Multi-scale monitoring of Arctic vegetation

Skip Walker
University of Alaska Fairbanks

I. Overview

- **Multi-scale plot-based monitoring**
- **Multi-scale geobotanical mapping: example from Toolik-Arctic Geobotanical Atlas**
- **Multi-scale satellite-based monitoring**
- **Application to Arctic Report Card**

Talk given at Sonnerupgaard, Denmark
CBMP / INTERARCT / IASC meeting, 12 Oct 2011

How to design an effective vegetation monitoring program?

- Multi-scale program
- Satellite observations provide the consistent coverage of the whole Arctic at regular rapid intervals.
- Ground observations, measured less frequently, provide the linkage to document changes in vegetation.

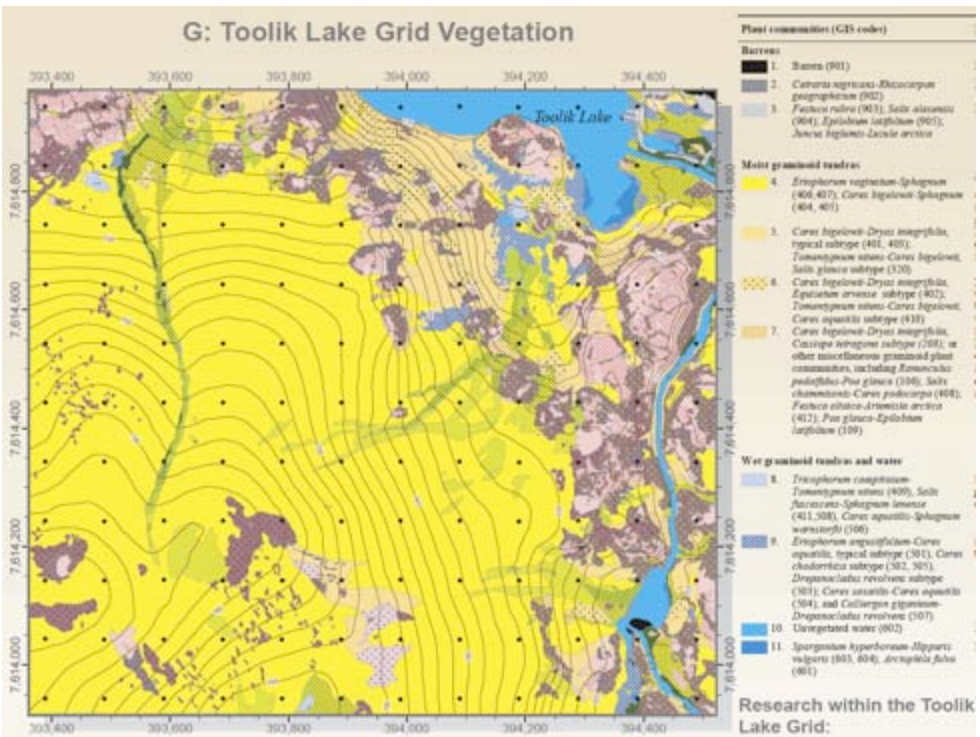
II. Plot-based monitoring of natural vegetation changes

- Keys are:
  - Permanently marked plots
  - Consistent methodology
  - Replication at numerous sites
- A. Species composition and canopy structure monitoring
  - Example from Toolik Lake permanent grids
- B. Biomass, LAI, NDVI monitoring
  - Example from North America and Eurasia Arctic Transects

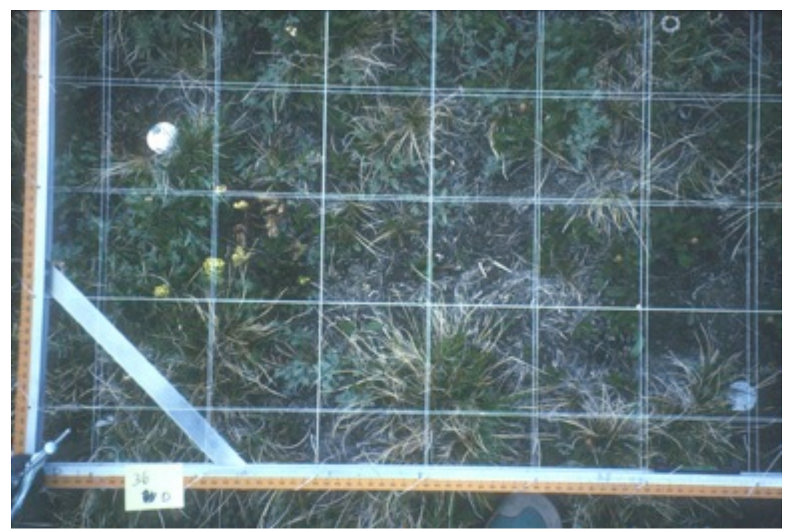
A. Species composition & canopy structure monitoring

Point quadrat example from Toolik Lake

Permanently marked 1 x 1m plots at grid points of 1 x 1km Toolik Lake Grid

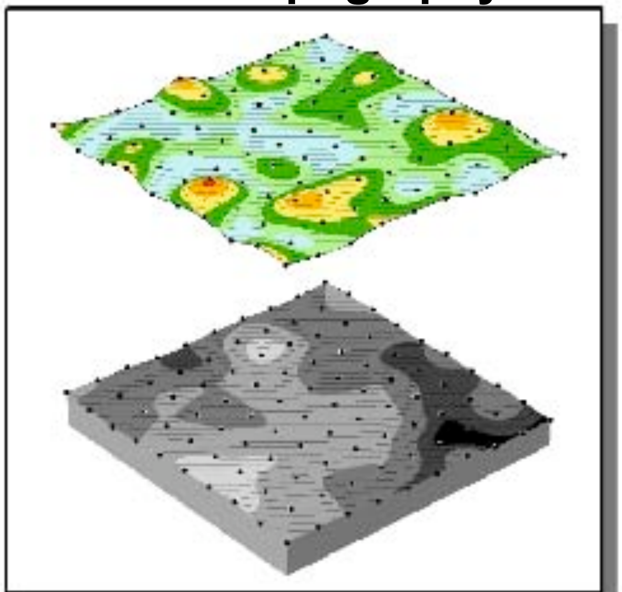


Microtopography, canopy height, and species, top and bottom of canopy at 100 grid ponts within 1m plots

