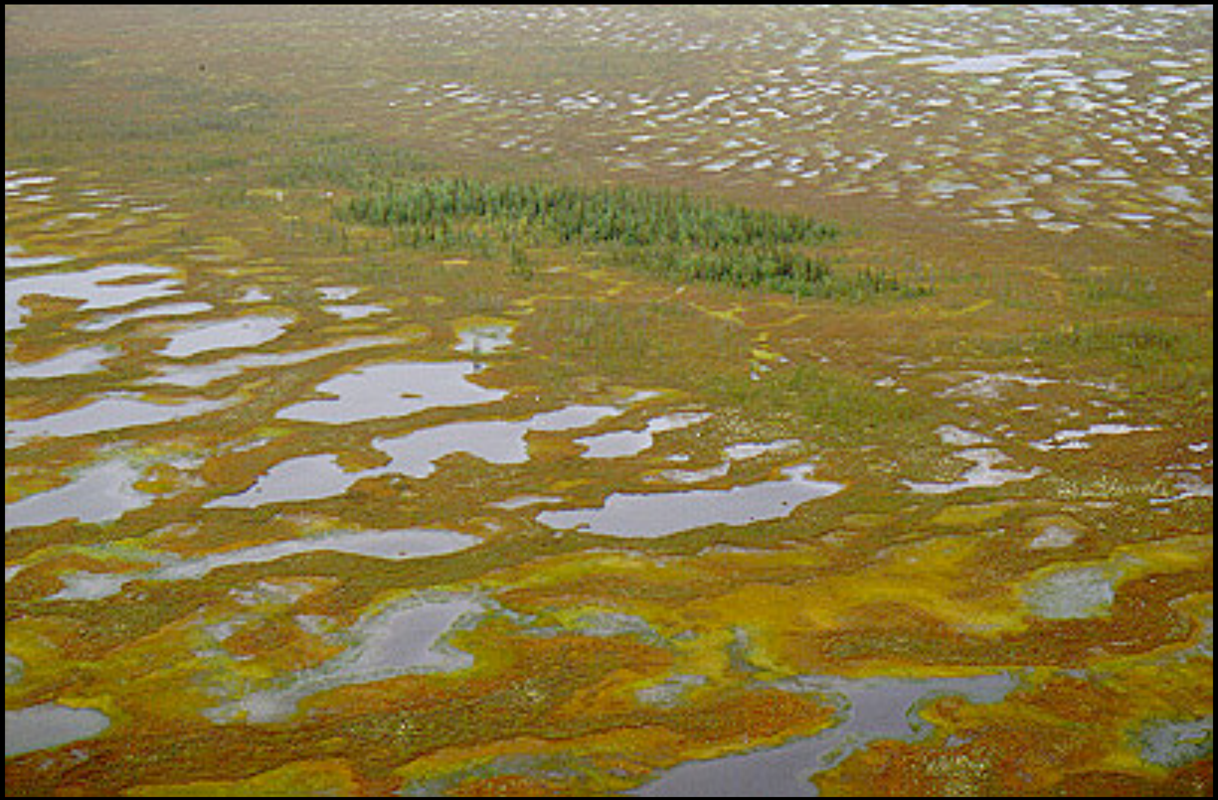
Greening of the Arctic: Climate change and circumpolar Arctic vegetation



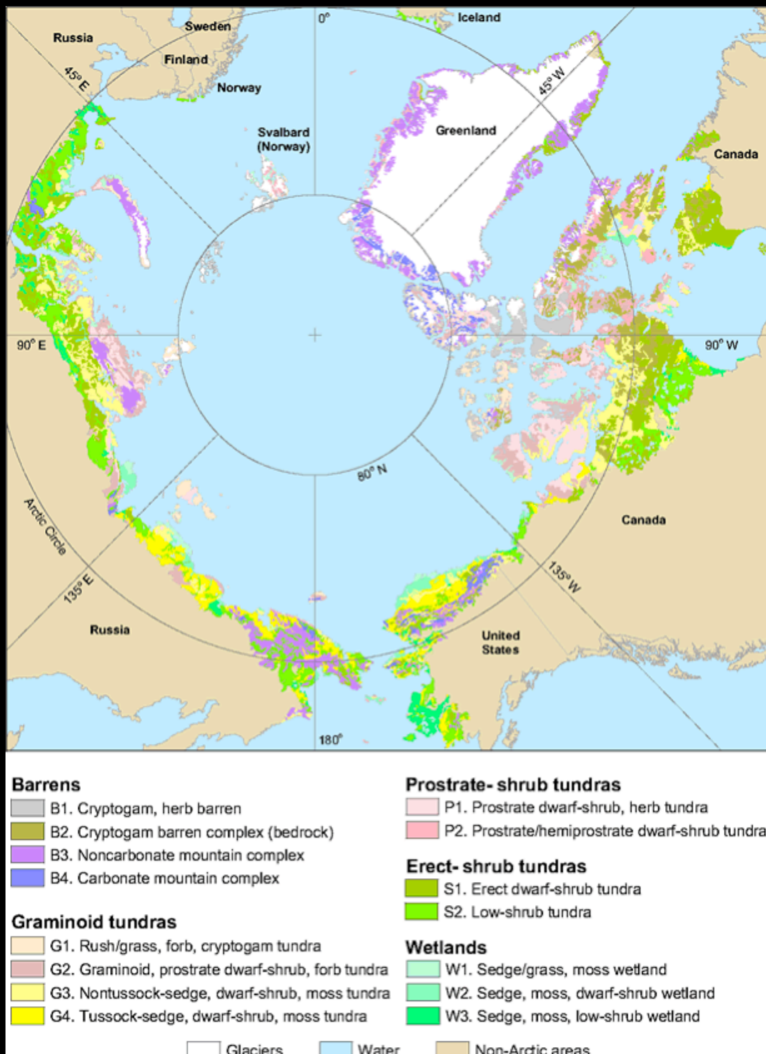
D.A. Walker, University of Alaska Fairbanks

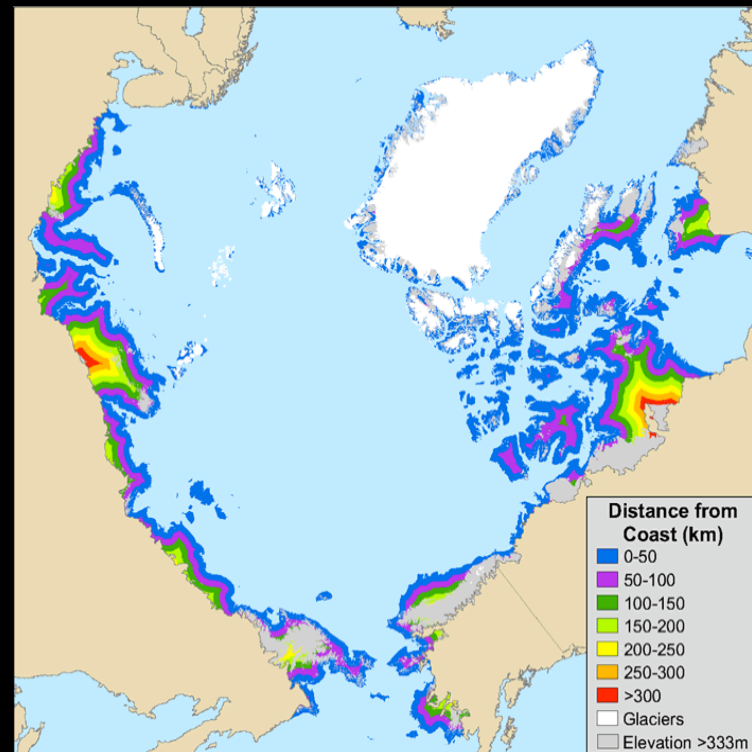
Fulbright Lecture

Ceske Budejovice, 27 April 2011

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

The Arctic tundra is a maritime biome



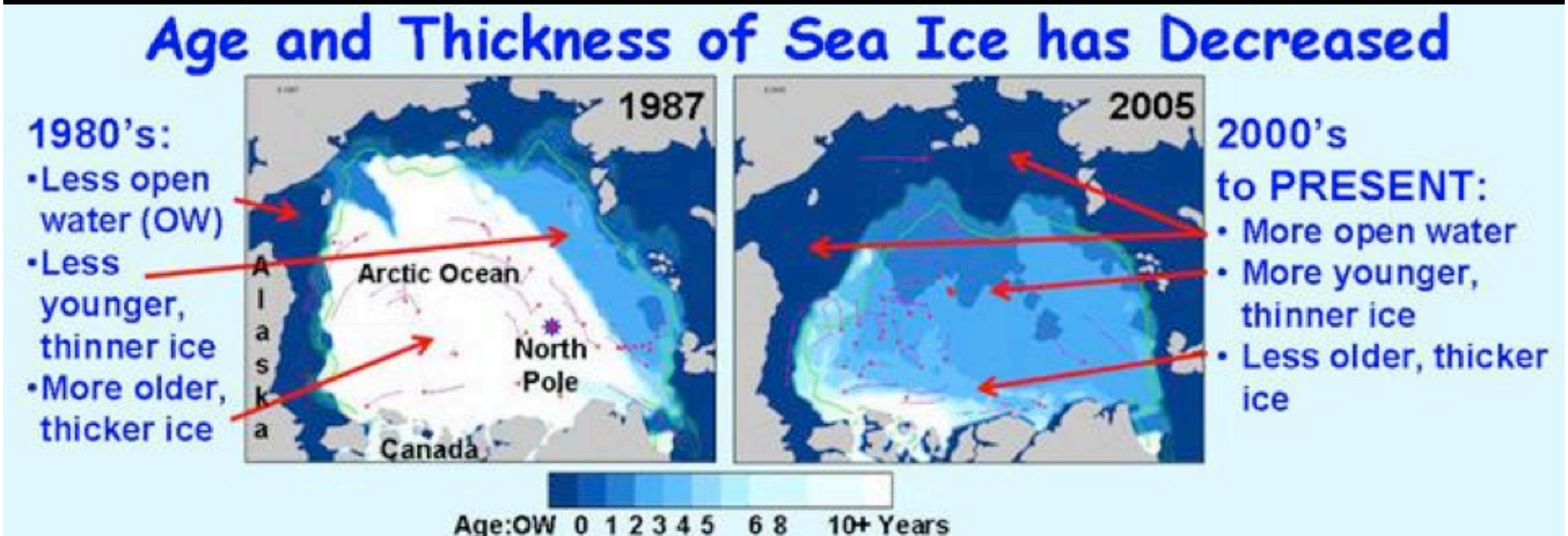


Map by Hilmar Maier.

- 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).

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

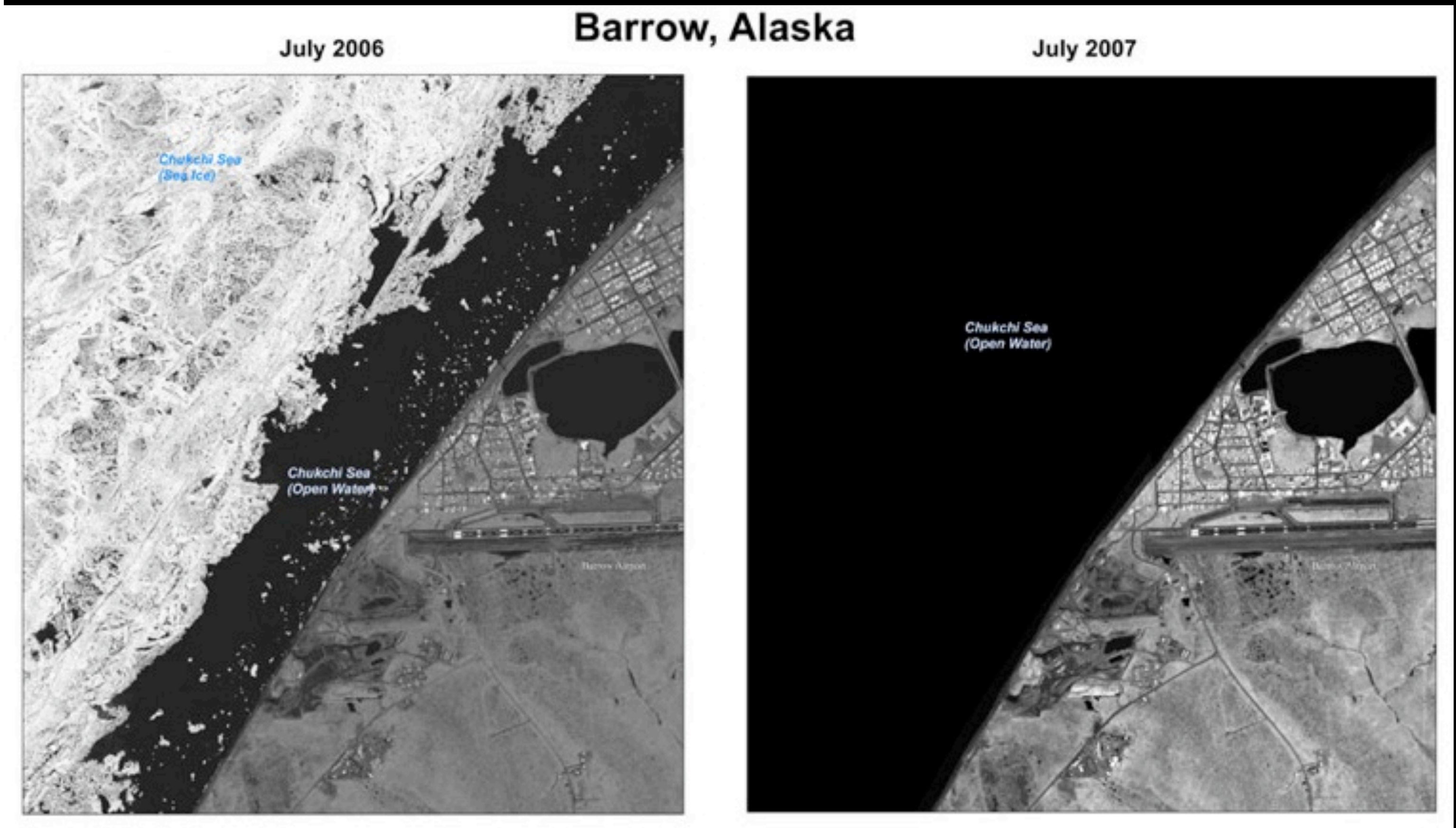
Change in multi-year sea ice

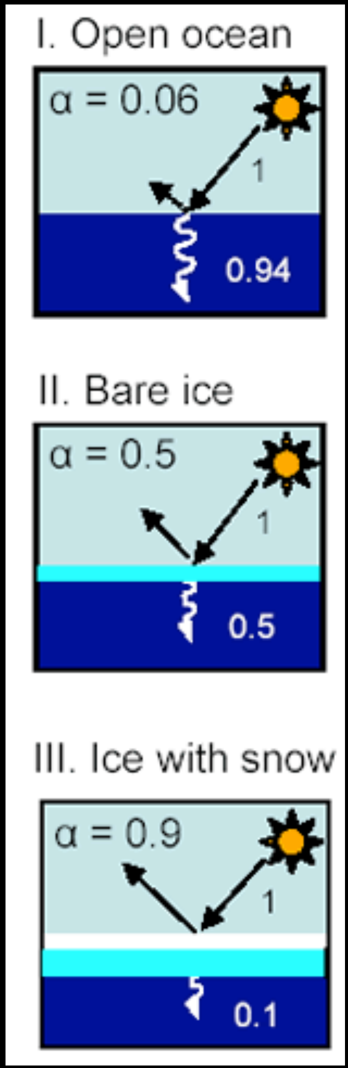


- **It is conceivable that the Arctic ocean could be ice free during September by as early as 2030.**

Rigor and Wallace 2004, updated to 2009

Albedo effects of ice

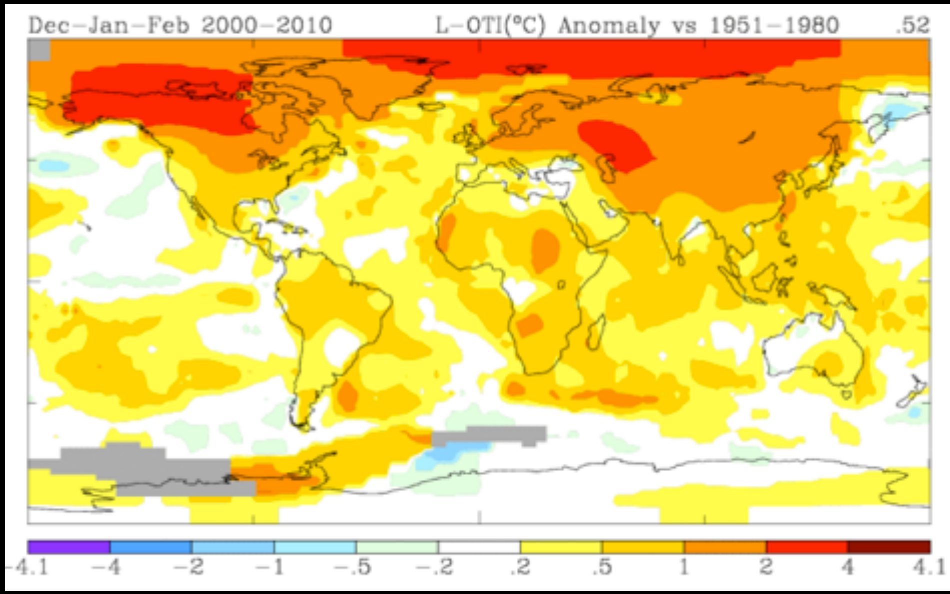




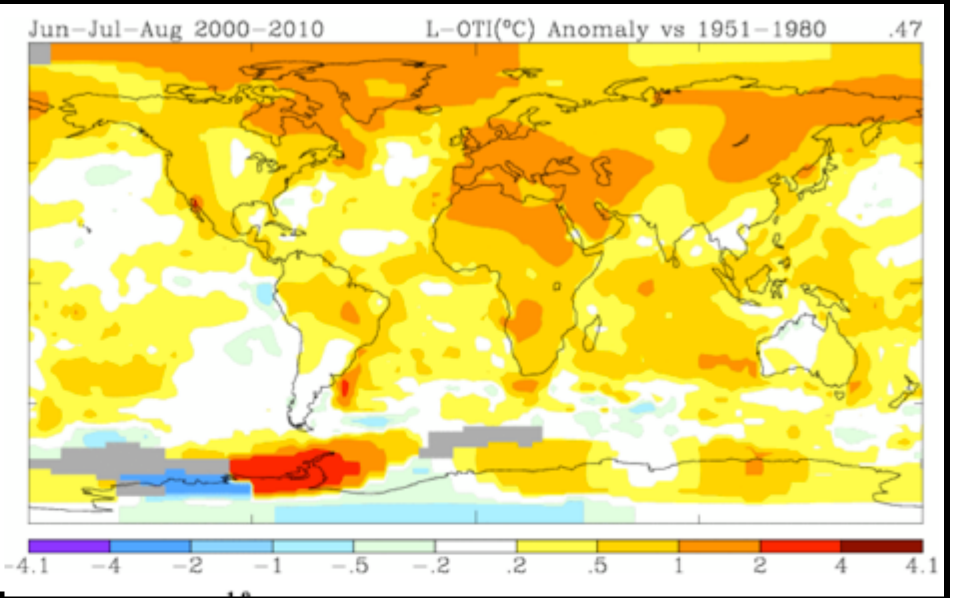
Courtesy of NSIDC: http://nsidc.org/seaice/processes/albedo.html

Trend in surface temperatures

Dec-Feb Anomalies (2000-2010)



Jun-Aug Anomalies (2000-2010)

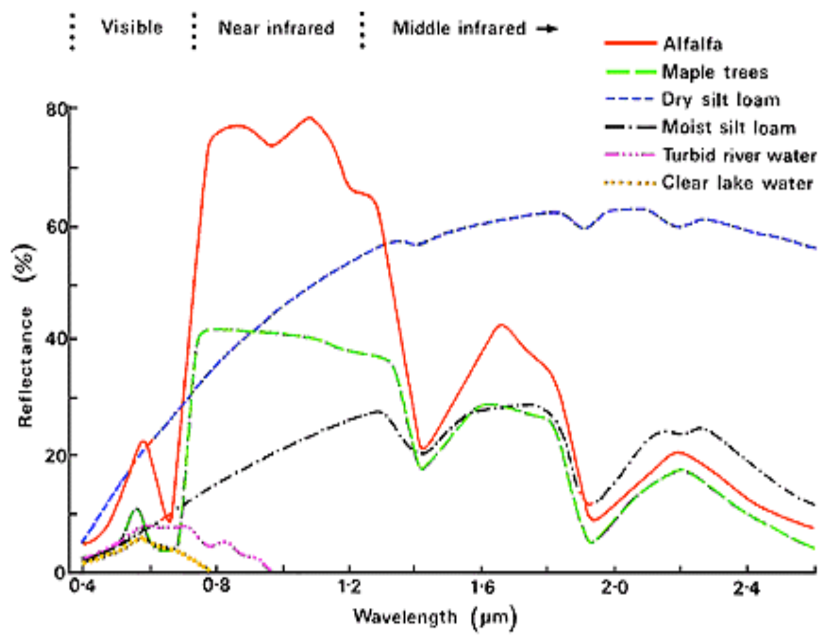


Courtesy of NASA: http://data.giss.nasa.gov/cgi-bin/gistemp/

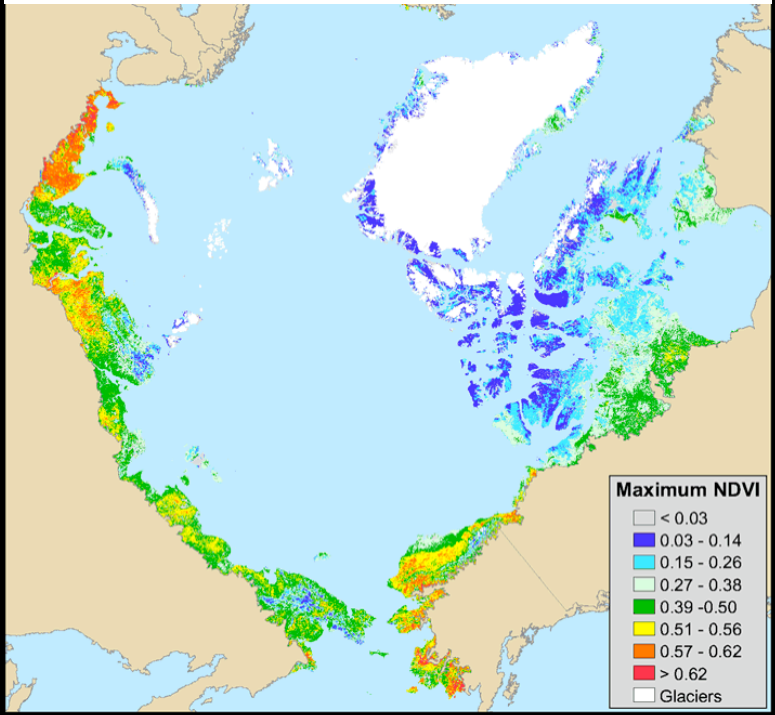
Land-surface temperatures of North America north of 60° N rose at rate of 0.84± 0.18 °C per decade between 1978 and 2006 (Comiso 2006).

