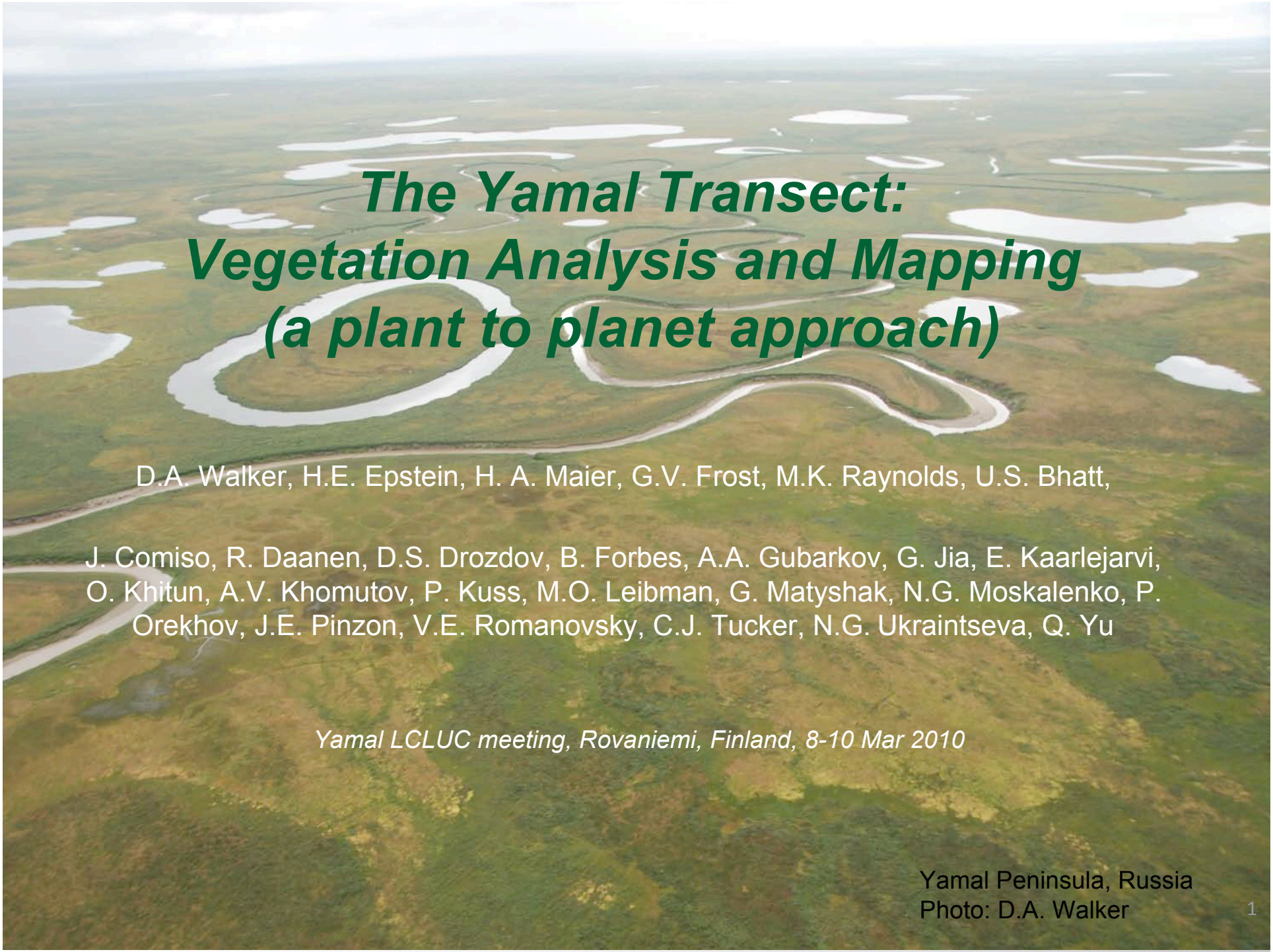


The Yamal Transect: Vegetation Analysis and Mapping (a plant to planet approach)

D.A. Walker, H.E. Epstein, H. A. Maier, G.V. Frost, M.K. Raynolds, U.S. Bhatt,

J. Comiso, R. Daanen, D.S. Drozdov, B. Forbes, A.A. Gubarkov, G. Jia, E. Kaarlejarvi, O. Khitun, A.V. Khomutov, P. Kuss, M.O. Leibman, G. Matyshak, N.G. Moskalenko, P. Orekhov, J.E. Pinzon, V.E. Romanovsky, C.J. Tucker, N.G. Ukraintseva, Q. Yu

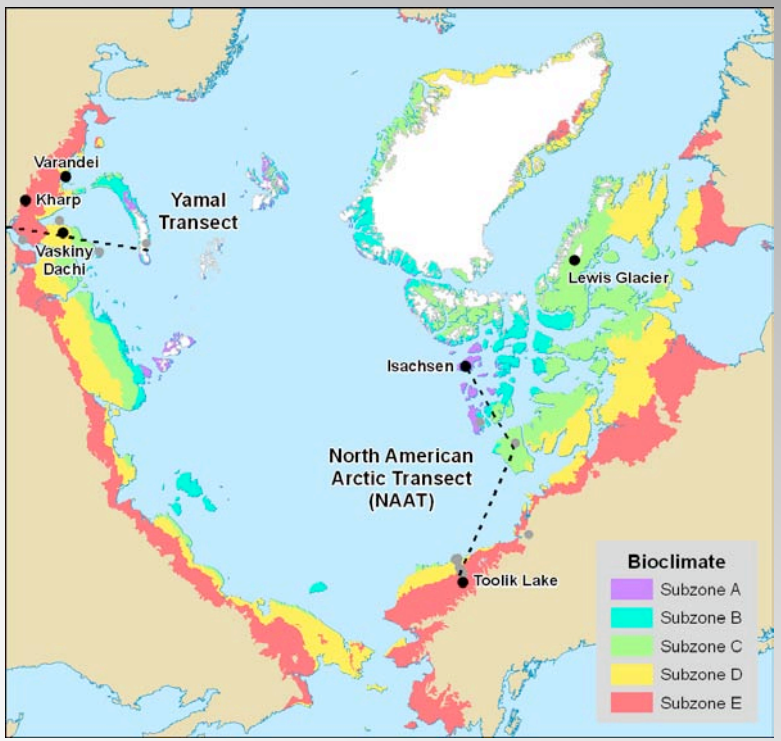
Yamal LCLUC meeting, Rovaniemi, Finland, 8-10 Mar 2010

Yamal Peninsula, Russia
Photo: D.A. Walker

Outline of Talk

- Ground observations along the Yamal transect
  - Data collected and data report
  - Vegetation analysis
- Hierarchy of mapping and NDVI analysis
  - Hand-held measurements of NDVI
  - Quickbird (60-cm resolution)
  - Landsat ETM+ (15 m)
  - Landsat TM (30 m)
  - AVHRR (1 km)
  - AVHRR (12.5 km and 50 km)
- The roles of climate, substrate and disturbance (Walker et al. 2009)

Two transects through all 5 Arctic bioclimate subzones

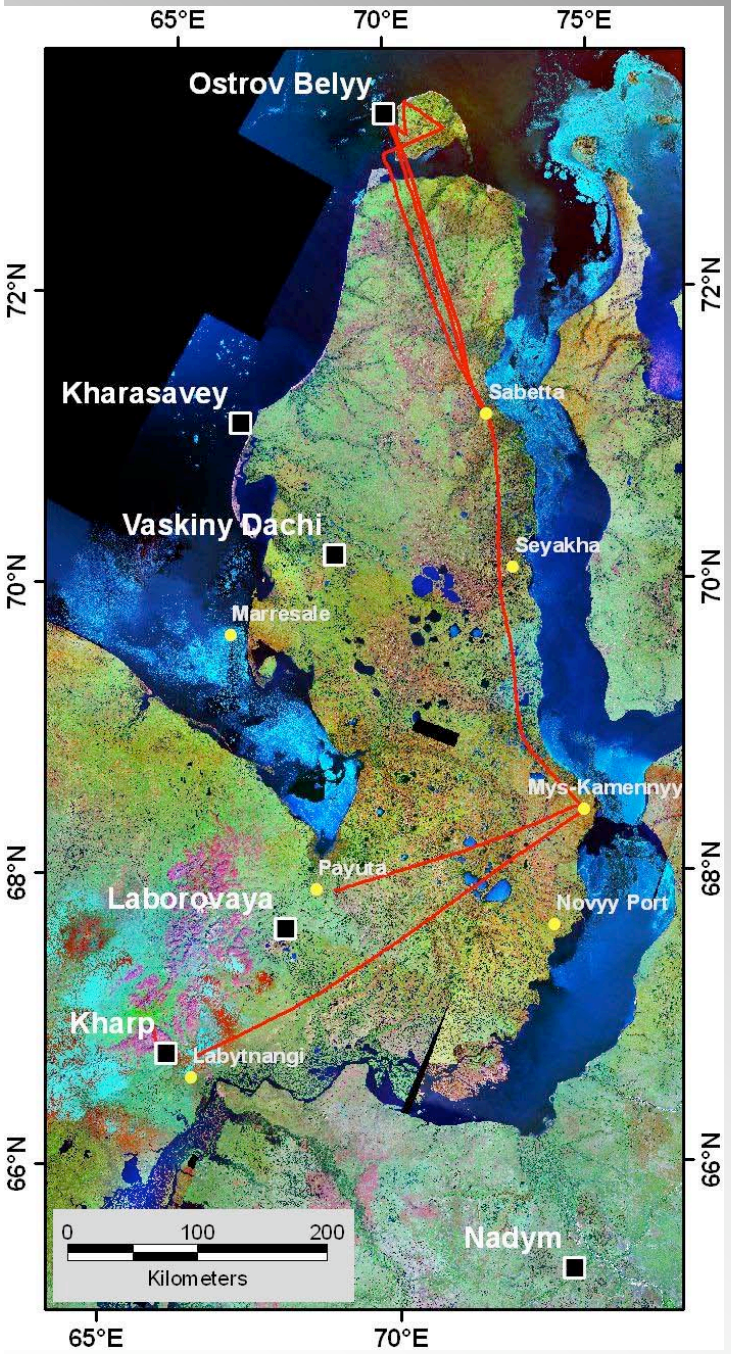


Sub-Zone	MJT	Shrubs
A	1-3 ˚C	none
B	3-5 ˚C	prostrate dwarf-shrubs
C	5-7 ˚C	hemi-prostrate dwarf shrubs
D	7-9 ˚C	erect dwarf-shrubs
E	9-12 ˚C	low-shrubs

Along the tundra bioclimate gradient:

- 10˚ C change in the MJT
- 10-fold change in zonal biomass
- 10-fold change in productivity
- 5 to 10-fold change in vascular-plant diversity

Bioclimate subzones as mapped by CAVM Team 2003

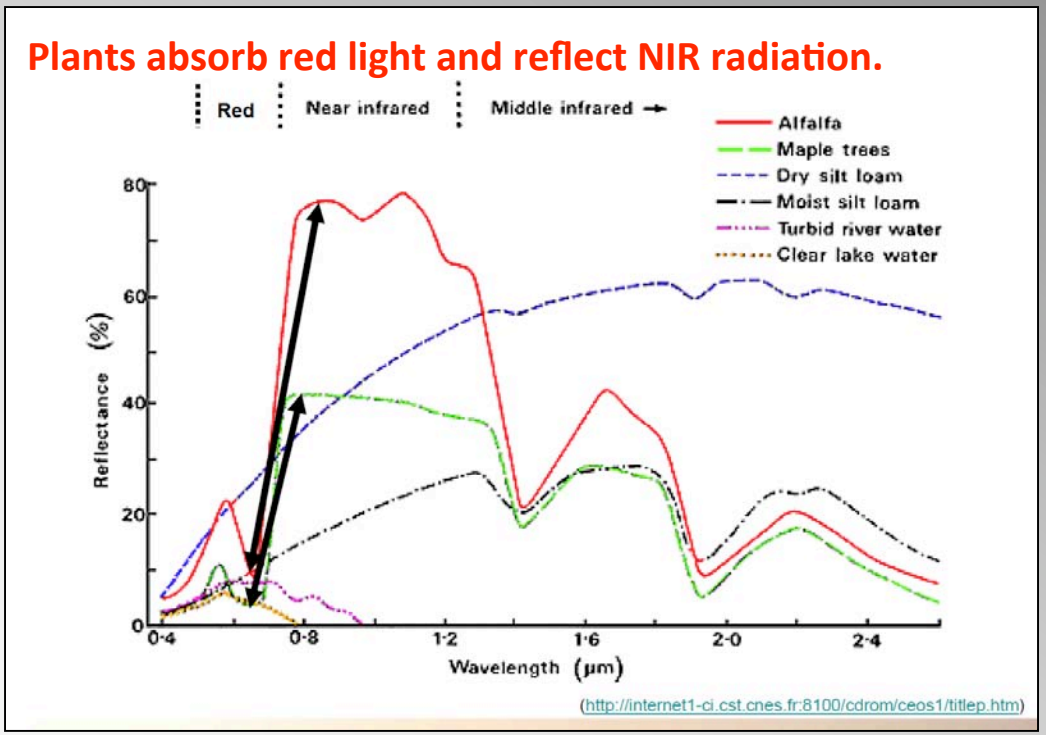


Study locations

- Forest-tundra transition: Nadym and Kharp
- Subzone E: Laborovaya
- Subzone D: Vaskiny Dachi
- Subzone C: Kharasavey
- Subzone B: Ostrov Belyy

Red line is the 2009 helicopter path.

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.

A hierarchical approach to examining greenness patterns and change

Plant- to plot-scale:

- Ground measurements of 5 x 5 m plots.
- Quickbird 60-cm pan-sharpened pixel size.