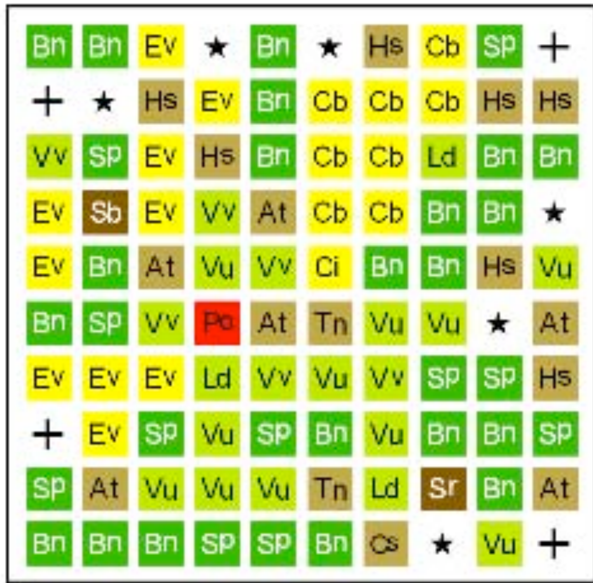


Point quadrat example from Toolik Lake

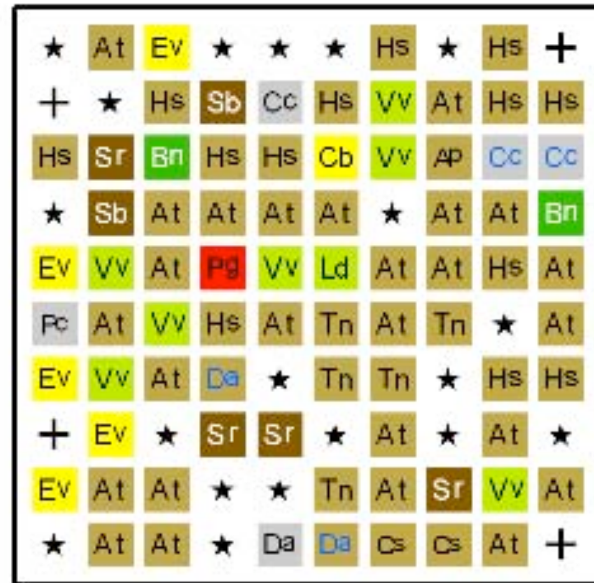
Canopy height & microtopography

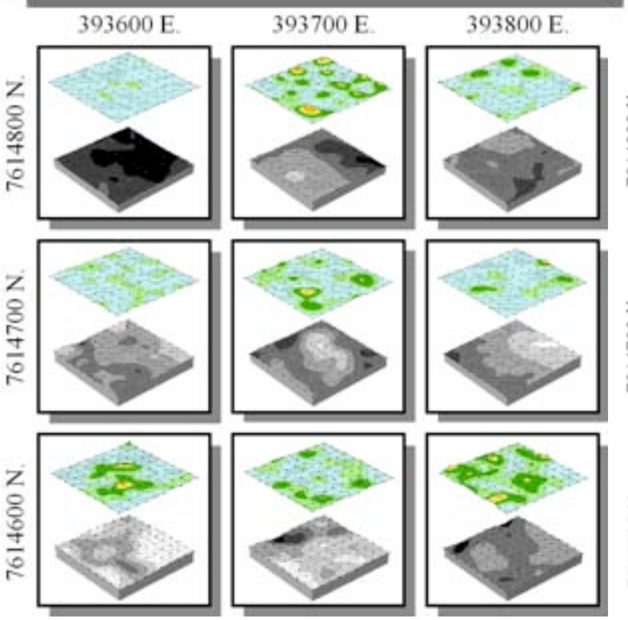


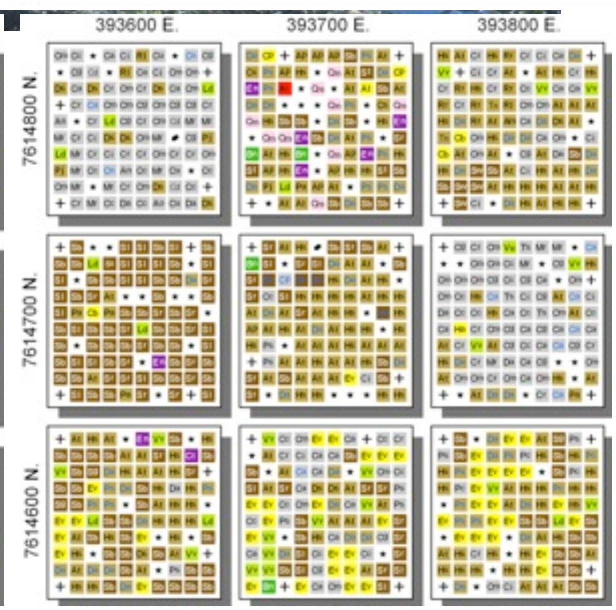
Growth form and species top of canopy



Growth form and species bottom of canopy

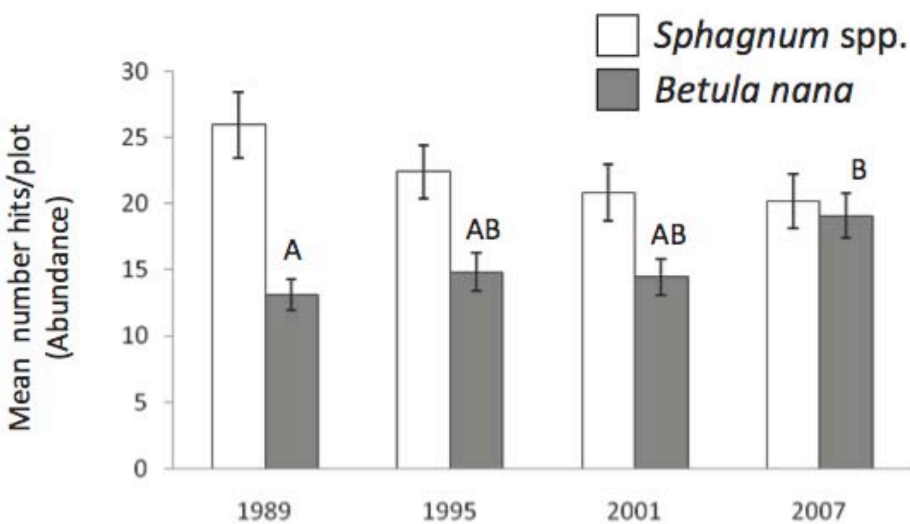






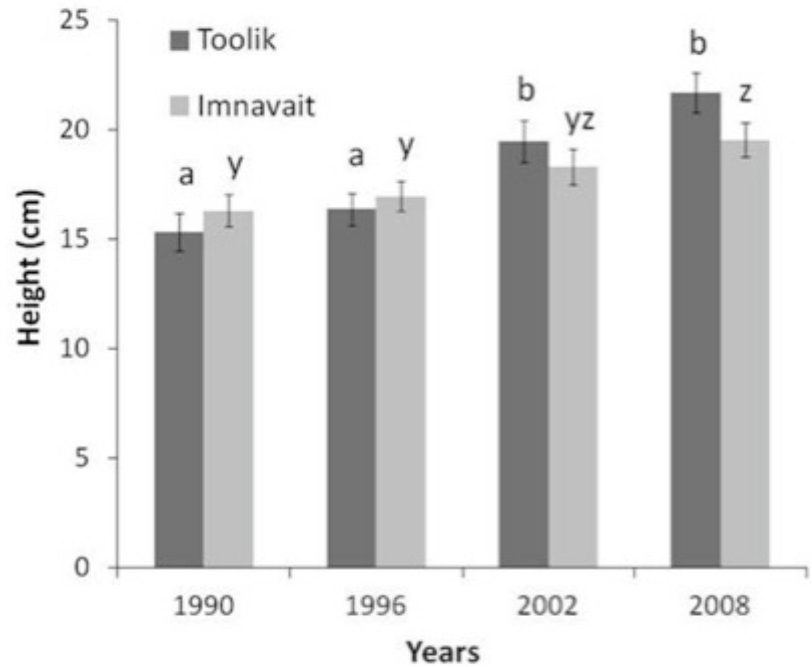
19 years of monitoring every 6-years at Toolik Lake and Imnavait Creek

Changes in species abundance at Imnavait Creek



- **23% decline in relative abundance of *Sphagnum***
- **46% increase in relative abundance of *Betula nana***

Changes in canopy structure

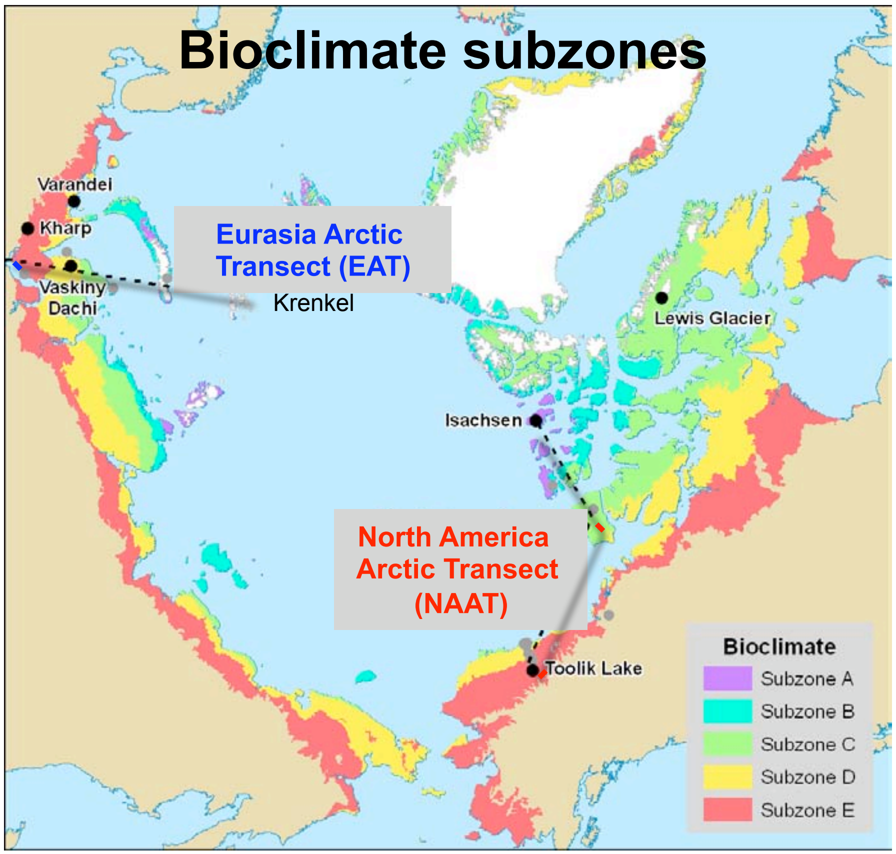


- **48% increase in maximum canopy height at Toolik**
- **18% increase at Imnavait Creek**

Gould and Mercado, in prep.

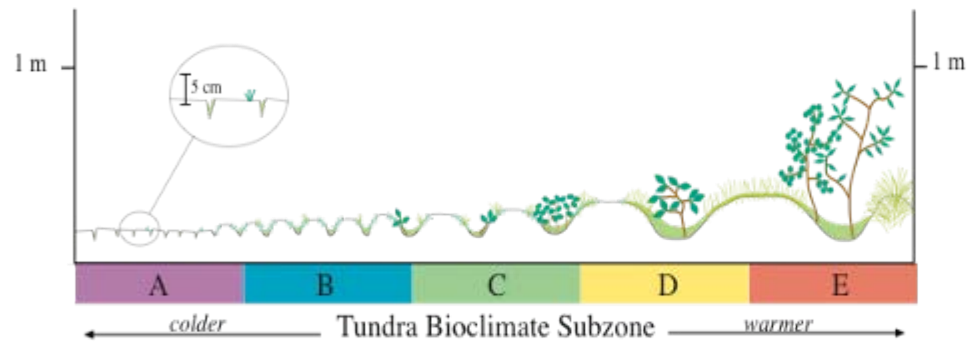
B. Biomass, LAI, NDVI monitoring along climate transects

Two transects through all 5 Arctic bioclimate subzones



CAVM Team 2003

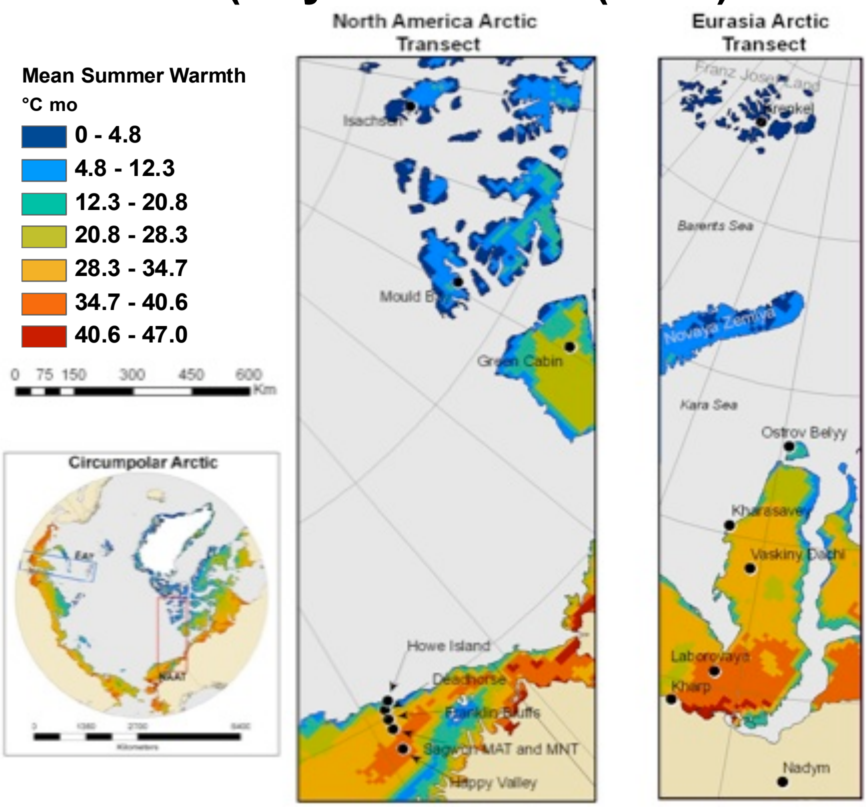
Shrub and hummock size along the bioclimate gradient



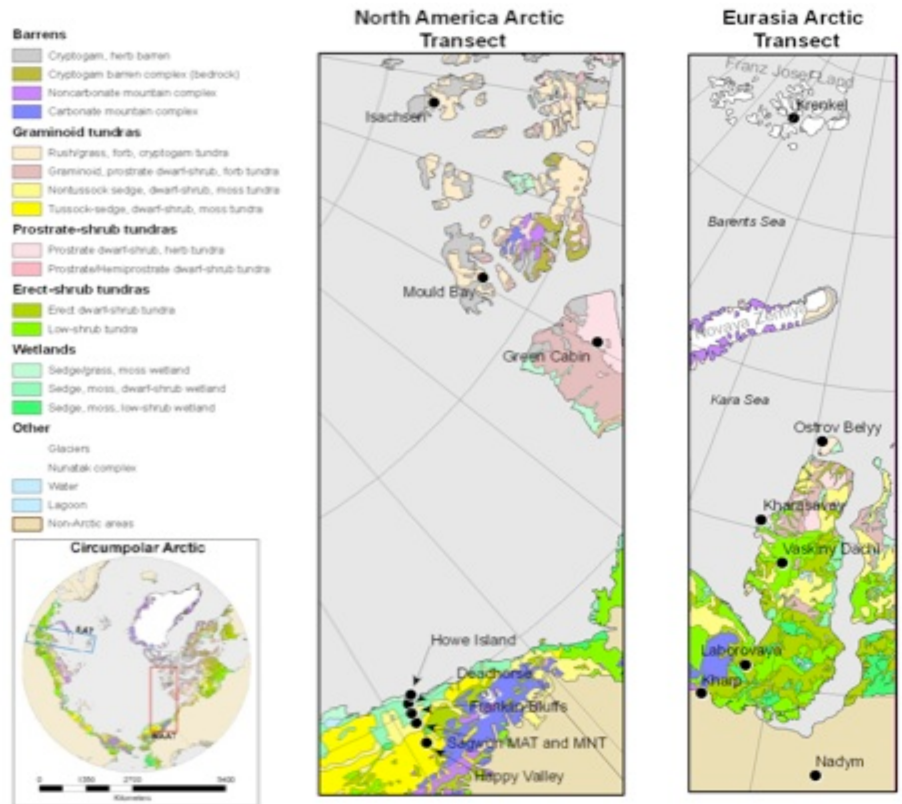
Subzone	MJT	Shrubs
A (Cushion forb)	**1-3 ˚C**	**none**
B (*Dryas*)	**3-5**	**prostrate dwarf (< 5 cm)**
C (*Cassiope*)	**5-7**	**hemi-prostrate dwarf (< 15 cm)**
D (*Betula*)	**7-9**	**erect dwarf (< 40 cm)**
E (*Alnus*)	**9-12**	**low (40-200 cm)**

Spatial variation in summer land temperature and vegetation along the transects

Summer Warmth Index (Raynolds et al. (2006)



Vegetation (CAVM Team 2003)



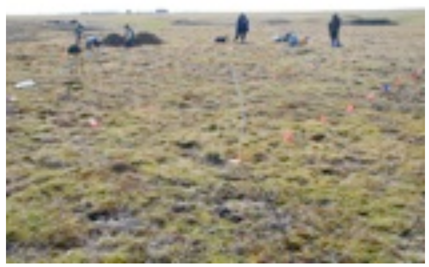
A major goal of the Greening of the Arctic IPY project was to link satellite-derived observations to ground observations along two Arctic transects.