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

Reflectance spectra of common ground-cover types



Circumpolar patterns of NDVI



CAVM Team. 2003

Normalized Difference Vegetation Index

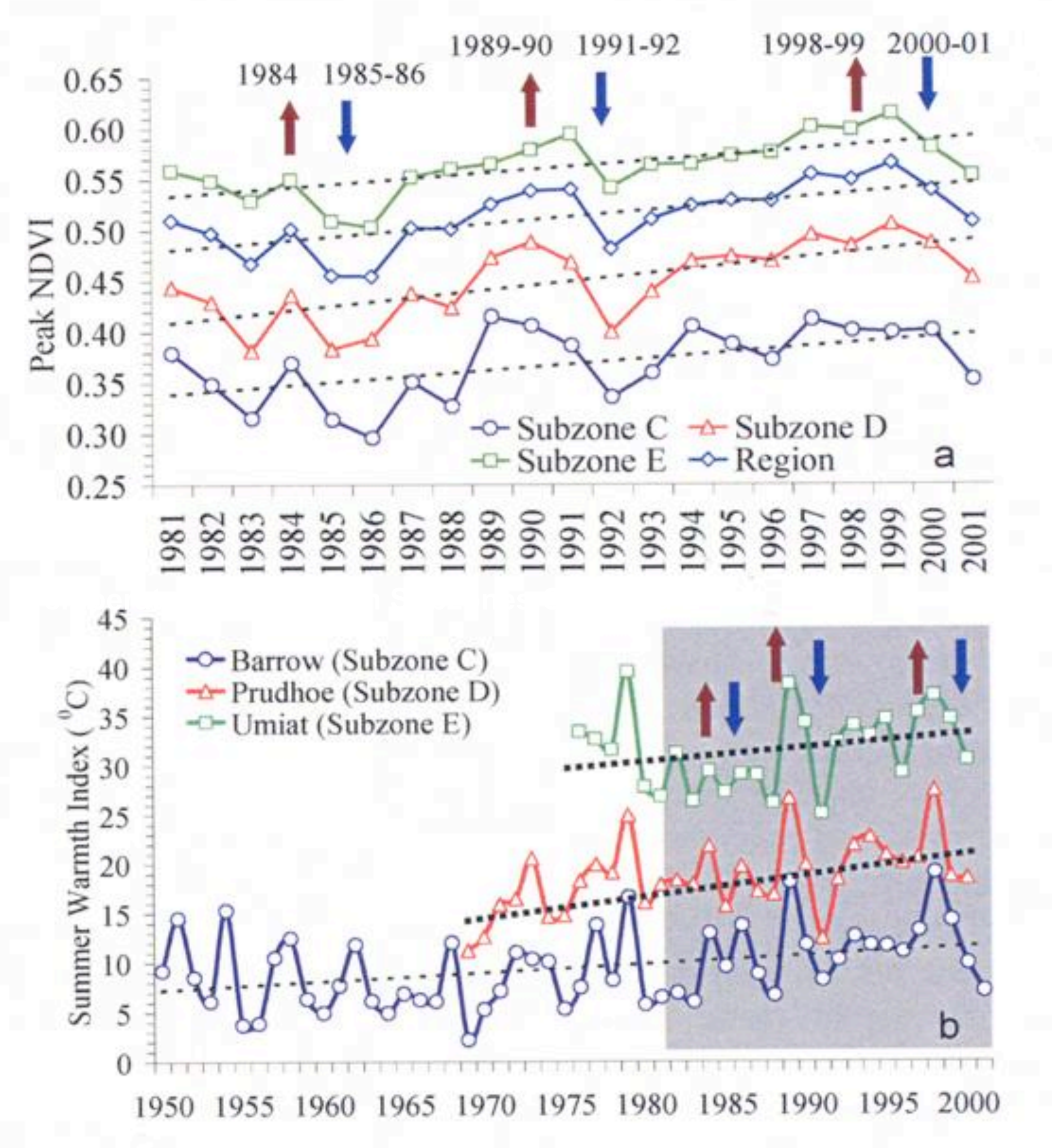
NDVI = *(NIR - VIS) / (NIR + VIS)*

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).**

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

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



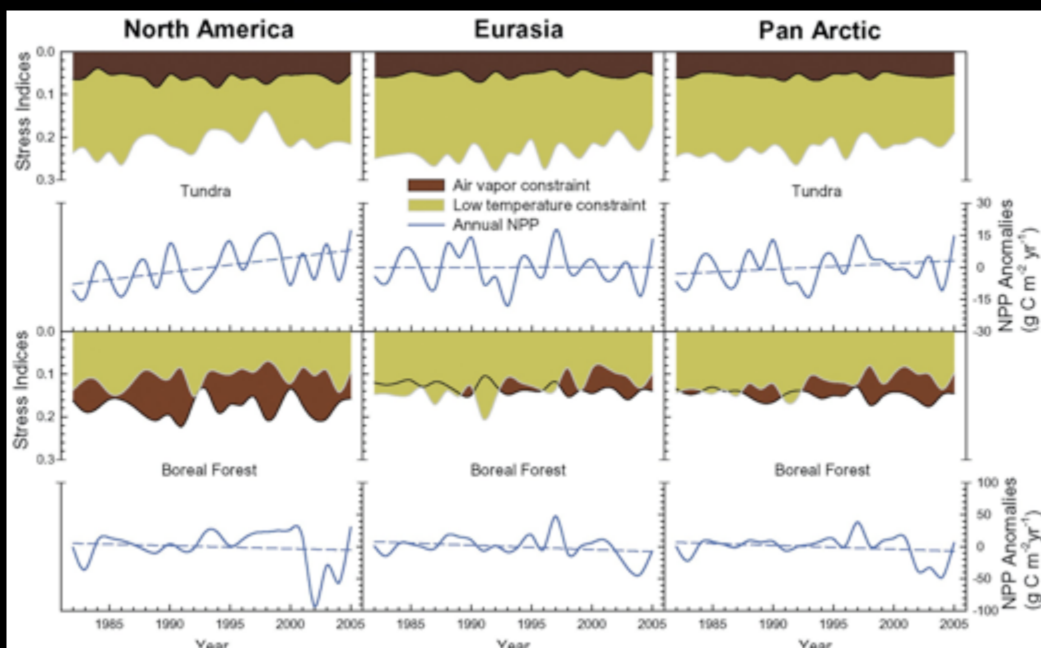
Jia et al. 2003 *Geophysical Research Letters.* 30: 2067.

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

- 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.

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.

Overview of lecture

- Recent trends in Arctic temperatures and sea ice.
- Overview of International Polar Year and Greening of the Arctic Project.
- Polar transects in North America and Russia.
- Global trends in near-shore open water, land-temperatures and vegetation greenness observed from space and on the ground.
- Some evidence of change from ground observations.
- Summary

The International Polar Year (2007-2009)

- The International Polar Year is a large scientific programme focused on the Arctic and the Antarctic from March 2007 to March 2009, currently still in its synthesis phase.
- Organized through the International Council for Science (ICSU) and the World Meteorological Organization (WMO)
- The fourth polar year. Others were in 1882-3, 1932-3, and 1957-8.

IPY goals

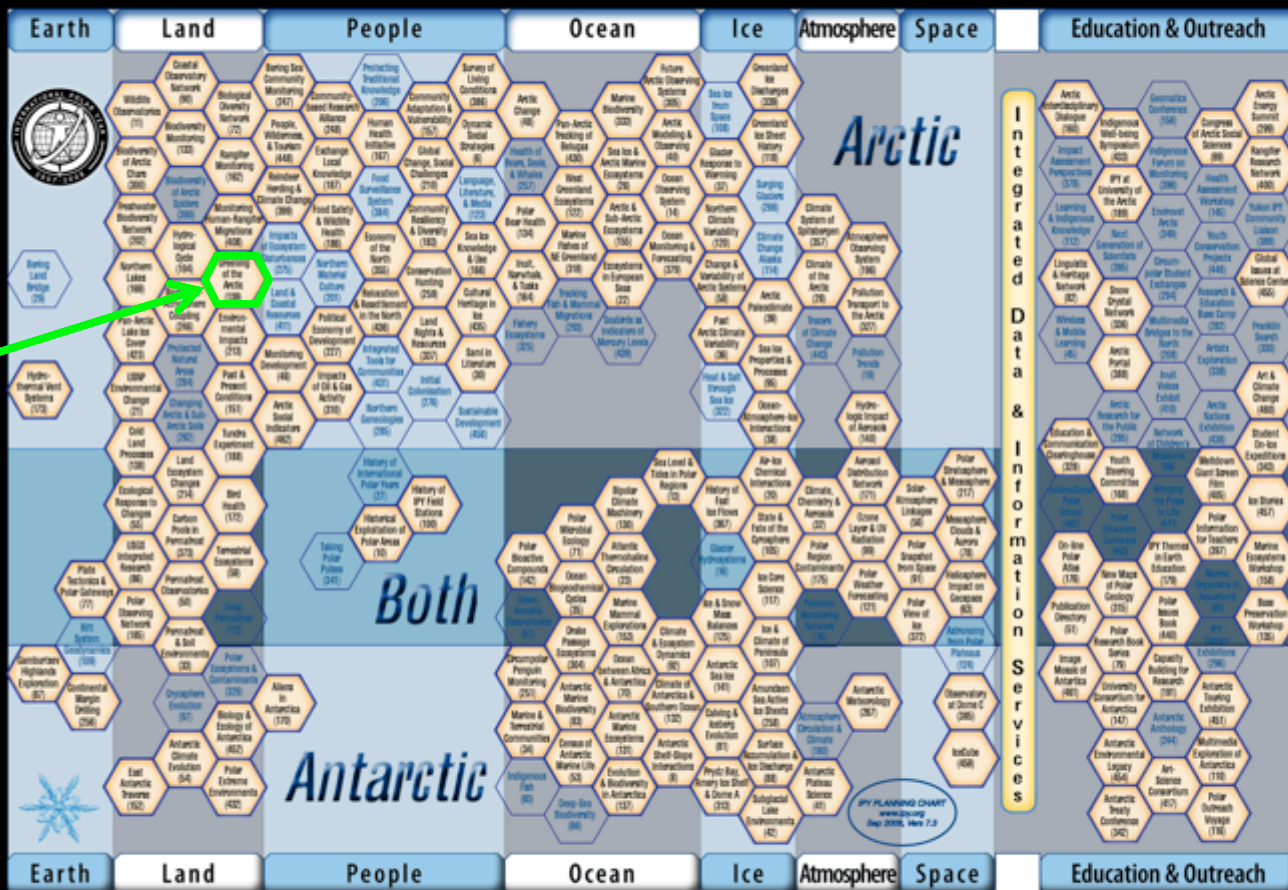
- An intense scientific campaign to explore new frontiers in polar science.
- Improve our understanding of the critical role of the polar regions in global processes.
- Educate the public about the polar regions.
- Projects were expected to be interdisciplinary in scope; involve a pulse of activity during the IPY period; leave a legacy of infrastructure and data; expand international cooperation; engage the public in polar discovery; and help attract the next generation of scientists and engineers.

Research supported

- **Understanding Environmental Change:** Research that advances the understanding of the physical, geological, chemical, human, and biological drivers of environmental change at the poles, their relationship to the climate system, their impact on ecosystems, and their linkages to global processes.
- **Human and Biotic Systems in Polar Regions:** Research to address fundamental questions about social, behavioral, and/or natural systems that will increase our understanding of how humans and other organisms function in the extreme environments of the polar regions.
- **60 countries involved:** Czech Republic was one!

Honeycomb chart of IPY projects

Greening of the Arctic



- **Over 200 projects, with thousands of scientists from over 60 nations examining a wide range of physical, biological and social research topics at both poles.**

Greening of the Arctic IPY intiative

- Documenting, mapping and understanding the rapid and dramatic changes to terrestrial vegetation expected across the circumpolar Arctic as a result of a changing climate.

Comprised of four subprojects:

North America Arctic Transect

Land-cover and land-use changes on the Yamal Peninsula

Synthesis of Arctic System Science: Greening of the Arctic

Toolik-Arctic Geobotanical Atlas

Major goal of the Greening of the Arctic project:

Link spatial and temporal trends of NDVI observed on AVHRR satellite images to ground observations along both transects.

- Climate
- Vegetation
- Soils
- Permafrost
- Spectral properties


NDVI and LAI


Plant species cover


Active layer depth


Site characterizatiion


Biomass

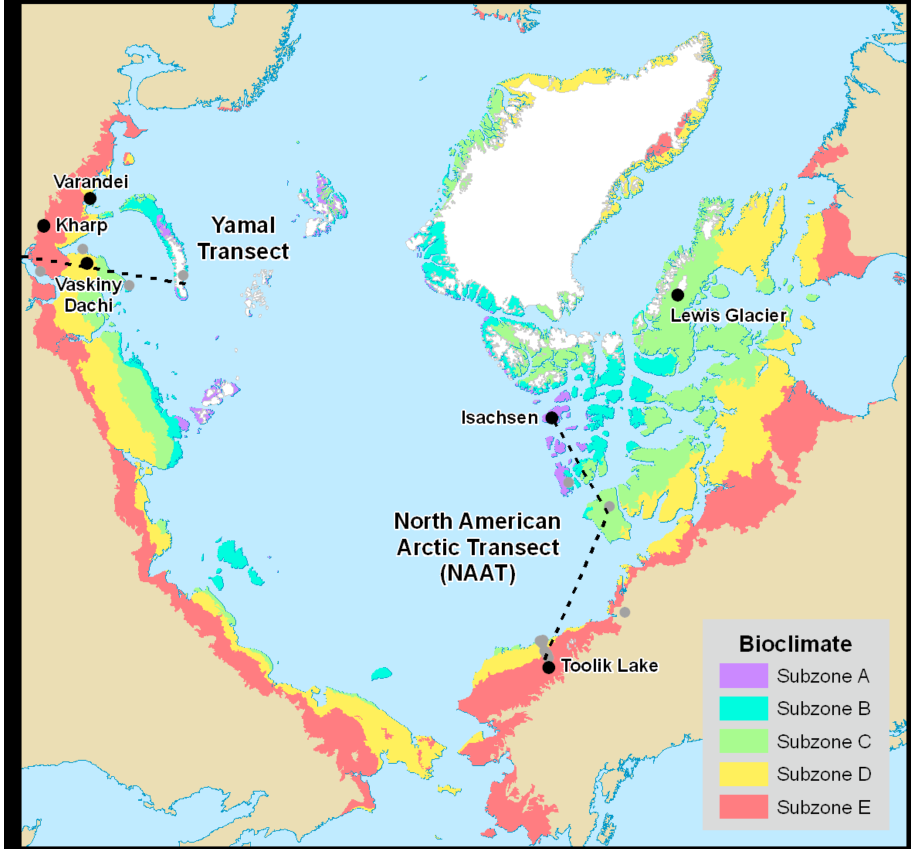

Soil characterization


N-factor


Permafrost boreholes

Two transects through all 5 Arctic bioclimate subzones

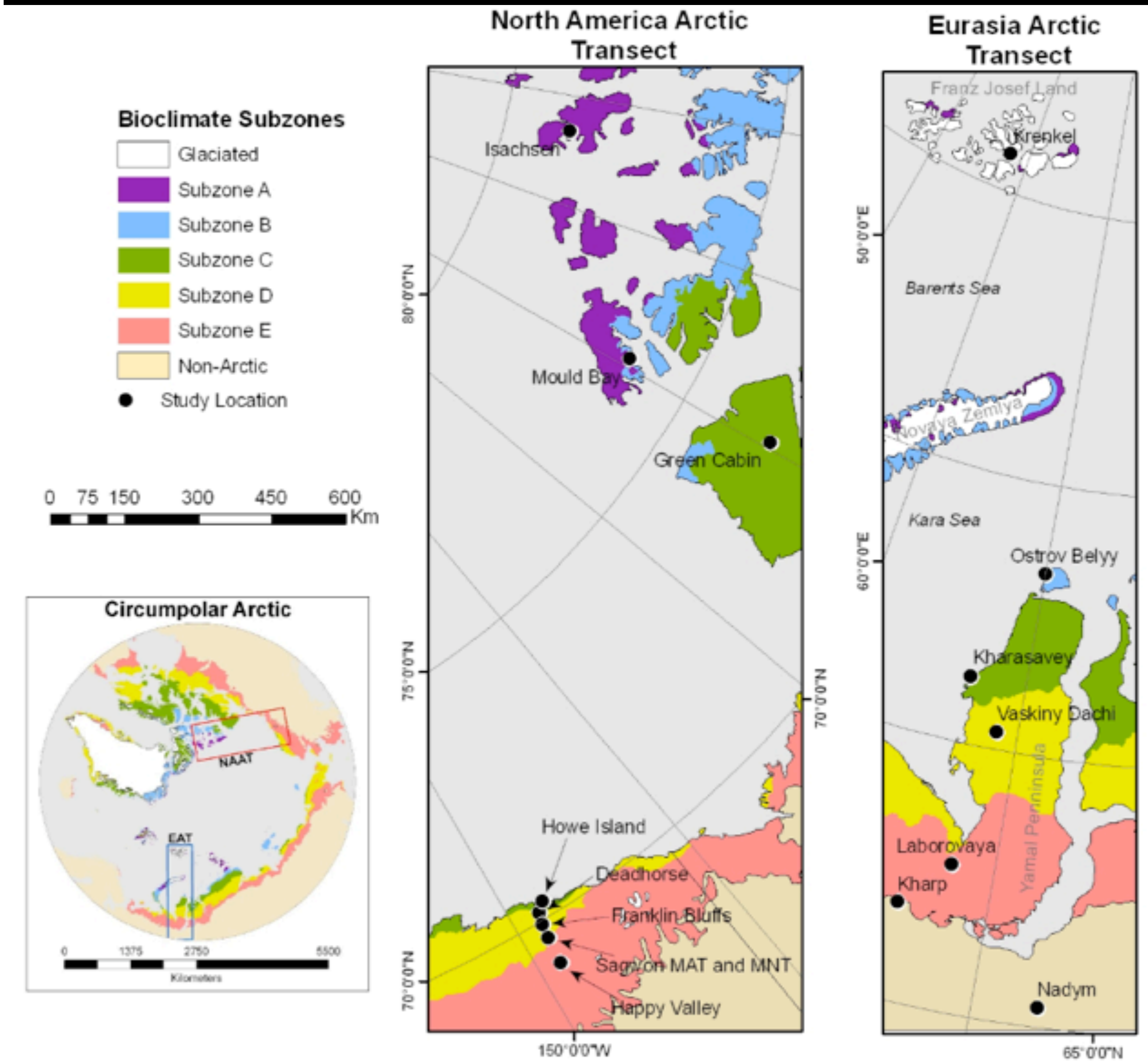
Bioclimate subzones



CAVM Team 2003

Sub-Zone	MJT	Shrubs
A	1-3 ˚C	none
B	3-5 ˚C	prostrate dwarf-shrubs
C	5-7 ˚C	hemi-prostrate dwarf shrubs
D	7-9 ˚C	erect dwarf-shrubs
E	9-12 ˚C	low-shrubs

Field studies along two 1800-km Arctic transects

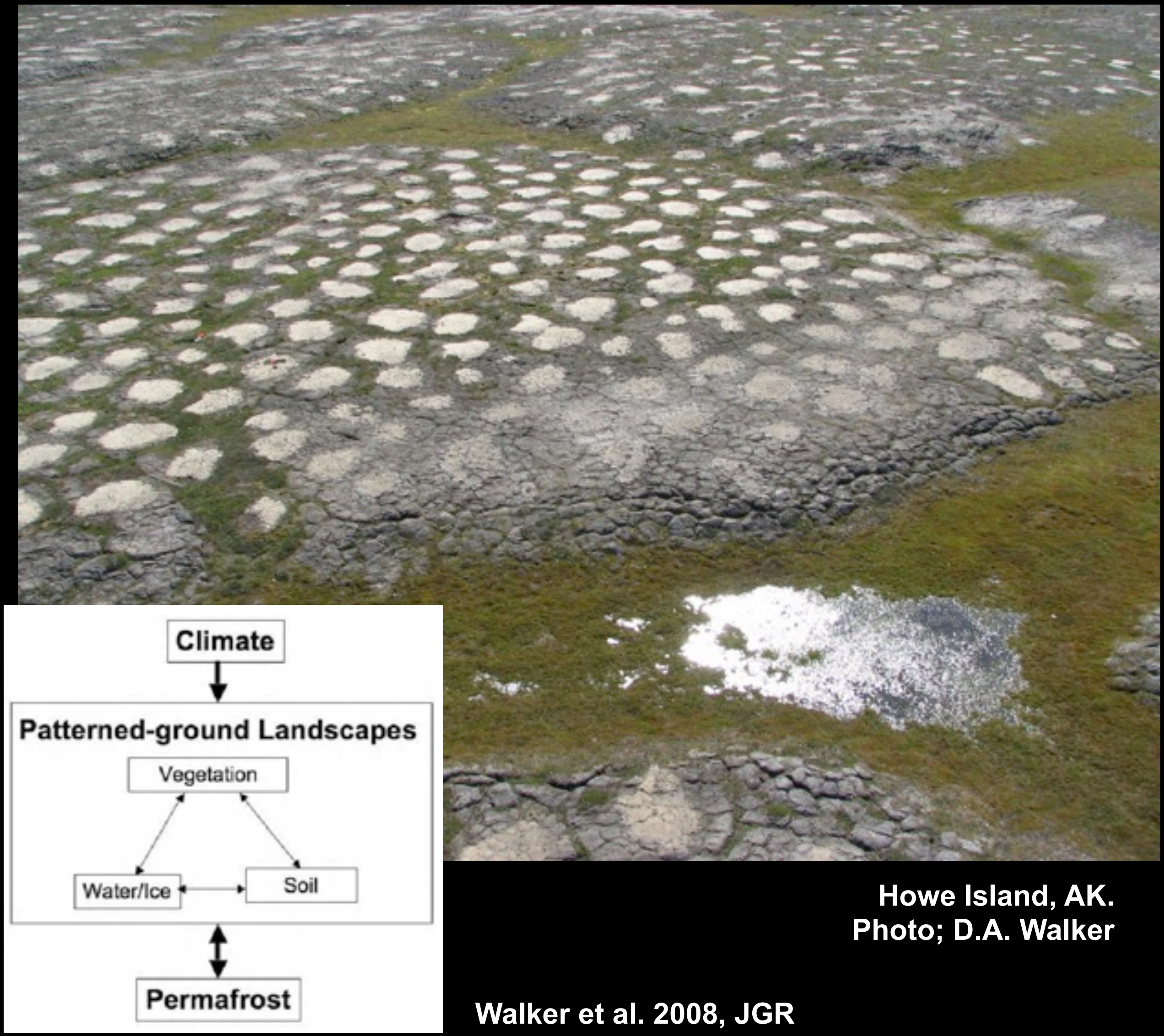


North America Arctic Transect:
2002-2006
Biocomplexity of Arctic Patterned Ground Ecosystems Project (NSF).

