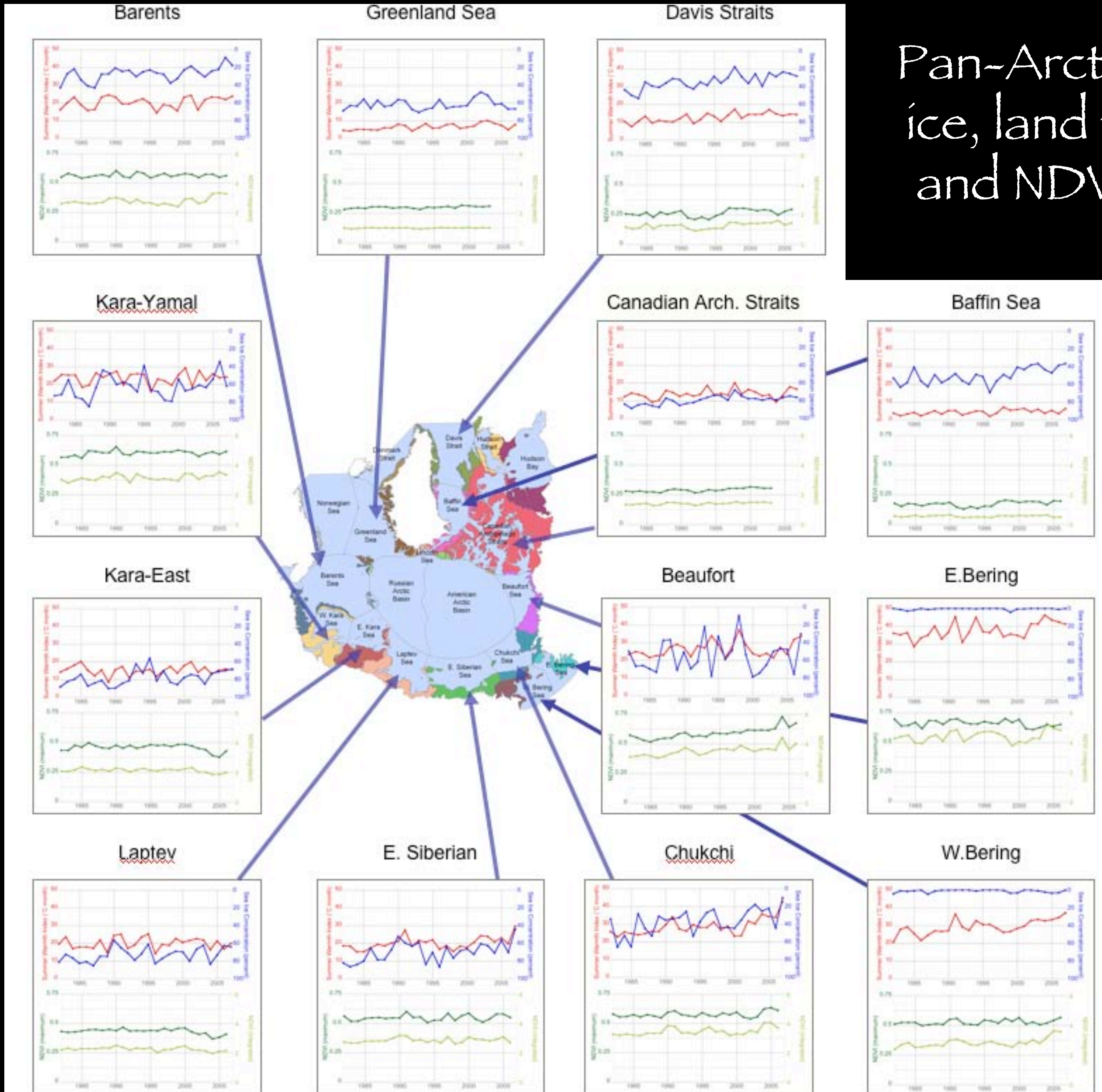
Division of Arctic Ocean and associated land masses according to Russian Arctic Atlas



Polar stereographic projection (J. Comiso)
Map by M. Raynolds, March 2008

- Analysis of 50-km buffers seaward and landward along each sea coast and also for entire tundra area below 330 m.
- 1982–2007 AVHRR data to analyze trends in sea ice concentration, LST, and NDVI.

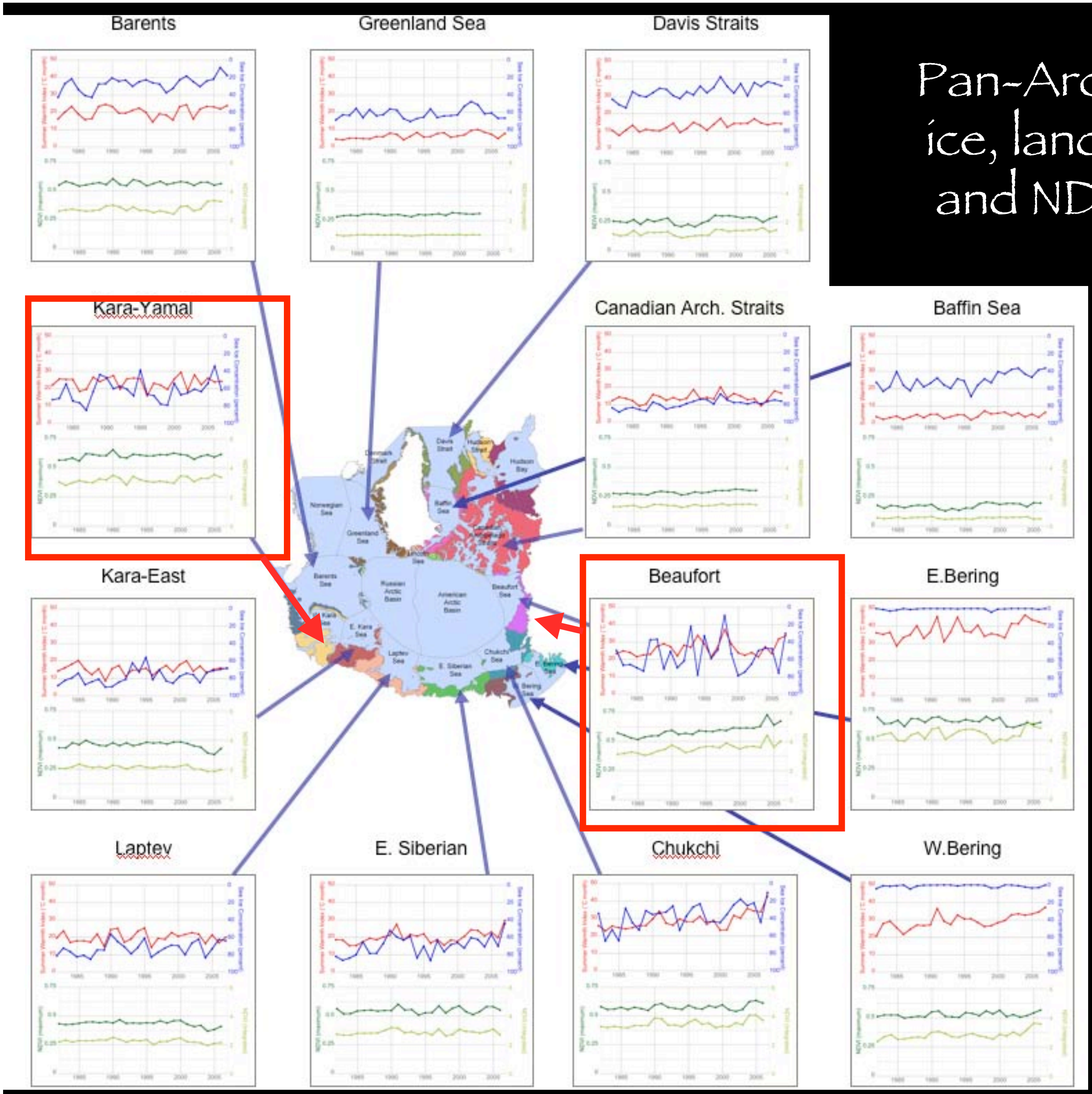
Pan-Arctic trends: Sea ice, land temperatures and NDVI, 1980-2007



- Mid July Sea Ice percentage cover
- Summer warmth index (SWI)
- Max NDVI
- Integrated NDVI

Bhatt et al: Yamal LCLUC Workshop, Moscow, 28–30 Jan 2008, and EGU 2008.

Pan-Arctic trends: Sea ice, land temperatures and NDVI, 1980-2007



- Mid July Sea Ice percentage cover
- Summer warmth index (SWI)
- Max NDVI
- Integrated NDVI

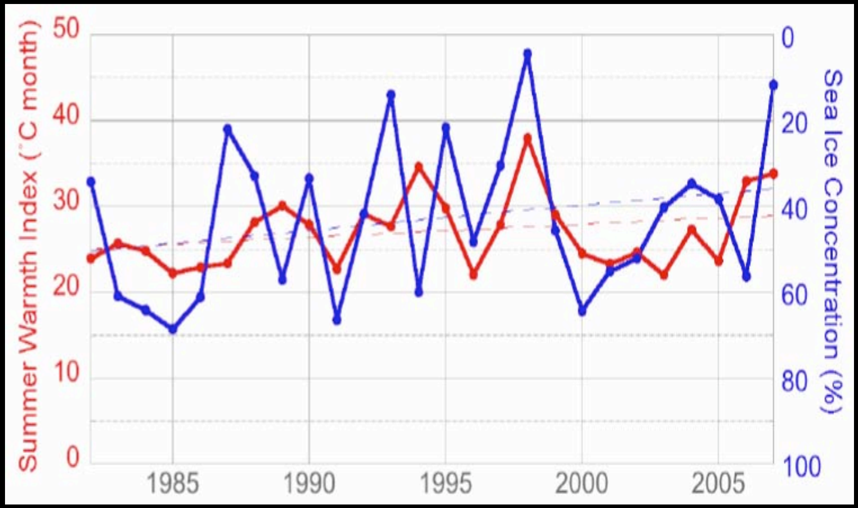
Focus on Kara/Yamal and Beaufort regions

Bhatt et al: Yamal LCLUC Workshop, Moscow, 28–30 Jan 2008, and EGU 2008.

Sea-ice and temperature trends in Beaufort Sea and Kara/Yamal region of Russia, 1982-2007

Beaufort

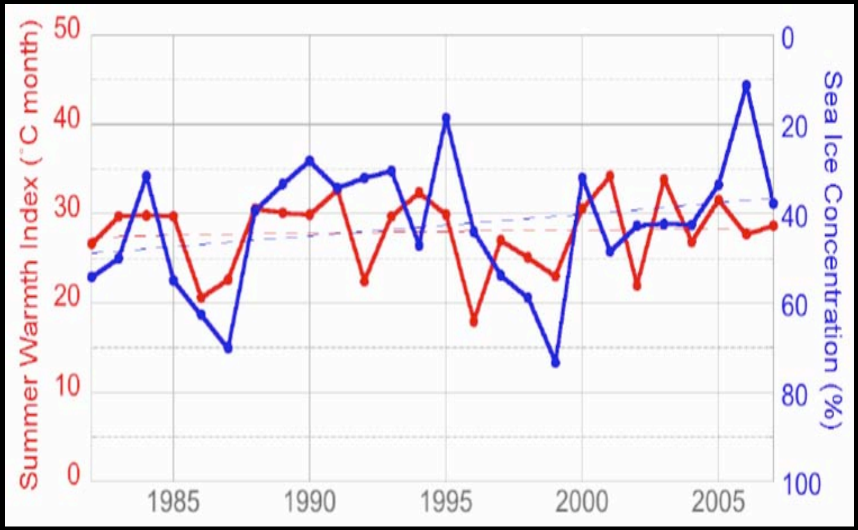
Negative sea-ice trend (-29%) correlated with positive temperature trend (+16%) and very high inter-annual variability.



Kara/Yamal

Negative sea-ice trend (-25%) but nearly flat temperature trend (+4%).

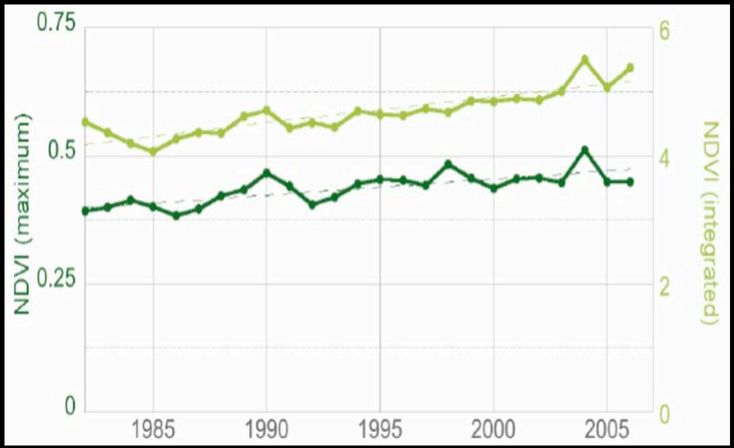
None of the trends are significant at $p = 0.05$ because of high interannual variability.



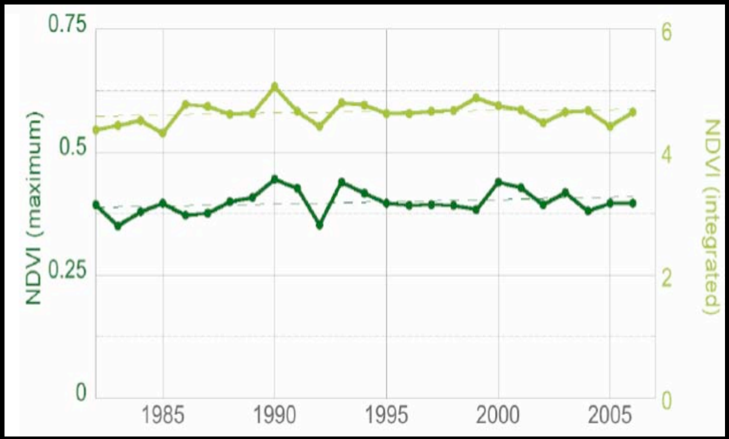
Bhatt et al.: NASA LCLUC Workshop, 2008.

NDVI trends in Beaufort Sea and Kara/Yamal region of Russia

Beaufort



Kara/Yamal

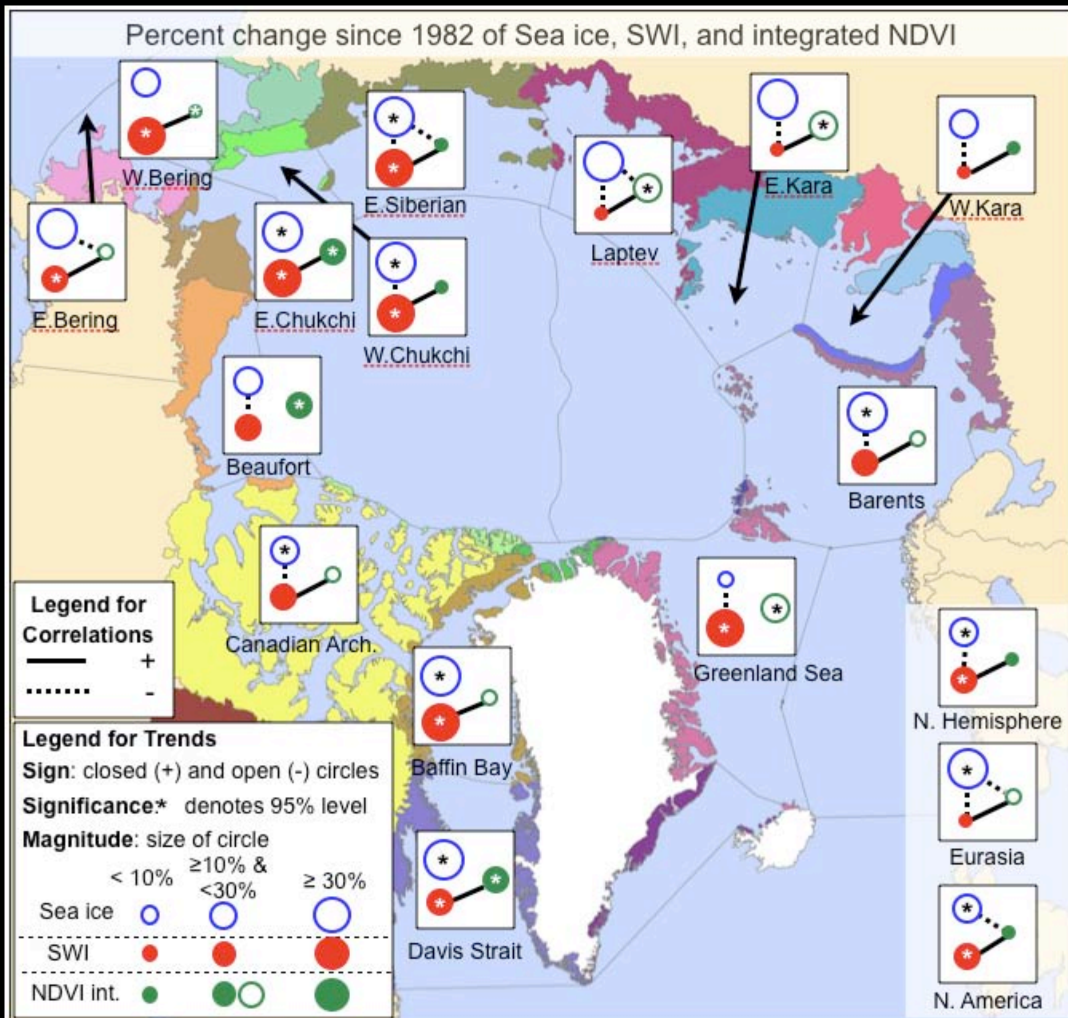


- Greater change in Beaufort Region maximum NDVI (+ 24%) vs. Kara/Yamal (+ 3%) most likely due to more positive trend in ground surface temperatures in the Beaufort region during the period of record.

- Beaufort trends are significant at $p = 0.05$.

Bhatt et al. EGU, Vienna, Proceedings, 2008.

Summary of trends



Bhatt et al., in progress, 2008.

- Sea ice is strongly decreasing throughout the Arctic except the Greenland Sea. The strongest most significant trends are in the E. Siberian to E. Chukchi region.
- Summer warmth is increasing most strongly in the Beringian region between the E. Siberian Sea and the E. Chukchi and also in the Greenland Sea and Baffin Bay. Relatively small increases are seen between the W. Kara and Laptev seas.
- NDVI is increasing most strongly in the E. Chukchi and Beaufort regions, and also Davis Straight. Negative trends are occurring in several areas, most notable along the E. Kara Sea and Laptev Sea.

Correlations with climate indices

50-km zones with climate indices during preceding winter (DJFM)

Red values are positive correlations, blue are negative. **Bold** values are significant at 90% level or greater.

