The idea of Greenland transects in the context of the IPY Greening of the Arctic project and Greenland biodiversity

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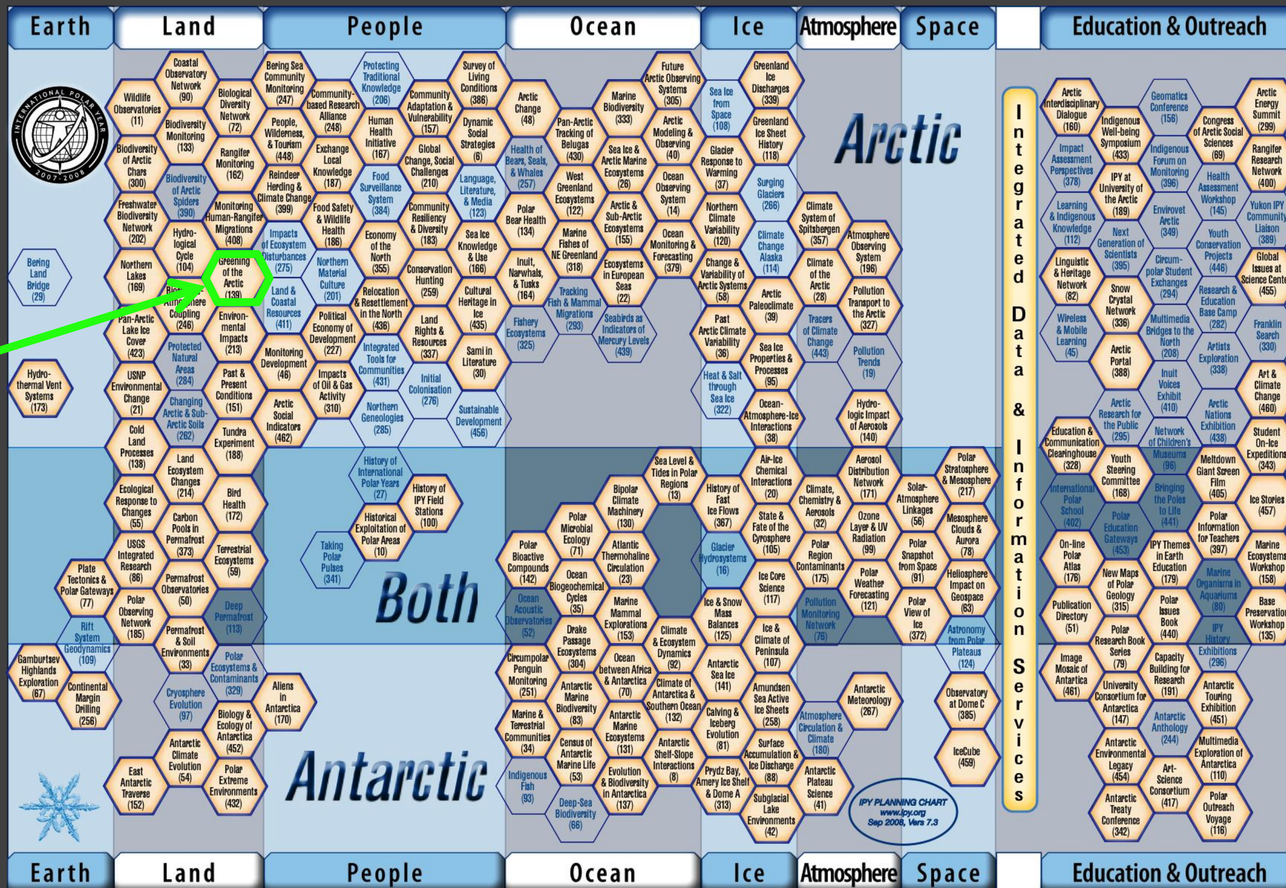
Honeycomb chart of IPY projects



Greening of the ArctIc Project ID 569

What are the causes of the greening observed in Arctic tundra regions during the period of satellite-based observations?

Principal GOA collaborators

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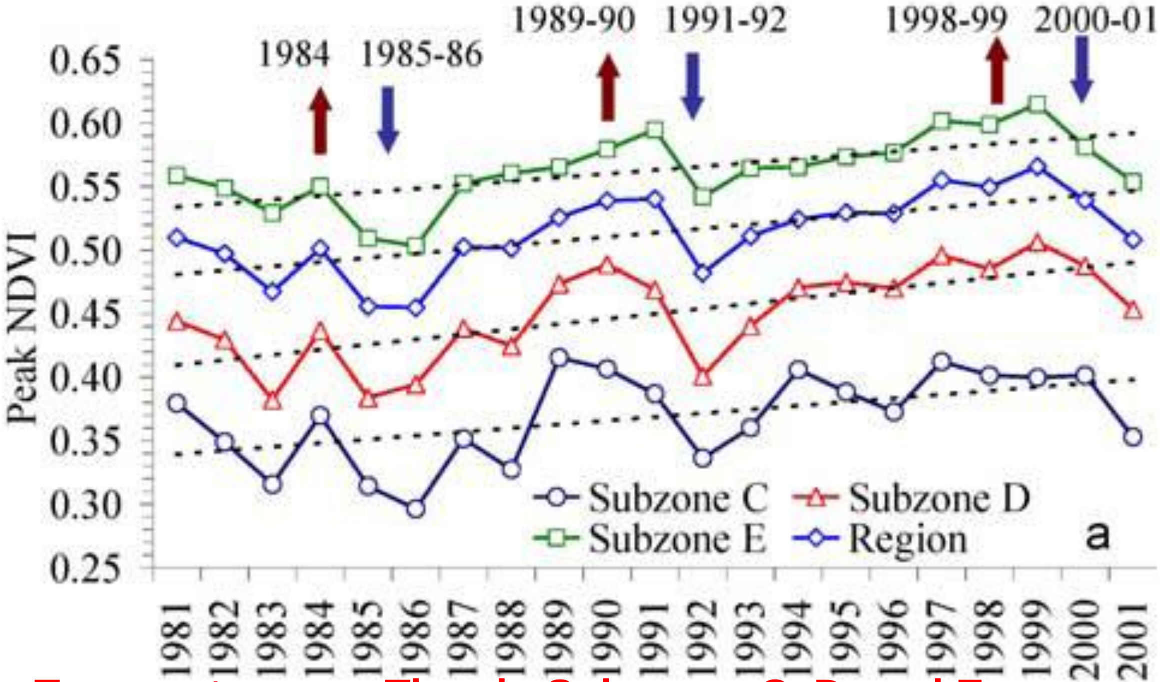
- Funding mainly from NSF (4 projects), NASA (2 projects), Russian Academy of Science and Finnish Government.

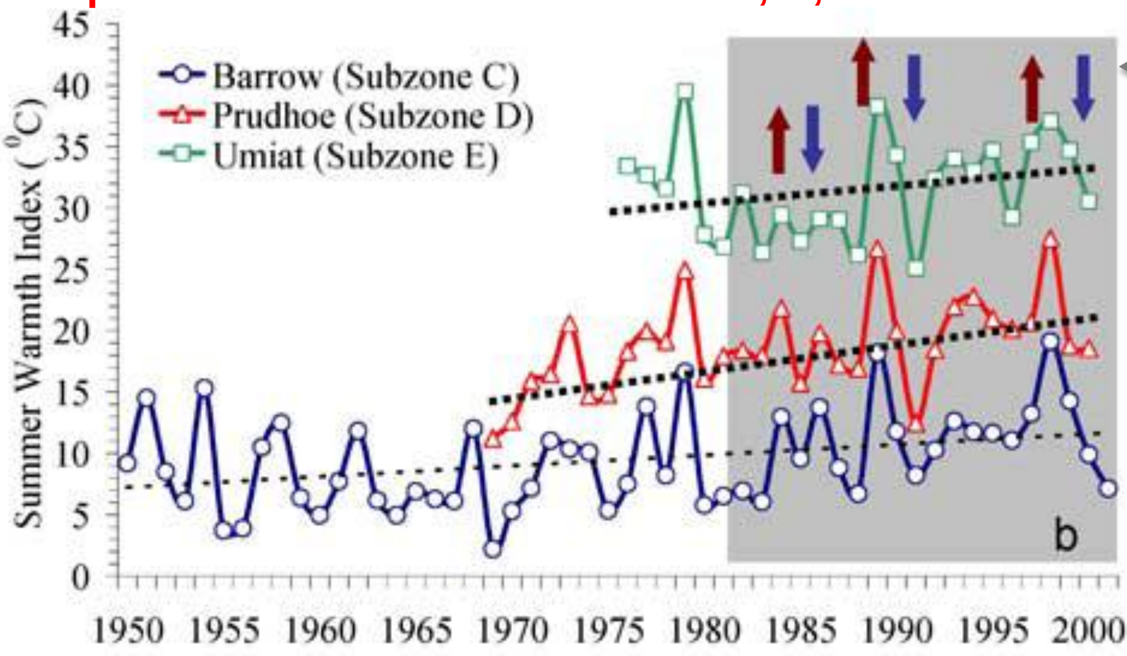
Overview of talk

- Hierarchical spatial and temporal analysis of Arctic greening
  - Quick overview of NDVI and early findings.
  - Update on spatial and temporal PanArctic sea ice, land temperature, and NDVI change emphasizing a recent change in these patterns possibly related to humidifcation of the Arctic.
  - Regional observations along Arctic transects in North America and Eurasia that help explain the PanArctic changes.
  - Two studies in Russia and at Toolik using Landsat and very high resolution satellite data to help understand the details of change.
  - Why two Greenland transects are needed.

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



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

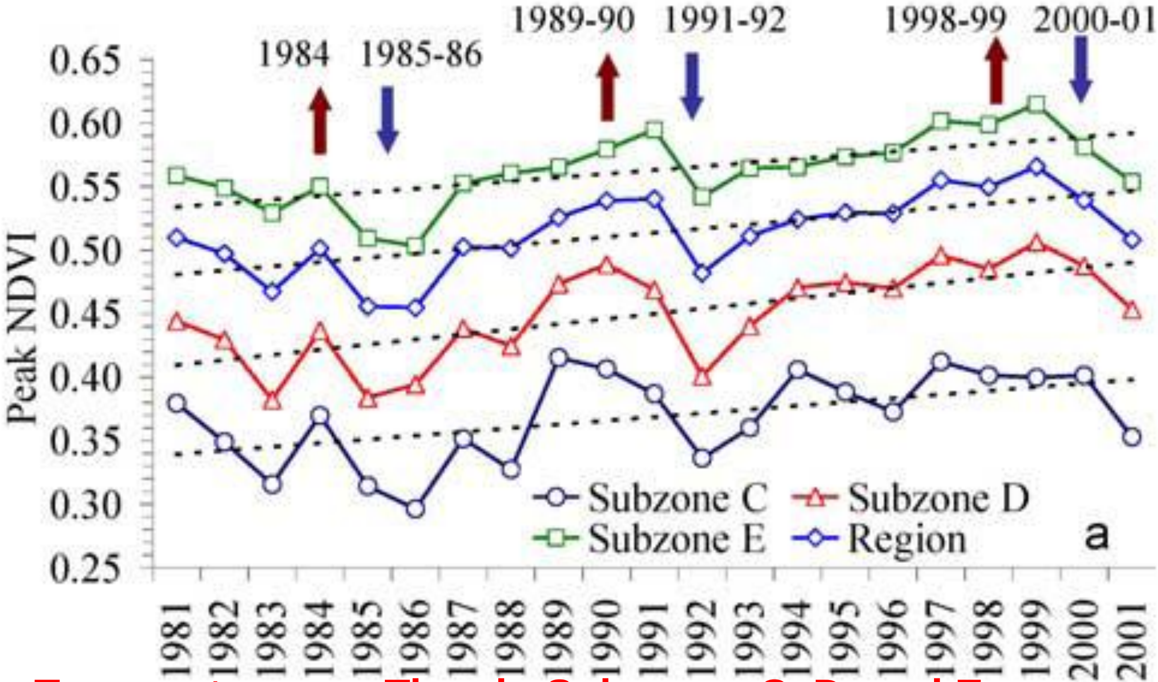


Tundra NDVI trend first noticed in time series of peak NDVI for northern Alaska (1981-2001)

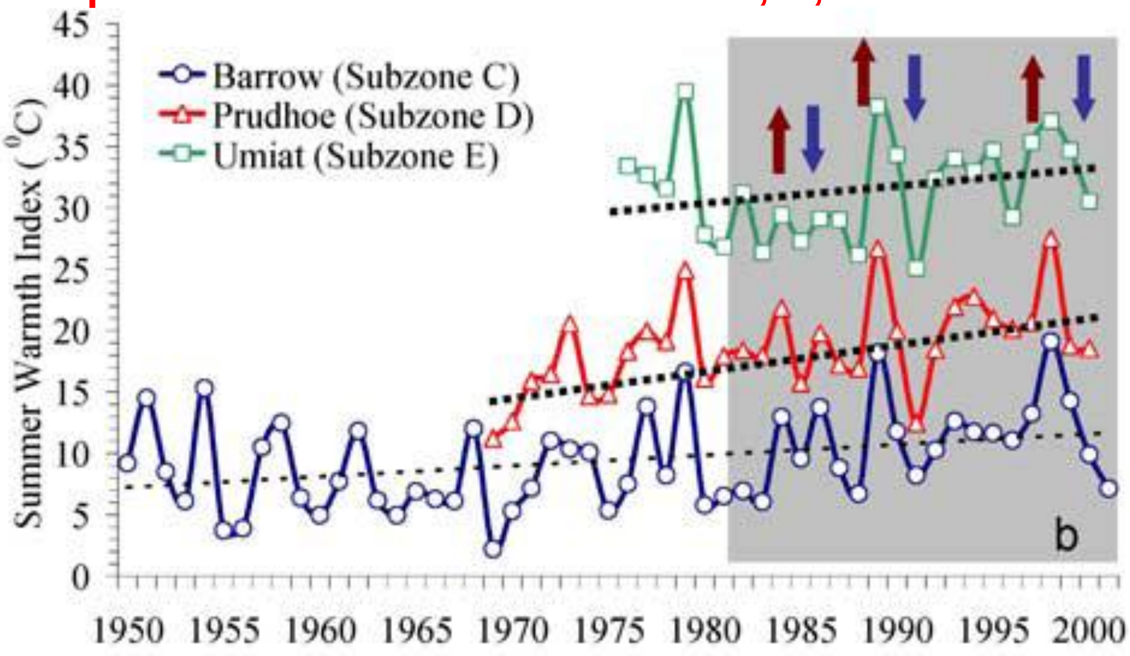
Gray area corresponds to AVHRR NDVI record in top graph.

Jia et al. 2003. Greening of Arctic Alaska, 1981-2001. *Geophysical Research Letters.* 30: 2067.

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



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



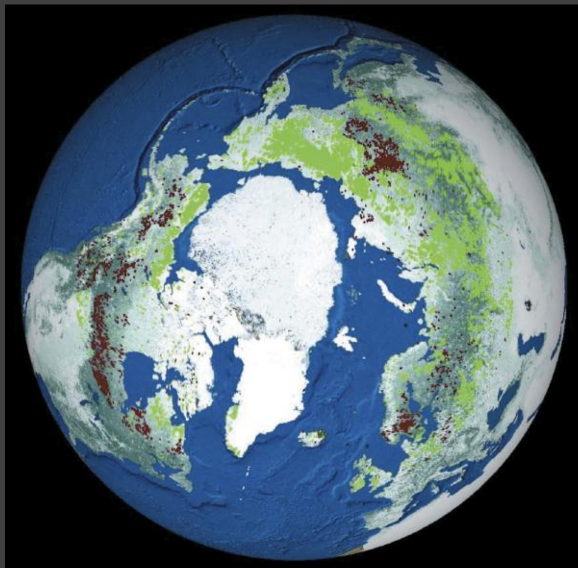
Tundra NDVI trend first noticed in time series of peak NDVI for northern Alaska (1981-2001)

- 17 ± 6% increase in peak regional NDVI (red line) from 1981-2001.
- Changes also appeared to correspond to yearly fluctuations in temperature.

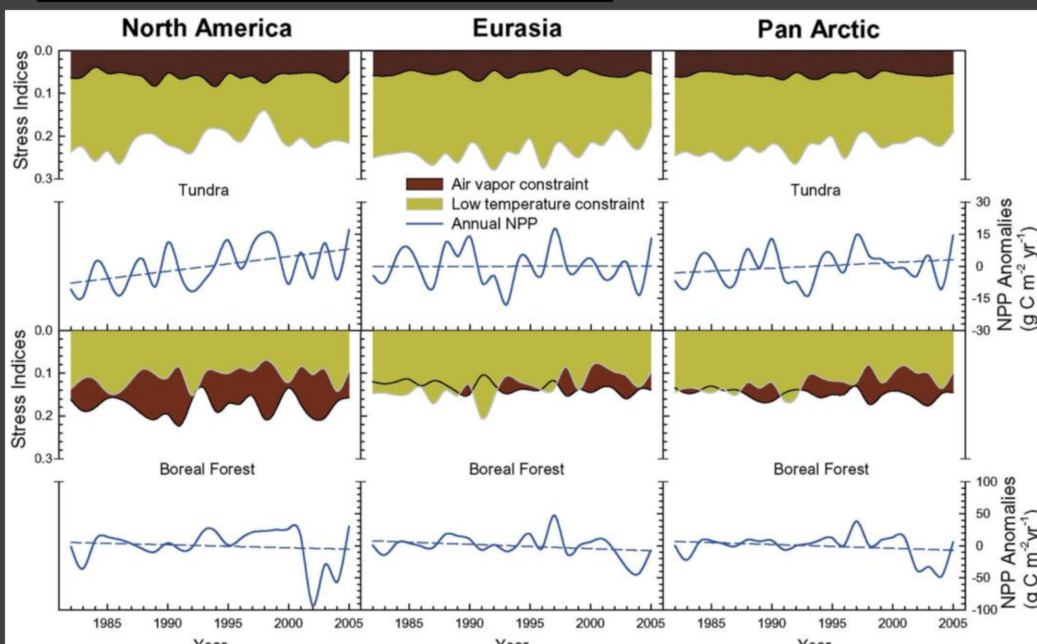
Rationale for the IPY project: Are these same magnitude of trends occurring on a PanArctic scale and what are the drivers?

Jia et al. 2003. Greening of Arctic Alaska, 1981-2001. *Geophysical Research Letters.* 30: 2067.

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

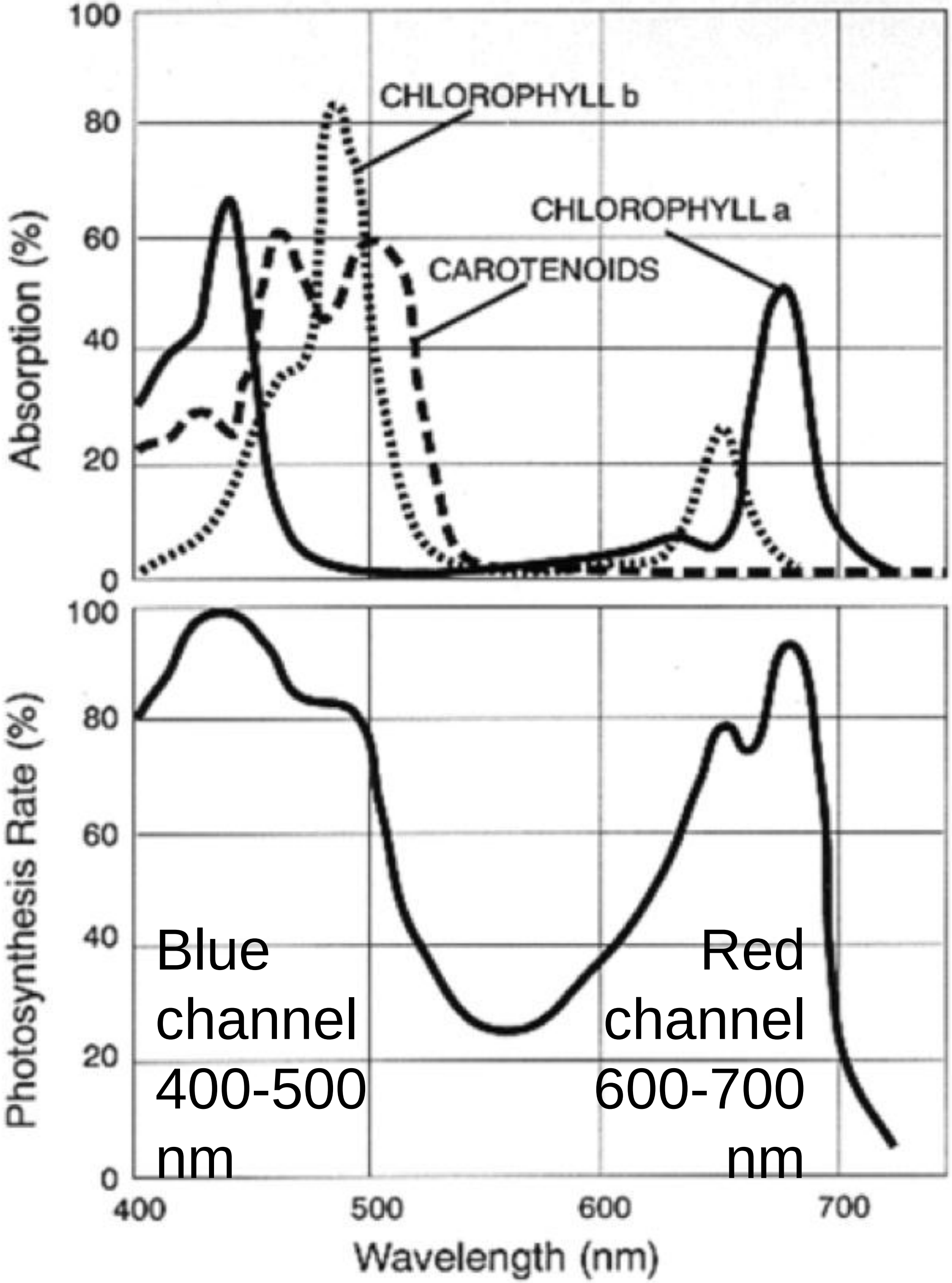


Green: increasing NDVI
Red: decreasing NDVI
White: no trend



- Most of the positive changes are in tundra areas, particularly in North America.
- Forest areas are showing an overall decline in NDVI.
- But focus was not in the Arctic and could not examine change in the High Arctic because of problems with the original GIMMS data set.

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



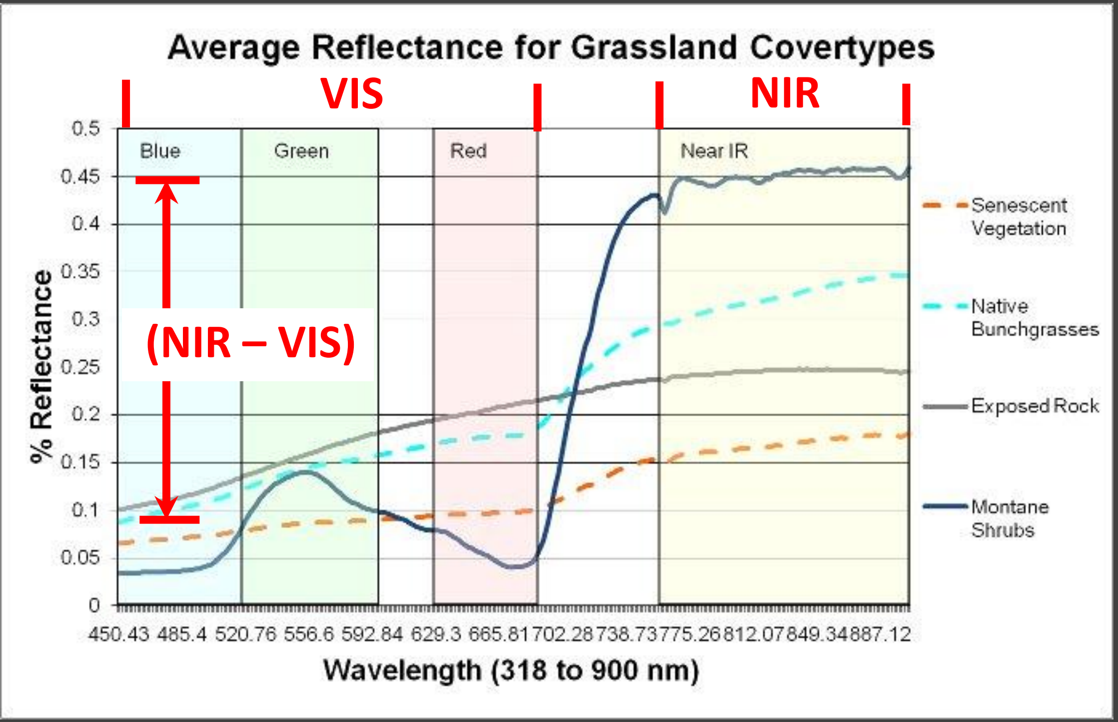
NDVI refresher

Absorption spectra for different plant pigments and photosynthetic response

The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis.

The Landscape Toolbox:http://wiki.landscapetoolbox.org/

Reflectance spectra for vegetation



CourtThe Landscape Toolbox:http://wiki.landscapetoolbox.org/doku.php/remote_sensing_methods:normalized_difference_vegetation_index

On the other hand, the cell structure of the leaves strongly reflects near-infrared light (from 0.7 to 1.1 μm).