Eurasian Arctic Transect:
2007-201
Greening of Arctic (NASA).

Both transects through all five Arctic bioclimate subzones.

North America Transect was created during the Biocomplexity of Patterned-Ground 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?


Why focus on these dumb spots?

WELL, BECAUSE:

- The processes involved in the formation of patterned-ground landscapes are not well understood.

- The importance of patterned ground with respect to biogeochemical cycling, carbon sequestration and other ecosystem processes is poorly known.

- They are an ideal natural system to to help predict the consequences of climate change of disturbed and undisturbed tundra across the full Arctic climate gradient.

IPY objectives of the North America Arctic Transect

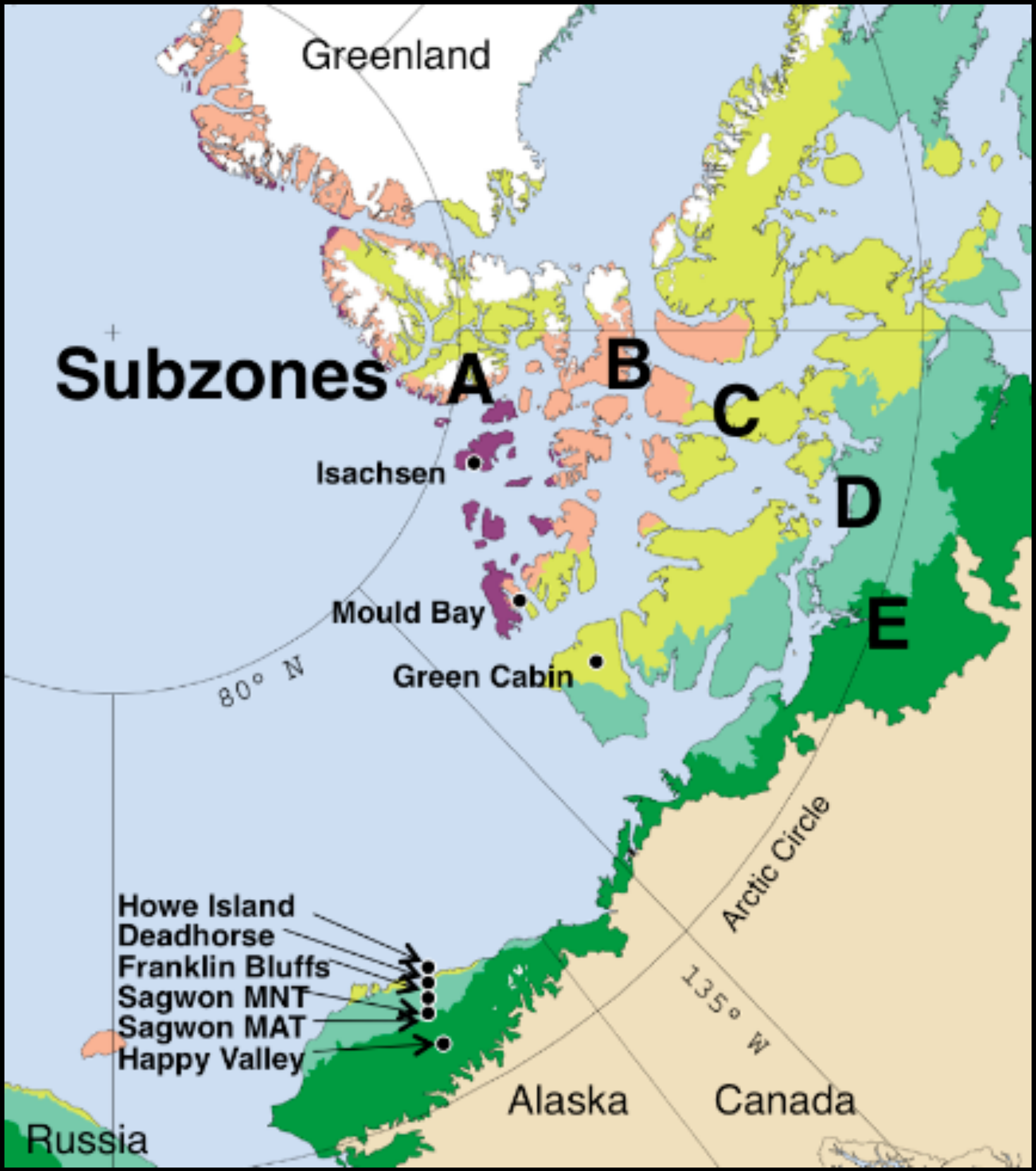
Biomass, leaf-area, spectral data and other site information were collected from each site to provide a baseline against which to monitor future changes.

- Create a legacy dataset of baseline information along the North American Arctic Transect (NAAT) that represents the full range of zonal vegetation types in the Arctic.
- Communicate the results of the studies through a three-part education/outreach component that includes an Arctic Field Ecology course, contributions to a new “Arctic Geobotanical Atlas” web site, and a field trip for the 9th International Conference on Permafrost.

North American Arctic Transect

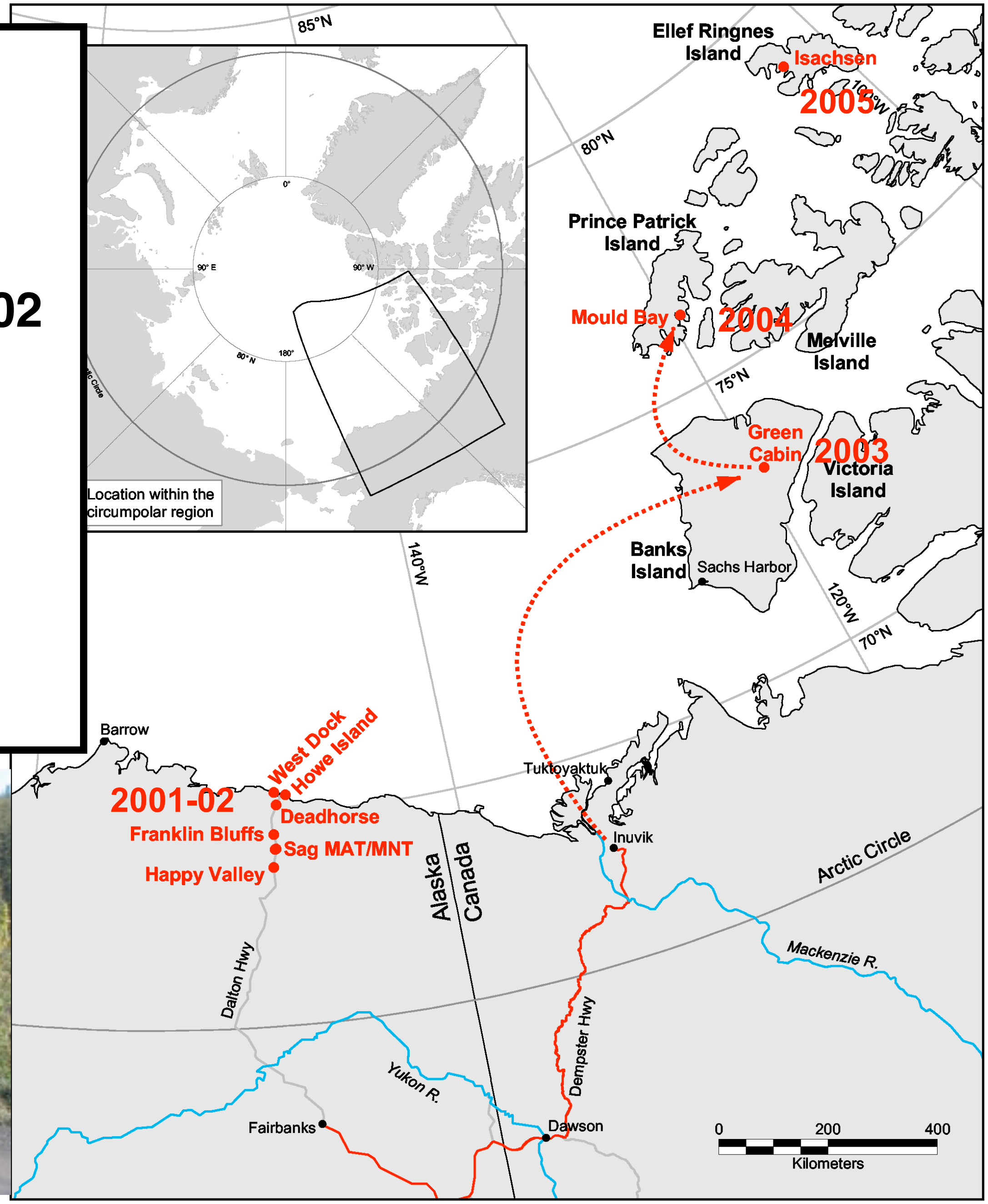
Arctic Bioclimate Subzones

Sub-zone	MJT (°C)	SWI (°C mo)
A	<3	<6
B	3-5	6-9
C	5-7	9-12
D	7-9	12-20
E	9-12	20-35
Forest	>12	>35



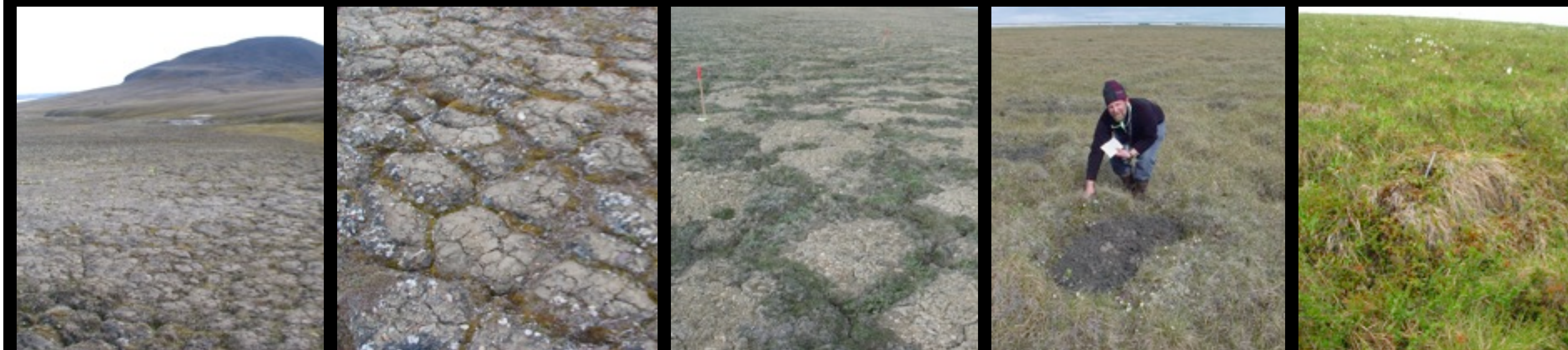
Expeditions and Timeline:

Dalton Highway: 2001-2002
Green Cabin: 2003
Mould Bay: 2004
Isachsen: 2005
Synthesis: 2006-2008

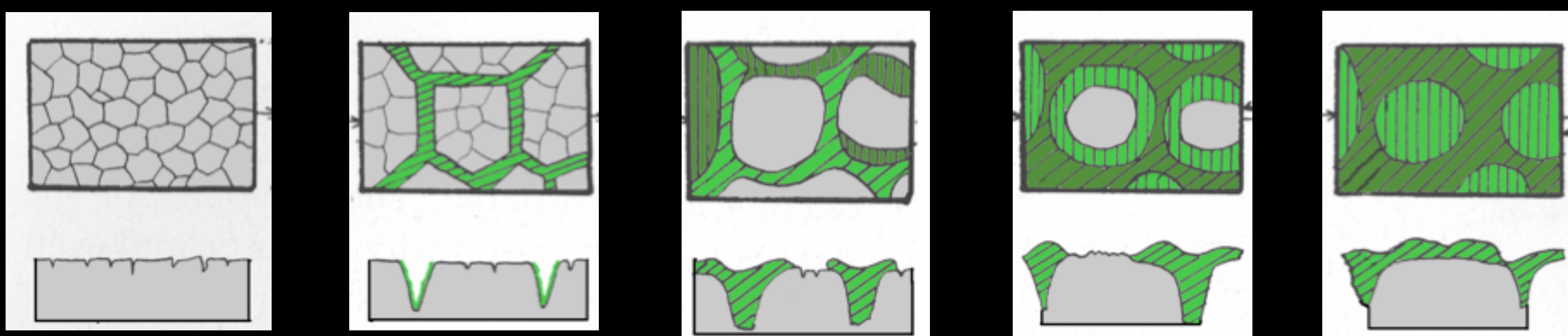


Field Camp at Green Cabin, Banks Island

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

Subzone A

Isachsen, Ellef Ringnes Island, mean July temperature = 3 ˚C, SWI = 4 ˚C mo

Subzone C

Howe Island, Ak and Green Cabin, Banks Island, MJT, 8 ˚C, SWI = 16 ˚C mo

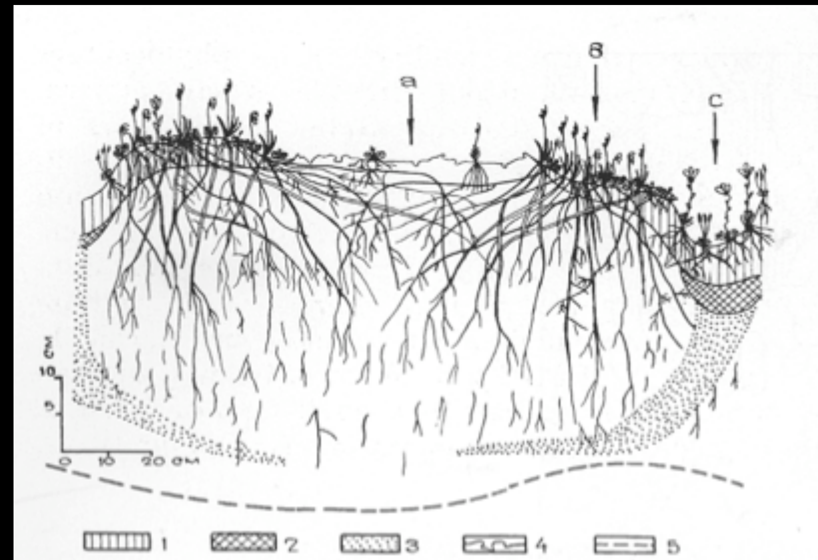
Subzone E

Tuktuyaktuk, NWT, Happy Valley, AK, MJT = 12 ˚C, SWI = 30 ˚C mo

The roles of vegetation in patterned formation

Plant cover:

- Insulates the surface decreasing the heat flux and summer soil temperatures.
- stabilizes cryoturbation and limits needle-ice formation.
- Promotes nitrogen and carbon inputs to the soil.



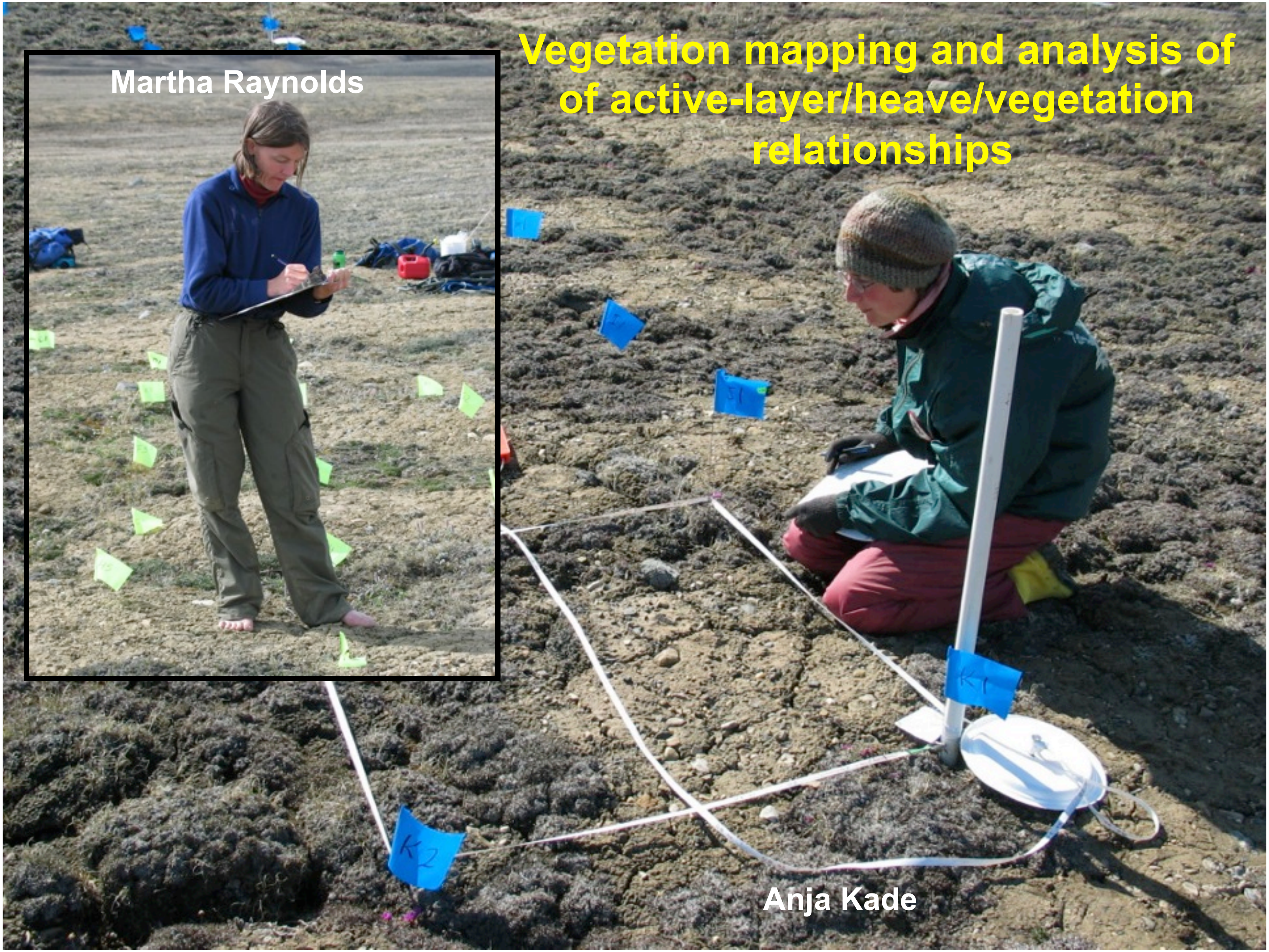
N, Matveyeva - Map and drawing of frost boil vegeation on the Taimyr Peninsula, Russia.

Bill Steere collecting Bryum wrightii *on a frost boil at Prudhoe Bay, July, 1971.*

North American Arctic Transect Activities

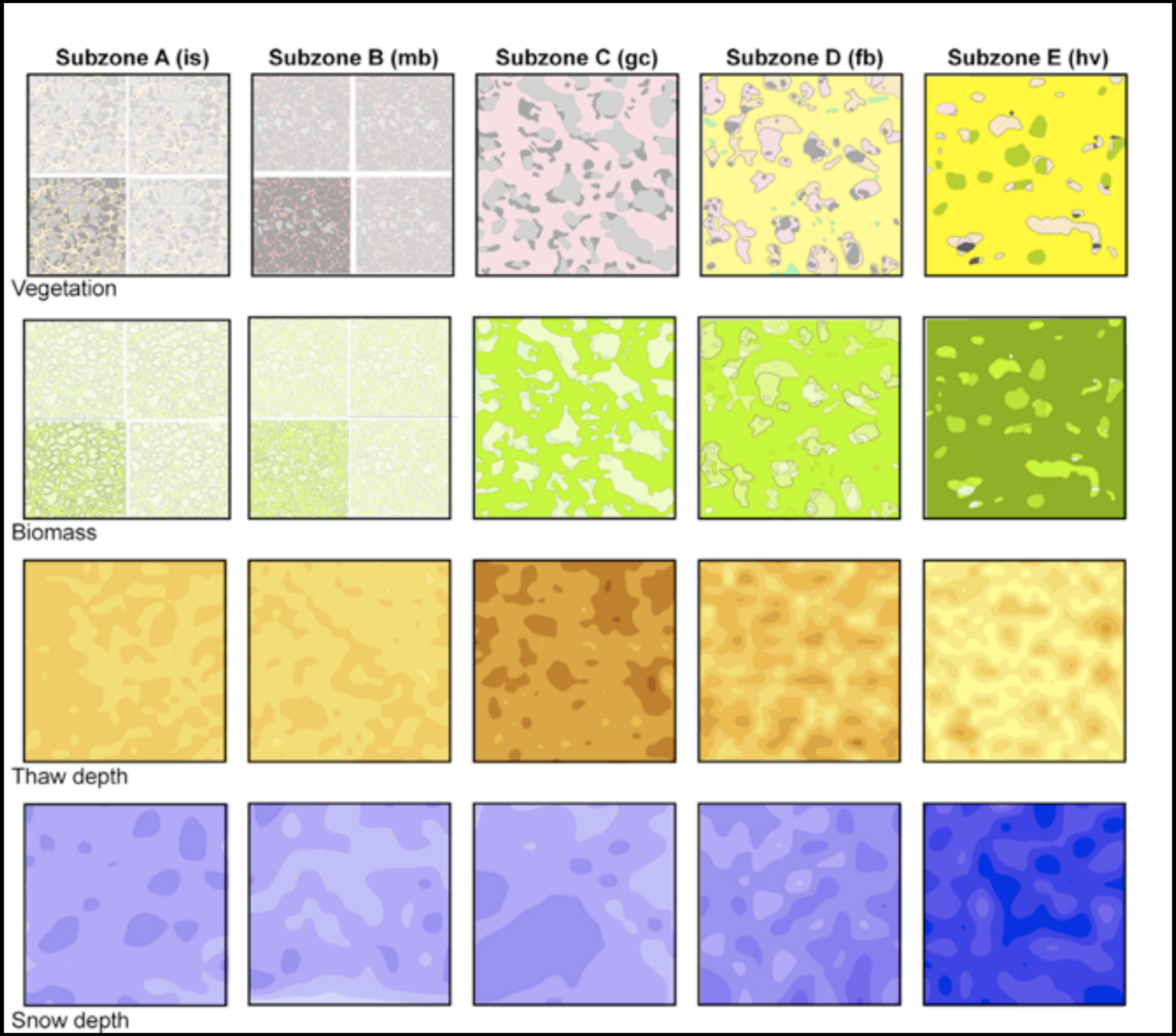
- CALM Grids
  - Active layer
  - Vegetation
  - Snow
- Climate /permafrost
  - Met station
  - Soil temperatures
  - Frost heave
- Soils
  - Characterization
  - Nitrogen mineralization
  - Decomposition
- Vegetation
  - Classification
  - Biomass
  - Mapping
- Remote sensing
  - NDVI
  - Mapping
-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