- Climate
- Vegetation
- Soils
- Permafrost
- Spectral properties


NDVI and LAI


Plant species cover


Active layer depth

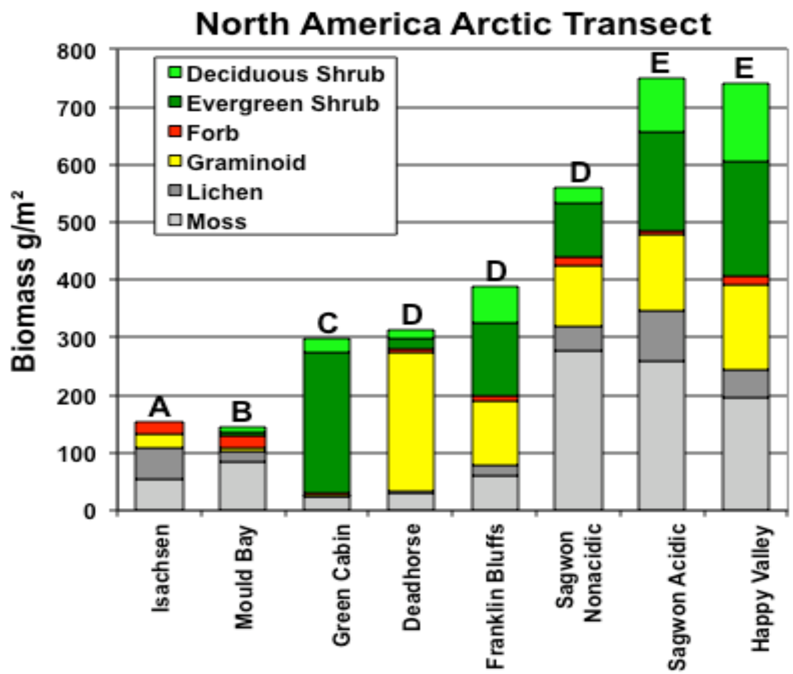

Site characterizatiion

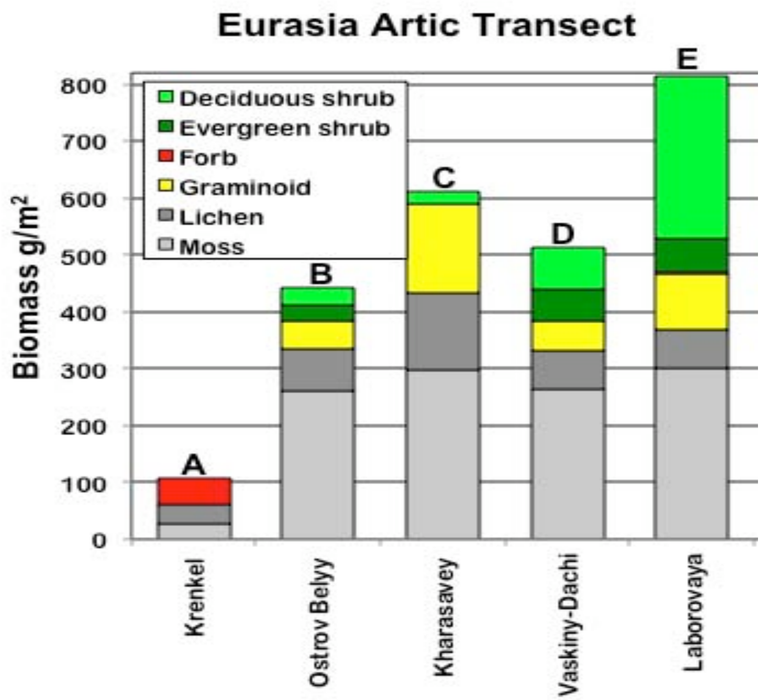

Biomass


Soil characterization


N-factor


Permafrost boreholes

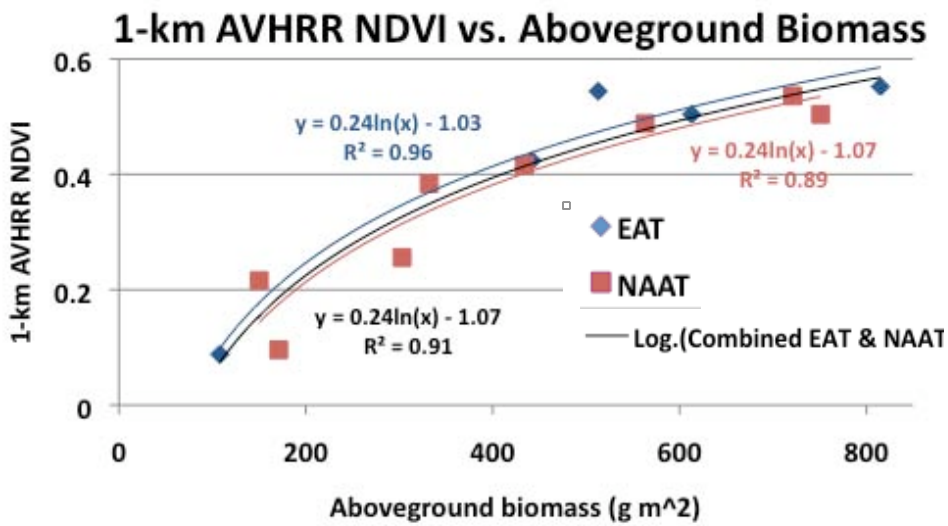




Biomass differences between the NAAT and EAT

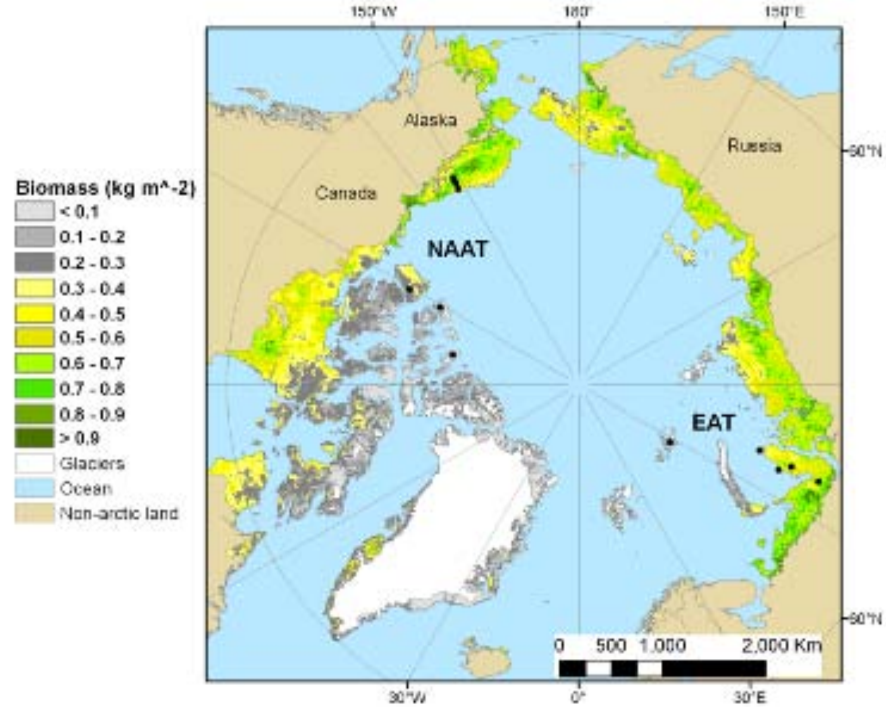
- **More evergreen shrubs along the NAAT, due mostly to substrate difference (abundant *Dryas* on nonacidic soils of NAAT).**
- **More mosses and biomass in subzones B, C, D of the EAT (moister climate, older landscapes of EAT in subzones particularly in B and C).**

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.



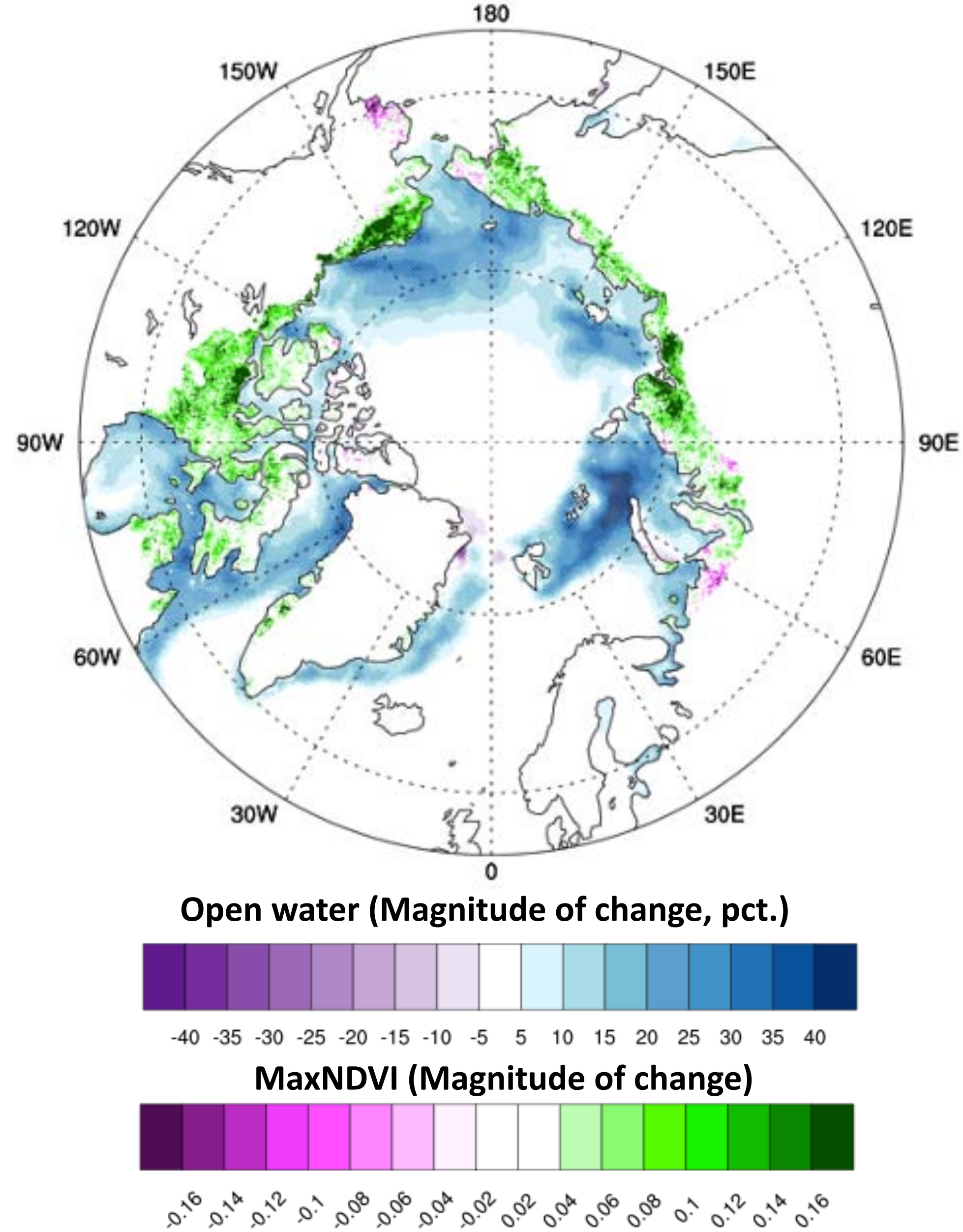
Raynolds et al. 2012, *Remote Sensing Letters*