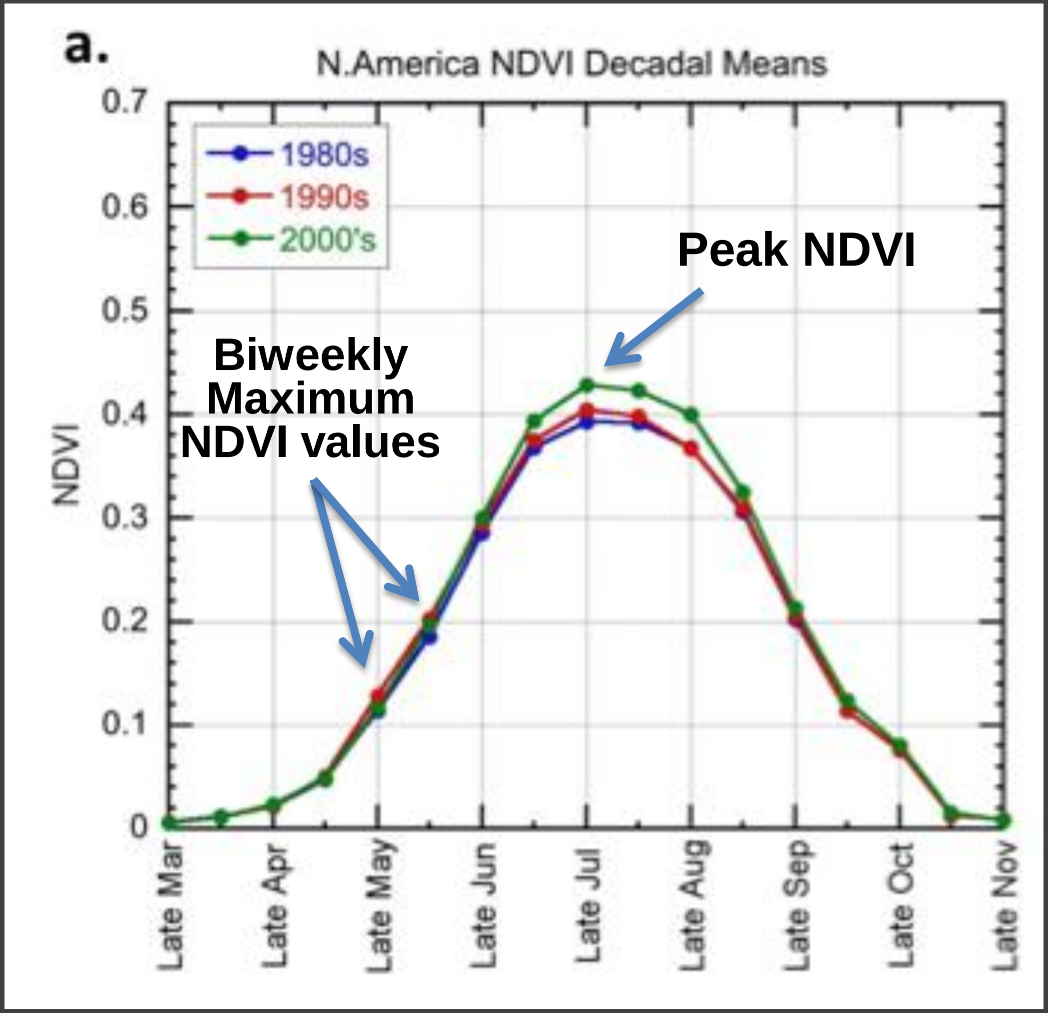
The difference in the reflectance in the NIR and visible regions, is a good proxy for the photosynthetic capacity of the vegetation.

Normalized Difference Vegetation Index:
NDVI = (NIR – VIS) / (NIR + VIS)

Dividing by the sum normalizes the index to help account for shadow and slope angle effects.

Tucker, C. J., 1979: Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sens. Environ.*,**8,** 127–150.

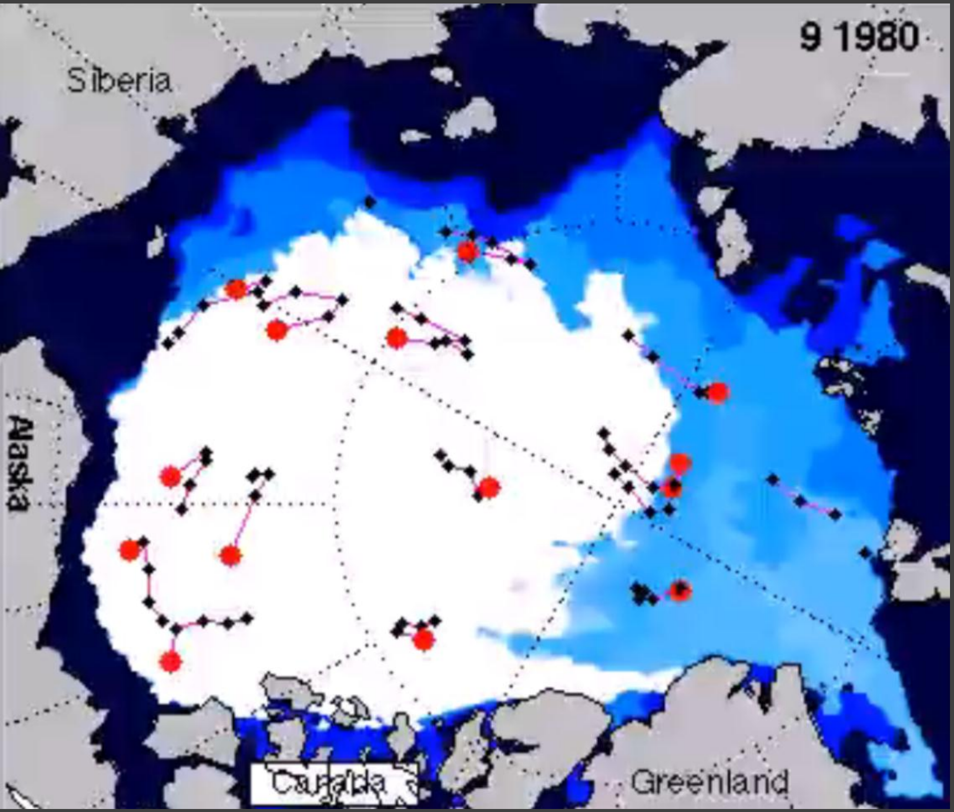
MaxNDVI and TI-NDVI

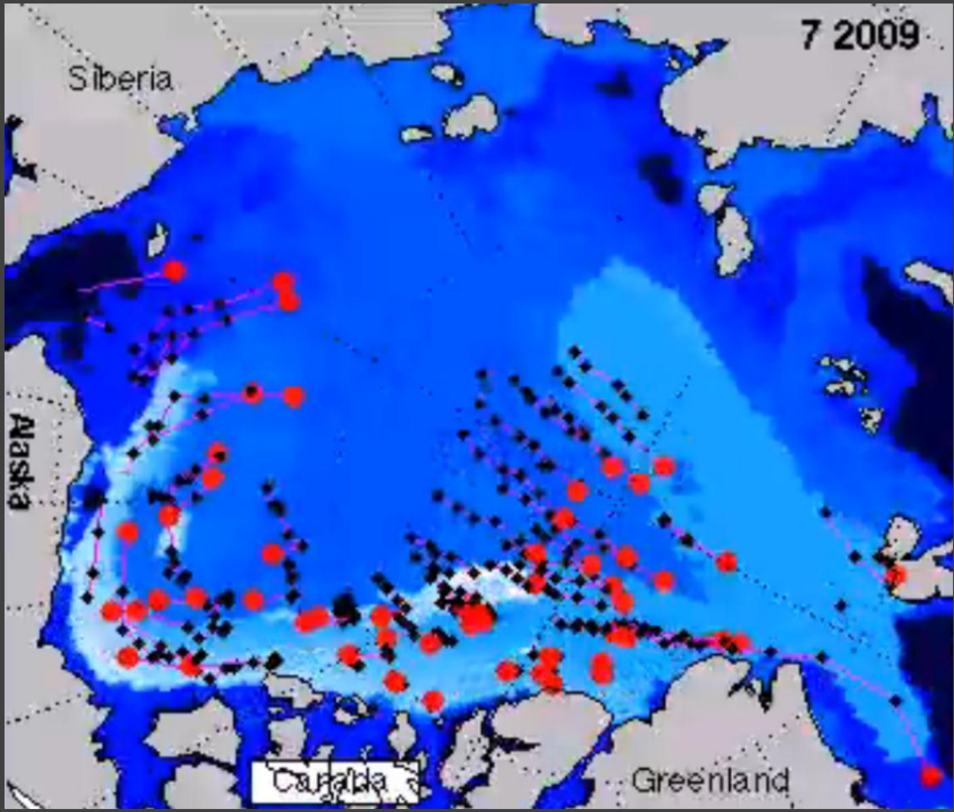


- **NDVI is measured twice daily for every spot on Earth using AVHRR and other sensors.**
- **Cloud cover may prevent getting good daily NDVI values, so the maximum values during biweekly collections of data are used to trace the seasonal trends in NDVI.**
- **Peak NDVI (also referred to here as MaxNDVI) is the highest value of NDVI reached in the summer and represents maximum greenness.**
- **Time-integrated NDVI (TI-NDVI) is the annual sum of bi-weekly NDVI values, a better index of total productivity.**

Change in multi-year sea ice

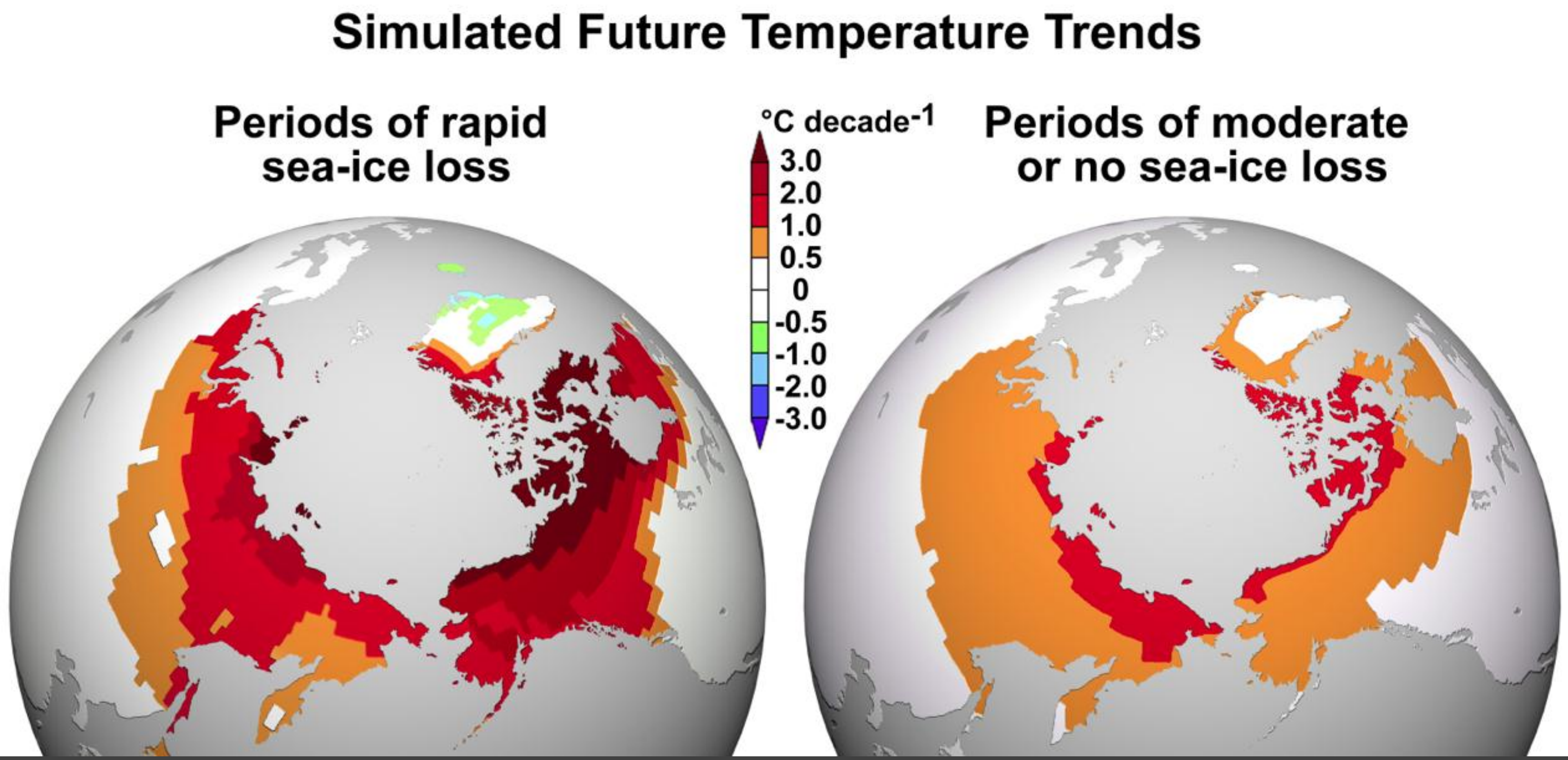
White areas are areas of multi-year ice in 1980 and 2009.





Rigor and Wallace 2004, updated to 2009

Models indicate that periods of rapid sea-ice loss are accompanied by strong land warming and permafrost degradation.



D.L. Lawrence et al. 2008. Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. *Geophysical Research Letters.* 15: L11506.

Linkage between climate, sea-ice shrinkage and vegetation.

Main PanArctic hypothesis:

Periods of reduced sea ice should correspond to periods of warmer land temperatures and this should in turn correspond to periods of more rapid greening.

Greening is highly variable across the Arctic and within landscapes.

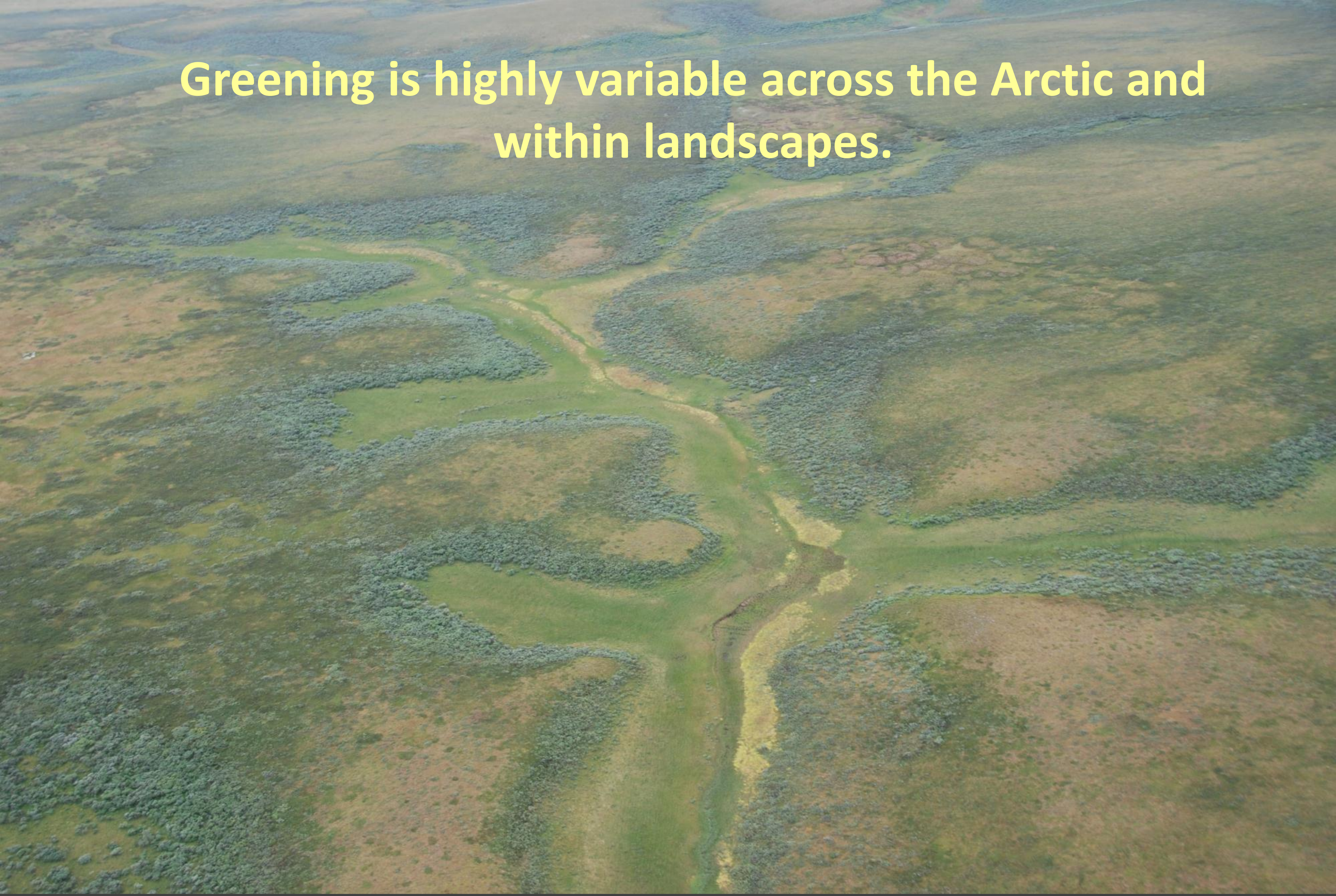
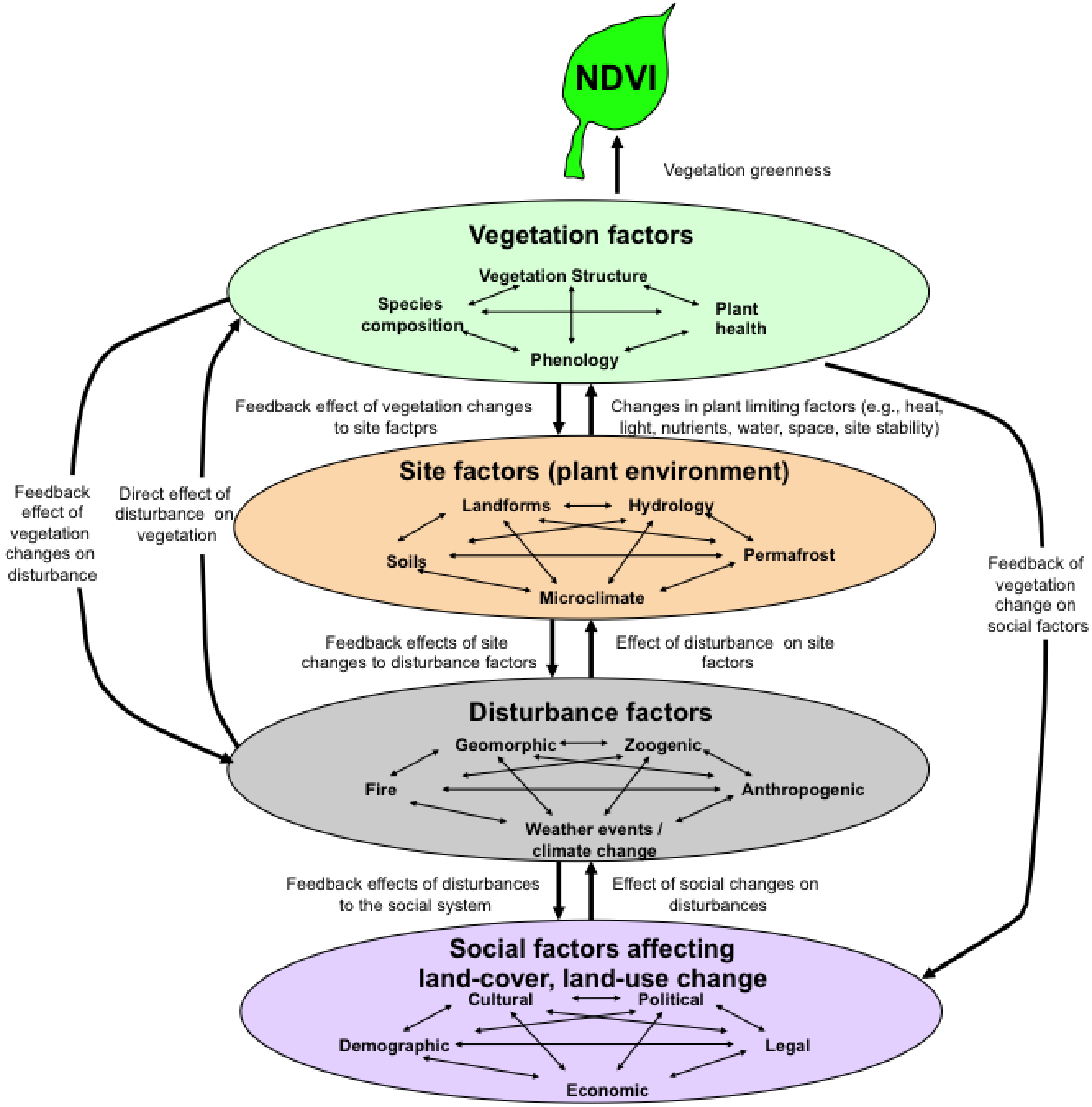


Photo: D.A. Walker

Landslide slopes in the central Yamal Peninsula, Russia



NDVI: Integrator of vegetation change

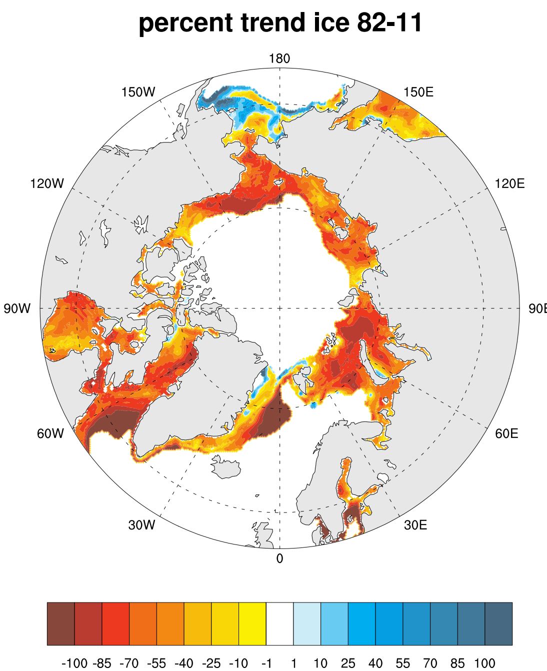
Webs of social and ecological factors that influence vegetation productivity and NDVI

Modified from Walker et al. 2009. *Environmental Research Letters*.

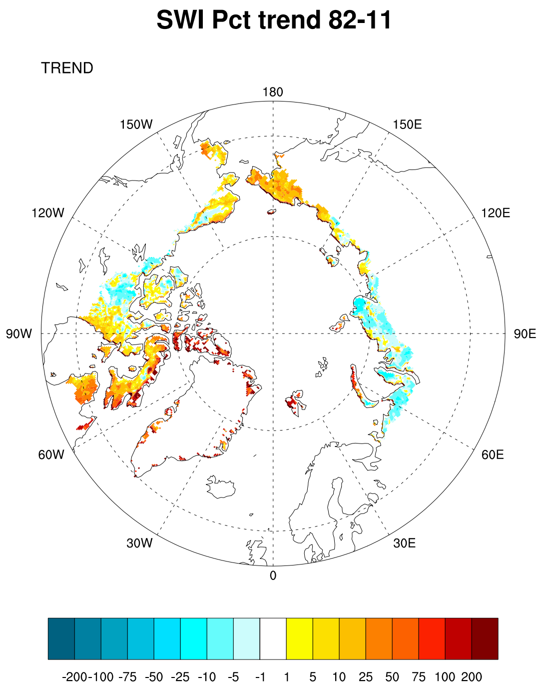
Main Landscape-level hypothesis:

Disturbance is the primary driver of NDVI change within landscapes.

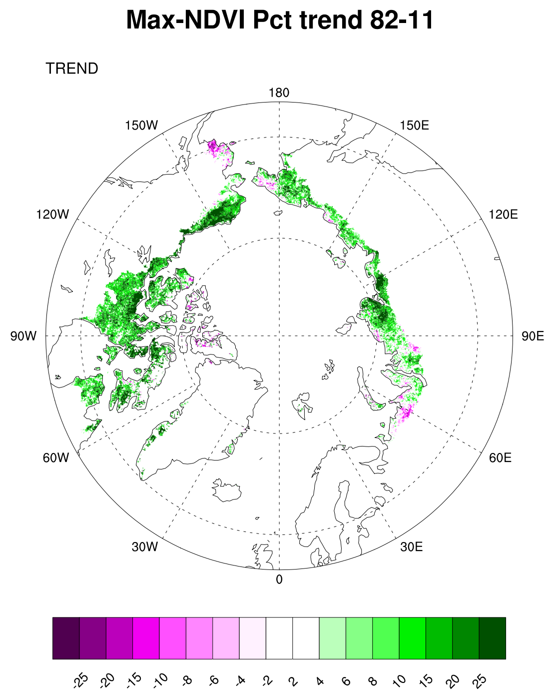
Circumpolar patterns of change of sea-ice, land temperature and NDVI change in the Arctic detected with AVHRR satellite sensors



Focused on areas within 100 km of coast lines.



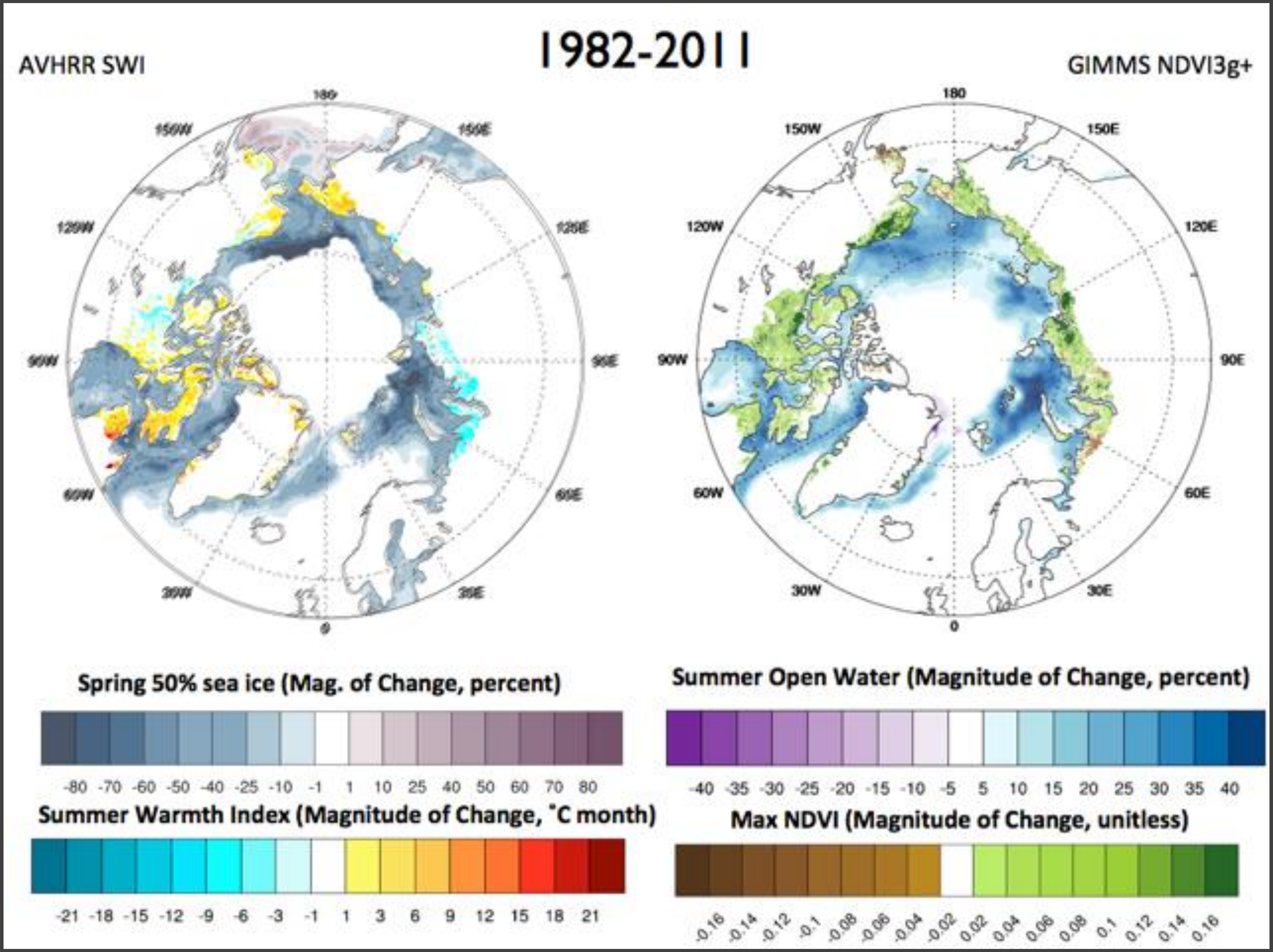
SWI = summer warmth index,
Trend of annual sum of mean monthly temperatures >0 ˚C.