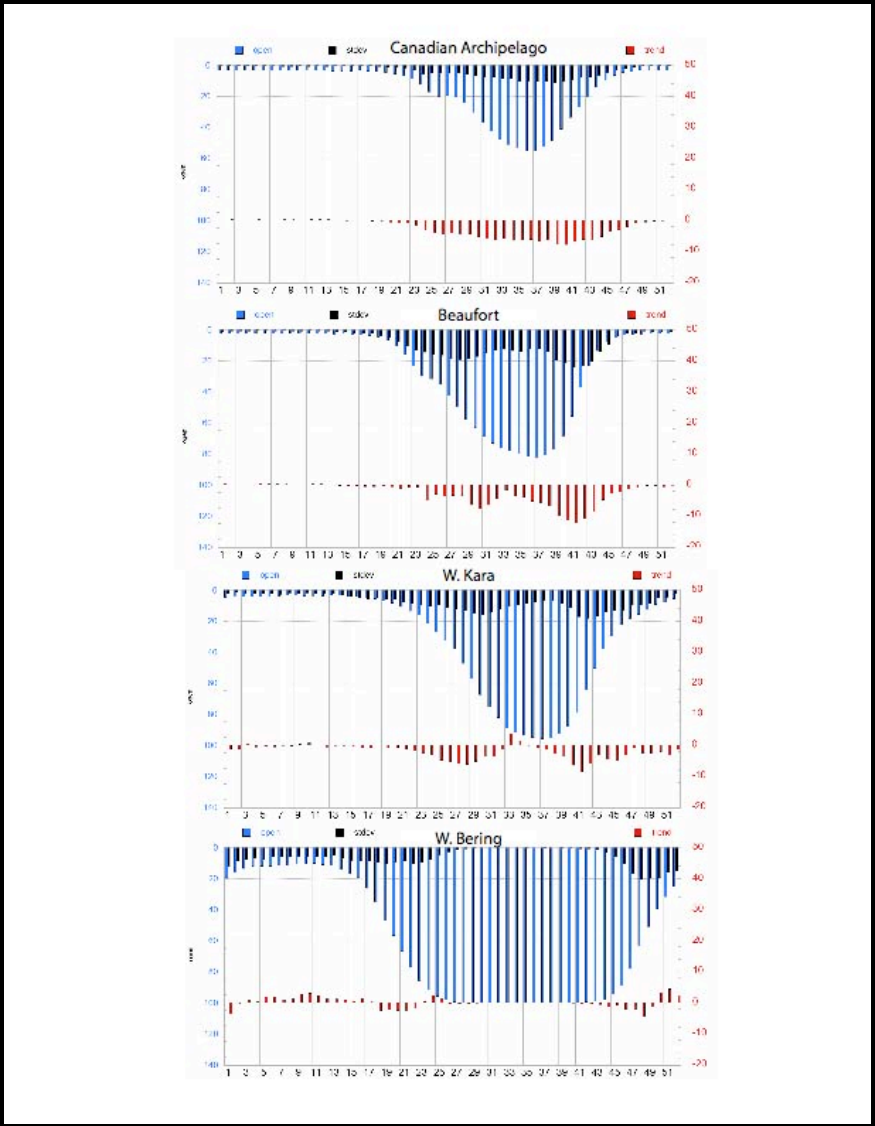
	SWI				Sea Ice				Integrated NDVI			
Climate index	NAO	AO	PDO	NPI	NAO	AO	PDO	NPI	NAO	AO	PDO	NPI
Barents	.38	**.3**	0	**.14**	**-0.2**	**-.3**	.42	**-.20**	.11	**.20**	**-.24**	**.23**
Kara-Yamal	**.27**	**.12**	0	**.14**	-.54	-.57	.48	-.34	0	**.14**	**-.29**	.40
Kara-East	**- .2**	-.40	**-.14**	**-.2**	0	0	0	0	0	**-.13**	0	**.16**
Laptev	**.33**	**.19**	**-.31**	**.15**	-.56	-.53	.43	**-.17**	0.60	.41	-.41	**.27**
E.Siberian	**.14**	**.33**	-.43	**.32**	**-.27**	-.56	.49	**-.26**	**0.19**	.45	-.63	.49
Chukchi	**-.1**	**.12**	**-.28**	.37	**.19**	**-.26**	**.20**	-.11	**-.17**	0	**-.26**	**.25**
W. Bering	0	0	**-.26**	**.13**	**-.11**	**-.24**	**.14**	0	0	0	**-.22**	0
E. Bering	0	0	**-.11**	**.22**	0	**-.25**	**.10**	0	0	0	0	**.15**
Beaufort	.48	.40	0	**.11**	0	0	**-.27**	**.16**	**-.12**	**.10**	**-.25**	**.22**
Canadian Arch	**.19**	**.13**	0	0	.14	0	0	0	0	**.14**	**-.16**	**.15**
Davis Straits	**-.2**	0	0	**.15**	.18	0	0	**-.11**	**-.31**	0	0	**.10**
Baffin Sea	0	0	**-.15**	**.16**	0	0	**.15**	**-.17**	0	0	0	**.24**
Grnland Sea	**-.1**	**.14**	**-.10**	**.19**	.43	**.26**	0	0	**.13**	0	0	0

- Sea ice is generally negatively correlated with the Arctic Oscillation and positively correlated with the Pacific Decadal Oscillation.
- SWI and NDVI are generally positively correlated with the AO and negatively correlated with the PDO.
- Correlations require more thought in terms of mechanisms. Analysis of wind correlations with NDVI and SWI are in progress.

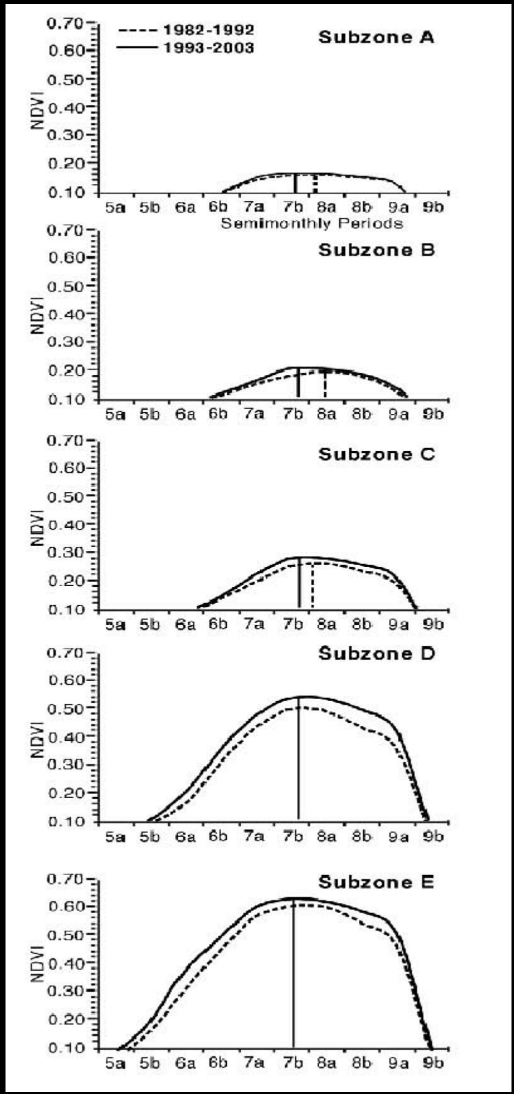
Bhatt et al., in progress, 2008.

Seasonality trends

Sea-ice concentration



NDVI

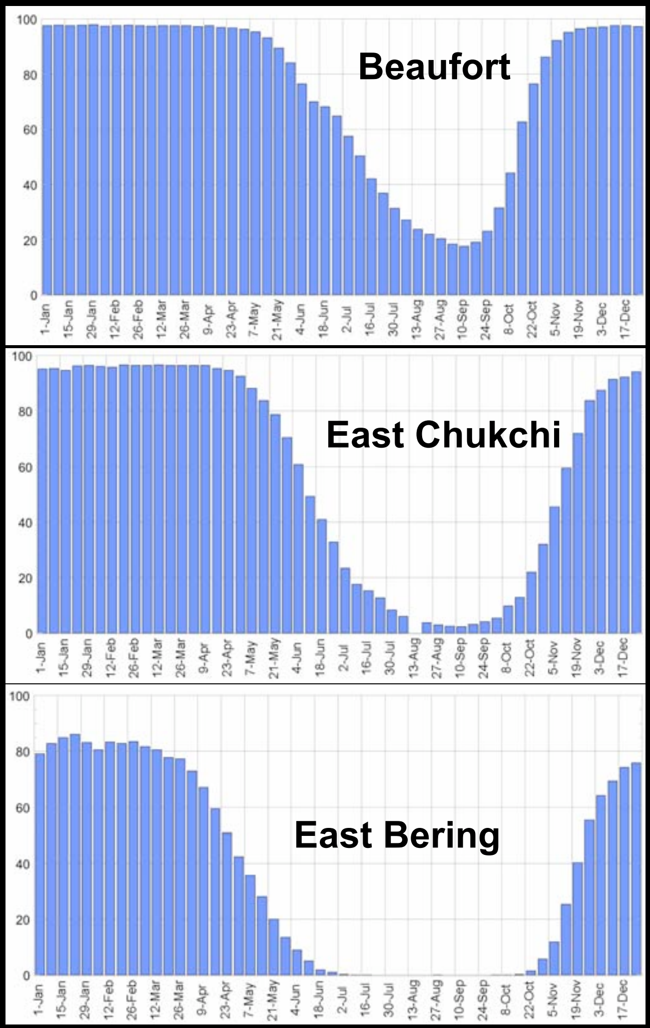


Bhatt et al. in prep., *Earth Interactions*

Jia et al. in press, *JGR-Biogeosciences*

Controls on seasonality

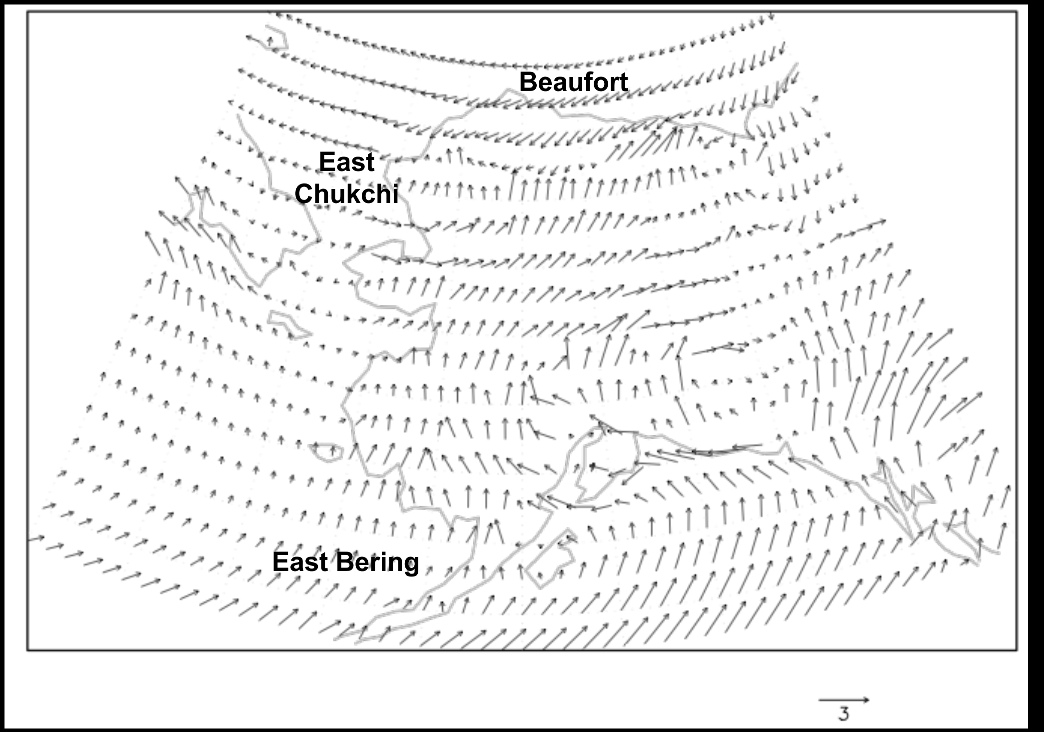
Biweekly sea-ice concentration in Arctic Alaska Seas



Weekly climatological sea ice based on the 1982-2007 period for the 50-km coastal ocean domain.

Bhatt et al. in prep., *Atmospheric Research*

Jun-Aug Wind patterns



NARR long term climatological 10-m vector winds (1979-2000) averaged for June-August in m s^{-1}. Data for image provided by the NOAA-ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.cdc.noaa.gov.

Future analyses will examine the controls of sea-ice, winds, snow, atmospheric circulation and ocean circulation on seasonal patterns of NDVI. Proposed to NSF by Epstein, Bhatt, Walker, and Steele.

Cumulative effects on the Yamal

Resource development:

- Indirect (unplanned) impacts (such as ORV trails, flooding from roads) are greater than the direct (planned) impacts (infrastructure).
- Roads and pipelines: serious barriers to migration corridors.
- Effects will increase as new field are developed.

Landscape factors and terrain sensitivity:

- High potential for extensive landscape effects due to unstable sandy soils, and extremely ice-rich permafrost near the surface.

Reindeer herding:

- Land withdrawals by industry, increasing Nenets population, and larger reindeer herds are all increasing pressure on the rangelands.
- Herders view: Threats from industrial development much greater than threats from climate change. Big concern is lack of power during negotiations.
- They currently generally view the gas development positively because of increased economic opportunities.

Climate change:

- Satellite data suggest that there has been only modest summer land-surface warming and only slight greening changes across the Yamal during the past 24 years. (Trend is much stronger in other parts of the Arctic, e.g. Beaufort Sea.)
- Kara-Yamal: negative sea ice, positive summer warmth and positive NDVI are correlated with positive phases of the North Atlantic Oscillation and Arctic Oscillation.

Circumpolar Summary

- **Temperature – sea ice linkages:** Strong linkages have been demonstrated between reduced sea-ice concentrations and increased land-surface temperatures.

- **NDVI trends:** Large regional differences in the NDVI trends:
  - Strongly positive trend in the northern Beringia region of E. Siberia, Chukchi, and Beaufort seas. This is the region with the strongest recent reductions in sea-ice concentrations.
  - Slight negative trend in northern Eurasia (E. Kara, Laptev seas).

- **NDVI controls:** Ground-based and remote-sensing studies along climate transects in North America and Yamal have very different spatial patterns of NDVI and factors affecting the NDVI in each region:
  - **North America**: age of glacial surfaces, differences in substrates (acidic vs. nonacidic soils), strong temperature controls.
  - **Yamal**: Large effect of natural disturbance, sandy vs. clayey substrates, heavily grazed systems (but still unknown what the actual effect of reindeer on NDVI is), weaker temperature control.

- **Climate drivers:** Throughout the Arctic including the Beaufort and Yamal, the general trend is positive summer warmth and NDVI with positive phases of the North Atlantic Oscillation and Arctic Oscillation, and negative correlations with positive phases of the Pacific Decadal Oscillation. The positive phase of NAO and AO is consistent with a warmer winter Arctic, reduced summer sea ice, increased SWI and increased integrated NDVI.

- **Replicated long-term vegetation studies and standardized protocols:** Needed across the Arctic and coordinated with other terrestrial monitoring of climate, permafrost, active layers, ITEX etc. — especially in areas currently surrounded by perennial sea ice and other areas where the changes are occurring most rapidly (e.g. Beringia region).