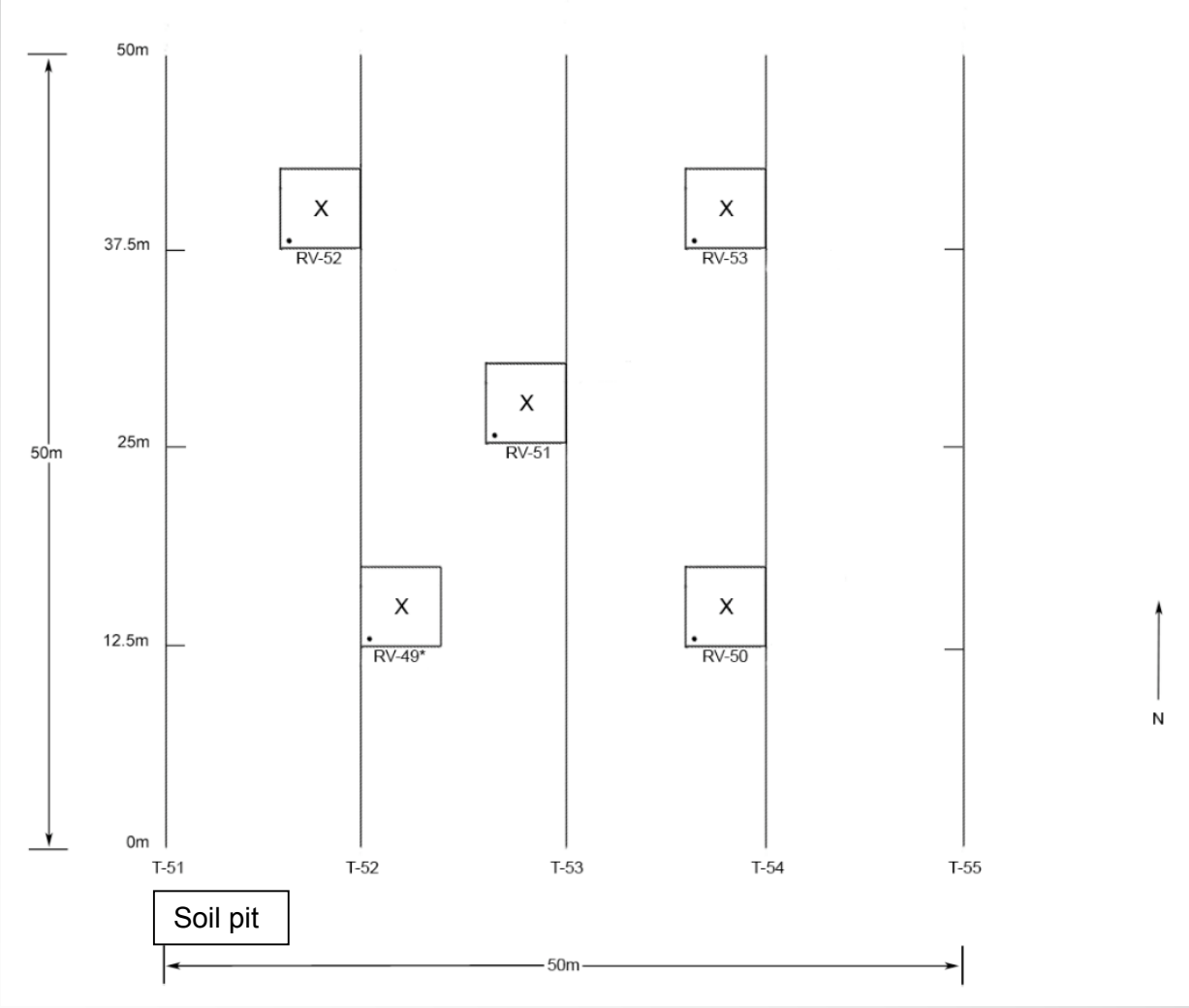
Landscape- to Regional-scale:

- Yamal 1-km AVHRR data from CAVM.
- Landsat ETM 30-m pixel size (USGS GLS 1990).

Global scale:

- Global 12.5 km data: NDVI (Pinzon).
- Global sea-ice, land-temperature and NDVI data: 25-km pixels based on Comiso sea-ice and temperature and cubic convolution of 8-km GIMMS NDVI.

Typical layout of transects and plots at each site



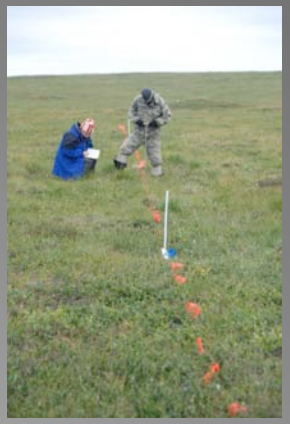
- Five 50-m transects
- Five 5 x 5-m plots (relevés)
- Biomass harvests in each plot (x)
- iButtons for n-factor in corner of each plot (•)
- Soil pit in SW corner

Data collected

- Transects

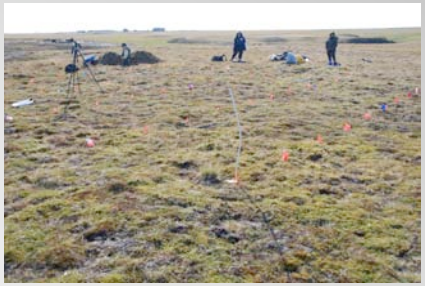
NDVI and LAI

Species cover



Active layer depth

- Plots



Species cover estimates, site factors

Biomass

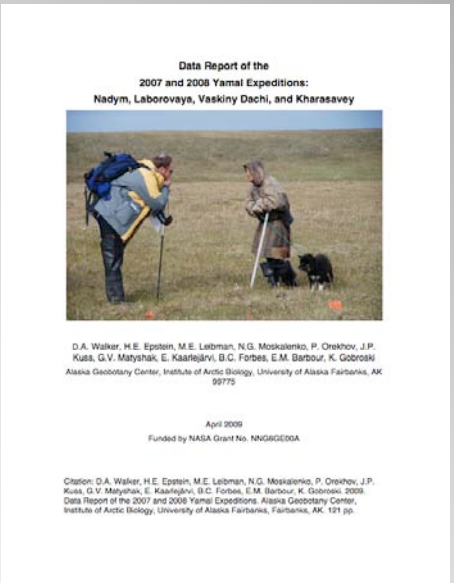
N-factor

- Soils

Soil pit profile descriptions

Top mineral horizon collected for chemical and physical analysis

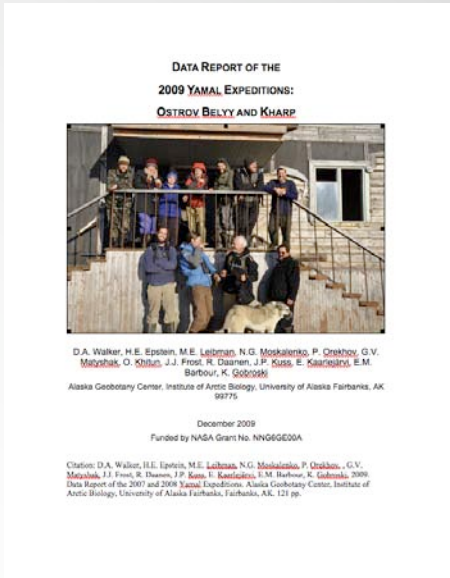
Yamal data reports


Data Report of the
2007 and 2008 Yamal Expeditions:
Nadym, Laborovaya, Vaskiny Dachi, and Kharasavey

D.A. Walker, H.E. Epstein, M.E. Leibman, N.G. Moskalenko, P. Orekhov, J.P. Kuss, G.V. Matyshak, E. Kaarlejärvi, B.C. Forbes, E.M. Barbour, K. Gobroski
Alaska Geobotany Center, Institute of Arctic Biology, University of Alaska Fairbanks, AK 99775

April 2009
Funded by NASA Grant No. NNG6GE00A

Citation: D.A. Walker, H.E. Epstein, M.E. Leibman, N.G. Moskalenko, P. Orekhov, J.P. Kuss, G.V. Matyshak, E. Kaarlejärvi, B.C. Forbes, E.M. Barbour, K. Gobroski. 2009. Data Report of the 2007 and 2008 Yamal Expeditions. Alaska Geobotany Center, Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK. 121 pp.


DATA REPORT OF THE
2009 YAMAL EXPEDITIONS:
OSTROV BELYY AND KHARP

D.A. Walker, H.E. Epstein, M.E. Leibman, N.G. Moskalenko, P. Orekhov, G.V. Matyshak, O. Khitun, J.J. Frost, R. Daanen, J.P. Kuss, E. Kaarlejärvi, E.M. Barbour, K. Gobroski
Alaska Geobotany Center, Institute of Arctic Biology, University of Alaska Fairbanks, AK 99775

December 2009
Funded by NASA Grant No. NNG6GE00A

Citation: D.A. Walker, H.E. Epstein, M.E. Leibman, N.G. Moskalenko, P. Orekhov, , G.V. Matyshak, J.J. Frost, R. Daanen, J.P. Kuss, E. Kaarlejärvi, E.M. Barbour, K. Gobroski. 2009. Data Report of the 2007 and 2008 Yamal Expeditions. Alaska Geobotany Center, Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK. 121 pp.

All locations:

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

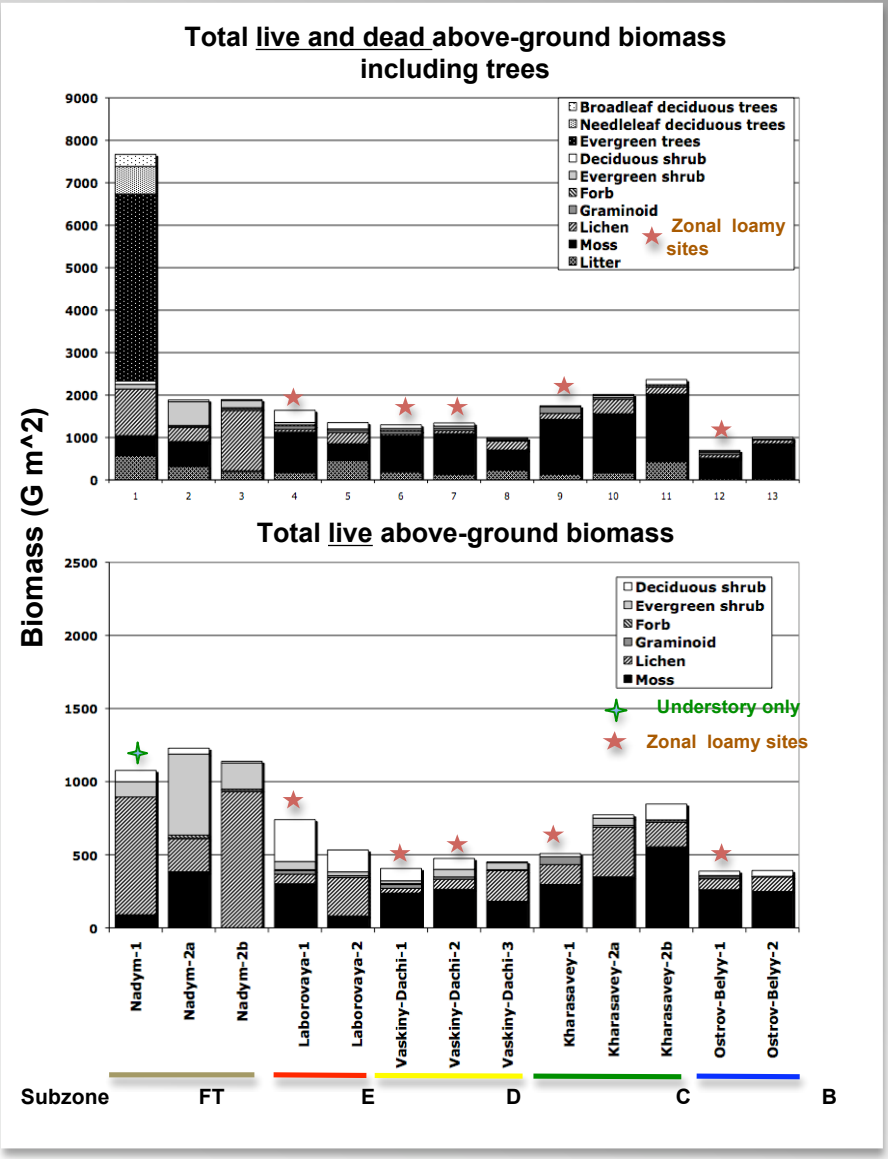
Transect data
- Plant species cover
- LAI
- NDVI
- Thaw depth
- Photos of transects

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

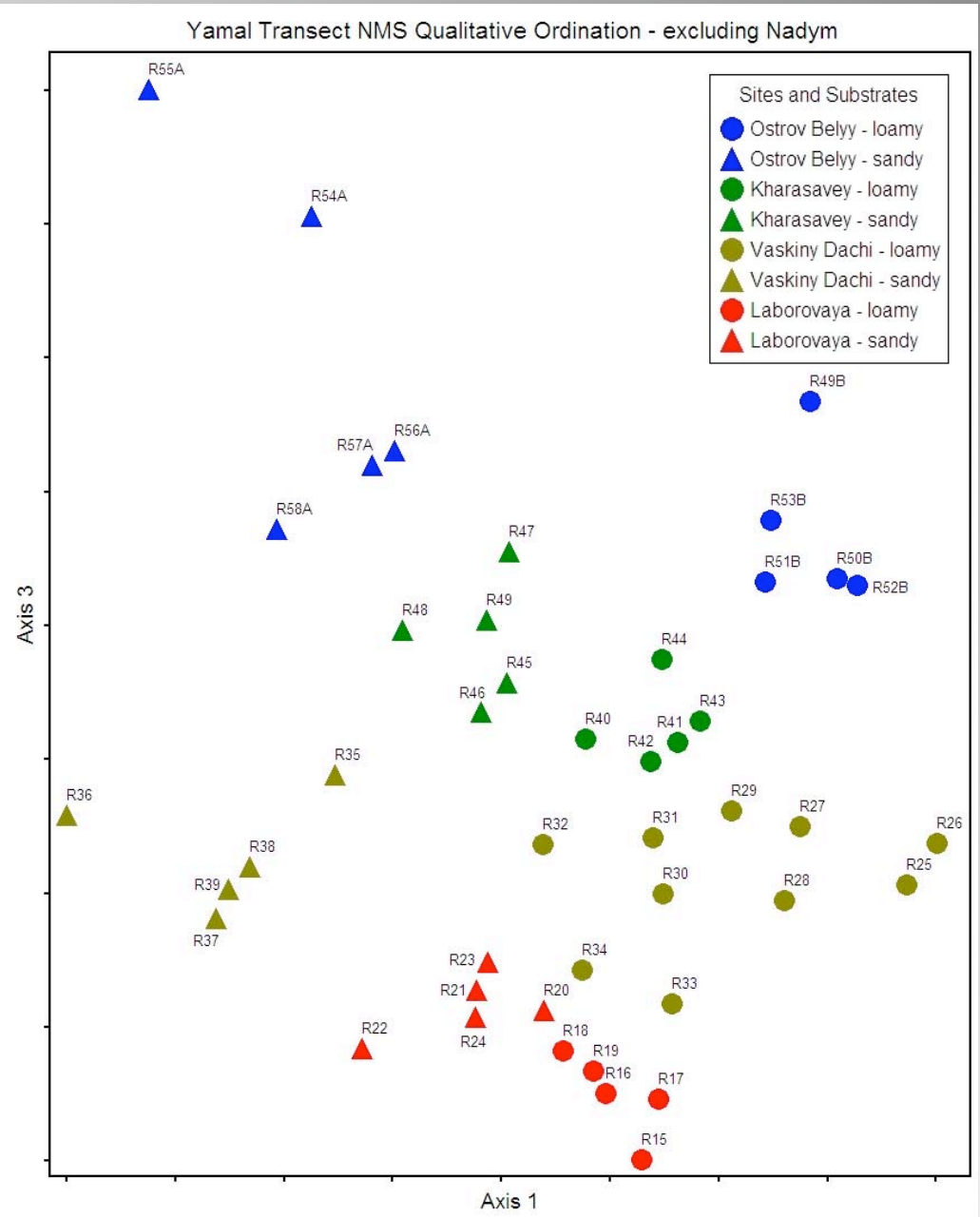
Ostrov Belyy:
- Vascular plant species list
- Bird list
- Mammal list
- Log of expedition

Yamal transect biomass



- Zonal sites show little variation across the peninsula, except in subzone E.
- Biomass values for zonal site in subzone E is close to tussock tundra values for Alaska (≈ 750 g m^2).
- Total live biomass values of zonal loamy sites in subzones C and D are close published values for mesic tundra Barrow and Prudhoe Bay (≈ 450 g m^2).