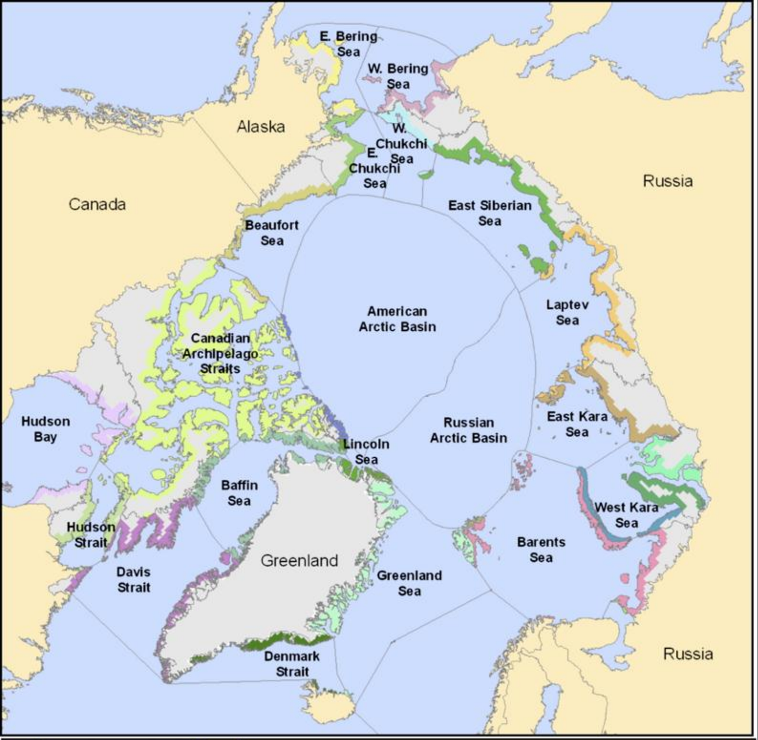
Percentage change in Maximum NDVI value reached in summer.

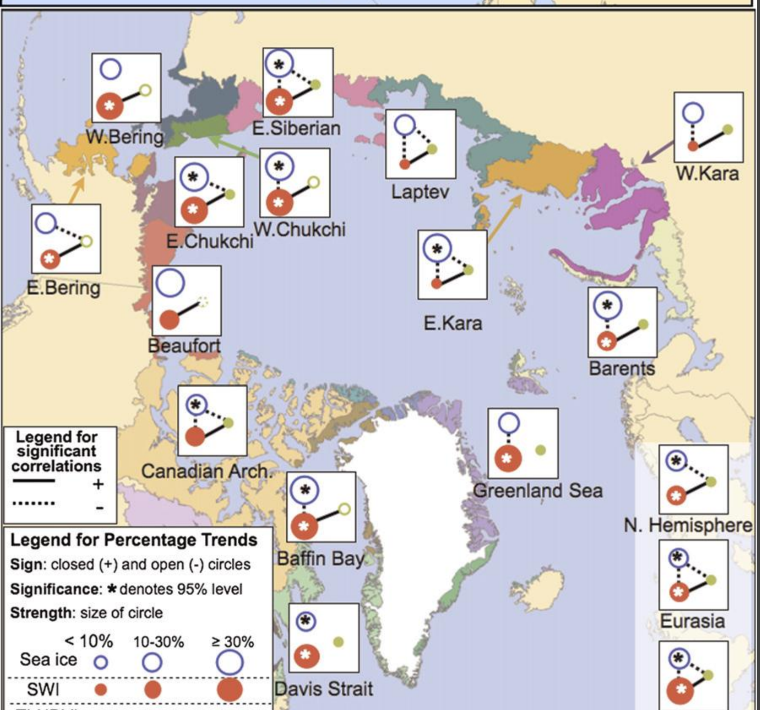
Bhatt et al. 2010. *Earth Interactions.* updated to 2011.

Examining the correspondence between the dfferent patterns



Bhatt et al. 2010. *Earth Interactions.*
Updated to 2011 for BAMS 2011 *State of the Climate*

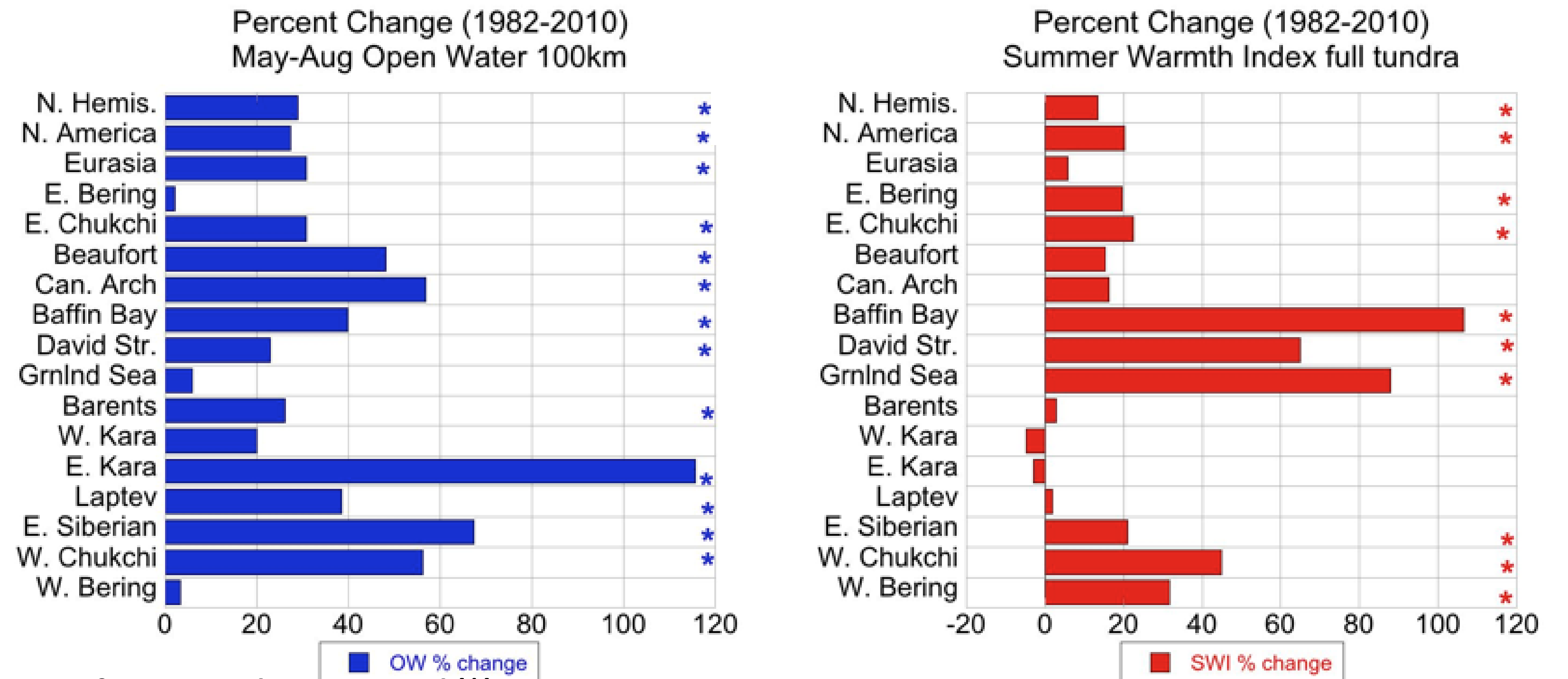




Analysis by sea basin Approach

- Division of the Arctic into sea basins and associated land areas based on Russian Arctic Atlas.
- Developed time series of coastal May-Sep sea-ice concentration (100-km coastal zone), summer land temperatures for the full tundra region (summer warmth index), and NDVI based on 1982-2011 AVHRR satellite data.
- Examined trends and correlations between factors for each sea.

Percentage change of coastal open water and summer land temperatures



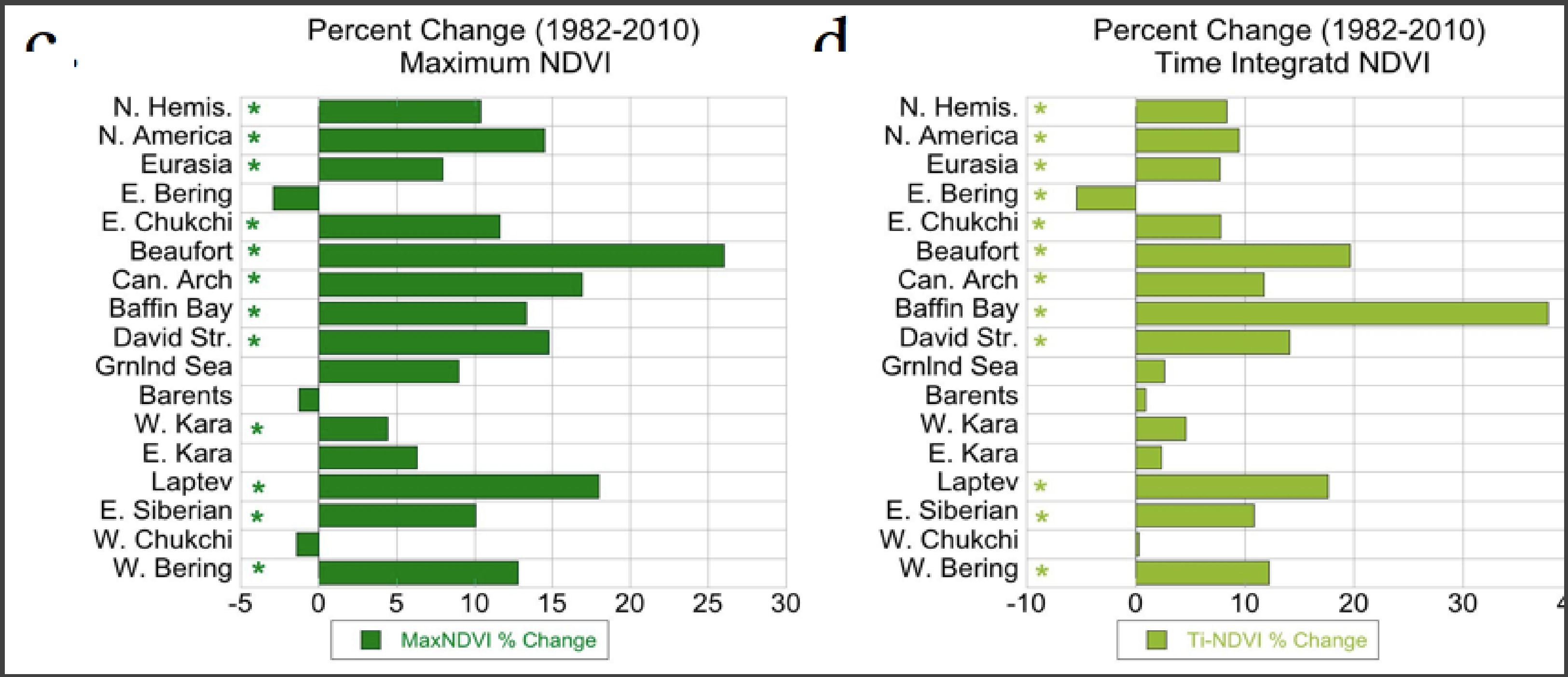
Significant trends are starred (*)

Most noticeable:

- Positive changes in open water across the Arctic.
- Greatest open water changes are in the E. Kara Sea.
- Greatest percentage warming changes are in the Baffin Bay, Davis St., Greenland Sea areas
- Cooling in the E. Kara region despite very large increases in open coastal water (More fog? More snow? Shorter growing season?)

Updated from Bhatt et al. 2010, *Earth Interactions.*

Percentage change of NDVI



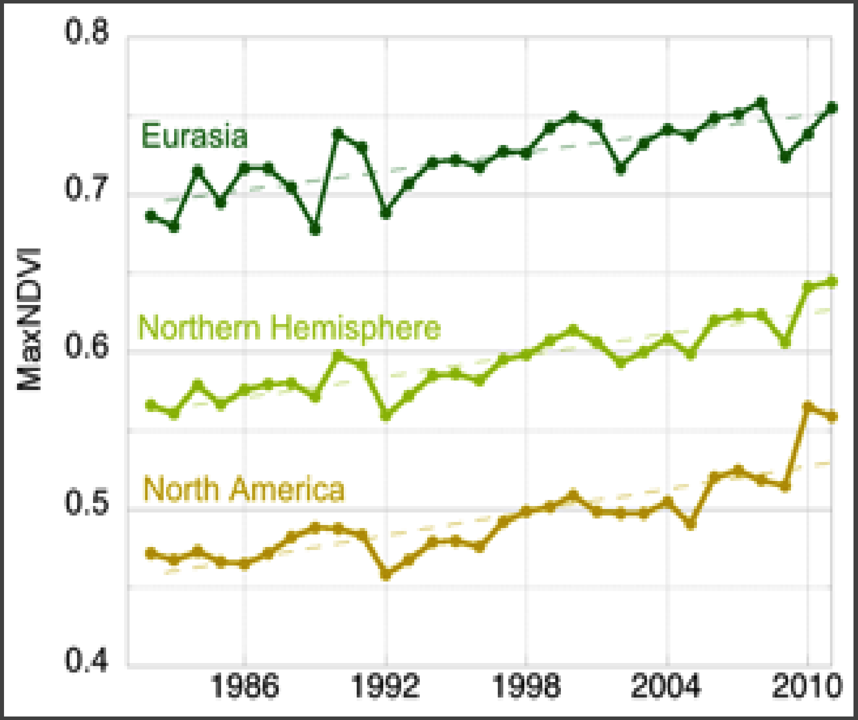
- **In general, areas of enhanced NDVI patterns are corresponding to areas of warmer land temperatures.**
  - **Strong greening in the Beaufort, Canada, Greenland and Laptev (all areas of strong warming).**
  - **Weak trend in the Barents / Kara region (area of cooling).**

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

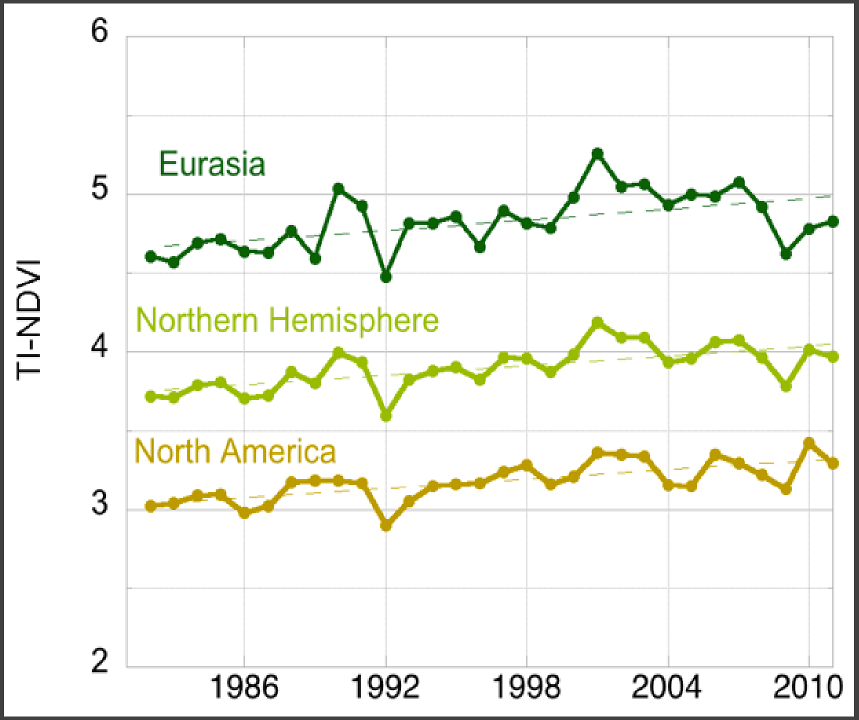
Updated from Bhatt et al. 2010, *Earth Interactions.*

Trends in NDVI

MaxNDVI



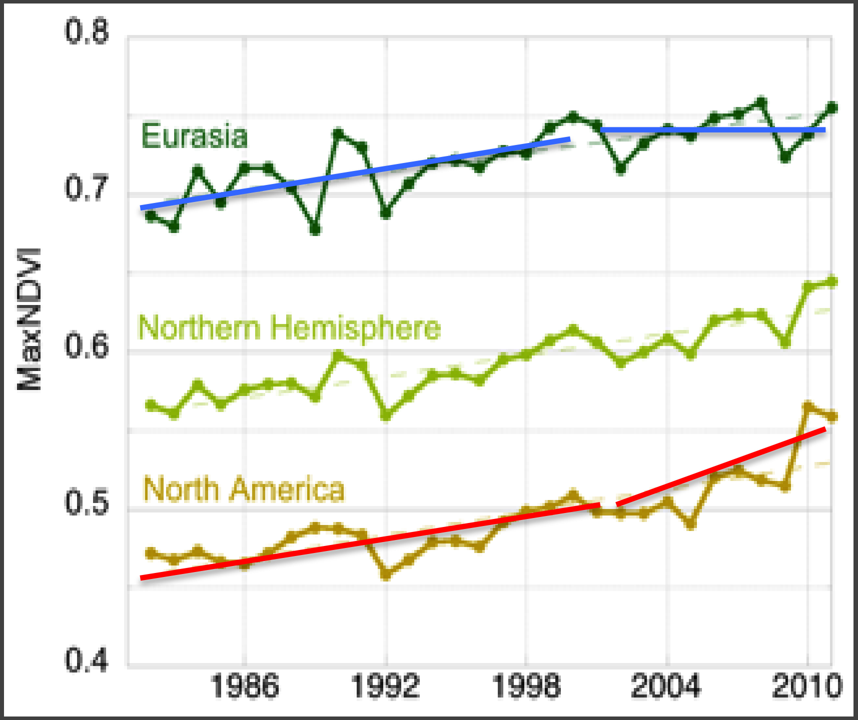
TI-NDVI



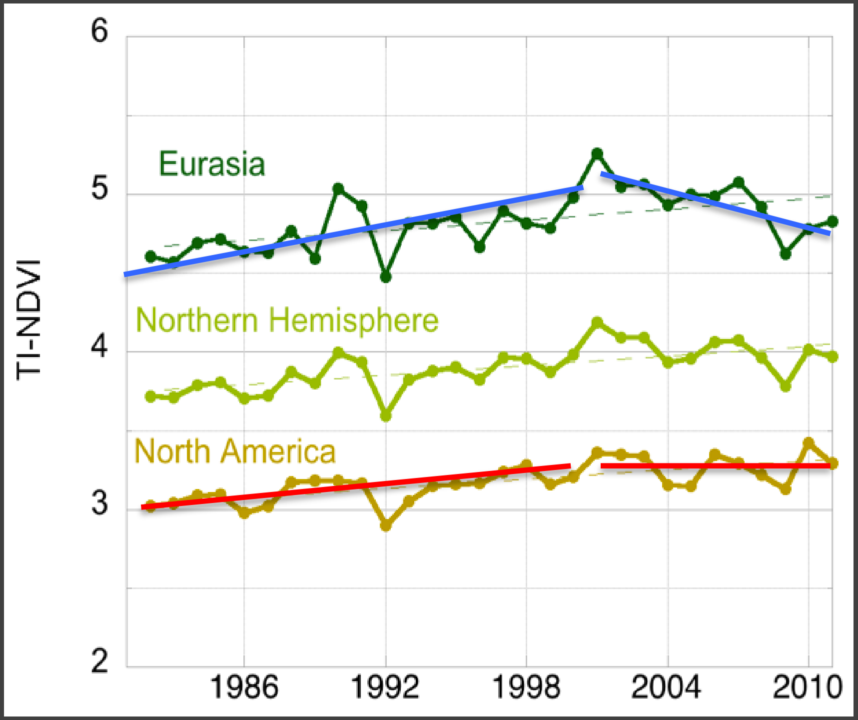
- General upward trend of NDVI in N. America and Eurasia.
- Much higher NDVI in Eurasia due to relative amount of land in the more productive Low Arctic.

Recent changes in NDVI trends

MaxNDVI

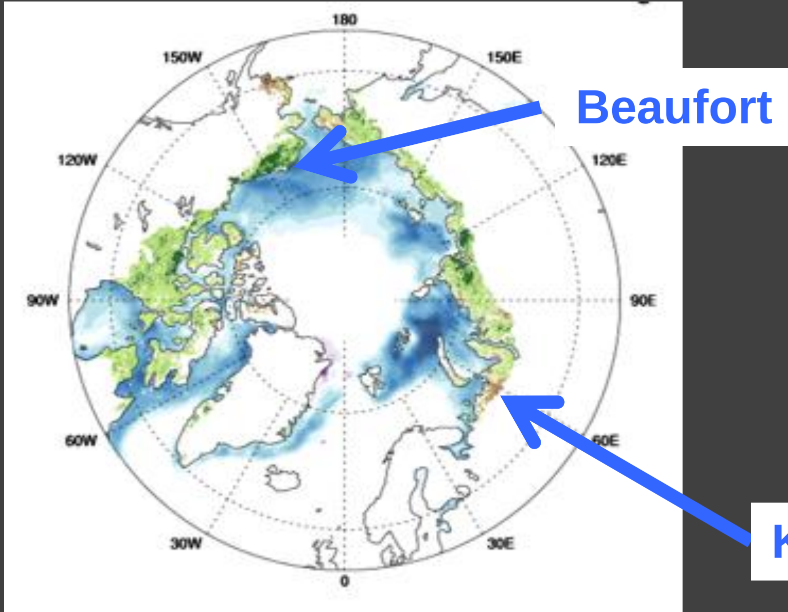


TI-NDVI



Diverging patterns after about 2001:

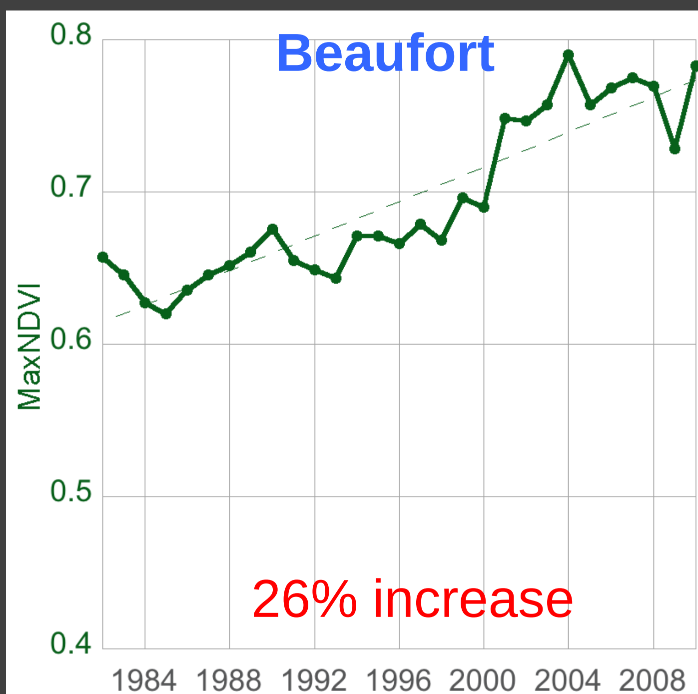
- **Eurasia: flat MaxNDVI and declining TI-NDVI.**
- **North America: strongly increasing NDVI, flat TI-NDVI.**

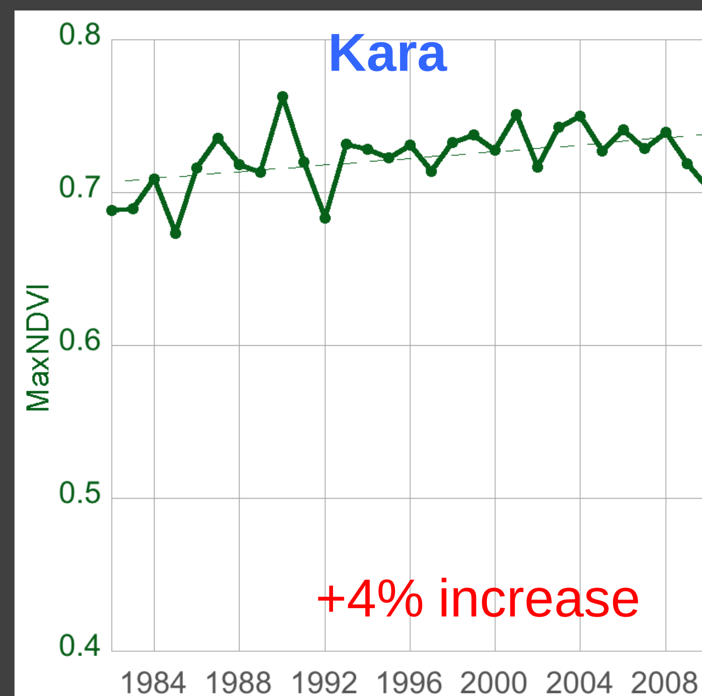


Diverging patterns of NDVI change in the Beaufort and Kara sea areas

Beaufort: 24% overall increase but trend flat since 2004.
Kara: 4% overall increase, essentially flat since 1990.