Yamal Transect

2007

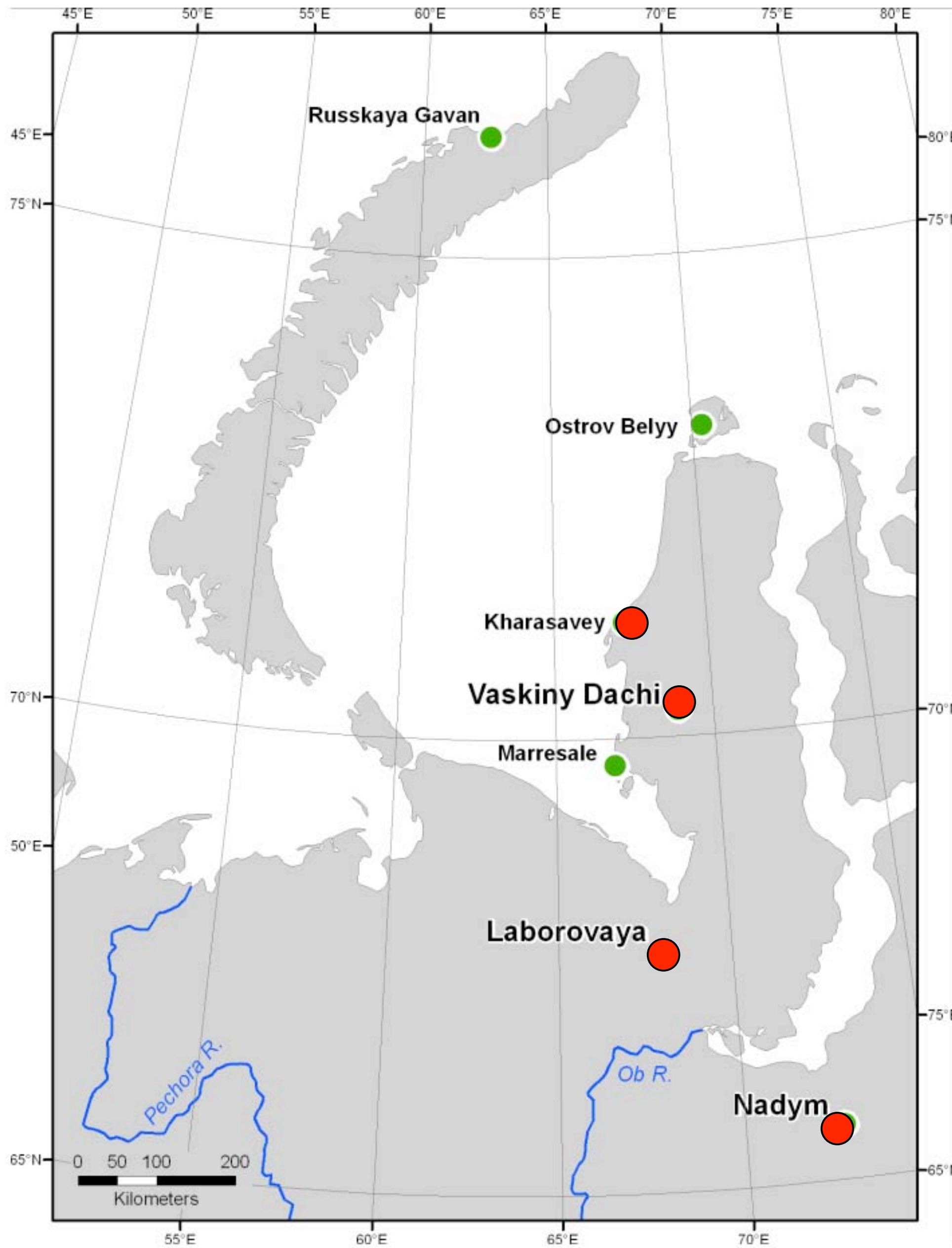
- Nadym
- Laborovaya
- Vaskiny Dachi

2008

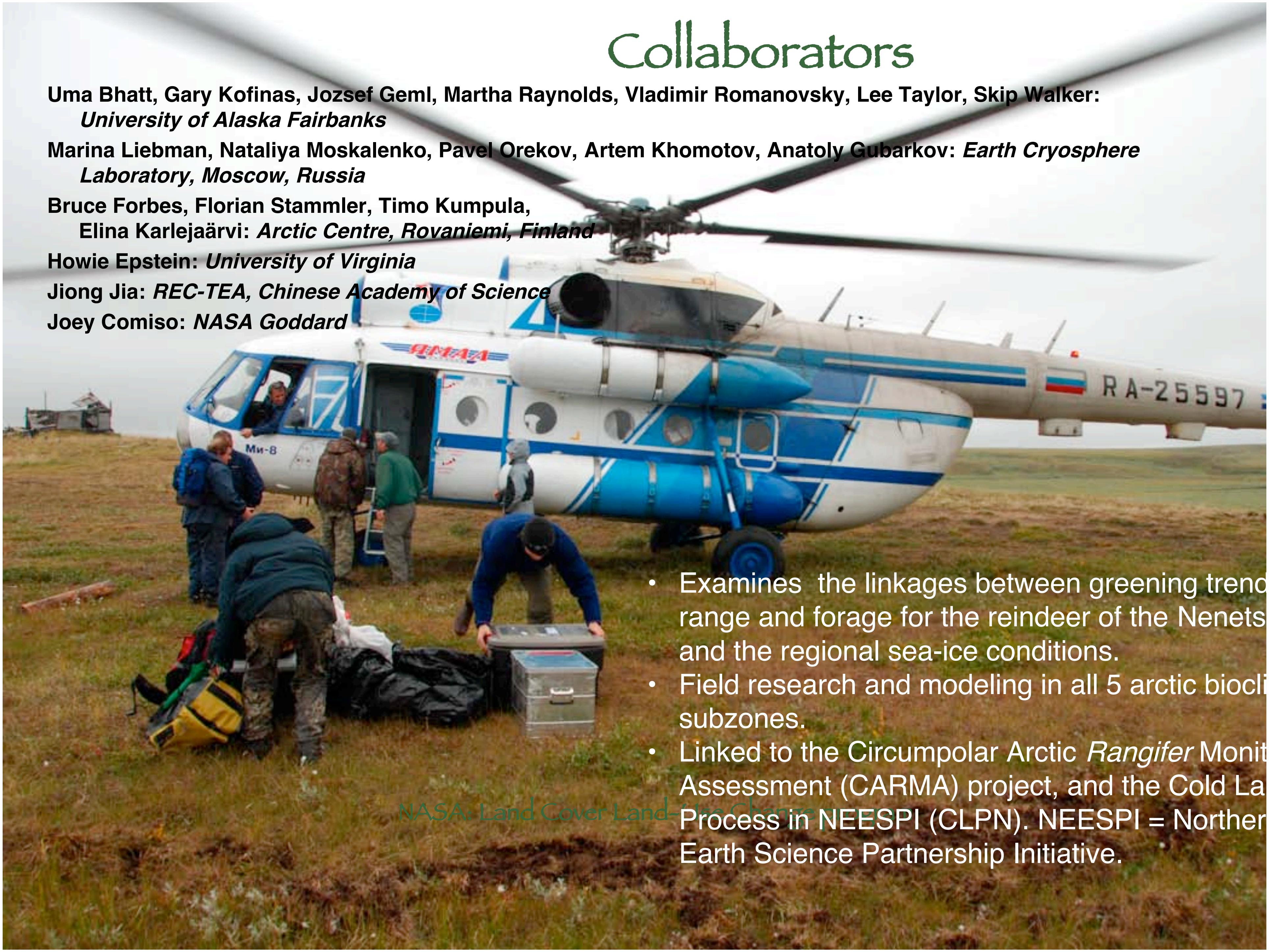
- Kharasavey

2010 (proposed)

- Ostrov Belyy
- Russkaya Gavan (or Franz Josef Land)
- Marresale (or site in N. Yamal)



Collaborators



Uma Bhatt, Gary Kofinas, Jozsef Geml, Martha Raynolds, Vladimir Romanovsky, Lee Taylor, Skip Walker: ***University of Alaska Fairbanks***

Marina Liebman, Nataliya Moskalenko, Pavel Orekov, Artem Khomotov, Anatoly Gubarkov: ***Earth Cryosphere Laboratory, Moscow, Russia***

Bruce Forbes, Florian Stammler, Timo Kumpula, Elina Karlejaärvi: ***Arctic Centre, Rovaniemi, Finland***

Howie Epstein: ***University of Virginia***

Jiong Jia: ***REC-TEA, Chinese Academy of Science***

Joey Comiso: ***NASA Goddard***

- Examines the linkages between greening trend range and forage for the reindeer of the Nenets and the regional sea-ice conditions.
- Field research and modeling in all 5 arctic biocli subzones.
- Linked to the Circumpolar Arctic *Rangifer* Monit Assessment (CARMA) project, and the Cold La Process in NEESPI (CLPN). NEESPI = Norther Earth Science Partnership Initiative.

NASA: Land Cover Land-Use Change

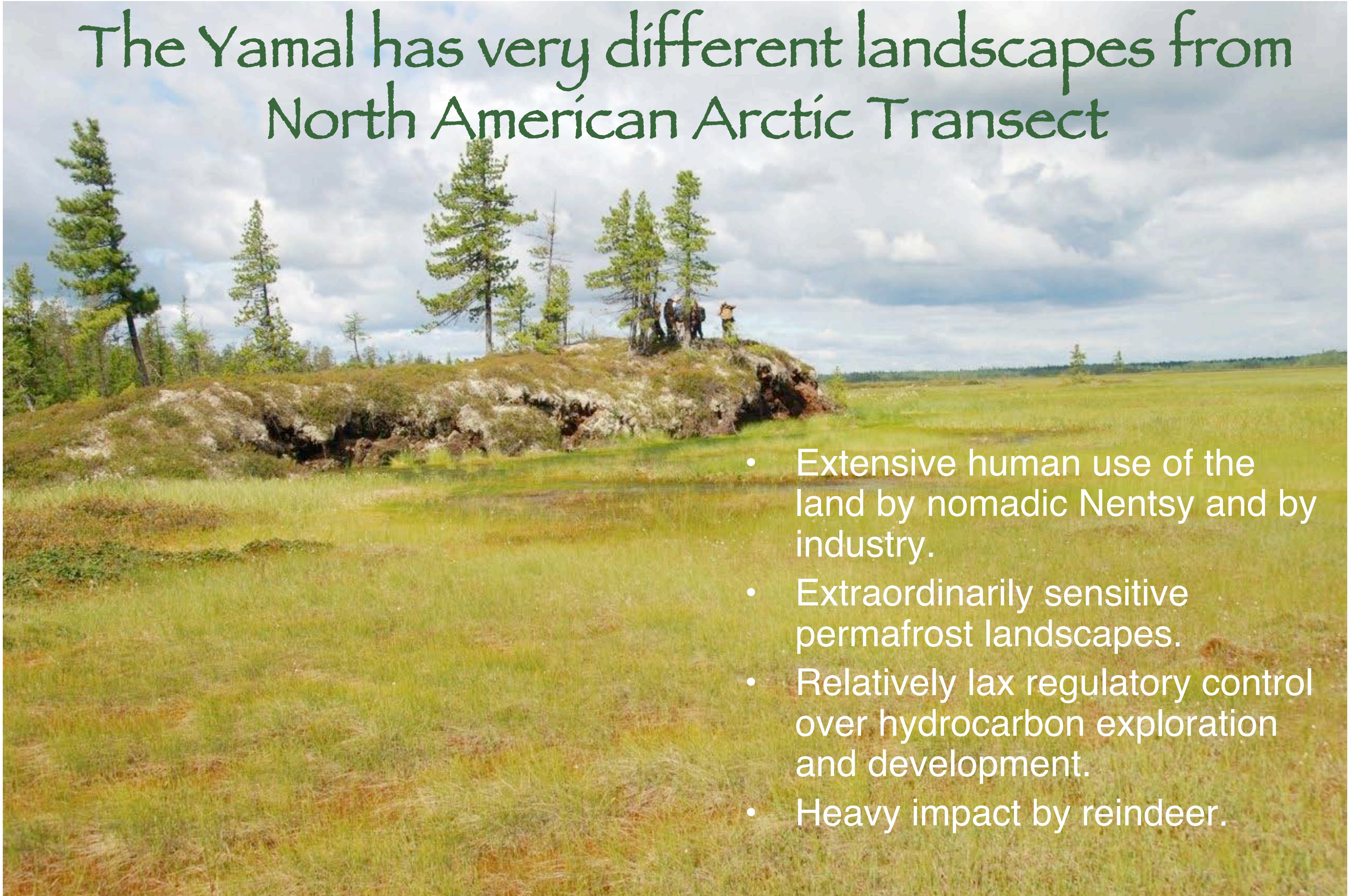
The Yamal

Typical of the sorts of changes that are likely to become much more common in tundra areas of Russia and the circumpolar region within the next decade.

- Currently, large areas of wilderness with no roads or development, but…
- large-scale gas and oil potential,
- extraordinarily sensitive permafrost environment
- traditional pasturelands for the nomadic Yamal Nenets people,
- rapid changes in climate.

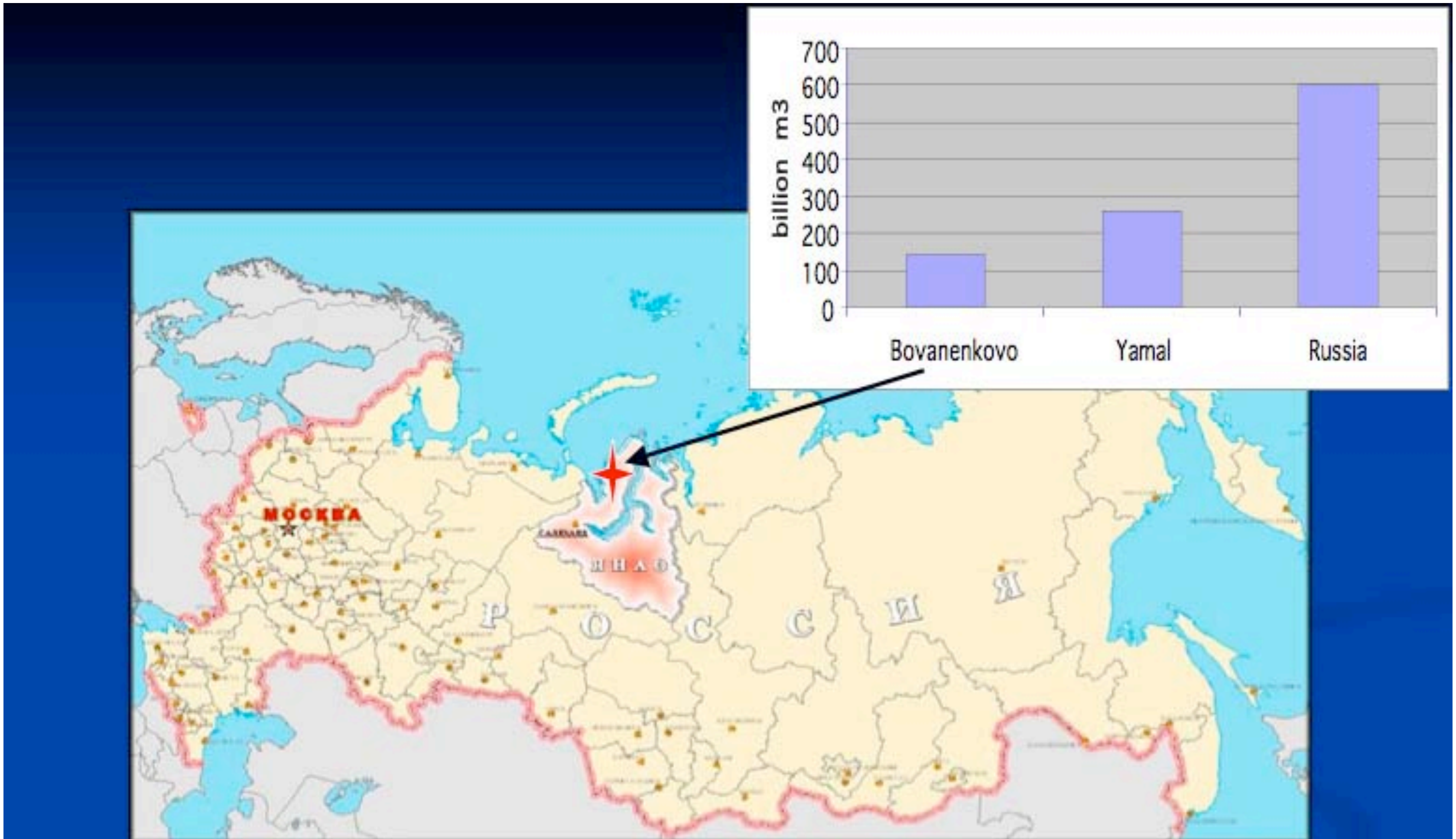
Goal: Develop tools using remote sensing and modeling to better predict the cumulative effects of resource development, climate change, reindeer herding, and the role of terrain factors in affecting changes in tundra regions.

The Yamal has very different landscapes from North American Arctic Transect



- Extensive human use of the land by nomadic Nentsy and by industry.
- Extraordinarily sensitive permafrost landscapes.
- Relatively lax regulatory control over hydrocarbon exploration and development.
- Heavy impact by reindeer.

Yamal: Center of future gas production in Russia



- Contemporary Russia's gas production is more than 600 billions m^3 of gas which makes up 20% of the world consumption.
- In 2030 gas production on Yamal will be as high as 250 – 260 billions m^3/yr.

Courtesy of A. Gubarkov

Existing and designed pipelines

- "Gazprom" has accepted the Yamal hydrocarbons transportation scheme of main pipeline across the Baidarata Bay of the Kara Sea. Four pipelines will transport 50–60 billions m³ of gas each.

Courtesy of A. Gubarkov

Relaxed Regulatory Environment

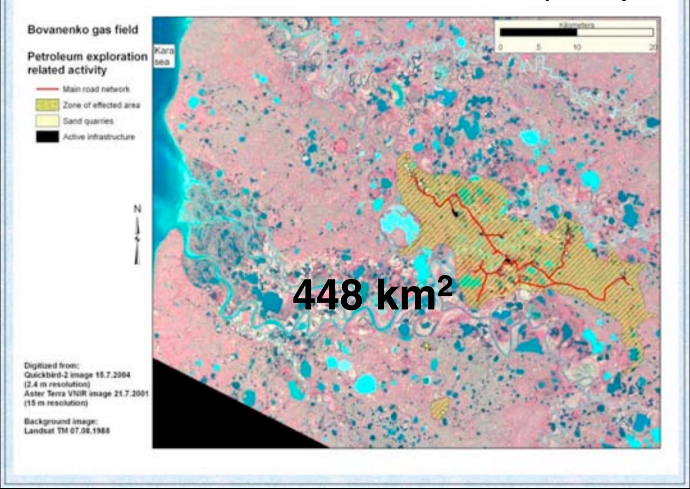
Photos: D.A. Walker

Extent of infrastructure of Bovanenkova Field compared to Prudhoe Bay

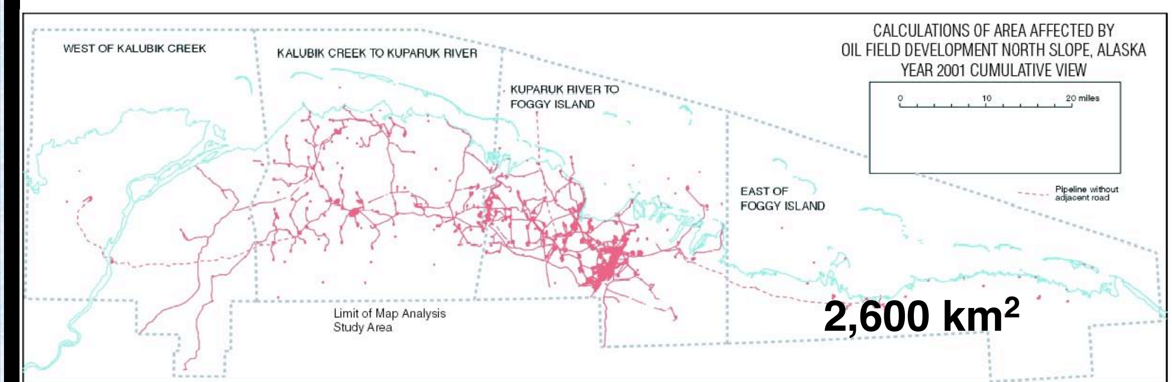
Area of infrastructure (km^2)

	Bovanenkovo, RU (Kumpula 2007)	**North Slope, AK** (NRC, 2003)
Construction pads	2.1	24.2
Quarries	4.3	25.8
Roads (all types)	2.9 (79 km)	12.2 (954 km)
Air strips	0	1.2
Total infrastructure	9.3 km^2	63.4 km^2
Other affected areas (major ORV trails, debris)	24 km^2	7.14 km^2
TOTAL DETECTIBLE CHANGED AREA	33.3 km^2	70.5 km^2
Approximate total extent of infrastructure (perimeter, including currently enclosed unimpacted areas no longer accessible to herders)	448 km^2	2,600 km^2

Extent of Bovanenkovo Gas Field (2001)



Extent of the North Slope, AK development (2001)



T. Kumpula: Yamal LCLUC Workshop, Moscow, 28–30 Jan 2008.

NRC, 2003. *Cumulative Environmental Effects of the Oil and Gas Development on the Alaska North Slope.*

Extraordinarily Sensitive Permafrost Landscapes

Extensive nutrient-poor surface sands.

Underlain by massive pure ice,

Subject to erosion and landslides,

That expose salt-rich and nutrient-rich clays, leading to

Complex successional process that results in willow-shrub tundra in the interior parts of the peninsula.

Photos: D.A. Walker
and M. Liebman (upper right)





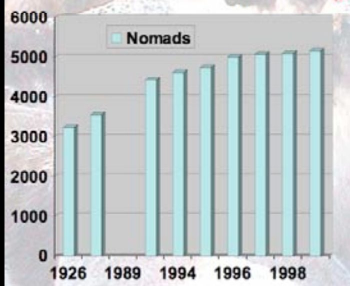

The Nentsy and their reindeer

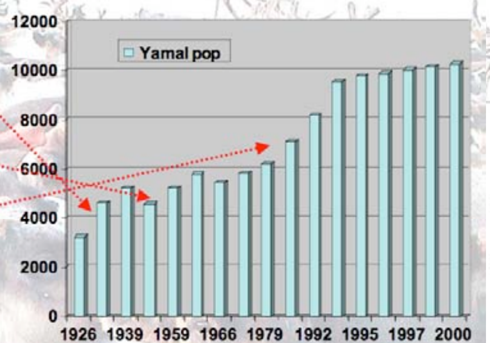
Increase of humans on Yamal

Euro-Nentsy escape to Yamal, early 1930s,

'Dekulakization' and prosecution of shamans under Stalin

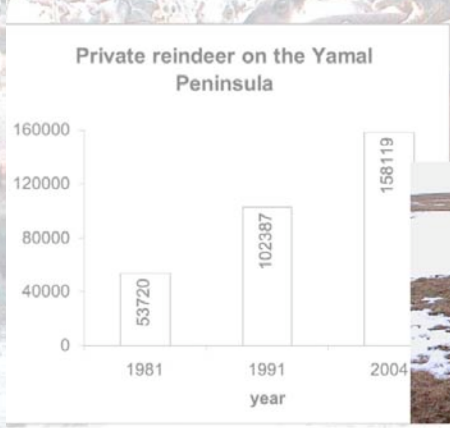
Steady growth after sovkhoz system stabilised





Before 1926: no permanent settlements on the Peninsula. Today: Half of Nentsy settled, plus another 5000 non-indigenous residents

Increase of private reindeer



Where do all these animals graze???