Biomass of Arctic zonal sites



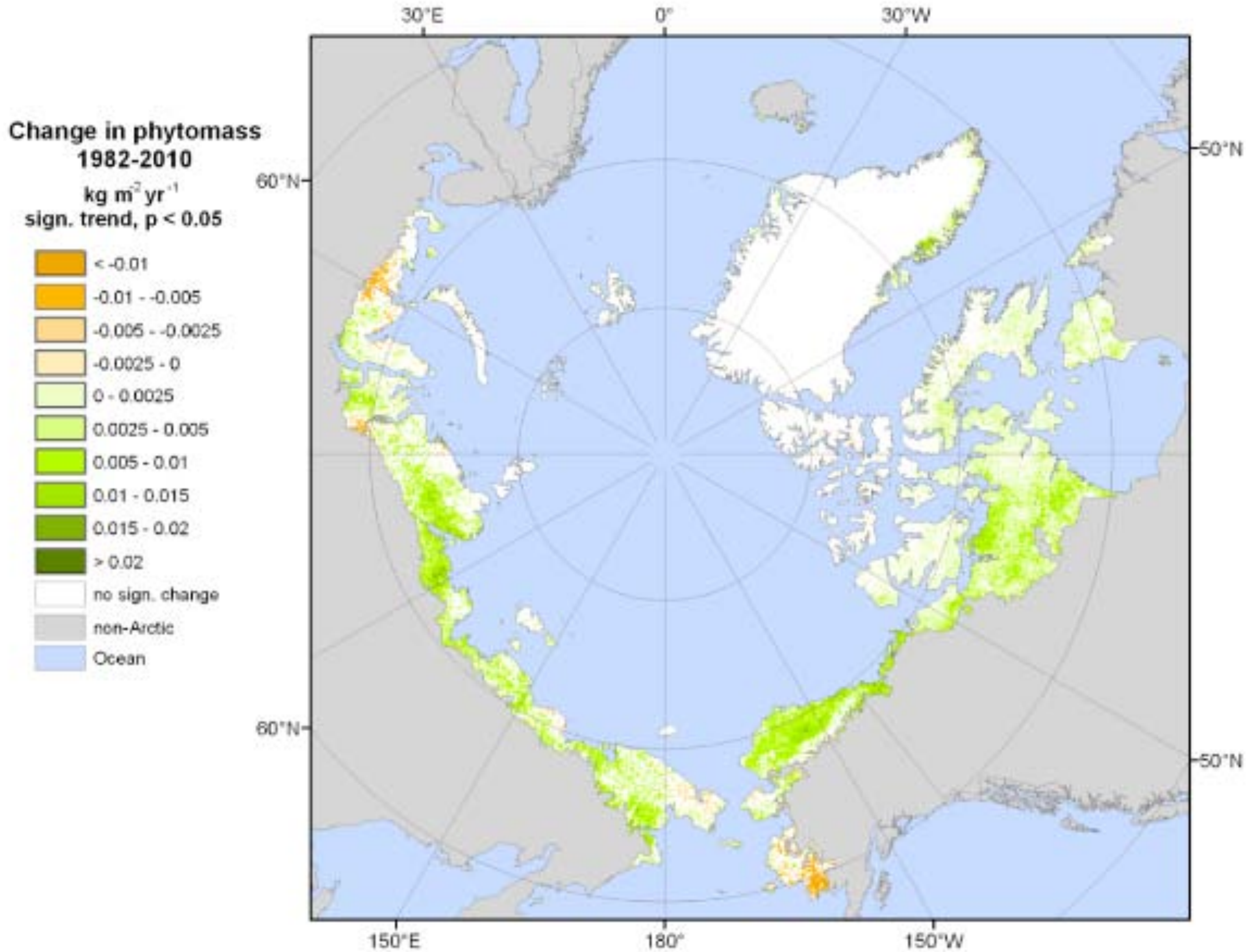
Changes in maximum tundra greenness (MaxNDVI) 1982-2010

Using the time series of NDVI change at each pixel in the global coverage and the NDVI-biomass relationship, it is possible to construct a map of biomass change for the whole Arctic.



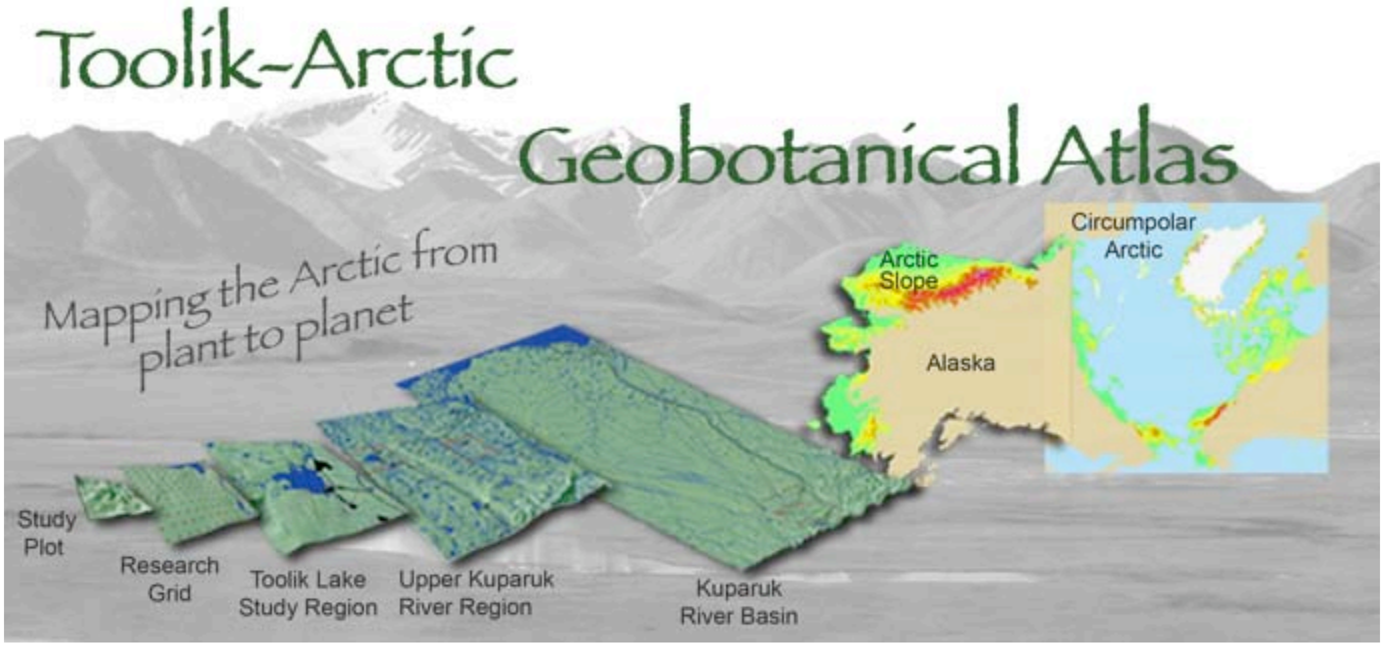
Updated from Bhatt et al. 2010

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



Epstein et al. submitted. *Environmental Research Letters*

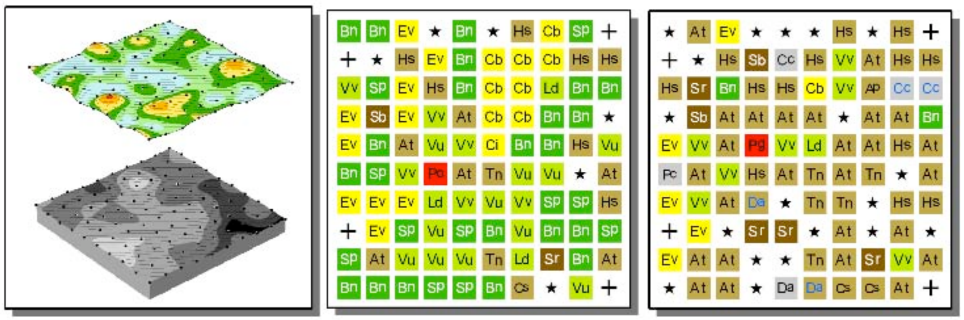
Hierarchy of maps in the Toolik-Arctic Geobotanical Atlas



- Global-level(circumpolar) maps
- Regional-level maps
- Landscape-level maps
- Plot-level maps

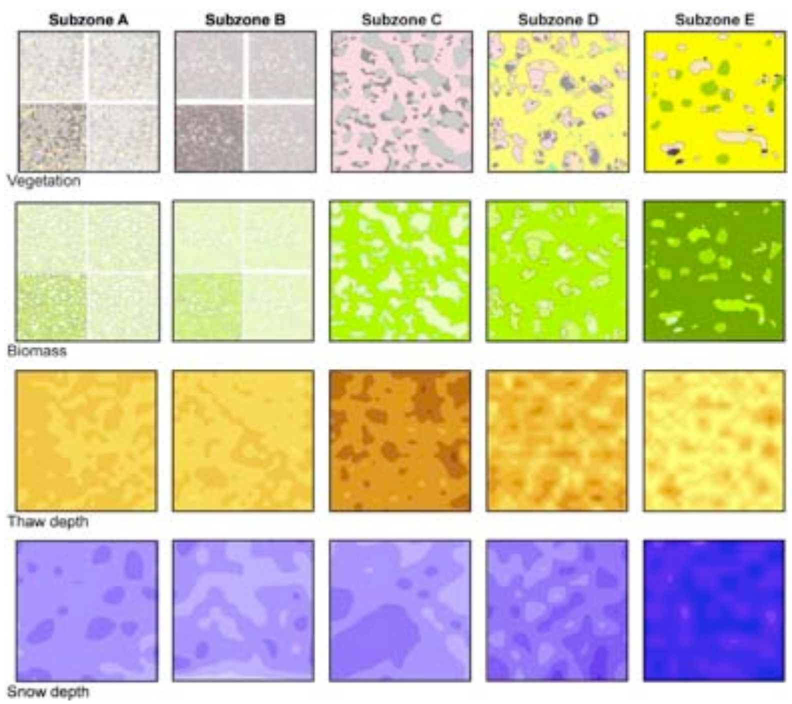
A. Plot maps

1. 1x1m maps at Toolik Lake

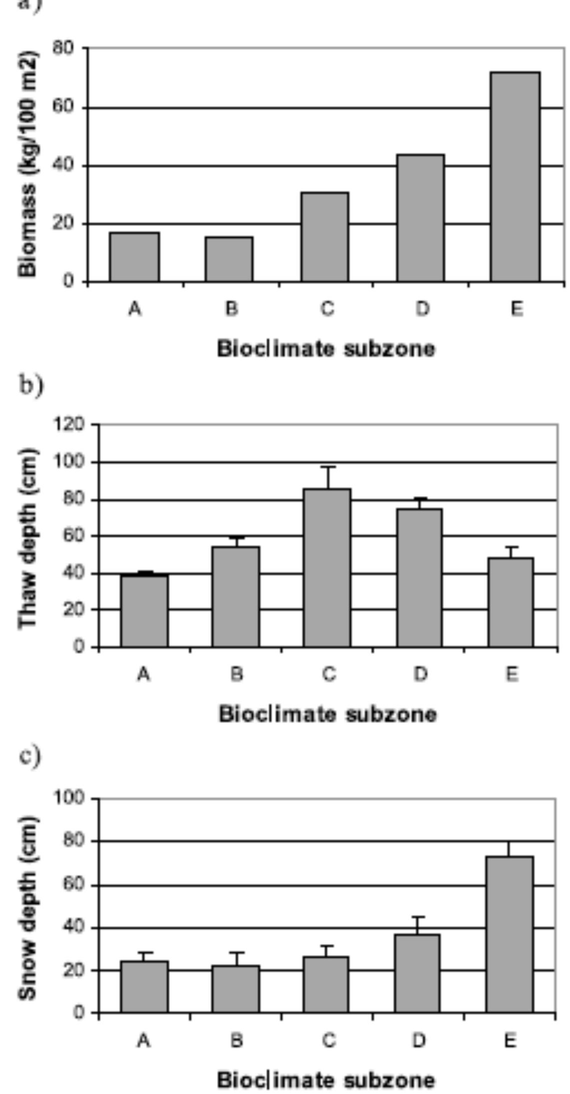


Walker et al. 2010, *Viten*

2a. 10 x 10m maps of patterned ground in each bioclimate subzone along the NAAT



2b. Trends of key variables along the NAAT



Raynolds et al. 2008,
Journal of Geophysical Research

B. Landscape-level maps portraying complexes of plant communities within habitats

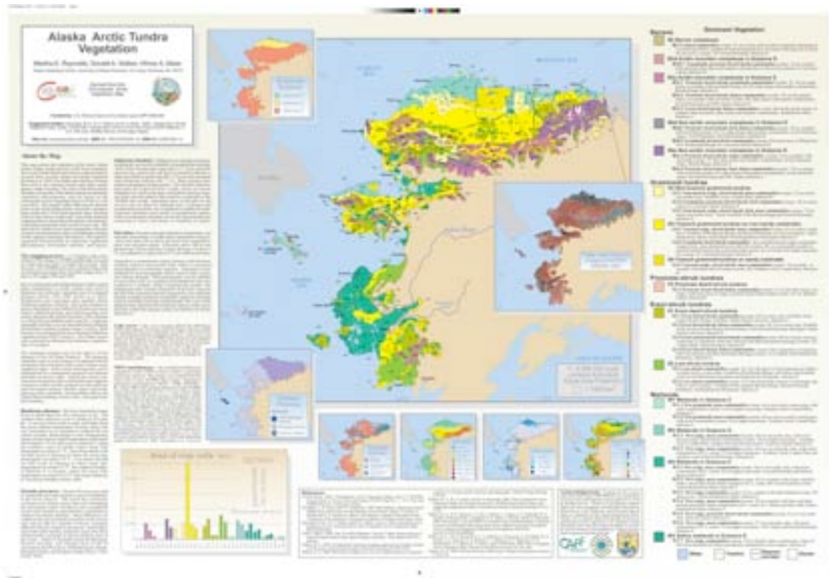
Hierarchy of maps at Toolik Lake at 3 scales