Pct. Change MaxNDVI (1982-2010)





PanArctic findings

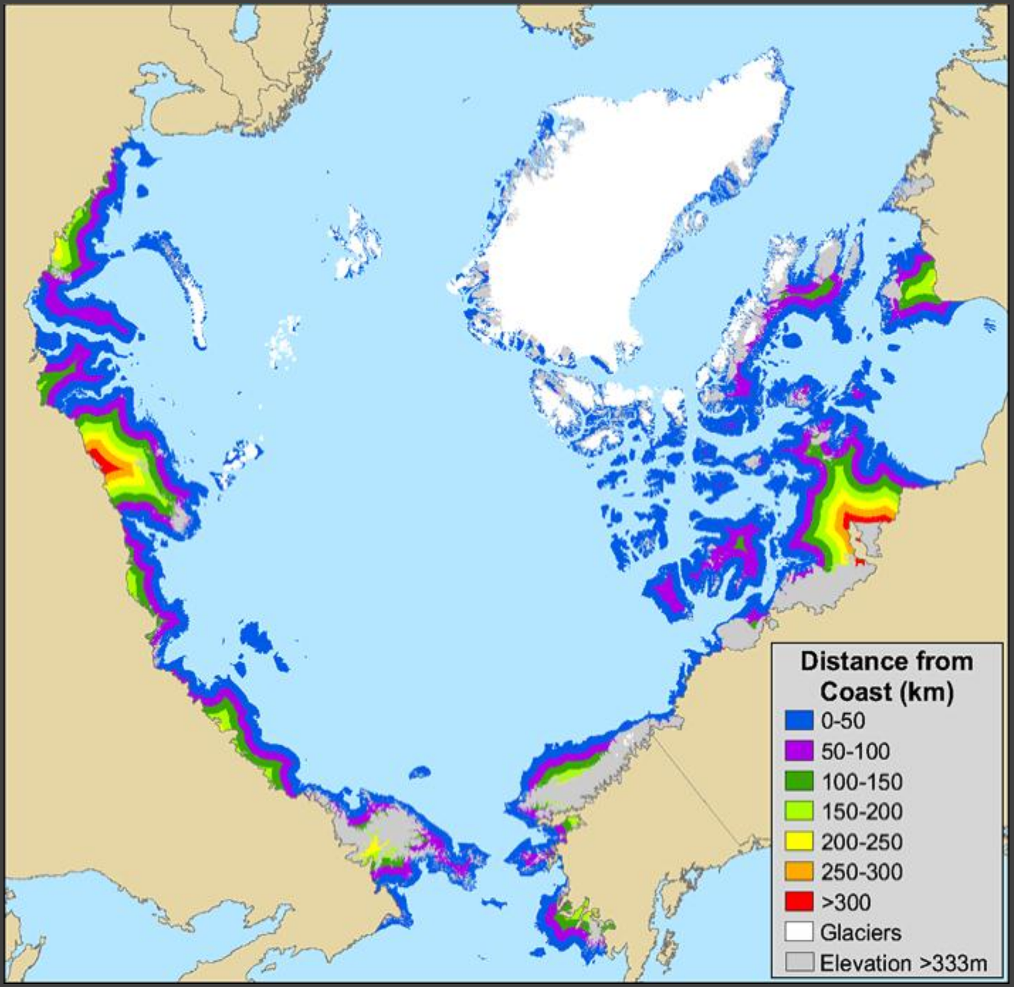
- Largest negative changes in sea-ice (positive changes in open-water) are in the regions of 1) the Kara/N. Barents seas, 2) the East Siberia/Chukchi/Beaufort seas, and 3) the Baffin Bay/Davis Straight/Foxe Basin/Hudson Bay. There are a few areas of positive sea-ice change (e.g. E. Bering Sea).

- Largest positive land-temperature changes are in the Greenland Sea/ Baffin Bay area. Cooling in the Y-K delta, parts of central northern Canada, and much of NW Siberia.

- Strongest positive NDVI changes are in Alaska and Beaufort Sea area. Some weak negative trends in NW Siberia.

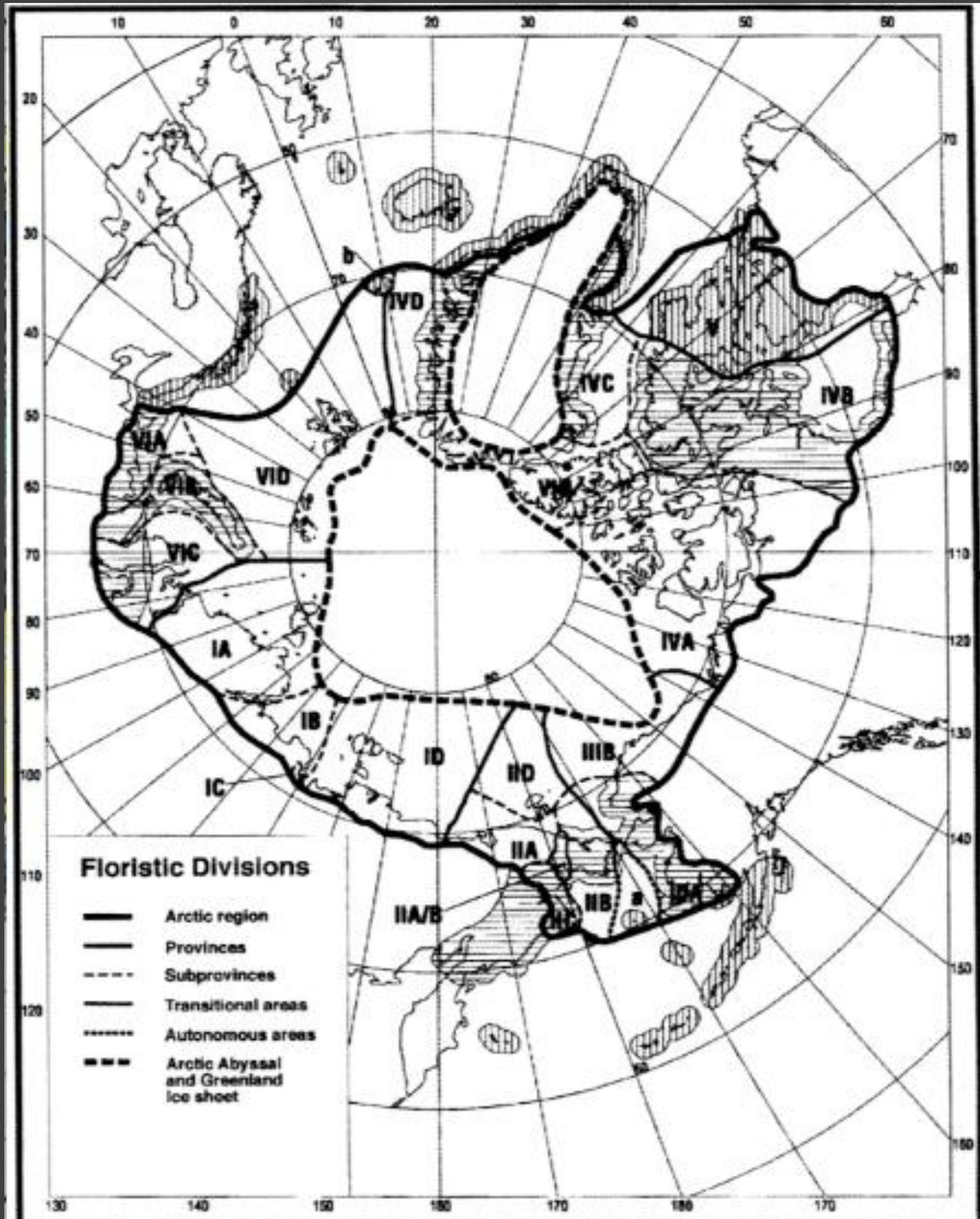
- **Why the strong contrast of NDVI change of the Beaufort and Kara sea areas?**

The Arctic tundra zone is a maritime biome



Map by Hilmar Maier.

- **177,000 km of coastline**
  - *1/5 of global total.*
  - *for a biome that comprises less than 5% of the Earth's land surface.*
- **But it is not all equally maritime because the ocean is covered by varying amounts of ice during the winter and summer.**
- **Which promotes relatively continental climates in areas with long periods of winter and summer sea ice.**

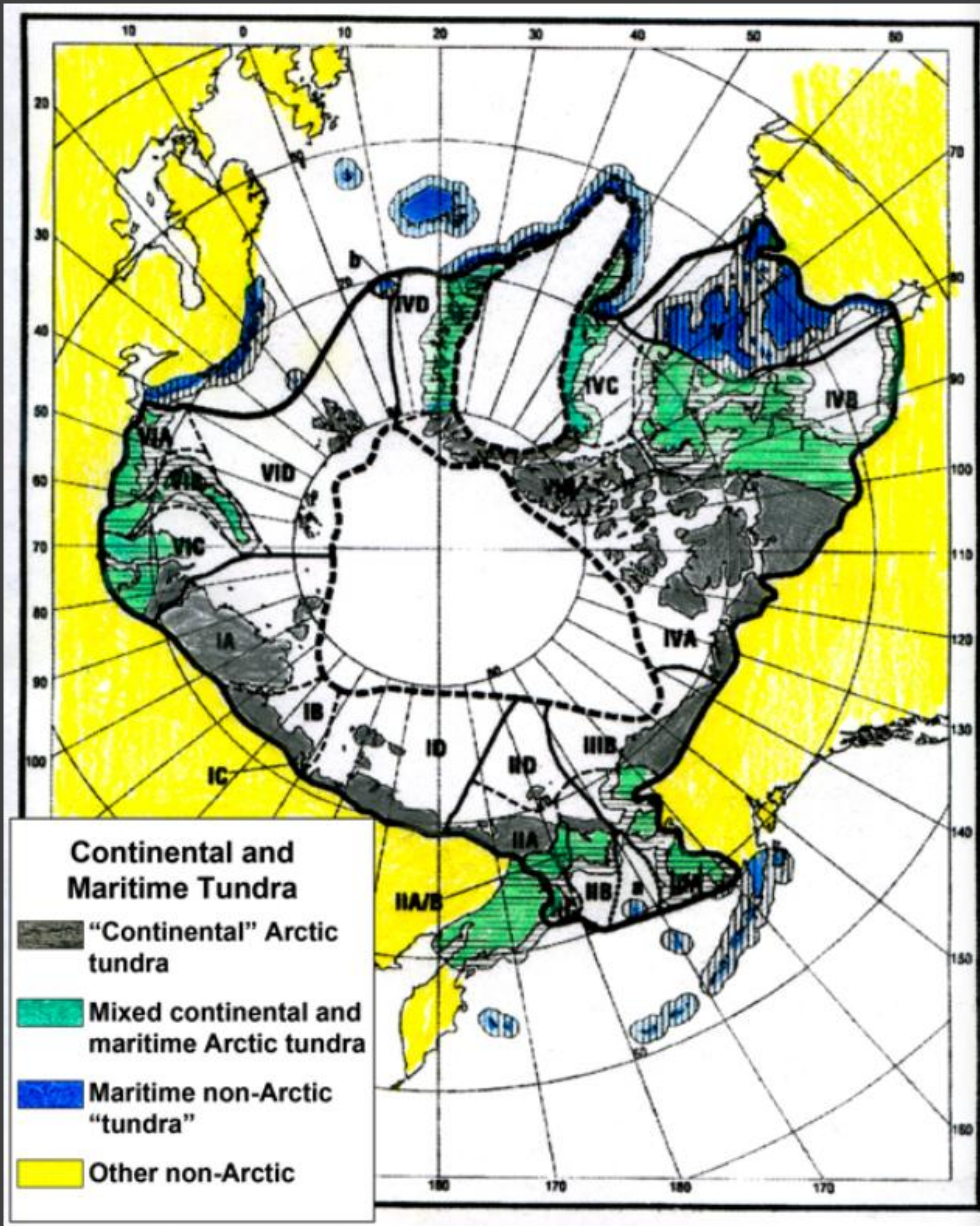


Arctic vegetation patterns are strongly linked to differences in sea ice

Yurtsev's (1994) floristic division of the Arctic:

- Divides the Arctic into 6 floristic provinces and 22 subprovinces.
- Separates oceanic and continental areas of the Arctic.

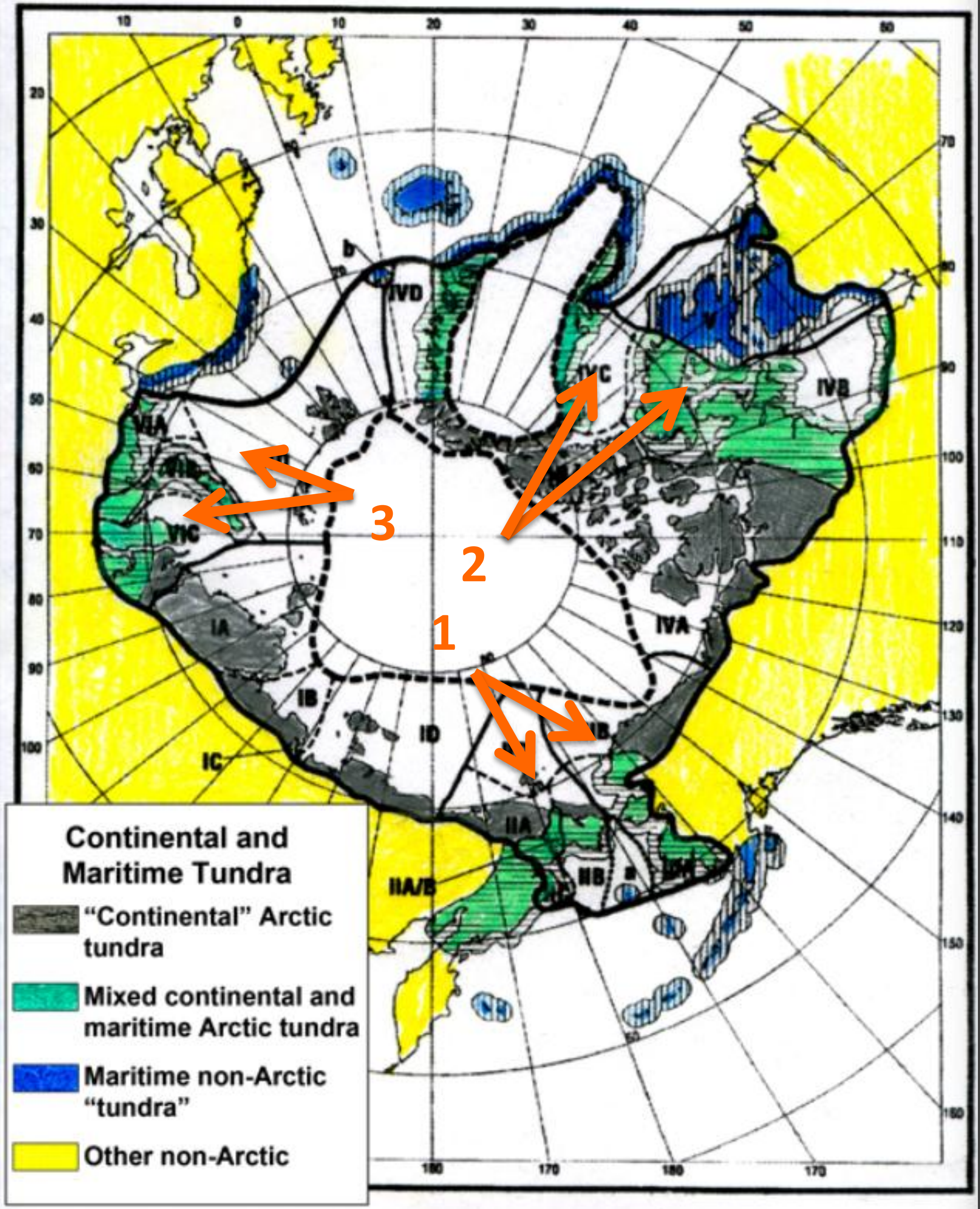
Yurtsev, B.A. 1994, *Journal of Vegetation Science*



Yurtsev's oceanic and continental regions within the Arctic

- **Gray areas:** continental Arctic areas with an Arctic climate, cold winters, long periods of summer sea ice, permafrost, and an Arctic flora.
- **Blue areas:** Treeless areas, mainly outside the true Arctic, with warm winters, no permafrost (except in mountains), and an oceanic boreal flora.
- **Green areas:** Intermediate Arctic tundra but with strong oceanic influence, long periods of ice-free ocean in fall and winter.

Yurtsev, 1994, *Journal of Vegetation Science*

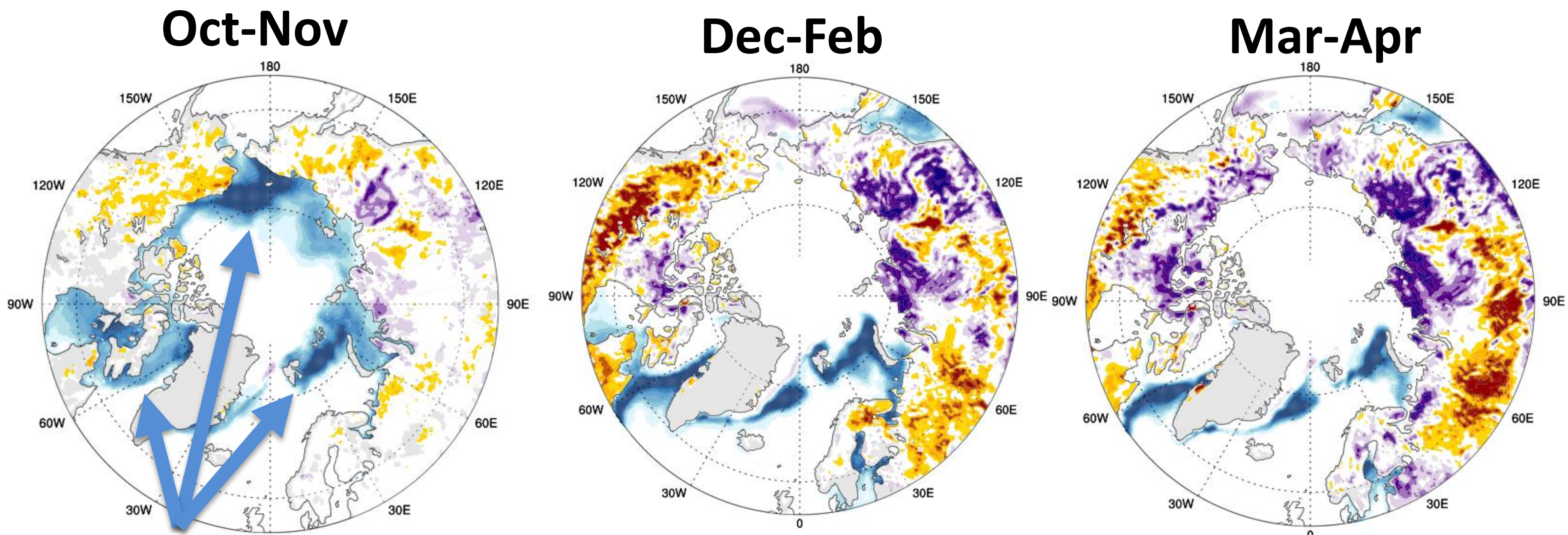


The transitional areas with mixed oceanic and continental influences are currently the areas where some of the greatest ocean and land changes are occurring.

1. N. Bering seas/ Chukchi
2. Foxe Basin/Baffin Bay/West Greenland
3. N. Barents/Kara seas

Yurtsev 1994, *Journal of Vegetation Science*

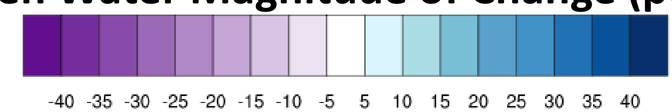
Seasonal trends in open water



Large fall increases in open water:

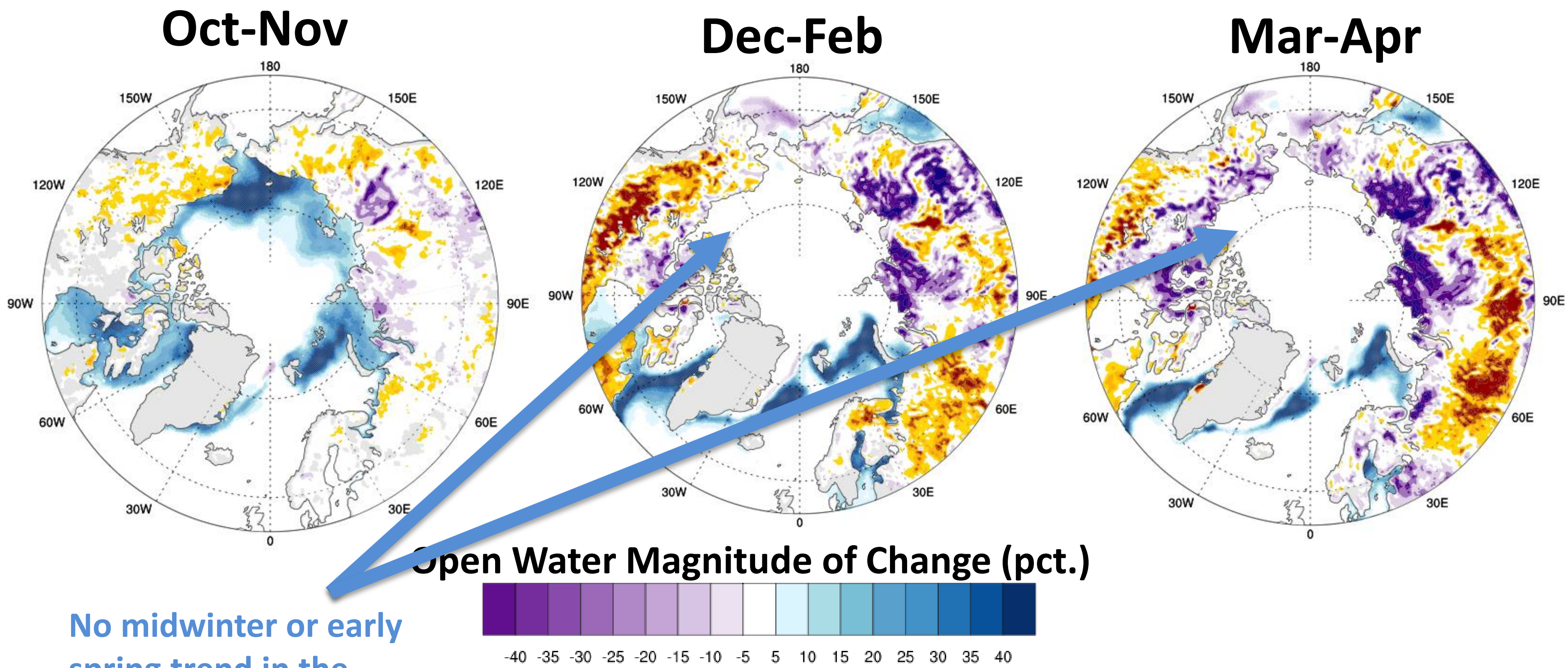
- Beaufort / Chuckchi
- N. Barents / Kara
- Baffin Bay / Hudson Bay / Foxe Basin

Open Water Magnitude of Change (pct.)



Bieniek, Bhatt, et al., in progress

Changes in open water



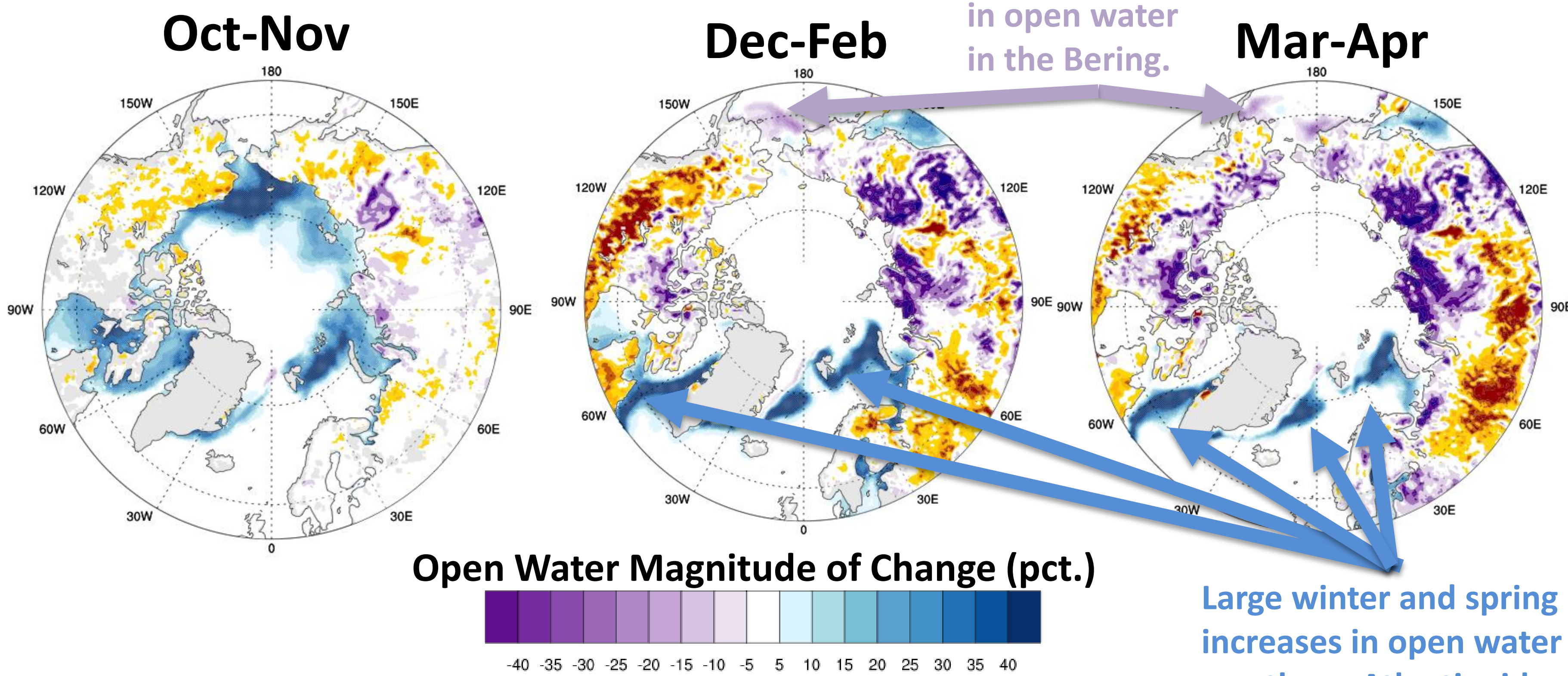
No midwinter or early spring trend in the Beaufort. Ocean frozen.

Snow trends based on CFSR reanalysis.

Bieniek, Bhatt, et al., in progress

Changes in open water

Some decrease in open water in the Bering.



Large winter and spring increases in open water mostly on Atlantic side:

- Davis Strait / Labrador Sea
- N. Barents
- Greenland Sea

Snow trends based on CFSR reanalysis.