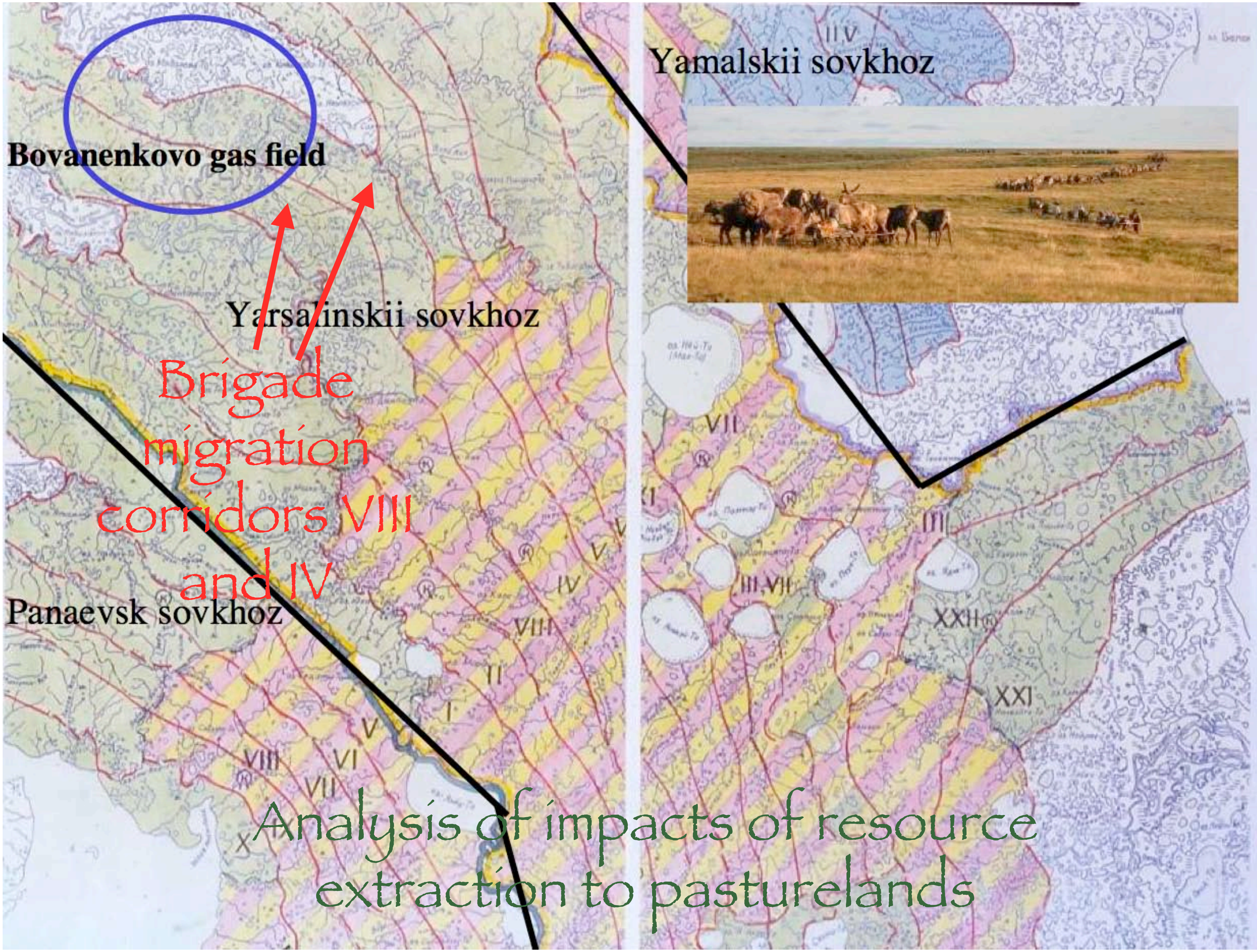
Graphics: Florian Stammler: Yamal LCLUC Workshop, Moscow, 28–30 Jan 2008.
Photos: D.A. Walker

Effects of reindeer herding

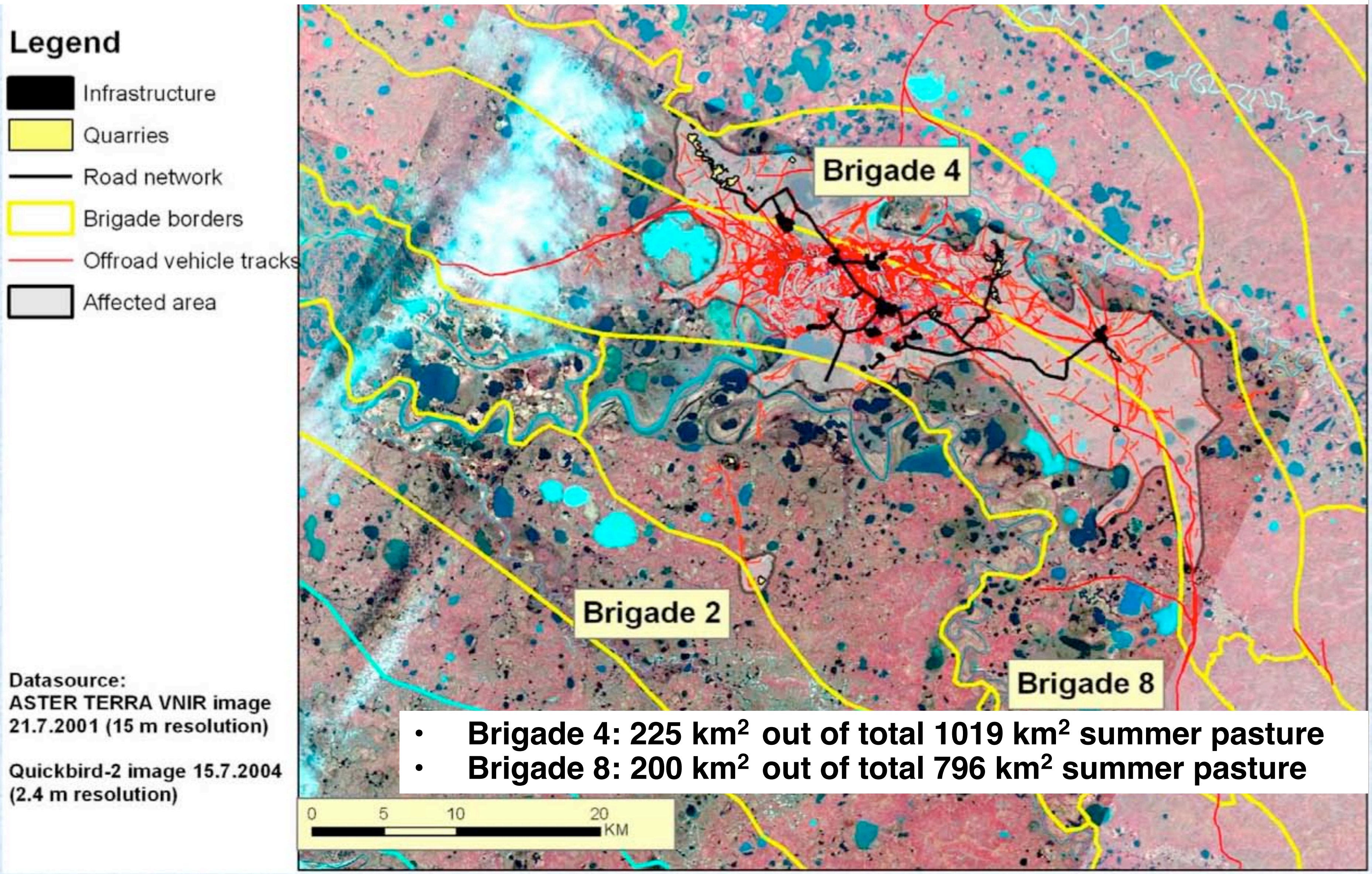
Photos: Bruce Forbes

The Nentsy use the entire Yamal Peninsula.

Photos: D.A. Walker


Bovanenkovo gas field
Yamalskii sovkhoz
Yarsalinskii sovkhoz
Brigade migration corridors VIII and IV
Panaevsk sovkhoz
Analysis of impacts of resource extraction to pasturelands

Impacts of Bovanenkovo gas field to summer pasture of Brigades 4 and 8



Datasource:
ASTER TERRA VNIR image 21.7.2001 (15 m resolution)

Quickbird-2 image 15.7.2004 (2.4 m resolution)

- **Brigade 4: 225 km^2 out of total 1019 km^2 summer pasture**
- **Brigade 8: 200 km^2 out of total 796 km^2 summer pasture**

Working with sociologists

Florian Stammler interviewing members of Nenets brigade. Combining remote sensing and traditional knowledge.

Photo: Bruce Forbes

Herders view:

- Land withdrawals by industry, increasing Nenets population, and larger reindeer herds are all increasing pressure on the rangelands.
- Threats from industrial development much greater than threats from climate change.
- They generally view the gas development positively because of increased economic opportunities.

Pavel Orekhov discussing parka technology with Nenets herder.

Photo: D.A. Walker

Analysis of biomass and NDVI trends across the climate gradient

Field data collected:

Soils

Plant Cover

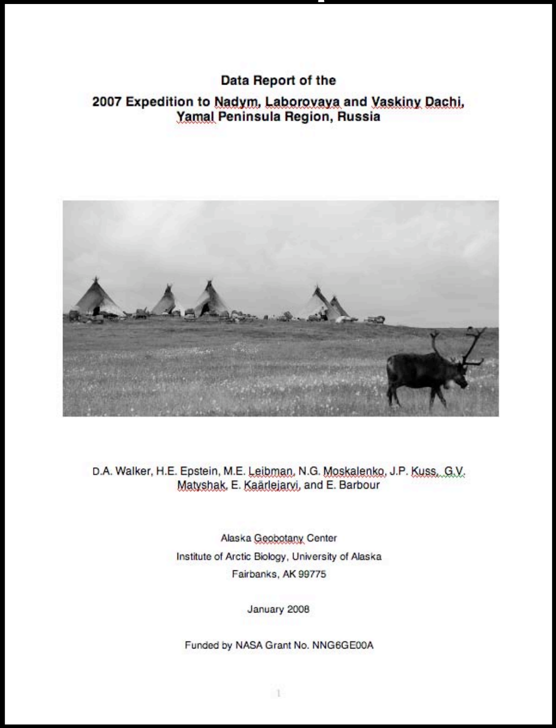
NDVI & LAI

Ground temperatures

Active layer

Plant Biomass

Data Report



Data Report of the
2007 Expedition to Nadym, Laborovaya and Vaskiny Dachi,
Yamal Peninsula Region, Russia

D.A. Walker, H.E. Epstein, M.E. Leibman, N.G. Moskalenko, J.P. Kuss, G.V. Matyshak, E. Kaärlejarvi, and E. Barbour

Alaska Geobotany Center
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Fairbanks, AK 99775

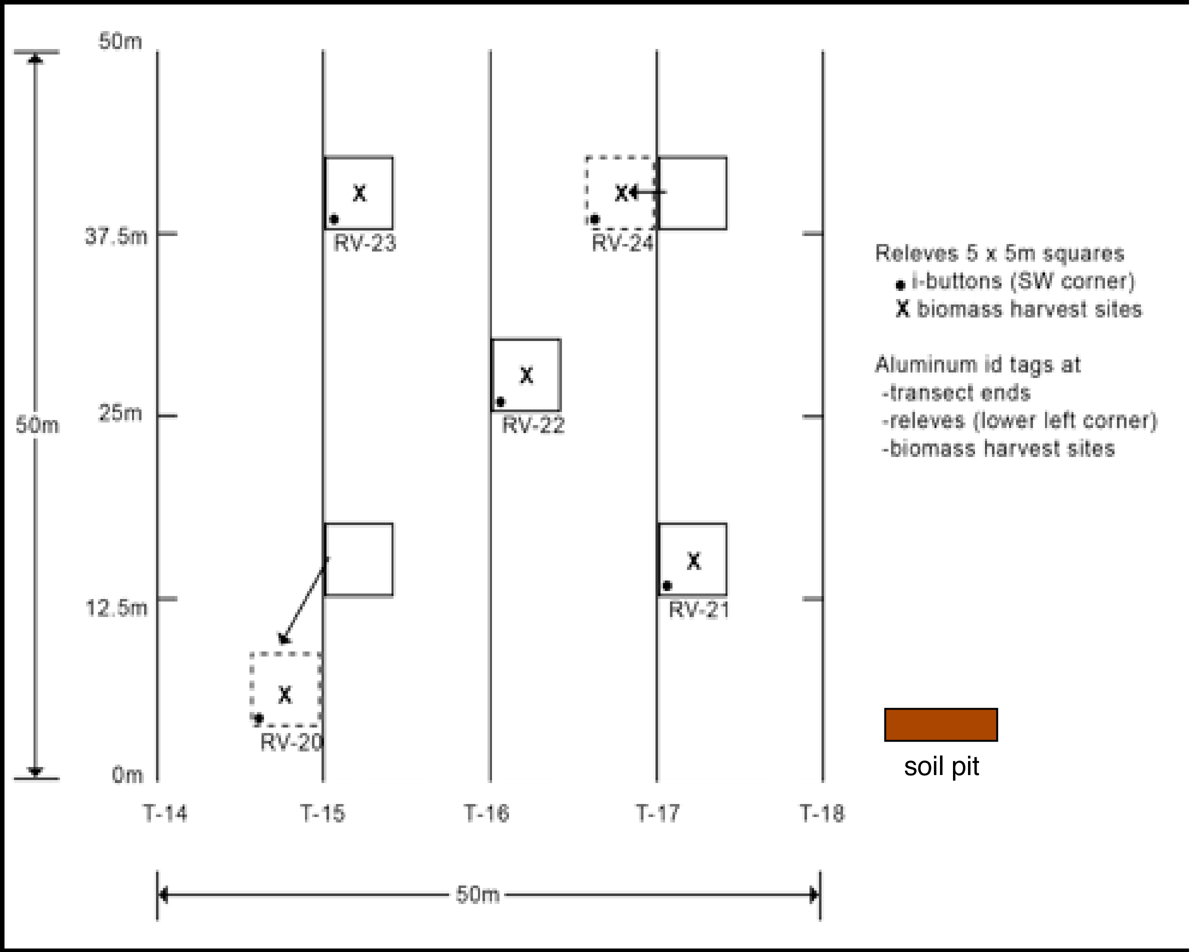
January 2008

Funded by NASA Grant No. NNG6GE00A

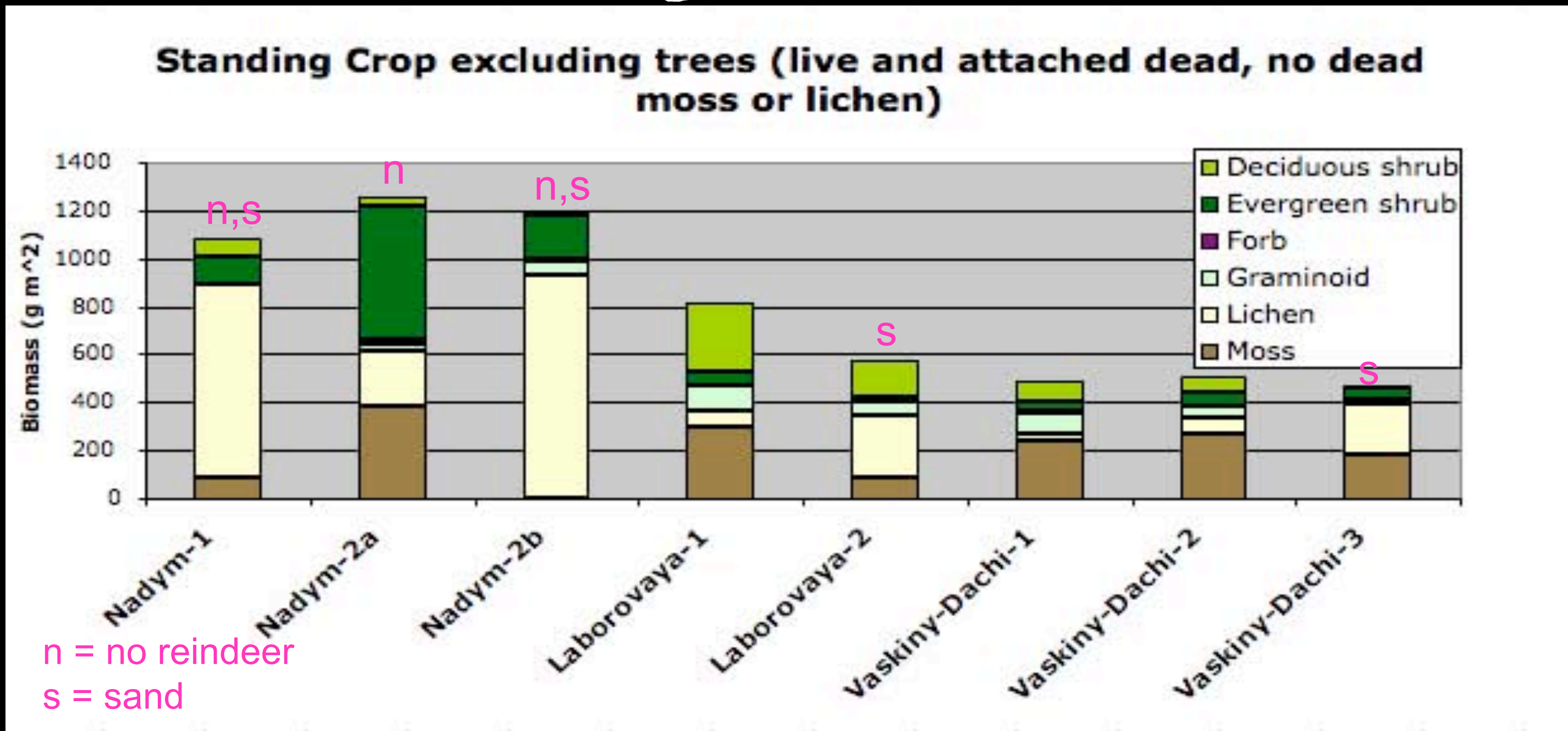
http://www.geobotany.uaf.edu/yamal/documents/yamal_2007_dr080211