Isachsen Grid, Subzone A
Photo D.A. Walker

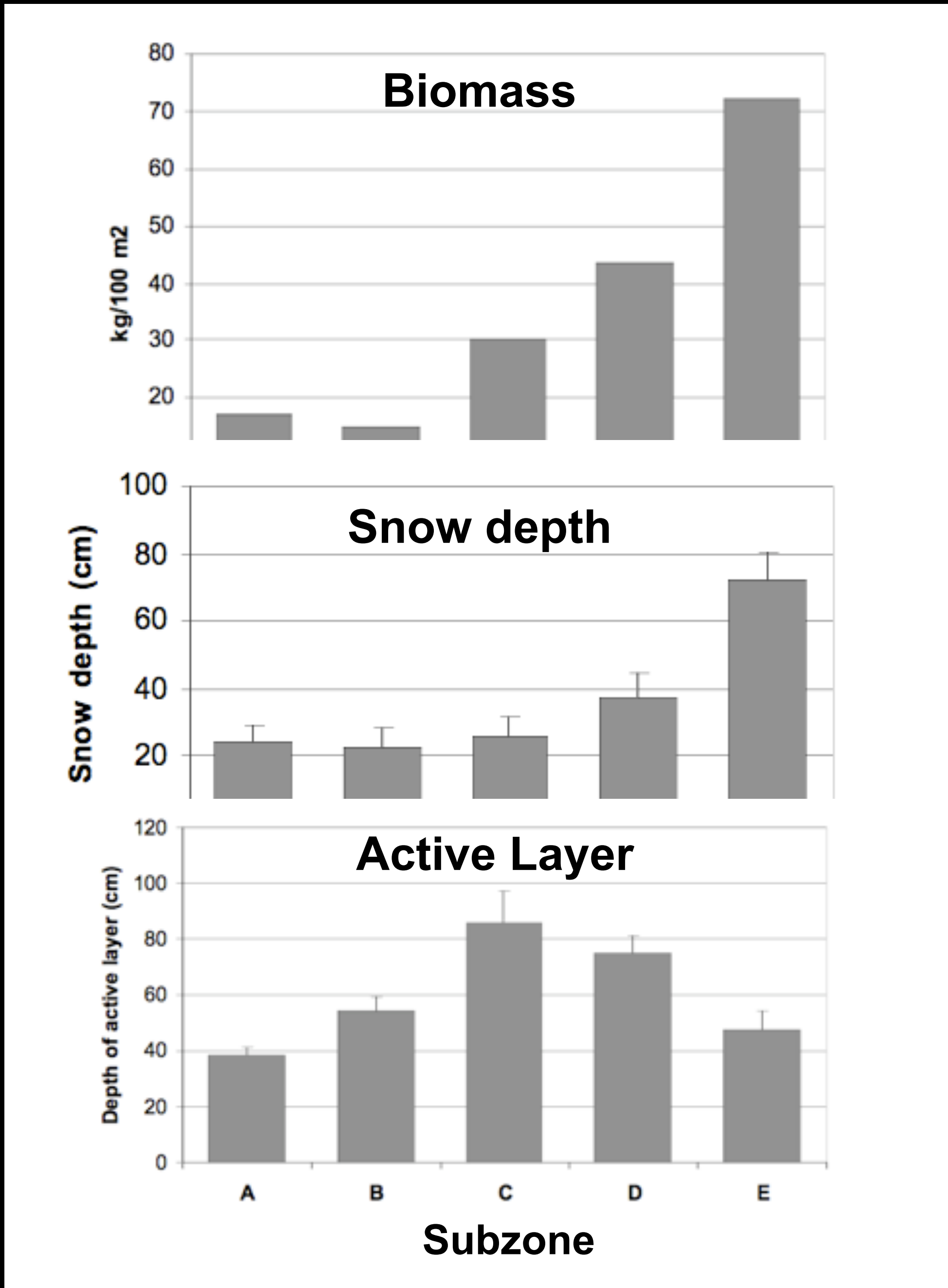

Vegetation mapping and analysis of of active-layer/heave/vegetation relationships
Martha Raynolds
Anja Kade

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.**



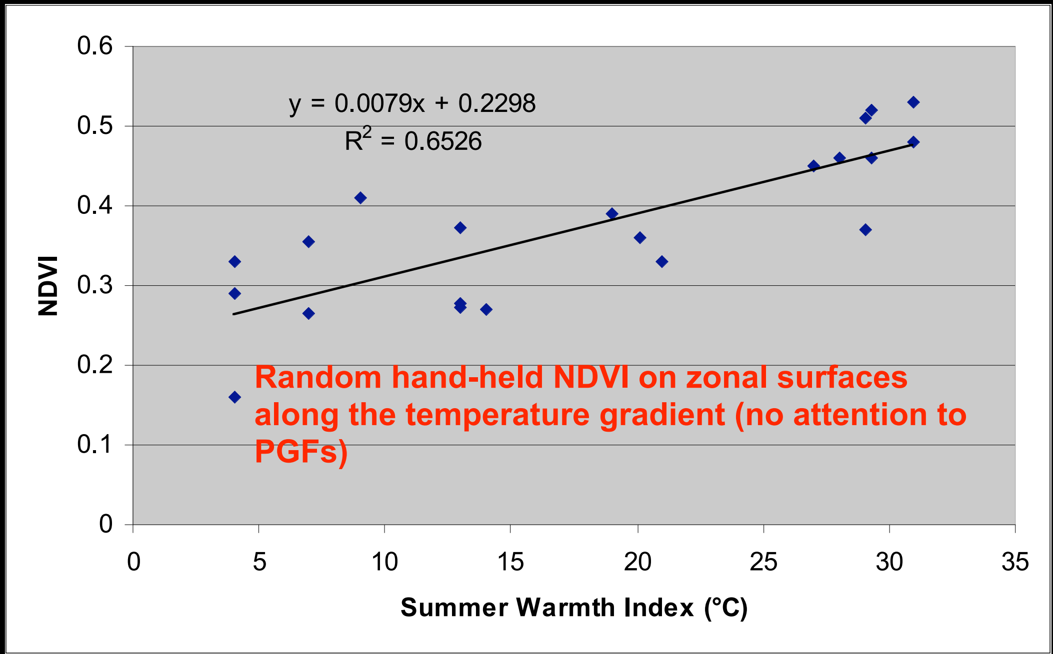
Trends in biomass, snow depth, and thaw on zonal grids



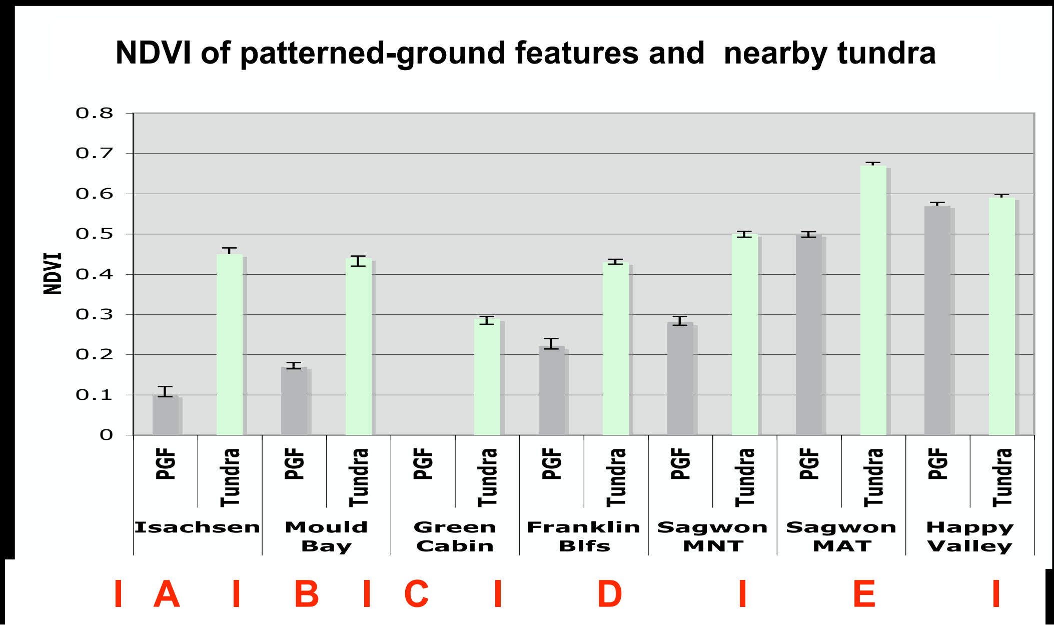
- Both biomass and snow depth depth increase toward the south and both have major effects on soil temperature regimes.

Raynolds et al. 2008, *JGR-Biogeosciences*

NDVI along the NAAT



- 2-fold increase of the NDVI on zonal surfaces.

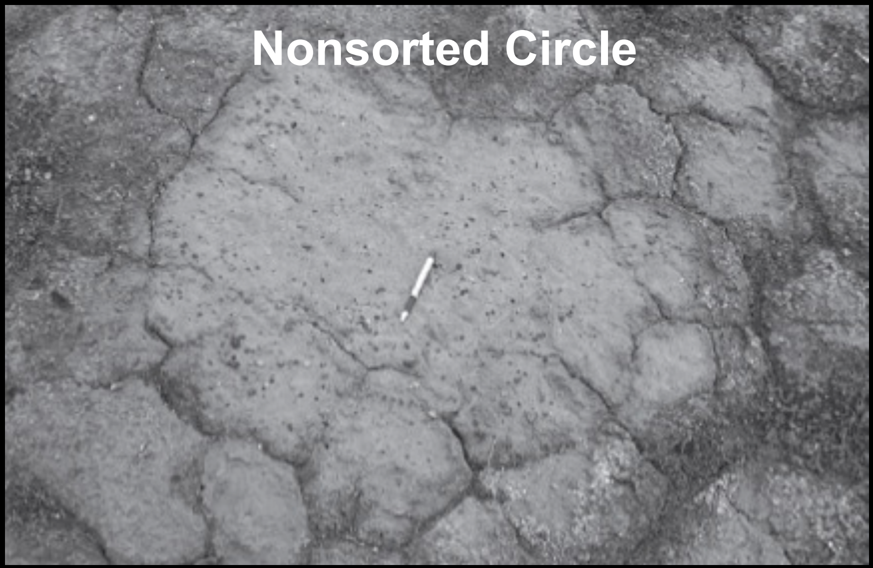


- 6-fold difference in NDVI on PGFs.
- 2-fold difference in NDVI between PGFs.

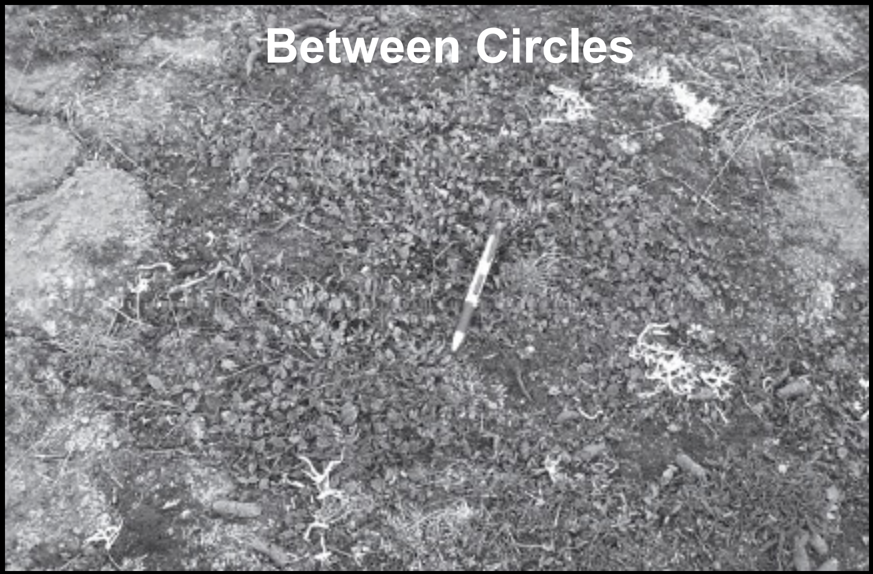
Courtesy of Howie Epstein and Alexia Kelley

Contrast in vegetation on and between frost features

Deadhorse Subzone C



Braya purpurascens-Puccinellia angustata community



Dryas integrifolia-Salix arctica community

Kade et al 2005

Classification of patterned-ground vegetation along the NAAT

Phytocoenologia, 38 (1–2), 23–63
Berlin–Stuttgart, August 22, 2008

Patterned-Ground Plant Communities along a bioclimate gradient in the High Arctic, Canada

by Corinne M. Vonlanthen, Donald A. Walker, Martha K. Raynolds, Anja Kade, Patrick Kuss (Fairbanks, Alaska, USA), Fred J. A. Daniels (Münster, Germany), and Nadezhda V. Matveyeva (St. Petersburg, Russia)

with 16 figures, 14 tables and 1 appendix

Phytocoenologia	35 (4)	761–820	Berlin–Stuttgart, December 13, 2005

Plant communities and soils in cryoturbated tundra along a bioclimate gradient in the Low Arctic, Alaska

by Anja Kade, Donald A. Walker and Martha K. Raynolds, Fairbanks, Alaska

with 24 figures, 12 tables and 1 appendix

Abstract. Nonsorted circles and earth hummocks are important landscape components of the arctic tundra. Here we describe the vegetation on these frost-heave features at seven study sites along a N-S-transect from the Arctic Ocean to the Arctic Foothills, Alaska. We established 117 relevés in frost-heave features and surrounding tundra and classified the vegetation according to the Braun-Blanquet sorted-table method. We used Detrended Correspondence Analysis to analyze relationships between vegetation and environmental variables. We identified nine communities: *Braya purpurascens-Puccinellia angustata* community (dry nonsorted circles, subzone C); *Dryas integrifolia-Salix arctica* community (dry tundra, subzone C); Salici rotundifoliae-Caricetum aquatilis ass. nov. (moist coastal tundra, subzone C); Junco biglumis-Dryadetum integrifoliae ass. nov. (moist nonsorted circles, subzone D); Dryado integrifoliae-Caricetum bigelowii Walker et al. 1994 (moist tundra, subzone D); *Scorpidium scorpioides-Carex aquatilis* community (wet tundra, subzone D); Cladino-Vaccinietum vitis-idaeae ass. nov. (dry nonsorted circles and earth hummocks, subzone E); Sphagno-Eriophoretum vaginati Walker et al. 1994 (moist tundra, subzone E); and *Anthelia juratzkana-Juncus biglumis* community (wet nonsorted circles, subzone E).

The DCA ordination displayed the vegetation types with respect to complex environmental gradients. The first axis of the ordination corresponds to a bioclimate/pH gradient, and the second axis corresponds to a disturbance/soil moisture gradient. Frost-heave features are dominated by lichens, whereas the adjacent tundra supports more dwarf shrubs, graminoids and mosses. Frost-heave features have greater thaw depths, more bare ground, thinner organic horizons and lower soil moisture than the surrounding tundra. The morphology of frost-heave features changes along the climatic gradient, with large, barren nonsorted circles dominating the northern sites and vegetated, less active earth hummocks dotting the southern sites. Thawing of permafrost and a possible shift in plant community composition due to global warming could lead to a decline in frost-heave features and result in the loss of landscape heterogeneity.

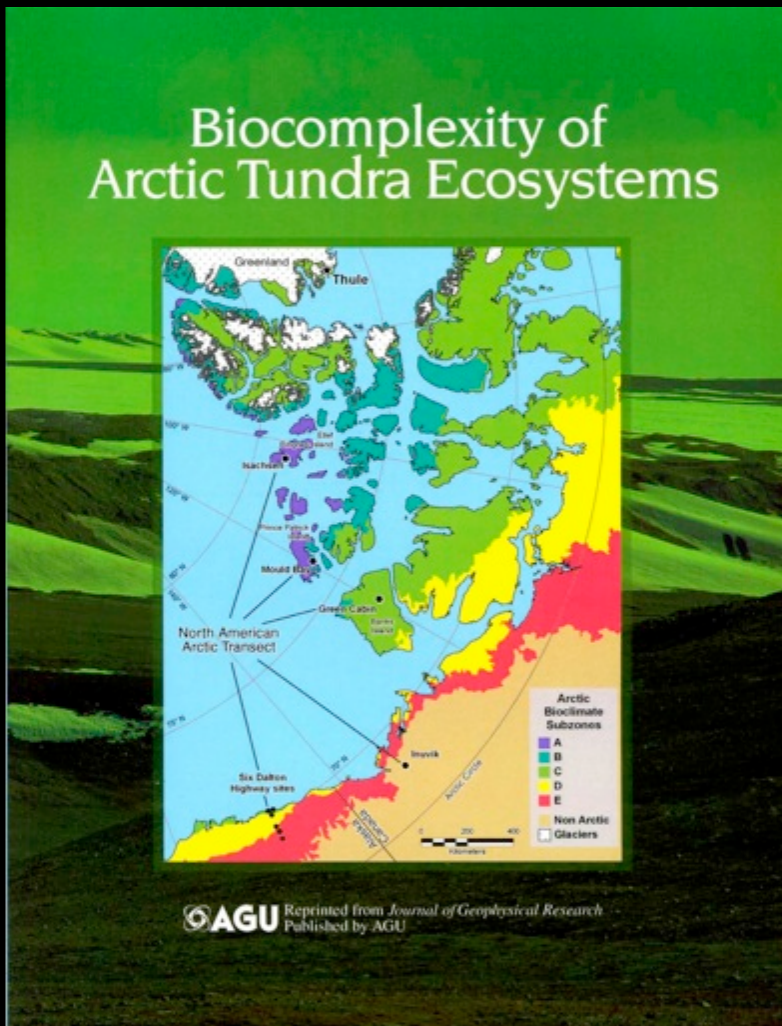
Keywords: biocomplexity, Braun-Blanquet classification, Detrended Correspondence Analysis, earth hummocks, frost heave, nonsorted circles.

1 Introduction

The vegetation and soil patterns in many arctic tundra regions are influenced by the distribution of frost-heave features such as nonsorted circles and earth hummocks (Washburn 1980). Nonsorted circles and earth hummocks form

- **Used the Braun-Blanquet appraoch.**
- **Low Arctic: Kade, A., Walker, D.A., and Raynolds, M.K., 2005, Plant communities and soils in cryoturbated tundra along a bioclimate gradient in the Low Arctic, Alaska: Phytocoenologia, v. 35, p. 761-820.**
- **High Arctic: Vonlanthen, C.M., Walker, D.A., Raynolds, M.K., Kade, A., Kuss, H.P., Daniëls, F.J.A., and Matveyeva, N.V., 2008, Patterned-ground plant communities along a bioclimate gradient in the High Arctic, Canada: Phytocoenologia, v. 38, p. 23-63.**

Synthesis of information from the North American Arctic Transect



- **Synthesis of the project 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.**

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.

Some conclusions from the NAAT:
Still a work in progress

1. The structure of the vegetation affects patterned-ground morphology on zonal sites in predictable ways that vary with differences in climate, soil-moistur and soil-texture.

2. Contrasts in the vegetation on and between patterned-ground features is best developed in Subzones C and D. These differences drive the movement of heat and water and the development of frost heave.

3. New and improved models are needed to include frost cracking in the physical processes.

4. More replication is needed and more sampling in different habitats, e.g. wetlands.

The Eurasia Arctic Transect: Vegetation Analysis and Mapping

Yamal Peninsula, Russia. Photo: D.A. Walker

Overview of EAT effort

- Hierarchical mapping analysis
  - AVHRR (1 km 12.5 km and 50 km)
  - Landsat ETM+ (15 m and 30 m)
  - GeoEye(40-cm resolution)
  - Hand-held measurements of NDVI

- Ground observations along the climate gradient
  - Data collected and data report
  - Vegetation analysis

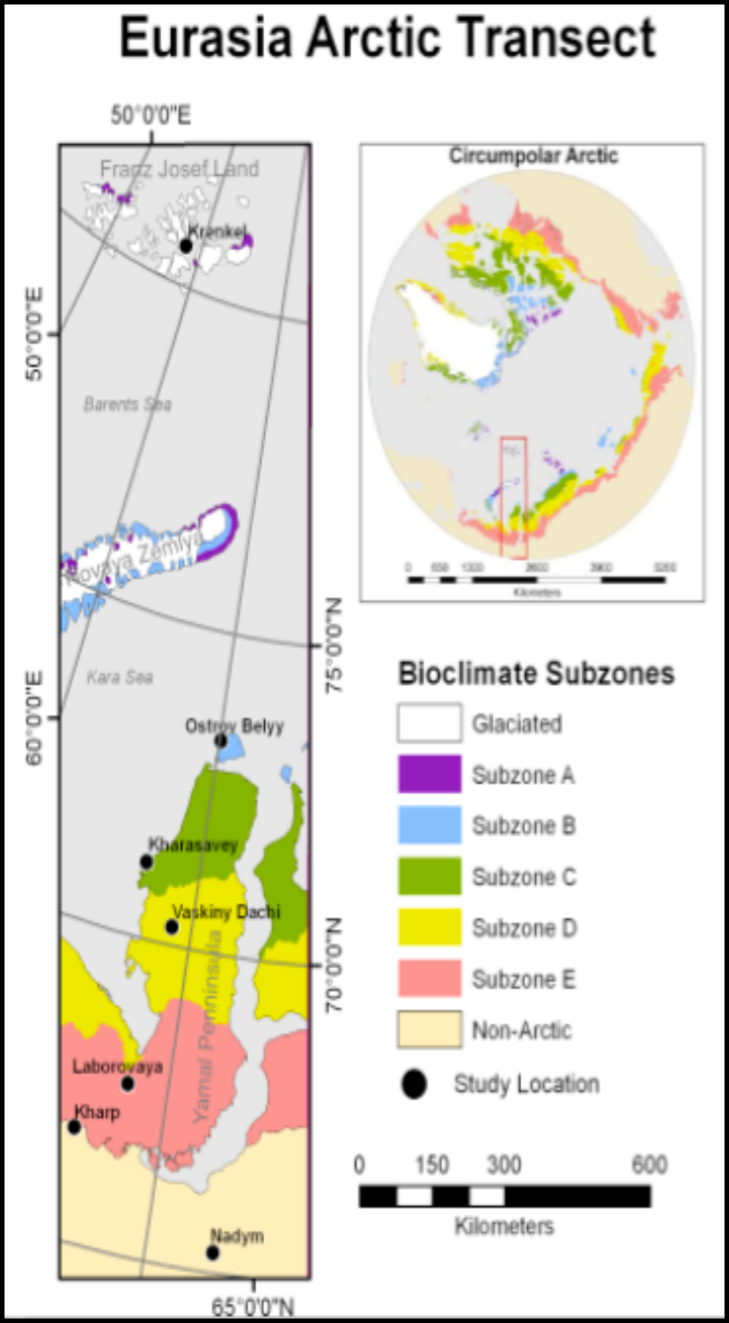
- Analysis of the linkages between climate change, sea-ice retreat and changes in the terrestrial vegetation.