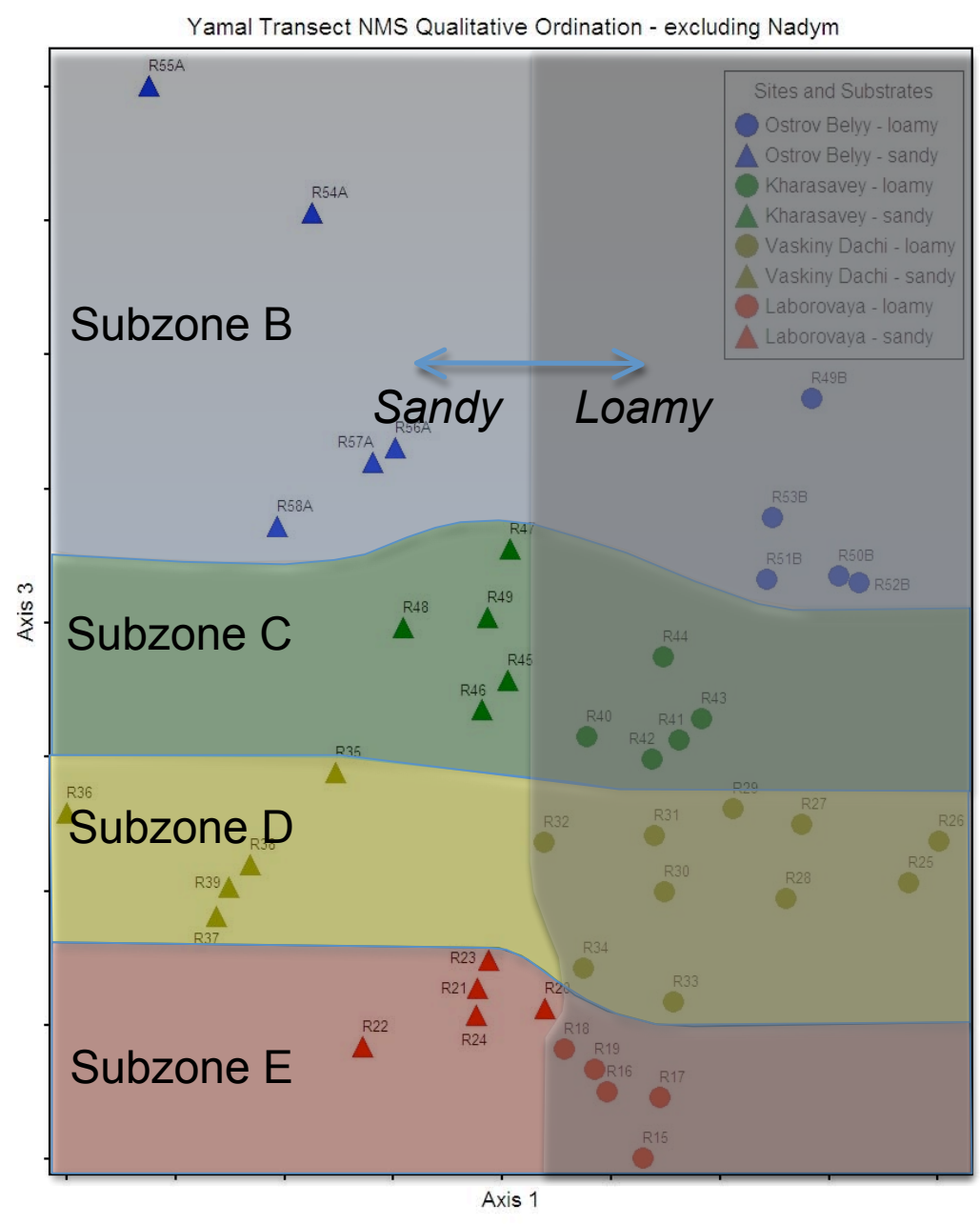
Vegetation Analysis: NMS Ordination of tundra study plots based on floristic similarity



- Colors according to CAVM bioclimate subzones:
  - Blue: Subzone B
  - Green: Subzone C
  - Tan: Subzone D
  - Red: Subzone E
- Shape of symbols represent soil texture:
  - Triangles: Sandy soils
  - Circles: Loamy soils

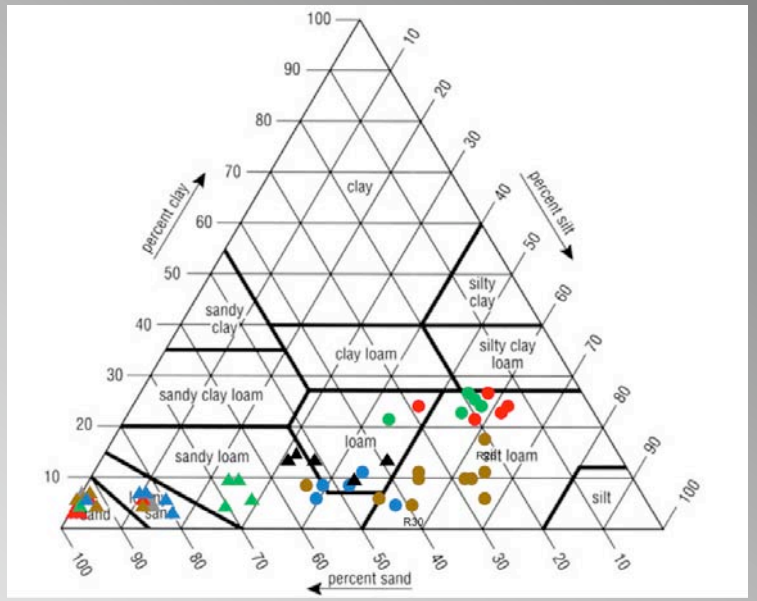
JJ Frost et al. 2010, Yamal LCLUC Workshop

Ordination space interpreted as an environmental space with clear bioclimate and soil texture gradients



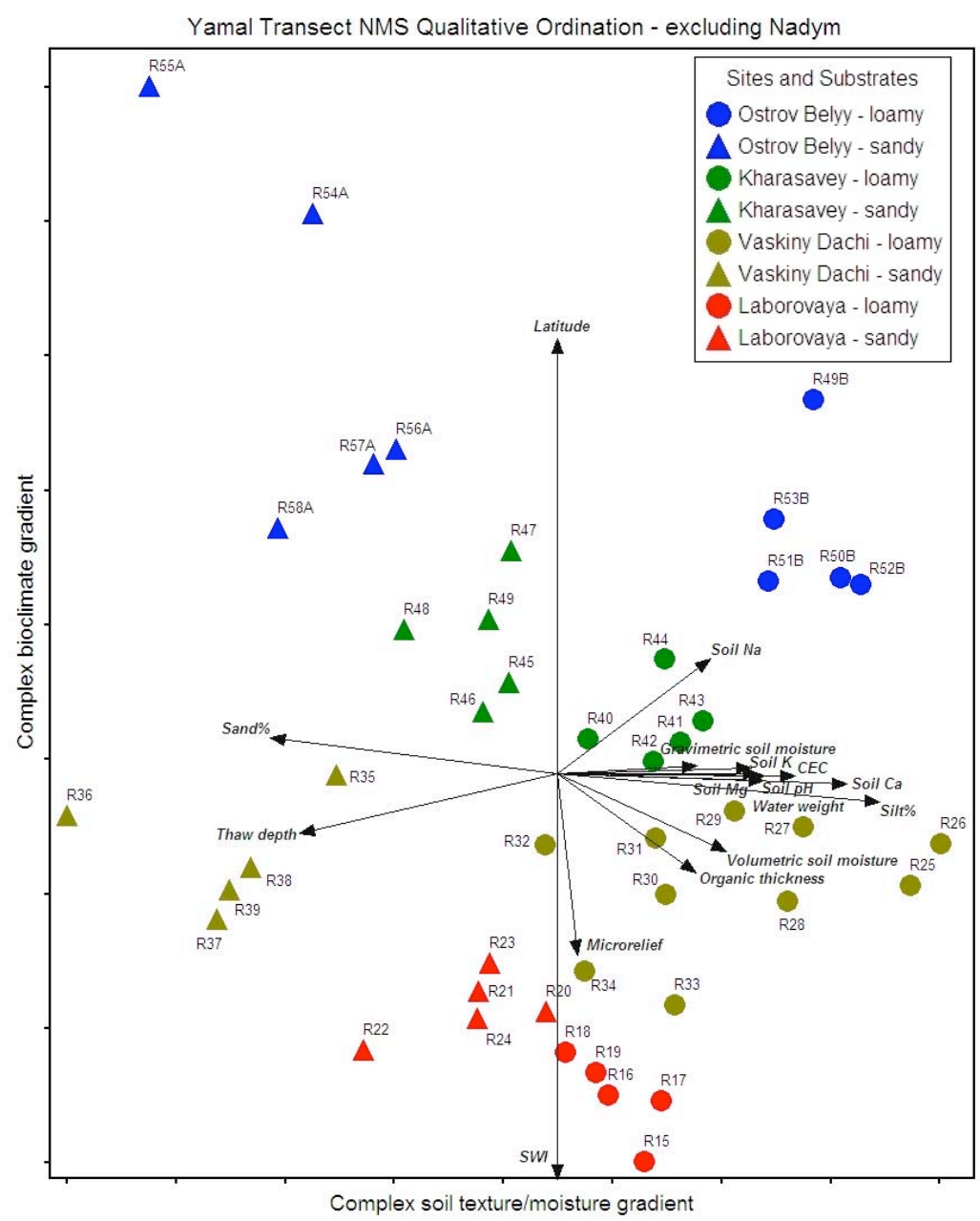
- First interpretation:
  - Horizonal axis: Sand to Loams
  - Vertical axis: Warm to cold

USDA Soil Texture Triangle



JJ Frost et al. 2010, Yamal LCLUC Workshop

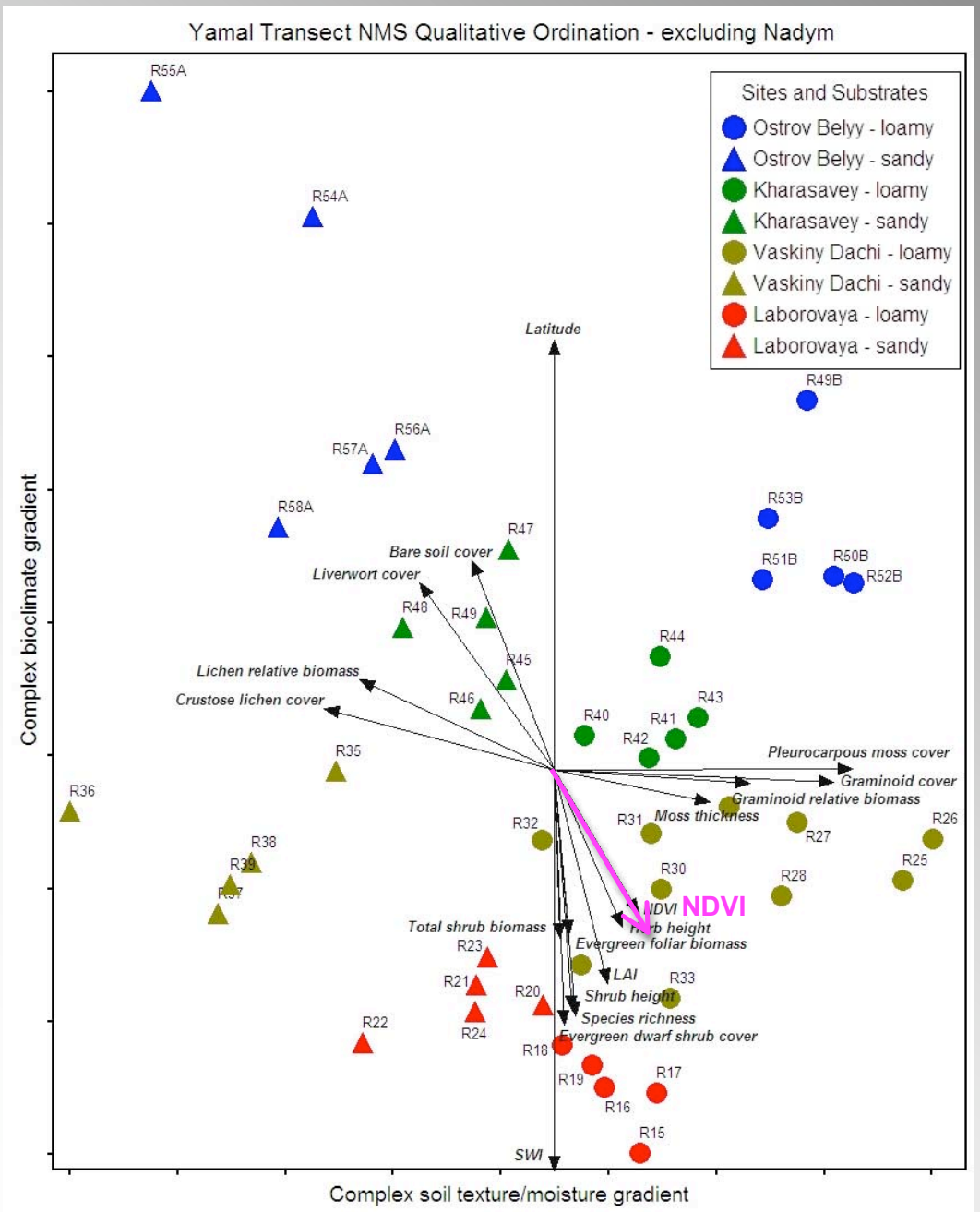
Ordination with biplot arrows showing environmental relationships



- Biplot arrows show direction and strength of correlations for each measured environmental variable. R^2 cutoff = 0.25.
- Variables pointing in the horizontal direction are correlated with percent silt:
  - (+): soil nutrients, soil moisture
  - (-): sand, thaw depth.
- Variables pointing in the vertical direction are more strongly correlated with latitude:
  - (-) Summer warmth, microrelief
- X and Y axes are interpreted as complex environmental gradients with numerous variables covarying along each axis:
  - X axis: soil texture/ pH/ moisture gradient
  - Y axis: latitude/ climate/ microrelief gradient

JJ Frost et al. 2010, Yamal LCLUC Workshop

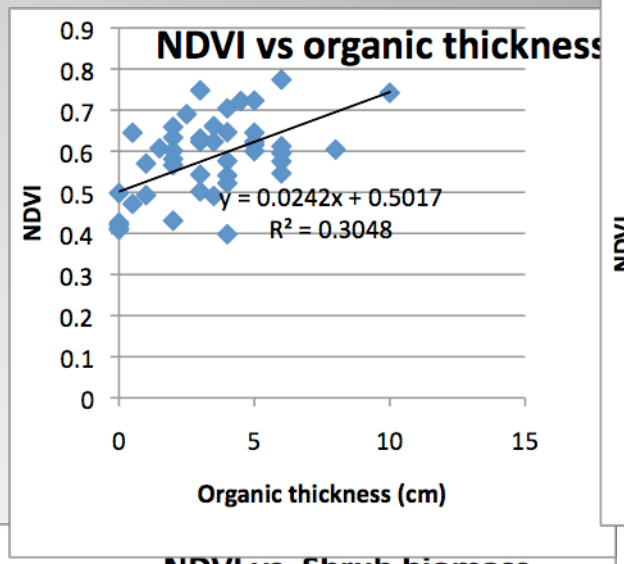
Ordination with bipolot plant-variables and NDVI correlations

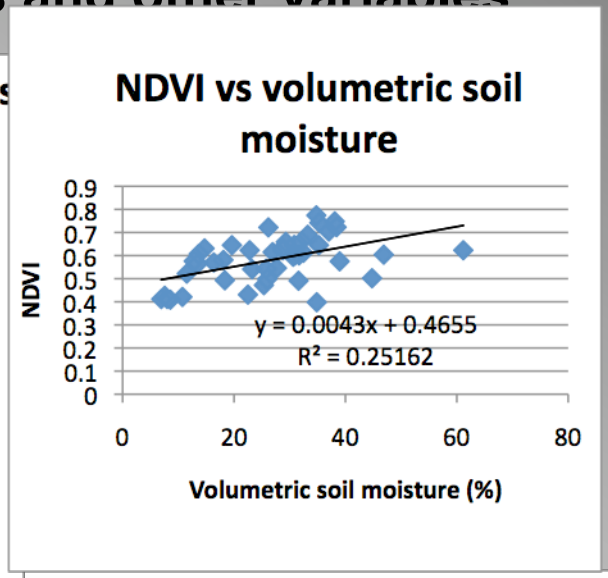


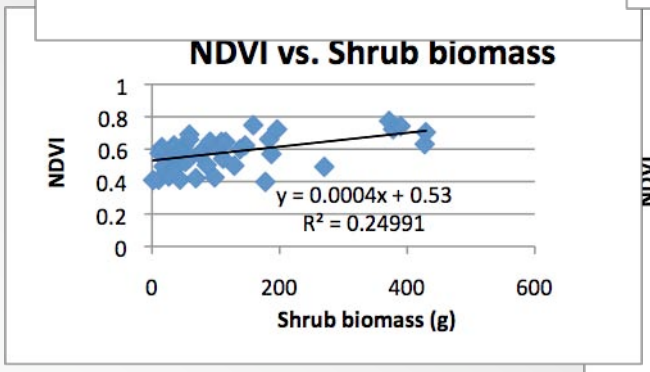
- Some plant variables have clear correlations with complex soil texture gradient [e.g. pleurocarpous mosses and graminoids (+) and crustose lichens (-)].
- Others are more clearly correlated with the latitude gradient [e.g. bare soil cover (+); evergreen shrubs, species richness, herb height (-)].
- NDVI shows strong relationships to both gradients.