Typical sampling strategy

- 5 50-m transects
- 5 5 x 5-m plots
- 1 x 3-m soil pit



Biomass along the Yamal transect

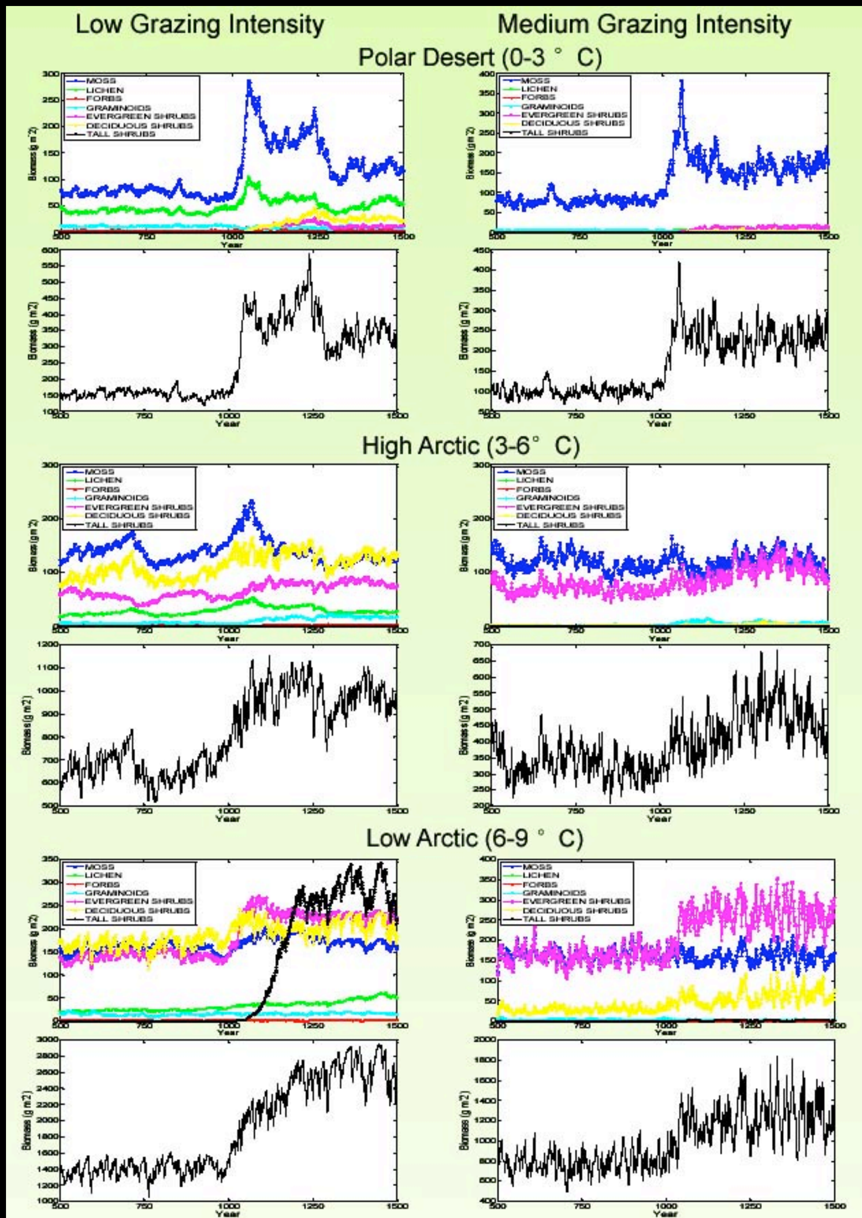


Climate trend:
2000–2300 g m^{-2} at Nadym to about 1000–1300 g m^{-2} at Vaskiny Dachi.

Effect of sandy soils:
- Sandy soils have 250–350 g m^{-2} less biomass than comparable clayey sites
- Much more lichen biomass and less mosses and graminoids.

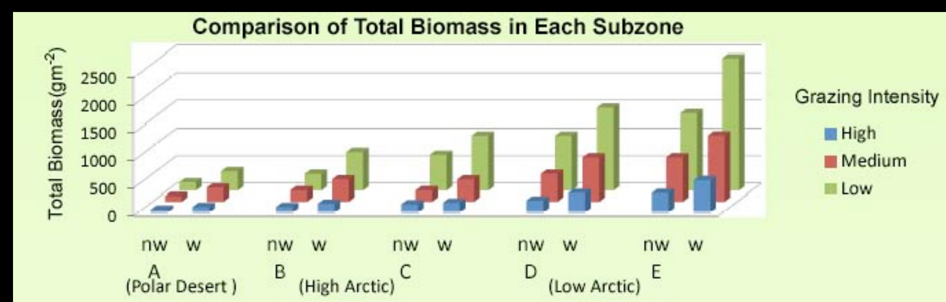
Effect of reindeer:
- Ungrazed sandy areas near Nadym – over 1000 g m^{-2}
- Less than 250 g m^{-2} in sandy areas where reindeer grazing has occurred annually.

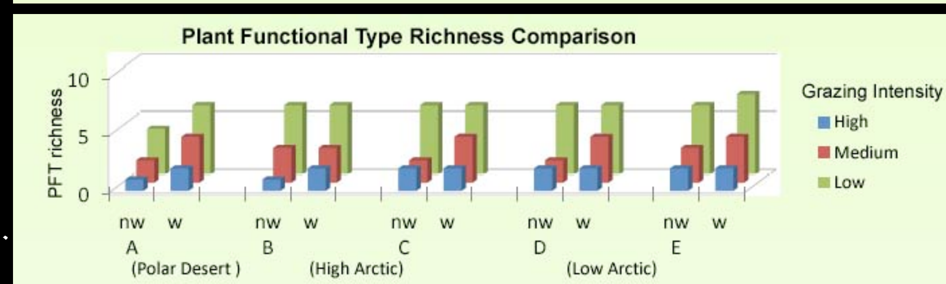
Epstein et al: NASALCLUC meeting 2008.



Modeled productivity of PFTs on the Yamal

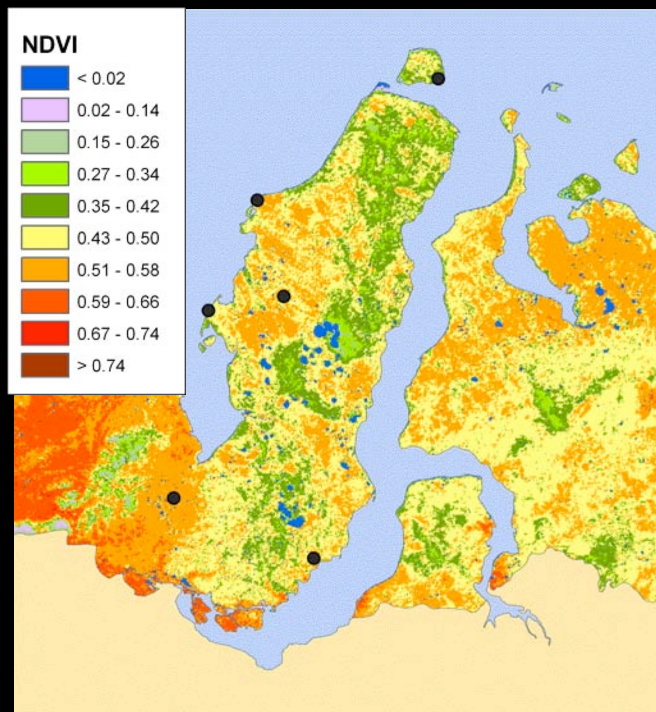
- ArcVeg model (Epstein et al. 2002)
- Examines succession of biomass for seven Arctic plant functional types.
- Five climate scenarios.
- Warming vs. non-warming treatments.
- Three grazing intensities.
- Next steps will incorporate soil type and disturbance regimes (dust and complete removal of vegetation), relate to NDVI and develop regional extrapolations.



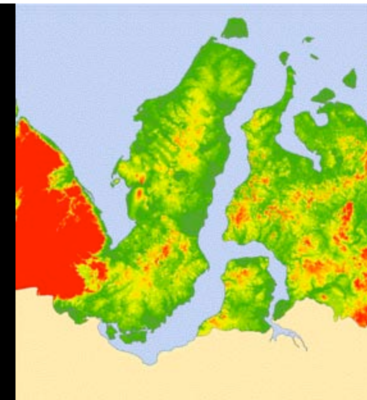


Yu and Epstein: 2008, NASA LCLUC conference.

Analysis of remotely sensed data and regional data in GIS databases



AVHRR-Derived NDVI of the Yamal Peninsula

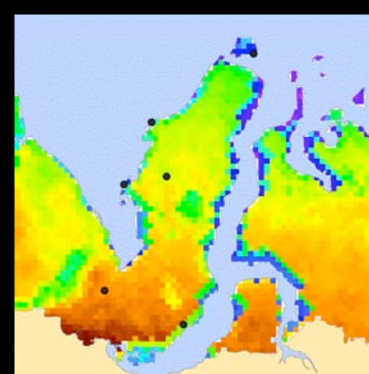


elevation

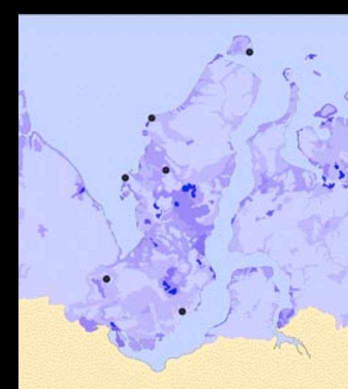
landschaft

lithology

veget-id

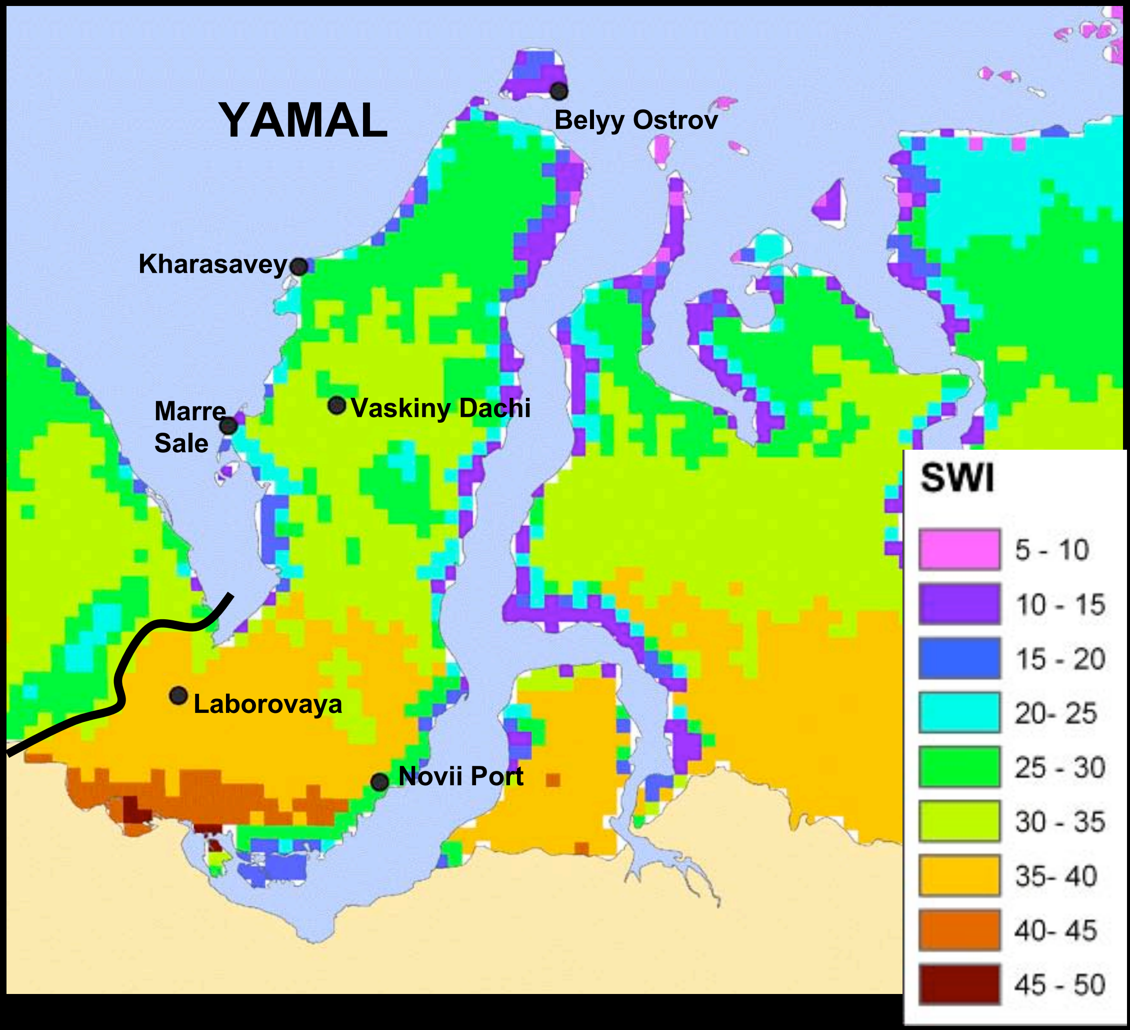


SWI



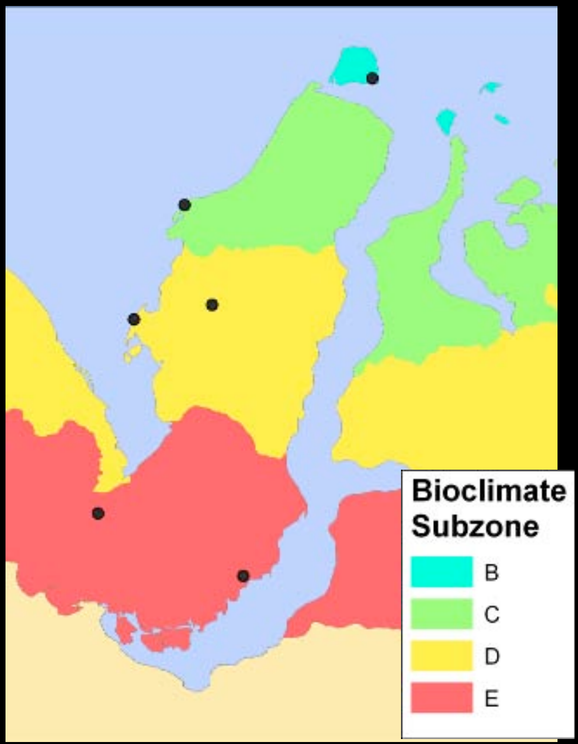
lake area

Martha Raynolds: Yamal LCLUC meeting, Moscow 28–31 Jan 2008.



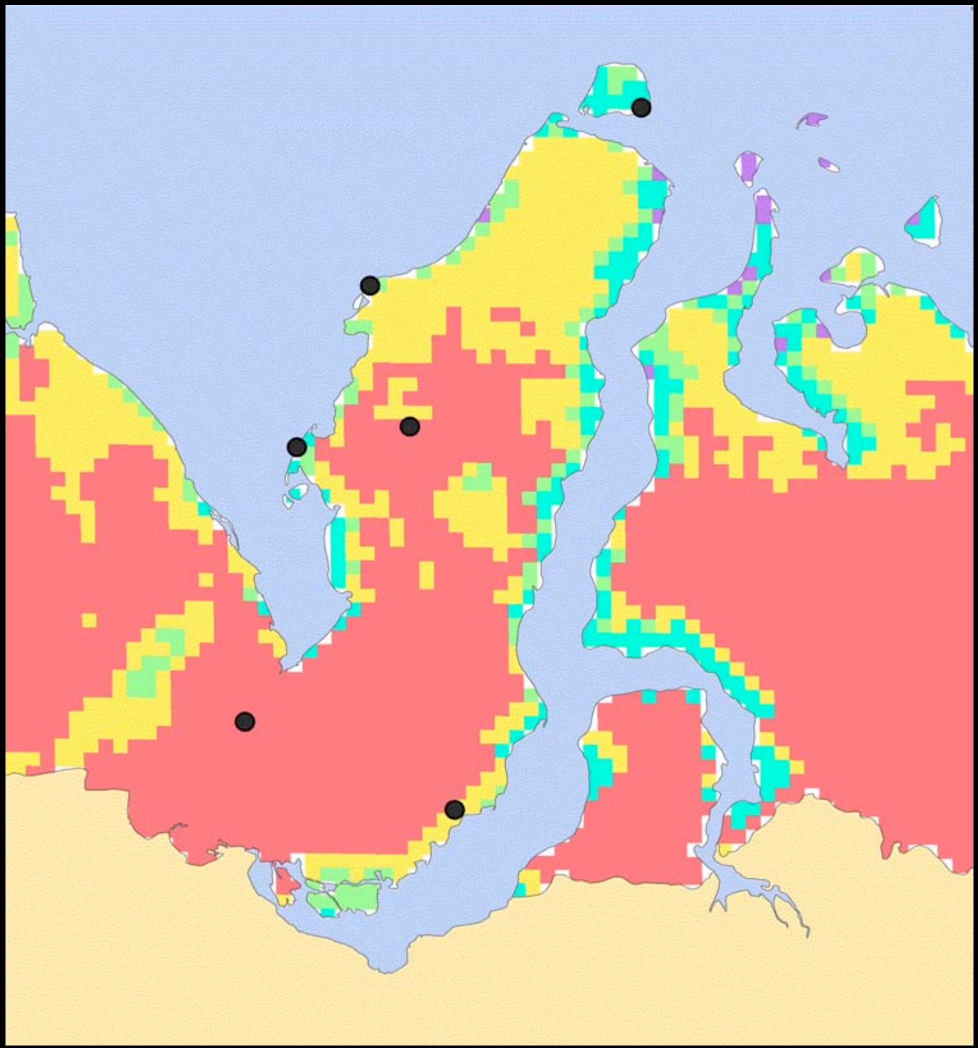
Summer warmth index (SWI) of Yamal Peninsula, based on satellite-derived land-surface temperatures (mean of 1982-2003, Comiso).