The Eurasia Arctic Transect

- About 1800 km from 65° 19' N to 80° 38'.

- Subzone A: Krenkel, Franz Josef Land
- Subzone B: Ostrov Belyy
- Subzone C: Kharasavey
- Subzone D: Vaskiny Dachi
- Subzone E: Laborovaya
- Forest-tundra transition: Nadym and Kharp

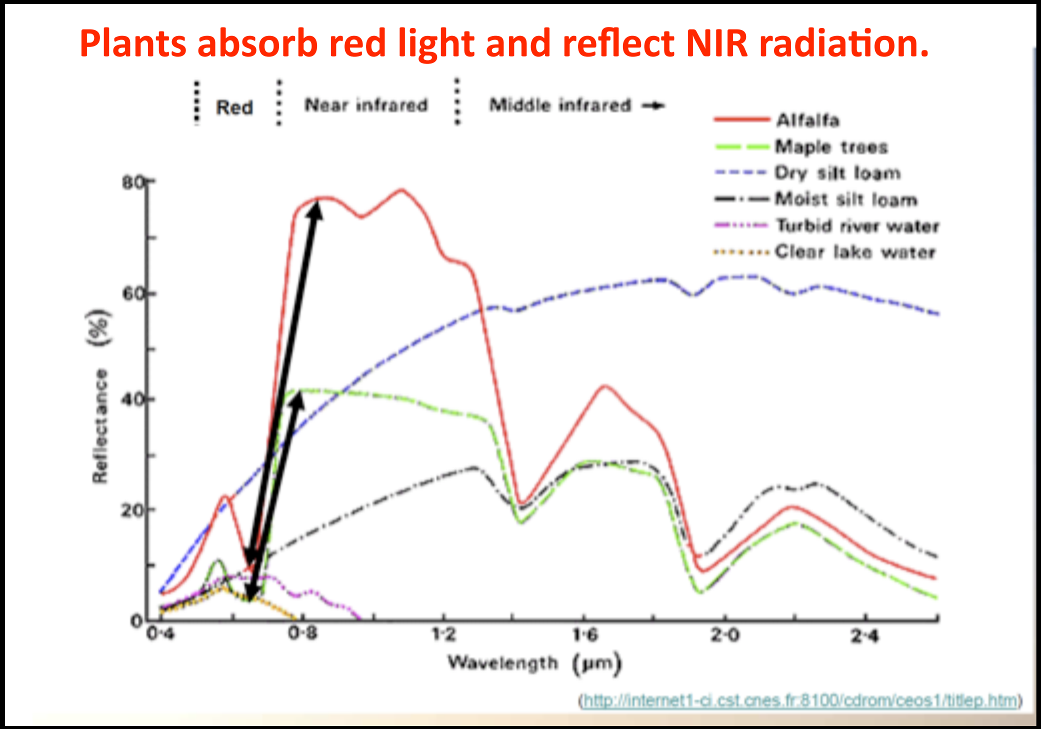
- Four expeditions (2007-10).



2010 Expedition to Hayes Island, Franz Josef Land

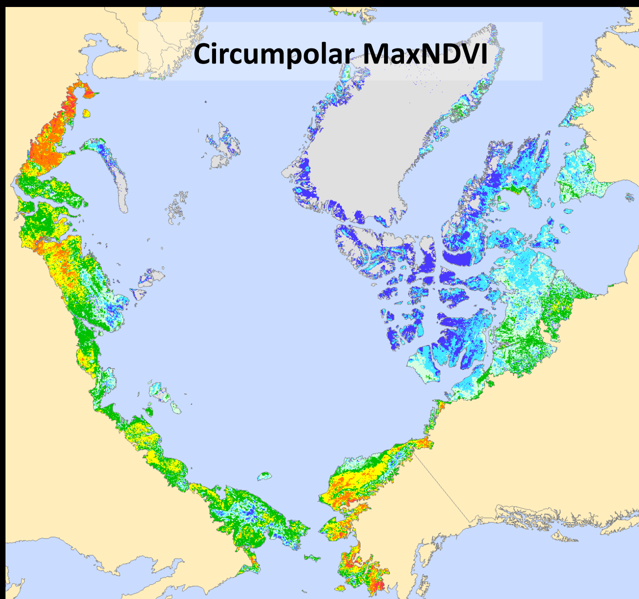
- Ground-based observations in Bioclimate Subzone A of the Eurasia Arctic Transect.
- Northern-most permafrost borehole in Russia at 80˚ 37’ N.
- Completed parallel transect studies in North America and Eurasia.

Much of project focuses on greenness patterns and change using the Normalized Difference Vegetation Index (NDVI)

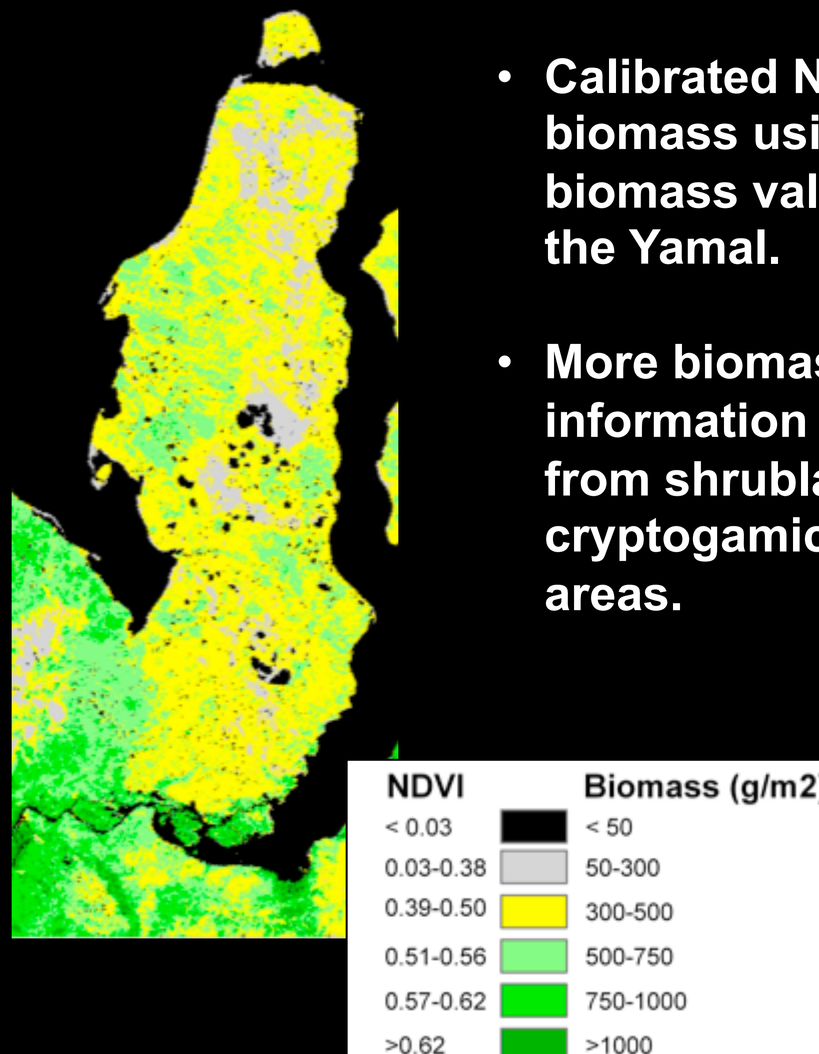


- **Chlorophyll absorbs red light for photosynthesis and reflects near infrared light.**
- **NDVI = (NIR-R)/(NIR + R). The difference between the reflectance in the NIR and R portions of the spectrum is a measure of the photosynthetic capacity of the surface. The difference is divided by the sum of the reflectances to adjust for variations in the index due to slope and shadows.**
- **NDVI is much greater in vegetation with high chlorophyll content.**

Multiple-scale analysis of Yamal NDVI:
1-km AVHRR NDVI derived from CAVM data set



USGS data set used for the CAVM

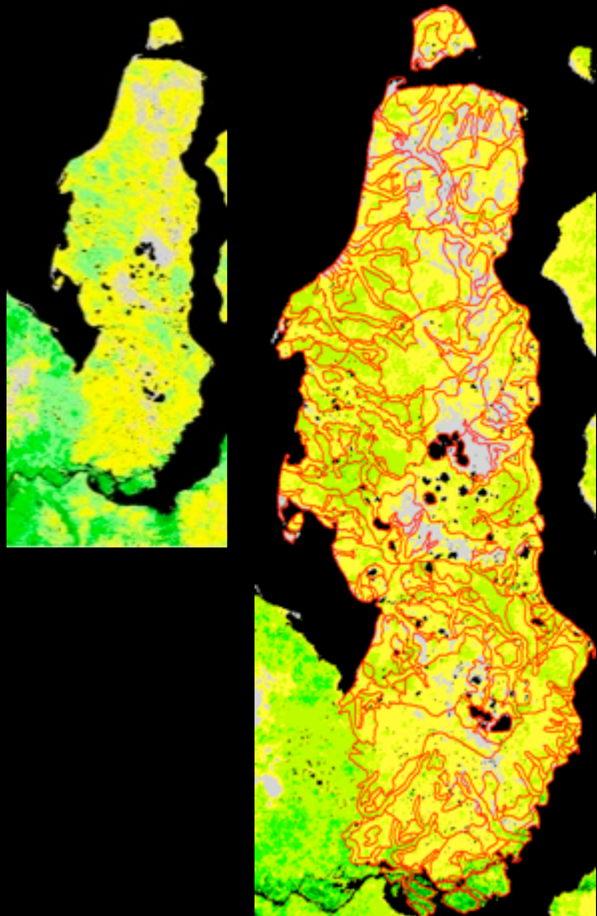


- **Calibrated NDVI to biomass using the zonal biomass values from the Yamal.**
- **More biomass information is needed from shrublands and cryptogamic tundra areas.**

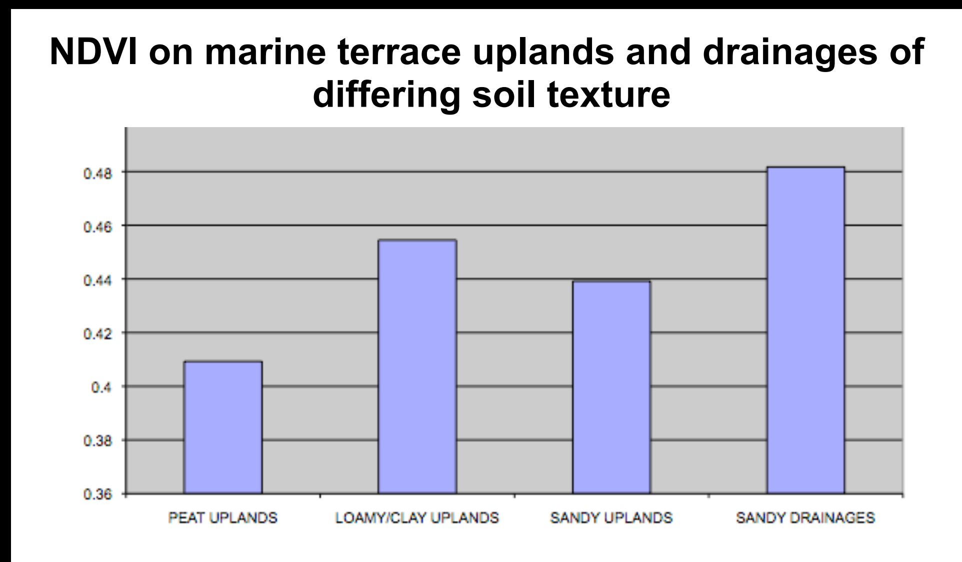
Courtesy of M.K. Raynolds. 2010.

Analysis of 1-km NDVI with Landschaft and CAVM map units

NDVI with Landschaft boundaries



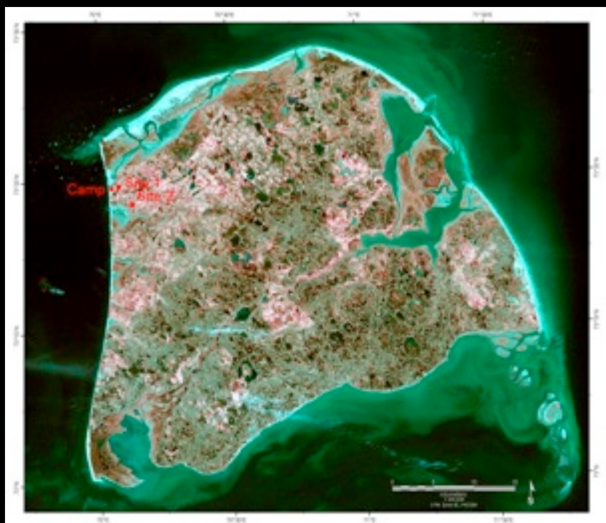
- **Loamy uplands have higher NDVI than sandy uplands. Landschaft does not delineate some known sandy areas (e.g. O. Belyy).**
- **Broad river channels have highest NDVI despite large amount of lakes in the valleys.**
- **1-km data is not fine enough to resolve the greening patterns within the highly eroded upland areas.**



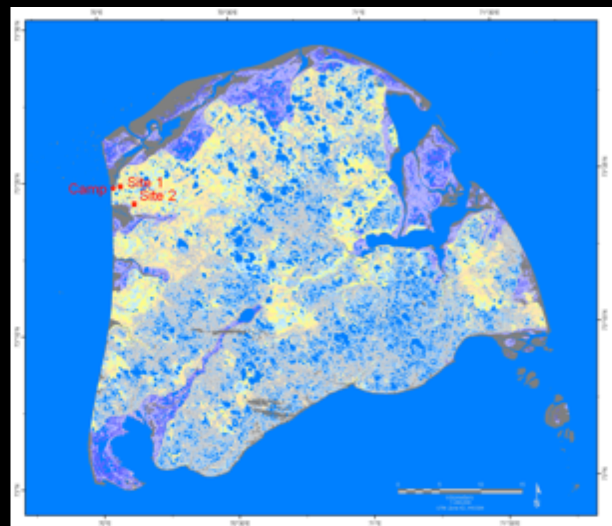
Courtesy of M.K. Raynolds. 2010.

Enhanced TM (15-m) derived maps of Ostrov Belyy

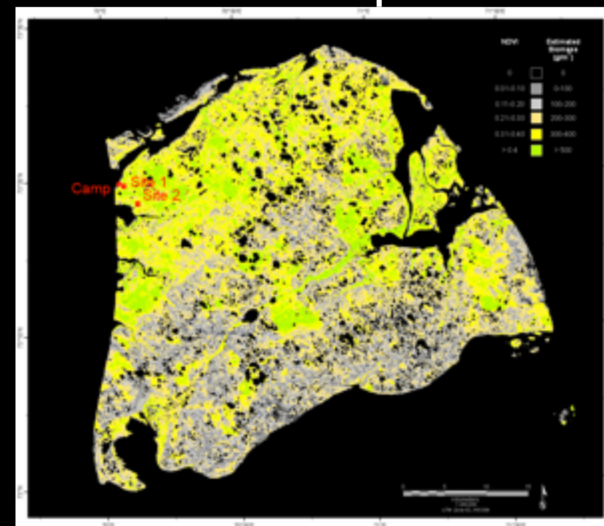
False-color image



Land-cover map



NDVI map

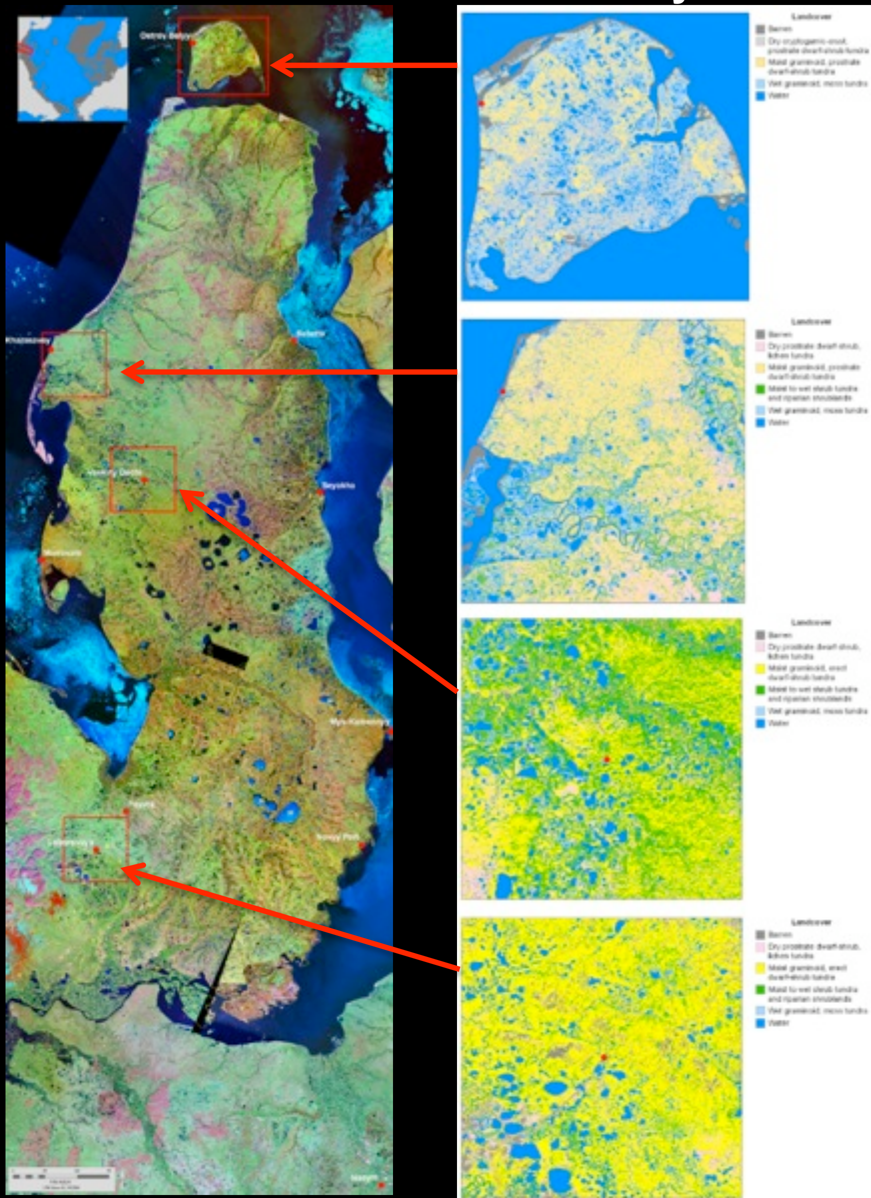


- **15-m resolution panchromatic band is used to enhance the 30-m resolution TM data.**
- **Single ETM+ scene covers all of Ostrov Belyy.**
- **Unsupervised classification used 15 spectral clusters. Salt marshes classified separately**
- **NDVI map shows clear relationship of productivity with respect soil moisture (predominantly moist loamy soils in the north vs. dry sandy soils in the south).**

Maier and Walker. 2010. Poster at 2^{nd} Yamal LCLUC Workshop

GLS-1990 mosaic

Land-cover maps of Yamal study locations



Maier and Walker. 2010. Poster at 2nd Yamal LCLUC Workshop

Land-cover mapping with 30-m Landsat TM data

- Landsat mosaic provides intermediate-resolution terrain information of the whole peninsula.
- Mosaic is composed of many scenes with different acquisition dates (May to September). Difficult to get consistent land-cover classification or MaxNDVI for the whole peninsula because of different phenology of scenes.
- However, Land-cover maps could be produced separately for each LCLUC location.
- May be possible to get consistent classification for whole area by combining all decadal and mid-decadal mosaics to get one coverage displaying MaxNDVI for all pixels

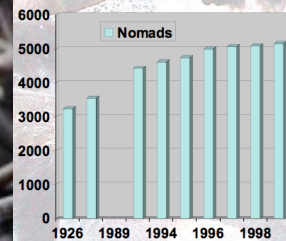
The Nenets people and their reindeer

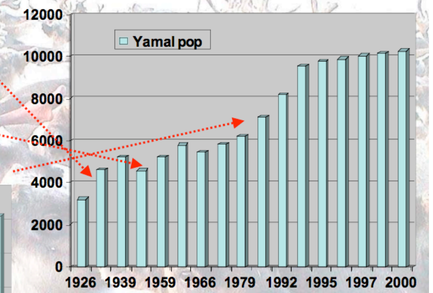
Increase of humans on Yamal

Euro-Nentsy escape to Yamal, early 1930s,

'Dekulakization' and prosecution of shamans under Stalin

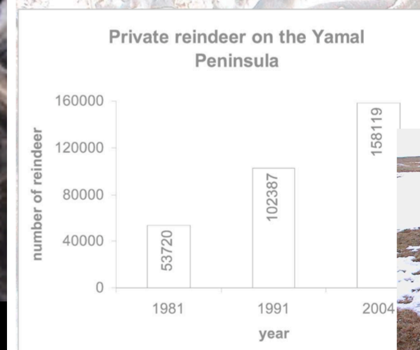
Steady growth after sovkhoz system stabilised





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???

Florian Stammler: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008; Central photo: D.A. Walker.

300,000 reindeer on the Yamal

- **Effects on reindeer on NDVI are unknown at present because of lack of control areas to study the effects (exclosures).**
- **Potential major effect in sandy areas.**

Photos: Bruce Forbes.

High-ice Permafrost Landscapes

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

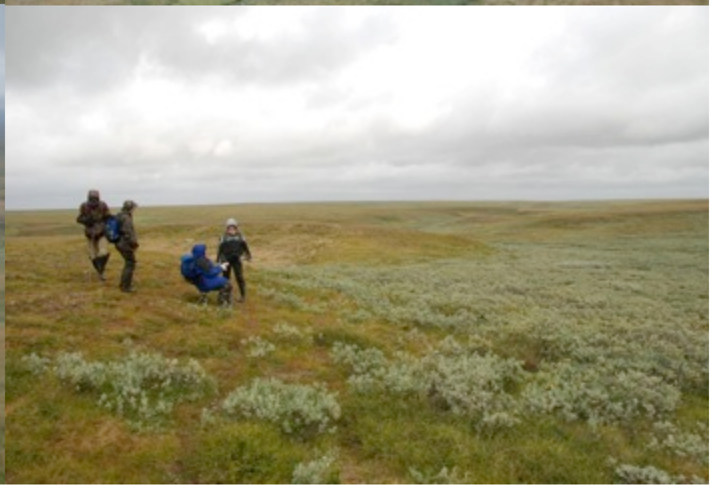
2. Underlain by permafrost with massive pure ice.