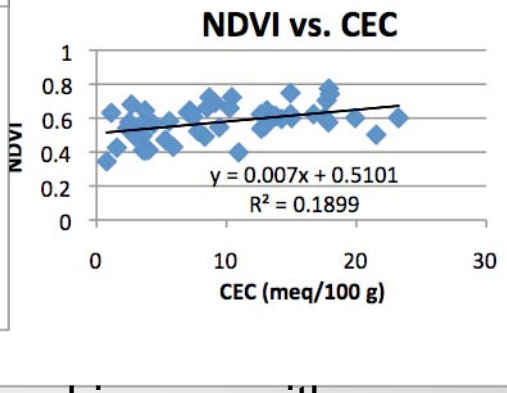
JJ Frost et al. 2010, Yamal LCLUC Workshop

Relationships between hand-held NDVI measurements and other variables









Key variables

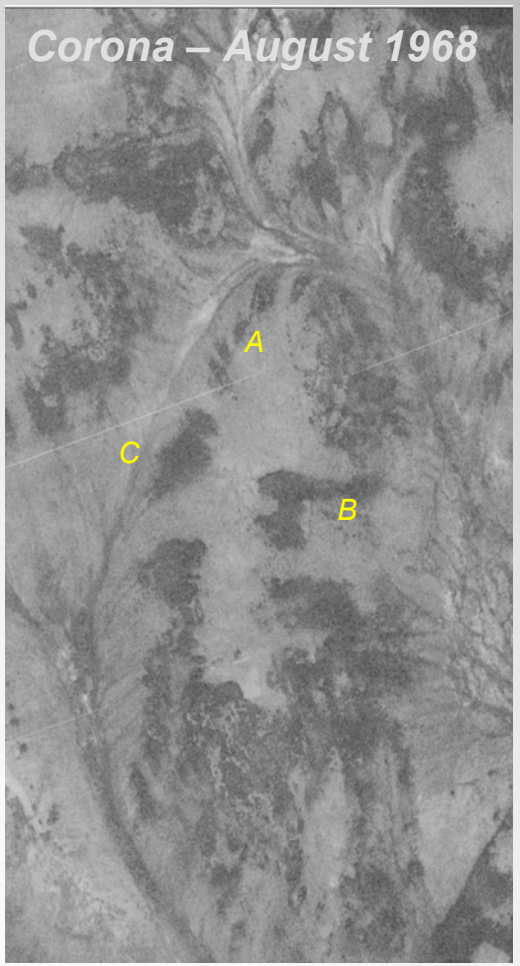
Variable	r-squared
%C_DShbE	0.378
%C_BryAc	0.3473
LAI	0.3402
%C_DeShb	0.3219
Moss_Ht	0.3175
Herb_Ht	0.3136
Org_Thk	0.3048
Moss_Thk	0.2876
Elev	0.2868
Dec_Stem	0.2637
%C_Dead	0.2552
Dec_Tot	0.2528
Volumetr	0.2516
Sand%	0.2499
Shrb_Tot	0.2499
Shrub_Ht	0.2433
Latitude	0.2316
Silt%	0.2273
Lichen%	0.2233
SWI	0.21
Mg	0.209
CEC	0.2048
Clay%	0.2039

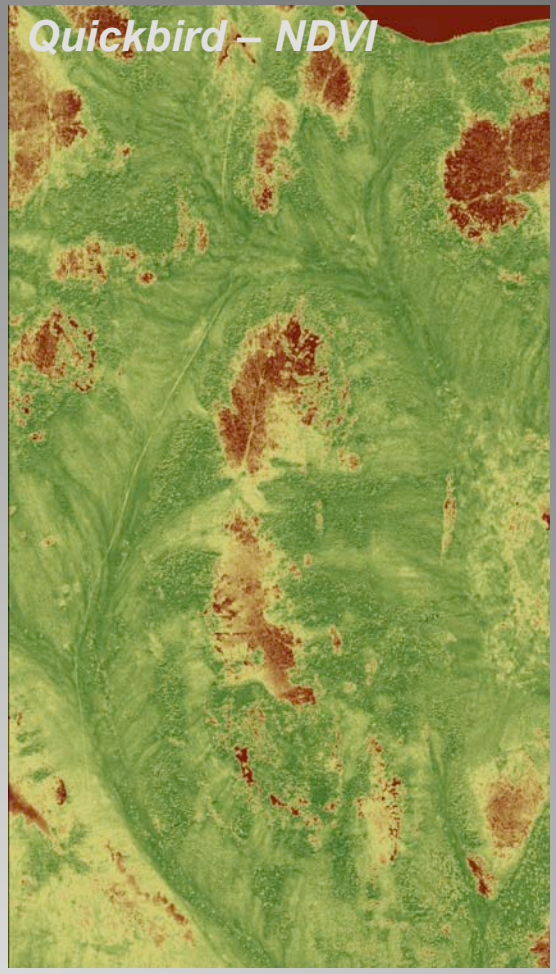
key biometric relationship

key environmental relationship

- Strongest NDVI relationships are with some plant cover variables (e.g. pct. cover of evergreen shrubs, acrocarpous mosses, deciduous shrubs, LAI, moss height, organic thickness).
- Also strong environmental correlations (e.g. vol. soil moisture, pct. sand, latitude, SWI) mostly related to soil moisture and warmth gradients.

Corona and Quickbird: Detailed analysis of 35-yr alder expansion at treeline near Kharp



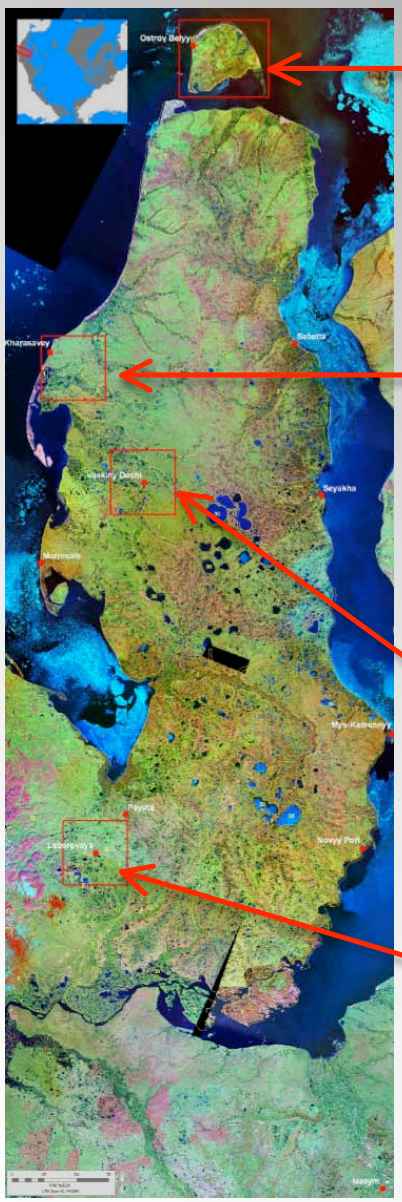


Panchromatic-sharpened 60-cm resolution Quickbird images provide detailed view of shrub expansion at the plant level, and…..

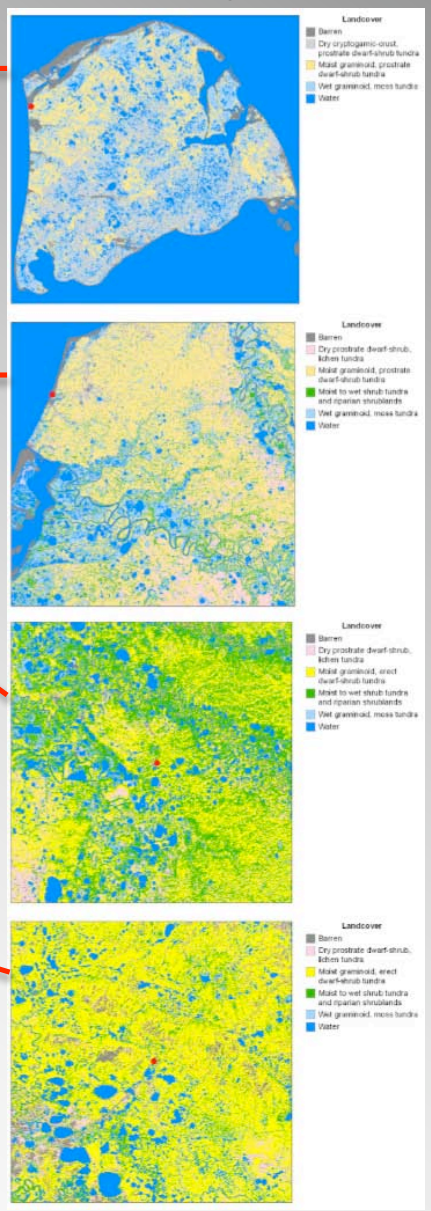
picture of productivity patterns in relationship to geology, hydrology and patterned ground.

Frost et al. 2010. Yamal LCLUC Workshop.

GLS-1990 mosaic



Land-cover maps of Yamal study locations



Land-cover mapping with 30-m Landsat TM data

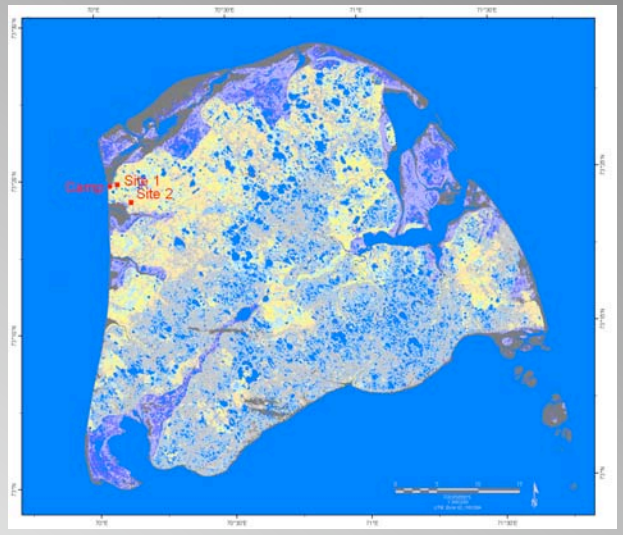
- Landsat mosaic provides intermediate-resolution terrain information of the whole peninsula.
- Mosaic is composed of many scenes with different acquisition dates (May to September). Difficult to get consistent land-cover classification or MaxNDVI for the whole peninsula.
- Land-cover maps produced separately 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.

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

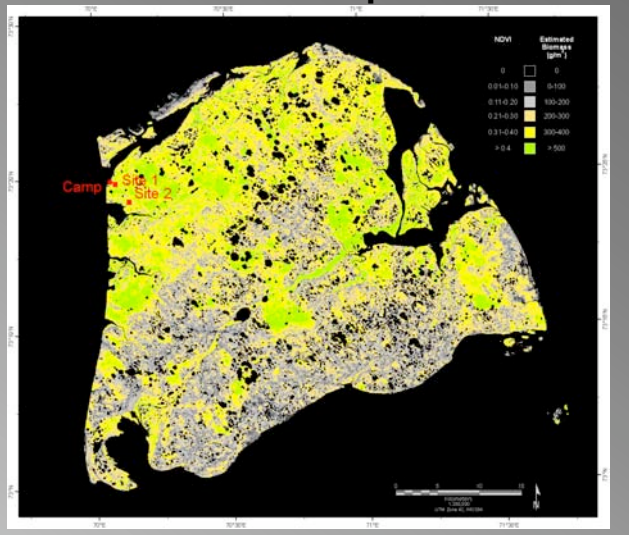
Enhanced TM (ETM+) derived maps of Ostrov Belyy

False-color image

Land-cover map



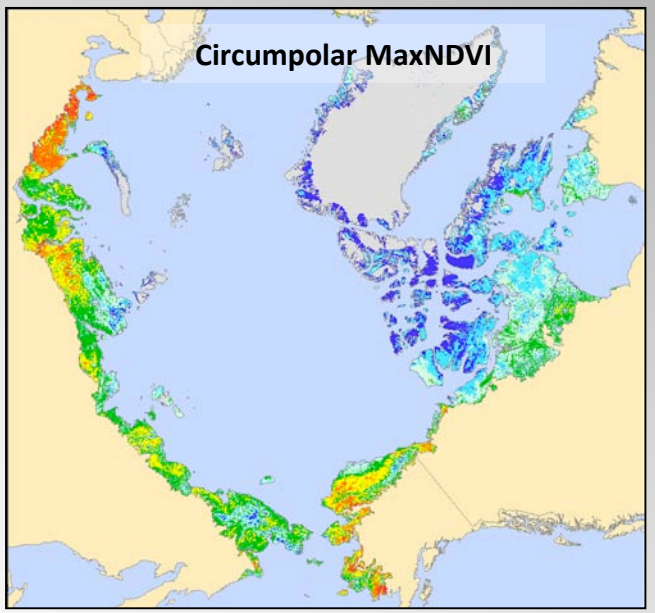
NDVI map



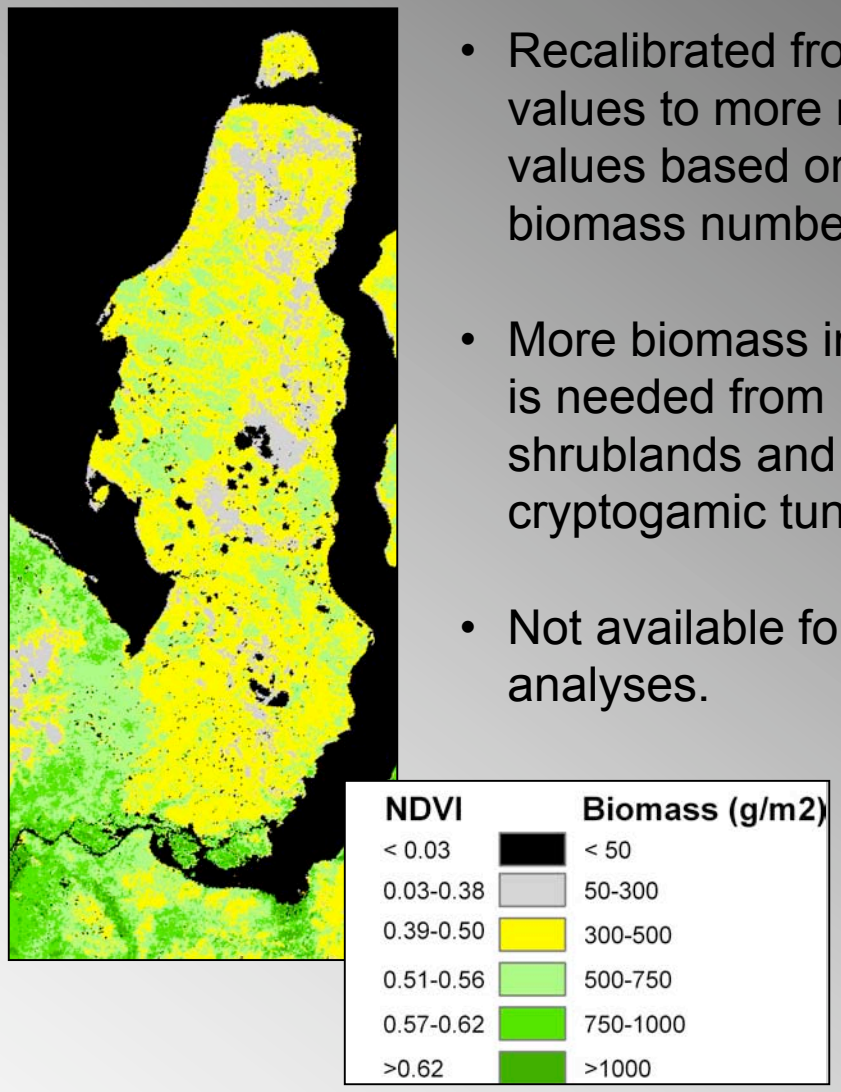
- 15-m resolution panchromatic band is used to enhance the 30-m resolution TM data.
- Single ETM+ scene covers all of Ostrov Belyy.
- Unsupervised classification used 15 spectral clusters. Salt marshes classified separately
- NDVI map shows clear relationship of productivity with respect soil moisture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

