The Arctic Tundra is a maritime biome.

Circumpolar changes in open water, humidity, snow, land temperatures, NDVI and phenology (1982-2010): Satellite- and ground-based observations

Skip Walker[1]

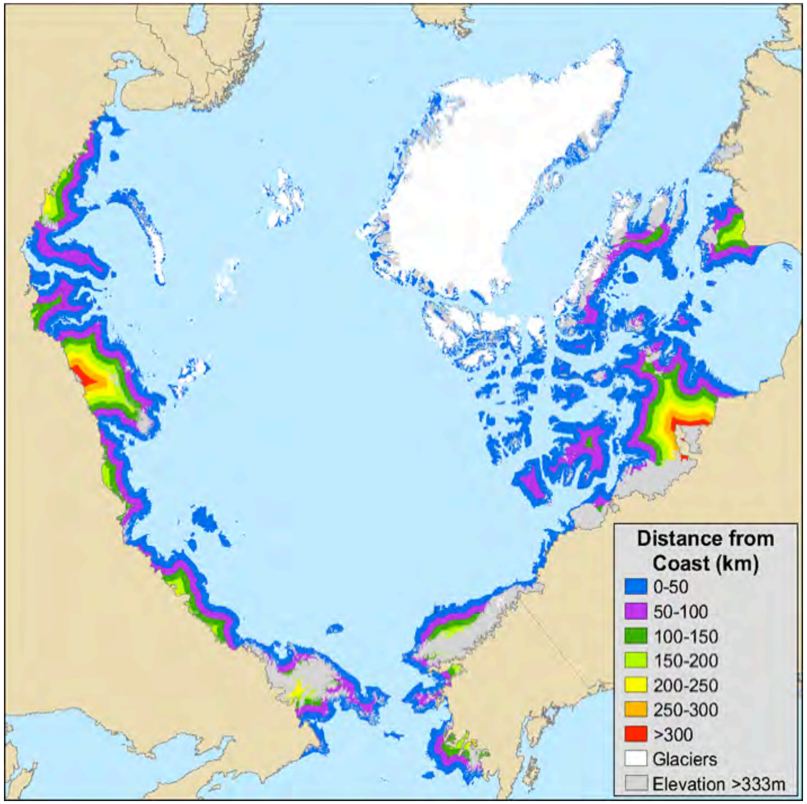
Major contributors: P. Bieniek[1], U.S. Bhatt[1], M.K. Raynolds[1], H.E. Epstein[2], G.J. Jia[3], J. Comiso[4], C.J. Tucker[4], J. Pinzon[4], M.O. Liebman[5], B.C. Forbes[6], T. Kumpula[6]

[1] University of Alaska Fairbanks, [2] University of Virginia, [3]Institute of Atmospheric Physics, Beijing,China, [4]NASA-Goddard, [5]Earth Cryosphere Institute, Tyumen, Russia, [6]Arctic Centre, Rovaniemi, Finland

Overview

- Introduction: Characterization of the Arctic as a maritime biome.
- 1982-2010 circum-Arctic trends in open water, snow, land temperatures, NDVI
- Summary of ground observations from North America and Eurasia transects
  - Implications for zonal biomass
  - Other sources of greening change

Why the Arctic tundra is a maritime biome



- ***Very important to first of all carefully define the Arctic. Too many references are including the boreal forest as part of the Arctic!***
- ***The Arctic (the region north of tree line with an Arctic climate, Arctic flora, and tundra vegetation) is a relatively narrow strip of land around the margins of the Arctic Ocean.***
- ***177,000 km of coastline, about one fifth of the total coastline of the world — for a biome that comprises less than 5% of the Earth's terrestrial surface.***
- ***Eighty percent of the non-alpine Arctic lies within 100 km of seasonally ice-covered seas.***
- ***Several bioclimatic subzones are compressed near the coastlines, resulting in extraordinarily long and narrow ecological transition zones that are highly susceptible to change resulting from arctic amplification.***

- ***<u>However,</u> the Arctic is different from most maritime areas because the Arctic Ocean is covered by varying amounts of ice during the winter and summer, which promotes more continental climates in many areas than would occur if the ocean were ice free.***

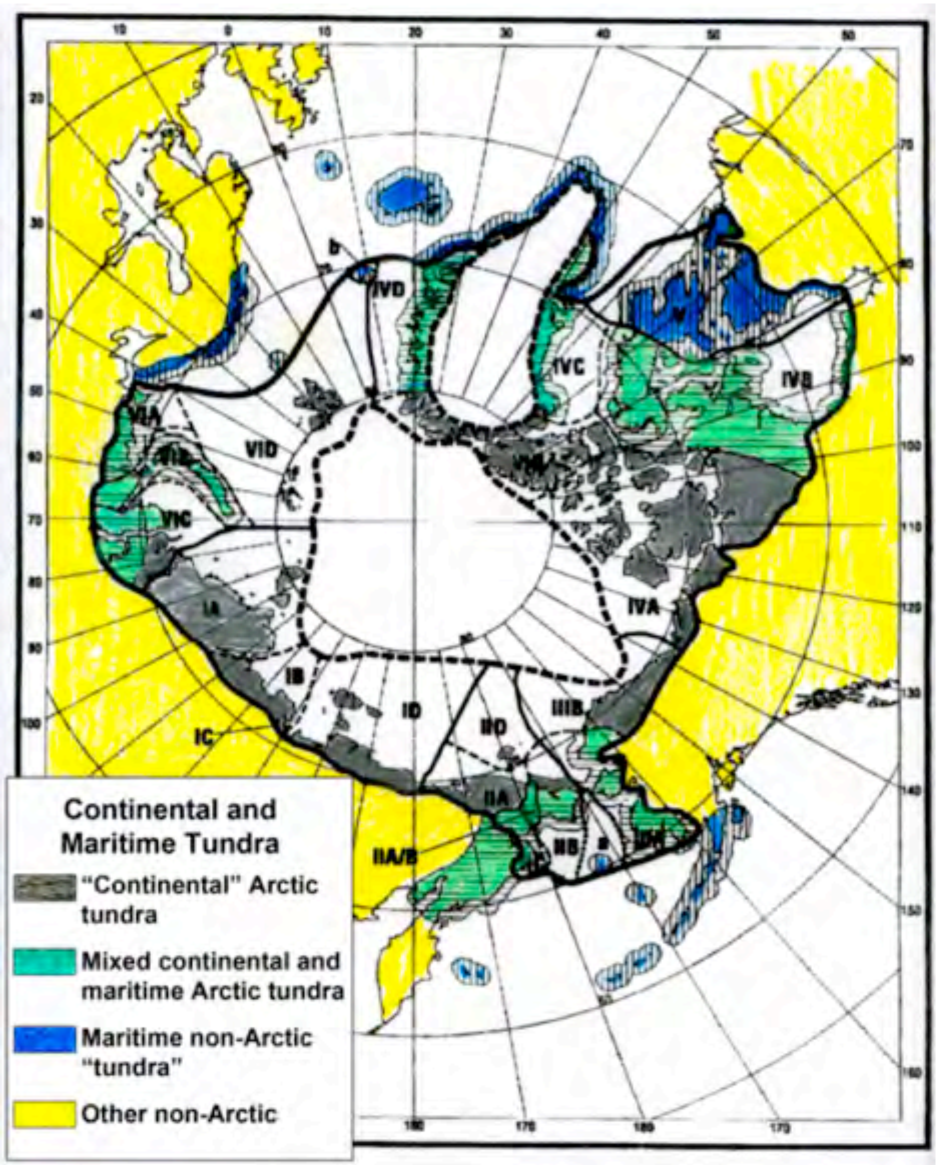
Yurtsev's floristic division of the Arctic

Divides the Arctic into 6 floristic provinces and 22 subprovinces.

Separates oceanic and continental areas of the Arctic.

Yurtsev 1994, Journal of Vegetation Science

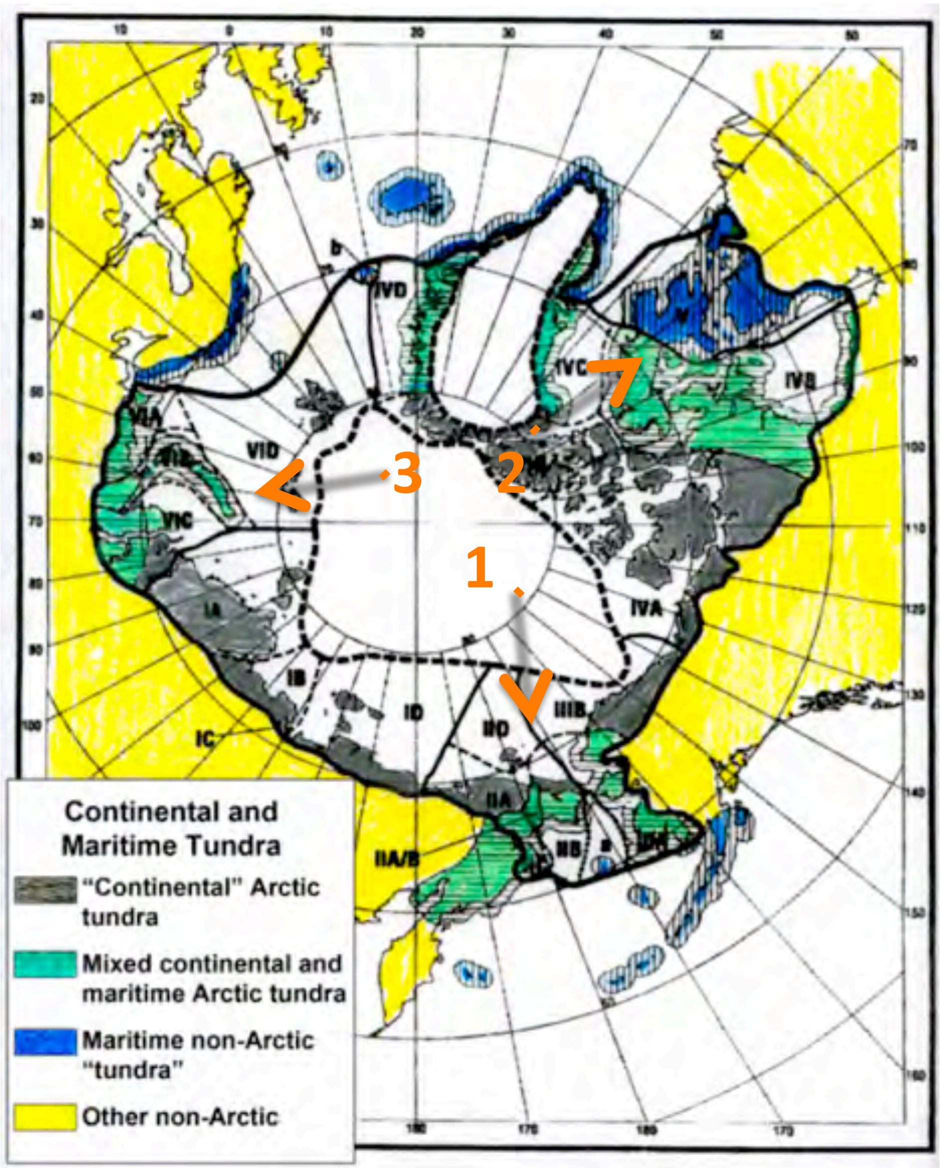
Yurtsev's recognition of oceanic and continental regions within the Arctic



- Gray areas are the continental Arctic areas with an Arctic climate, cold winter deep permafrost, and and Arctic flora.
- Blue areas are non-Arctic treeless areas with warm winters, no permafrost (except in mountains), and an oceanic boreal flora.
- Green areas are 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 the greatest ocean and land changes are occurring.



- THESE ARE ALSO APPROXIMATELY THE AREAS WHERE THE LARGEST CHANGES ARE PRESENTLY OCCURRING.
  1. BERING/CHUKCHI/BEAUFORT SEAS
  2. FOXE BASIN/BAFFIN BAY/HUDSON BAY
  3. BARENTS/KARA SEA

Yurtsev 1994, *Journal of Vegetation Science*

An earlier analog of massive maritime change in the Arctic associated with the opening of Bering Strait: Guthrie's mesic tundra "buckle" in Beringia during the era of the mammoth steppe


PERGAMON
QSR

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

R. Dale Guthrie*

Abstract

1. Introduction

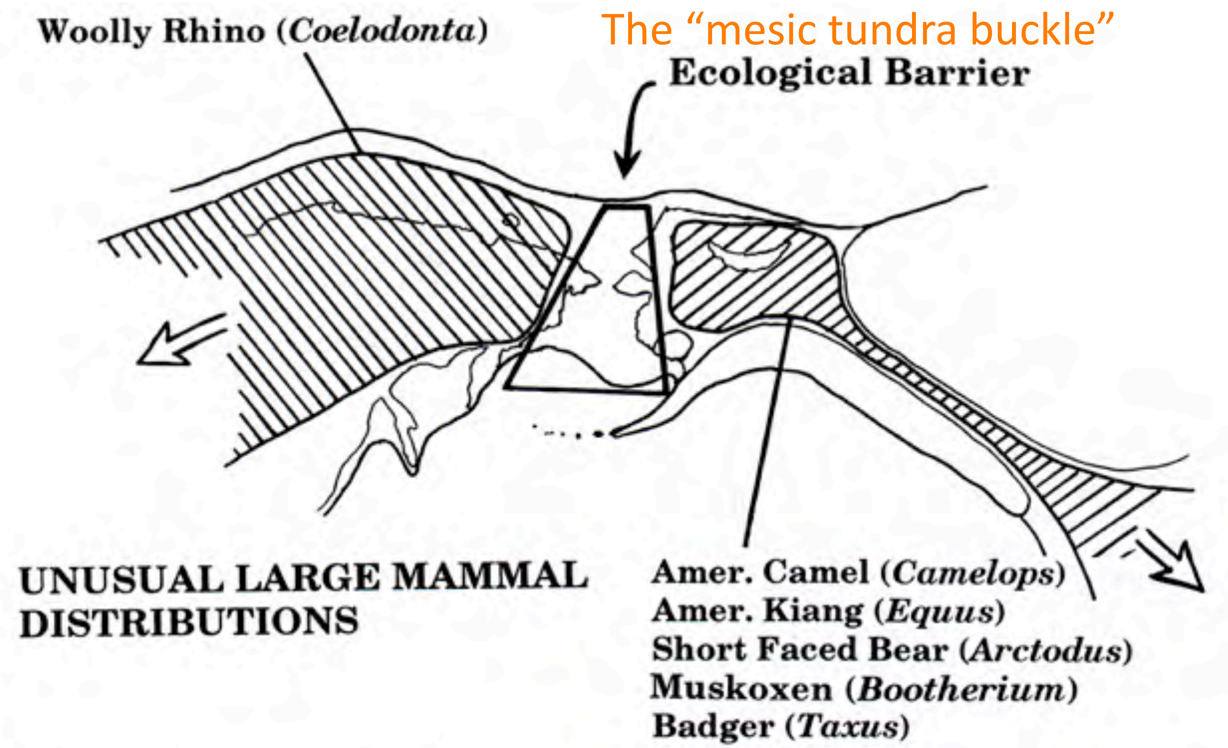


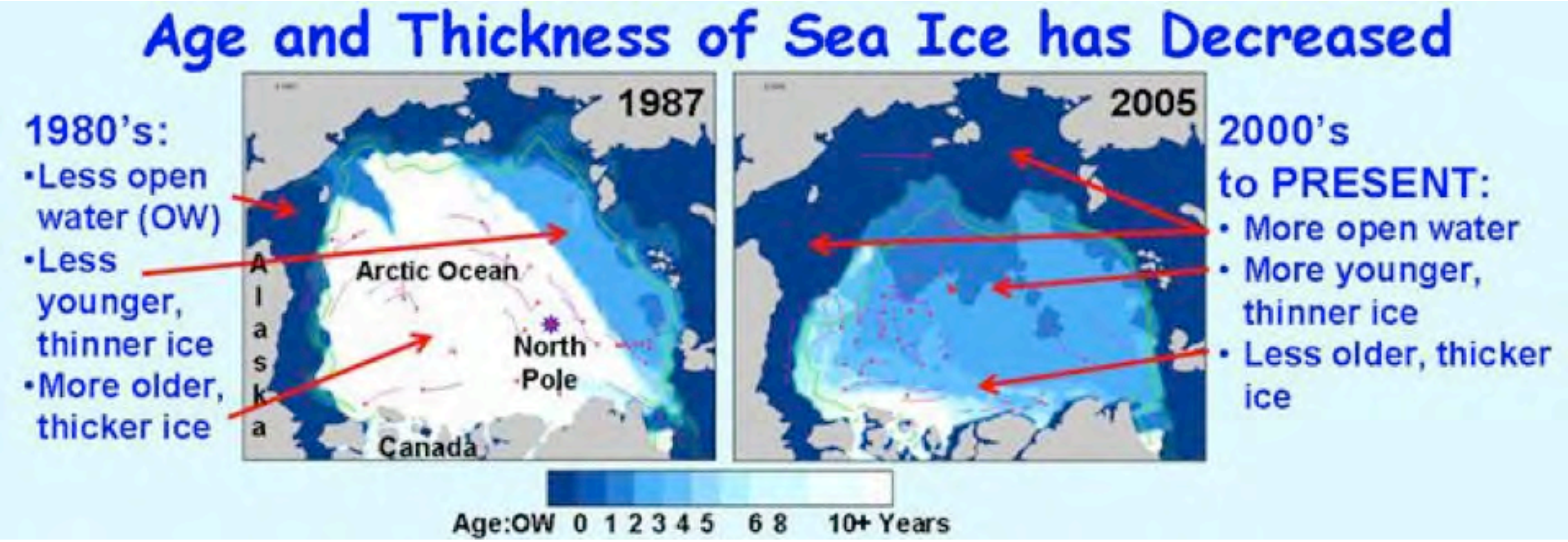
Fig. 8. Mammalogists have puzzled over the several Pleistocene species whose distribution approaches the Bering Strait then apparently ends. This pattern is not typical of most of northern species in the Pleistocene. There does appear to have been some kind of barrier in that region, but has received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