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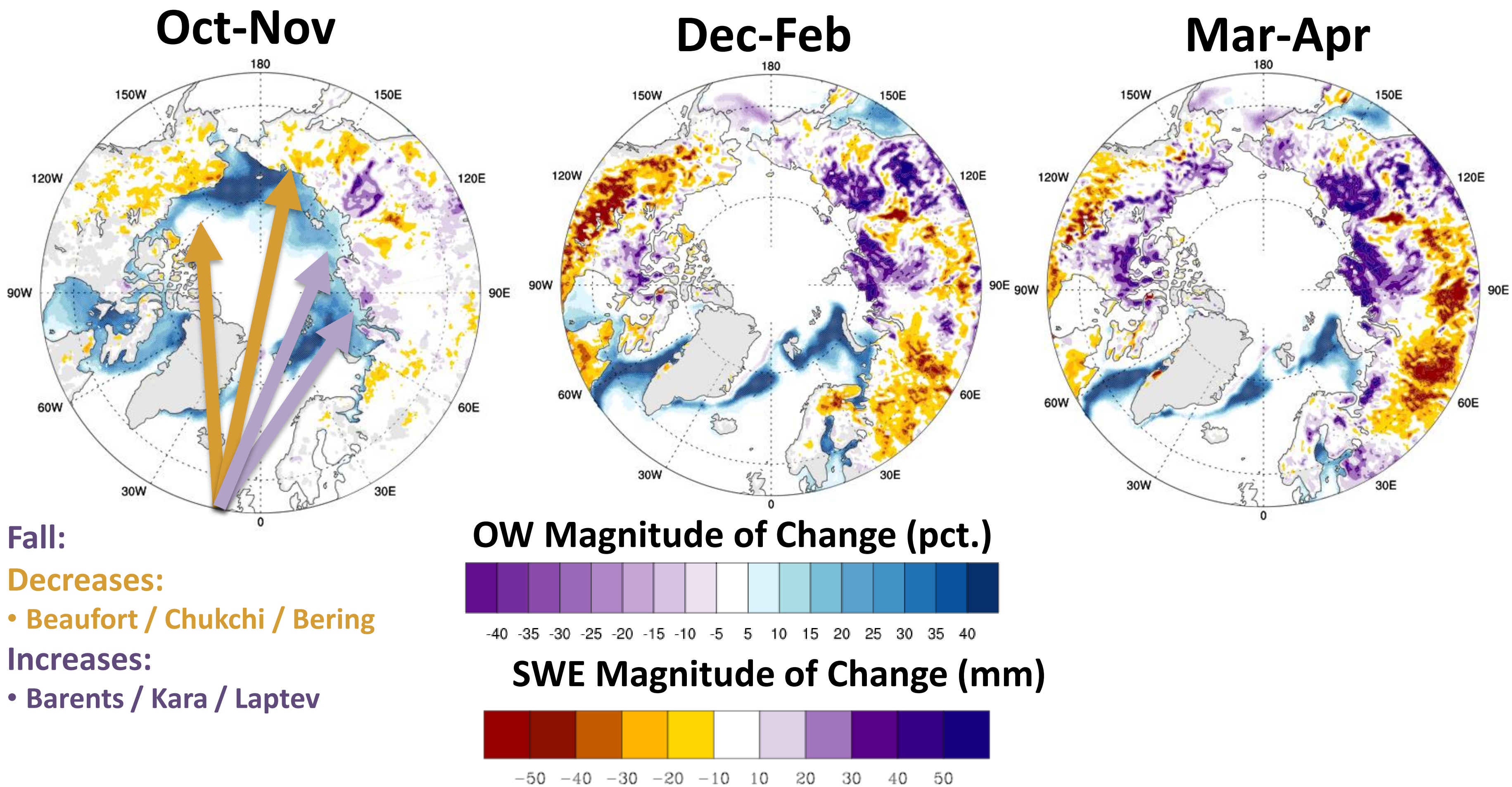
Changes in snow water equivalent



Fall:

Decreases:

- **Beaufort / Chukchi / Bering**

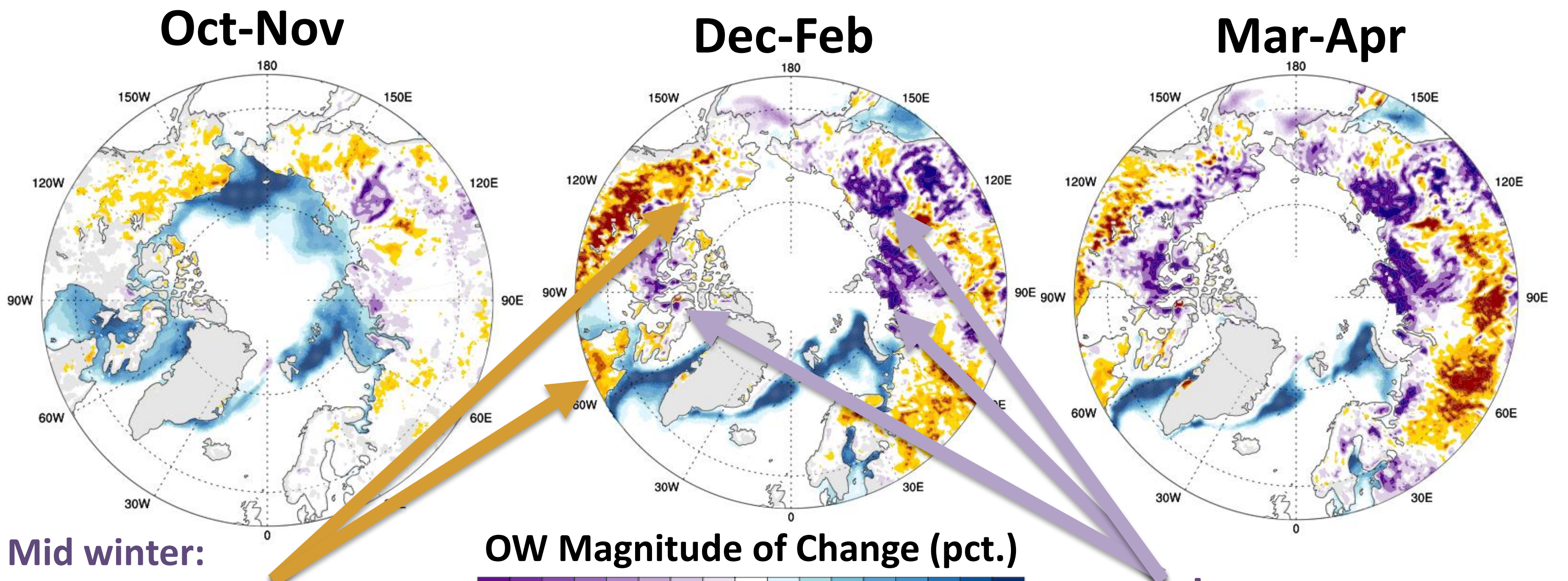
Increases:

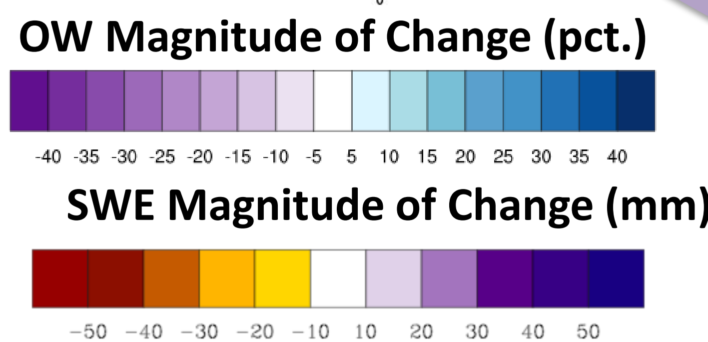
- **Barents / Kara / Laptev**

Snow water equivalent data are from CFSR reanalysis trends.

Bieniek, Bhatt, et al., in progress

Changes in snow water equivalent





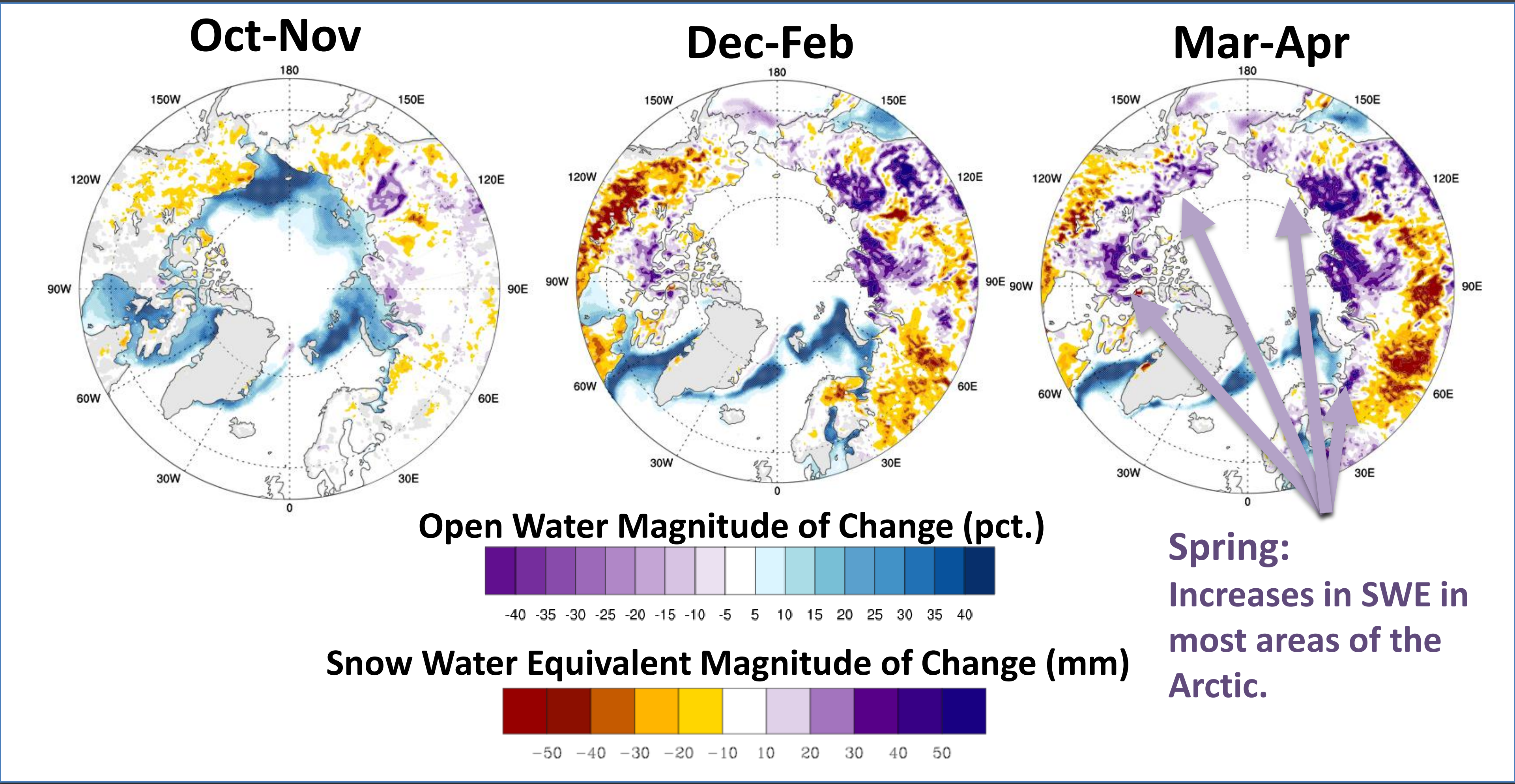
Mid winter:

Decreases:
- **Beaufort / Chukchi / Bering**
- **Ungava Peninsula / S. Baffin I.**

Increases:
- **Barents / Kara / Laptev**
- **N. Canada W. of Hudson Bay**

Bieniek, Bhatt, et al., in progress

Changes in snow water equivalent



Snow trends based on CFSR reanalysis.

Bieniek, Bhatt, et al., in progress

Recent reports on Arctic snow increases

IOP Publishing Environmental Research Letters
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Arctic warming, increasing snow cover and widespread boreal winter cooling

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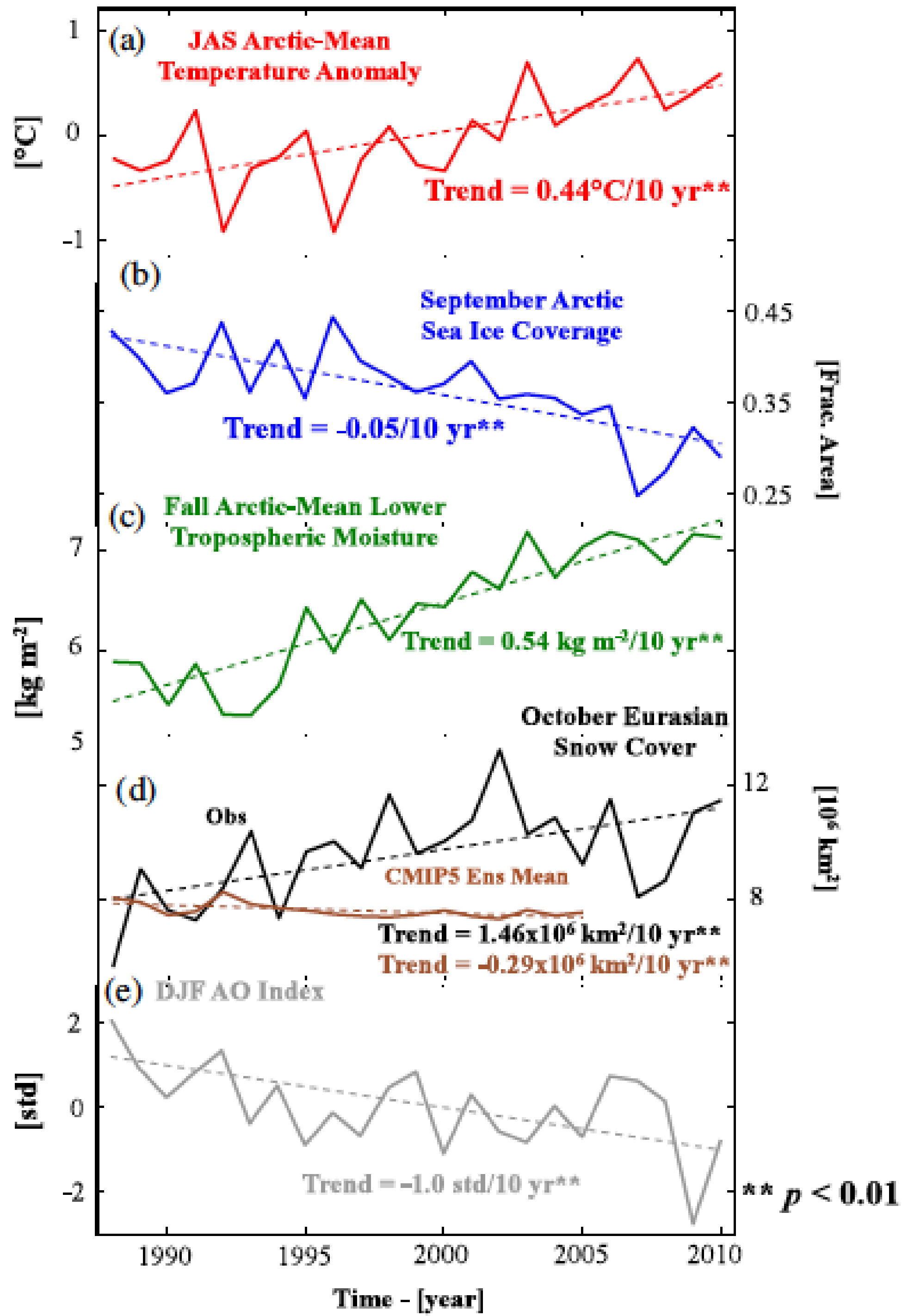
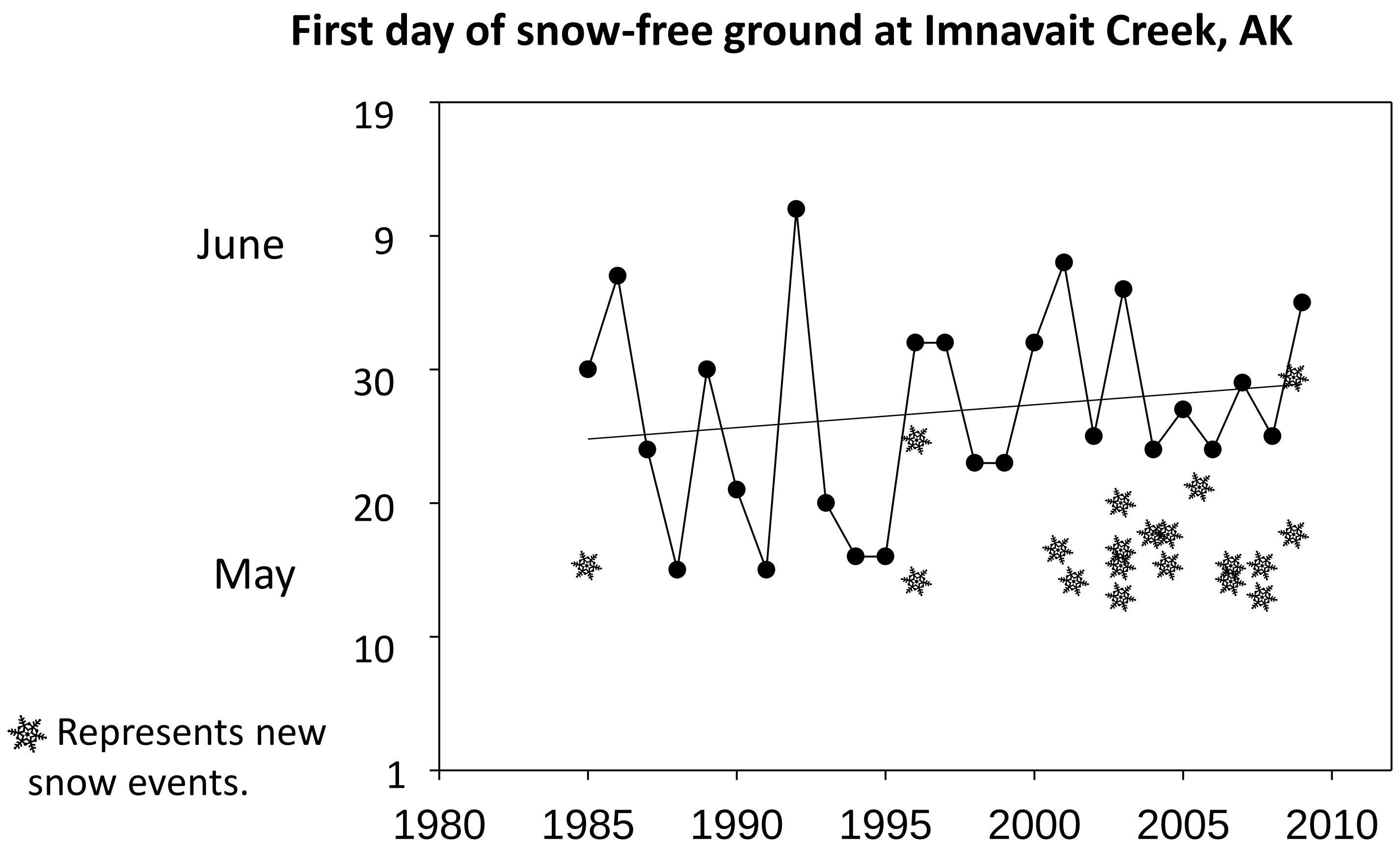
Abstract
The most up to date consensus from global climate models predicts warming in the Northern Hemisphere (NH) high latitudes to middle latitudes during boreal winter. However, recent trends in observed NH winter surface temperatures diverge from these projections. For the last two decades, large-scale cooling trends have existed across large stretches of eastern North America and northern Eurasia. We argue that this unforeseen trend is probably not due to internal variability alone. Instead, evidence suggests that summer and autumn warming trends are concurrent with increases in high-latitude moisture and an increase in Eurasian snow cover, which dynamically induces large-scale wintertime cooling. Understanding this counterintuitive response to radiative warming of the climate system has the potential for improving climate predictions at seasonal and longer timescales.

Keywords: winter trends, snow cover, Arctic Oscillation, prediction, global warming
S Online supplementary data available from stacks.iop.org/ERL/7/014007/mmedia

- Cohen, J. et al. 2012. Arctic warming, increasing snow cover and widespread boreal winter cooling. Environmental Research Letters 7:8.
- Liu, J. et al. 2012. Impact of declining Arctic sea ice on winter snowfall. Proceedings National Academy of Science 109:4074-4079.
- Muskett, R. R. 2012. Multi-Satellite and Sensor Derived Trends and Variation of Snow Water Equivalent on the High-Latitudes of the Northern Hemisphere. International Journal of Geosciences 3:1-13.



Toolik Lake snow-free date trend suggests later snow melt



Courtesy of Brian Barnes, data Institute of Northern Engineering, UAF

However, MODIS record for last 10 years years shows a generally earlier snow free date across most of Arctic Alaska.

An earlier analog of massive maritime change in the Arctic:

Dale Guthrie's mesic tundra "buckle" in Beringia during the era of the mammoth steppe followed by the opening of the Bering Strait.

PERGAMON

Quaternary Science Reviews 20 (2001) 549–574

QSR

Origin and causes of the mammoth steppe: a story of cloud cover, woolly mammal tooth pits, buckles, and inside-out Beringia

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Abstract

To account for the vastness of the northern arid steppes during Glacial episodes, I propose the proximate key variable was simply frequent clear skies. This hitherto under-emphasized point is the hub which best explains many questions. Low maritime cloud cover best accounts for today's tundra, and in a related way, the cloudy Polar Front accounts for the whole of the taiga. Even during Glacial maxima, the proximity of the sea to the Bering isthmus created intermittent maritime cloud cover. This regional cloud cover produced an ecological interruption, or buckle, of the arid steppe belt. While this Beringian mesic buckle did not serve as an intercontinental ecological barrier to most steppe-adapted species, it does seem to have limited the distributions of woolly rhinos, camels, American kiangs, short-faced bears, badgers, and some others. At the beginning of the Holocene, this narrow refugium seems to have been a source of some mesic-adapted species which colonized westward into the now tundra vegetation of northern Asia and eastward into northern North America. This Holocene expansion from a limited and regional Pleistocene refugium created our present misconceptions about Beringia. The mid-strait mesic ecological conditions were the exception to the more extensive, arid-adapted, communities of the Mammoth Steppe.

1. Introduction

Today, the north is primarily wetlands. Most northern soils are paludified, or waterlogged, lakes are common, and the summer air is alive with wetland insects. Today's boreal vegetation is predominantly wet and cold-adapted and it is mostly inedible to large mammalian herbivores. Yet physical and biotic evidence from the late Pleistocene portrays a very different pattern of habitats that has no extensive analog in the far north, as we know it. We can only conclude from the fossil evidence that during the last full glacial (LGM), say 18,000 B.P., most of the north was unimaginably arid. Compared to today, there were virtually no standing lakes, trees or boglands, and only in rare spots were peats forming. Rivers were reduced to streams and low-sward herbaceous communities were widespread. These low-profile plants were apparently more deeply rooted than are today's tundra plants. We can conclude that loess sheets, sand seas, dune fields and wind were common features of this aridity; therefore, Pleistocene skies must have often been dusty. Winter winds would have caused drifting snow and the dirtying of those drifts from blown silt. For those of us accustomed to many months of downy pristine snow-cover and frequent summer drizzles, swarms of insects, tussocks, thick humus mats, cushiony forest floors, tea-colored ponds, impenetrable alder and willow thickets, this emerging image of intense aridity in boreal environments during the late Pleistocene is sometimes difficult to credit.

I propose that we have made a series of mistakes in our pursuit of Pleistocene paleoecology of the north. Not very long ago, it was assumed that the Pleistocene unglaciated north was much like today, except colder. Because cold is such a critical variable today it was the obvious feature we could use to explain things like the elimination of trees. And acceptance of the Milankovich insolation cycles made it easy to derive more cold by ratcheting-up these extra-terrestrial forces. That simplistic assumption was a mistake.

As new fossil data began to show no-analog differences with the present, the next variable identified, in addition to cold, was aridity. Instead of looking closely at the various potential forces for aridity we assumed the most obvious, simply reduced precipitation. This bias also got us off on another inappropriate route. That was our second mistake.

Hultén (1937) described Beringia, a special Pleistocene floristic refugium for mesic-adapted tundra plants. This

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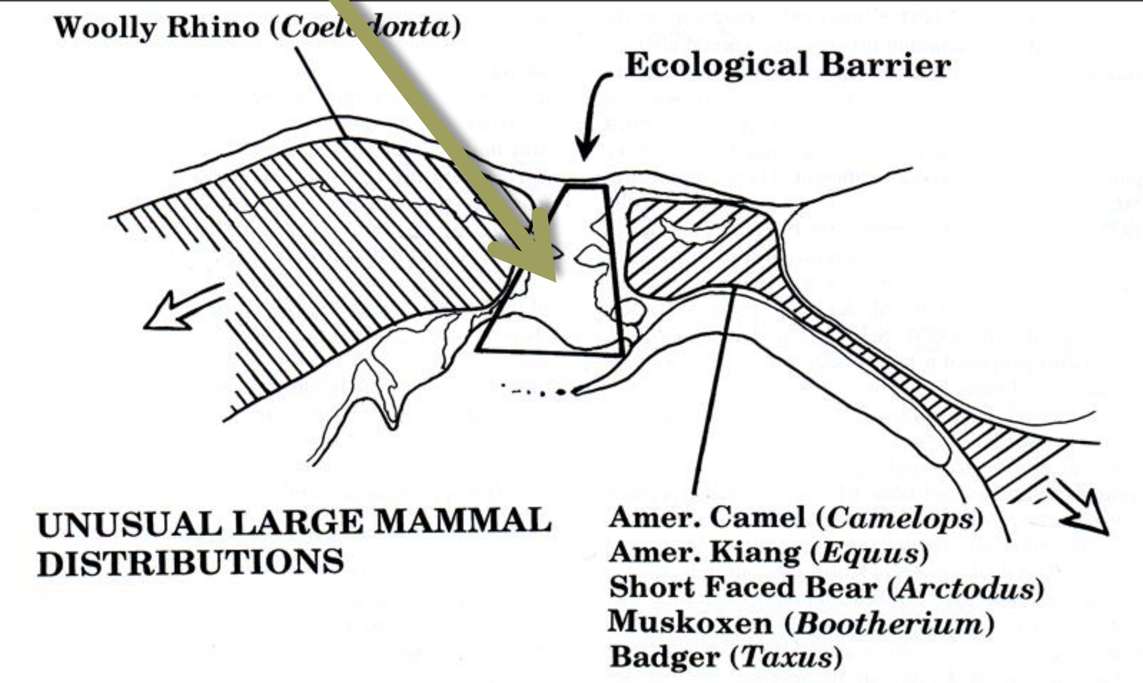


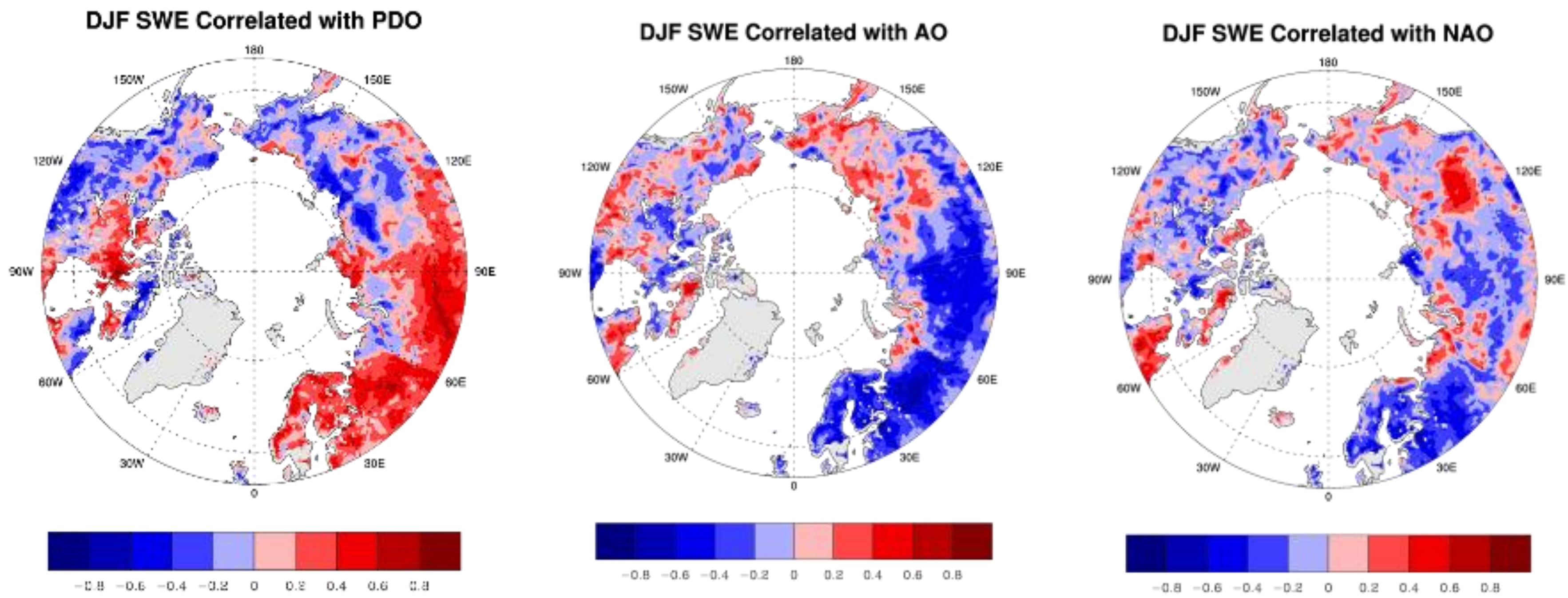
Fig. 8. Mammalogists have puzzled over the several Pleistocene species whose distribution approaches the Bering Strait then apparently ends. This pattern is not typical of most of northern species in the Pleistocene. There does appear to have been some kind of barrier in that region, but has received little speculation as to its nature. It is probable that this filter was related to the more mesic buckle.