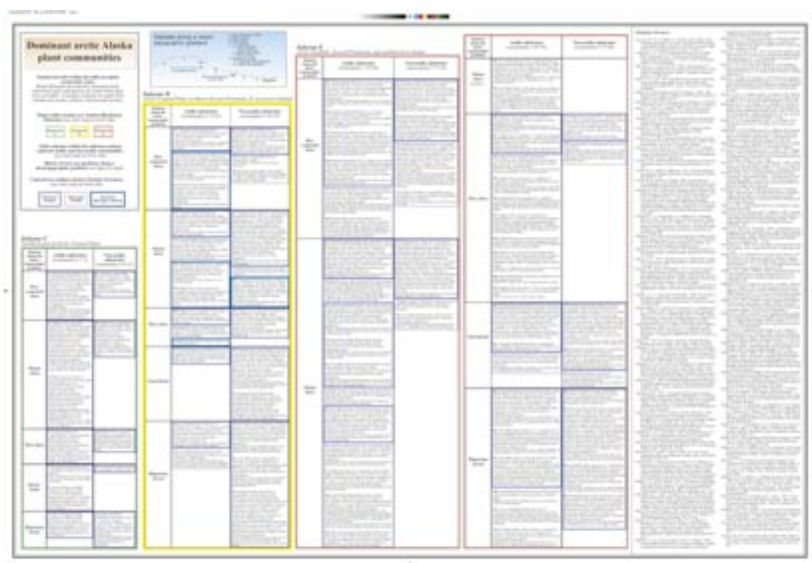
- **1:25,000 scale - Upper Kuparuk river**
  - **1:5000 scale – Toolik Lake area**
    - **1:500 scale – Toolik Grid**

Walker & Maier, 2009, *Biological Papers of the University of Alaska No. 28*

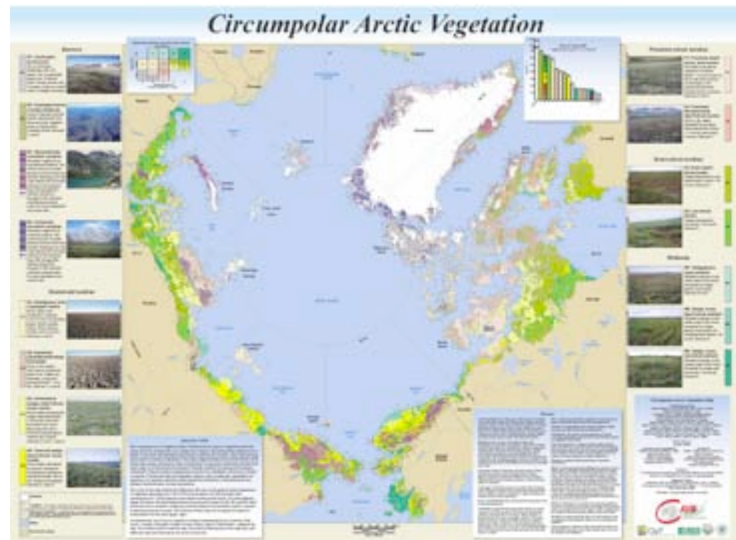
C. Regional-scale and Circumpolar-scale maps

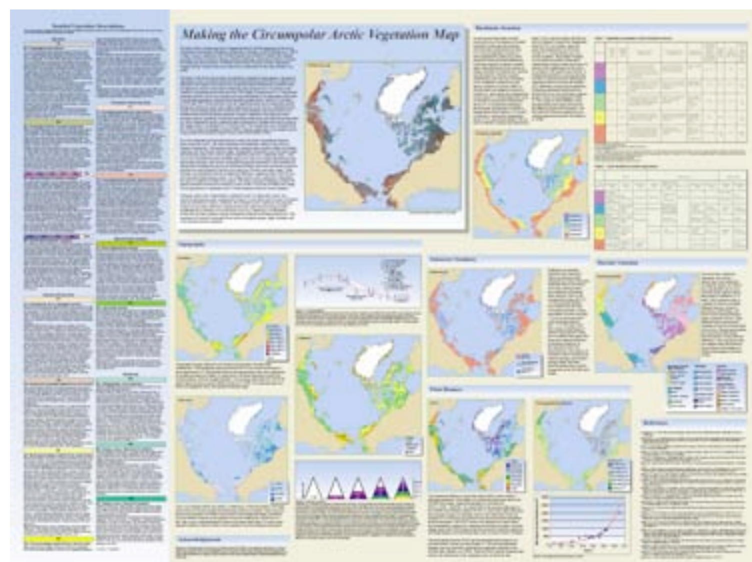
Arctic Alaska





Circumpolar Arctic



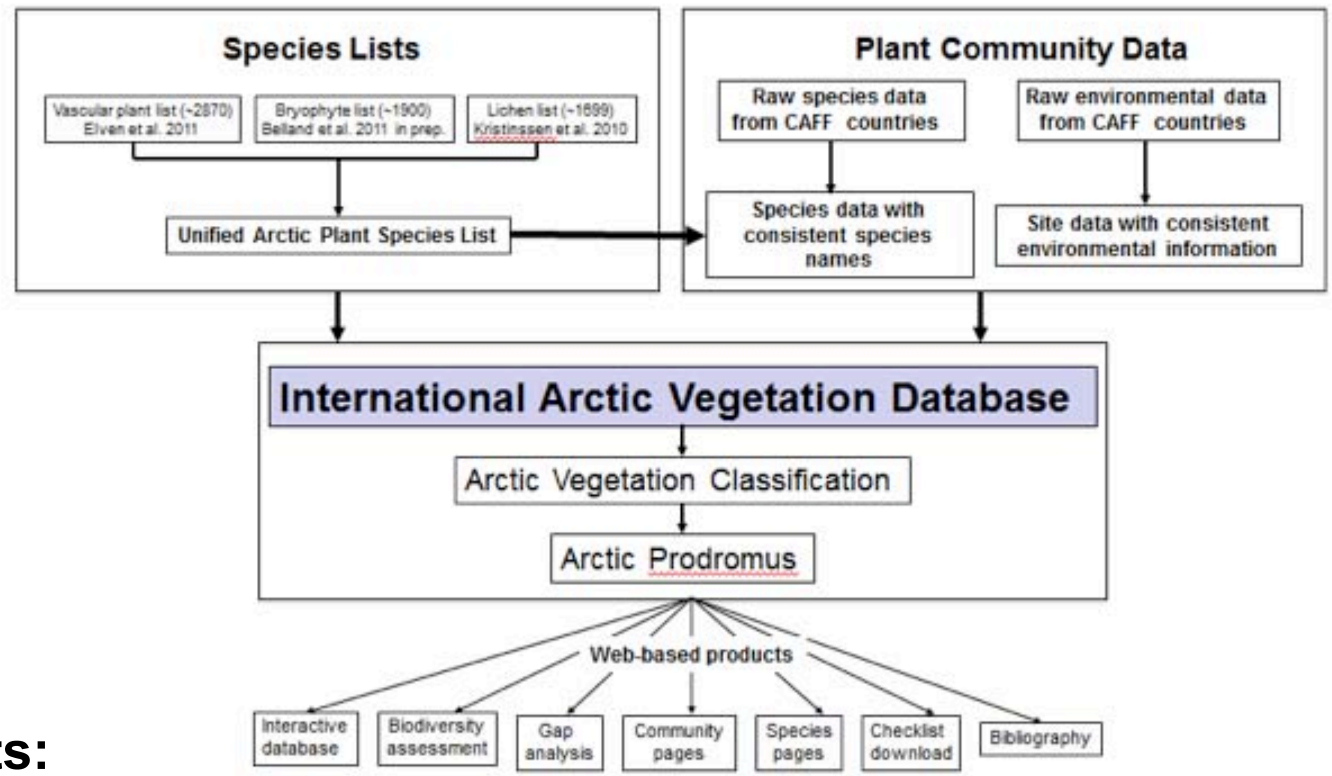


Needs for mapping and classification

- Standardized approaches to describing and mapping vegetation.
- Classification framework for Arctic plant communities at multiple scales.
- Arctic-wide vegetation database:
  - Containing existing relevé data

First we need an International Arctic Vegetation Database

This requires retrieving and then linking Arctic plant community data to the Panarctic Flora to form the International Arctic Vegetation Database



Walker and Raynolds, 2011 draft

Plant Lists:

Vascular plants: Elven et al. 2011
Lichens: Kristinsson 2011
Mosses: Balladin in prep.

Only biome in the world that has complete plant species lists for the biome.

CAFF CONCEPT PAPER
An Arctic Vegetation Database – a foundation for Panarctic biodiversity studies

Contents

Photo: M.K. Raynolds

IV. Multi-scale satellite-based monitoring

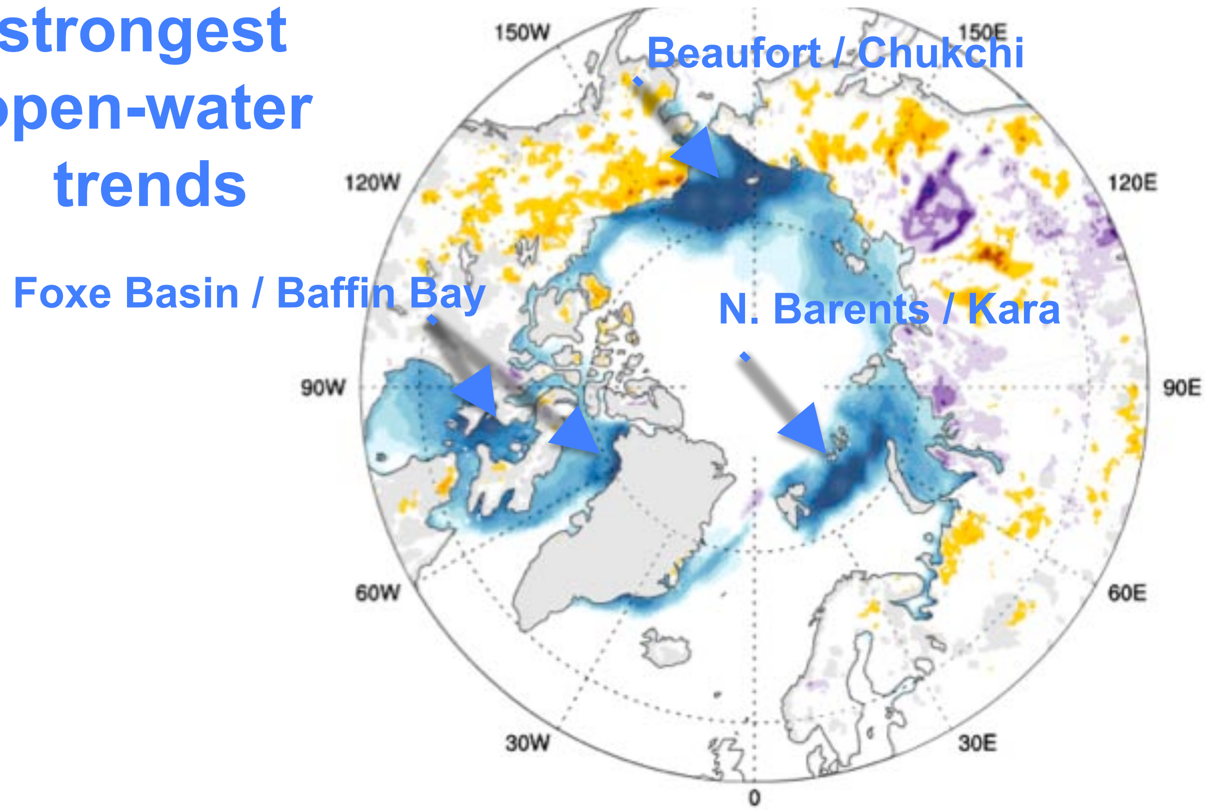
A. Global-scale 1 to 25 km resolution

- Trends in open water: AVHRR visible and microwave sensors
- Humidity: CFSR reanalysis
- Snow: microwave sensors SMMI
- Land temperatures: AVHRR microwave sensors
- Vegetation: AVHRR NDVI (MaxNDVI, Seasonality, Trends)