Reevaluation of circumpolar zonal boundaries using AVHRR LST data



Bioclimate subzones as mapped on the Circumpolar Arctic Vegetation Map

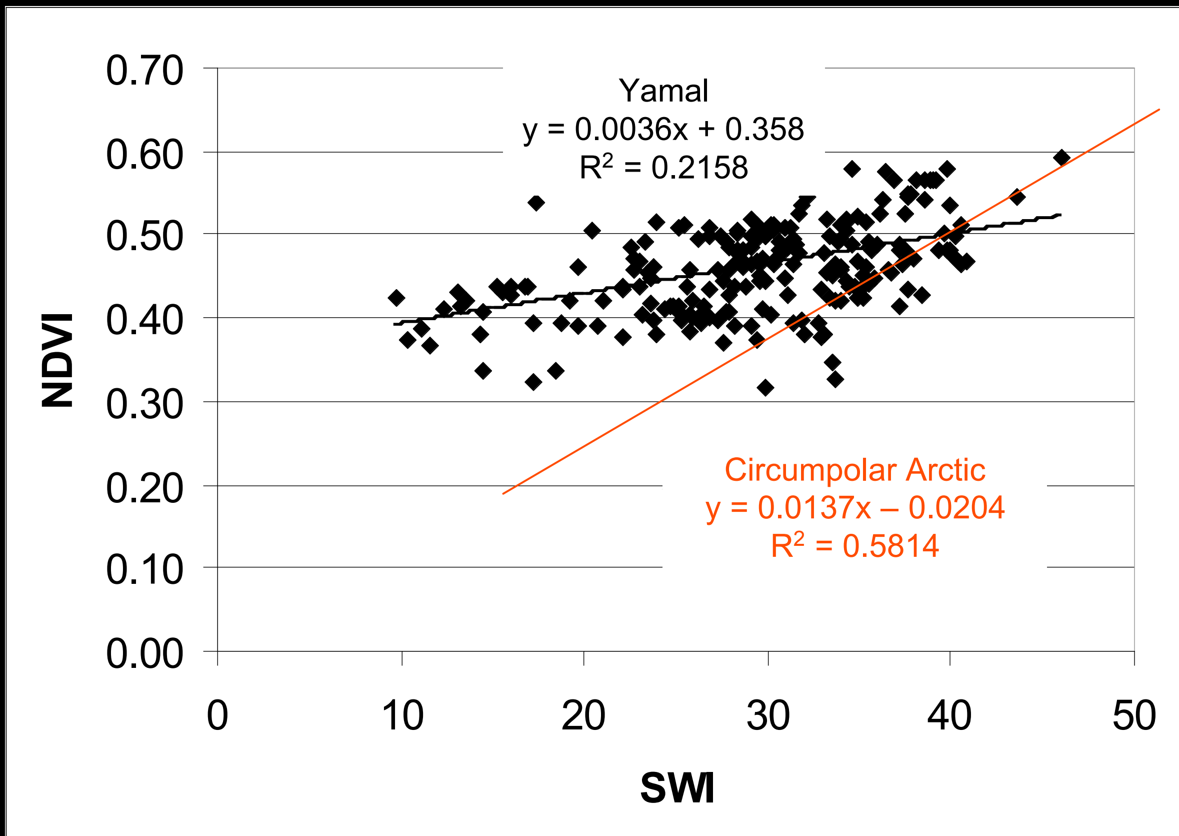
- Colder coastal strips
- Interior areas warmer
- Mountains colder



Bioclimate subzones as mapped by SWI

Martha Raynolds: Yamal LCLUC meeting, Moscow 28–31 Jan 2008.

NDVI vs. Summer Warmth on the Yamal compared to the Circumpolar Arctic

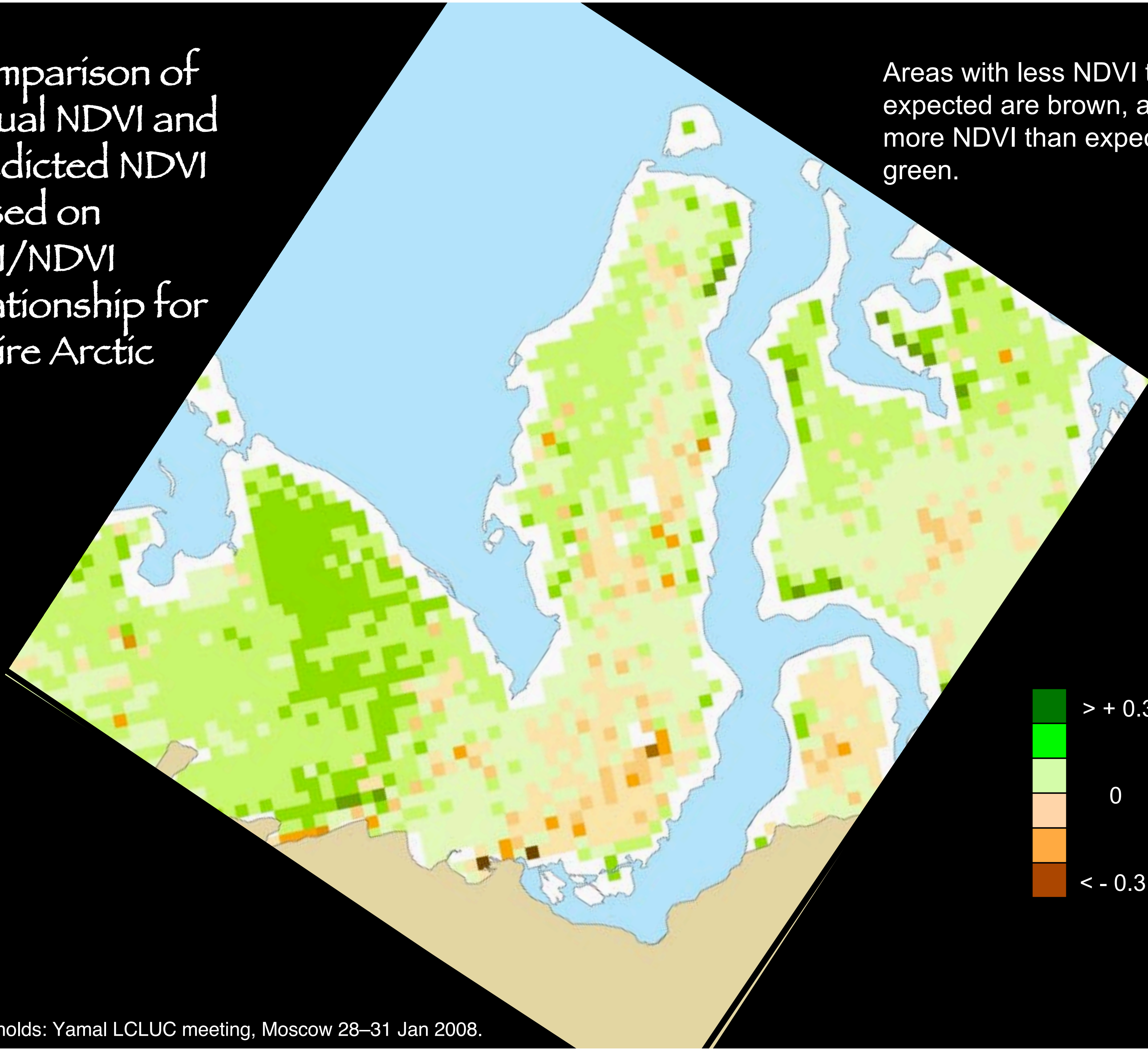


- Arctic as a whole has steeper increase of NDVI with SWI and much stronger correlations.
- Possibly due to a combination of factors:
  - High disturbance regimes and abundance of shrubs on landslides.
  - Effects of grazing.
  - Nutrient poor soils on uplands.
  - Increase in NDVI on better drained soils and higher elevations toward the south on the Yamal.

Martha Raynolds: Yamal LCLUC meeting, Moscow 28–31 Jan 2008.

Comparison of actual NDVI and predicted NDVI based on SWI/NDVI relationship for entire Arctic

Areas with less NDVI than expected are brown, areas with more NDVI than expected are green.



Martha Raynolds: Yamal LCLUC meeting, Moscow 28–31 Jan 2008.

Analysis of Circumpolar patterns of NDVI

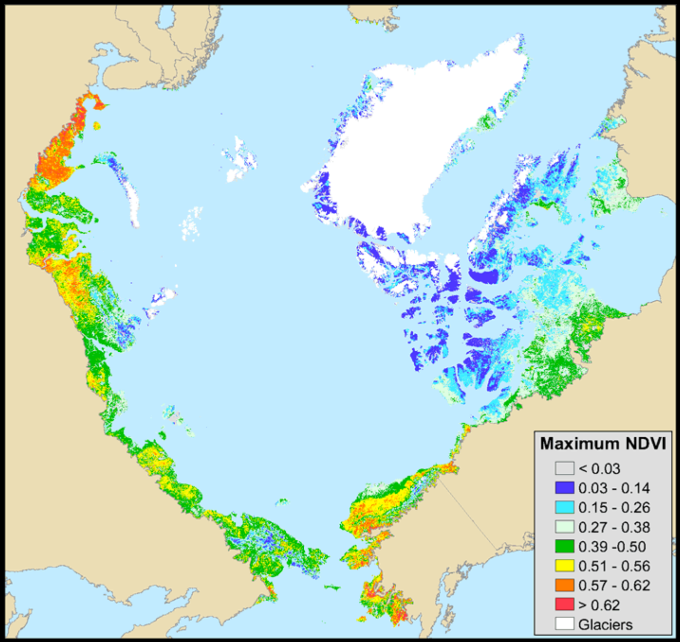
Martha Raynolds: Ph.D. Thesis

Raynolds, M.K., D. A. Walker and H. A. Maier. 2006. NDVI patterns and phytomass distribution in the circumpolar Arctic. Remote Sensing of Environment 102:271–28 .

Raynolds, M. K., J. C. Comiso, D. A. Walker, D. Verbyla. 2008. Relationship between satellite-derived land surface temperatures, arctic vegetation types, and NDVI. Remote Sensing of Environment 112:1884–1894.

Raynolds, M. K. and Walker, D. A. 2008. Relationship of permafrost characteristics, NDVI, and arctic vegetation types. Proceedings of the Ninth International Conference on Permafrost: 1469–1474.

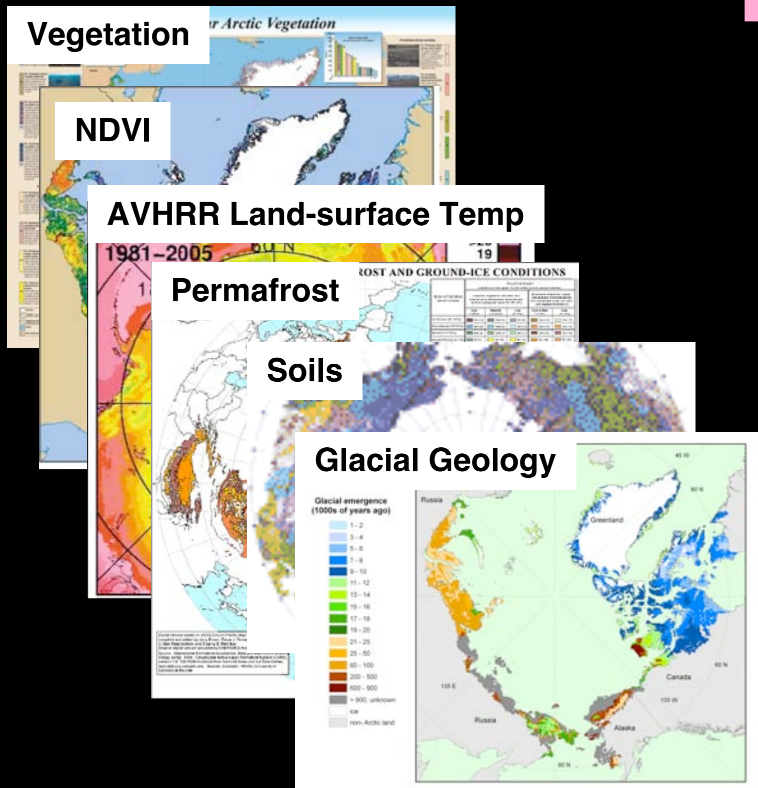
Raynolds, M. K. and Walker, D. A. 2008 (submitted): The effects of deglaciation on circumpolar distribution of arctic vegetation. Canadian Journal of Remote Sensing.



CAVM Team. 2003

Controls on Circumpolar NDVI patterns

Circumpolar Data Sets



Land-Surface Temperature → **Climate** ← **Precipitation**

Climate → **Vegetation** ← **Substrate**

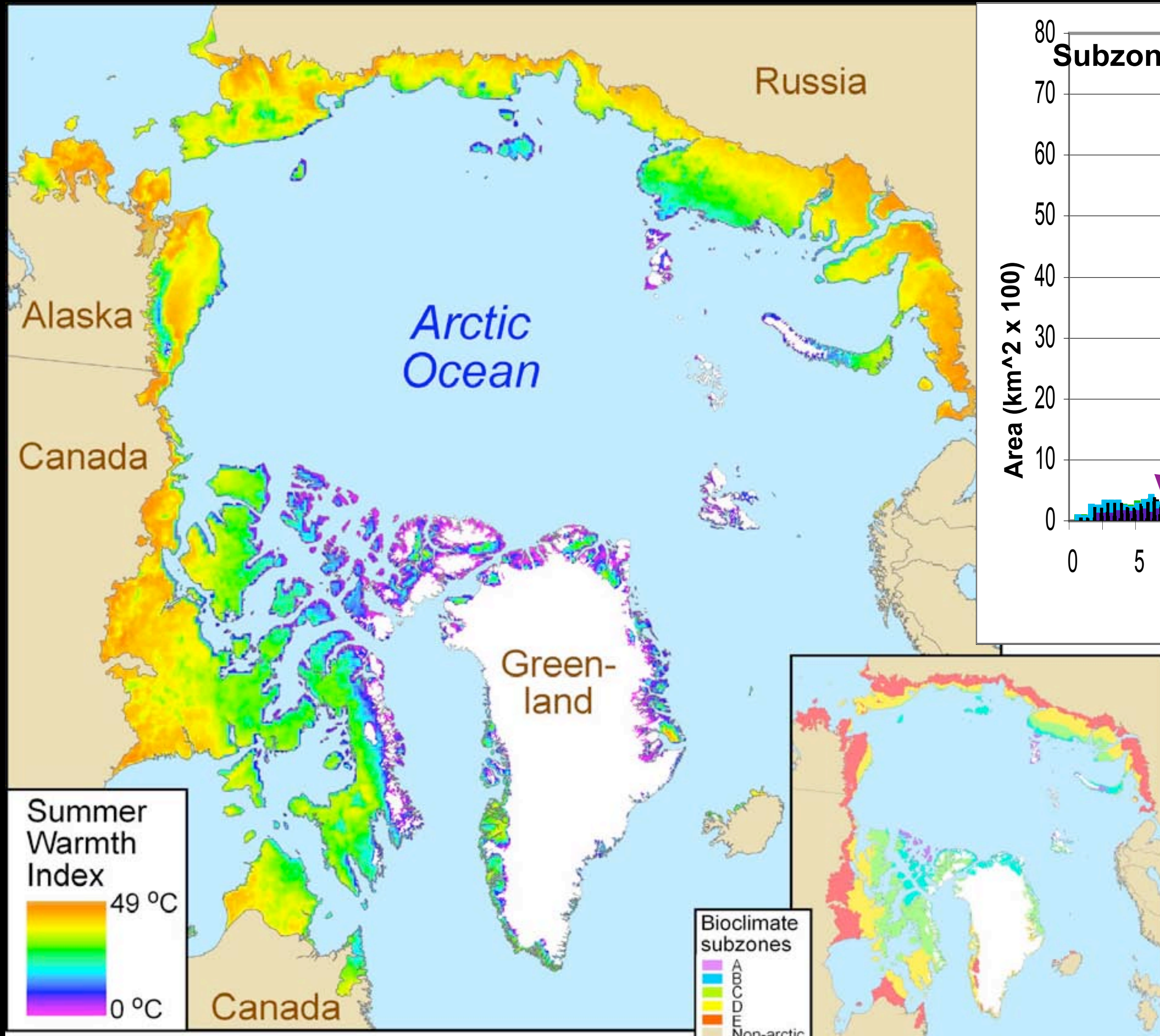
Permafrost, **Landscape age**, **Peatlands**, **Soil chemistry** → **Substrate**

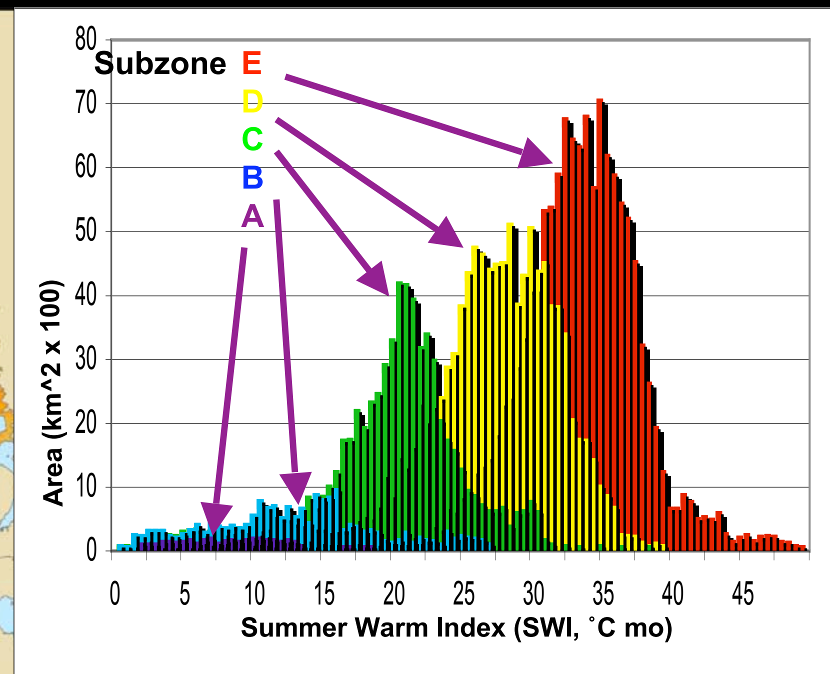
Primary controls at pan-Arctic scale:

- Summer temp
- Lake cover
- Glacial history
- Soil type

M.K. Raynolds, Ph.D. Thesis

Summer land-surface temperature as shown by the summer warmth index (SWI)

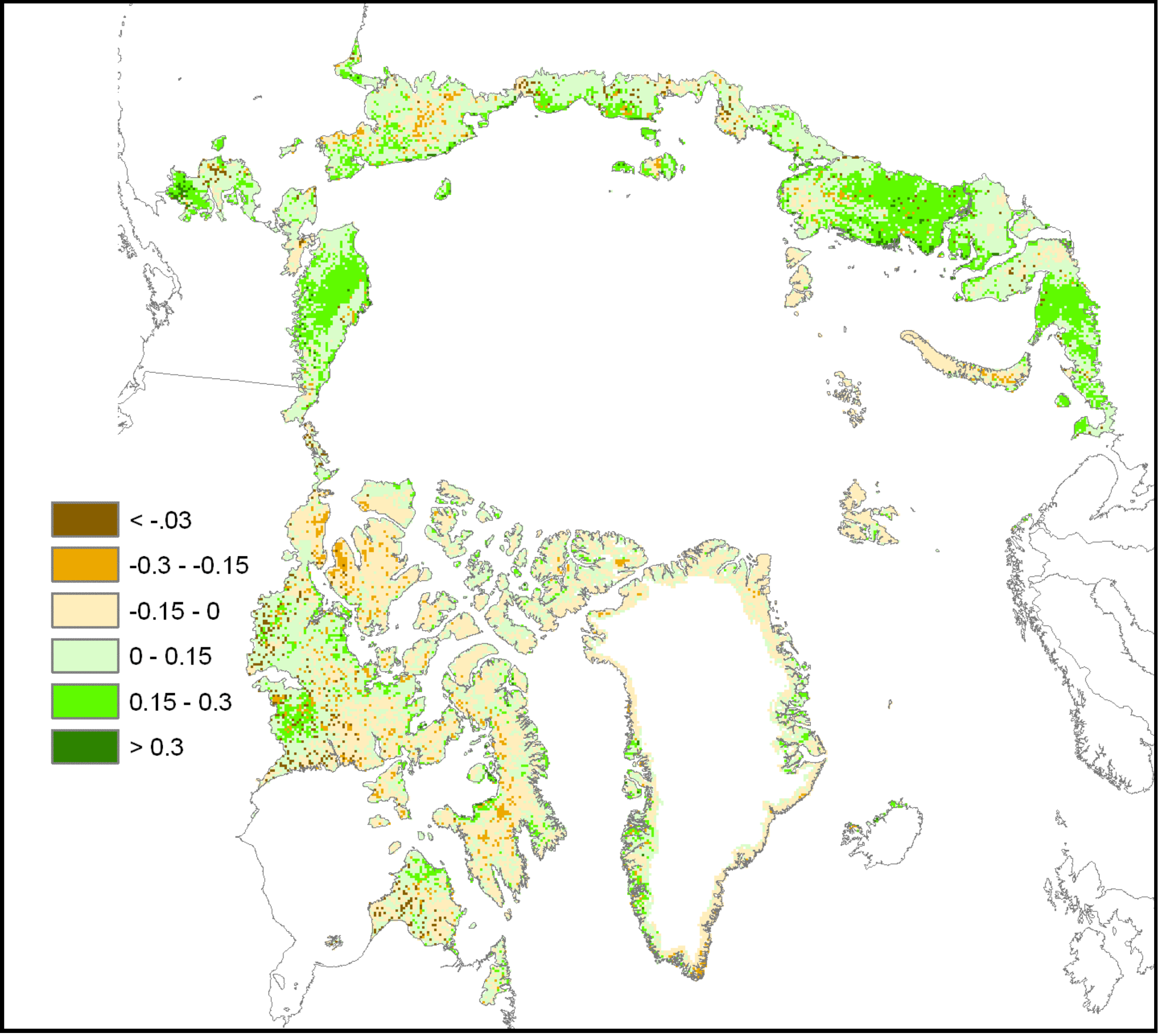




SWI derived from 20-yr mean AVHRR thermal data (Raynolds et al. 2008 *Rem. Sens. Envir.)*