3. Extensive landslides are rapidly eroding the landscape.

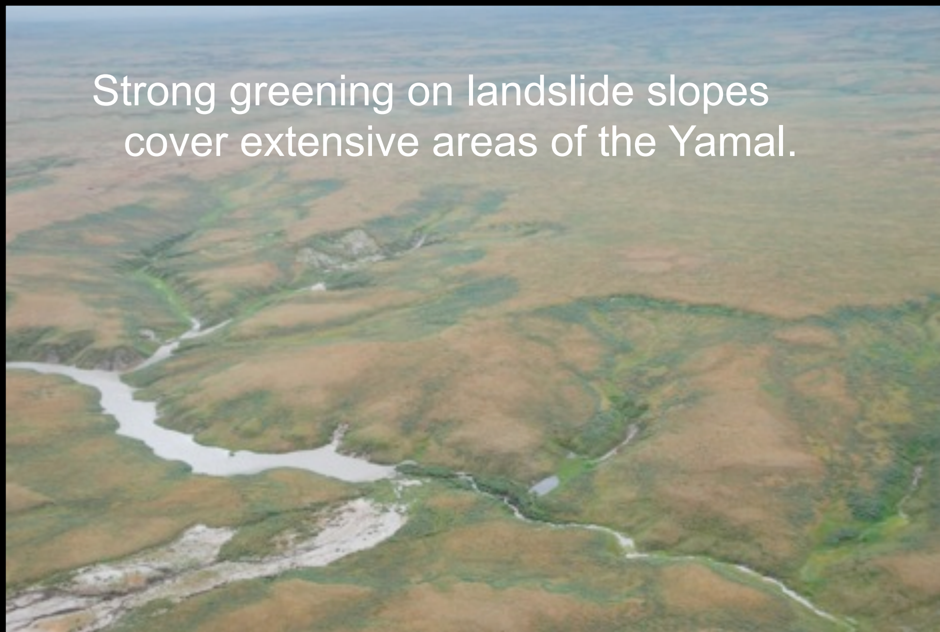
4. This exposes salt-rich and nutrient-rich clays.

5. Complex vegetation succession process that results in willow-shrub tundra and much greener vegetation in the eroded valleys.

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

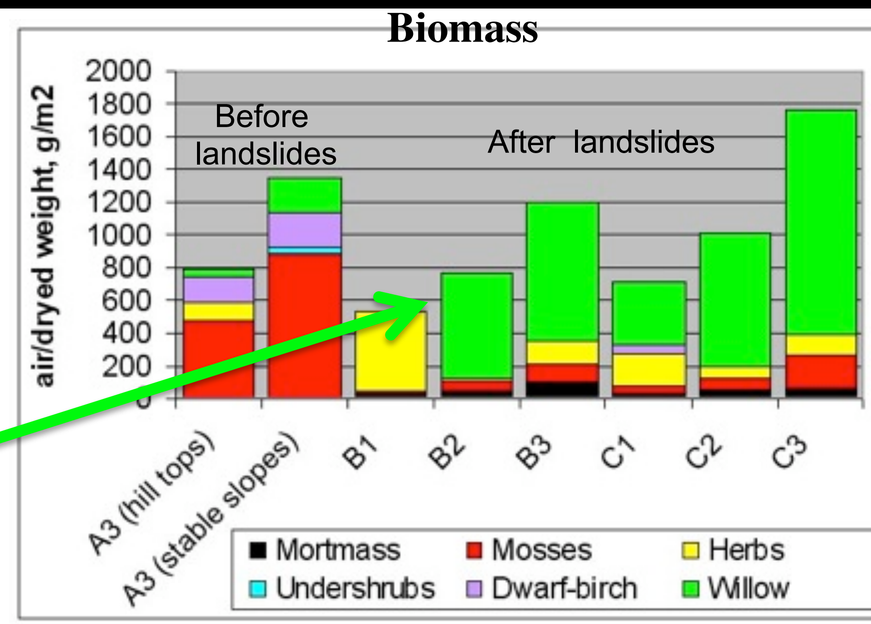


Greening associated with eroded sandy uplands



Landslides and cryogenic erosion

- **Large effect on patterns of greenness in many areas.**
- **Need temporal series of high-resolution satellite images and/or photos in landslide areas to assess the rate of change.**



Key:
A – stable areas
B – shear surface
C – landslide body

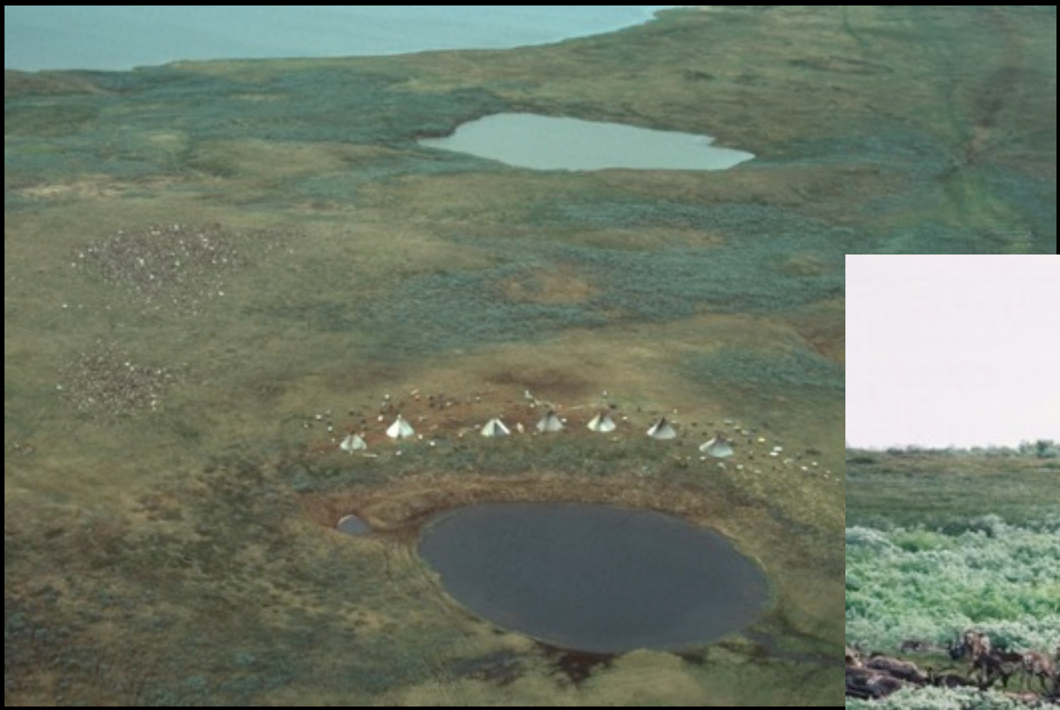
1 – young landslide
2 – old landslide
3 – very old landslide

Ukraintseva and Leibman et al.
2000, 2007, 2008

Erosional patterns are clearly discernable on new GeoEye scene.

0.41 m resolution should permit analysis of rate of erosion and related greening.

The changes in willow growth are affecting reindeer management.



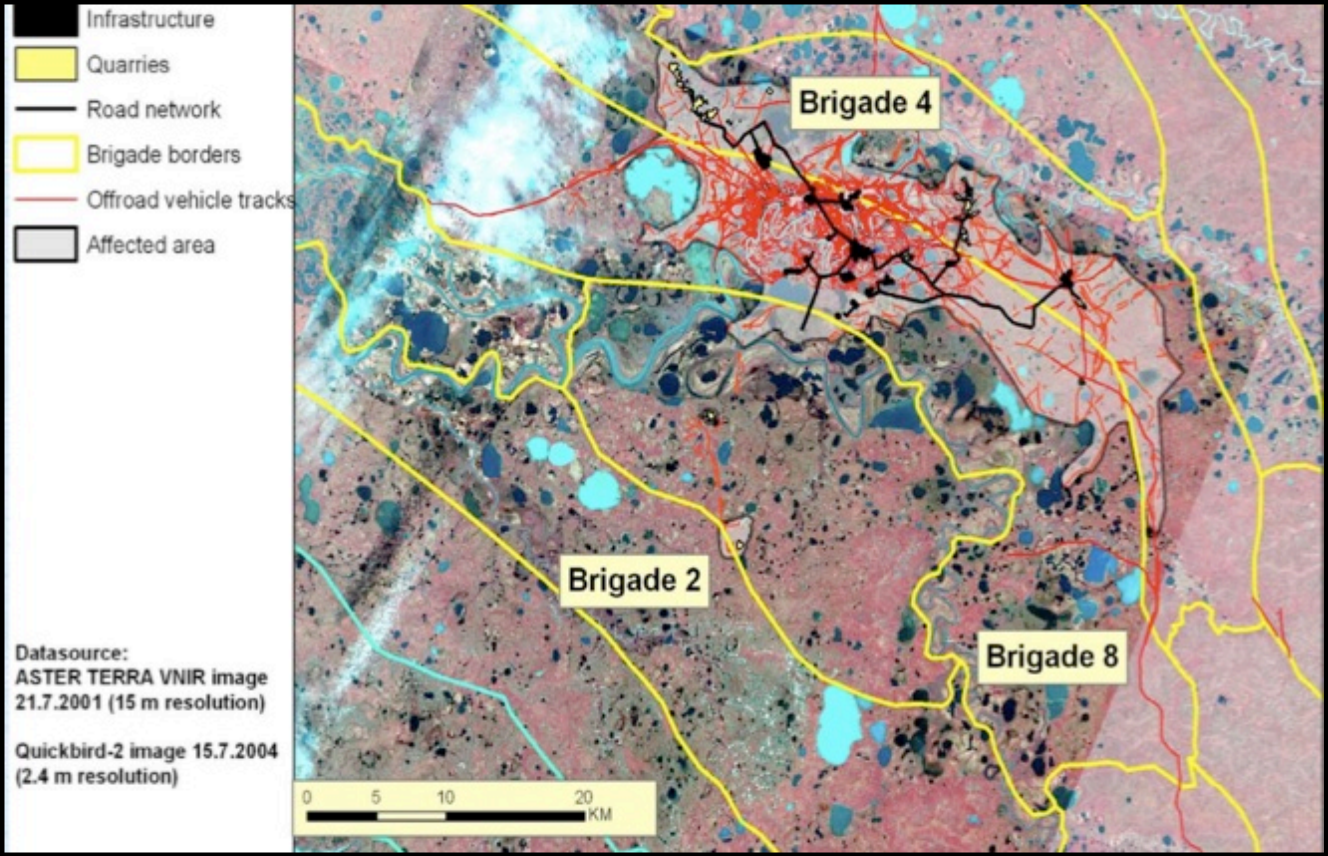
Nenets camp on Yamal in *Salix* low shrub tundra

Reindeer grazing *Salix* thickets in Nenets Okrug. If they grow over ≈ 2 m high, herders can lose sight of animals.

Forbes et al. 2009 *PNAS*, ENSINOR project
Photos courtesy of Bruce Forbes.

Other factors affecting greening patterns: Impacts of gas development

- Locally important but still relatively small extent.
- Need development scenario models to help predict and plan for expansion of road networks.



Timo Kumpula: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

EAT data reports

Descriptions of each study location
- General description of the region and study sites
- Physiography and geology
- Climate summary

Transect data
- Plant species cover
- LAI
- NDVI
- Thaw depth
- Photos of transects

Relevé data
- Cover abundance of plant species
- Soil chemical and physical data
- Site factors
- Biomass by plant functional type
- Photos of relevés

Soil pits
- Descriptions
- Photos

Toward a synthesis of the two transects

Although the research along the two transects had different objectives. There is a common primary data set from both transects:

1. Vegetation, soils, and site factors from zonal vegetation along the complete Arctic bioclimate gradient.
2. Ground measurements of key plant productivity variables: biomass, LAI, and NDVI.
3. A circumpolar remote-sensing data set that contains vegetation, land temperatures, and NDVI data for both transects <u>and</u> changes in NDVI since 1982.

This allows us to compare the spatial and temporal trends in vegetation, biomass, and NDVI between the two transects in response to ongoing changes in climate and land-use.

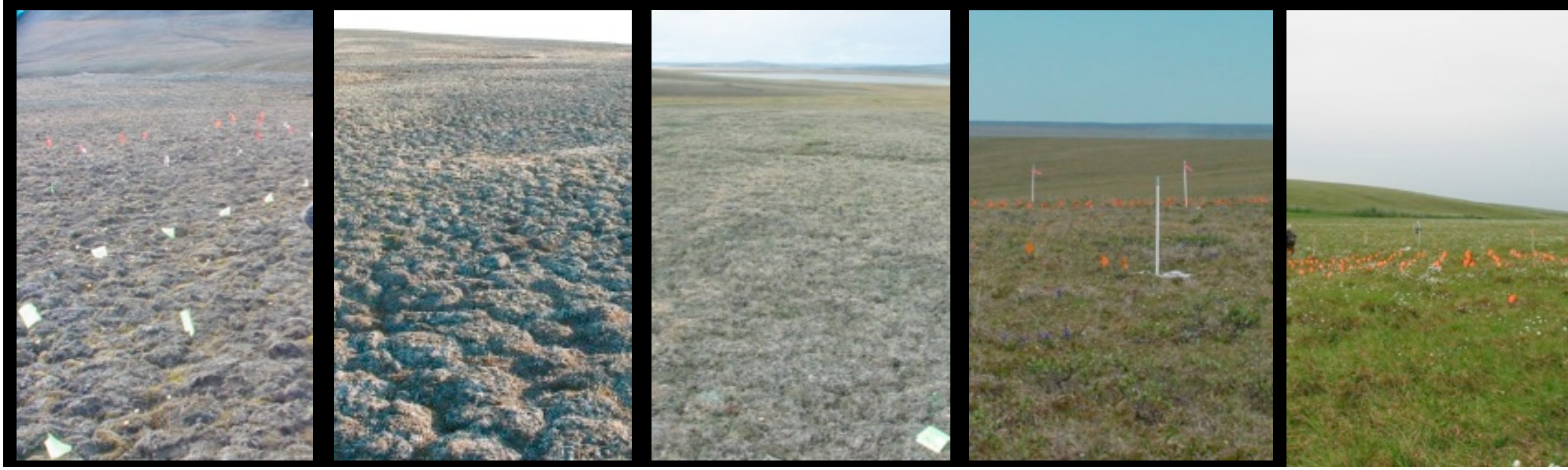
Zonal vegetation along both transects

Eurasia Transect

A - Hayes Island B - Ostrov Belyy C – Kharasavey D - Vaskiny Dachi E - Laborovaya

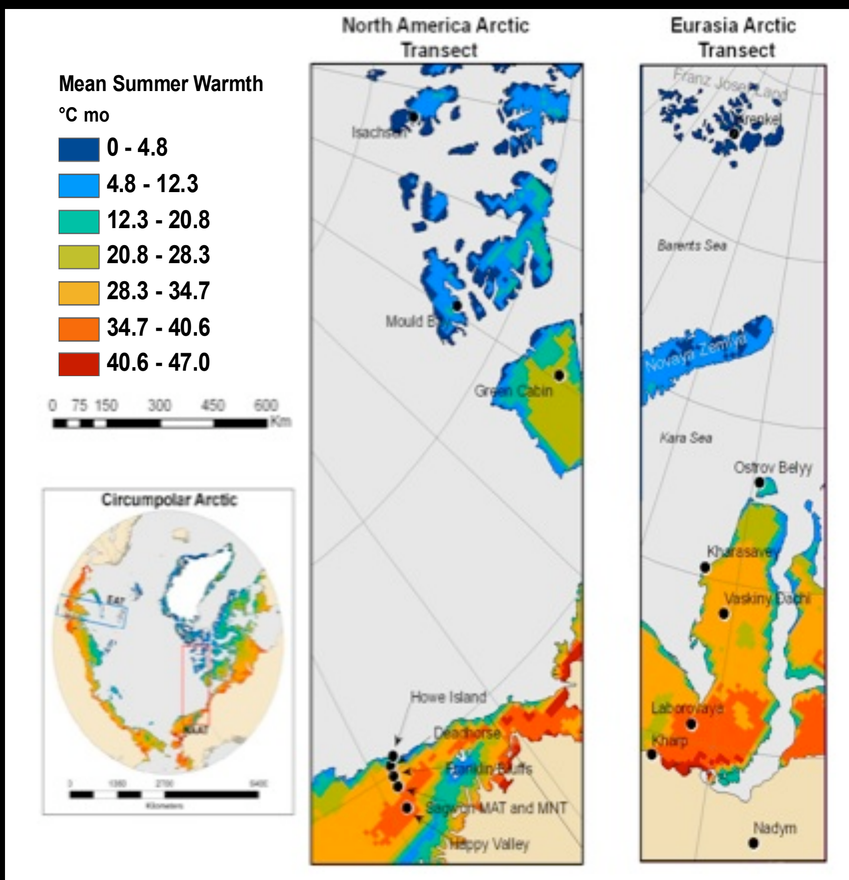
North America transect

A - Isachsen B- Mould Bay C - Green Cabin D - Sagwon MNT E - Happy Valley

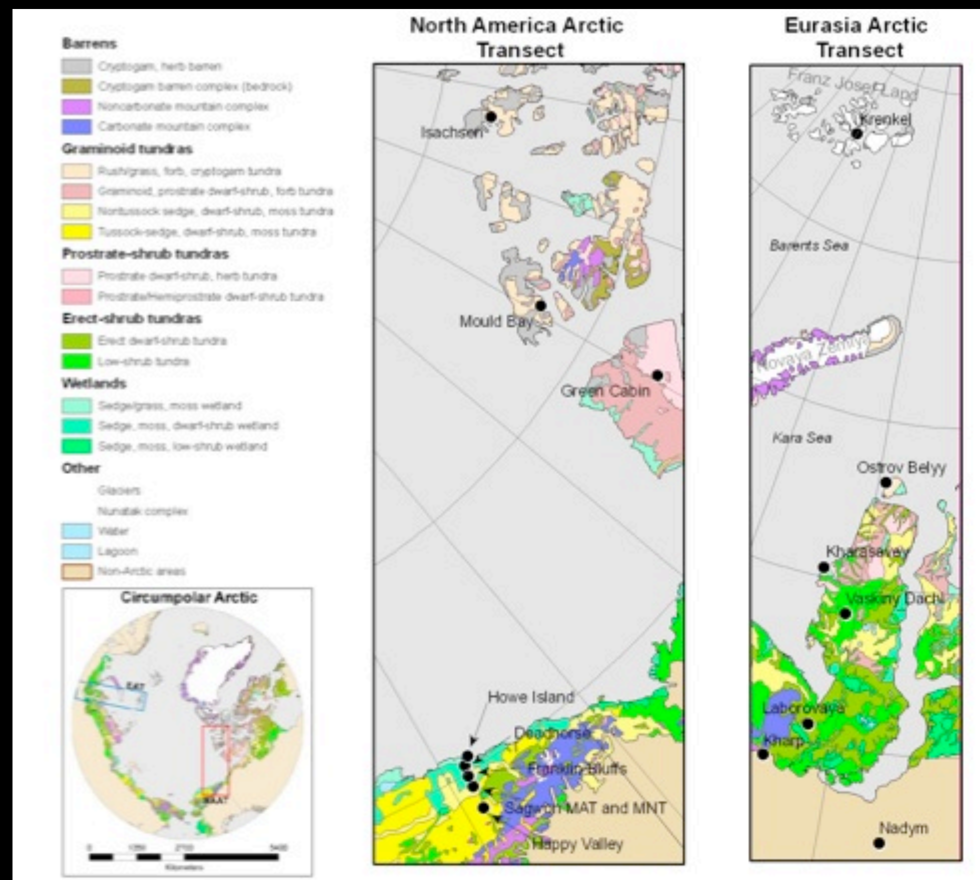


Variation in summer land temperature and vegetation along the transects

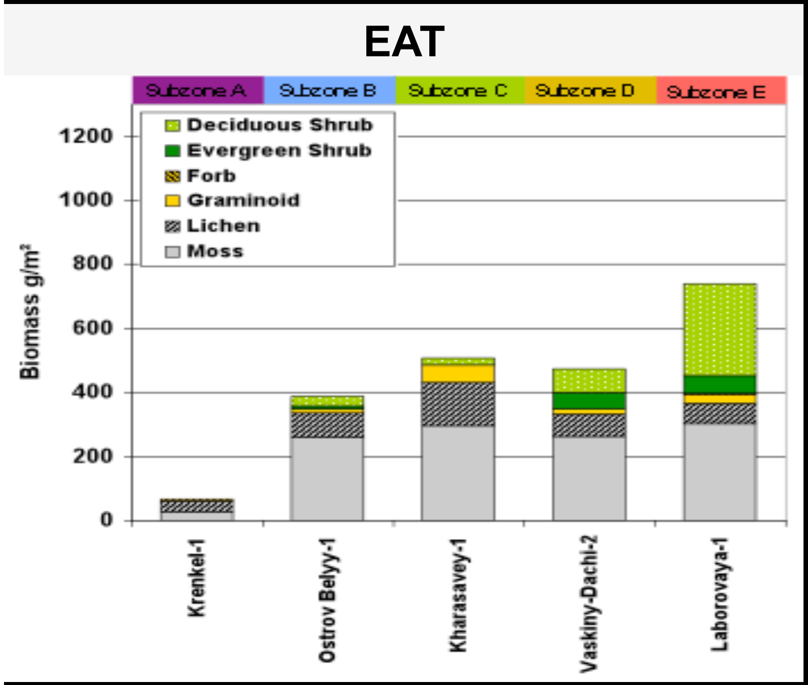
Summer Warmth Index

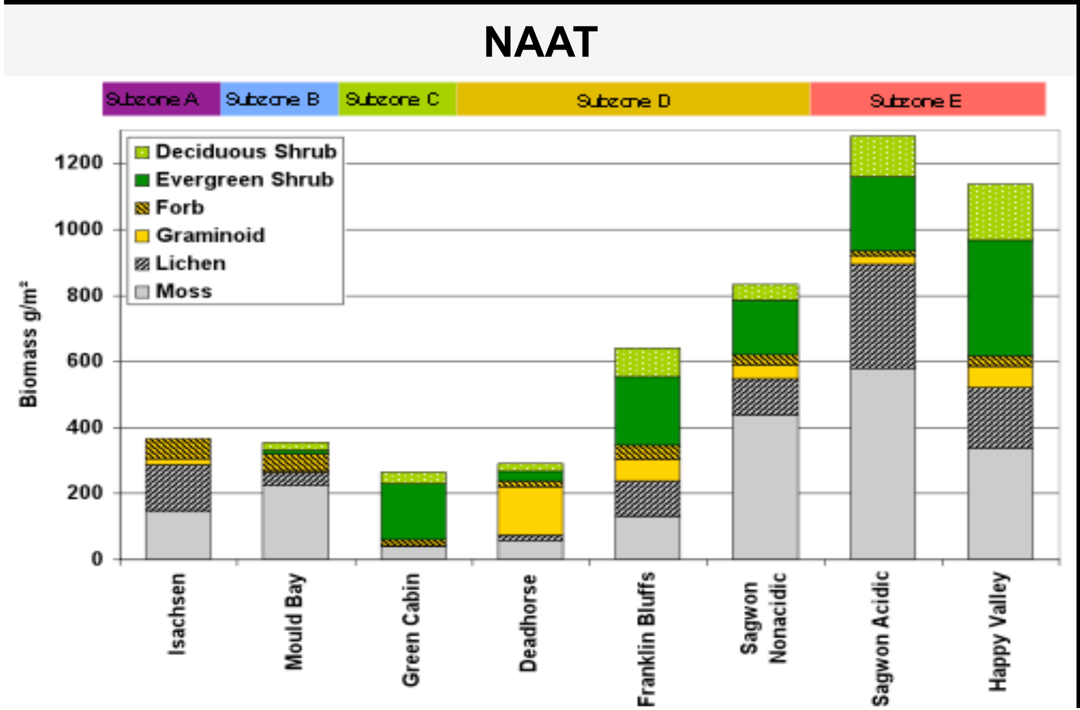


Vegetation (CAVM Team 2003)