Guthrie 2001, *Quaternary Science Reviews*

Warming and Humidification of the Arctic

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

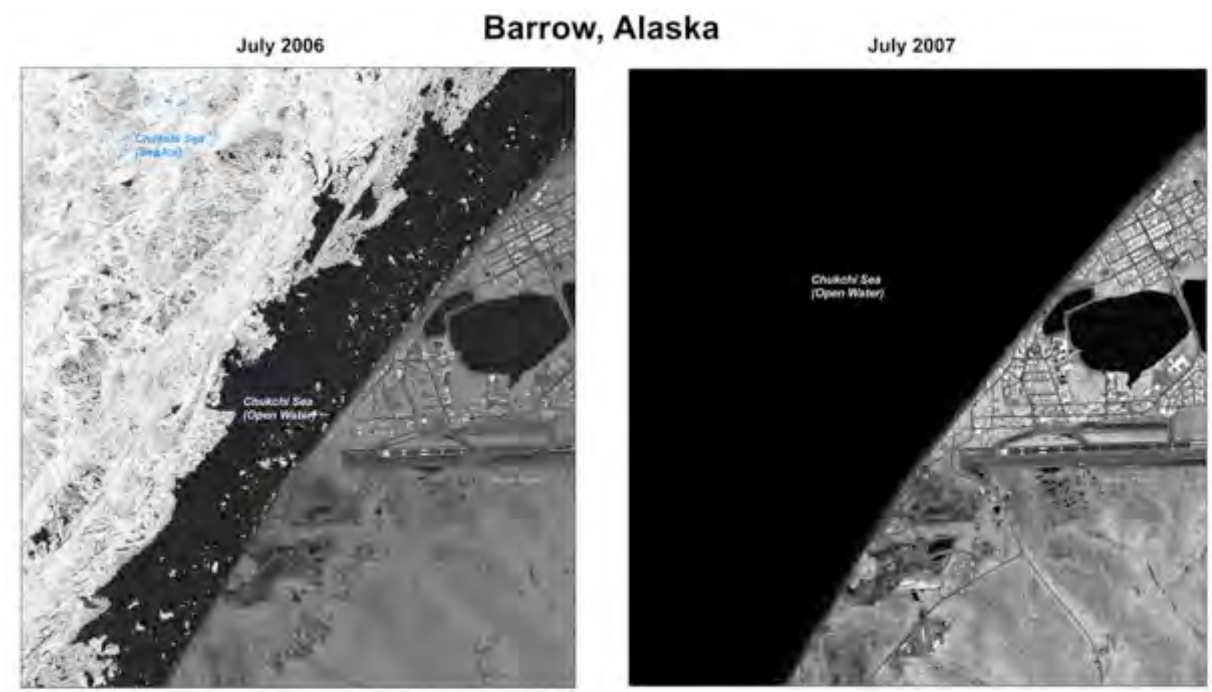
Change in multi-year sea ice



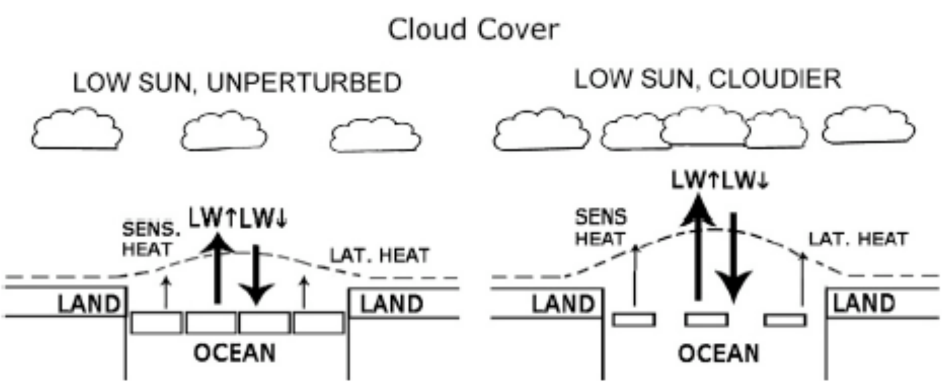
- **It is conceivable that the Arctic ocean could be ice free during September by as early as 2030.**

Rigor and Wallace 2004, updated to 2009

Arctic amplification largely (but not entirely*) a consequence of reduced ocean albedo during summer and fall



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

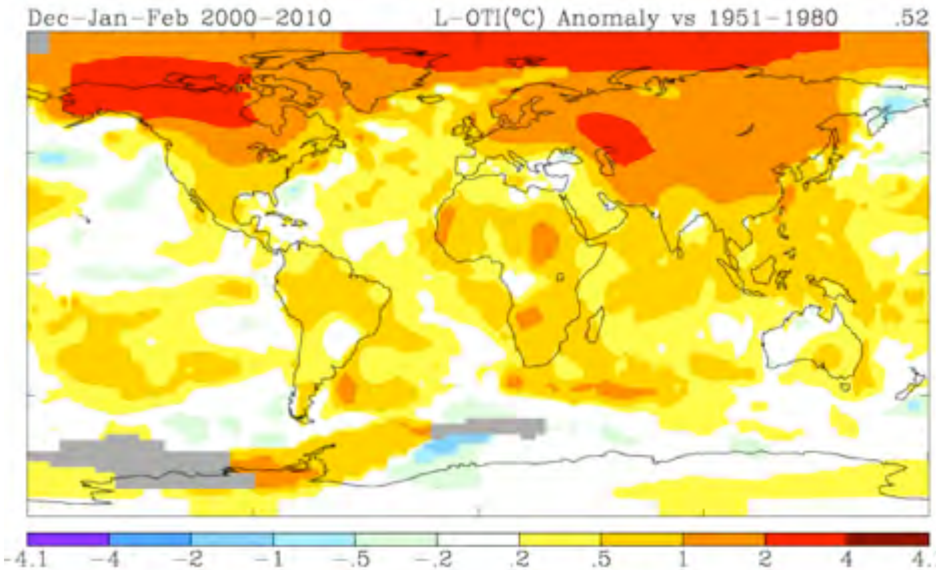


***e.g. Feedbacks from increased cloudiness:**

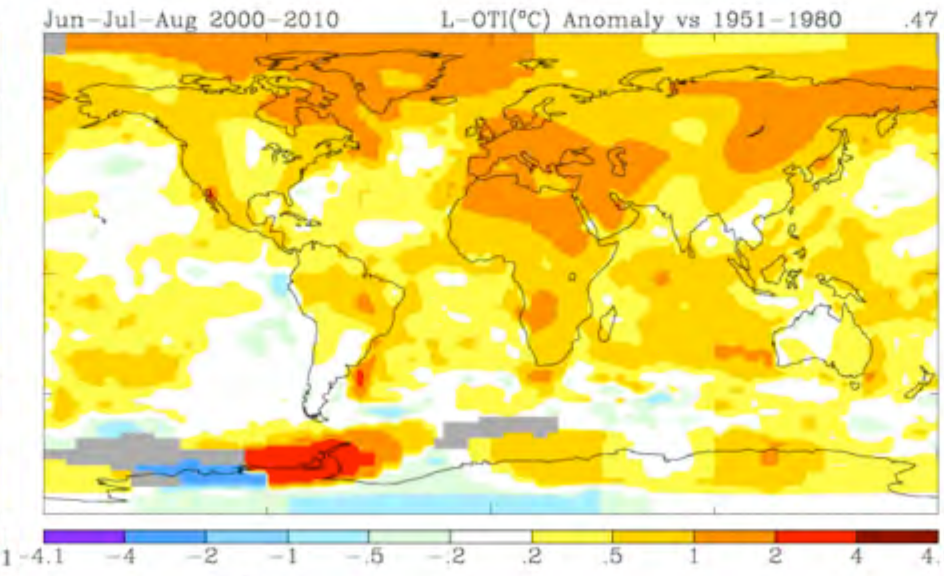
Serreze and Barry. 2011. Processes and impacts of Arctic amplification: A research synthesis. *Global and Planetary Change.*

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/

- **This talk will focus on the summer trends in temperature because of the strong direct impact of summer temperature on productivity.**
- **Long-term summer temperature trends are weaker than the winter trends.**

Analysis of circumpolar trends in magnitude of change of open water, snow water equivalent, land temperatures, humidity, winds, NDVI, and seasonal trends of these variables.

Uma Bhatt, Peter Bieniek, Skip Walker, Martha Raynolds

Data:

Sea Ice / open water): Passive microwave sea ice concentration (25-km pixels). 100-km coastal zone. 1982-2010. (29 yrs, weekly)

Snow: SSM/I SWE: Snow Water Equivalent (mm), 25-km, monthly 1987-2007, IMS (multisensor) snow cover, 24-km, daily 1999-2010

Land Temperatures: AVHRR (25-km). SWI = sum of mean monthly temperatures above freezing (˚C mo).

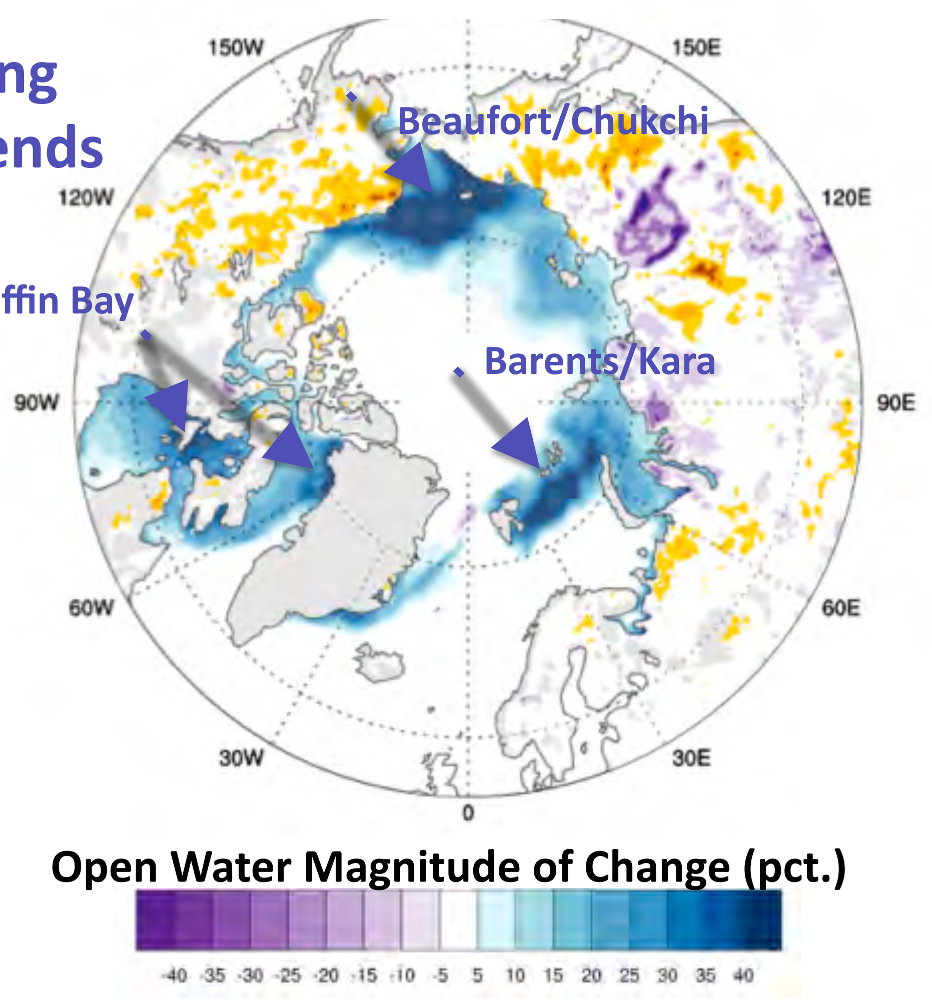
Greening: Gimms3g (New version corrected for Arctic) AVHRR NDVI (Max and Integrated) (14-km pixels, full tundra).

Humidity & Winds: CFSR gridded reanalysis. 38-km, monthly 1979-2010, 2m specific humidity (kg kg^{-1}) & 10m U and V components (m s^{-1})

Late Fall Open-Water Trends

Oct-Nov

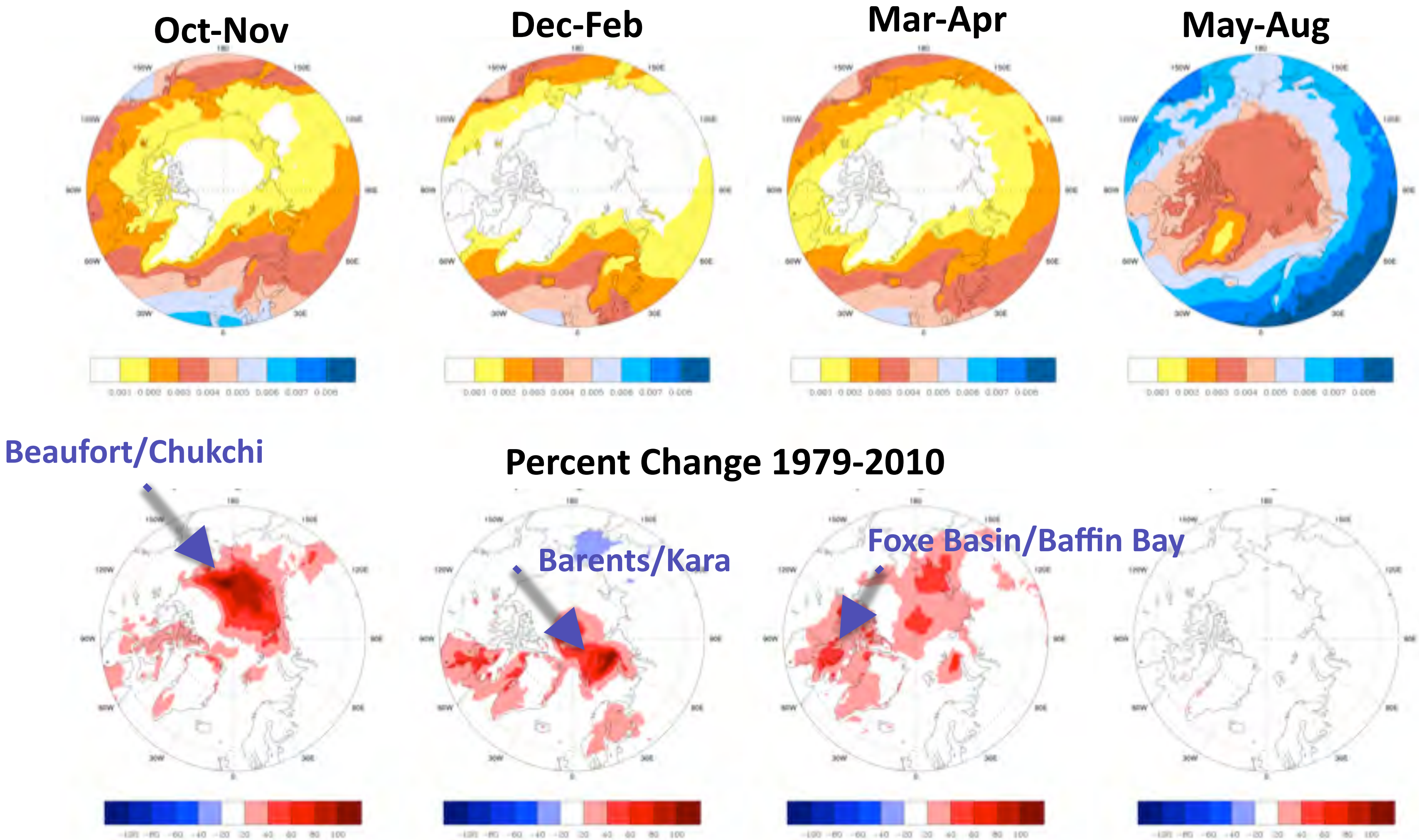
Areas of strong open-water trends



Bieniek, Bhatt, et al., in progress

Humidity

Average specific humidity (q, kg water/kg air)

