

# Multi-scale monitoring of Arctic vegetation

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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

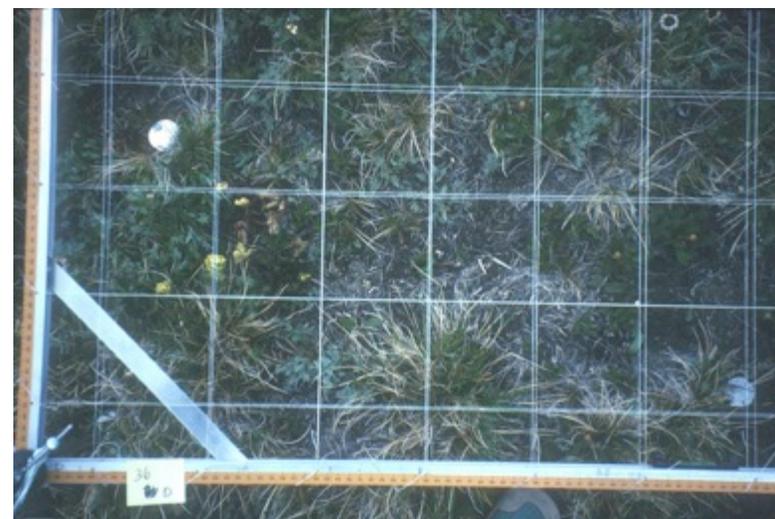
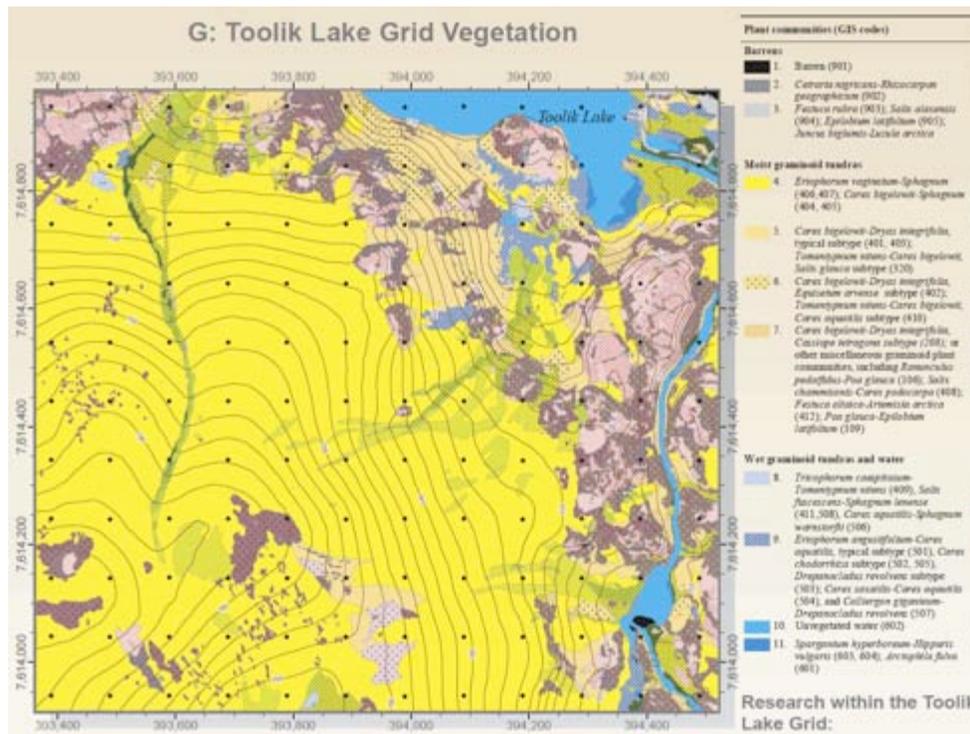
- Keys are:
  - Permanently marked plots
  - Consistent methodology
  - Replication at numerous sites
- A. Species composition and canopy structure monitoring
  - Example from Toolik Lake permanent grids
- B. Biomass, LAI, NDVI monitoring
  - Example from North America and Eurasia Arctic Transects