Plot-level biomass trends along the EAT and NAAT

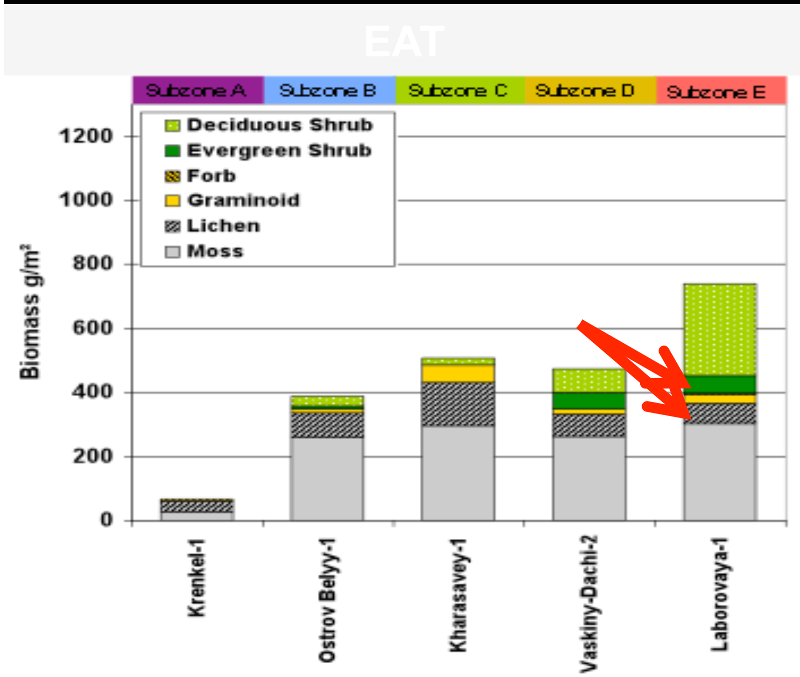


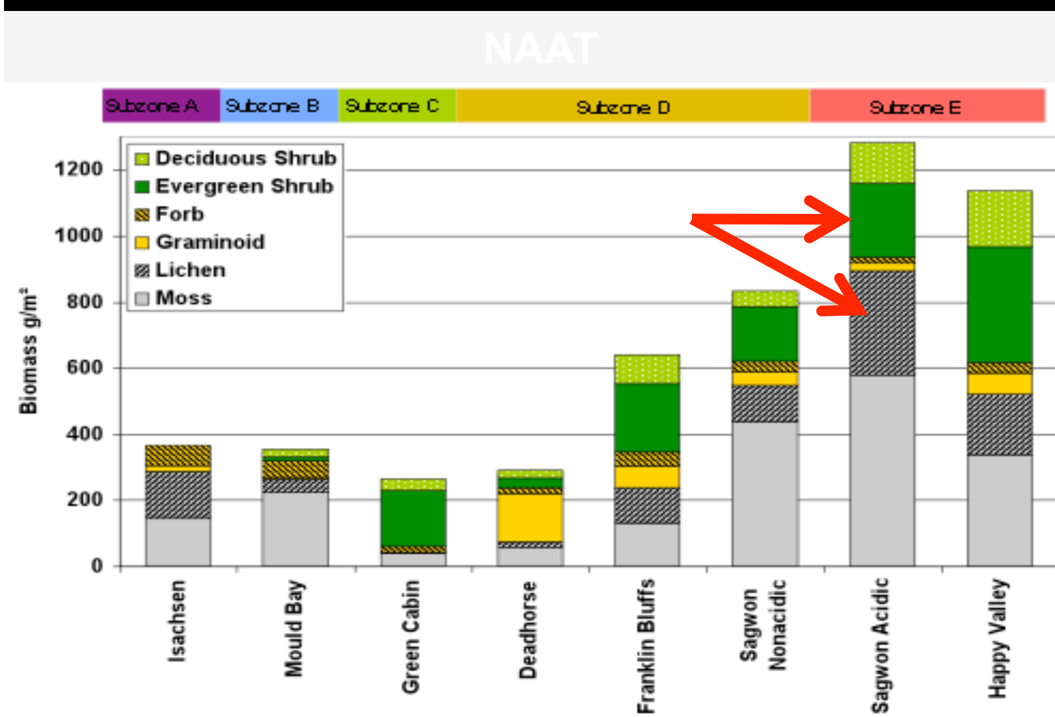


Differences between the transects:

- EAT has less biomass in subzone A (Wetter, much colder).
- EAT has more biomass in subzone C, (Wetter, unglaciated, more nutrients?)
- EAT has much less biomass in subzone E (grazing effect?).

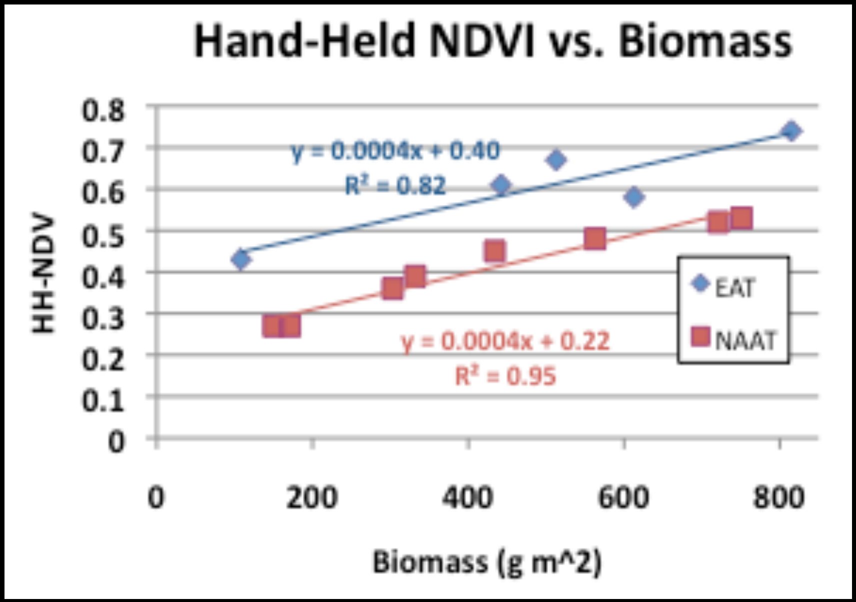
Differences between EAT and NAAT

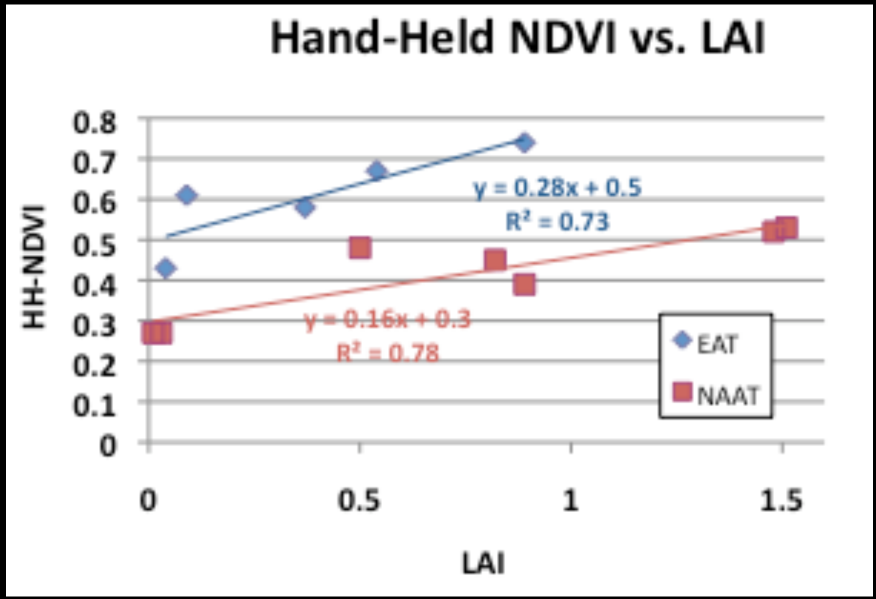




- Fewer evergreen shrubs and lichens along the EAT especially in subzones D and E. (Reindeer?)

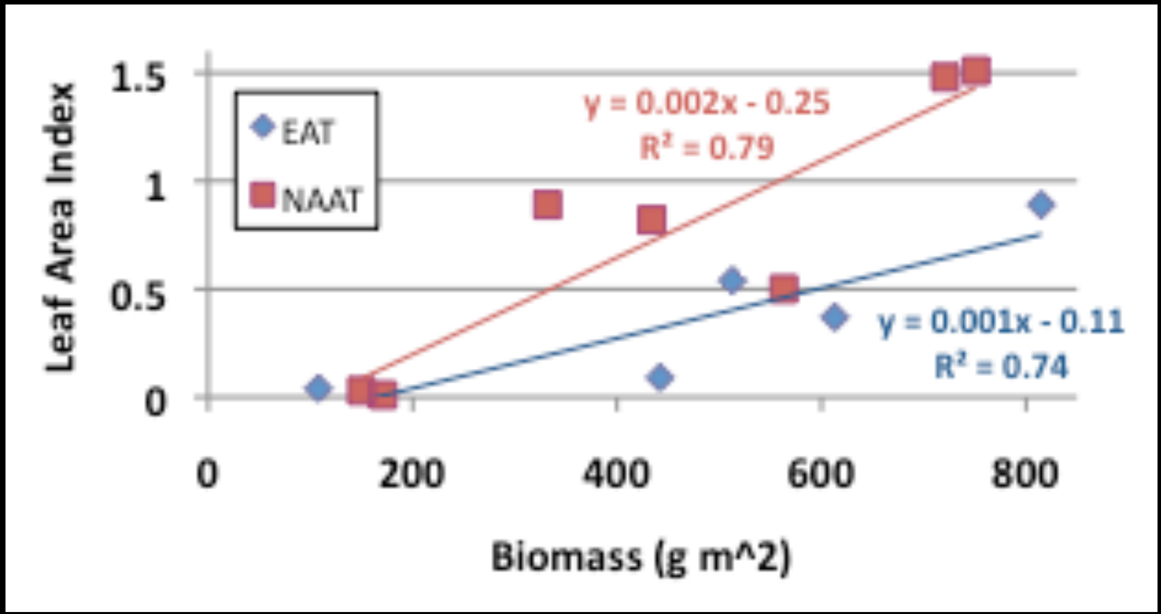
Comparison of EAT and NAAT
Hand-held NDVI vs. biomass, and LAI





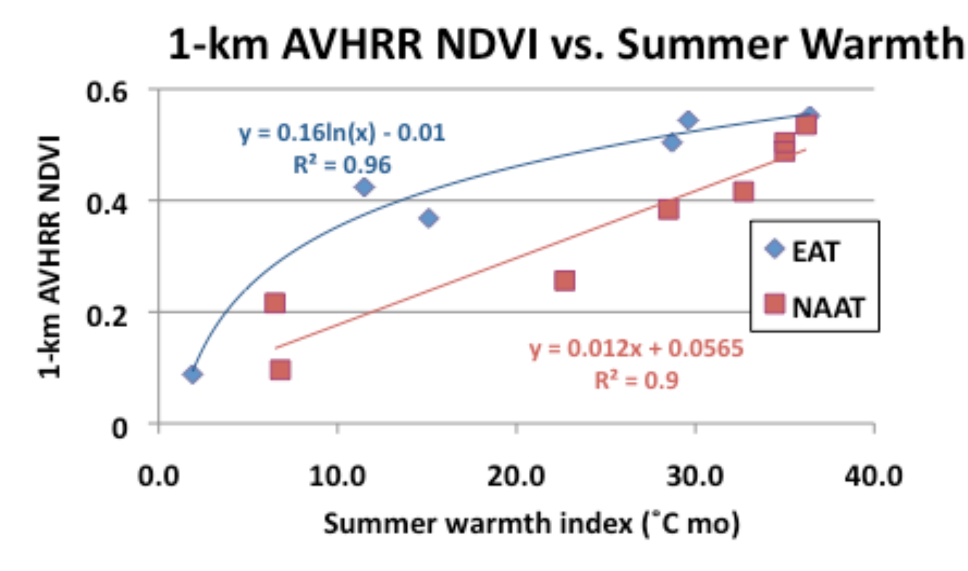
- For equivalent amounts of biomass and LAI, the HH-NDVI readings were much higher along the EAT.

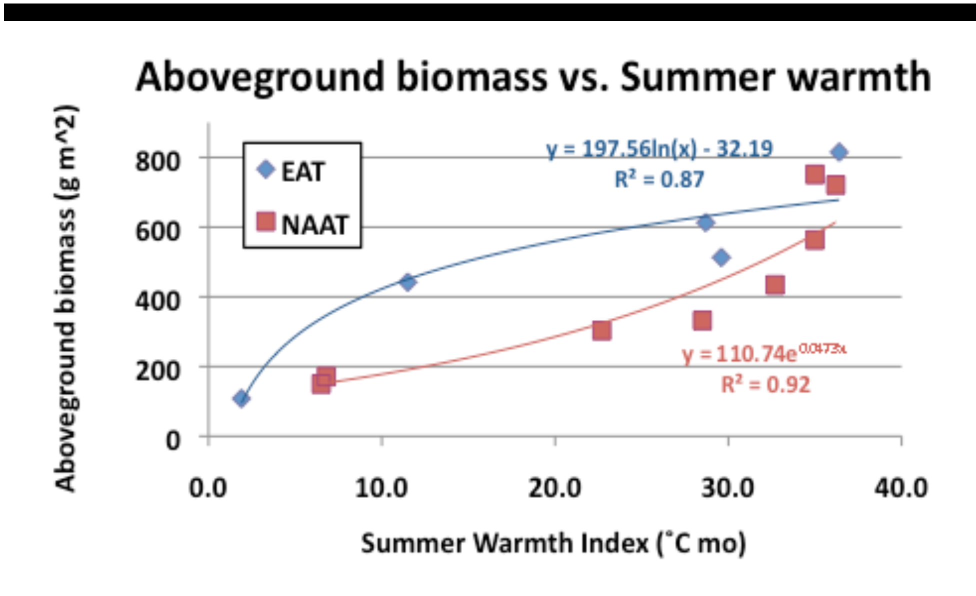
Comparison of EAT and NAAT Leaf Area Index vs. Biomass



- **An equivalent amount of biomass has consistently much higher LAI values along the NAAT than along the EAT and the difference increases at higher biomass values.**
- **Reflects the different structure of the vegetation along the two transects. Higher proportion of the total biomass is non-green along the NAAT (more wood, taller plants?).**

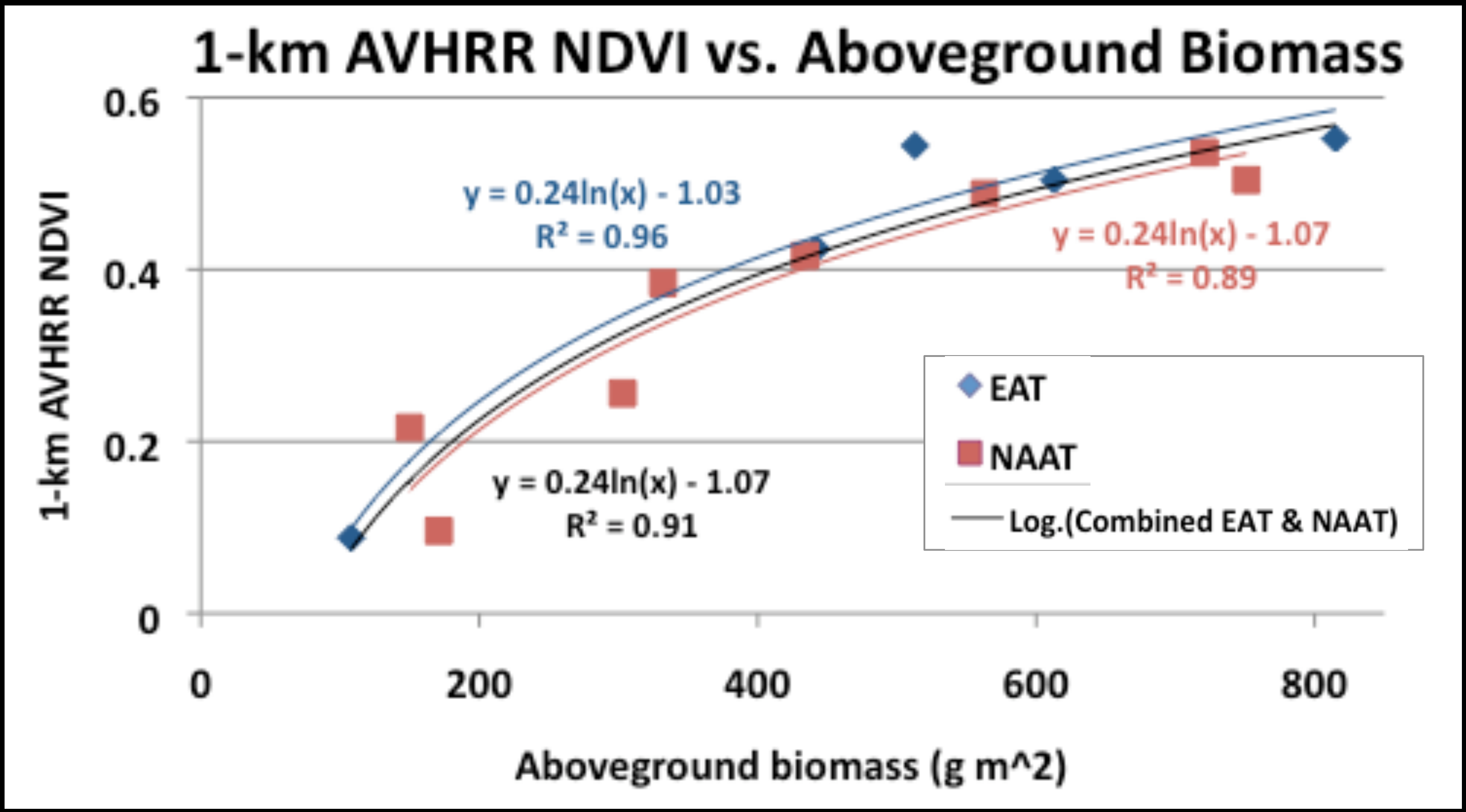
Comparison of EAT and NAAT
1-km AVHRR NDVI & biomass, vs. summer warmth index





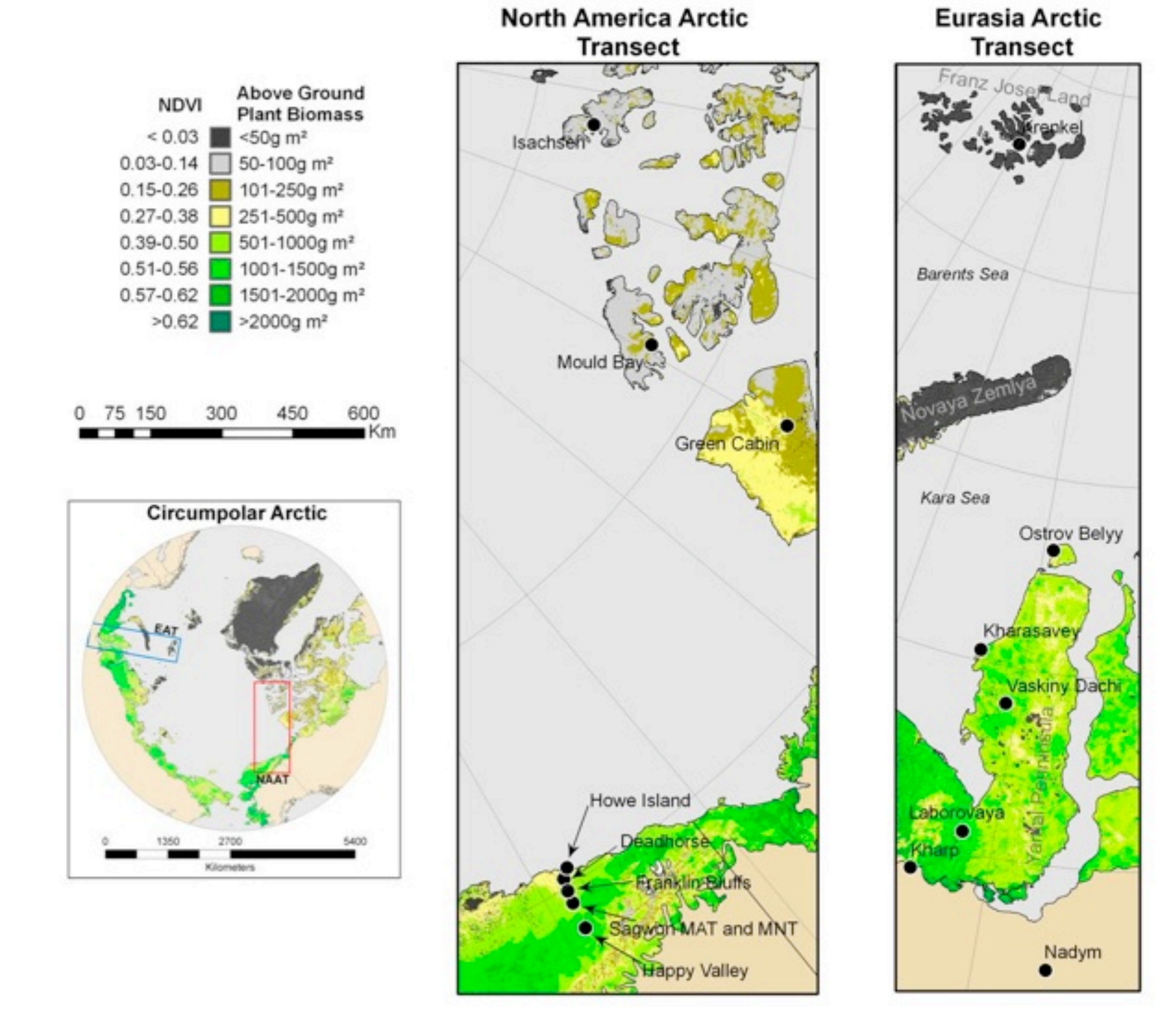
- Biomass values are landscape-level averages for zonal landscapes.
- Greater biomass and NDVI for equivalent temperature along the EAT compared to NAAT.
- EAT is greener in equivalent summer climates.