Fall Open-Water Trends

Areas of strongest open-water trends

Oct-Nov 1982-2010

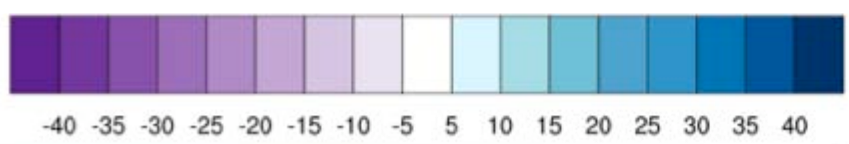


Sea Ice / open water / snow water equivalent concentrations

Passive microwave sensors

1979-1987: SMM/R;
1987-2007: SSM/I;
1999-2010: IMS

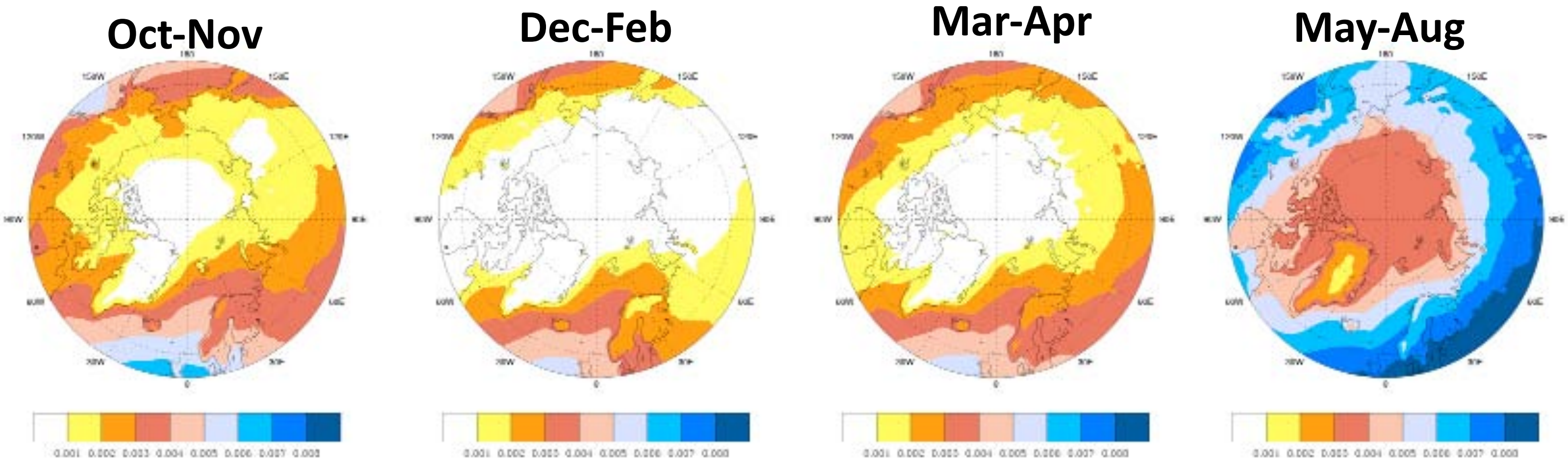
Open Water Magnitude of Change (pct.)

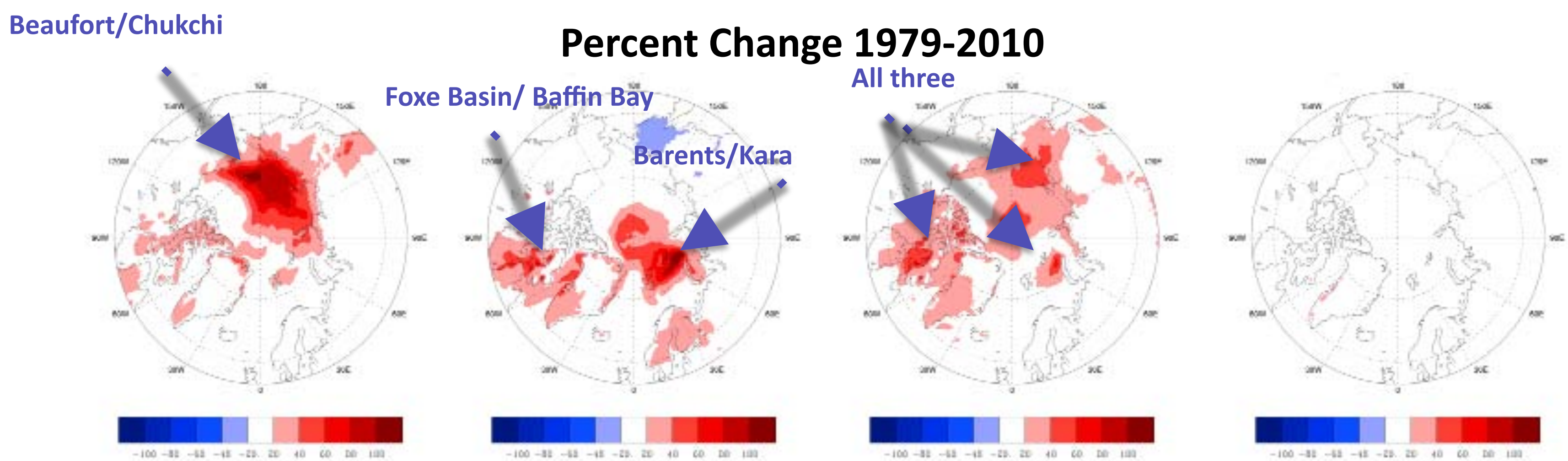


Bieniek, Bhatt, et al., in progress

Humidity seasonal means and trends

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.

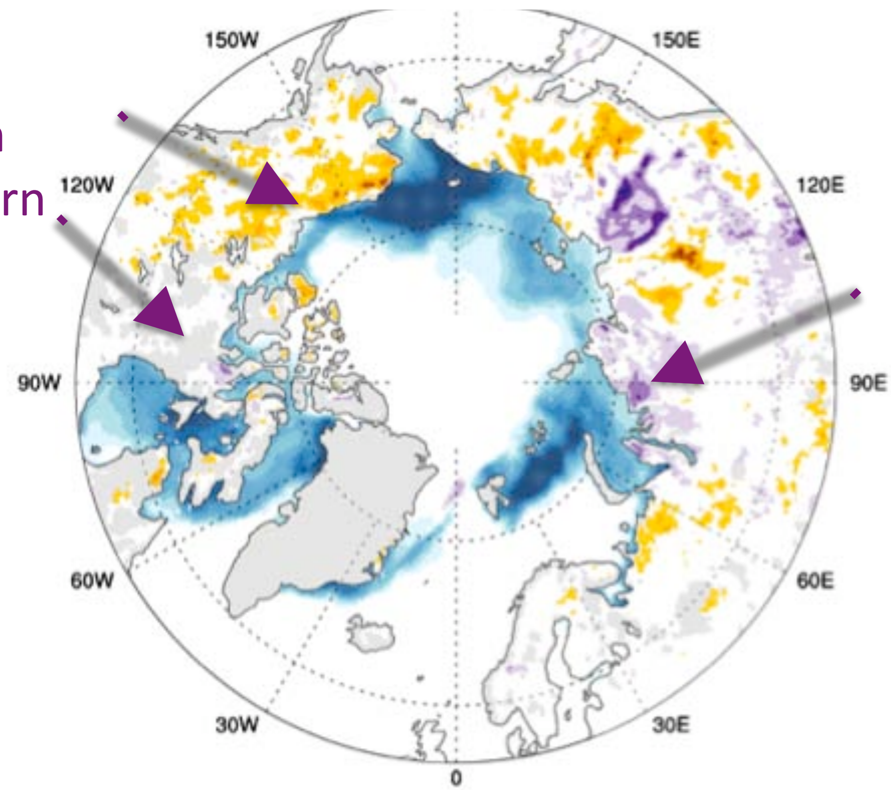
Humidity & Winds: CFSR (Coupled Forecast System Reanalysis)

Bieniek, Bhatt, et al., in progress

Late Fall Snow Trends (land areas)

Oct-Nov 1982-2010

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



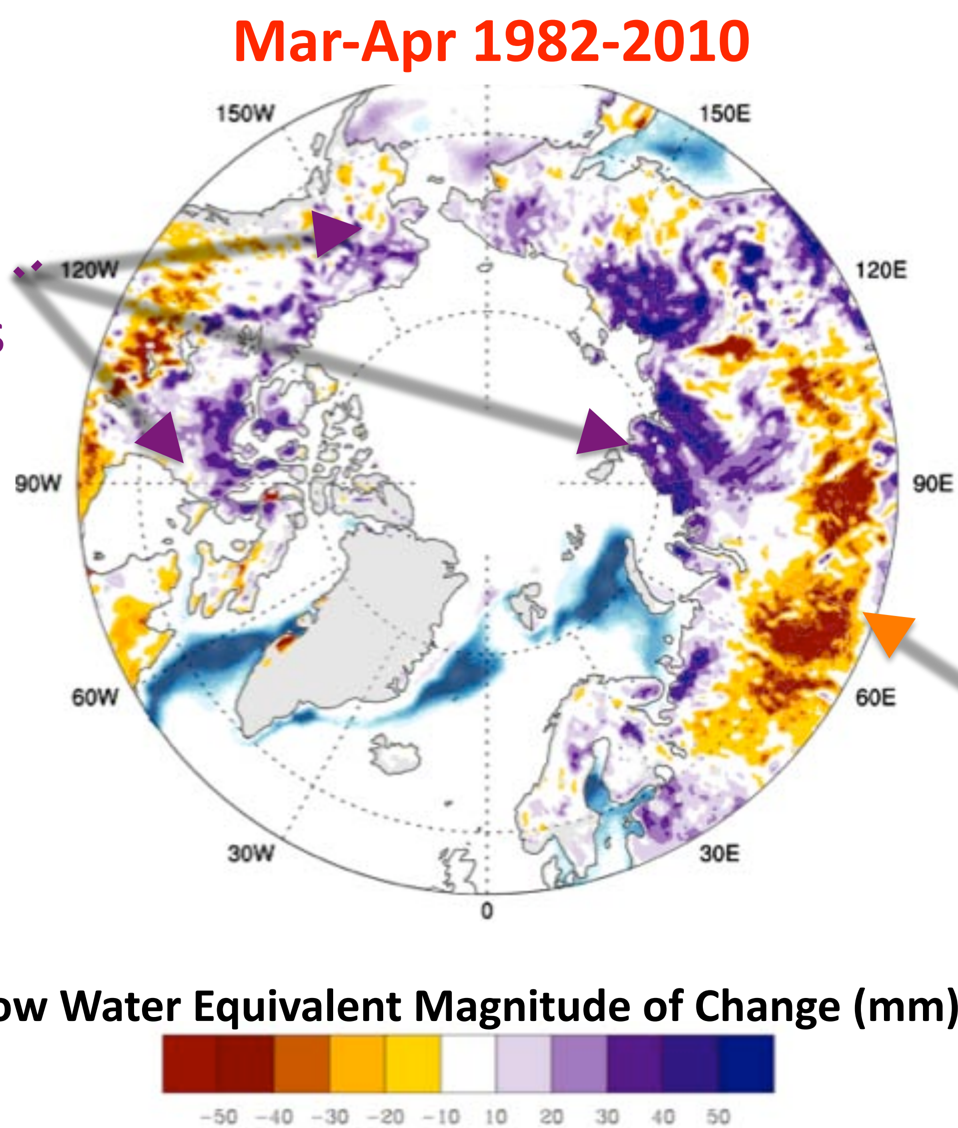
Positive trend in N. Yamal to Taimyr Pen.