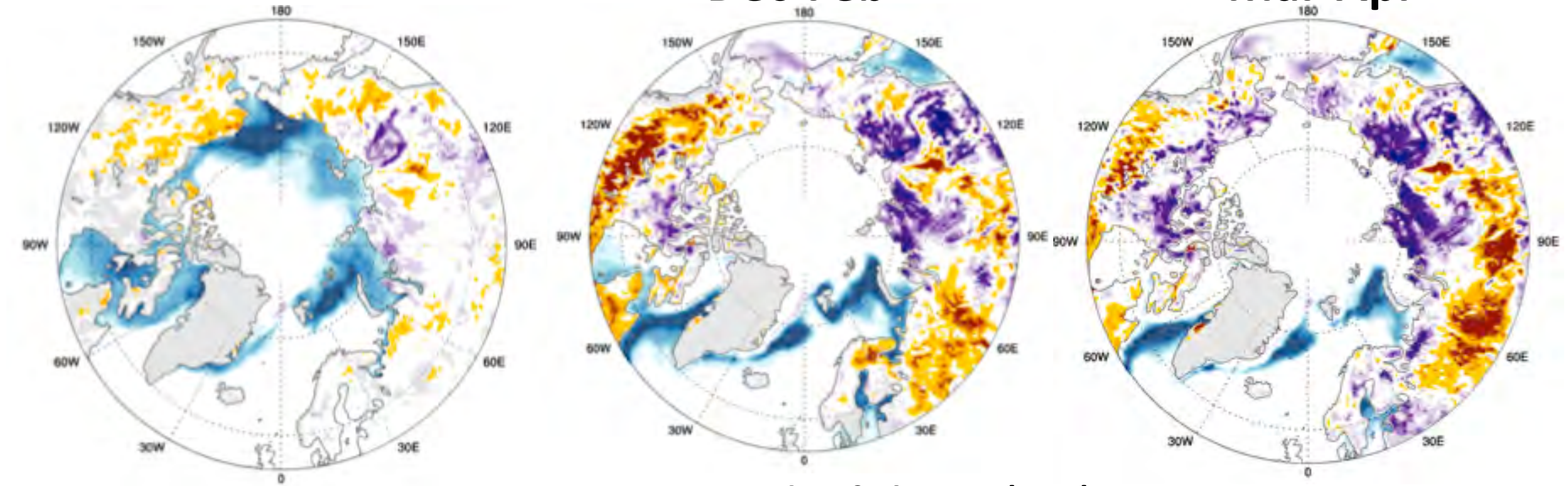


Beaufort - Chukchi change occurring mainly in Fall.
Barents - Kara mainly in winter.
Fox Basin - Baffin Bay winter and spring.

Bieniek, Bhatt, et al., in progress

Seasonal trends of Open Water and Snow Water Equivalent

Oct-Nov | Dec-Feb | Mar-Apr



Open Water Magnitude of Change (pct.)

Snow Water Equivalent Magnitude of Change (mm)

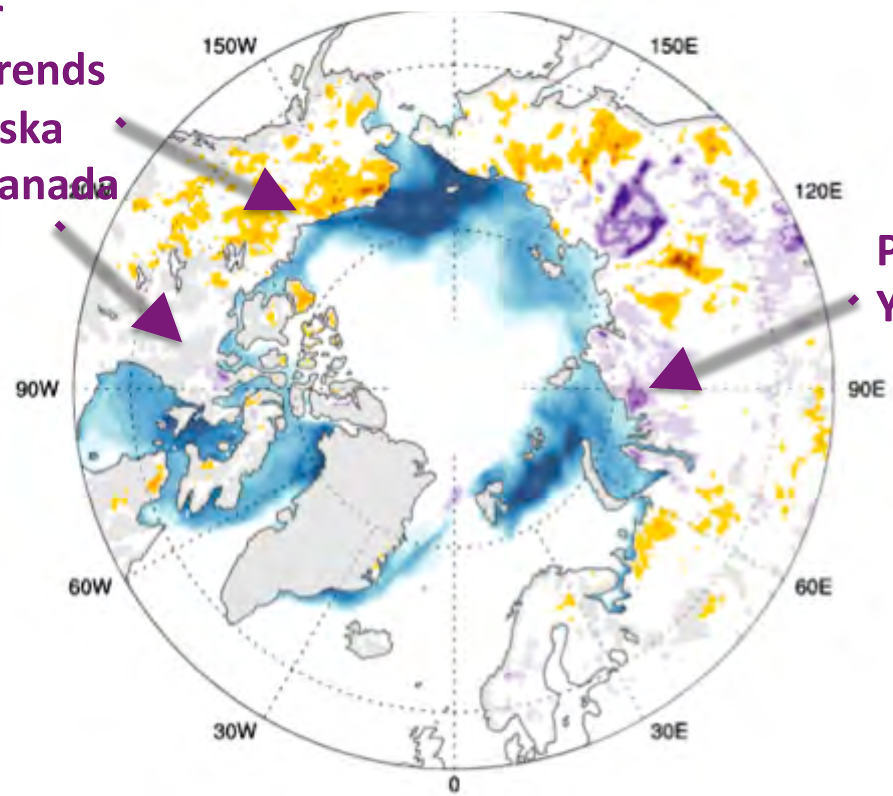
Bieniek, Bhatt, et al., in progress

Late Fall Snow Trends

Oct-Nov

Generally no or negative SWE trends in northern Alaska and northern Canada

Positive trend in N. Yamal to Taimyr Pen.



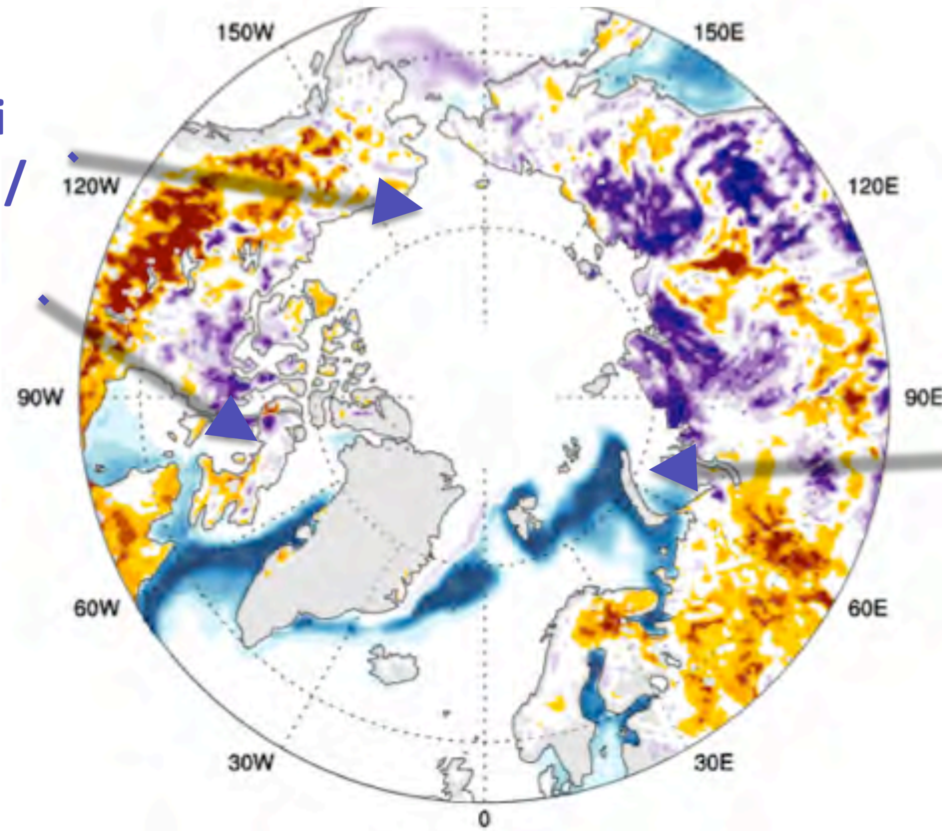
Snow Water Equivalent Magnitude of Change (mm)

Bieniek, Bhatt, et al., in progress

Winter Open Water Trends

Dec-Feb

Beaufort/Chukchi and Foxe Basin / Baffin Bay: no trend (ocean frozen).



Barents: continued strong positive open- water trend.

Open Water Magnitude of Change (pct.)

Bieniek, Bhatt, et al., in progress

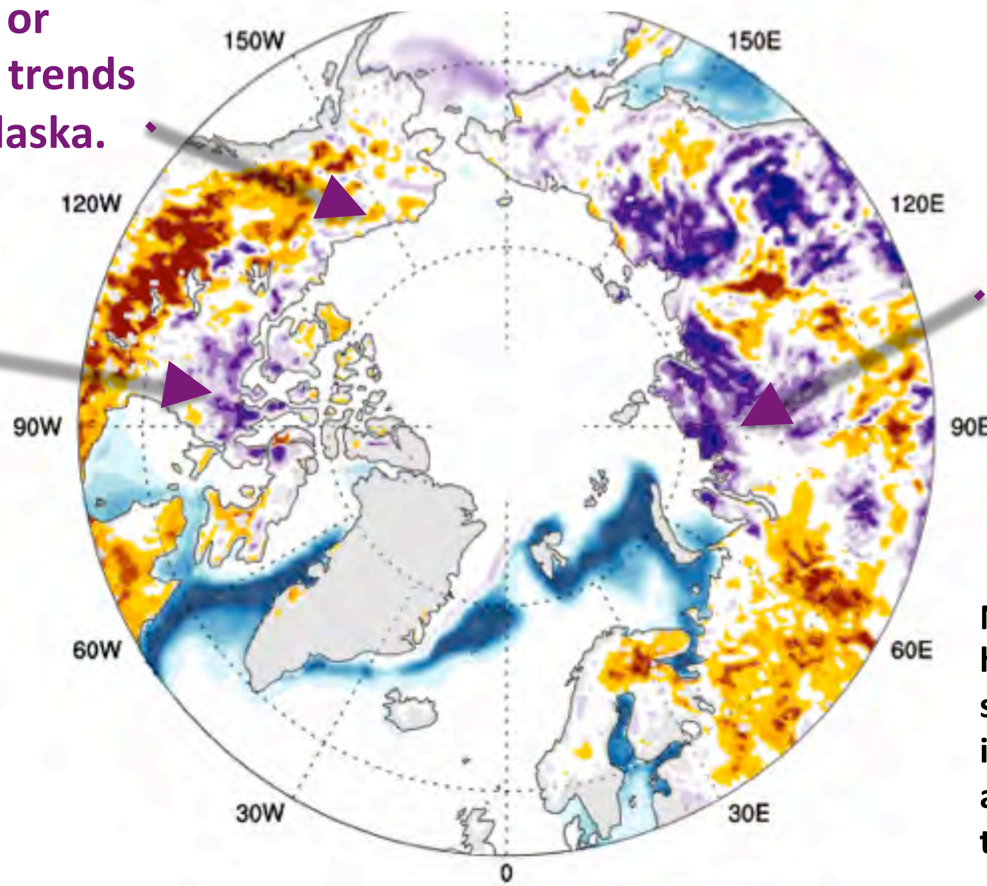
Winter Snow Trends

Dec-Feb

Continued no or negative SWE trends in northern Alaska.

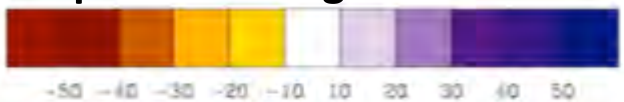
Positive SWE trends in northern Canada.

Strong positive trend in N. Yamal to Taimyr Pen.



Note: Tundra snow often has a density of 0.2 to 0.4 so the equivalent changes in snow depth can be approximated as about 3x the ∂SEW values.

Snow Water Equivalent Magnitude of Change (mm)

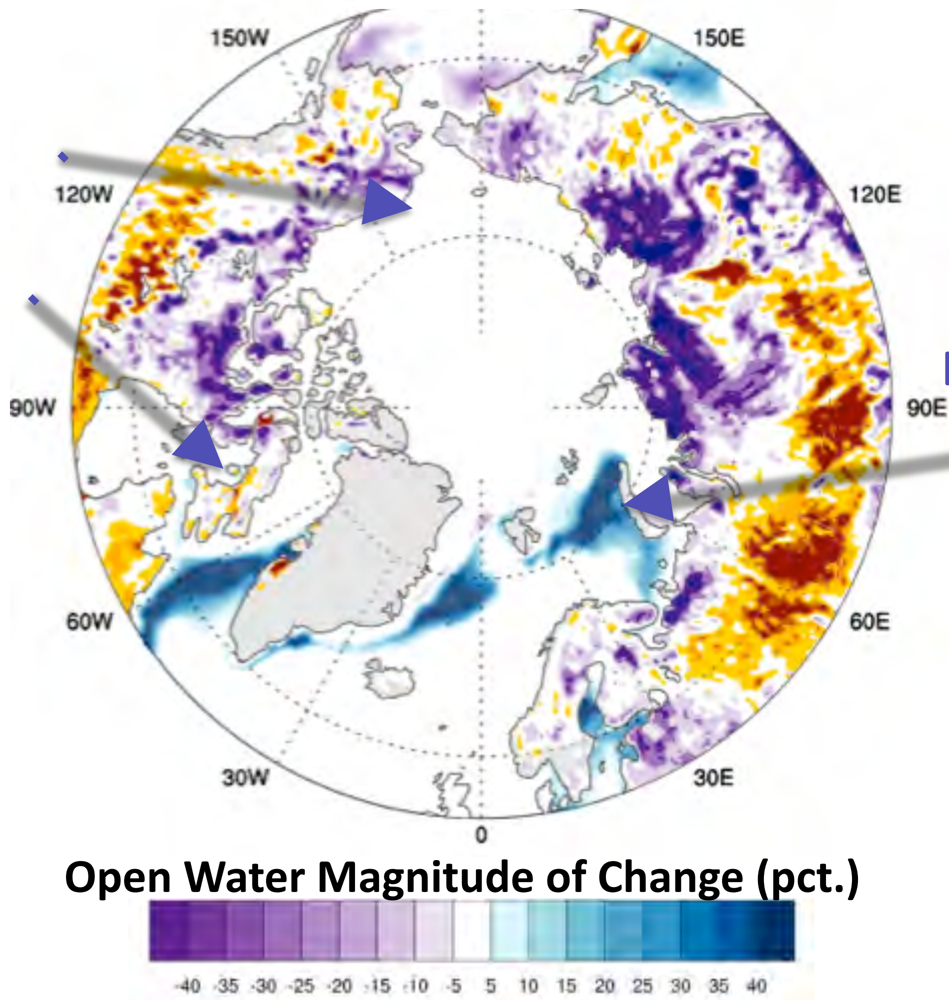


Bieniek, Bhatt, et al., in progress

Spring Open-Water Trends

Mar-Apr

Continued no trend in Beaufort/ Chukchi and Foxe Basin /Baffin Bay.