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

Yamal 1-km AVHRR NDVI derived from CAVM data set



USGS data set used for the CAVM

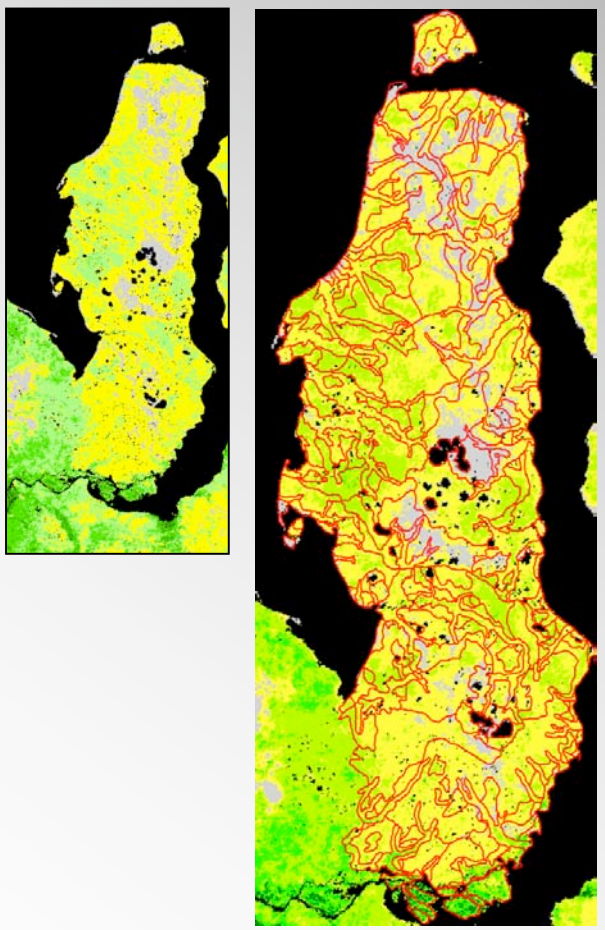


- Recalibrated from CAVM values to more realistic values based on Yamal biomass numbers.
- More biomass information is needed from shrublands and cryptogamic tundra area.
- Not available for temporal analyses.

Courtesy of M.K. Raynolds. 2010.

Analysis of NDVI with Landschaft and CAVM map units

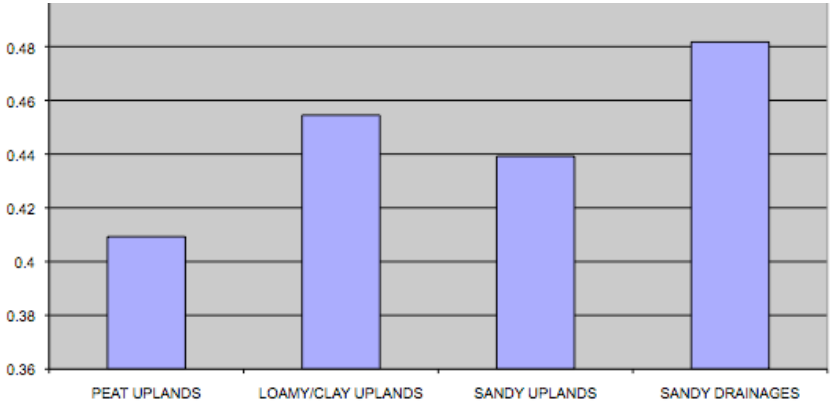
NDVI with Landschaft boundaries



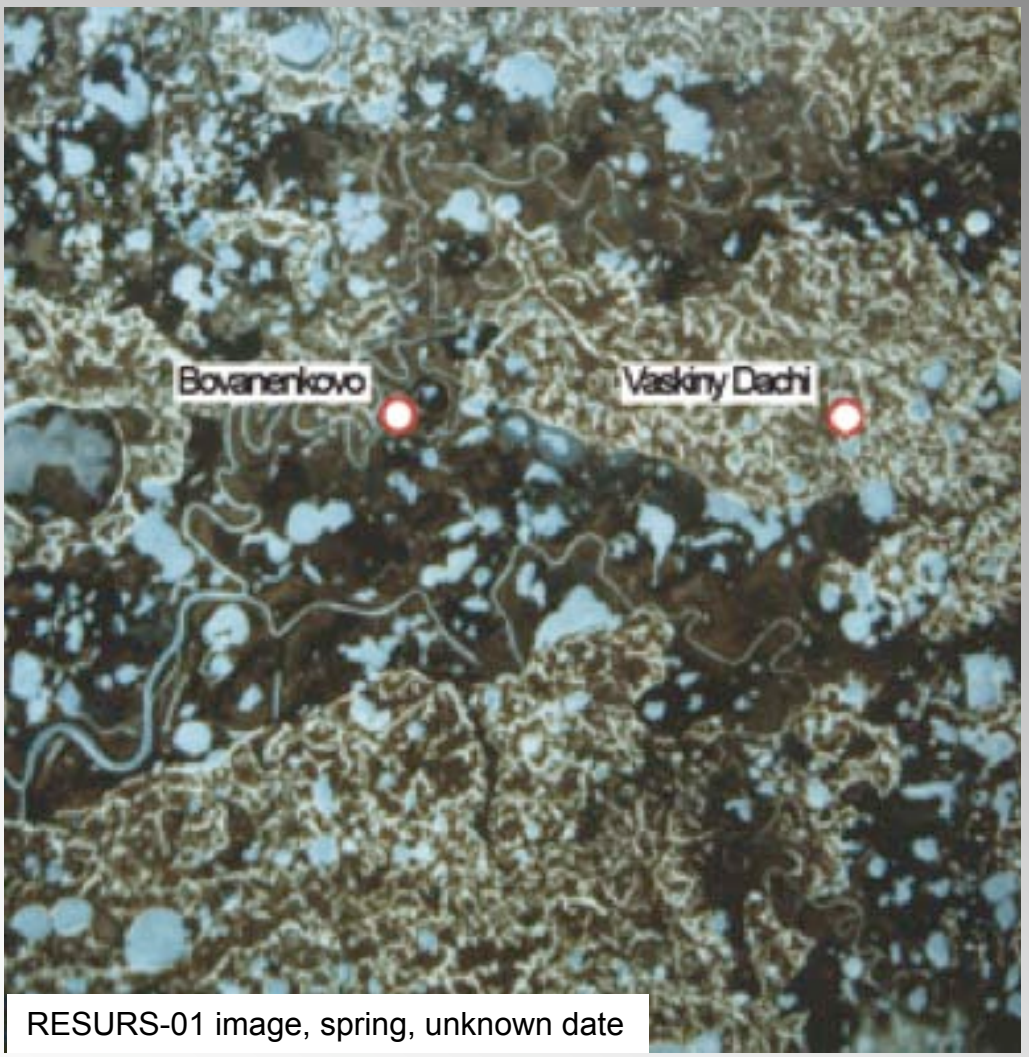
Courtesy of M.K. Raynolds. 2010.

- 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.

NDVI on marine terrace uplands and drainages of differing soil texture



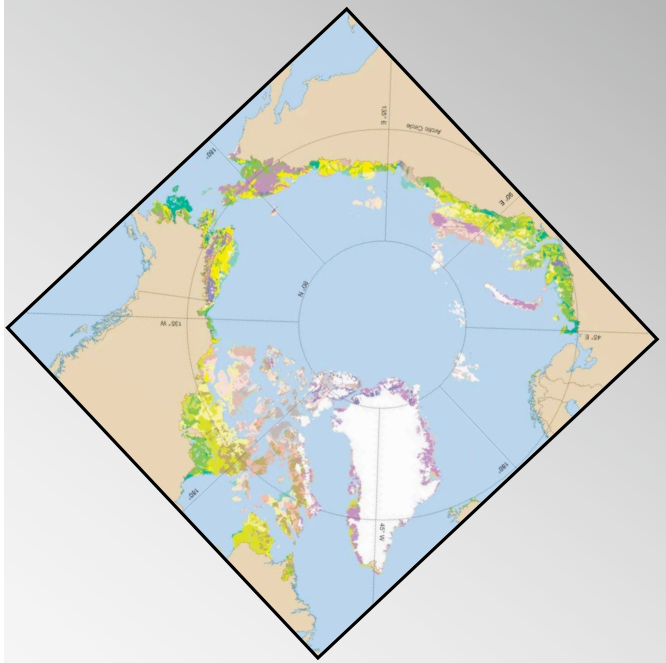
Snow, hydrology, NDVI relationships in landslide areas



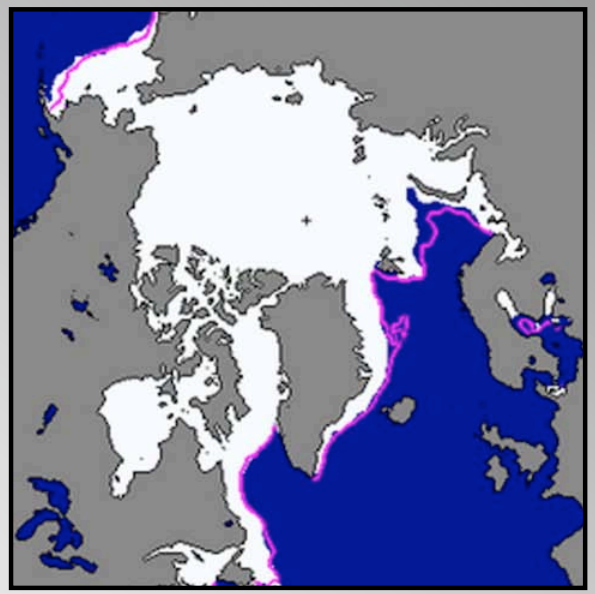
RESURS-01 image, spring, unknown date

- Expansion of the major river valleys and mosaic of smaller drainages is occurring very rapidly.
- Need better understanding of the rate of growth of the drainage networks.
- Need models and high-resolution imagery to address expansion of drainage networks

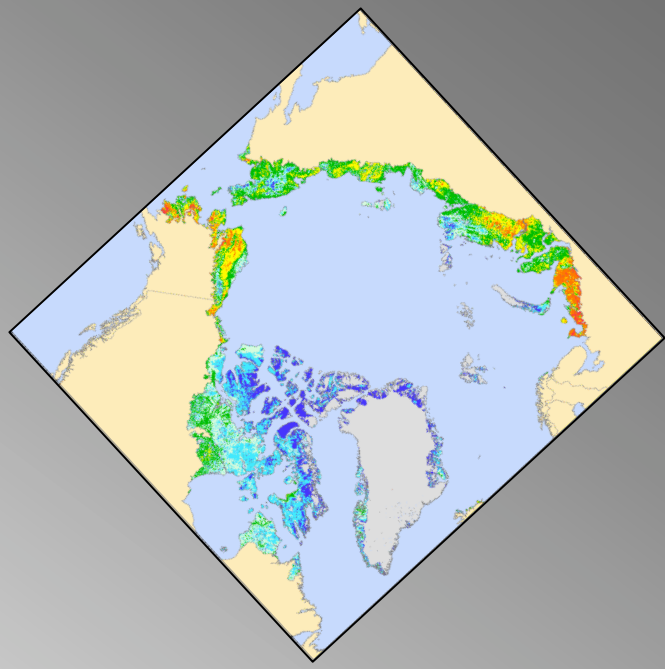
Circumpolar analysis: Does the presence of summer sea ice affect tundra vegetation productivity and seasonality?