Guthrie 2001, *Quaternary Science Reviews*

Leading to warming <u>and</u> humidification of the Arctic

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

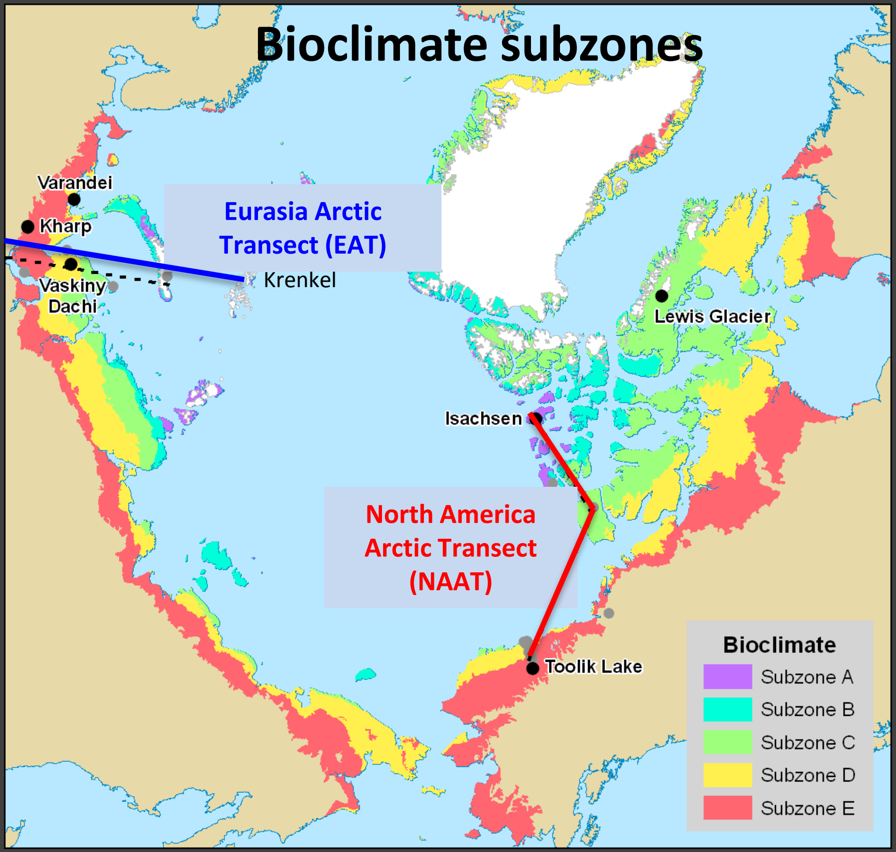
Correlations of Mar-Apr SWE with Climate Indices



- **Patterns in snow are driven by large-scale climate phenomena. Correlations exist but it is very complex.**
- **Uma and Peter are now trying find the mechanism (e.g. changes in weather patterns).**
- **They are first focusing on Alaska with local weather experts first.**

Bieniek, Bhatt, et al. in prep.

What do the changes in NDVI mean at the ground level in terms of biomass change?



Two transects through all 5 Arctic bioclimate subzones

Subzone	MJT	Shrubs
A (Cushion forb subzone)	1-3 ˚C	none
B (*Dryas* subzone)	3-5 ˚C	prostrate dwarf (< 5 cm)
C (*Cassiope* subzone)	5-7 ˚C	hemi-prostrate dwarf (< 15 cm)
D (*Betula* subzone)	7-9 ˚C	erect dwarf (< 40 cm)
E (*Alnus* subzone)	9-12 ˚C	low (40-200 cm)

CAVM Team 2003

Linking spatial and temporal trends of NDVI observed on satellite images to ground observations.

- Climate
- Vegetation
- Soils
- Permafrost
- Spectral properties


NDVI and LAI


Plant species cover


Active layer depth


Site characterization


Biomass

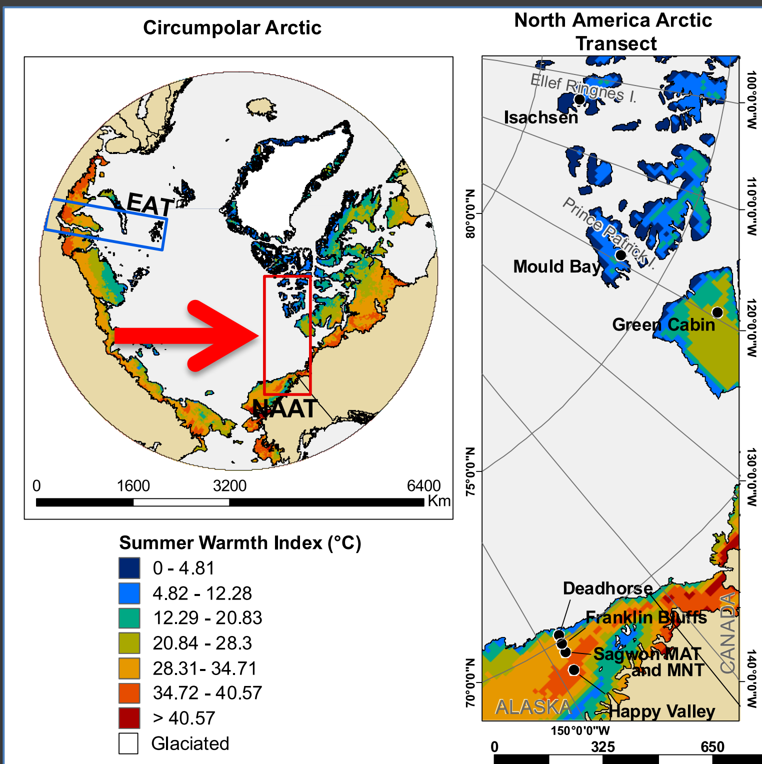

Soil characterization

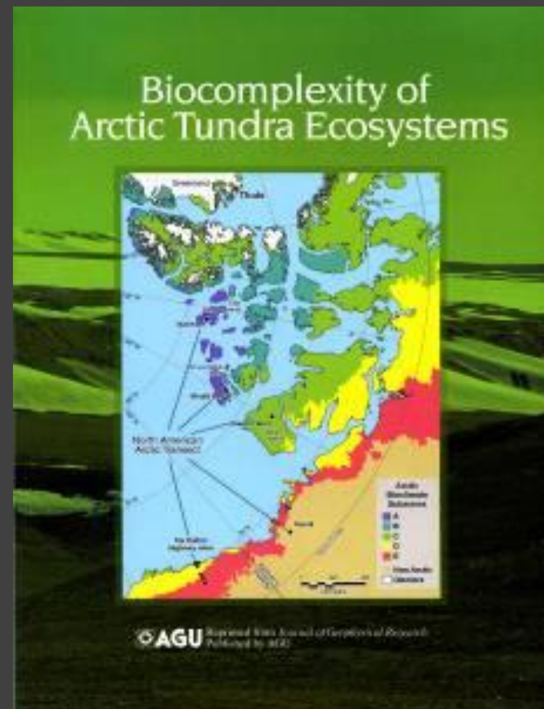

Soil temperature

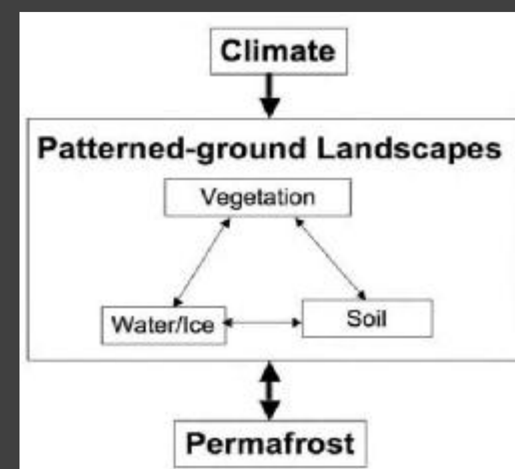

Permafrost boreholes

The North America Arctic Transect (NAAT)

Biocomplexity of Arctic Patterned Ground Ecosystems Project (NSF)
2002-2006



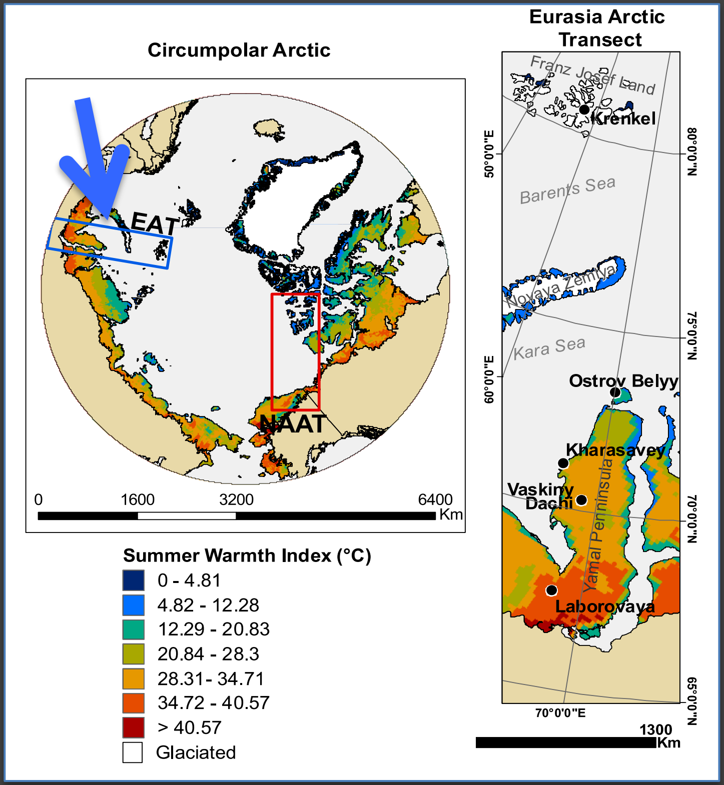




Walker, D. A. et al. 2008. Arctic patterned-ground ecosystems: a synthesis of field studies and models along a North American Arctic Transect. *Journal of Geophysical Research - Biogeosciences* 113:G03S01,

The Eurasia Arctic Transect (EAT)

Adaptation to rapid land-use and climate changes on the Yamal Peninsula, Russia: Remote sensing and models for analyzing cumulative effects (NASA) 2007-2011



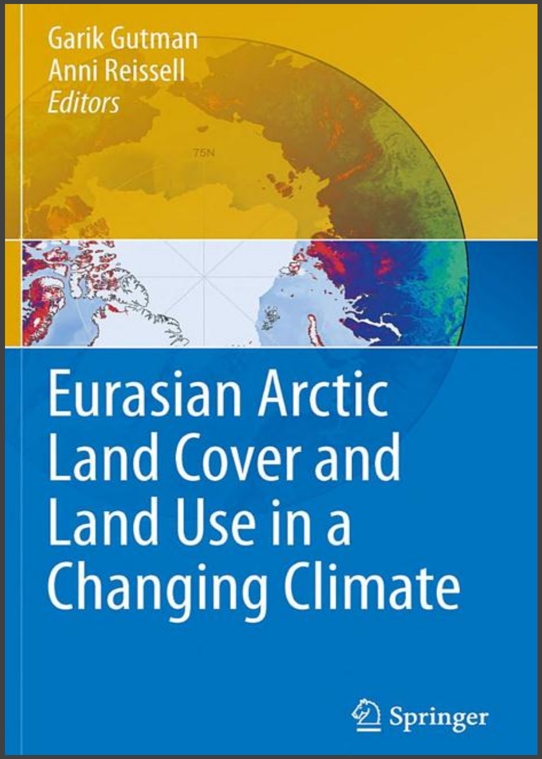


Photo: Courtesy of Don and Cherry Alexander

Walker, D. A., 2011. Cumulative effects of rapid land-cover and land-use changes on the Yamal Peninsula, Russia Pages 206-236 in G. Gutman and A. Reissel, editors. Eurasian Arctic Land Cover and Land Use in a Changing Climate. Springer, New York.

Integrated field studies at zonal study sites along both transects

Hayes Island, Russia
Photo: D.A. Walker

Zonal vegetation along both transects

Eurasia Transect

A - Hayes Island

B - Ostrov Belyy

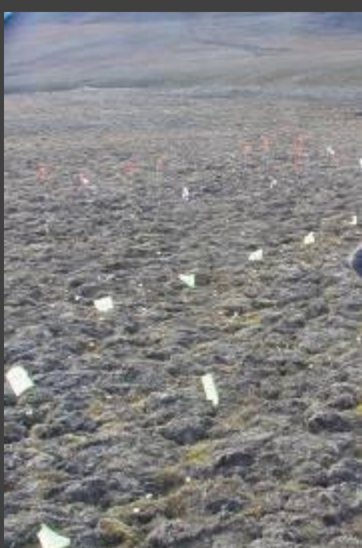
C – Kharasavey

D - Vaskiny Dachi

E - Laborovaya

North America transect

A - Isachsen



B- Mould Bay

C - Green Cabin

D - Sagwon MNT

E - Happy Valley

Climate and soil at key zonal sites in each subzone along the NAAT and EAT

Arctic Bioclimate subzone (Walker 2005)	Transect: location	Latitude Longitude	SWI (˚C mo)		Precipitation (mm)			Soil texture pH
			Air (SWIa)	Surface (SWIs)	Total	Summer JJA	Winter S-May	
A	NAAT: Isachsen	78.7˚ N 103.6˚ W	3	6.8	114	53	61	Clay 5.8
	EAT: Krenkel	80.6˚ N 57.9˚ E	1	1.9	282	56	211	Sandy loam 6.2
B	NAAT: Mould Bay	76.2˚ N 119.3˚ W	4.6	6.5	104	47	66	Sandy loam 7.8
	EAT: Ostrov Belyy	73.3˚ N 70.1˚ E	11.5	11.5	234	74	154	Loam 4.6
C	NAAT: Green Cabin	73.2˚ N 119.6˚ W	16.6	22.7	156	63	91	Sandy loam 7.7
	EAT: Kharasavey	71.2˚ N 67.0˚ E	15.5	28.7	298	89	192	Silt loam 4.5
D	NAAT: Franklin Bluffs	69.7˚ N 148.7˚ W	24.2	32.7	179	61	86	Loam 7.4
	EAT: Vaskiny Dachi	70.3˚ N 68.90˚ E	na	29.6	277	100	186	Silt loam 4.5
E	NAAT: Happy Valley	69.147˚ N 148.8˚ W	29.5	36.2	198	72	99	Silty clay loam 5.1
	EAT: Laborovaya	67.7˚ N 68.0˚ E	na	36.4	664	224	443	Clay loam 4.6

Walker et al. ERL 2012

Comparison of a mainly continental transect (NAAT) and a more maritime transect (EAT)

NAAT:

Beaufort / Canadian Archipelago, a relatively continental area

Continental Subzone A, Isachsen, Ellef Ringnes, I., NAAT

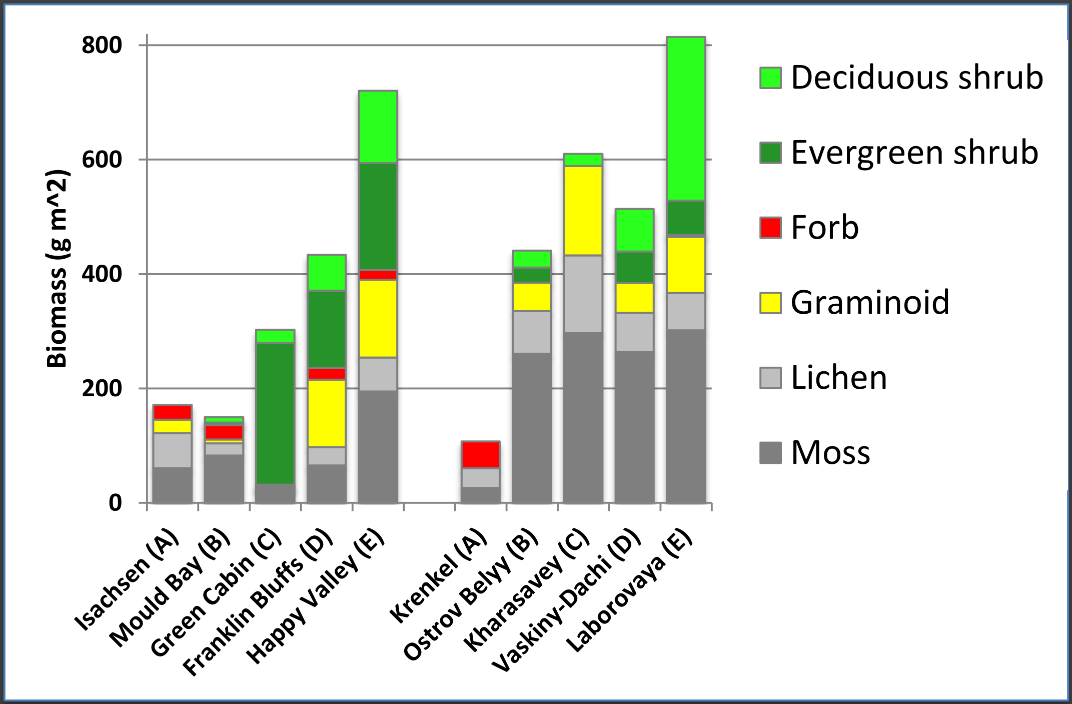
EAT:

N. Barents / Kara, a relatively maritime area

Oceanic Subzone A, Krenkel, Franz Josef Land, EAT

Photos D.A. Walker

Zonal biomass differences between NAAT and EAT

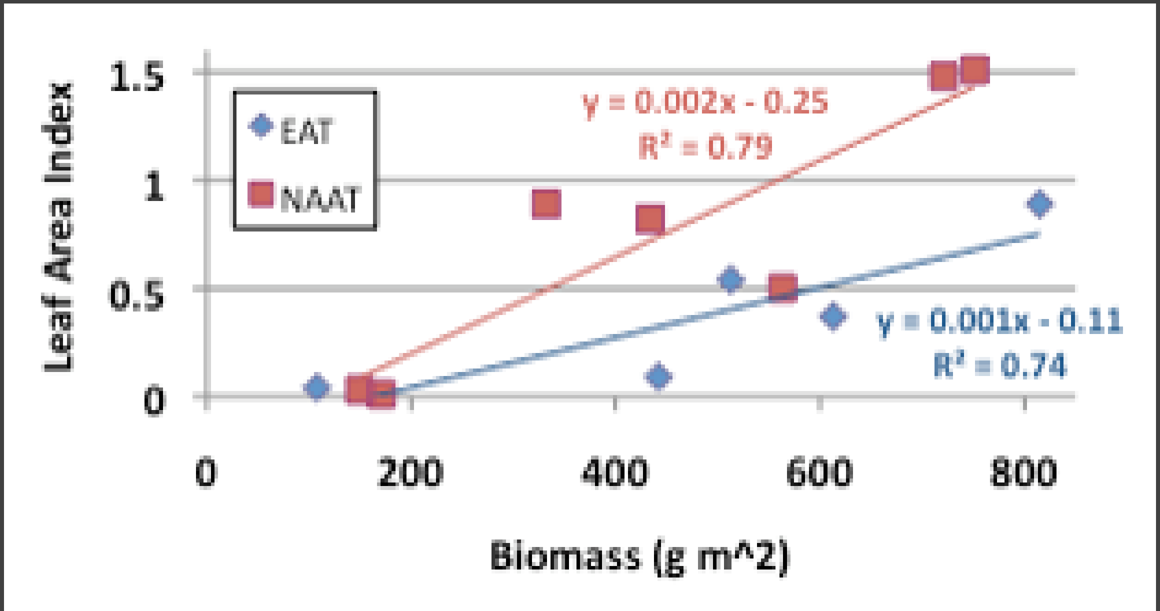


Walker et al. ERL 2012

- **More forbs & evergreen shrubs (mostly *Dryas integrifolia*) along the NAAT, due mostly to higher soil pH of the NAAT.**
- **More mosses and biomass in subzones B, C, D of the EAT (moister climate, older landscapes of EAT particularly in subzones B and C).**

Dryas integrifolia

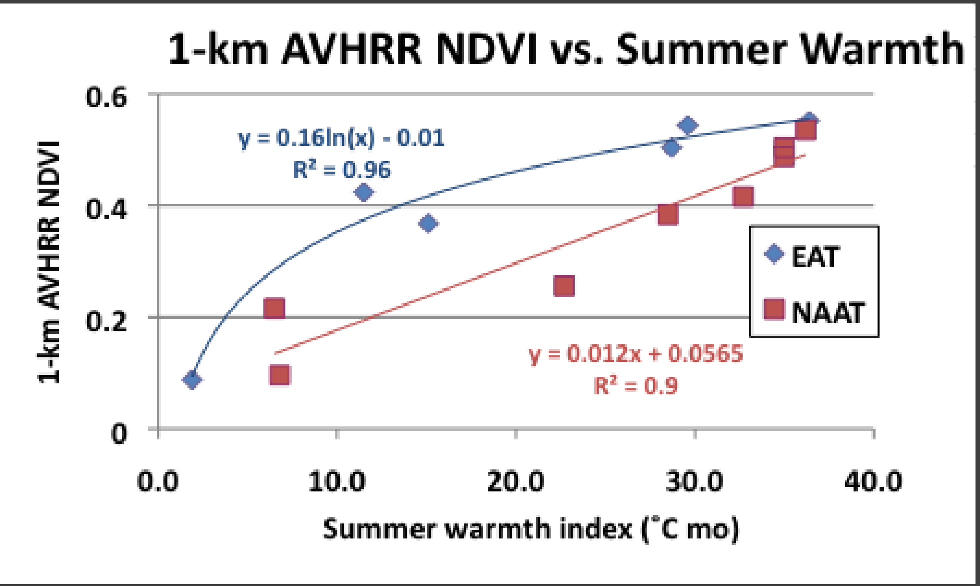
Leaf Area Index vs. Biomass: EAT and NAAT

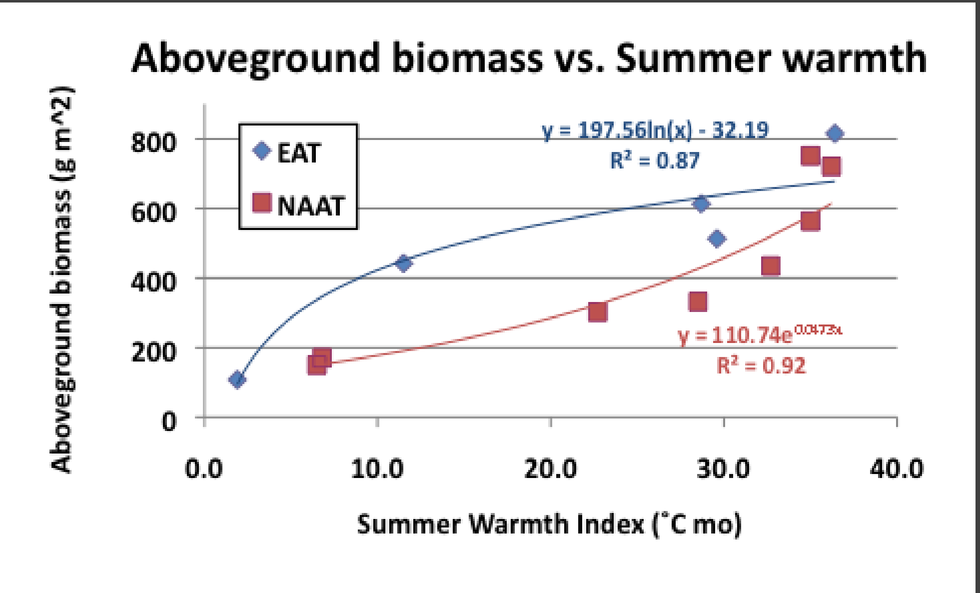


- An equivalent amount of biomass has higher LAI values along the NAAT than along the EAT and the difference increases at higher biomass values.
- Reflects the different structure of the vegetation along the two transects. Higher proportion of the total biomass is woody along the NAAT (more wood, taller plants) vs. reindeer-foraged and mossy vegetation along the EAT.