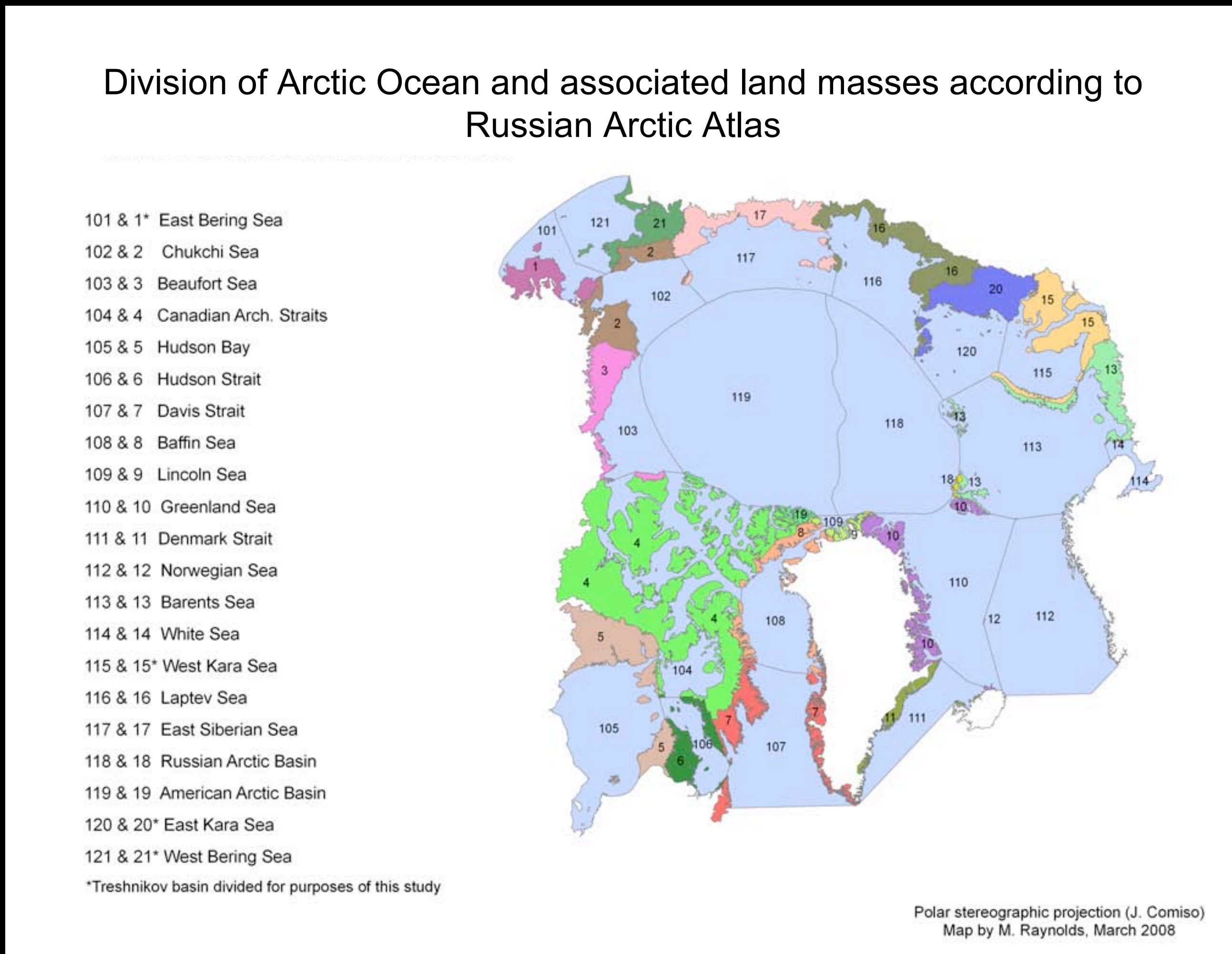
Expected NDVI value as calculated by SWI regression equation

Areas with less NDVI than expected are brown, areas with more NDVI than expected are green.



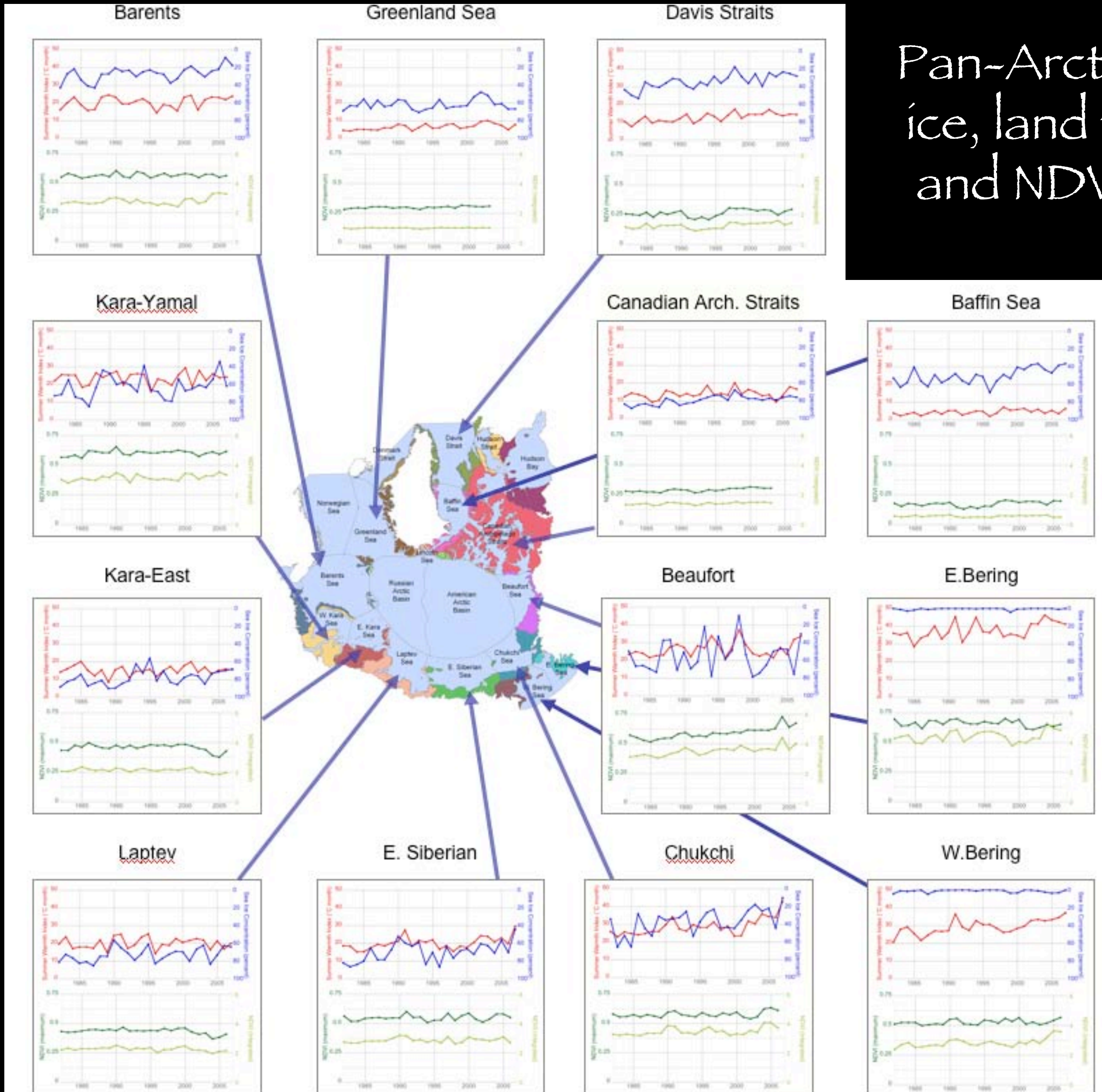
Analysis of sea-ice, land surface temperature and NDVI trends:

Uma Bhatt, D.A. Walker, M.K. Raynolds, J. Comiso



- Analysis of 50-km buffers seaward and landward along each sea coast and also for entire tundra area below 330 m.
- 1982–2007 AVHRR data to analyze trends in sea ice concentration, LST, and NDVI.

Pan-Arctic trends: Sea ice, land temperatures and NDVI, 1980-2007



- Mid July Sea Ice percentage cover
- Summer warmth index (SWI)
- Max NDVI
- Integrated NDVI

Bhatt et al: Yamal LCLUC Workshop, Moscow, 28–30 Jan 2008, and EGU 2008.

Focus on Kara/Yamal and Beaufort regions

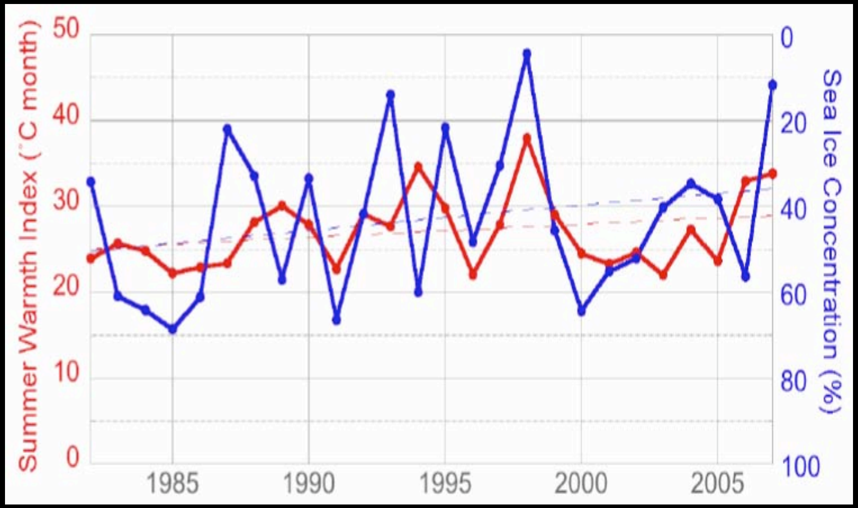
- Mid July Sea Ice percentage cover
- Summer warmth index (SWI)
- Max NDVI
- Integrated NDVI

Bhatt et al: Yamal LCLUC Workshop, Moscow, 28–30 Jan 2008, and EGU 2008.

Sea-ice and temperature trends in Beaufort Sea and Kara/Yamal region of Russia, 1982-2007

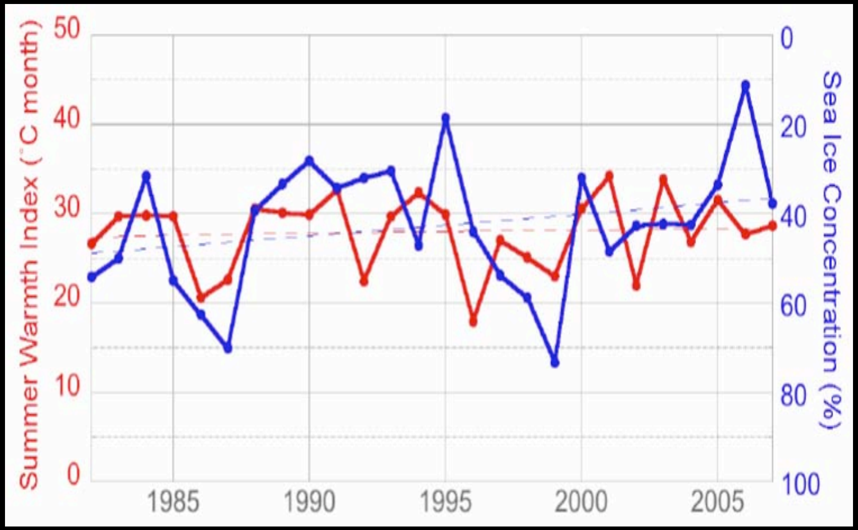
Beaufort

Negative sea-ice trend (-29%) correlated with positive temperature trend (+16%) and very high interannual variability.



Kara/Yamal

Negative sea-ice trend (-25%) but nearly flat temperature trend (+4%).

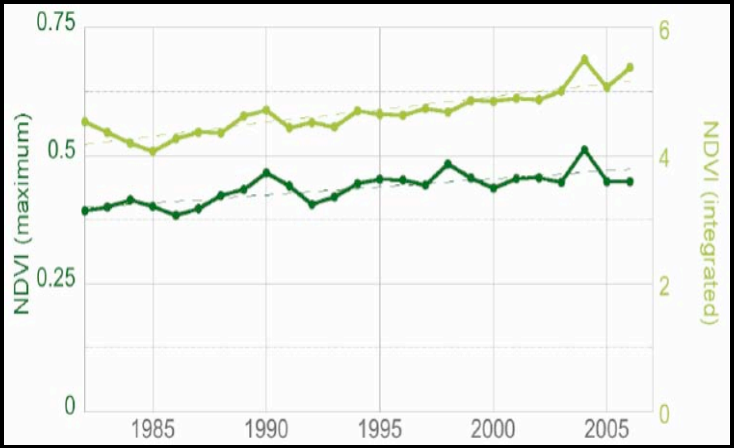


None of the trends are significant at $p = 0.05$ because of high interannual variability.

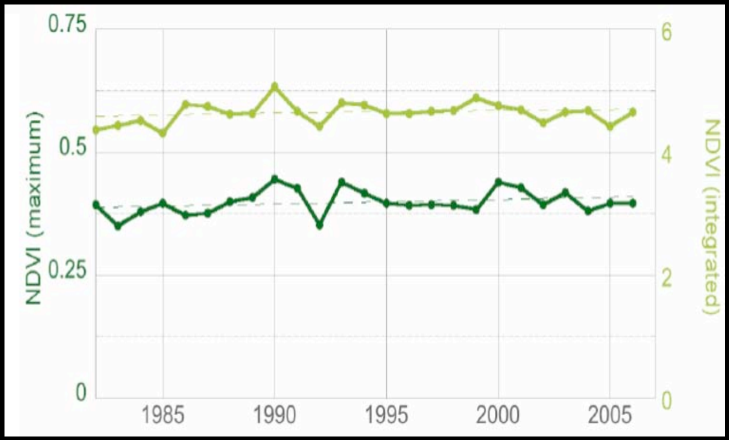
Bhatt et al.: NASA LCLUC Workshop, 2008.

NDVI trends in Beaufort Sea and Kara/Yamal region of Russia

Beaufort



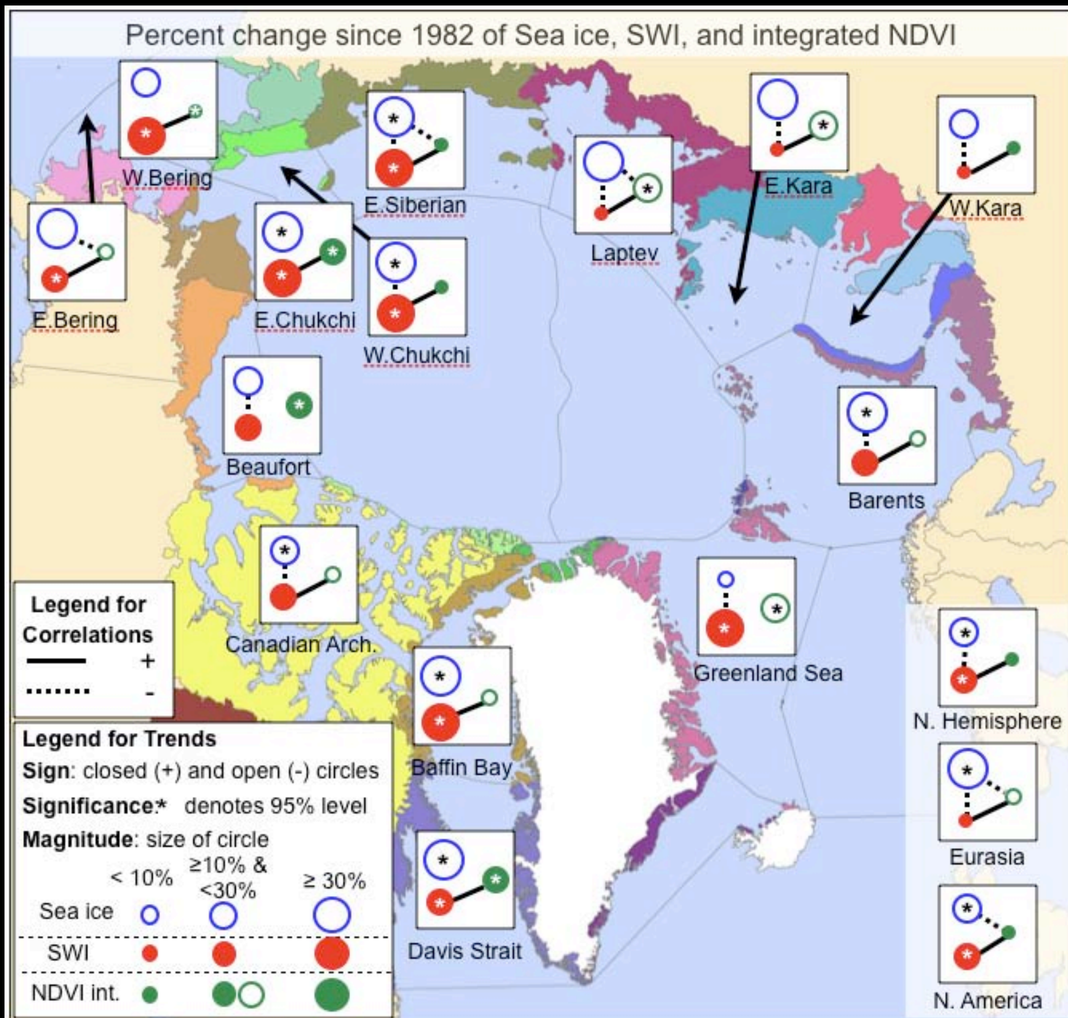
Kara/Yamal



- Greater change in Beaufort Region maximum NDVI (+ 24%) vs. Kara/Yamal (+ 3%) most likely due to more positive trend in ground surface temperatures in the Beaufort region during the period of record.
- Beaufort trends are significant at $p = 0.05$.