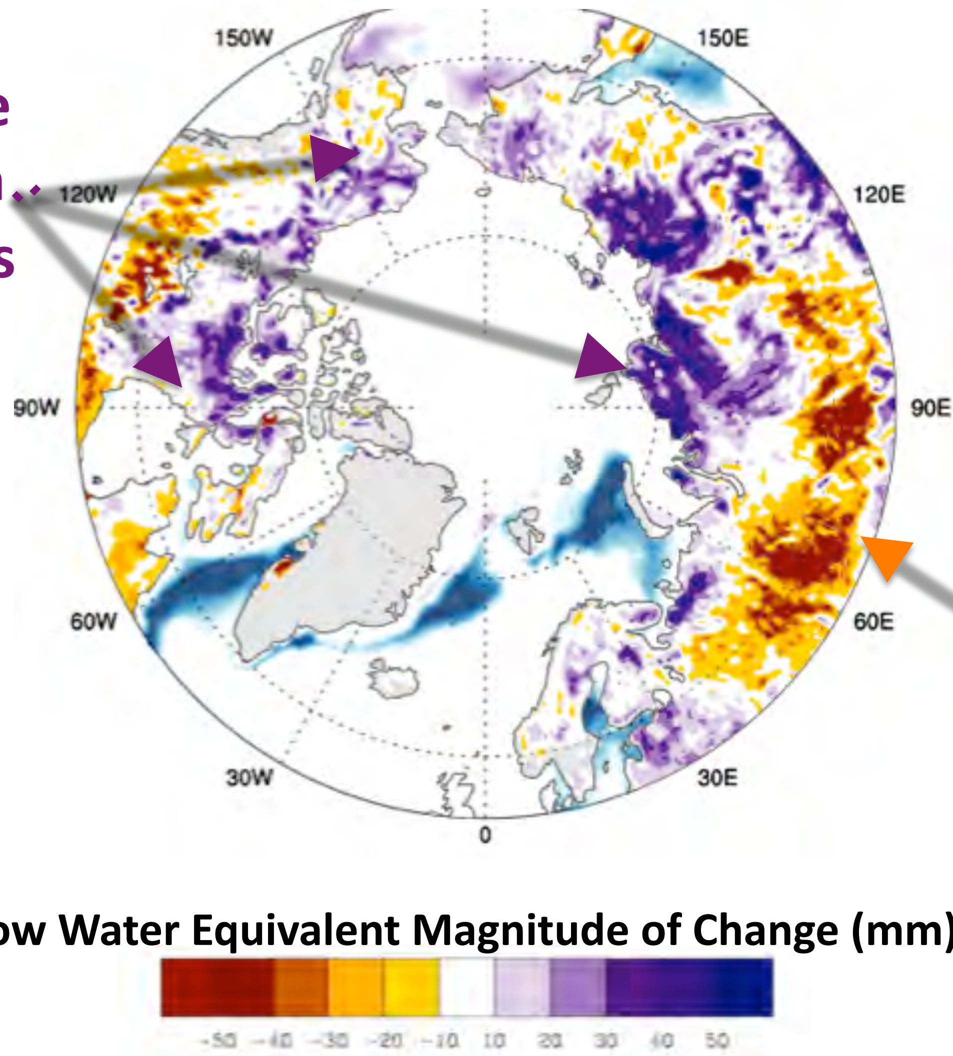


Barents: continued strong positive open- water trend even into Spring!

Bieniek, Bhatt, et al., in progress

Spring Snow Trends

Mar-Apr



Strong positive snow trends in nearly all areas of the Arctic.

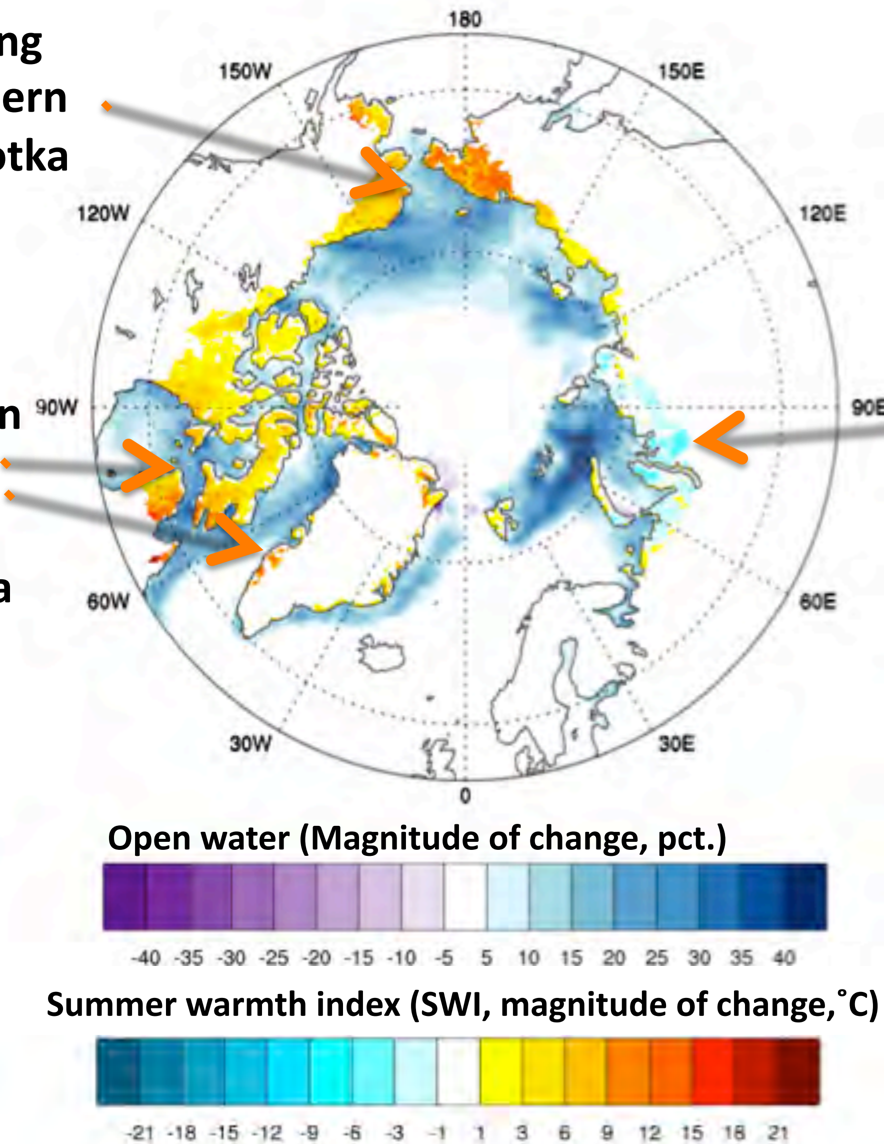
In contrast with boreal forest where much of the area has negative snow trends.

Bieniek, Bhatt, et al., in progress

Changes in summer land temperatures: Mean May-Aug change, 1982-2010

Moderate to strong warming in northern Alaska and Chukotka

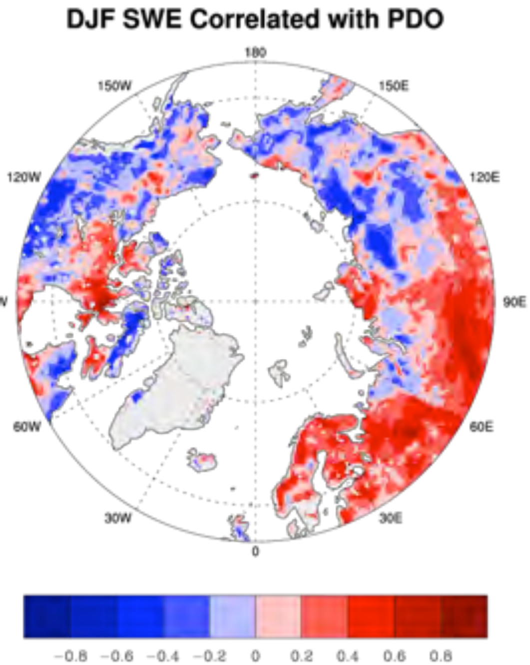
Moderate to strong warming in the Baffin Island, West Greenland, Ungava Peninsula regions

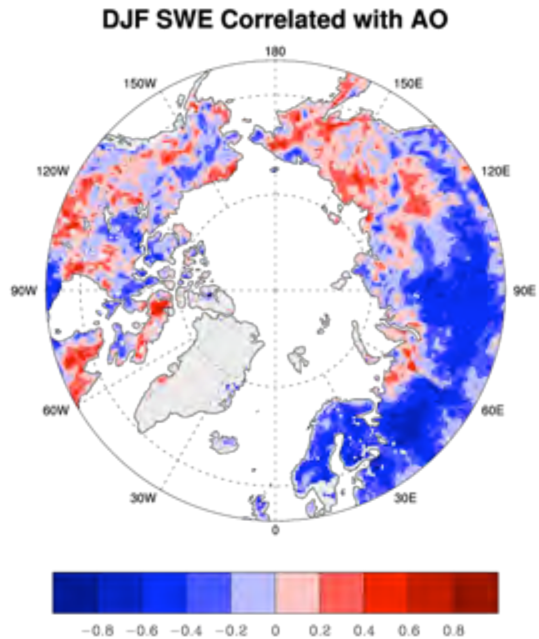


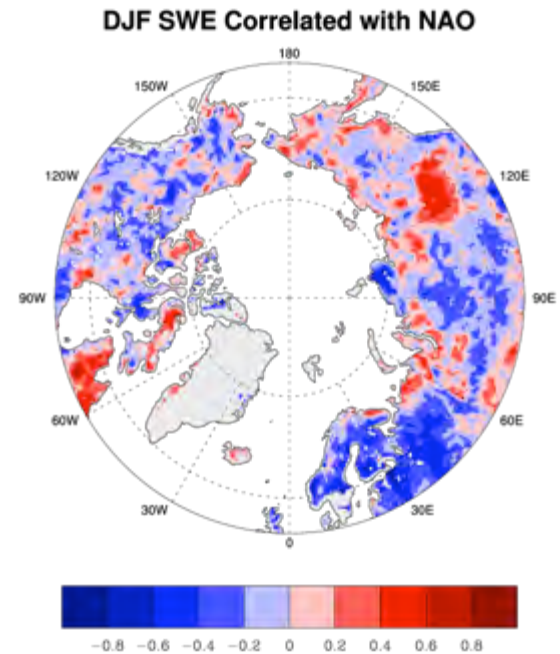
Cooling to neutral change in the Yamal/ Taimyr region

Updated from Bhatt et al. 2010

Correlations of Mar-Apr SWE Climate Indices

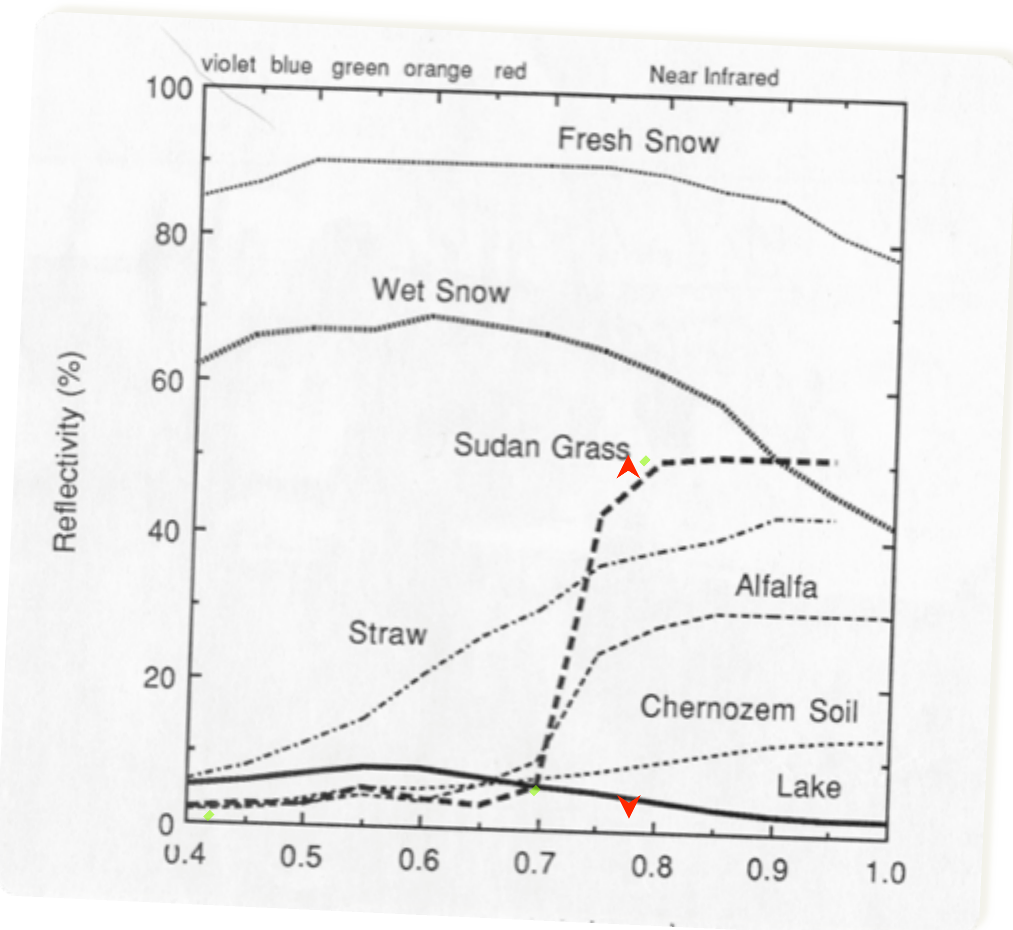






- **Patterns in snow are driven by large-scale climate phenomena. Correlations exist but it is very complex.**
- **Uma and Peter are now trying find the mechanism (e.g. changes in weather patterns).**
- **They will first focus on Alaska with local weather experts.**

NDVI refresher



Photosynthetically active (0.4-0.7 µm)

[Hartmann 1994]

- NDVI is a proxy for the photosynthetic capacity of the vegetation.
- Green plants have low albedo in visible (0.4-0.7 µm) range.
- And high albedo in the near infrared (0.7-1.2 µm).

Normalized Difference Vegetation Index

NDVI = (NIR – VIS) / (NIR + VIS)

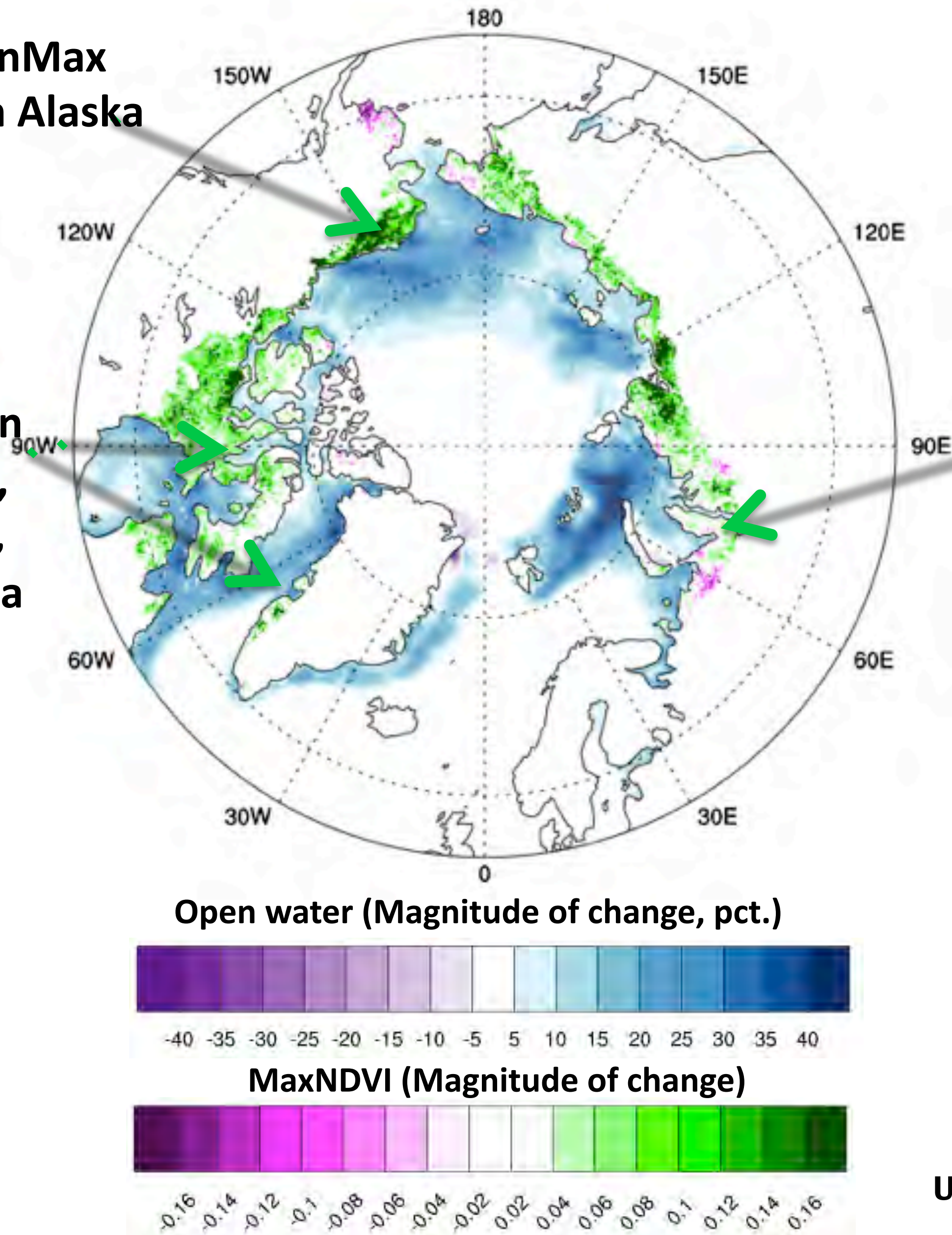
- Dividing by the sum normalizes the index to help account for shadow and slope angle effects.