Walker et al. ERL 2012

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



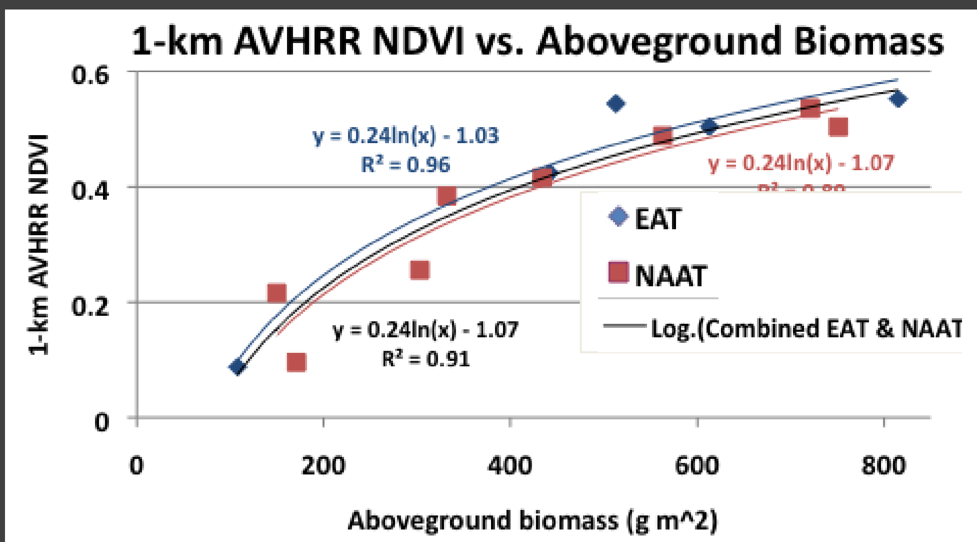


- Biomass values are landscape-level averages for zonal landscapes.
- EAT is greener and has more biomass at equivalent summer warmth.
- Possibly a function of more maritime conditions along the EAT.

Walker et al. ERL 2012

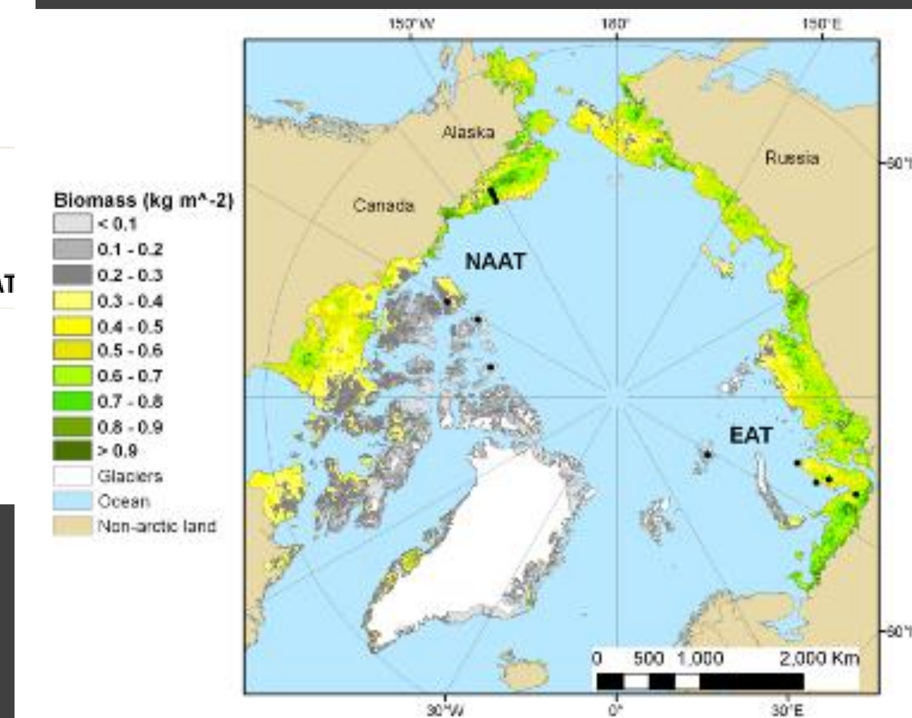
Strong correlation between NDVI and aboveground biomass

- Despite differences in vegetation structure, glacial history, pH, grazing regimes, phenology, etc. there is a very similar relationship between AVHRR NDVI and biomass along both transects.
- Gives us moderate confidence that it is possible to construct Arctic biomass map based on the NDVI.

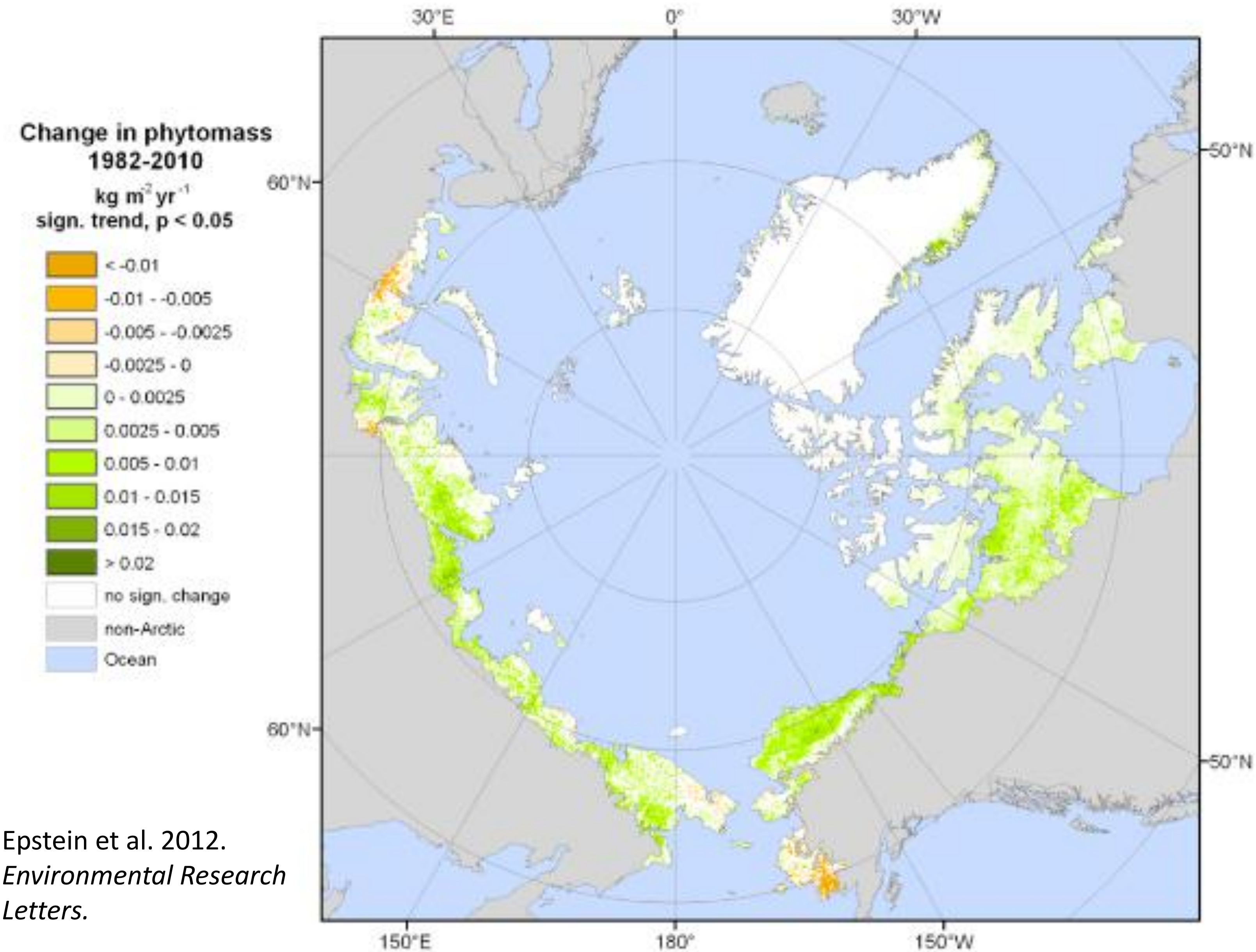


Raynolds et al. 2012, *Remote Sensing Letters*

Aboveground biomass of Arctic zonal sites

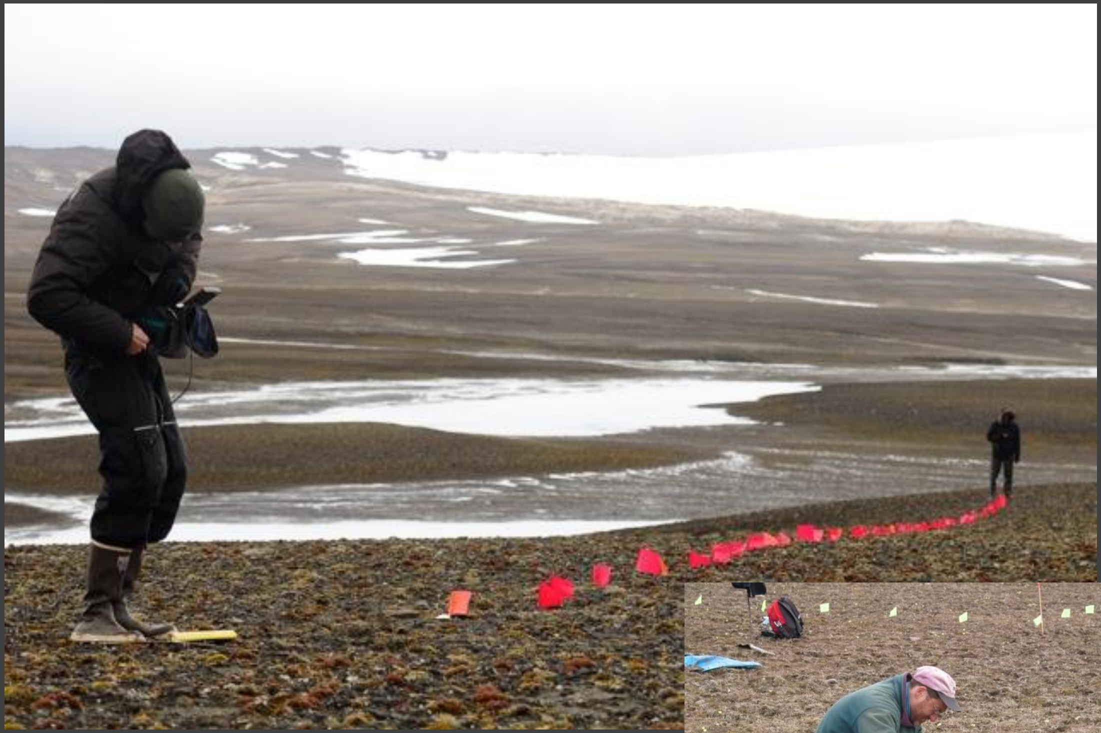


Rate of change in zonal biomass 1982-2010 (kg m^{-2} y^{-1})



Epstein et al. 2012.
Environmental Research Letters.

Plot-based evidence for change in biomass?



Photos: Gosha Matyshak and Fred Daniëls

- Numerous groups are measuring NDVI and biomass, but integrated long-term, panArctic monitoring using consistent standardized protocols are lacking.

New information on long-term changes:

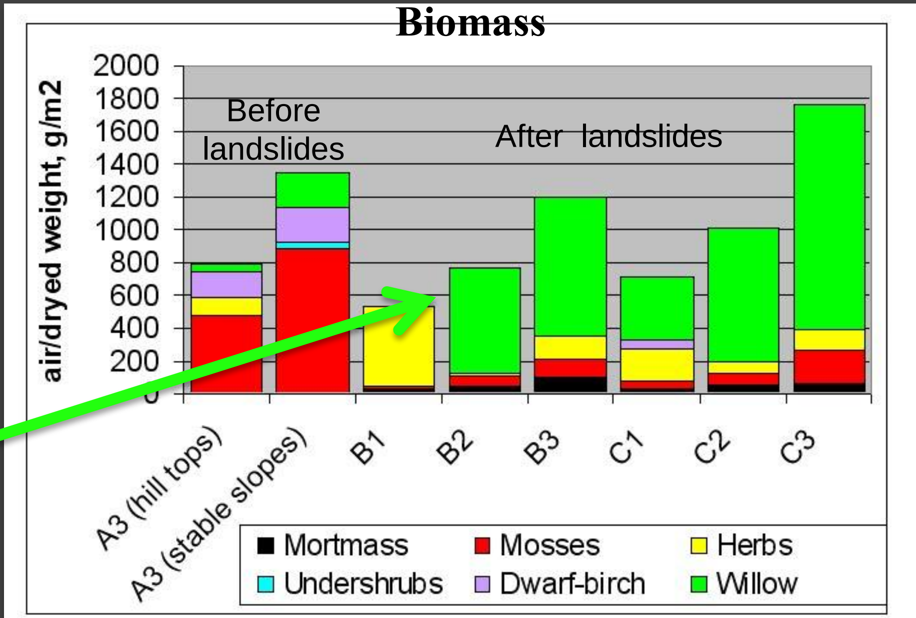
BTF synthesis (Callaghan and Tweedie 2011),
ITEX synthesis (Elmendorf et al. in 2012)
ERL special shrub issue (Epstein et al. 2012)

Other factors influencing the NDVI:

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.**

Photos D.A. Walker



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

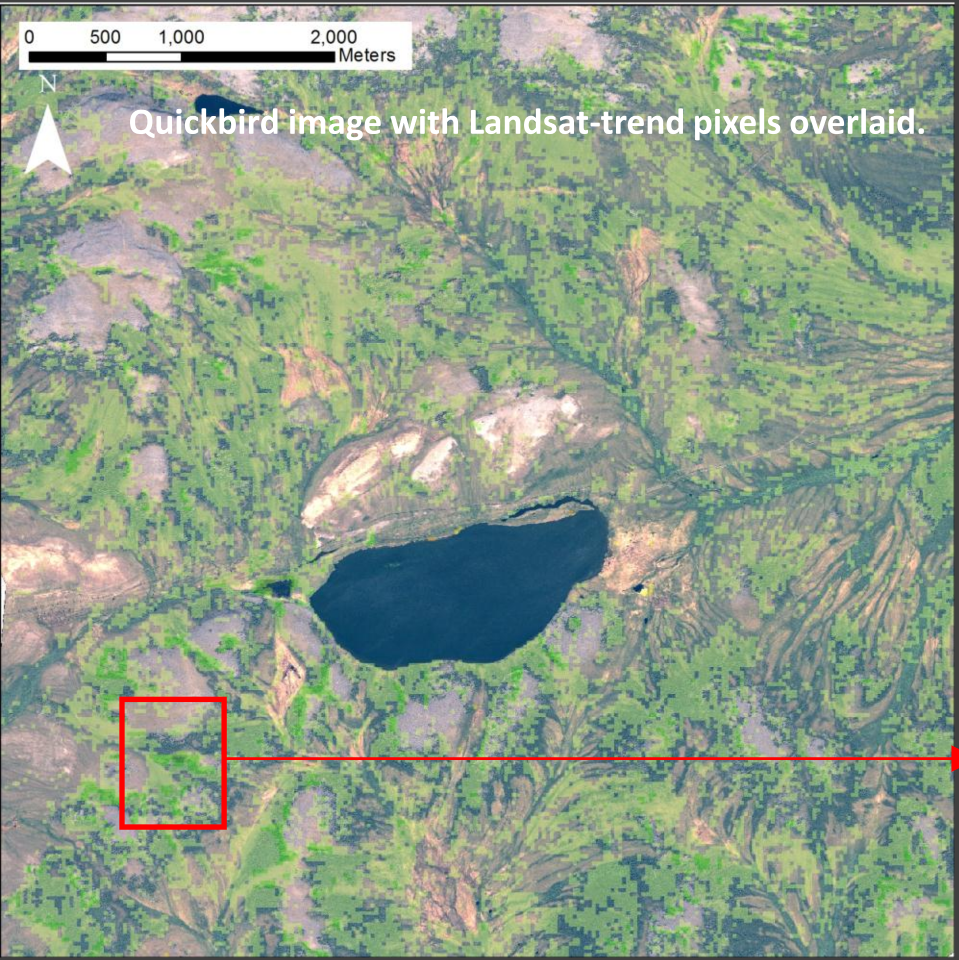
Other factors influencing the NDVI: The Nenets people and their 300,000 reindeer

Photo: D.A. Walker.

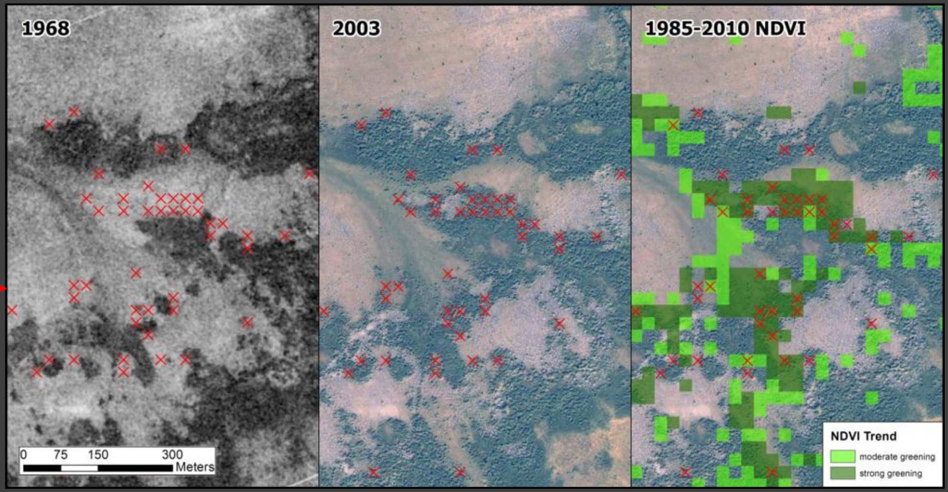
Effects of landscape-scale disturbances on panArctic NDVI patterns are presently unknown, but new high-resolution satellite data show great promise for studying the effects.

Cryogenic erosion and greening patterns on the Yamal are clearly discernable on new GeoEye scene (0.41 m resolution).

Analysis of greening trend and alder growth near treeline in Polar Urals



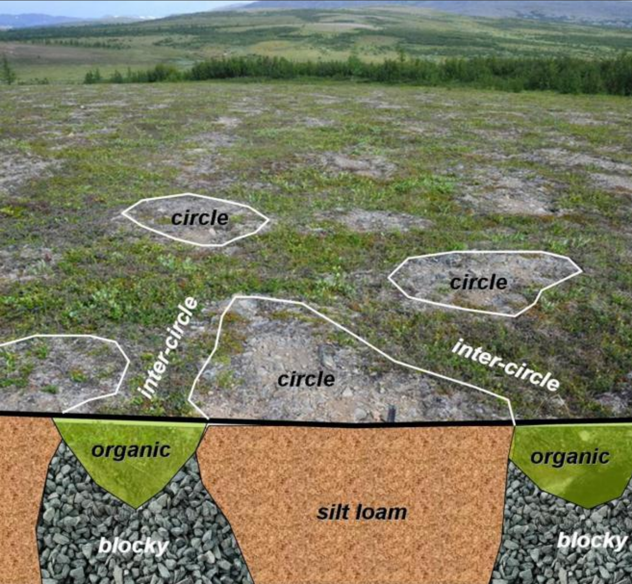
Corona 1968 **Quickbird 2003** **Landsat Trend 1985-2010**



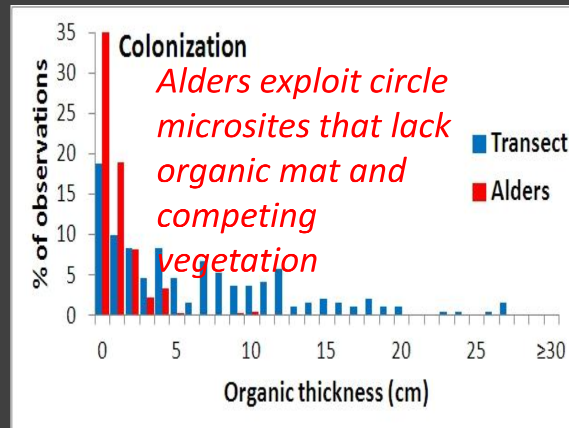
X grid points with new alder cover since 1968.

JJ Frost (U. Virginia): Ph.D. research

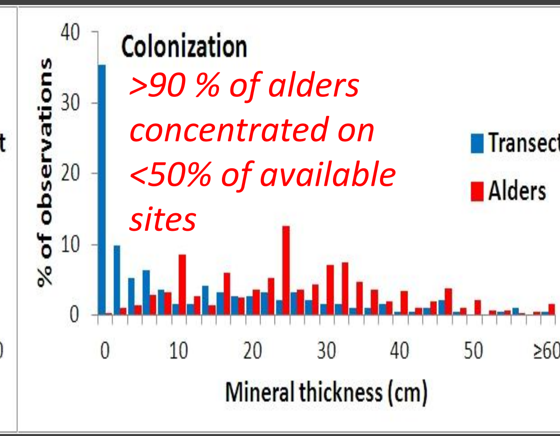
Alder establishment on patterned ground features

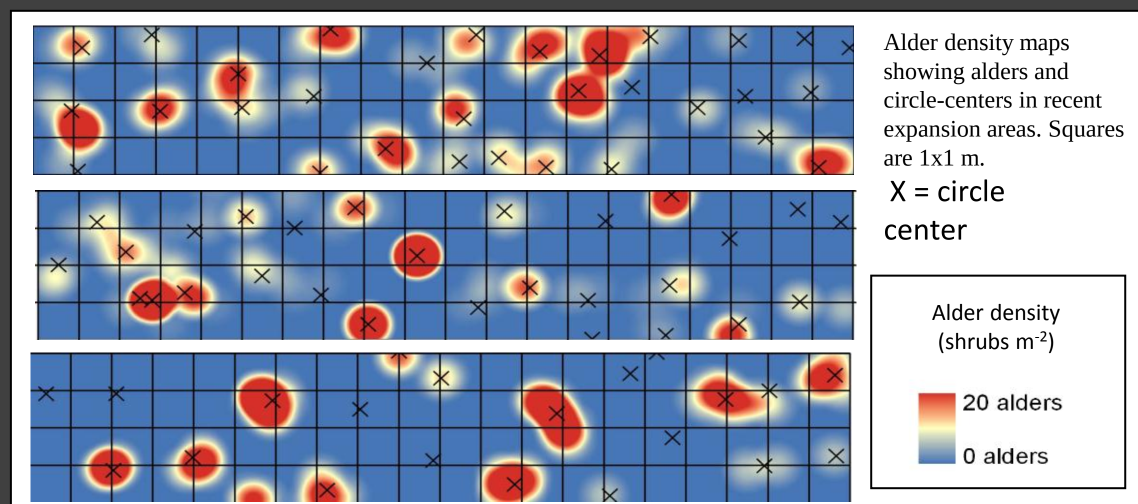


Organic thickness



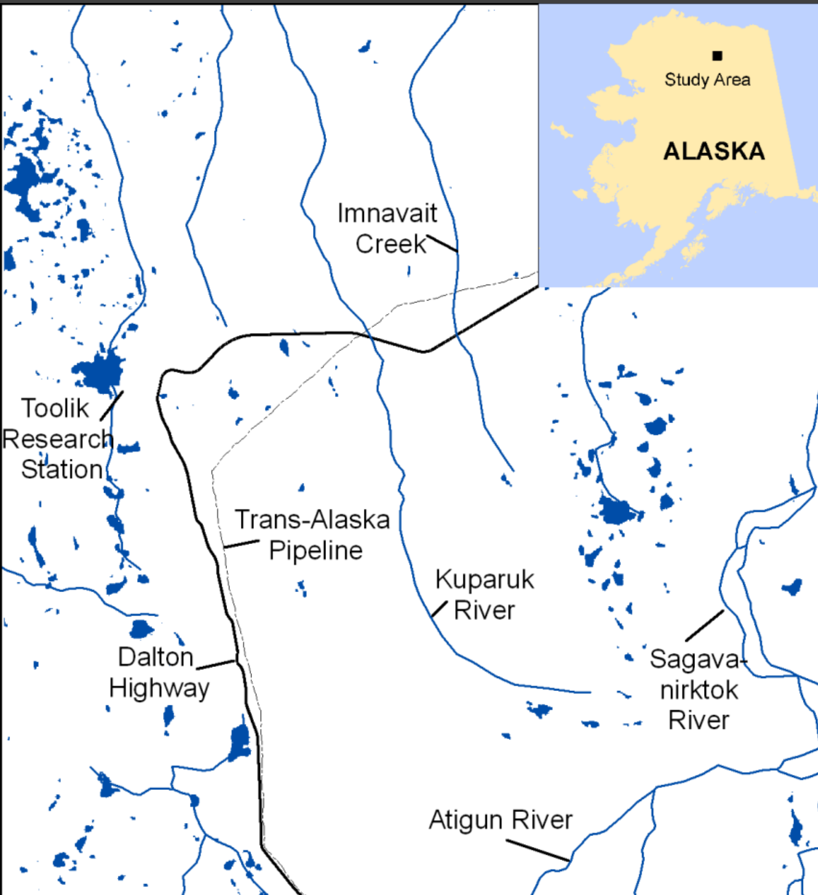
Mineral thickness



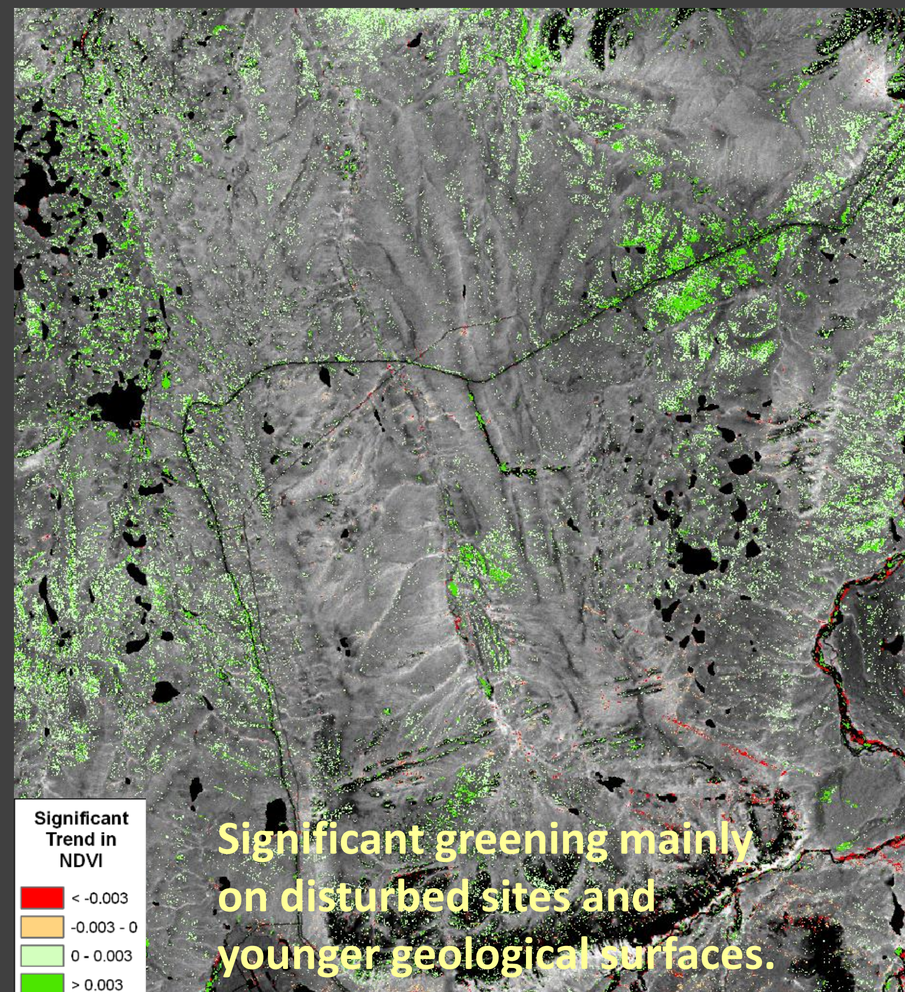


JJ Frost: Ph.D. research

Analysis of greening trends at Toolik Lake using Landsat data (30 m pixels)