Bhatt et al. EGU, Vienna, Proceedings, 2008.

Summary of trends



Bhatt et al., in progress, 2008.

- Sea ice is strongly decreasing throughout the Arctic except the Greenland Sea. The strongest most significant trends are in the E. Siberian to E. Chukchi region.
- Summer warmth is increasing most strongly in the Beringian region between the E. Siberian Sea and the E. Chukchi and also in the Greenland Sea and Baffin Bay. Relatively small increases are seen between the W. Kara and Laptev seas.
- NDVI is increasing most strongly in the E. Chukchi and Beaufort regions, and also Davis Straight. Negative trends are occurring in several areas, most notable along the E. Kara Sea and Laptev Sea.

Correlations between trends

Region	Week of 50% ice conc.	Correlation, sea ice & SWI	Correlation, SWI & integrated NDVI	Correlation, sea ice & integrated NDVI
N. Hemisphere	23-29 July	**-0.42**	**0.45**	-0.25
N. America	30 July - 5 August	-0.27	**0.41**	**-0.40**
Eurasia	16-22 July	**-0.42**	**0.58**	**-0.46**
Beaufort	7-15 July	**-0.41**	*0.37*	-0.25
W. Kara	16-22 July	**-0.39**	**0.57**	-0.29

Blue: Negative correlations.
Red: Positive correlations.
Bold: Significant at p = 0.05.
Italics: Significant at p = 0.10.

- Year to year variation in summer land surface temperature (SWI) is generally strongly negatively correlated with mid-July ice cover within 50-km of the coast.
- Correlations weaken at greater distances from the ocean (not shown).
- Integrated NDVI is positively correlated with trend in summer land temperatures and negatively correlated with the trend in sea-ice.

Bhatt et al., in progress, 2008.

Correlations with climate indices

50-km zones with climate indices during preceding winter (DJFM)

Red values are positive correlations, blue are negative. **Bold** values are significant at 90% level or greater.

	SWI				Sea Ice				Integrated NDVI			
Climate index	NAO	AO	PDO	NPI	NAO	AO	PDO	NPI	NAO	AO	PDO	NPI
Barents	.38	**.3**	0	**.14**	**-0.2**	**-.3**	.42	**-.20**	.11	**.20**	**-.24**	**.23**
Kara-Yamal	**.27**	**.12**	0	**.14**	-.54	-.57	.48	-.34	0	**.14**	**-.29**	.40
Kara-East	**- .2**	-.40	**-.14**	**-.2**	0	0	0	0	0	**-.13**	0	**.16**
Laptev	**.33**	**.19**	**-.31**	**.15**	-.56	-.53	.43	**-.17**	0.60	.41	-.41	**.27**
E.Siberian	**.14**	**.33**	-.43	**.32**	**-.27**	-.56	.49	**-.26**	**0.19**	.45	-.63	.49
Chukchi	**-.1**	**.12**	**-.28**	.37	**.19**	**-.26**	**.20**	-.11	**-.17**	0	**-.26**	**.25**
W. Bering	0	0	**-.26**	**.13**	**-.11**	**-.24**	**.14**	0	0	0	**-.22**	0
E. Bering	0	0	**-.11**	**.22**	0	**-.25**	**.10**	0	0	0	0	**.15**
Beaufort	.48	.40	0	**.11**	0	0	**-.27**	**.16**	**-.12**	**.10**	**-.25**	**.22**
Canadian Arch	**.19**	**.13**	0	0	.14	0	0	0	0	**.14**	**-.16**	**.15**
Davis Straits	**-.2**	0	0	**.15**	.18	0	0	**-.11**	**-.31**	0	0	**.10**
Baffin Sea	0	0	**-.15**	**.16**	0	0	**.15**	**-.17**	0	0	0	**.24**
Grnland Sea	**-.1**	**.14**	**-.10**	**.19**	.43	**.26**	0	0	**.13**	0	0	0

Bhatt et al., in progress, 2008.

Correlations with climate indices

50-km zones with climate indices during preceding winter (DJFM)

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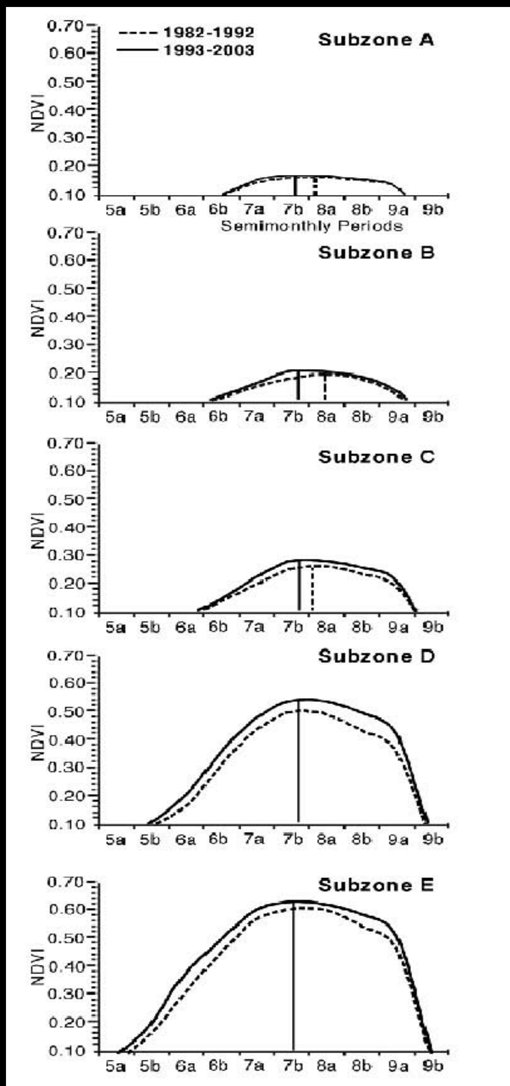
E. Bering	0	0	**-.11**	**.22**	0	**-.25**	**.10**	0	0	0	0	**.15**
Beaufort	.48	.40	0	**.11**	0	0	**-.27**	**.16**	**-.12**	**.10**	**-.25**	**.22**
Canadian Arch	**.19**	**.13**	0	0	.14	0	0	0	0	**.14**	**-.16**	**.15**
Davis Straits	**-.2**	0	0	**.15**	.18	0	0	**-.11**	**-.31**	0	0	**.10**
Baffin Sea	0	0	**-.15**	**.16**	0	0	**.15**	**-.17**	0	0	0	**.24**
Grnland Sea	**-.1**	**.14**	**-.10**	**.19**	.43	**.26**	0	0	**.13**	0	0	0

- Sea ice is generally negatively correlated with the Arctic Oscillation and positively correlated with the Pacific Decadal Oscillation.
- SWI and NDVI are generally positively correlated with the AO and negatively correlated with the PDO.
- Correlations require more thought in terms of mechanisms. Analysis of wind correlations with NDVI and SWI are in progress.

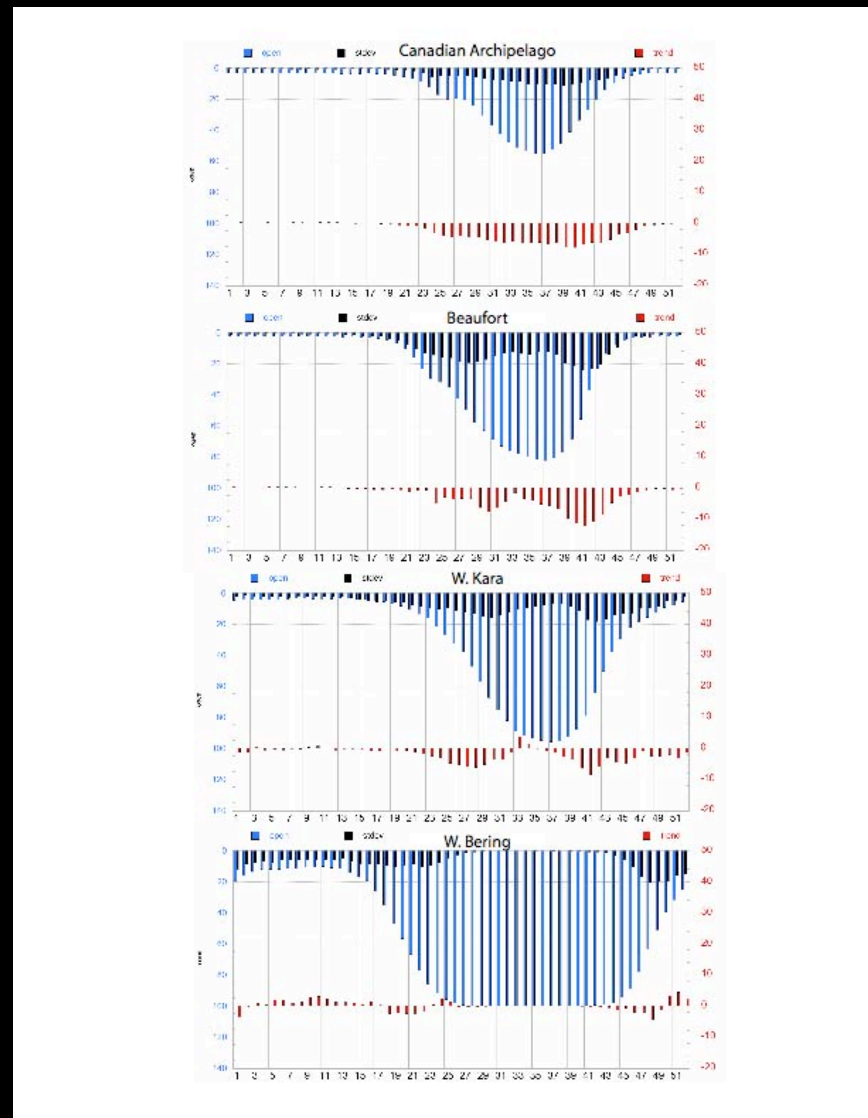
Seasonality trends

NDVI



Jia et al. in press, *JGR-Biogeosciences*

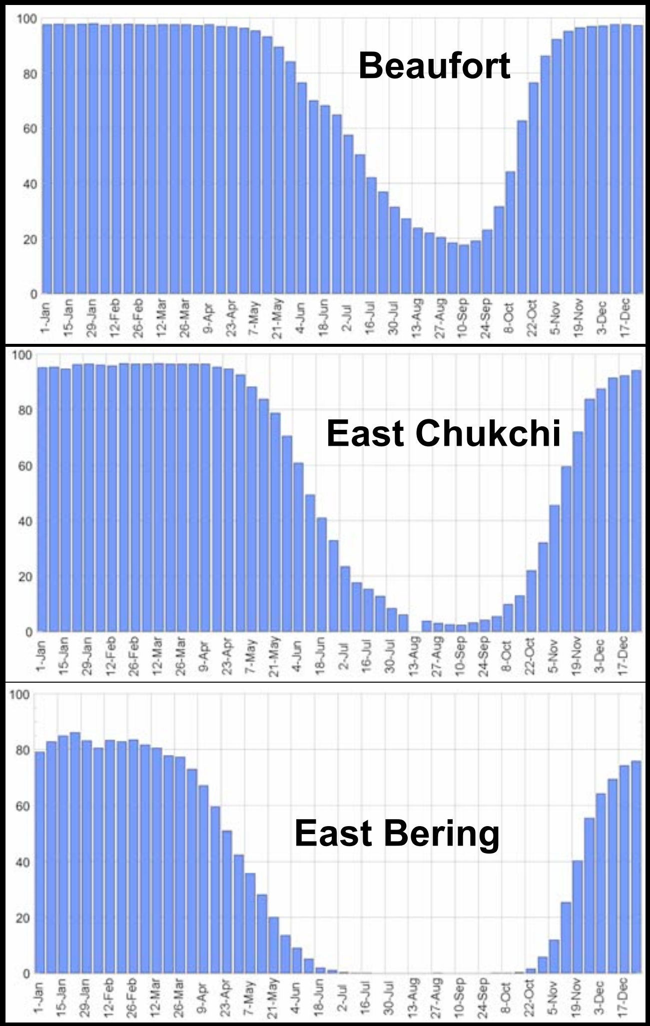
Sea-ice concentration



Bhatt et al. in prep., *Earth Interactions*

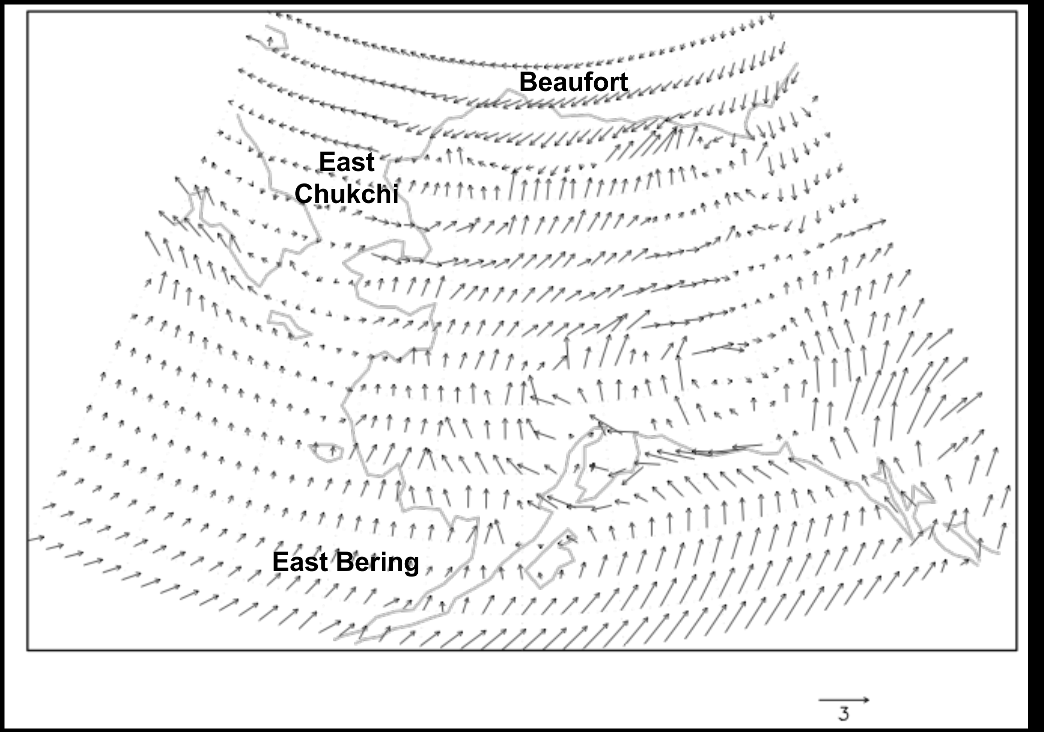
Controls on seasonality

Biweekly sea-ice concentration in Arctic Alaska Seas



Weekly climatological sea ice based on the 1982-2007 period for the 50-km coastal ocean domain.

Jun-Aug Wind patterns



NARR long term climatological 10-m vector winds (1979-2000) averaged for June-August in m s^{-1}. Data for image provided by the NOAA-ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.cdc.noaa.gov.

Future analyses will examine the controls of sea-ice, winds, snow, atmospheric circulation and ocean circulation on seasonal patterns of NDVI. Proposed to NSF by Epstein, Bhatt, Walker, and Steele.

Bhatt et al. in prep., *Atmospheric Research*

Some problems with existing arctic biomass data in the literature

- Although trends in NDVI are clear, there are still no convincing ground-based studies of changes in Arctic plant biomass.
- Real vegetation type is often unknown.
- Soil and site factor information missing.
- Harvest methods not documented.
- Not georeferenced.
- Replication not documented.
- Not linked to NDVI, LAI, or other cover properties of the vegetation.
- Definitions of biomass components unclear.

"What is above-ground biomass?"

“What does NDVI really mean in tundra systems… particularly for reindeer and caribou?”

Some areas with low NDVI have high forage quality for reindeer.

Lichen-woodland at Nadym

Bright green areas may be dominated by species such as alder or dwarf-birch, which have abundant toxic secondary plant compounds that protect them from grazing.

Shrub tundra at Laborovaya

Photos: D.A. Walker

Cumulative effects on the Yamal

Resource development:

- Indirect (unplanned) impacts (such as ORV trails, flooding from roads) are greater than the direct (planned) impacts (infrastructure).
- Roads and pipelines: serious barriers to migration corridors.
- Effects will increase as new field are developed.

Landscape factors and terrain sensitivity:

- High potential for extensive landscape effects due to unstable sandy soils, and extremely ice-rich permafrost near the surface.

Reindeer herding:

- Land withdrawals by industry, increasing Nenets population, and larger reindeer herds are all increasing pressure on the rangelands.
- Herders view: Threats from industrial development much greater than threats from climate change.
- They generally view the gas development positively because of increased economic opportunities.

Climate change:

- Satellite data suggest that there has been only modest summer land-surface warming and only slight greening changes across the Yamal during the past 24 years. (Trend is much stronger in other parts of the Arctic, e.g. Beaufort Sea.)
- Kara-Yamal: negative sea ice, positive summer warmth and positive NDVI are correlated with positive phases of the North Atlantic Oscillation and Arctic Oscillation.

Circumpolar Summary

- **Temperature – sea ice linkages:** Strong linkages have been demonstrated between reduced sea-ice concentrations and increased land-surface temperatures.
- **NDVI trends:** Large regional differences in the NDVI trends:
  - Strongly positive trend in the northern Beringia region of E. Siberia, Chukchi, and Beaufort seas. This is the region with the strongest recent reductions in sea-ice concentrations.
  - Slight negative trend in northern Eurasia (E. Kara, Laptev seas).
- **NDVI controls:** Ground-based and remote-sensing studies along climate transects in North America and Yamal have very different spatial patterns of NDVI and factors affecting the NDVI in each region:
  - **North America**: age of glacial surfaces, differences in substrates (acidic vs. nonacidic soils), strong temperature controls.
  - **Yamal**: Large effect of natural disturbance, sandy vs. clayey substrates, heavily grazed systems (but still unknown what the actual effect of reindeer on NDVI is), weaker temperature control.
- **Climate drivers:** Throughout the Arctic including the Beaufort and Yamal, the general trend is positive summer warmth and NDVI with positive phases of the North Atlantic Oscillation and Arctic Oscillation, and negative correlations with positive phases of the Pacific Decadal Oscillation. The positive phase of NAO and AO is consistent with a warmer winter Arctic, reduced summer sea ice (-), increased SWI (+) and increased integrated NDVI (+).
- **Replicated long-term studies:** Needed across the Arctic and coordinated with other terrestrial monitoring of climate, permafrost, active layers, ITEX etc. — especially in areas currently surrounded by perennial sea ice and other areas where the changes are occurring most rapidly (e.g. Beringia region).
- **Standardized protocols:** Need standardized protocols for biomass and vegetation monitoring at a network of sites for a coordinated Circumpolar Terrestrial Ecosystem Baseline.