Deering [Ph.D. 1978] & Tucker [1979]

Changes in open water maximum tundra greenness (MaxNDVI)

Strong increase inMax NDVI in northern Alaska and Chukotka

Moderate to strong increase in the Baffin Island, West Greenland, Ungava Peninsula regions



Neutral to negative MaxNDVI change in Yamal W. Taimyr area

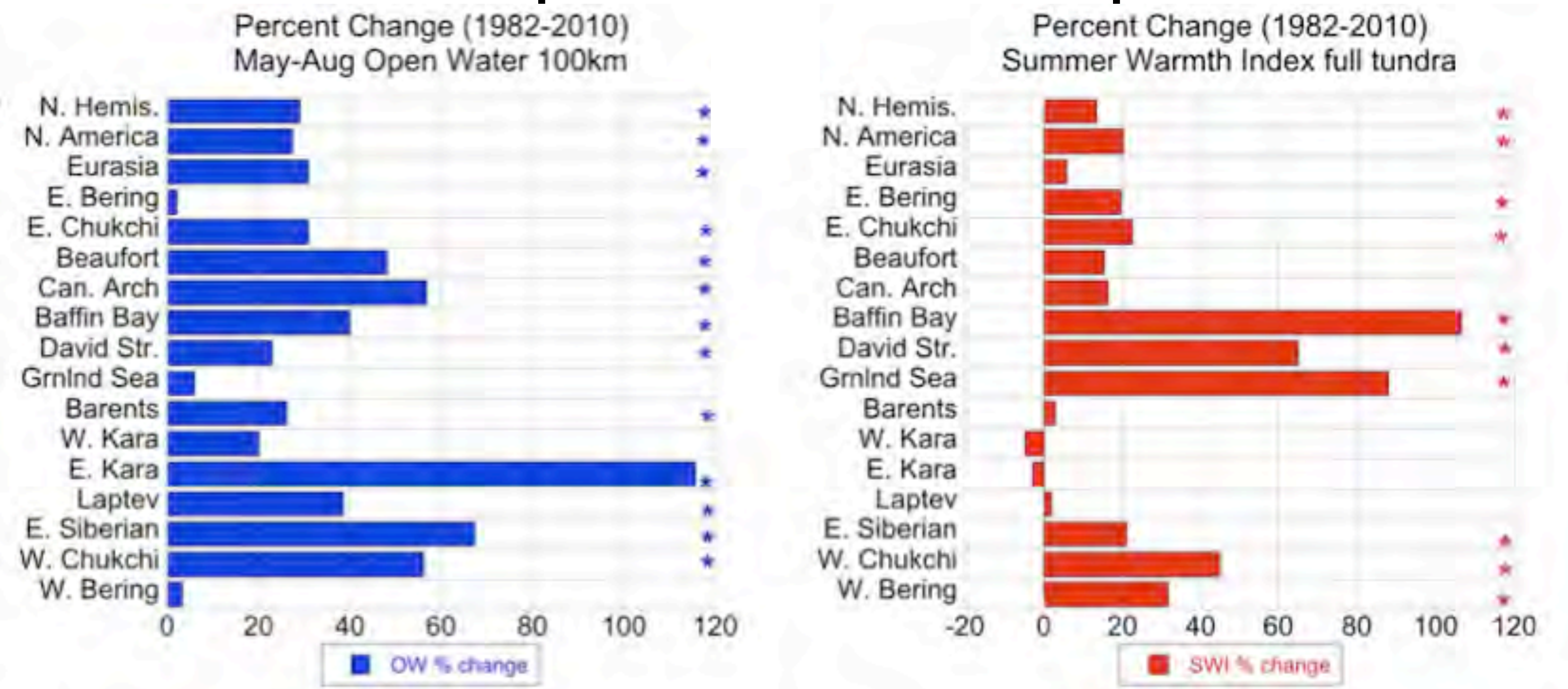
Updated from Bhatt et al. 2010

Division of ocean and land areas

- **Divided Arctic Ocean (slight modification of Treshnikov, 1985.**
- **Trends of sea ice within 50 & 100-km coastal areas.**
- **Land divided according to Yurtsev floristic provinces.**

Bhatt et al. 2010. Earth Interactions.

Percentage change (based on least squares fit method) in coastal open water and land temperatures

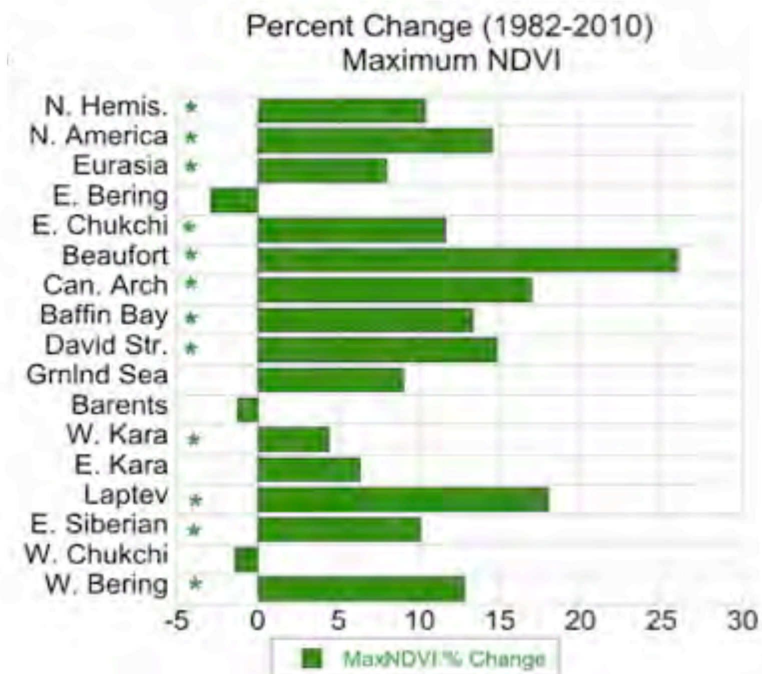


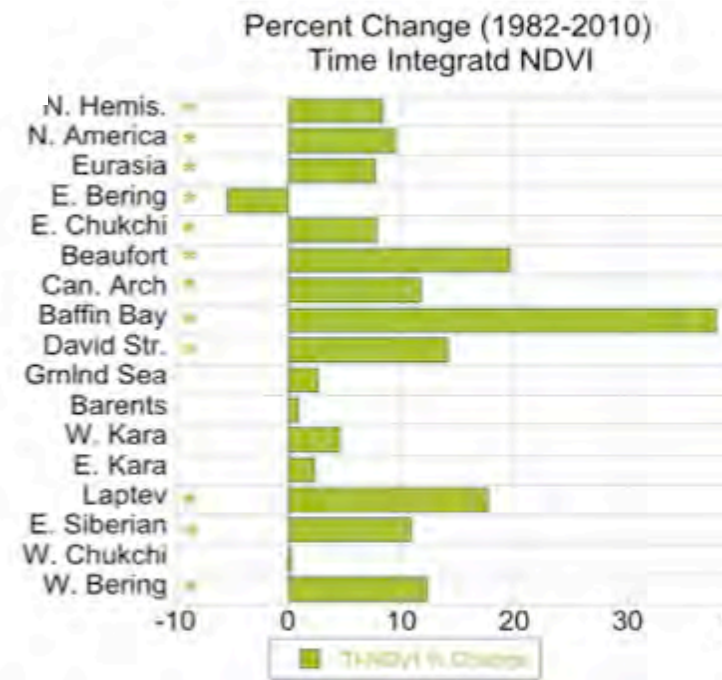
Significant trends are starred (*)

- **Maybe not the best way to subdivide because ocean divisions have mixed trends, but does give idea of the percentage of changes.**
- **Most noticeable:**
  - **Cooling in the E. Kara region despite very large increases in open coastal water (More fog? More snow? Shorter growing season? Off-shore winds?)**
  - **Greatest percentage warming changes are in the Baffin Bay, Davidson St., Greenland Sea areas**
  - **Beaufort does not stand out in this comparison because of huge E. Kara trend. But still a 50% increase in OW.**

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

Percentage change of NDVI

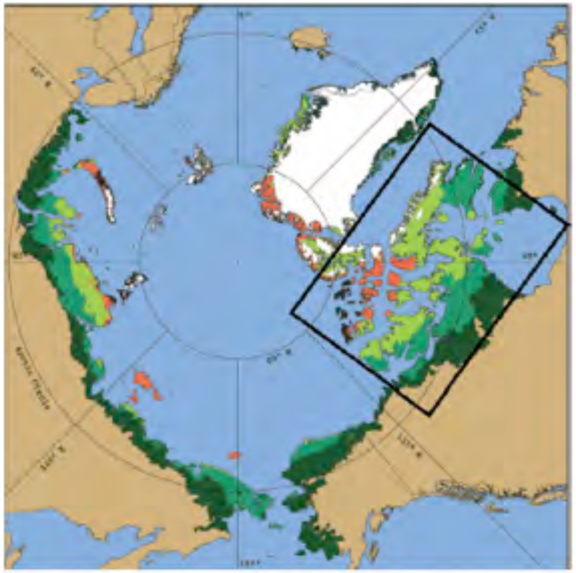




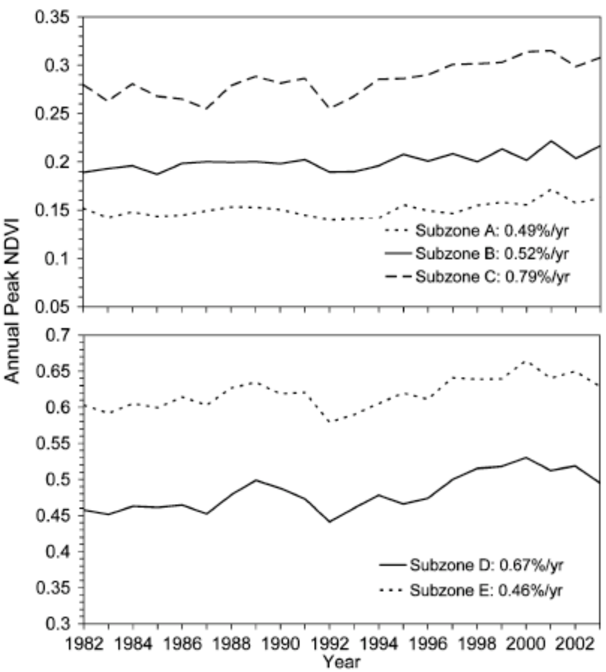
- **In general, areas of enhanced NDVI patterns are corresponding to areas of warmer land temperatures.**
  - **Strong greening in the Beaufort, Canada, Greenland and Laptev.**
  - **Weak trend in the Barents / Kara region.**

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

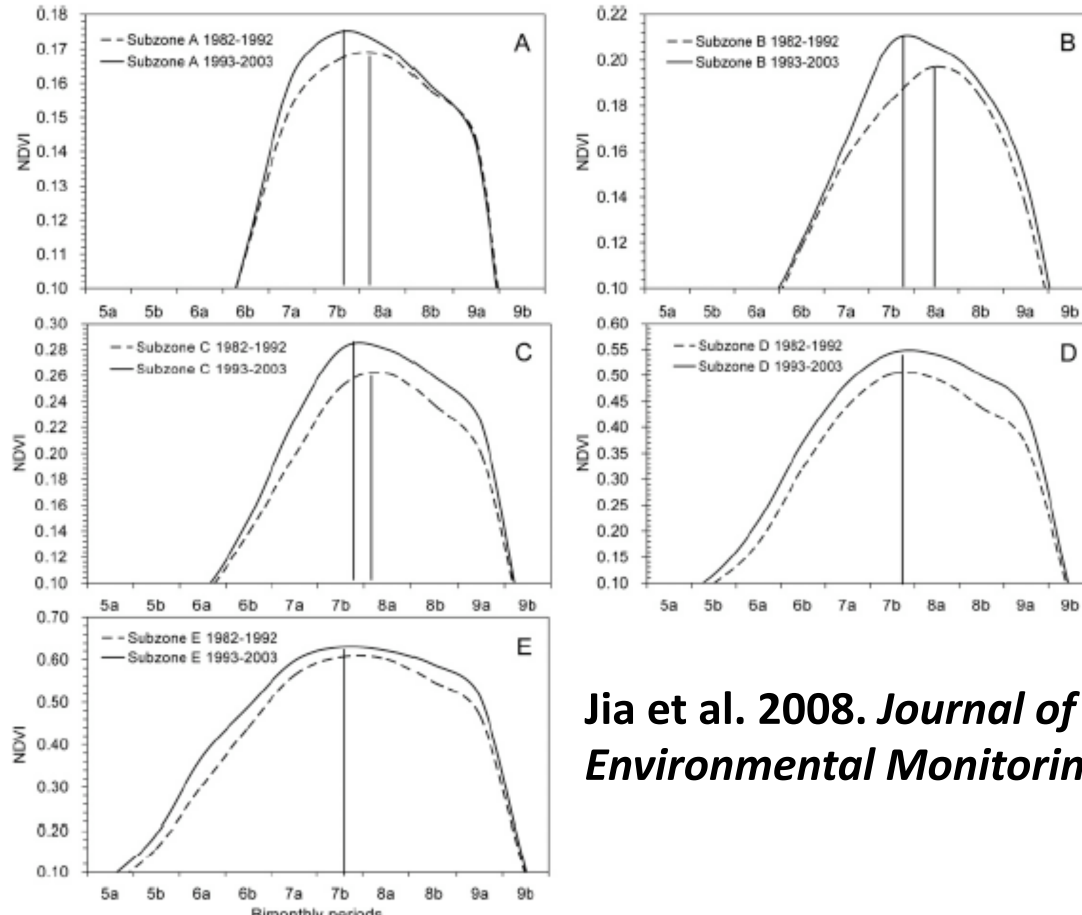
Changes in phenology along a bioclimate gradient in Canada