Arctic Tundra Vegetation



March Sea-Ice Extent



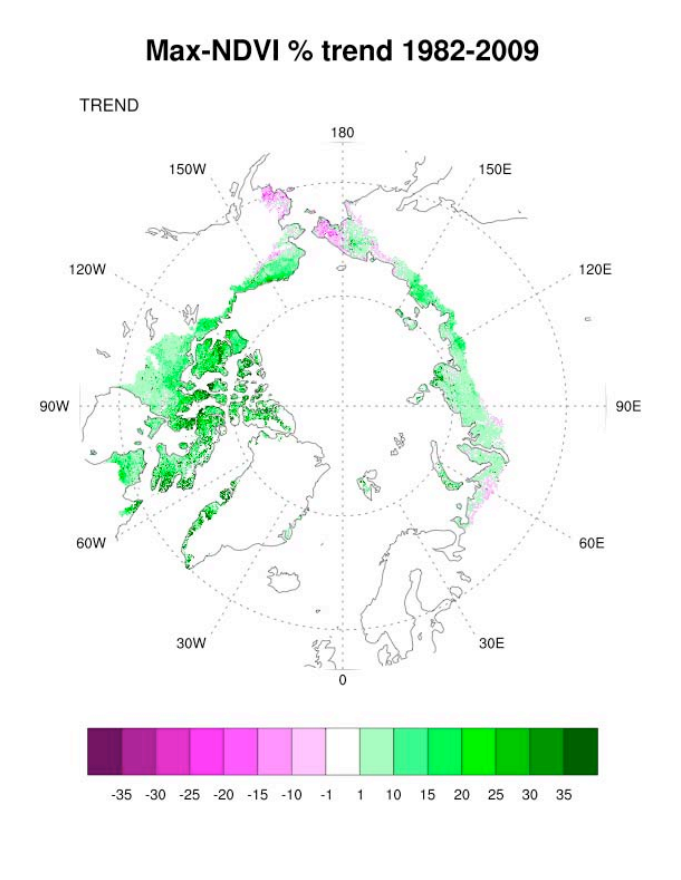
Max NDVI

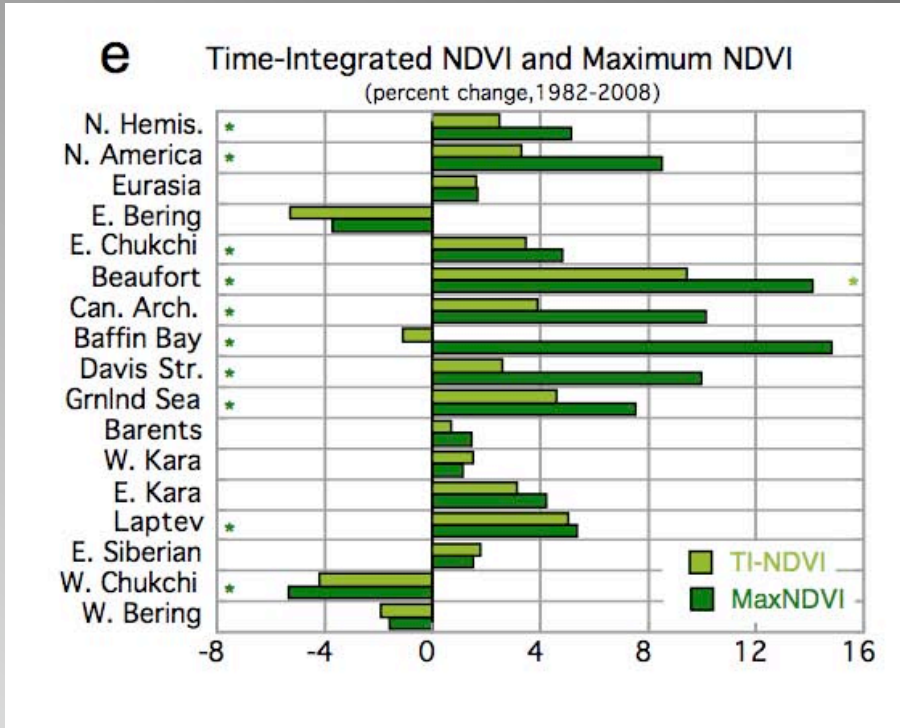
- 80% of Arctic tundra is within 100 km of ice-covered seas (100% is within 350 km).
- Changes is summer sea-ice distribution should affect land temperatures and the productivity of tundra.
- Models have shown that melting the sea ice will affect land temperatures and permafrost even at great distances from the Arctic Ocean

Sea Ice: http://www.arctic.noaa.gov/reportcard/figures/seaice2009fig1.jpg

Vegetation and NDVI: http://www.arcticatlas.org/maps/themes/cp/cpvg

Percentage MaxNDVI change (1982-2008)





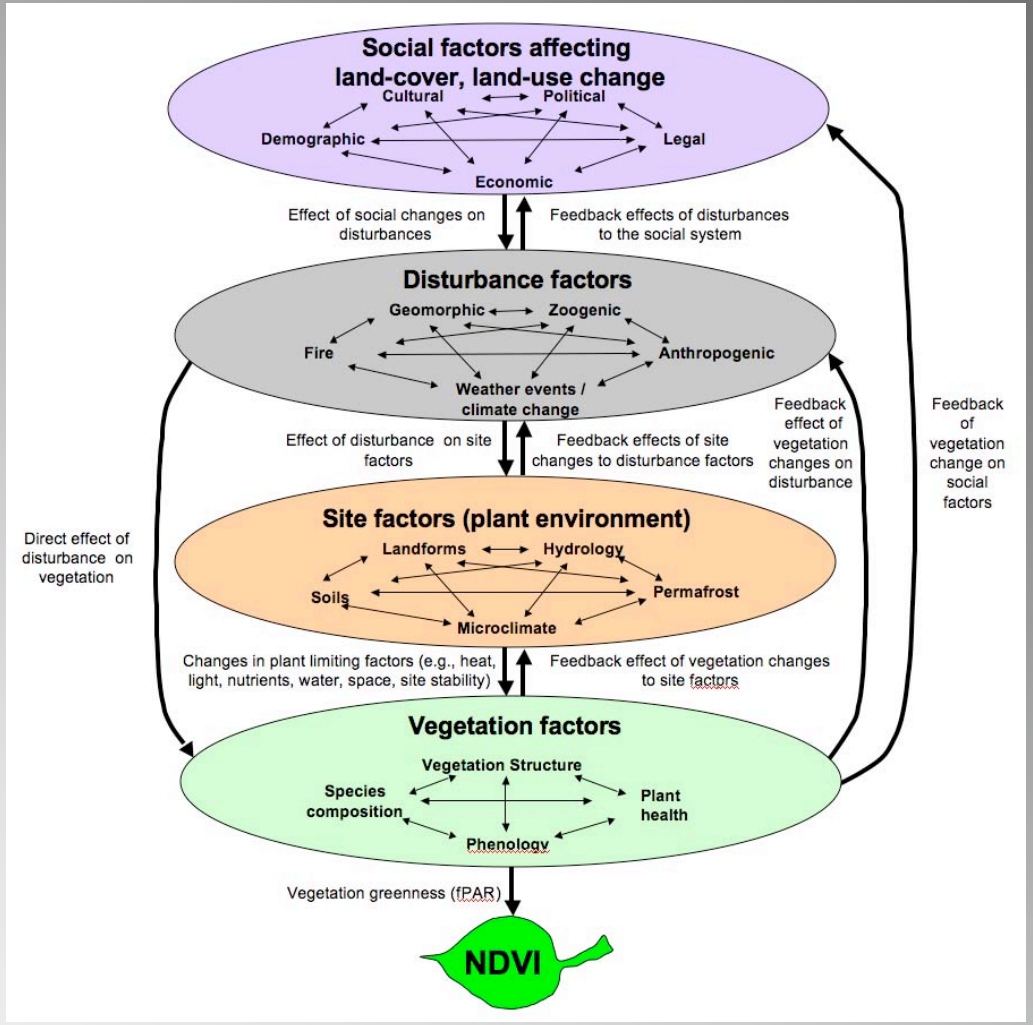
Bhatt et al. 2009 submitted, Earth Interactions.

- Arctic wide: +5%
- Much greater change in North America (+9%) than in Eurasia (+3%).
- Large increases in (10-15%) in the High Arctic (northern Canada and Greenland) and the Beaufort Sea area.
- Other analyses (not shown) revealed strong positive correlations between NDVI and land temperatures and strong negative correlations with the percentage of coastal sea ice.

Arctic plants respond mainly to changes to their immediate plant environment (summer temperature, moisture, and nutrients)

It is usually not possible to ascribe causality to the changes —e.g., climate change, reindeer, landslides, or a vehicle trail.

NDVI is a good integrator of the total changes to plant productivity, but is a poor tool for determining the causes.



Walker et al. 2009. Environmental Research Letters

Effects of reindeer

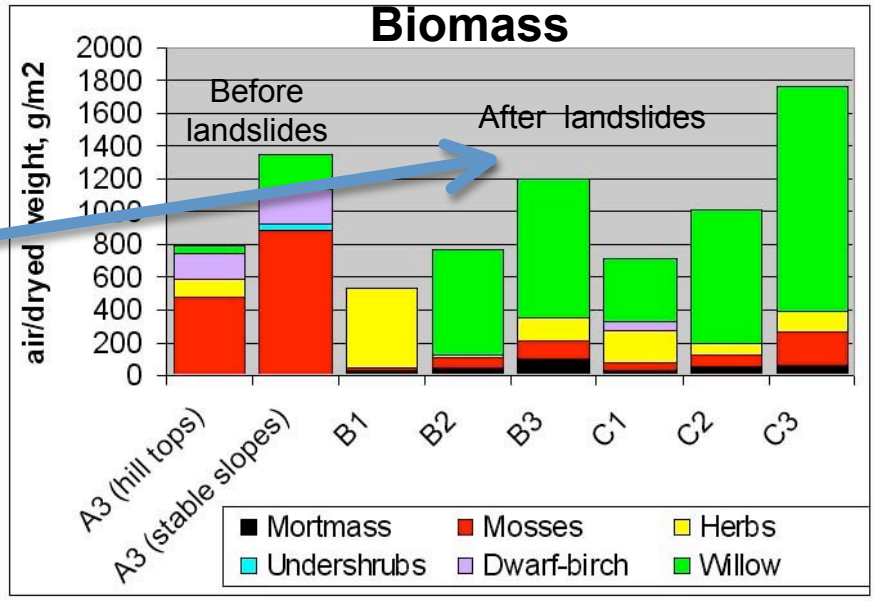
- Effects on reindeer on NDVI are unknown at present because of lack of control areas to study the effects (exclosures).
- Potential major effect in sandy areas.

Photos: Bruce Forbes.

Photos D.A. Walker

Landslides and cryogenic erosion

- Large effect on patterns of greenness in many areas.
- But without quantitative measures of the rate of change, it is hard to determine if this is a factor with respect to greening trends.
- Need temporal series of high-resolution satellite images and/or photos in landslide areas to assess the rate of change.



Key:

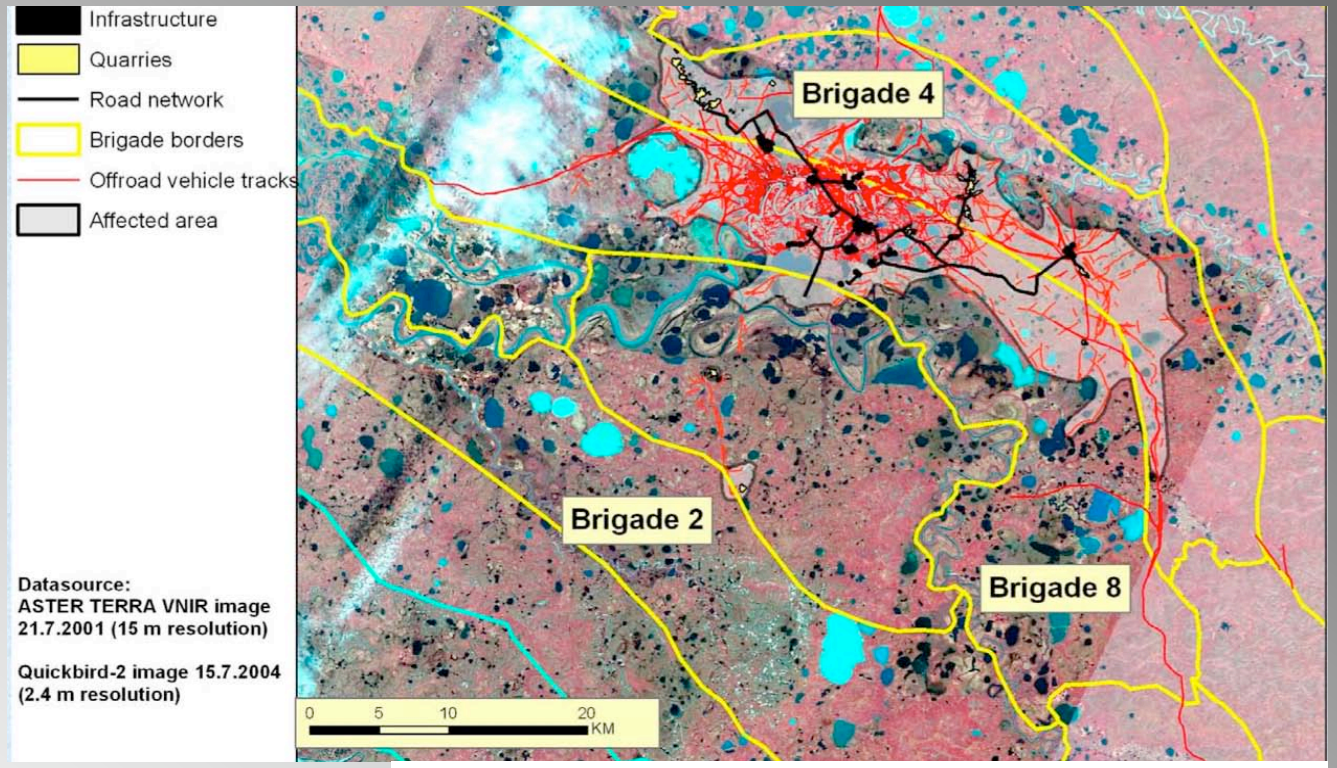
A – stable areas
B – shear surface
C – landslide body

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

Ukraintseva and Leibman et al. 2000, 2007, 2008

Impacts of gas development

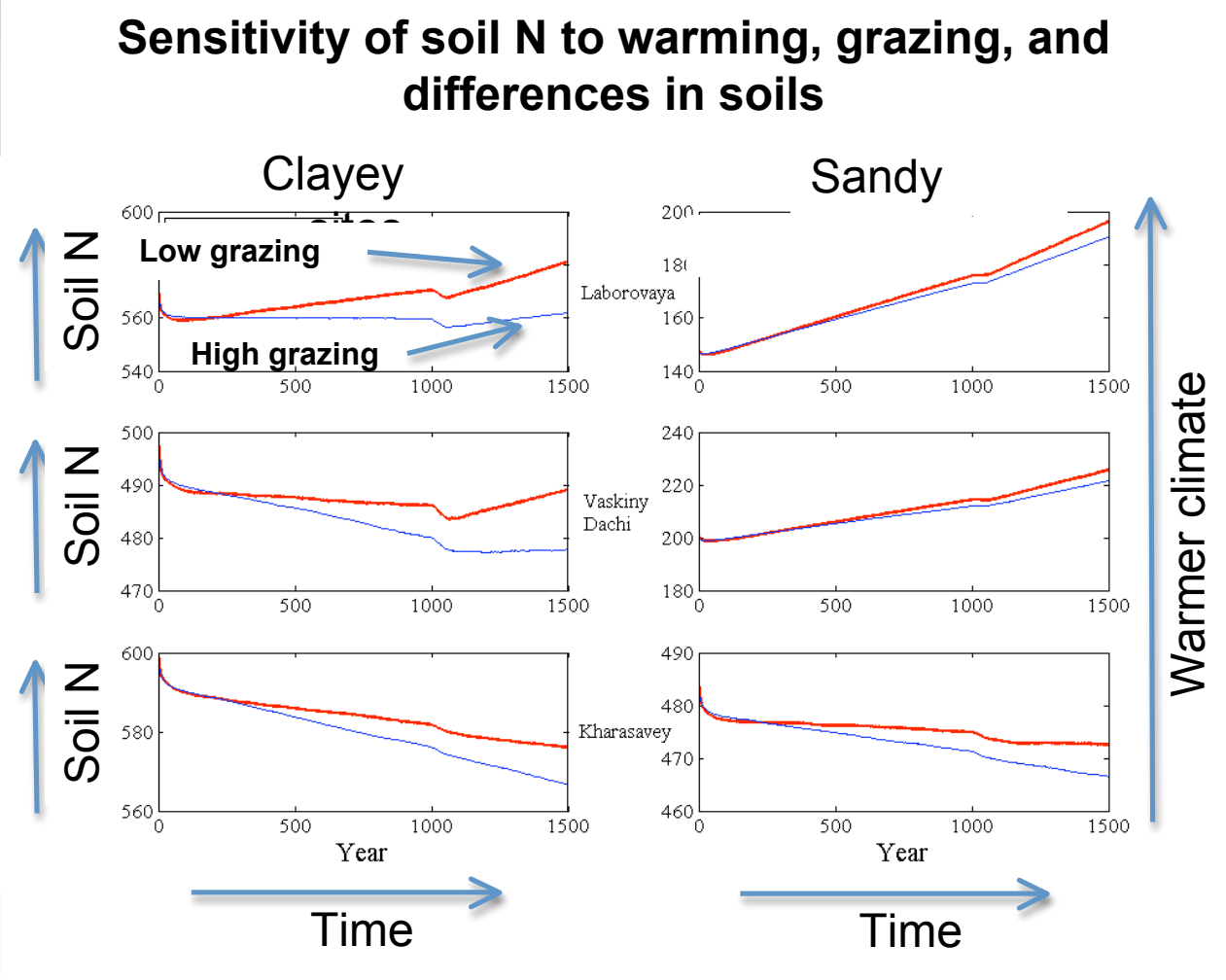
- Potential large effects on reindeer assess to rangelands.
- Locally important but still relatively small extent.
- Need development scenario models to help predict and plan for expansion of road networks.