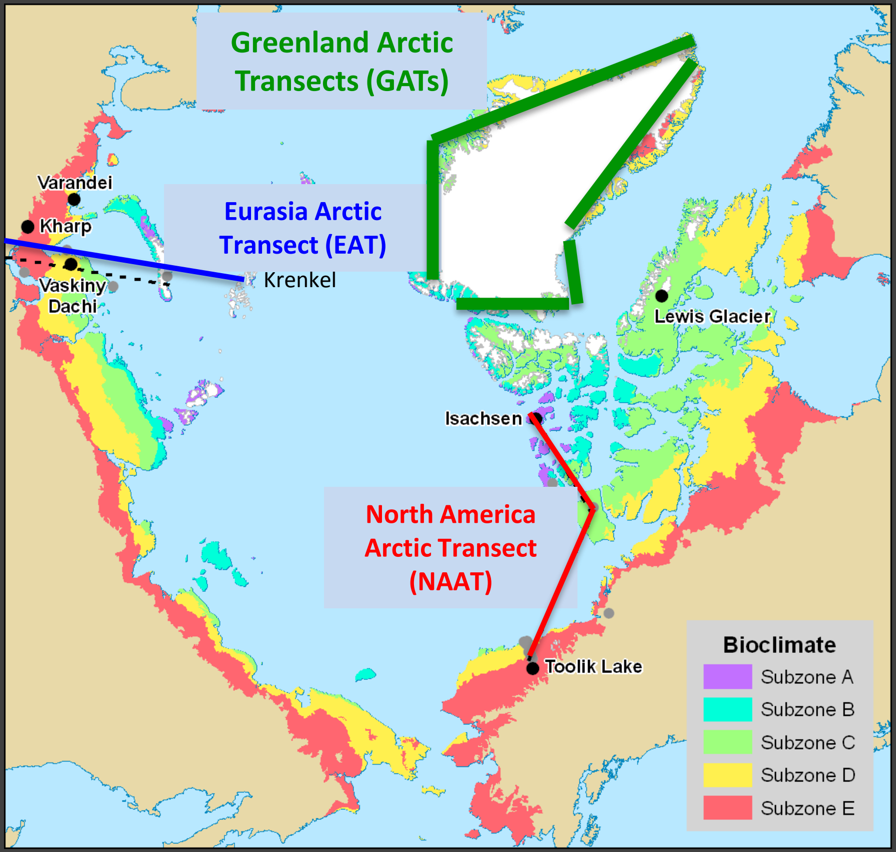


Glacial Geology (based on Hamilton 2003)



M.K. Raynolds.
CRSS Conf. 2012

Transects in Greenland to examine greening trends and biodiversity through all five bioclimate subzones



Two transects along E & W coasts through all 5 Arctic bioclimate subzones

Subzone	MJT	Shrubs
A (Cushion forb subzone)	1-3 ˚C	none
B (*Dryas* subzone)	3-5 ˚C	prostrate dwarf (< 5 cm)
C (*Cassiope* subzone)	5-7 ˚C	hemi-prostrate dwarf (< 15 cm)
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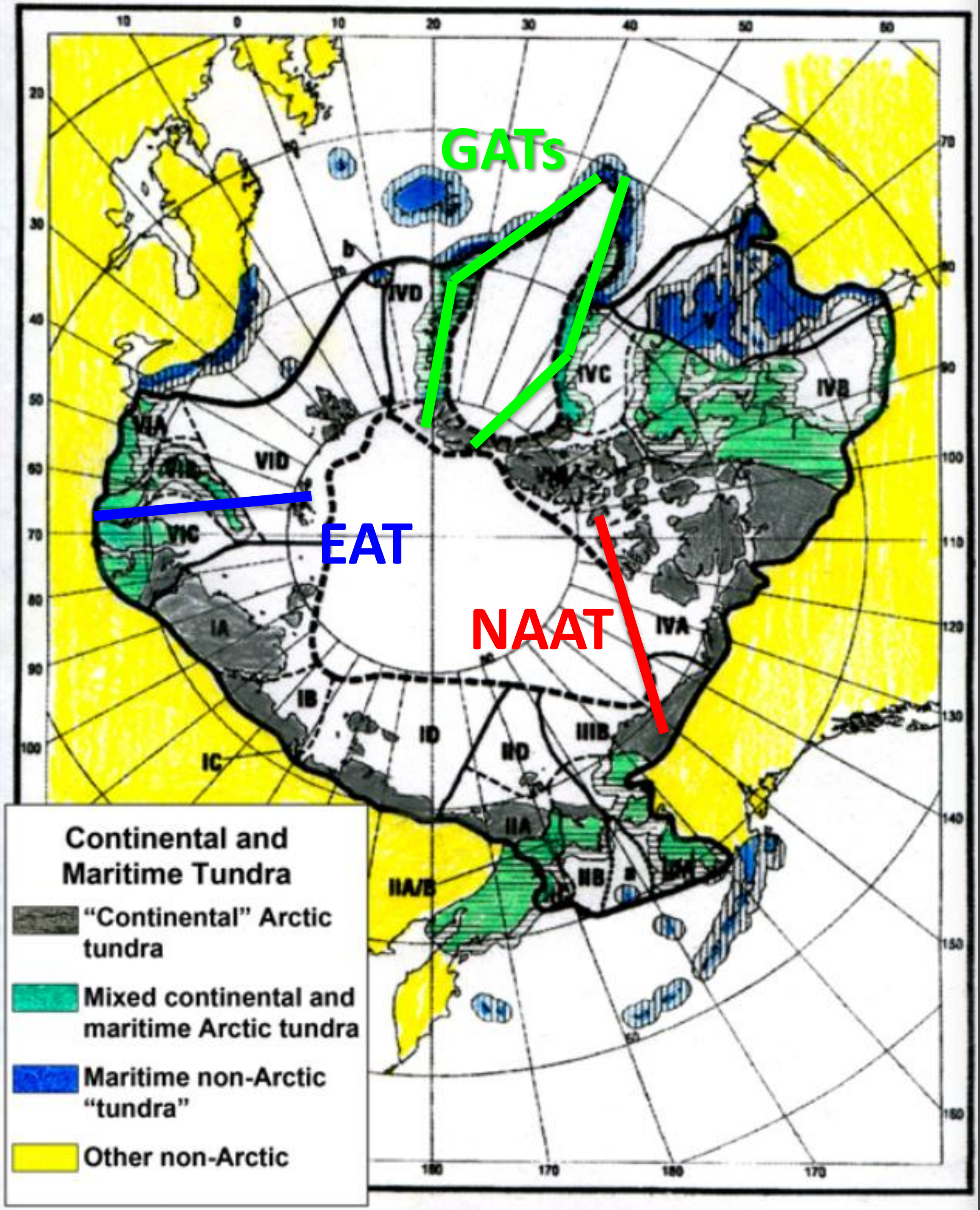
CAVM Team 2003



Both transects are in mainly maritime climates except in the north, but fiord climate gradients offer opportunity to examine continental-maritime transitions along the full Arctic gradient.

Take Home Points

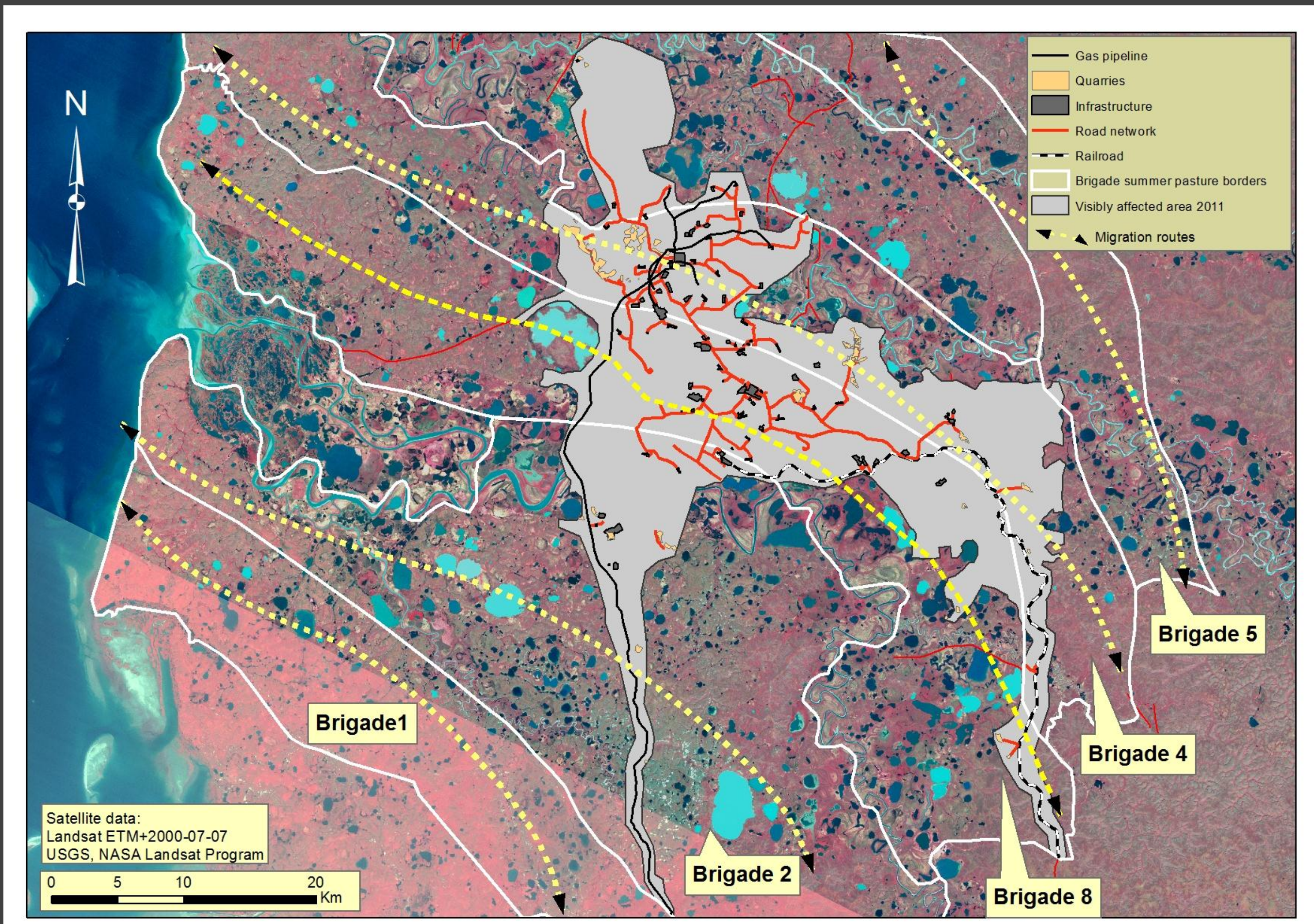
- A general greening of Arctic tundra vegetation occurred from 1982-2011.
- The trends are stronger in N. America than in Eurasia.
- Remote sensing and reanalysis products indicate that the trend of more open water is focused in several areas (three largest highlighted here, West Greenland is located in one of these.).
- The effects of more open water appear to be stronger in the relatively continental areas of the Arctic.
- Ground-based information from two Arctic transects help to interpret the remotely-sensed information in maritime versus more continental areas of the Arctic.
- A third transect is needed to verify the trends noted along the EAT and NAAT.
- Greenland offers the opportunity to study maritime-continental trends along the full Arctic climate grandient.
- Greenland is particularly attractive because of the rapid transitions occurring there, the relatively easy access along the full gradient, and already existing infrastructure along much of the gradient, and it is one of the best know areas of the Arctic.

Effects of industrial development and reindeer grazing

Courtesy of Pam Miller.

Prudhoe Bay oil field.

History of infrastructure expansion on the Yamal

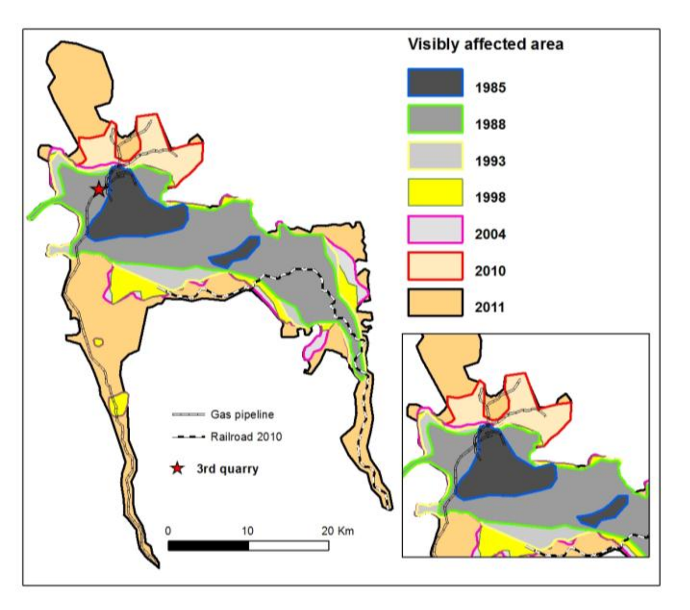


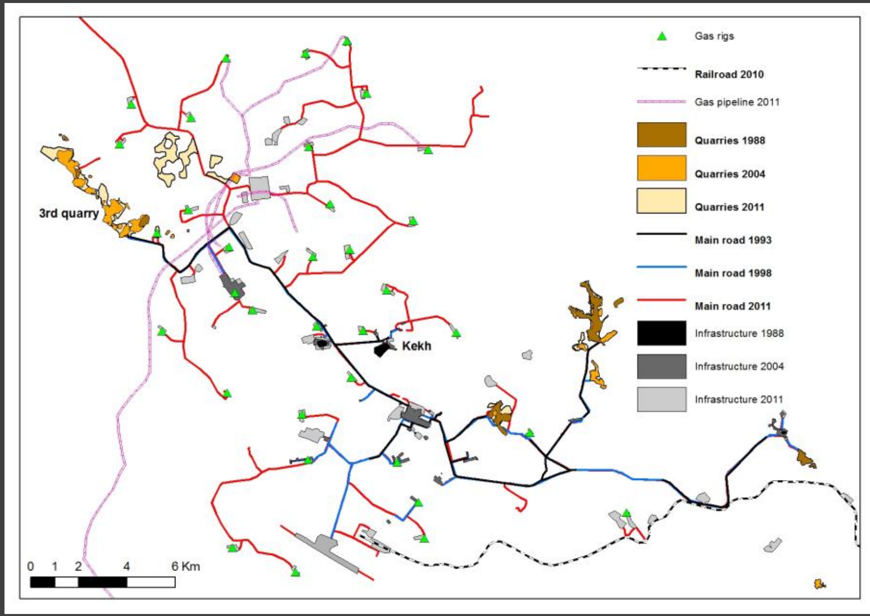
Courtesy of Timo Kumpula.

Landsat image of Bovanenkovo gas field.

- ***Bovanenkovo transportation and pipeline networks and the main area impacted by gas-field activities as of 2011.***
- ***Routes of five Nenets reindeer-herder brigades (yellow dotted lines).***

History of infrastructure expansion, Bovanenkovo gas field, Yamal (1988-2011)



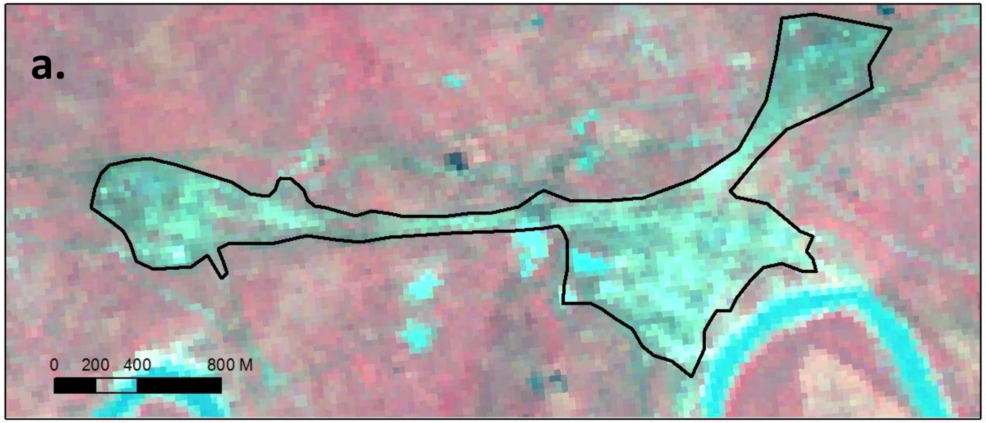


Courtesy of Timo Kumpula.

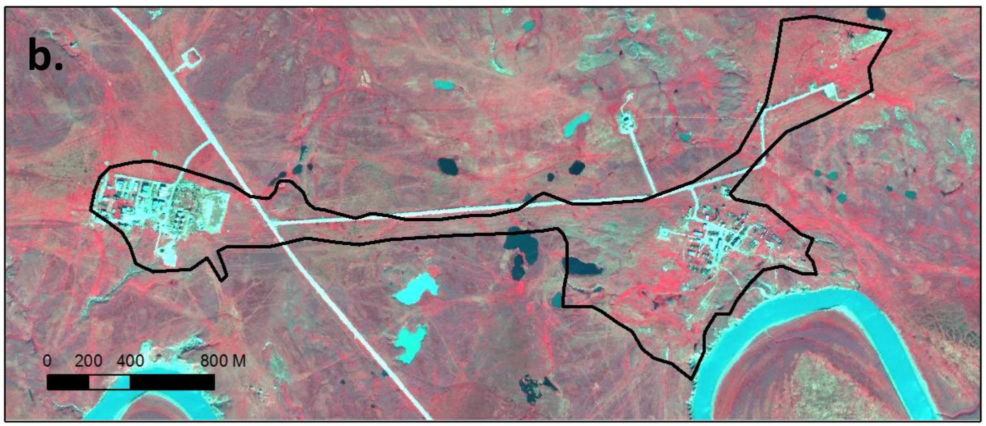
- ***(Left) The stages of visibly affected area expansion encompassing off-road tracks, roads, quarries and residential or other buildings.*** *The last three years has been a period of rapid infrastructure expansion, including railroad and pipeline building.*

- ***(Right) Growth of permanent infrastructure development including roads, pipelines, quarries and residential or other buildings.*** *Since the mid-1990's new infrastructure advanced slowly. Most of the expansion since 1998 has occurred between 2009-2011 (red lines + light gray and tan areas).*

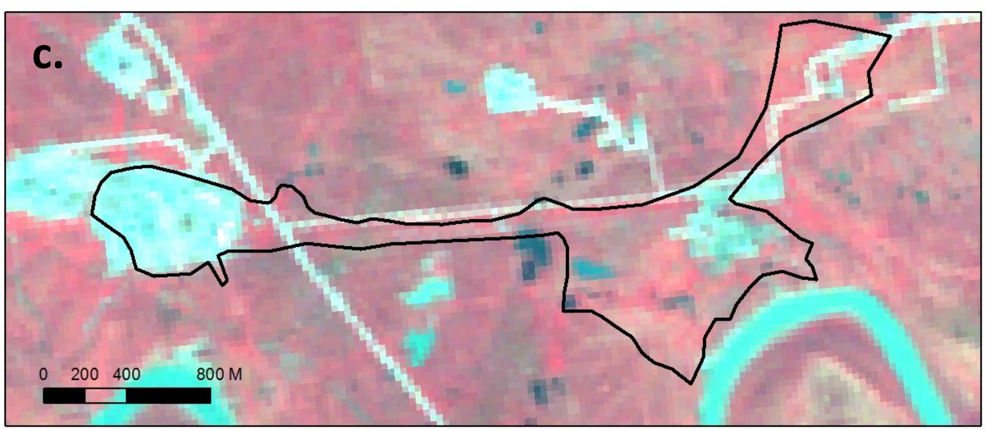
- *A similar mapping analysis is underway for the Prudhoe Bay oil field 1968-2011, building on the NRC (2003) report.*



Landsat TM 1988



Quickbird-2 2004



Landsat TM 2011

Courtesy of Timo Kumpula.

Effects of industrial expansion on greening patterns

Kekh, *the first area affected at Bovanenkovo in 1988.*

a. Large zone of exposed mineral soils (marine clay) denuded of vegetation by heavy off-road vehicle traffic and construction activities. The black polygon circumscribes the extent of disturbance

b. VHR Quickbird-2 shows the extent of revegetation after 14 years of natural regeneration.

c. Much of the bare ground has been totally revegetated by 2011. But, a significant amount of new permanent infrastructure has been built since 2004.

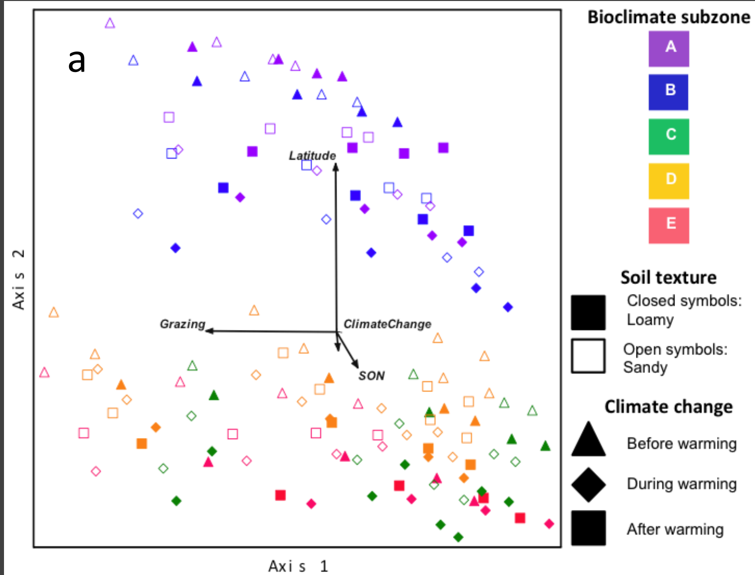
Nenets perception of changes

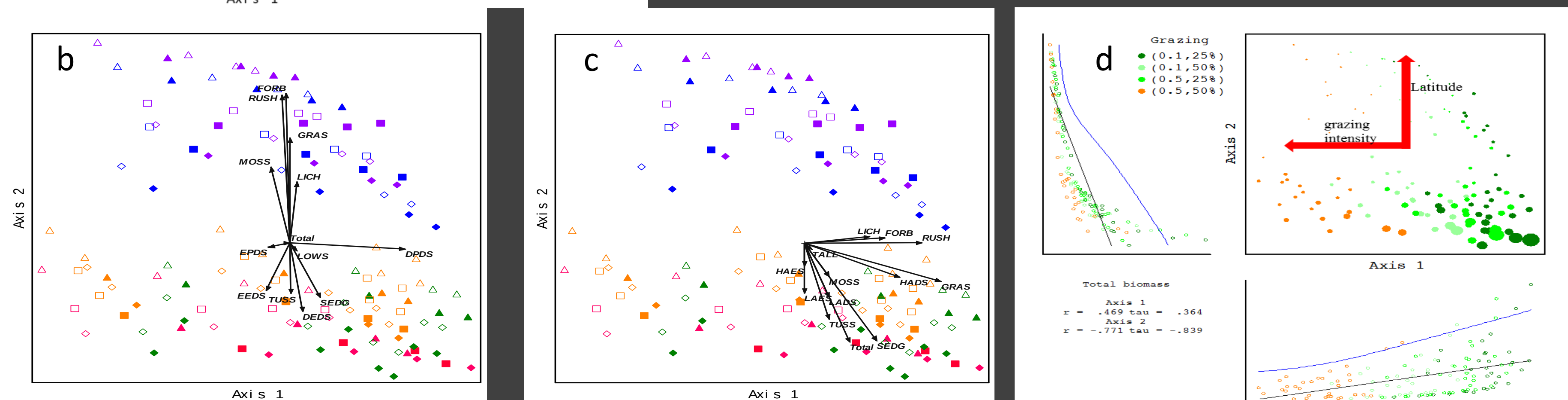
Nenets brigade crossing the Se-yakha river in the center of Bovanenkovo gas field on 5 July 2011. *(Photo by Timo Kumpula).*

Participant observation in winter pastures on the south side of Ob Bay:
left Dr. Nina Meschtyb and right Nenets reindeer herding brigadier Nyadma Khudi from Yarsalinskii sovkhoz brigade 4. Photo from Nina Meschtyb archive.

Modeling the effects of climate change and reindeer grazing

Effects of climate change, soil texture, and grazing on plant-functional-type and total-aboveground tundra biomass (Yu et al. 2011)





NMS ordination showing relative effects of climate change and grazing scenarios on tundra plant-functional-type and total biomass in the five bioclimate subzones and two dominant soil types on the Yamal. *Biplots (cluster of vectors in the centers of the plots) show relative direction and strength of (**a**) original latitudinal gradient and treatment factors (climate change, grazing, and soil organic nitrogen (SON, as a function of soil texture). Axis 2 is strongly correlated with the latitudinal summer temperature gradient (~12 °C MJT) (42% of total variance), Axis 1 is strongly correlated with the grazing gradient (13% of total variance); (**b**) trends in relative biomass of plant functional types; and (**c**) trends in absolute biomass of plant functional types. (**d**) Total biomass for each simulation scenario; each point represents one model simulation; color indicates different grazing intensities, size of dot is relative total biomass. Grazing is parameterized with two components: frequency of each grazing event and percent biomass removal. For example, (0.1, 25%) indicates the grazers will graze the same area every ten years and each time a maximum of 25% biomass will be removed. Percent biomass removal matters more than frequency of visit: (0.1, 50%) is of greater grazing intensity than (0.5, 25%) through this analysis. Side plots show trend in biomass along each axis. The biomass trend is strongest along the latitudinal gradient. (Modified from Yu et al. 2011).*