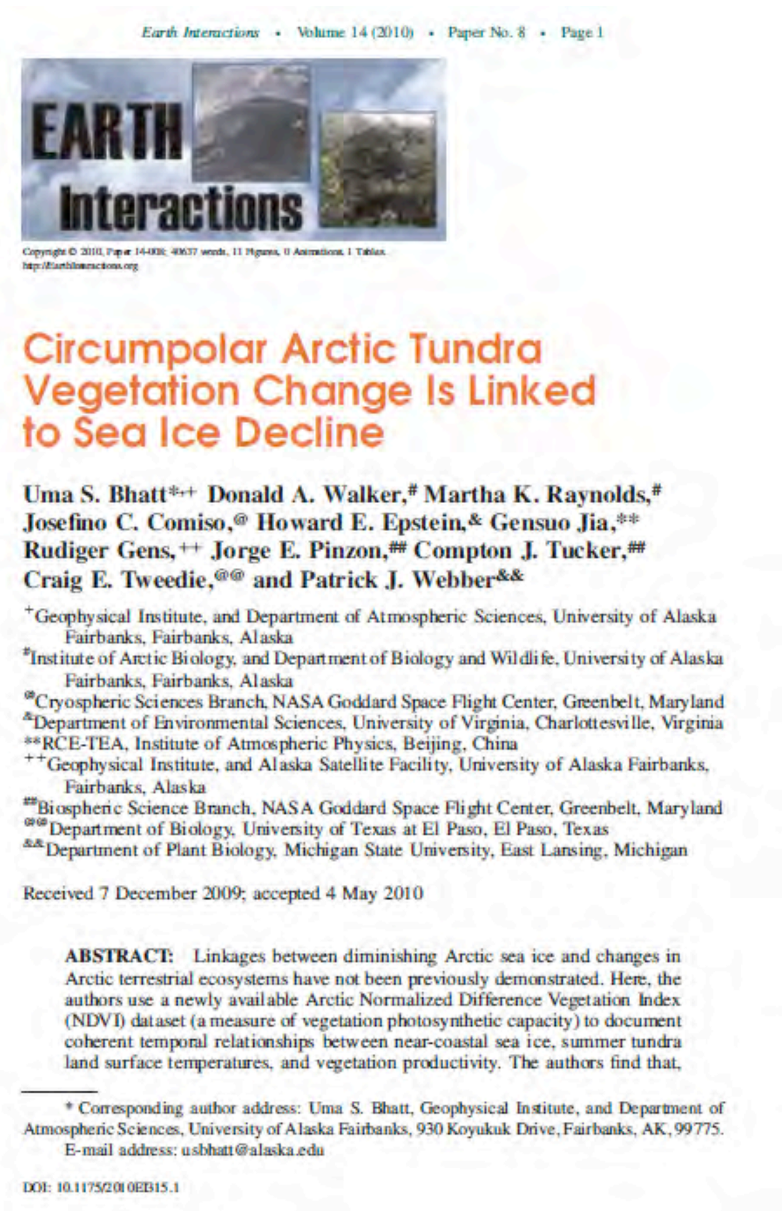
Temporal trends of MaxNDVI in bioclimate subzones



Temporal phenological trends (TI-NDVI) in bioclimate subzones



Jia et al. 2008. *Journal of Environmental Monitoring*



Earth Interactions • Volume 14 (2010) • Paper No. 8 • Page 1

EARTH Interactions

Circumpolar Arctic Tundra Vegetation Change Is Linked to Sea Ice Decline

Uma S. Bhatt*,+ Donald A. Walker,# Martha K. Raynolds,# Josefino C. Comiso,@ Howard E. Epstein,& Gensuo Jia, Rudiger Gens,++ Jorge E. Pinzon,## Compton J. Tucker,## Craig E. Tweedie,@@ and Patrick J. Webber&&**

[+] Geophysical Institute, and Department of Atmospheric Sciences, University of Alaska Fairbanks, Fairbanks, Alaska
[#] Institute of Arctic Biology, and Department of Biology and Wildlife, University of Alaska Fairbanks, Fairbanks, Alaska
[@] Cryospheric Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland
[&] Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia
[**] RCE-TEA, Institute of Atmospheric Physics, Beijing, China
[++] Geophysical Institute, and Alaska Satellite Facility, University of Alaska Fairbanks, Fairbanks, Alaska
[##] Biospheric Science Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland
[@@] Department of Biology, University of Texas at El Paso, El Paso, Texas
[&&] Department of Plant Biology, Michigan State University, East Lansing, Michigan

Received 7 December 2009; accepted 4 May 2010

ABSTRACT: Linkages between diminishing Arctic sea ice and changes in Arctic terrestrial ecosystems have not been previously demonstrated. Here, the authors use a newly available Arctic Normalized Difference Vegetation Index (NDVI) dataset (a measure of vegetation photosynthetic capacity) to document coherent temporal relationships between near-coastal sea ice, summer tundra land surface temperatures, and vegetation productivity. The authors find that,

* Corresponding author address: Uma S. Bhatt, Geophysical Institute, and Department of Atmospheric Sciences, University of Alaska Fairbanks, 930 Koyukuk Drive, Fairbanks, AK, 99775.
E-mail address: usbhatt@alaska.edu

DOI: 10.1175/2010EI315.1

Major points:

- Arctic vegetation has become ‘greener’ & is linked to ice changes.
- This greening has varied in strength in different parts of the the Arctic.
- Causes are complex!

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

A major goal of the Greening of the Arctic IPY project is to link spatial and temporal trends of NDVI observed on AVHRR satellite images to ground observations along two Arctic transects.

- **Climate**
- **Vegetation**
- **Soils**
- **Permafrost**
- **Spectral properties**

NDVI and LAI

Plant species cover

Active layer depth

Site characterizatiion

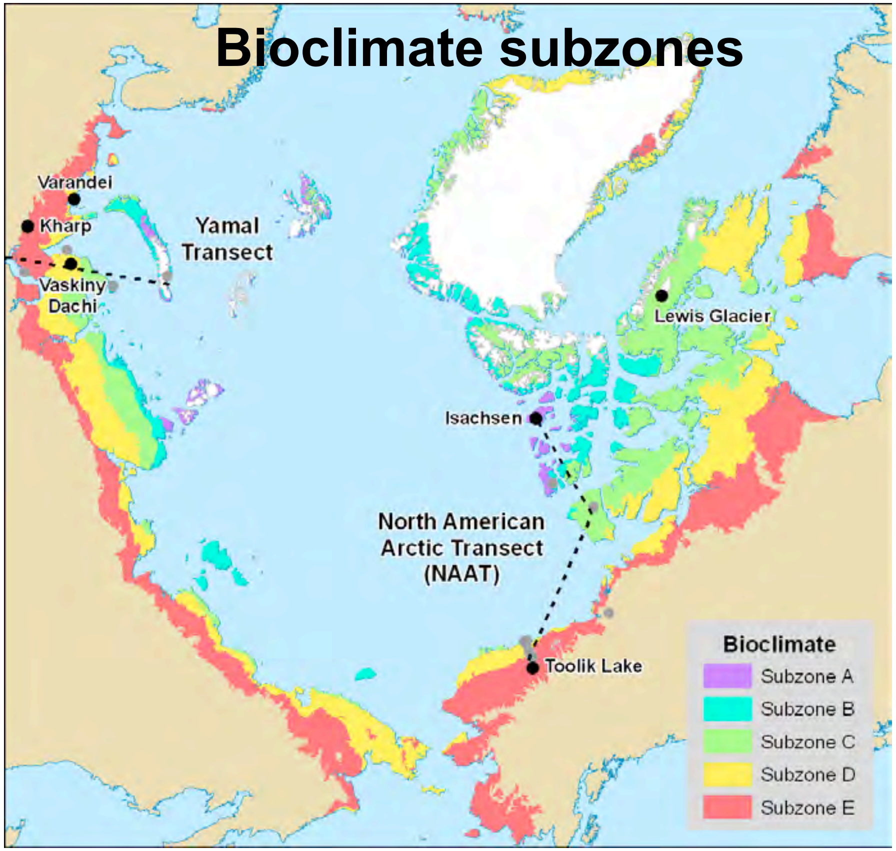
Biomass

Soil characterization

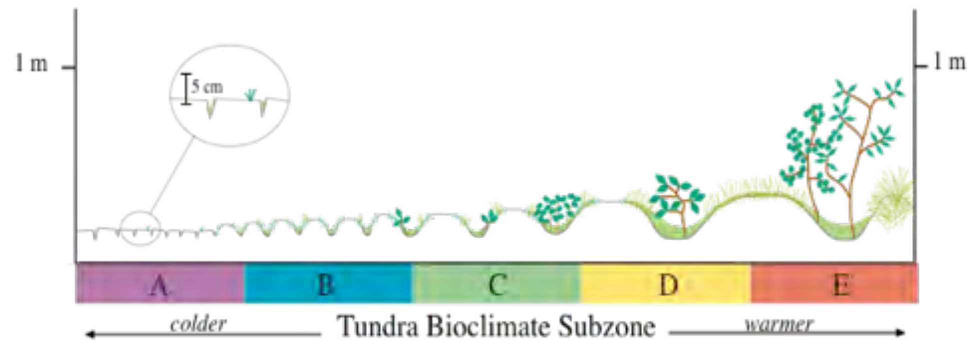
N-factor

Permafrost boreholes

Two transects through all 5 Arctic bioclimate subzones



Shrub and hummock size along the bioclimate gradient



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

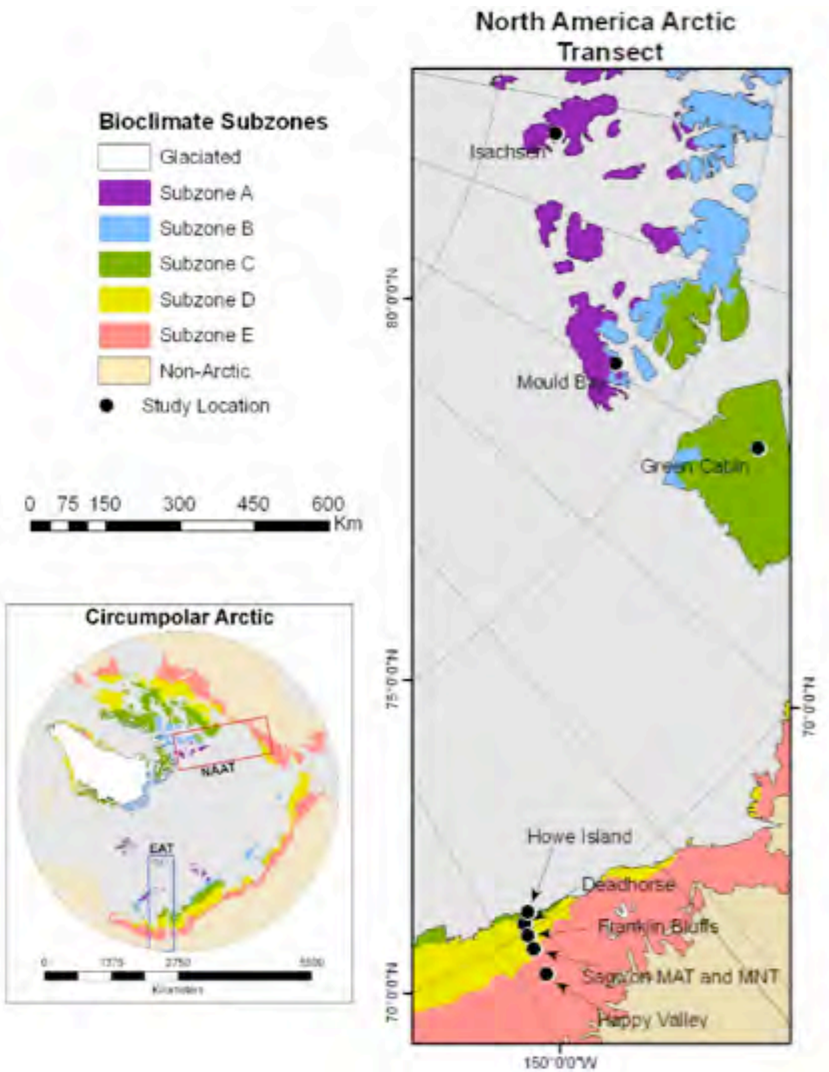
Comparison of mainly a continental transect (NAAT) and a more maritime transect (EAT)

Continental Subzone A, Isachsen, NAAT

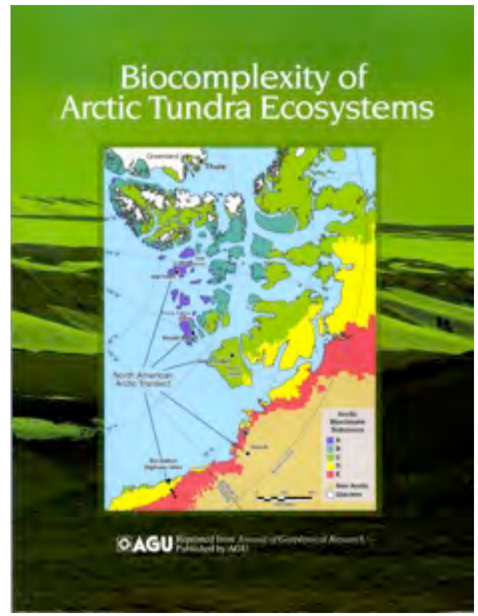
Oceanic Subzone A, Krenkel, Franz Josef Land, EAT

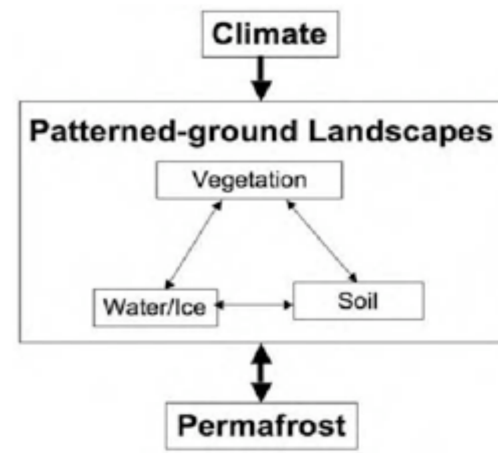
Photos D.A. Walker

The North America Arctic Transect



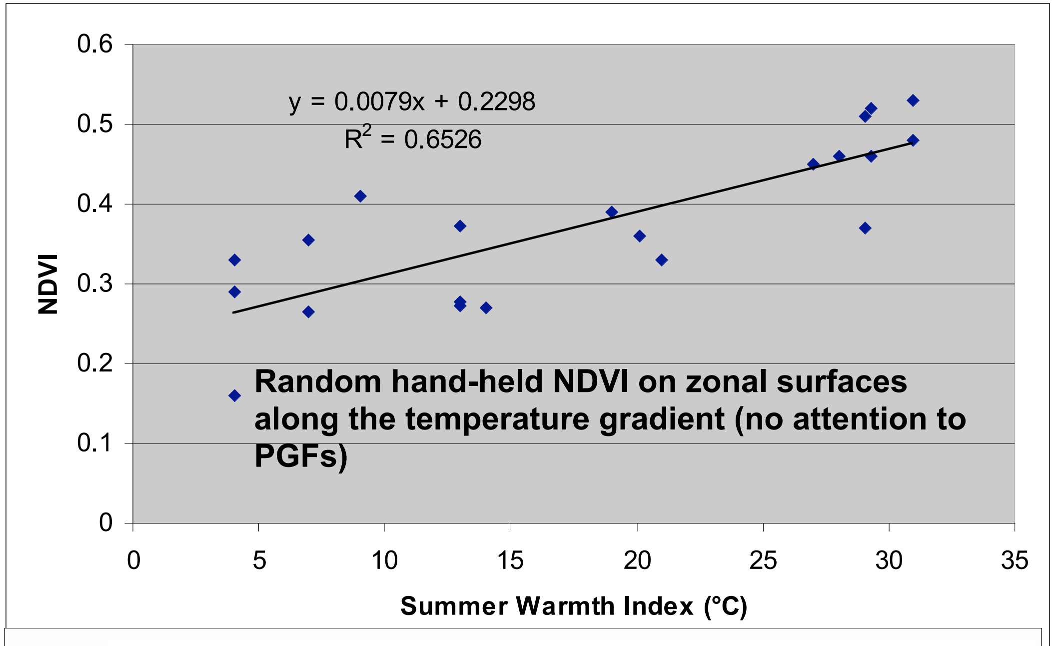
Biocomplexity of Arctic Patterned Ground Ecosystems Project (NSF). 2002-2006