Land Areas Snow Water Equivalent, Magnitude of Change (mm)

Bieniek, Bhatt, et al., in progress

Spring Snow Trends

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



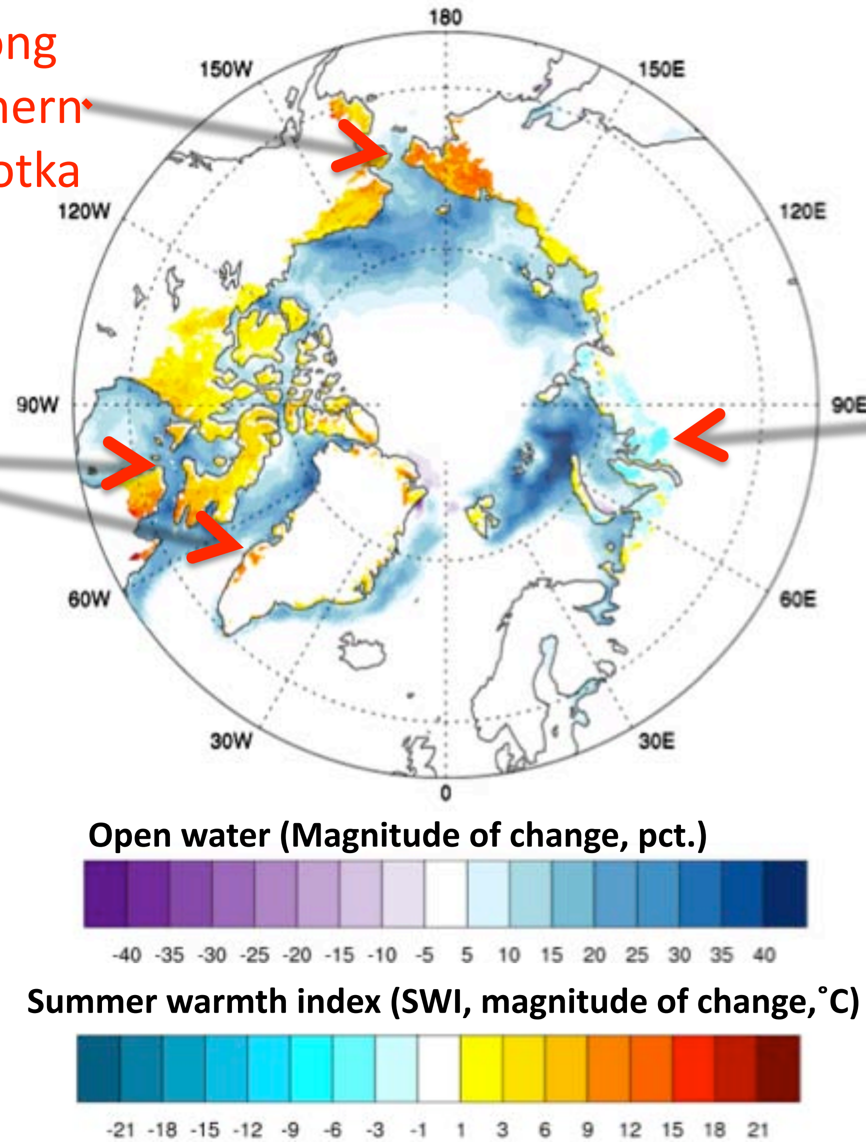
In contrast with boreal forest where much of the area has negative snow trends.

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

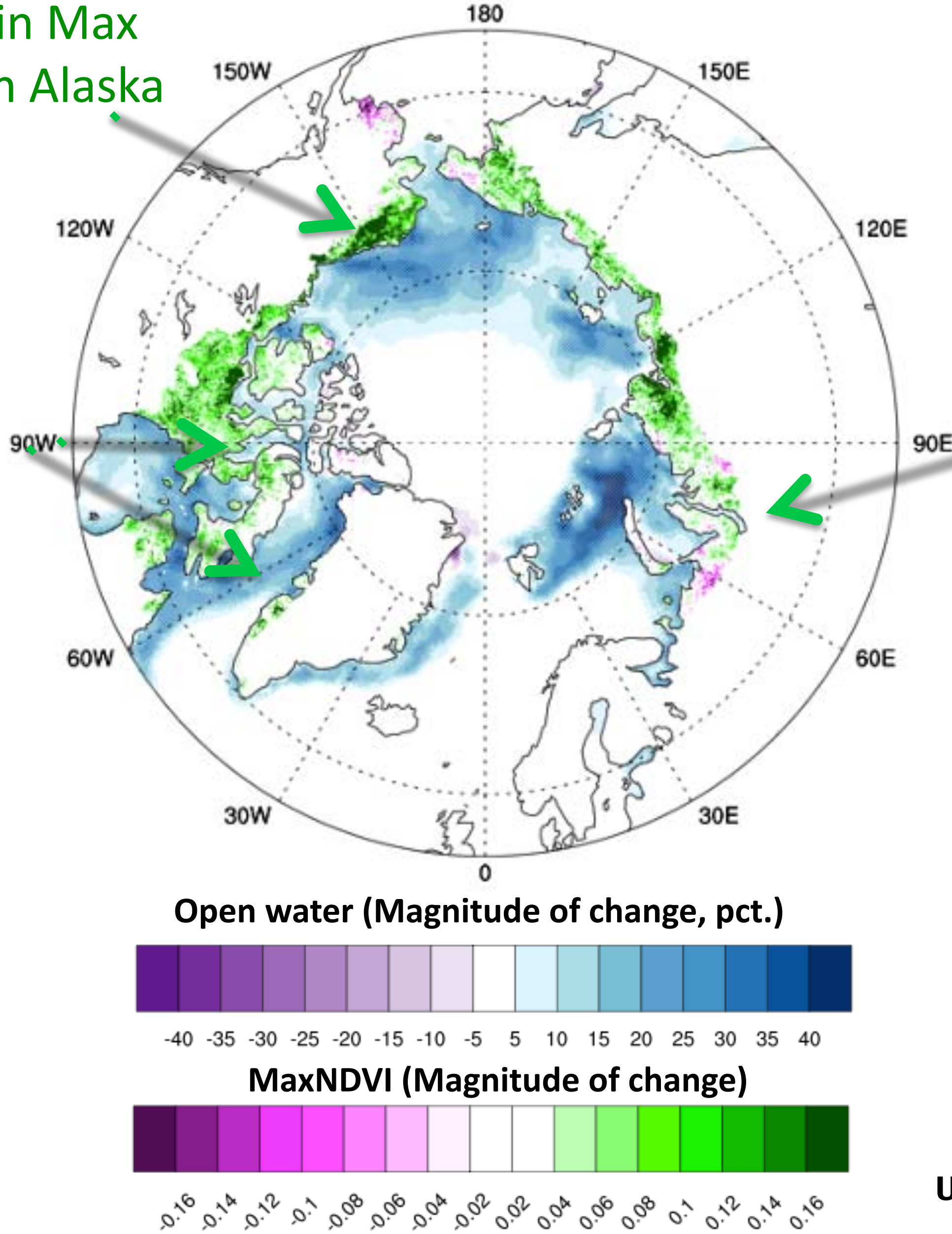
Land Temperatures: AVHRR (25-km). SWI = sum of mean monthly temperatures above freezing (˚C mo).

Updated from Bhatt et al. 2010

Changes in maximum tundra greenness (MaxNDVI) 1982-2010

Strong increase in Max 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

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

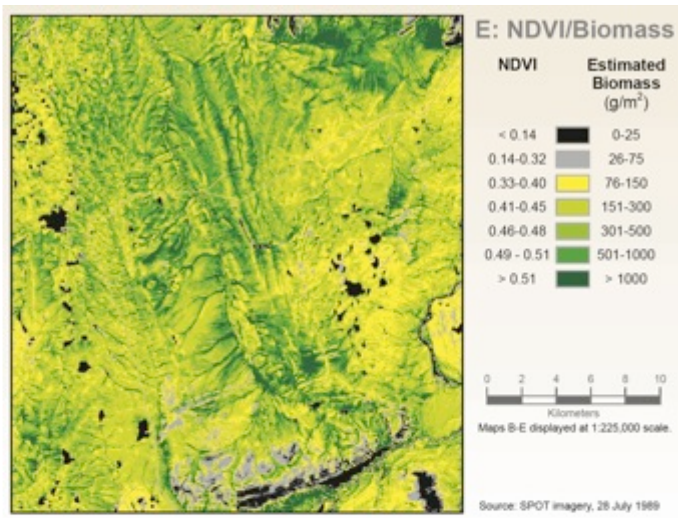
Updated from Bhatt et al. 2010

Remote sensing evidence documents humidification, warming and greening of the Arctic

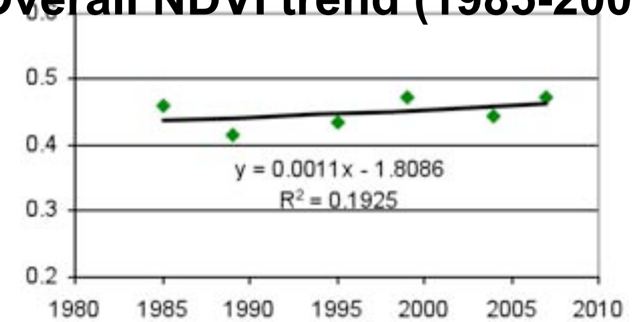
B. Regional scale: 1-10s of meters resolution

22-yr Landsat-TM NDVI trend Toolik Lake region, AK

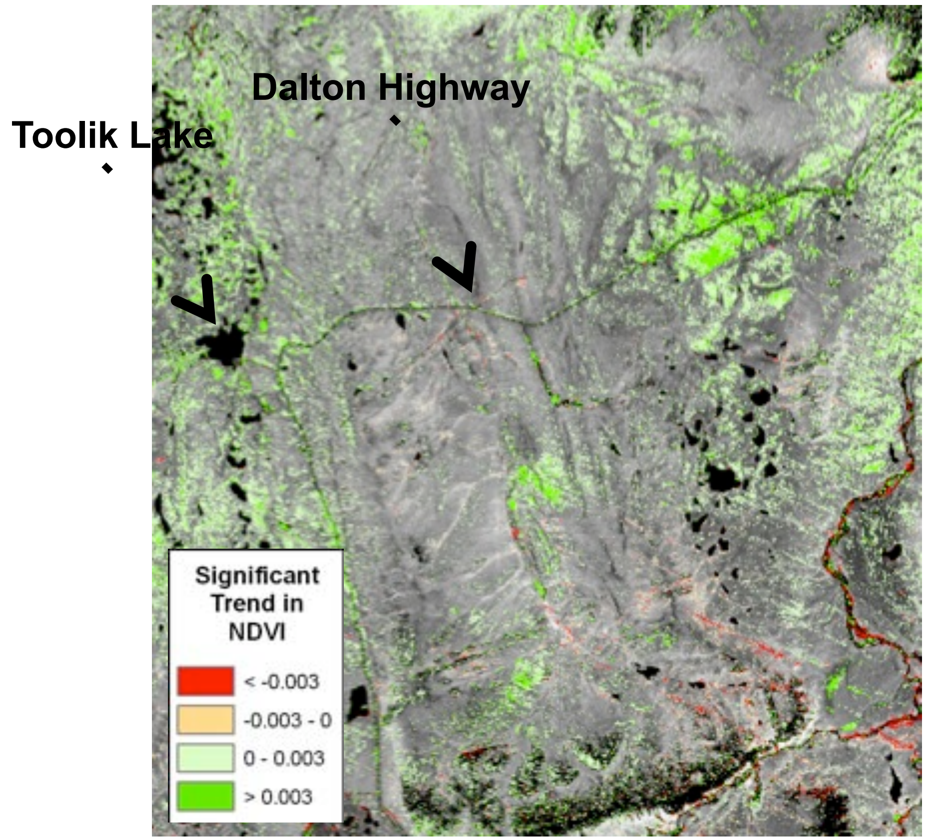
SPOT NDVI & Biomass 1989



Overall NDVI trend (1985-2007)