Comparison of EAT and NAAT: 1-km AVHRR NDVI and zonal landscape-scale biomass

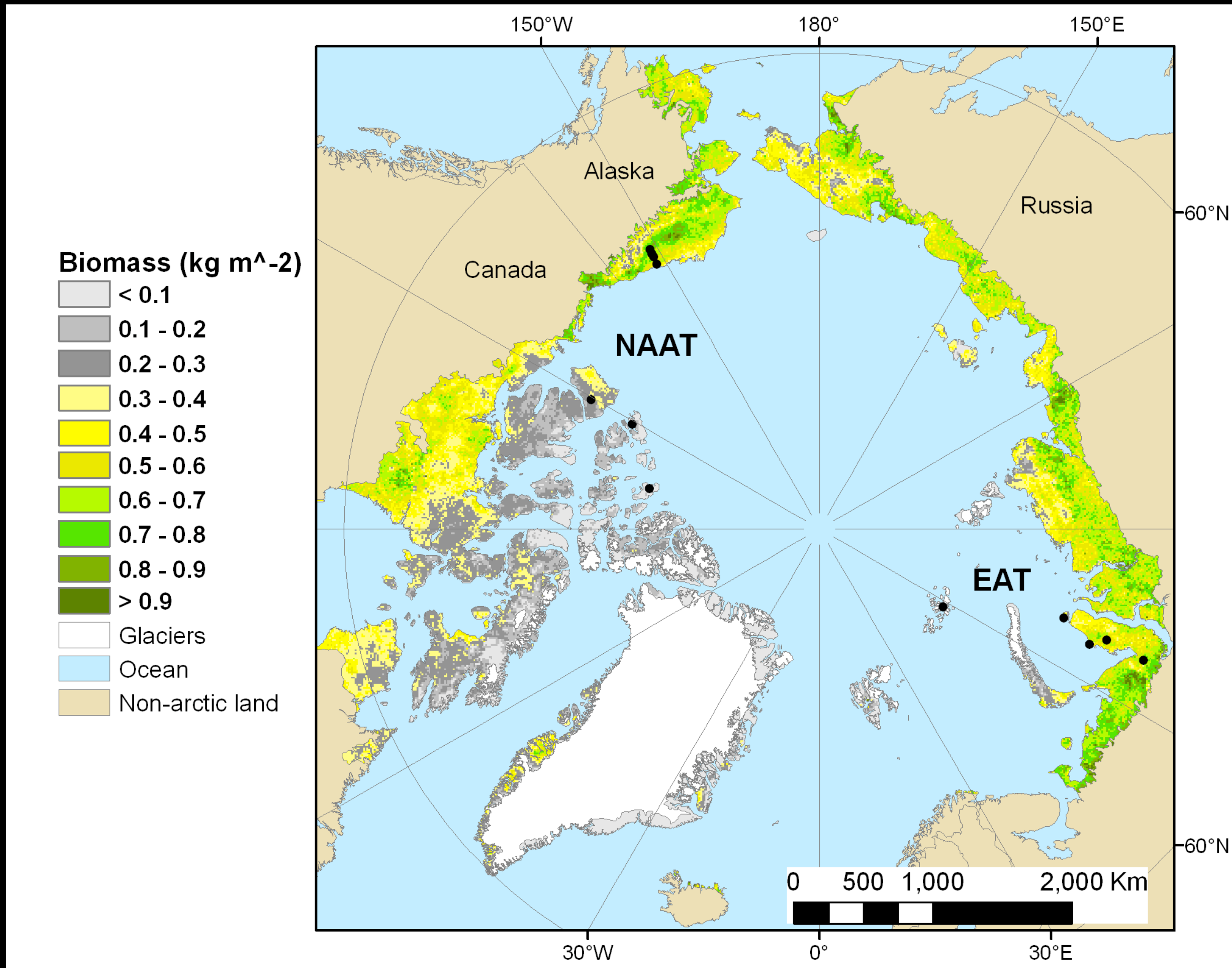


- Very strong correlation between AVHRR NDVI and biomass along both transects and for combined data set.

Use of ground data to calibrate regional AVHRR-NDVI /biomass data

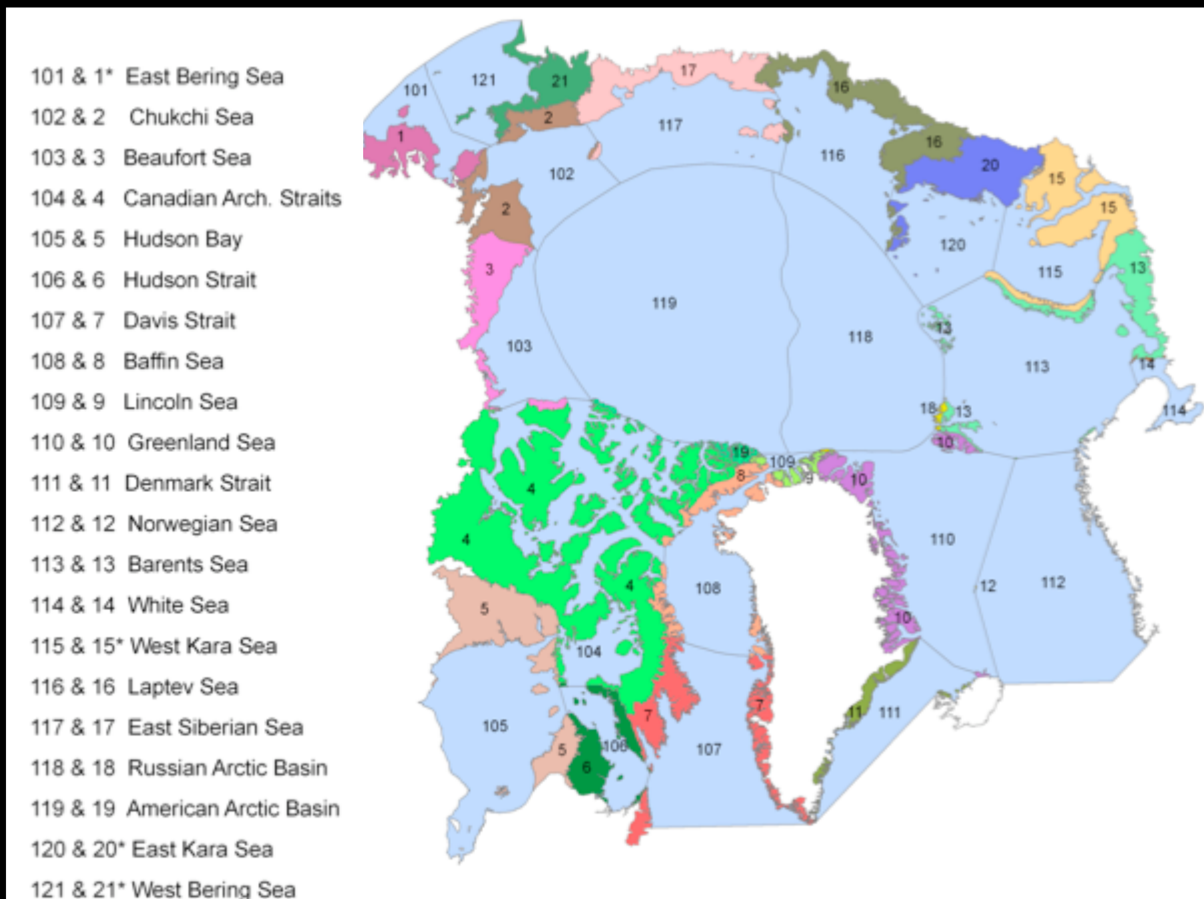


Circumpolar aboveground biomass derived from NDVI



Raynolds et al. 2011 submitted, Geophysical Research Letters

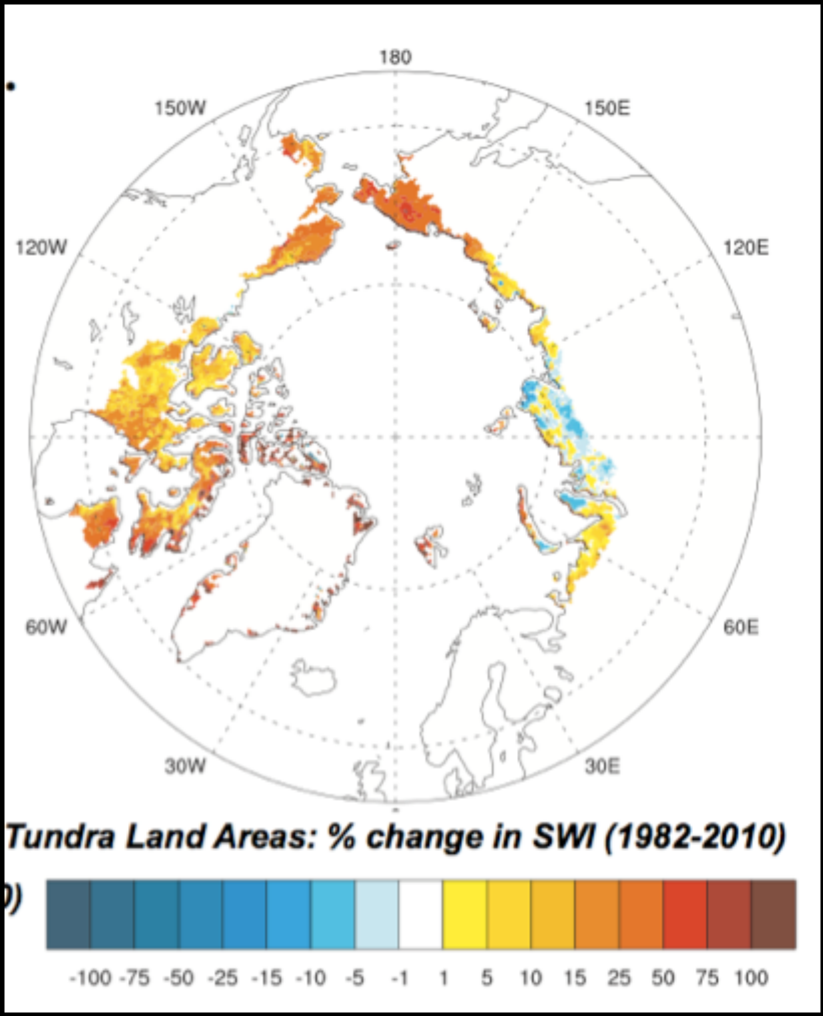
Temporal analysis of circumpolar change: Study Framework: Division of Arctic Ocean and associated land masses

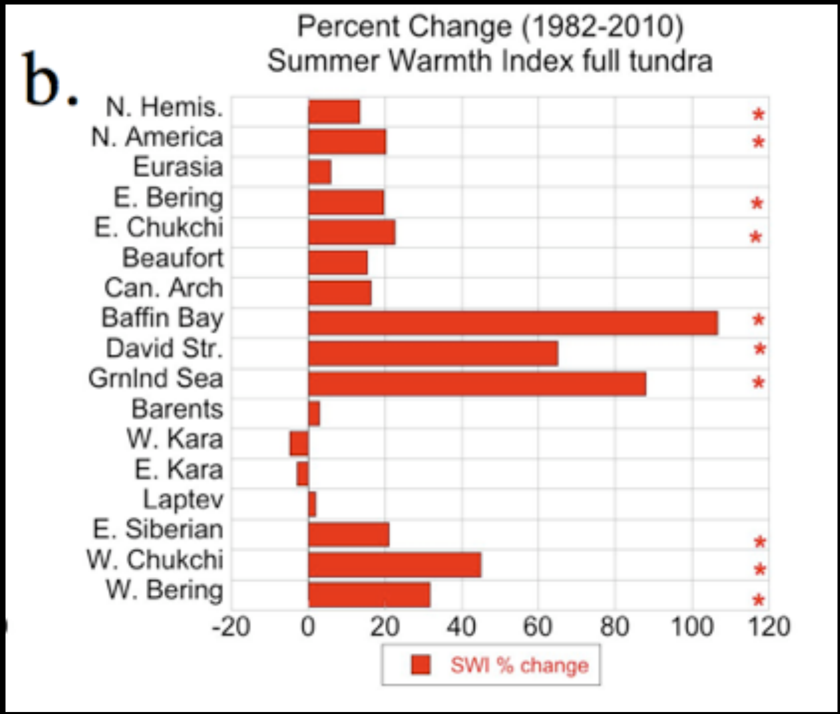


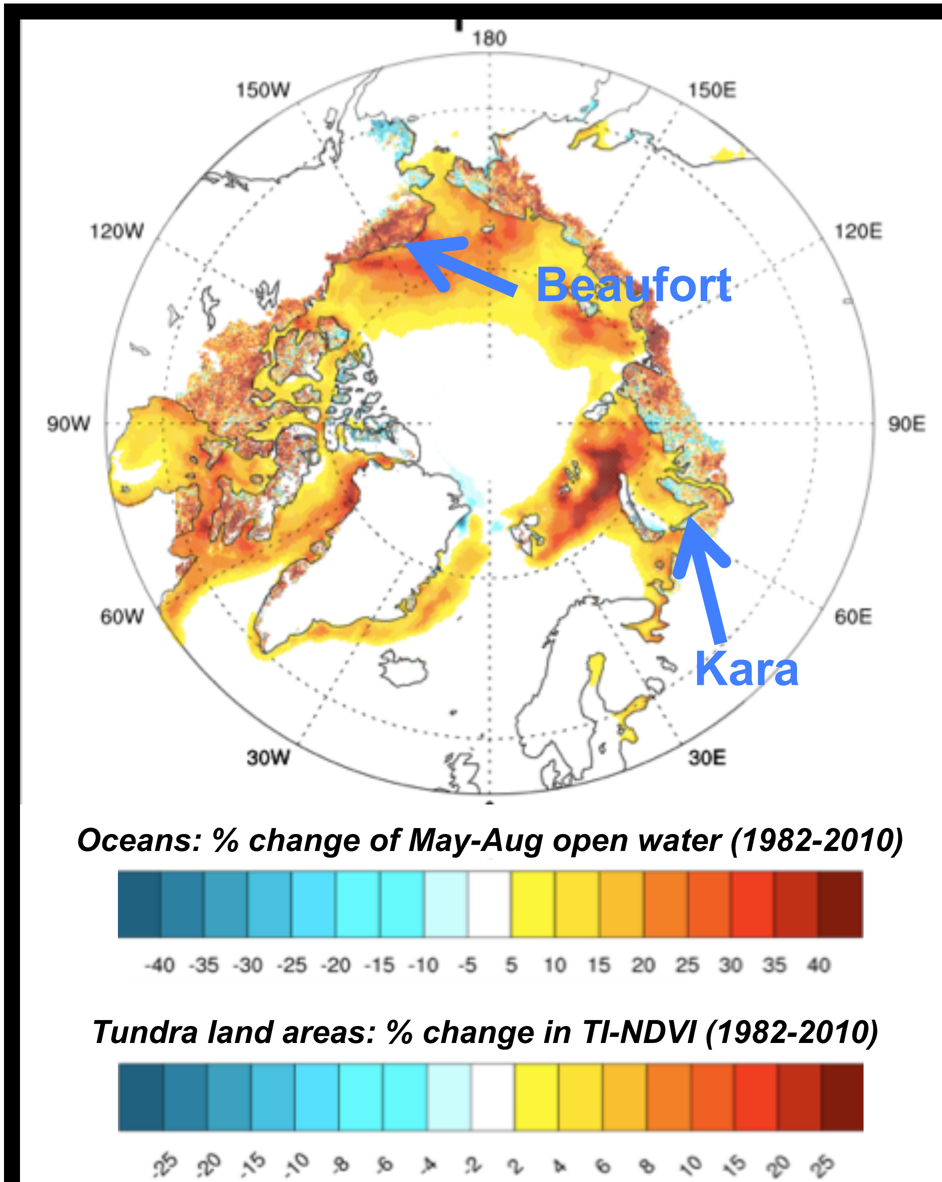
- **Russian Arctic Atlas for seas.**
- **CAVM Florist provinces for land masses.**
- **Analysis of 50-km buffers seaward and landward along each sea coast and also for entire non-alpine tundra area.**

Uma Bhatt, D.A. Walker, M.K. Raynolds, J. Comiso, H.E. Epstein, G.J., Jia, J. Pinzon, and C.J. Tucker, 2010, Earth Interactions.

Changes in summer land-surface temperature (1982-2010)







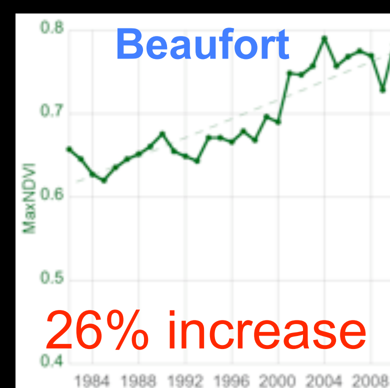
From Bhatt et al. 2010, *AGU Fall Meeting*

Temporal patterns of NDVI in relationship to changes in area of summer open water

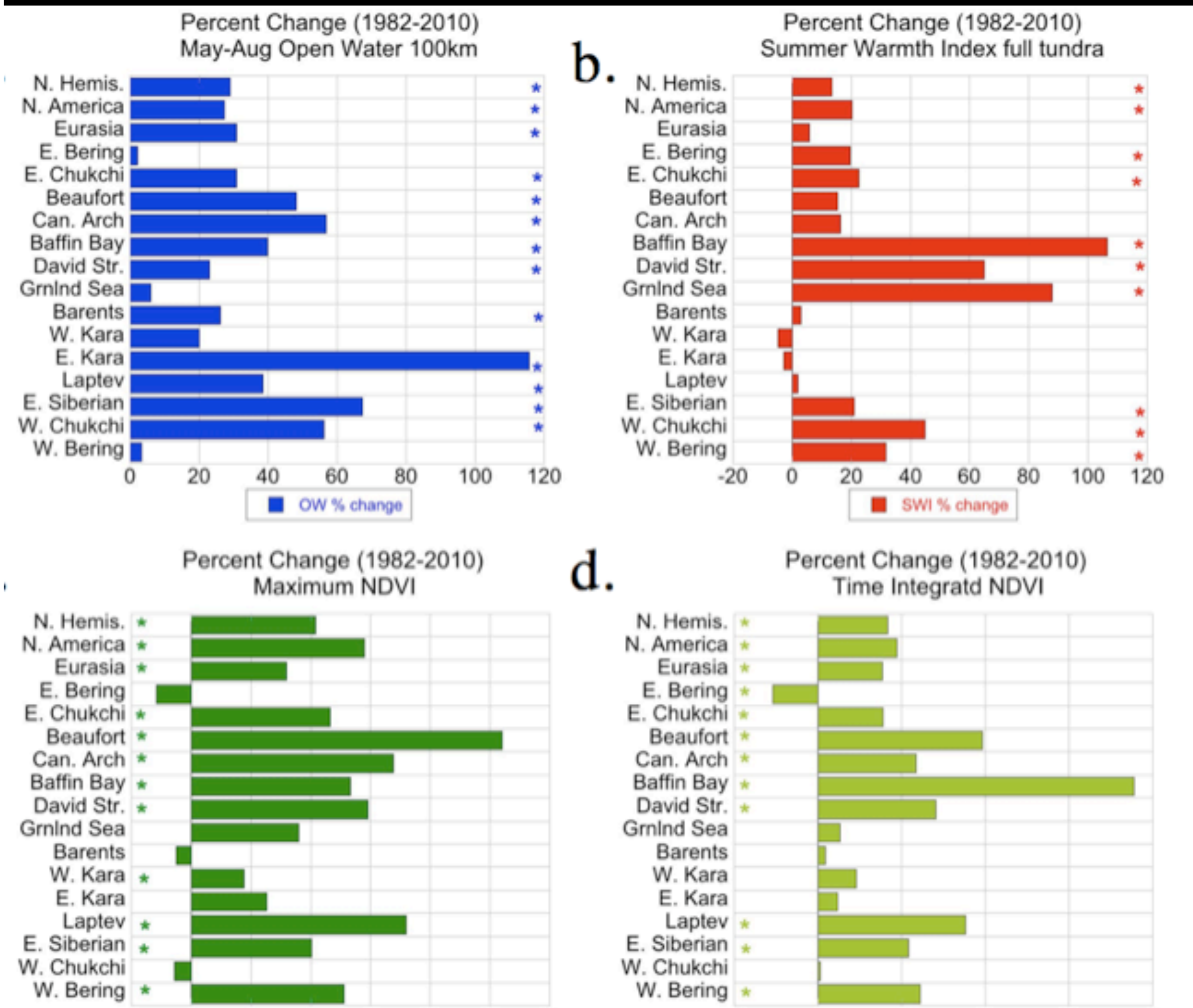
Walker et al. 2011. *Bulletin American Meteorological Society.* State of the Climate.

New analysis based on new GIMMS 3g AVHRR NDVI data by Pinzon et al. 2010 (in progress) and sea ice data by Comiso et al. 2010.

Pct. Change MaxNDVI (1982-2010)



Percentage change (based on least squares fit method) in coastal open water, land temperatures, and NDVI and significance of trends



Walker et al. 2011, BAMS State of the Climate, in prep.

- **In general, areas of enhanced NDVI patterns are corresponding to areas of warmer land temperatures.**
- **The connections between land warming and more open water are less clear in 2010 than they were previously.**
- **Cooling in the Kara region despite very large increases in open coastal water (more fog, more winter precip. Shorter growing seasson?)**

There still 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.

This is changing. In the past year, there have been several major syntheses from international research projects that are examining change. And these will be published soon.

This study has shown:

- The feasibility of studying and monitoring zonal landscape-level biomass and NDVI across the full Arctic bioclimate gradient at a circumpolar scale.

- Broad similarities in biomass between North America and Eurasia along the Arctic temperature gradient, but also major differences related to different disturbance regimes, geology, and precipitation patterns. Very good correlation between AVHRR NDVI and zonal landscape-level biomass.

- Strong linkages between change in NDVI and summer land temperatures, but weaker linkages with coastal sea-ice concentrations.

- Good start, but more replication is needed for ground observations in all subzones along both gradients. And more long-term studies of biomass trends are needed.

Collaborations

Institutions:

– University of Alaska
– University of Virginia
– Earth Cryosphere Institute (RAS),
– Arctic Centre, Rovaniemi

Funding

* U.S.: NSF, NASA
* Finland: ENSINOR
* Russian Academy of Science

Děkuji!

Members of 2010 Expedition to Hayes Island