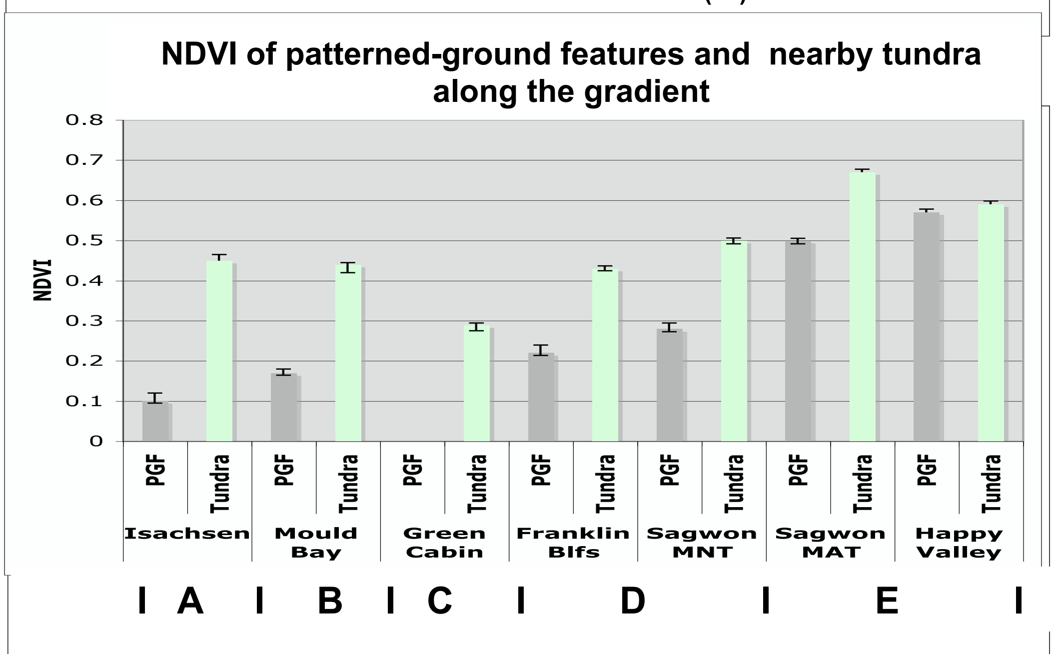


Walker, D. A. et al. 2008. Arctic patterned-ground ecosystems: a synthesis of field studies and models along a North American Arctic Transect. *Journal of Geophysical Research - Biogeosciences* 113:G03S01,

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

The Eurasia Arctic Transect: Vegetation Remote Sensing Analysis and Mapping

Funded by NASA as part of the Land-cover Land-Use Change (LCLUC) Program

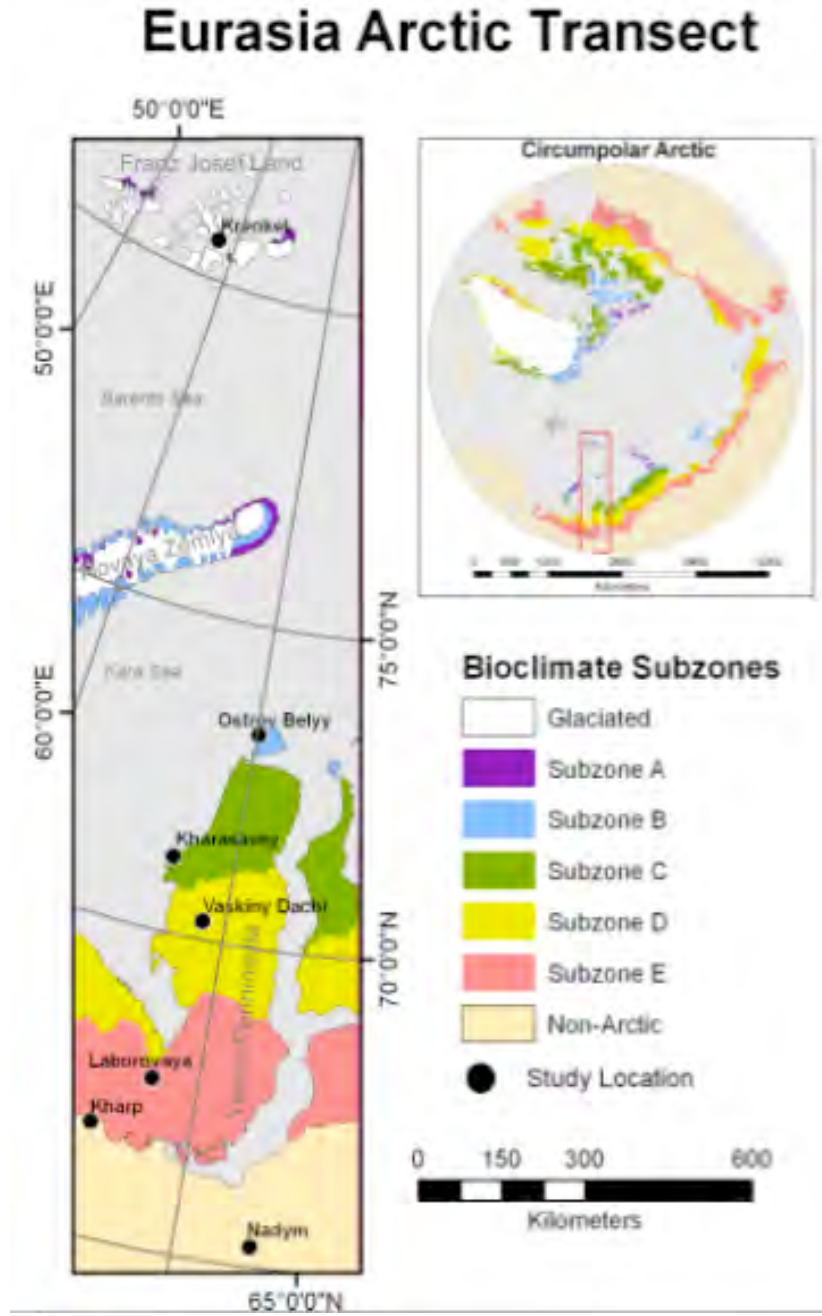
Yamal Peninsula, Russia. Photo: D.A. Walker

The Eurasia Arctic Transect

- About 1800 km
- 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

- Five expeditions (2007-11).



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.

Zonal vegetation along both transects

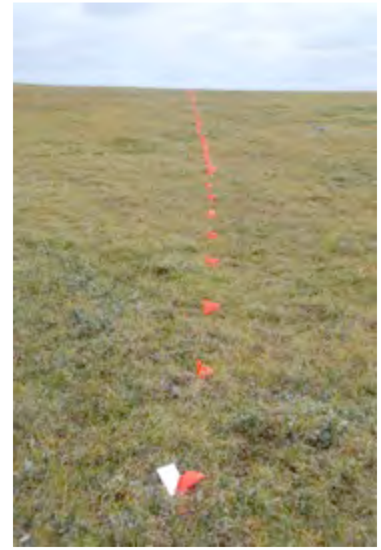
Eurasia Transect

A - Hayes Island

B - Ostrov Belyy

C – Kharasavey

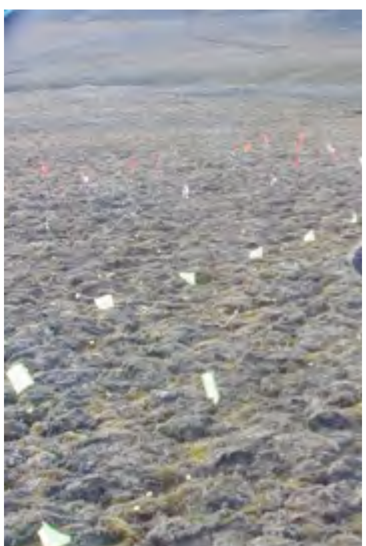
D - Vaskiny Dachi



E - Laborovaya

North America transect

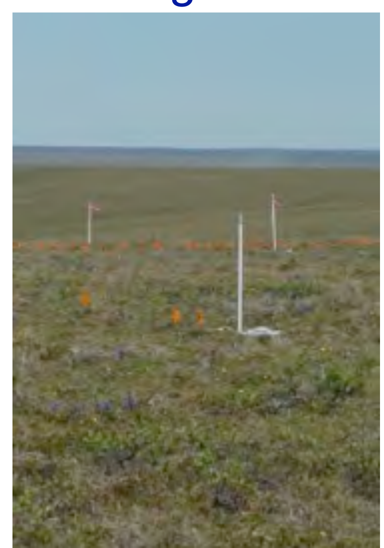
A - Isachsen



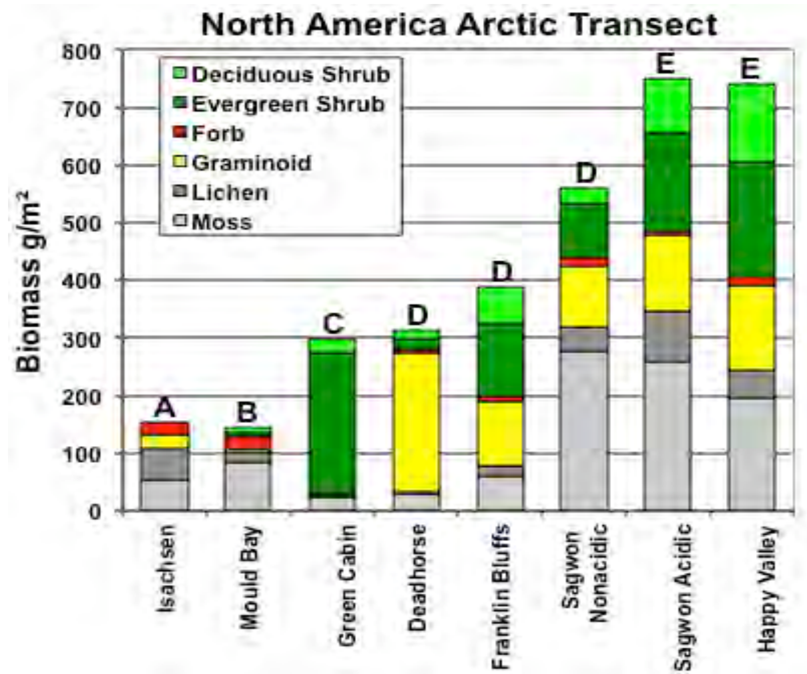
B- Mould Bay

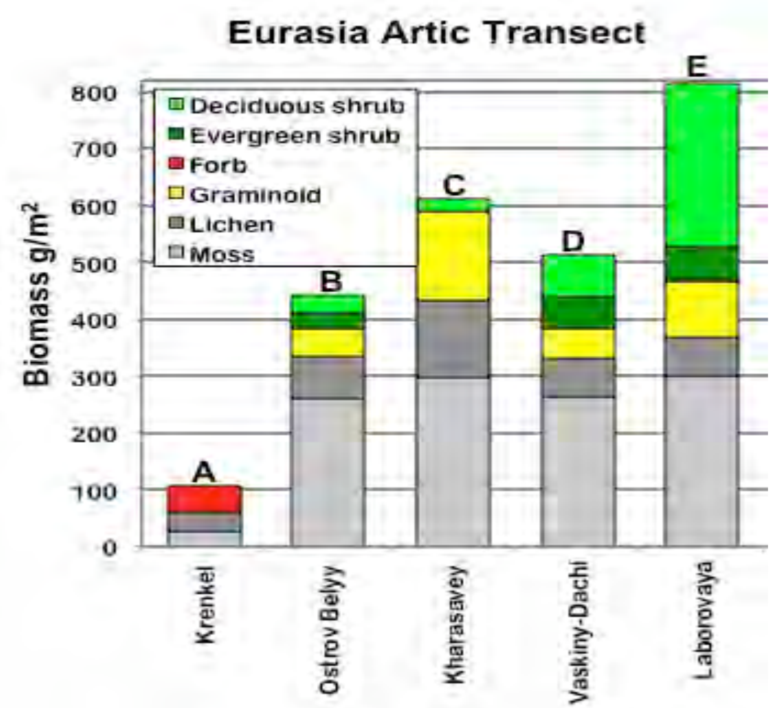
C - Green Cabin

D - Sagwon MNT



E - Happy Valley



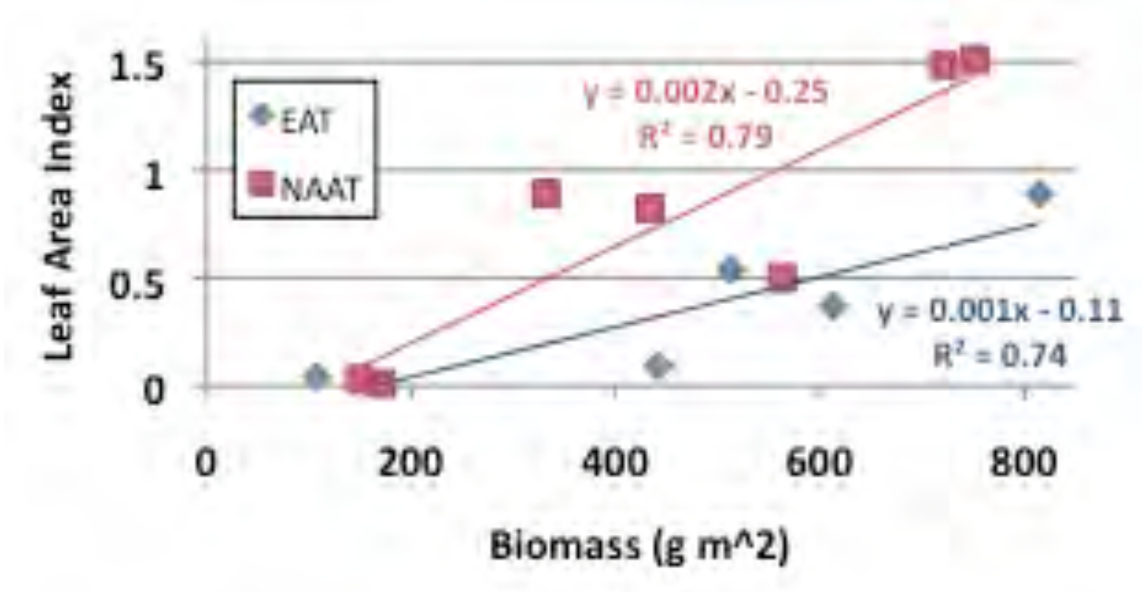


Biomass differences between NAAT and EAT

- **More evergreen shrubs along the NAAT, due mostly to substrate difference (abundant *Dryas* on nonacidic soils of NAAT).**

- **More mosses and biomass in subzones B, C, D of the EAT (moister climate, older landscapes of EAT in subzones B and C).**

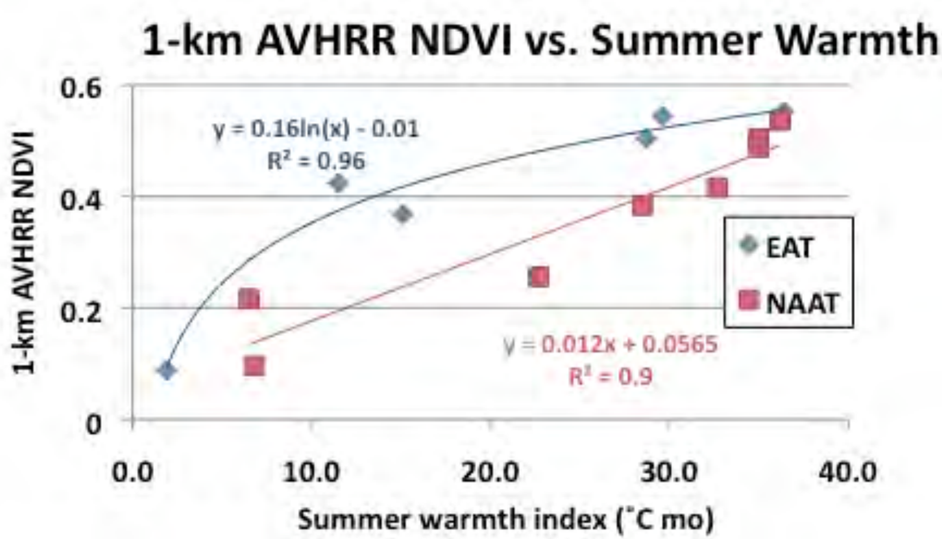
Comparison of EAT and NAAT Leaf Area Index vs. Biomass

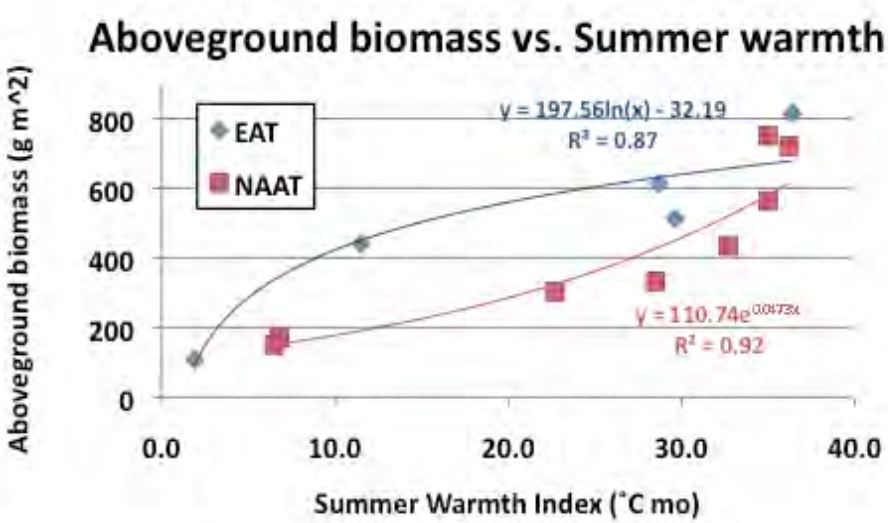


- **An equivalent amount of biomass has consistently much higher LAI values along the NAAT than along the EAT and the difference increases at higher biomass values.**