- 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

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

Models are helping to unravel the effects of various types of disturbance



- Grazing suppresses vegetation response to warming.
- Herbivory has greater effect in clayey (nutrient-rich) sites.

Yu, Q. et al. 2009 AGU poster: Simulating the effects of soil organic nitrogen and grazing on arctic tundra vegetation dynamics on the Yamal Peninsula, Russia

Where to go now

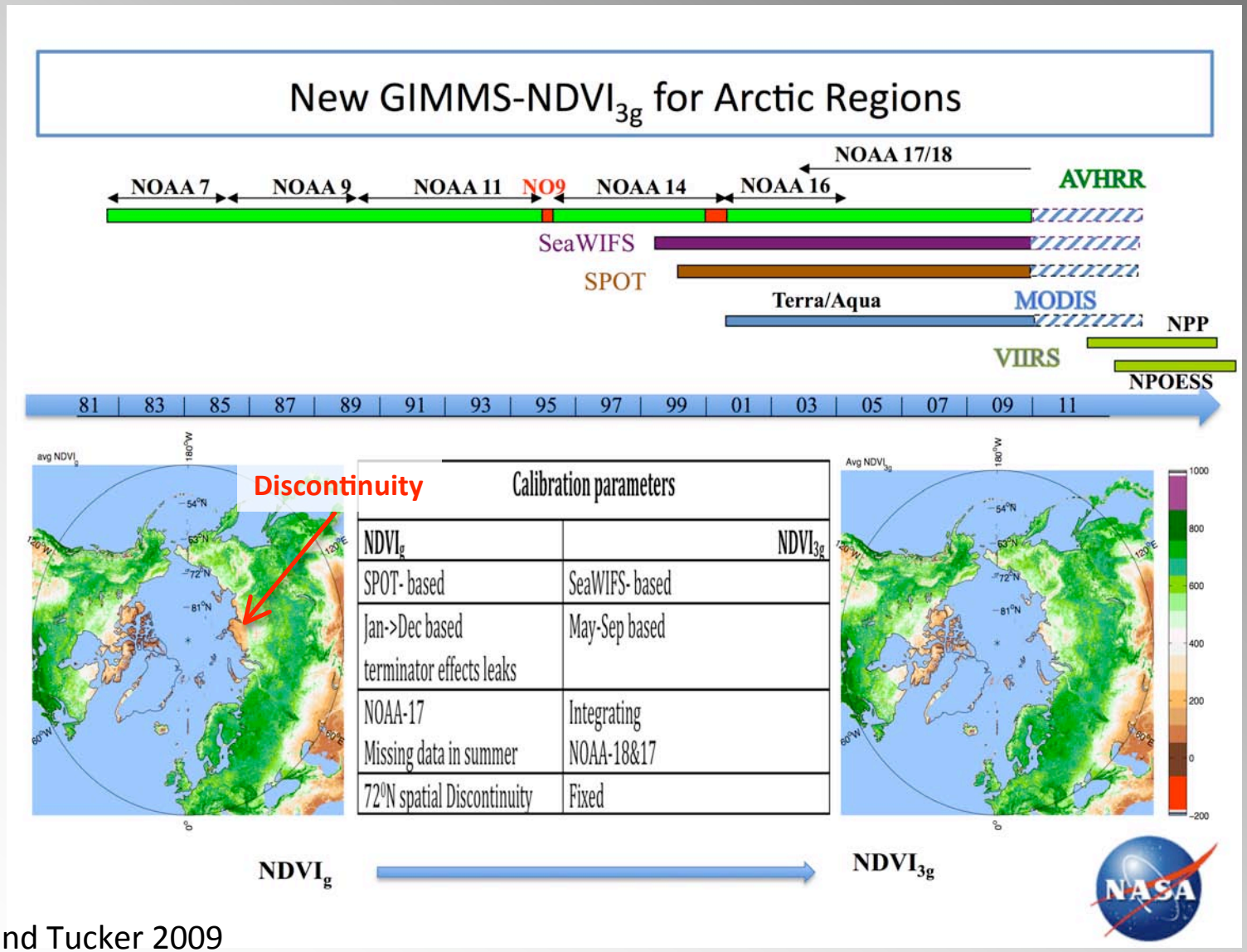
Vegetation component:

- Subzone A to complete the Eurasia bioclimate gradient.
- Finish vegetation analysis of Yamal transect.
- Comparison of Eurasia and NAAT transects.
- More detailed ground studies of azonal environments on Yamal (e.g. landslides, shrublands, lichen rangelands, wetlands).

Collaborative efforts:

- Models to examine NDVI-disturbance relationships.
- Models to examine vegetation-permafrost relationships.
- Local examination of the climate-drivers for sea-ice, land temperatures, phenology, for the global and Yamal NDVI analysis.
- Models to help predict expansion of road networks (?).
- Models to help predict expansion of hydrological networks and expansion of shrublands (?).

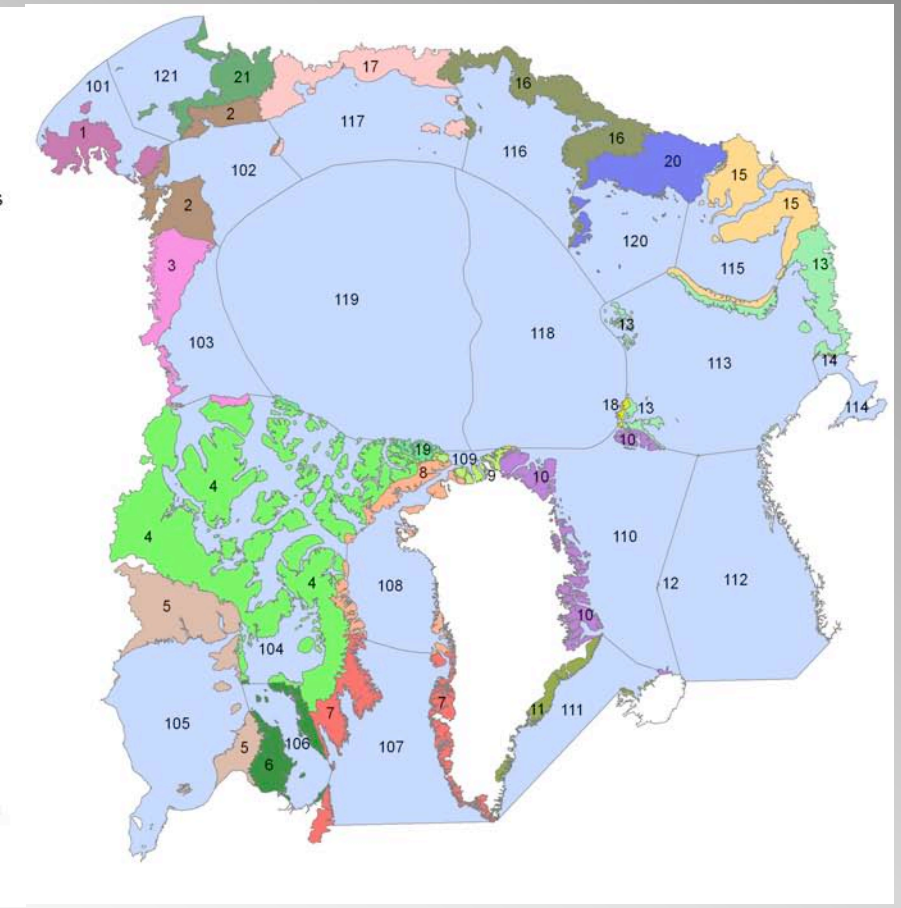
New $GIMMS_{3g}$ corrects previous NDVI problems in the High Arctic



Pinzon and Tucker 2009

Study Framework: Division of Arctic Ocean and associated land masses

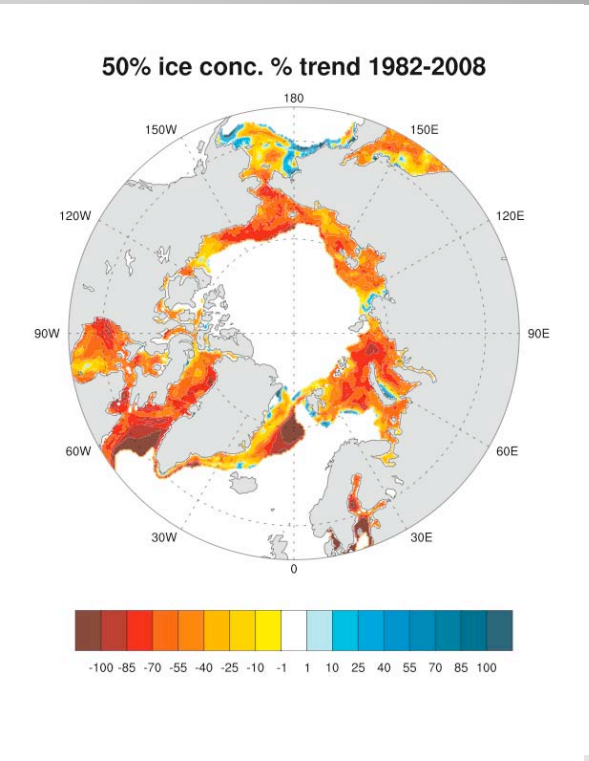
101 & 1* East Bering Sea
102 & 2 Chukchi Sea
103 & 3 Beaufort Sea
104 & 4 Canadian Arch. Straits
105 & 5 Hudson Bay
106 & 6 Hudson Strait
107 & 7 Davis Strait
108 & 8 Baffin Sea
109 & 9 Lincoln Sea
110 & 10 Greenland Sea
111 & 11 Denmark Strait
112 & 12 Norwegian Sea
113 & 13 Barents Sea
114 & 14 White Sea
115 & 15* West Kara Sea
116 & 16 Laptev Sea
117 & 17 East Siberian Sea
118 & 18 Russian Arctic Basin
119 & 19 American Arctic Basin
120 & 20* East Kara Sea
121 & 21* West Bering Sea

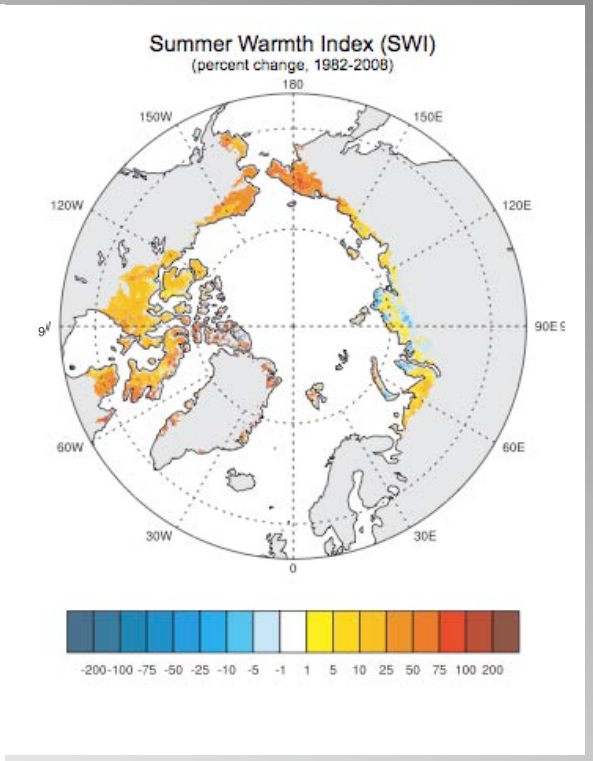


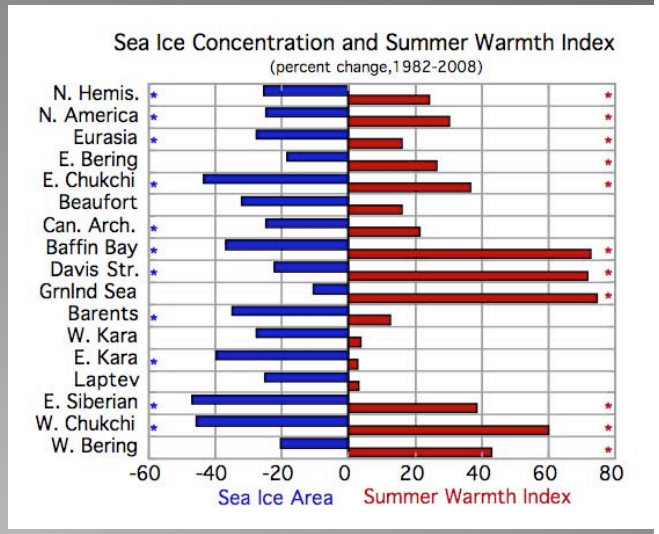
- Russian Arctic Atlas for seas.
- CAVM Florist provinces for land masses.
- Analysis of 50-km buffers seaward and landward along each sea coast and also for entire non-alpine tundra area.

Uma Bhatt, D.A. Walker, M.K. Raynolds, J. Comiso, H.E. Epstein, G.J., Jia, J. Pinzon, and C.J. Tucker, 2009 submitted, Earth Interactions.