+3.2% Landsat
+13.8% AVHRR, GIMMS3g

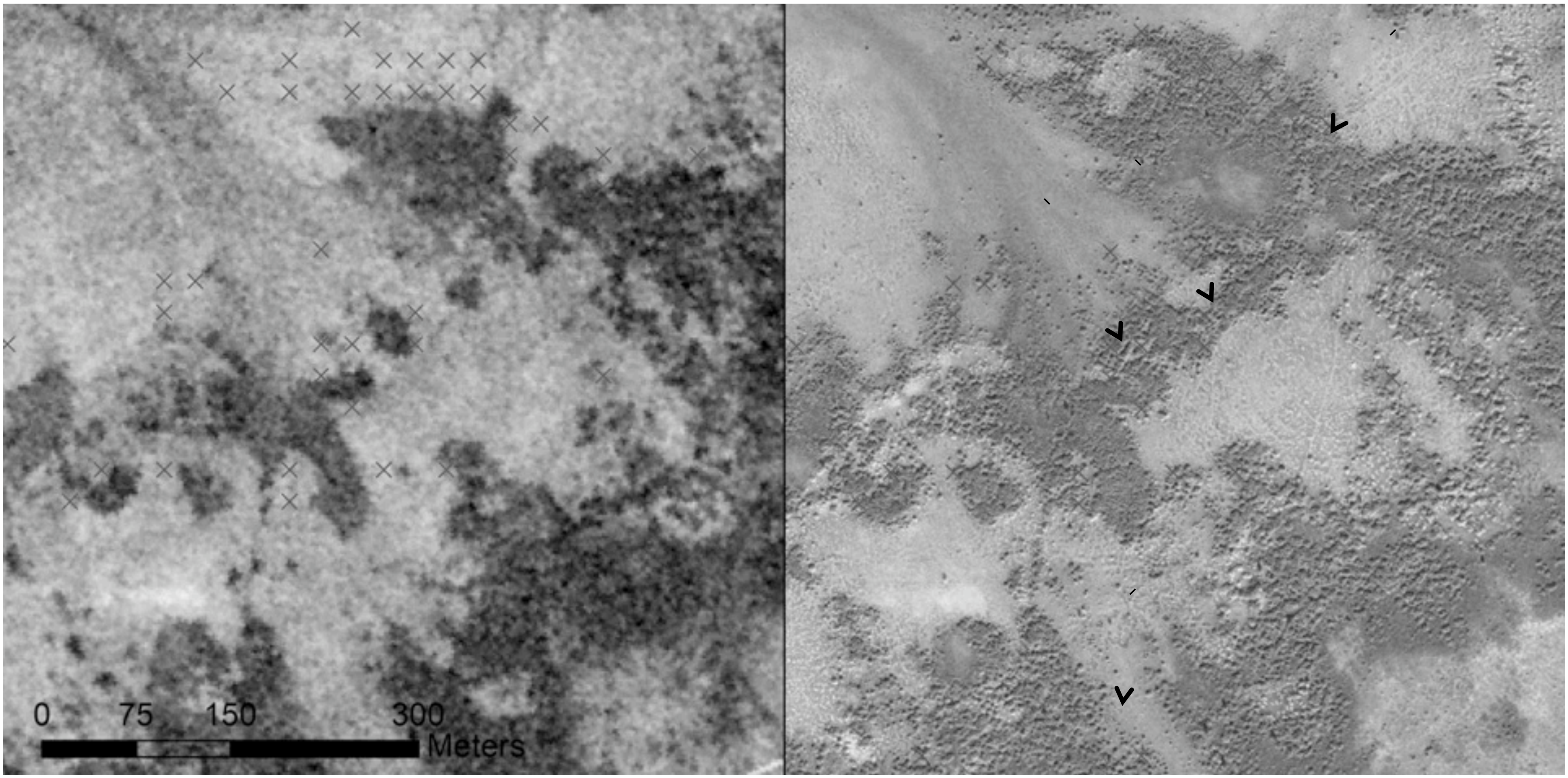


- **Used to detect where in landscapes the NDVI change is the greatest.**
- **Lack of corroboration for magnitude of change indicated by GIMMS 3g.**
- **Need for calibration of remote sensing data sets and ground measurements.**

Raynolds et al. 2010, Poster AGU Fall Meeting.

Application of very-high-resolution imagery will greatly change our ability to monitor change: Monitoring alder invasion in the Polar Ural foothills

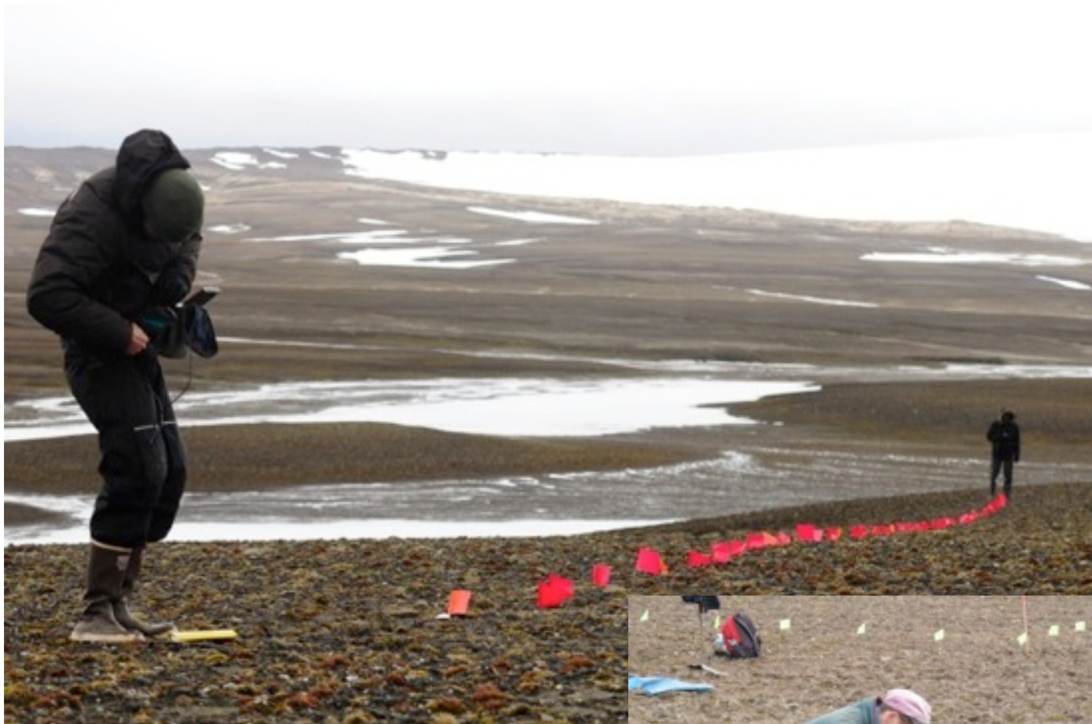
1968 Corona spy satellite | **2003 Quickbird**



Frost et al. submitted, 2012 TICOP meeting

- **Sub-meter resolution permits monitoring of individual shrubs and patterned ground features..**
- **8% change in alder cover in 35 yr.**

Plot-based evidence for change in biomass?



Monitoring NDVI and biomass, Krenkel Station, Russia and Isachsen, Canada. Photos: Gosha Matyshak and Fred Daniëls

- **Not a lot of direct evidence of temporal biomass change to support space-based observations. (Toolik plots are an exception).**
- **Mostly experimental evidence (Green-house experiments, Chapin et al., ITEX experiments).**
- **Very few long-term biomass studies (e.g., Hudson & Henry 2009; Shaver et al. 2002).**

Needed:

- **Standardized approaches for clip harvest, sorting, and reporting.**
- **Regular harvest at sites across the full climate gradient.**

V. NOAA Annual State of the Climate & Arctic Report Card: Annual monitoring at the pan-Arctic scale with links to ground-based evidence

Arctic Report Card: ***Update for 2010***

Tracking recent environmental changes

Home Atmosphere Sea Ice Ocean Land Greenland Biology

Return to previous Arctic conditions is unlikely

Record high temperatures across Canadian Arctic and Greenland, a reduced summer sea ice cover, record snow cover decreases and links to some Northern Hemisphere weather support this conclusion

Atmosphere (red)	Biology (yellow)	Greenland (red)
Sea Ice (red)	Ocean (yellow)	Land (yellow)

Red boxes: Consistent evidence of warming.
Yellow boxes: Many indications of warming.

Atmosphere
Arctic climate is impacting mid-latitude weather, as seen in Winter 2009-2010

Sea Ice
Summer sea ice conditions for previous four years well below 1980s and 1990s

Ocean
Upper ocean showing year-to-year variability without significant trends

Land
Low winter snow accumulation, warm spring temperatures lead to record low snow cover duration

Greenland
Record setting high temperatures, ice melt, and glacier area loss

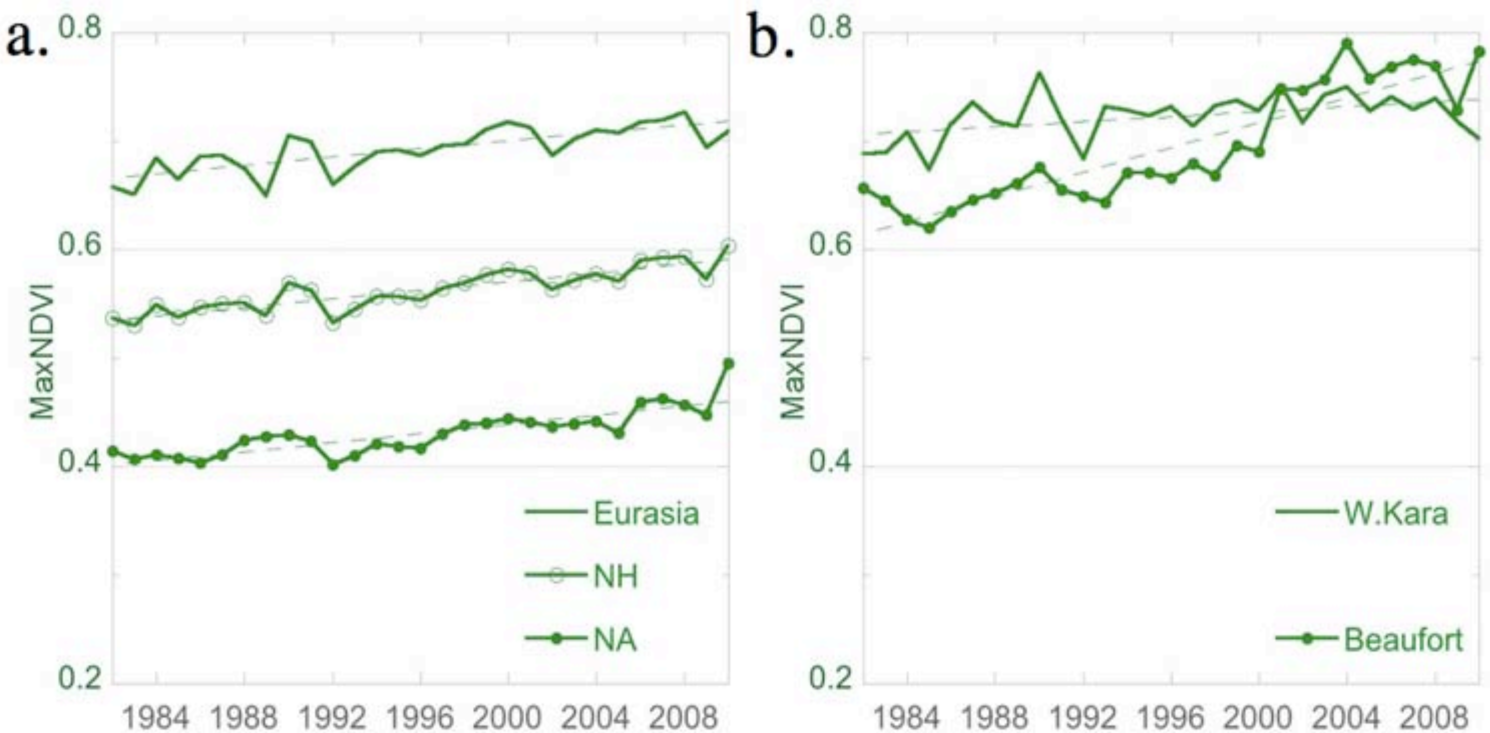
Biology
Rapid environmental change threatens to disrupt current natural cycles

About the Report Card

Printable Handout :: Executive Summary :: Full Arctic Report Card (PDF)
NOAA Arctic Theme Page

V. Arctic Report Card: 2010 vegetation headlines

- **The circumpolar "greenness" of Arctic vegetation showed a dip in 2009 that corresponded to elevated atmospheric aerosols over the Arctic and generally cooler summer temperatures across the Arctic.**
- **Information from long-term ground-based observations shows that greening is occurring in response a wide variety of disturbance factors including landslides and erosional features related to thawing permafrost, tundra fires and factors related to increased human presence in the Arctic.**



Take Home Points

- **Detecting vegetation change requires multi-scale and multi-temporal approaches for describing, mapping, and analysis.**
  - **Ground Observations**
  - **Maps**
  - **Remote sensing imagery**
- **Satellite data document trend of more winter open water, humidity, more snow on nearby land areas, generally warmer temperatures (mainly in North America) and increased tundra productivity.**
- **Remote-sensing data for sea-ice, snow, land temperatures, and NDVI lend themselves to rapid reporting required by the Arctic Report Card, but more and standardized ground-based measurements reported less frequently are needed to verify the trends.**