- **Reflects the different structure of the vegetation along the two transects. Higher proportion of the total biomass is woody along the NAAT (more wood, taller plants).**

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



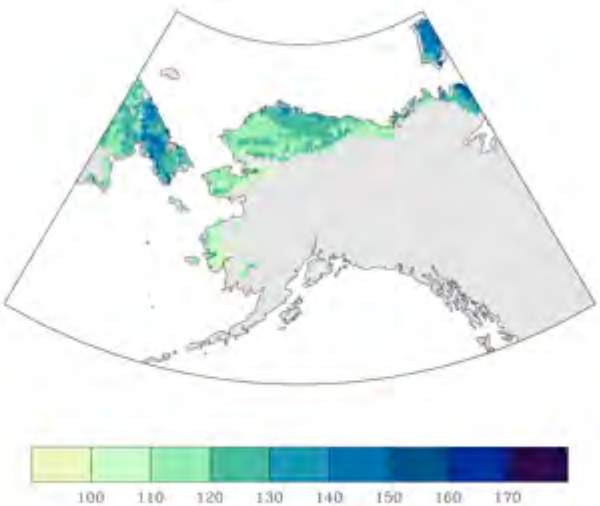


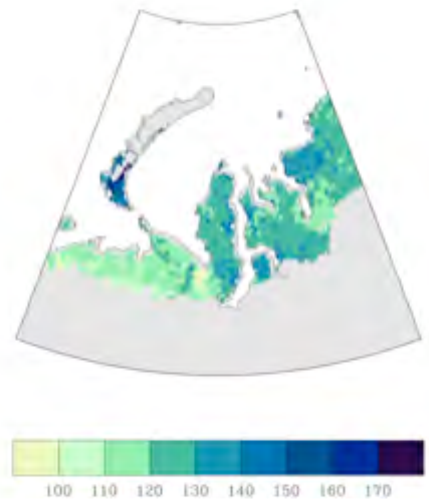
- Biomass values are landscape-level averages for zonal landscapes.
- EAT is greener and has more biomass at equivalent summer warmth. (Partially a function of more maritime conditions along the EAT?)

Also quite different phenological patterns along the transects

Alaska | **Yamal**

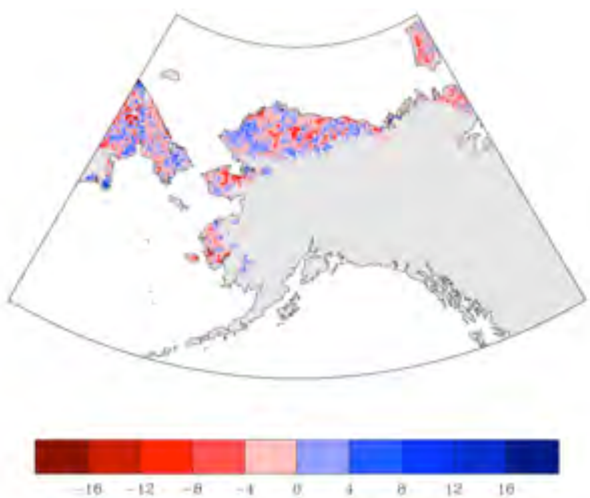
Average first day of greenup

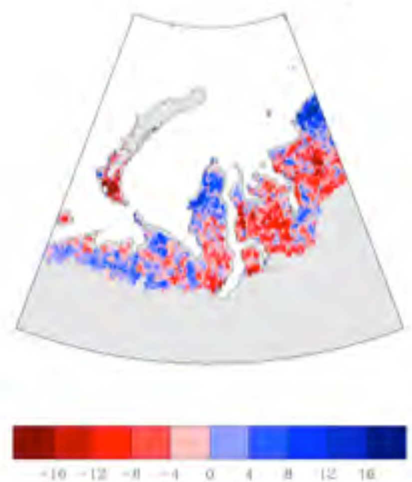




Eurasia generally greens up about 10 days later and senesces later.

Shifts in initiation of greening



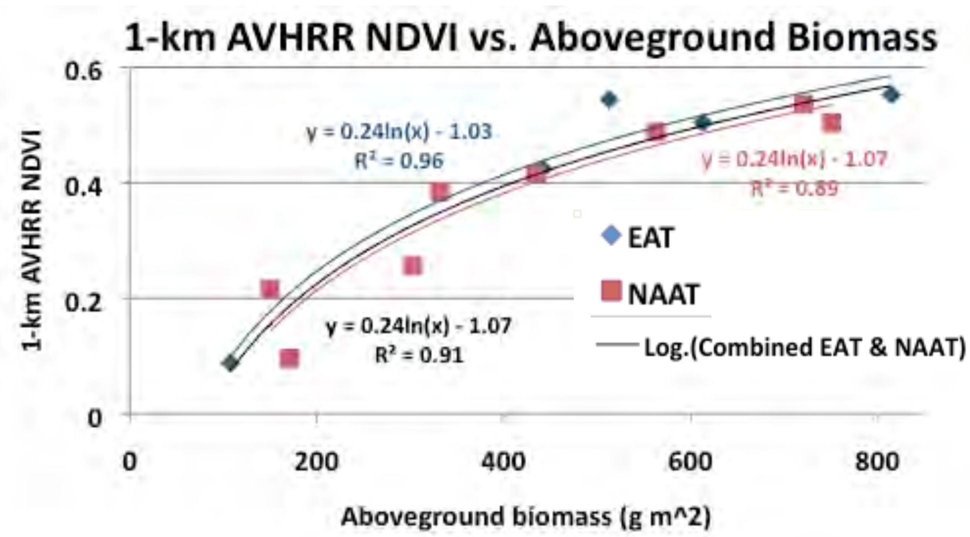


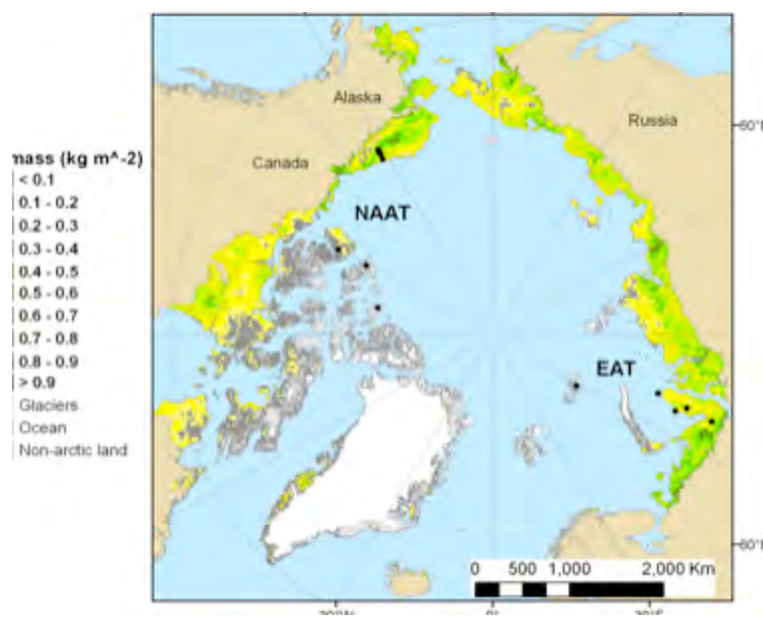
Northern Yamal much later (and also snowier). Southern Yamal is earlier.

At the other end of summer, Barrow still has not had a frost this year!

Bieniek & Bhatt et al. 2010

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.

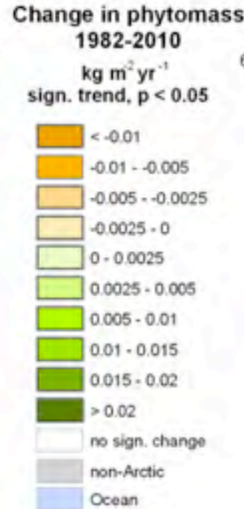


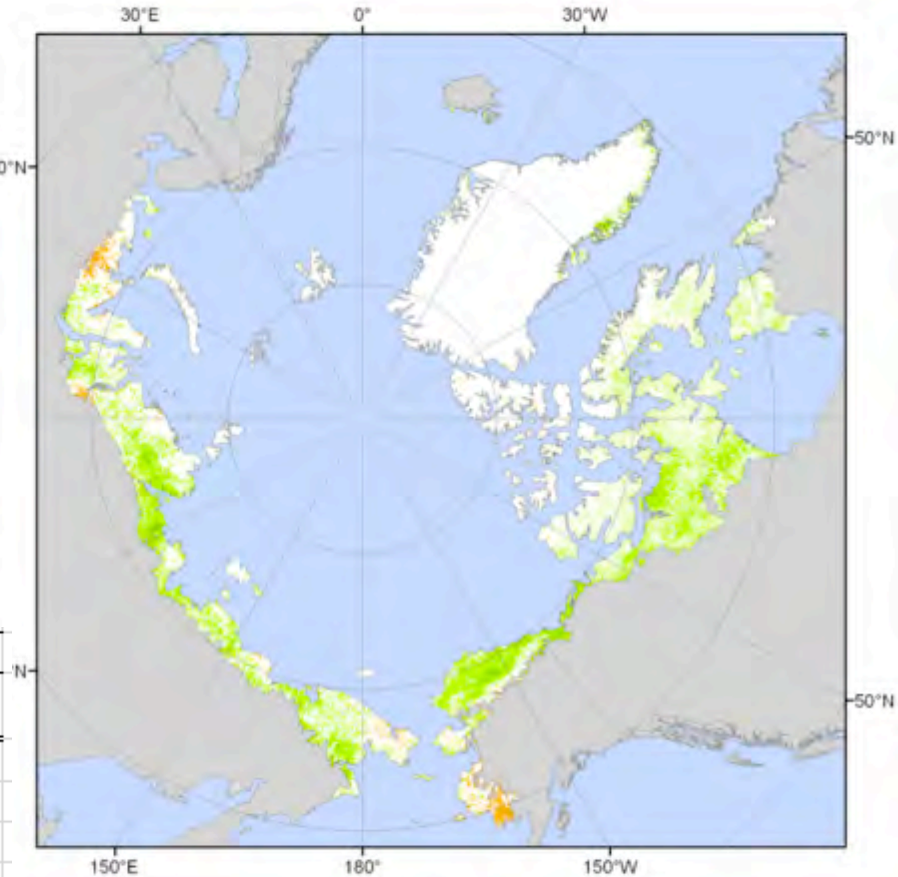


Raynolds et al. 2012, *Remote Sensing Letters*

Change in zonal Arctic phytomass

Total Arctic Biomass (Pg)		
1982	2010	% change
2.02	2.41	19.8





Bioclimate Subzone	Area (km2)	Mean biomass (g/m2)				
		1982	SD	2010	SD	Change
A	200964	98.33	39.16	100.34	53.38	2.01
B	530780	142.67	100.93	151.79	118.37	9.11
C	1380760	199.61	116.59	241.24	148.69	41.63
D	1708430	319.79	145.63	401.51	195.20	81.72
E	2027020	467.52	142.54	563.60	153.12	96.09

Assuming biomass is 50% carbon:

Arctic sink is about 0.014 Pg C y^{-1}

Estimated sink of northern permafrost areas 0.3-0.6 Pg y^{-1} (McGuire et al. 2009)
Estimated northern hemisphere carbon sink (2002-2004) = 1.7 Pg (Ciais et al. 2010)
Estimated total land sink for carbon = 2.3 Pg C y^{-1} (Le Quéré et al. 2009)

Epstein et al. submitted. *Environmental Research Letters.*

Plot-based evidence for change in biomass?

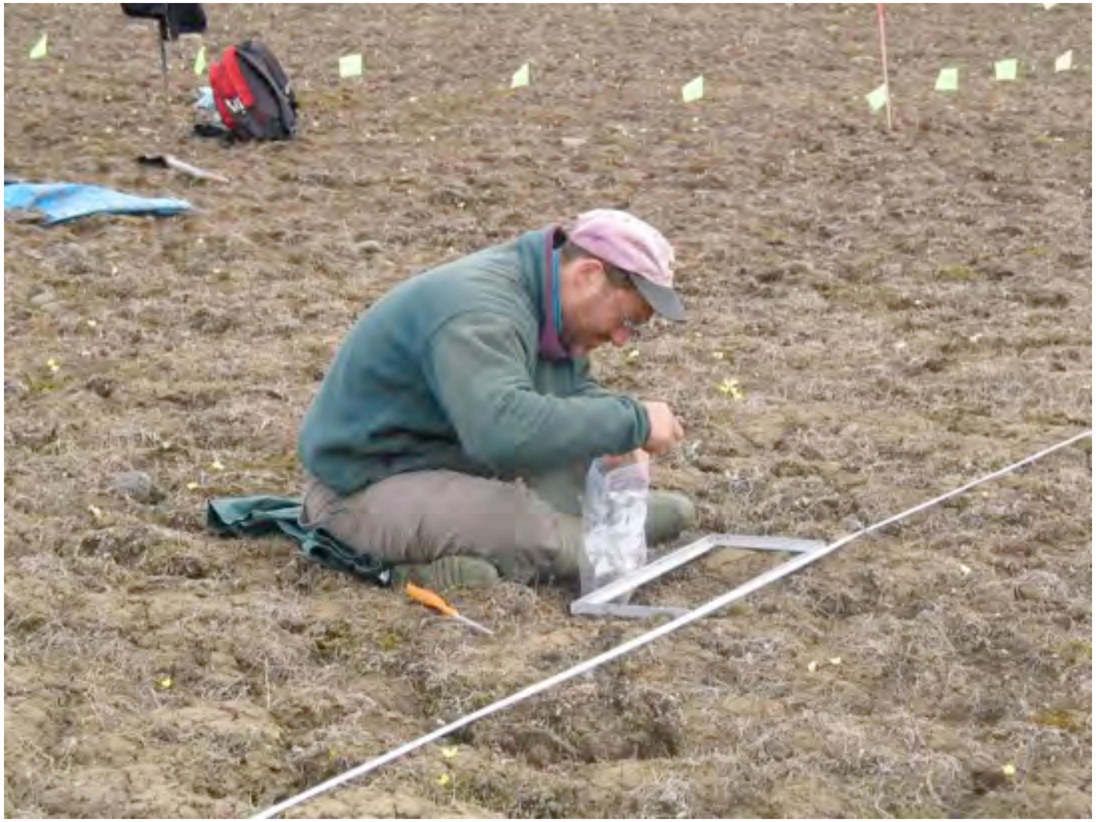


Photo – Fred Daniëls

New information on long-term changes:

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

- Not a lot of direct evidence of temporal biomass change to support space-based observations.
- Photo record of shrub cover change in northern AK and Mackenzie River delta (Sturm et al. 2001, Tape et al. 2006; Lantz et al. 2009, 2010).
- Mostly experimental evidence (Green-house experiments, Chapin et al., ITEX experiments).
- A few long-term biomass studies (e.g., Hudson & Henry 2009; Shaver et al. 2002).
- Needed: Long-term biomass studies at many sites using standardized protocols.

Take Home Points

- **The real Arctic is a result of its proximity to the Arctic Ocean, and it will become increasingly maritime as the open water becomes more abundant.**
- **Remote sensing and reanalysis products indicate that the trend of more open water is focused in three primary areas.**
- **Associated with the more open waters are a trend of increased winter humidity, more snow on nearby land areas, generally warmer temperatures (mainly in North America) and increased tundra productivity.**
- **Some areas with increased snow appear to be delaying green-up and reducing the annual sum of thawing degree days.**
- **Ground-based information from two Arctic transects help to interpret the remotely-sensed information in maritime versus more continental areas of the Arctic.**