Circumpolar changes to early summer coastal sea ice, and summer land temperatures (1982-2008)



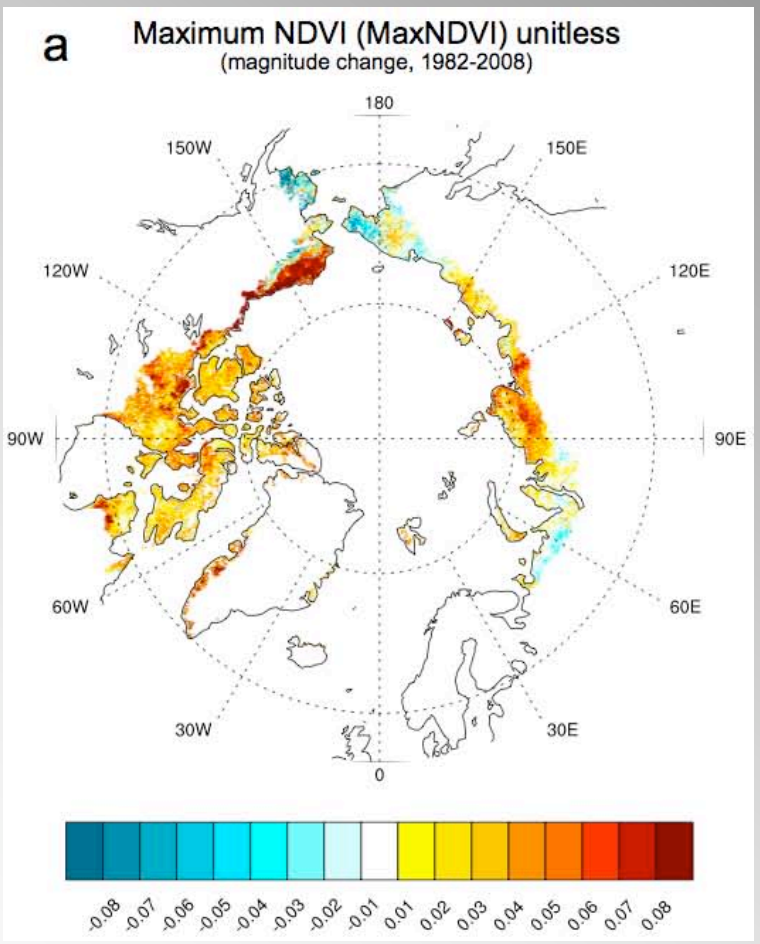


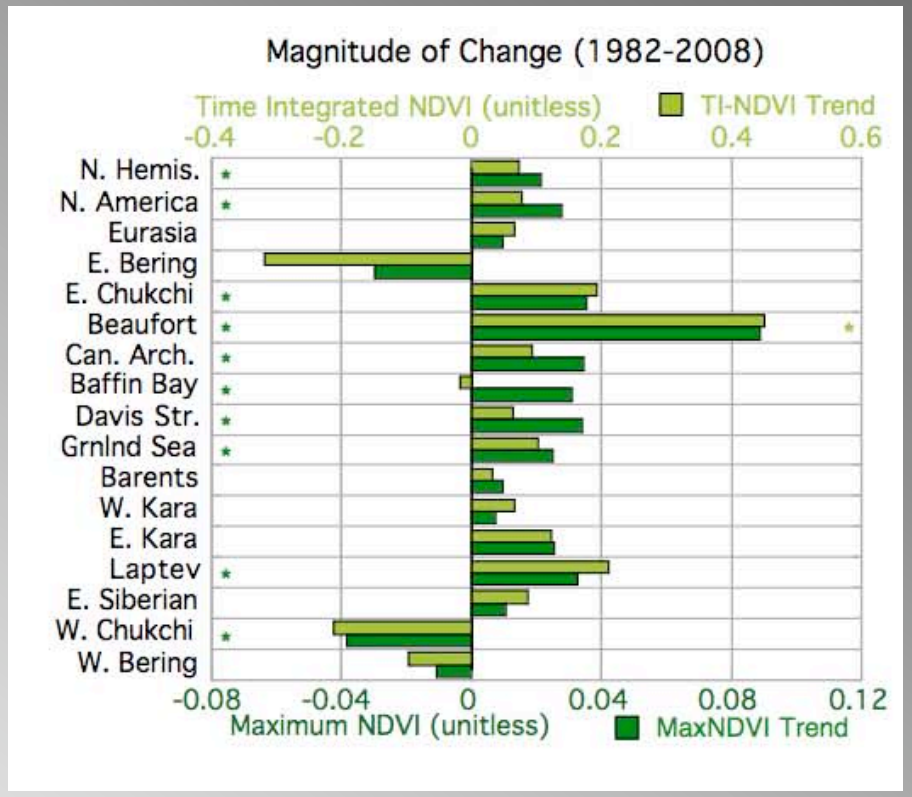


- **Coastal sea ice**: strongly decreasing throughout the Arctic except coastal areas of the Greenland Sea and parts of the Bering Sea. The strongest most significant trends are in the E. Siberian to Chukchi, and E. Kara regions (-40 to -44%).
- **Summer warmth**: increasing most strongly in the Canadian High Arctic and Greenland and in the Beringian region between the E. Siberian Sea and the E. Chukchi. Relatively small increases are seen between the Kara and Laptev seas.

Bhatt et al. 2009 submitted, *Earth Interactions*.

Magnitude of MaxNDVI change 1982-2008

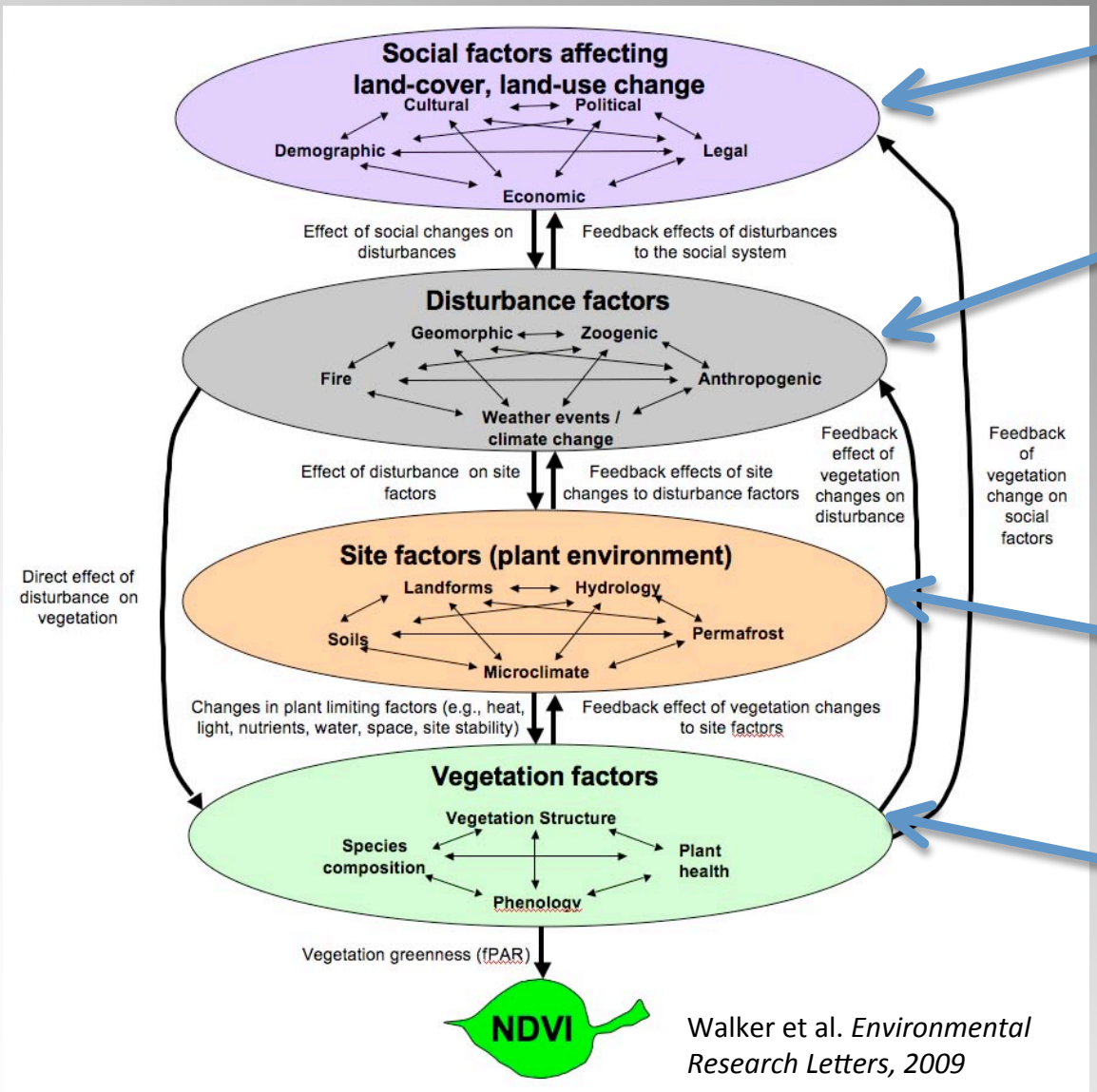




- **General increases except in W. Chukchi and Bering seas.**
- **By far the largest changes are in the Beaufort Sea/northern Alaska area**.

Bhatt et al. 2009 submitted, *Earth Interactions*.

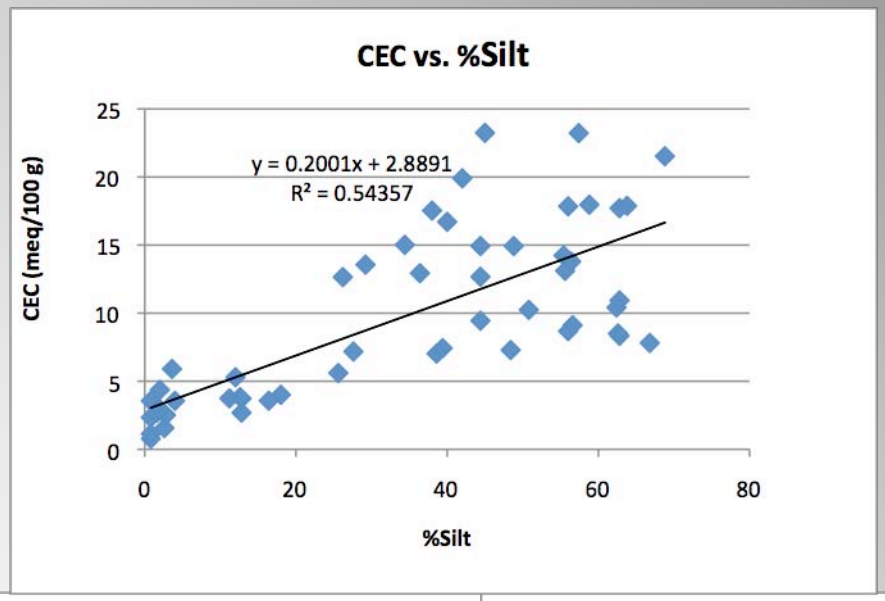
The effects of climate, substrate, disturbance, and social factors on NDVI

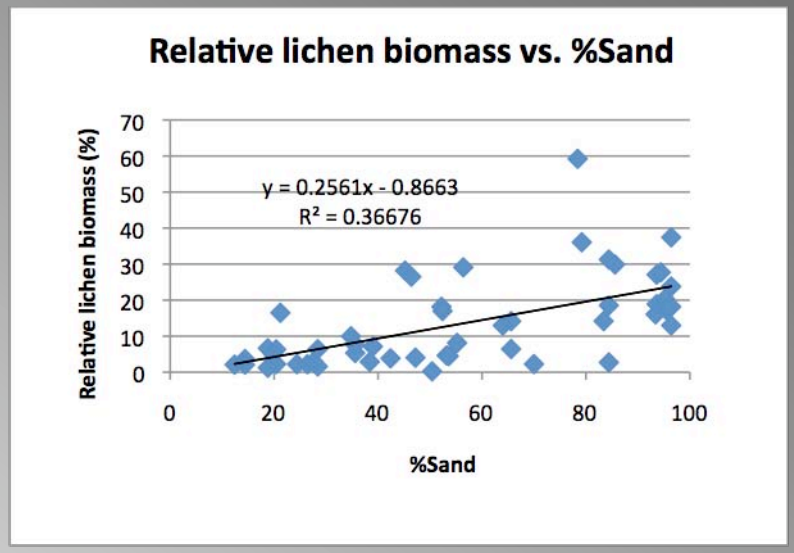


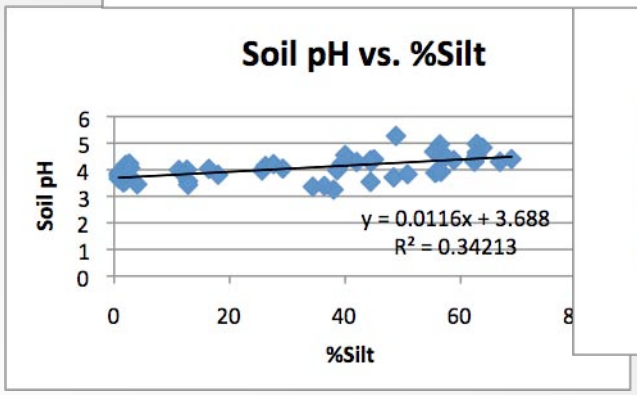
Walker et al. *Environmental Research Letters, 2009*

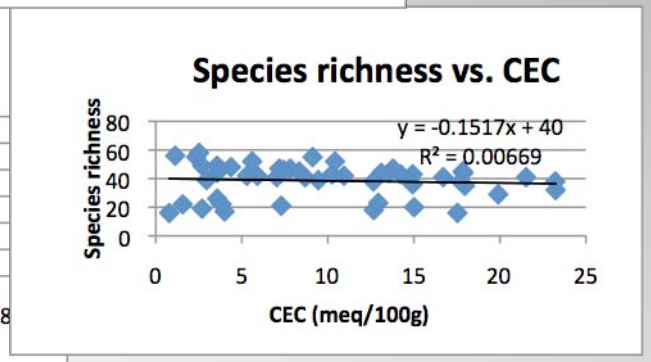
- A wide variety of social factors affect many tundra disturbance regimes.
- Climate is one of several disturbance factors affecting tundra productivity and NDVI patterns.
- Immediate plant environment controls plant production and composition.
- A wide variety of vegetation-related factors affect NDVI.

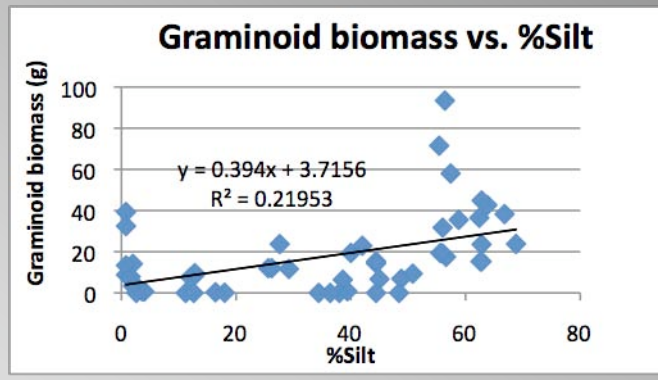
Environment and plant relationships



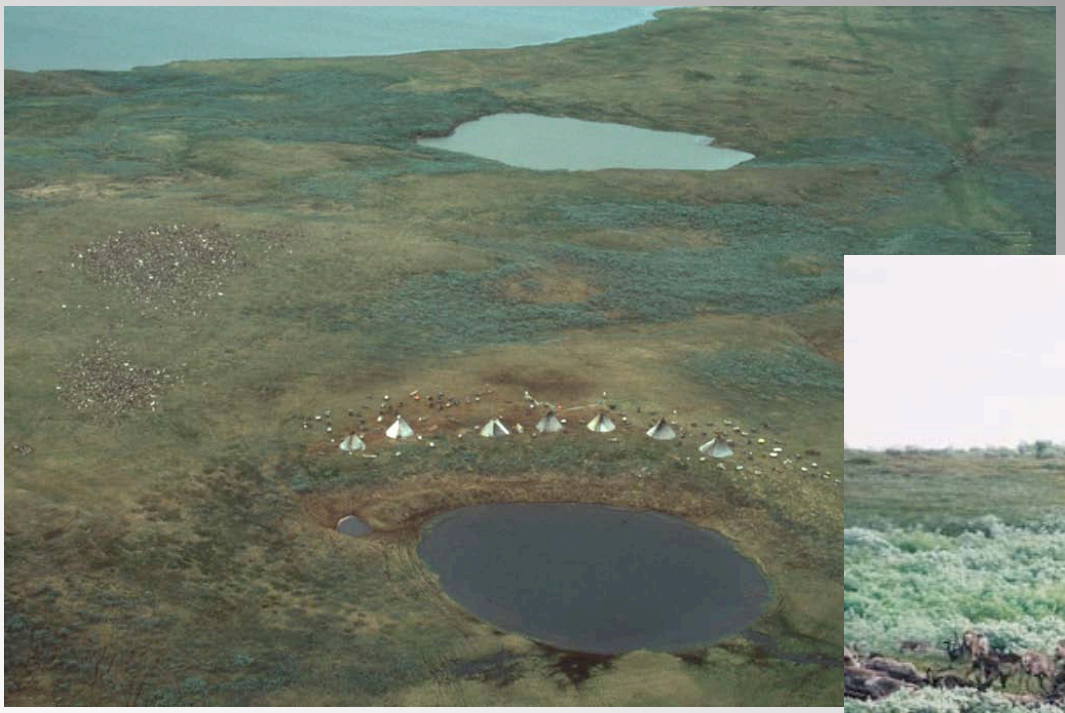








The changes in willow growth are affecting reindeer management.



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.