# A. Species composition & canopy structure monitoring

## Point quadrat example from Toolik Lake

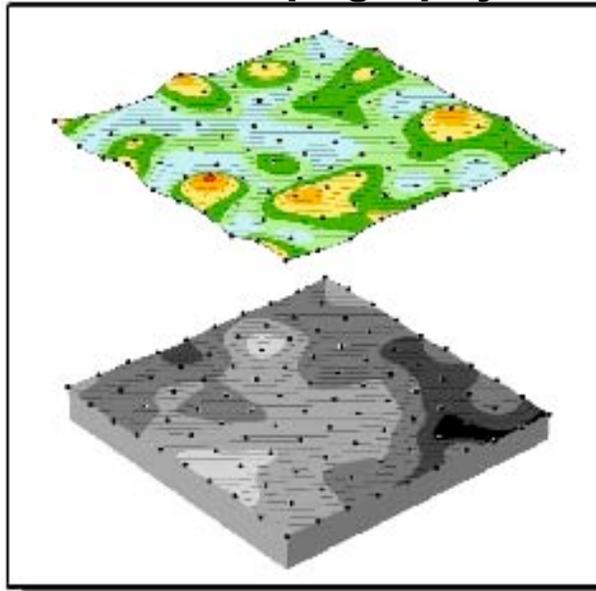
Permanently marked 1 x 1 m plots at grid points of 1 x 1 km Toolik Lake Grid

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

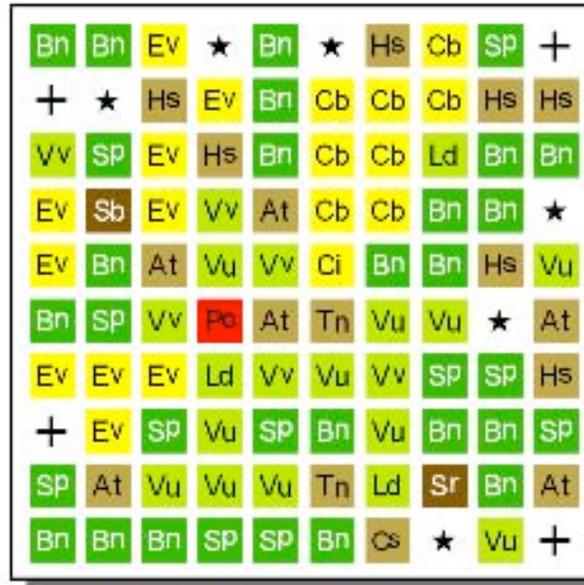


# Point quadrat example from Toolik Lake

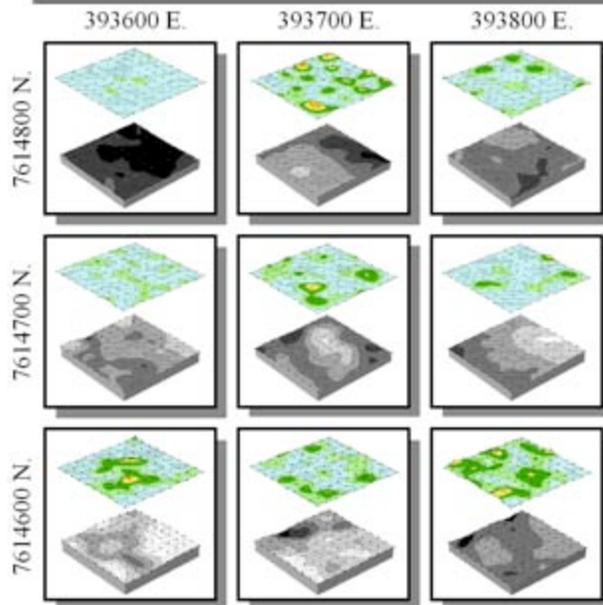
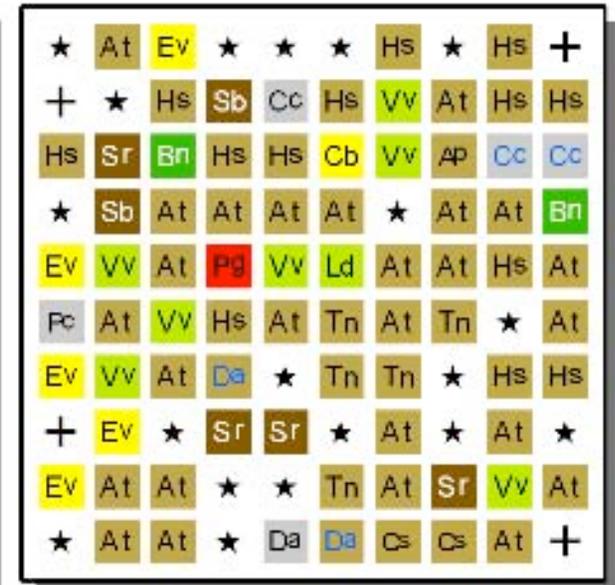
Canopy height & microtopography



Growth form and species top of canopy

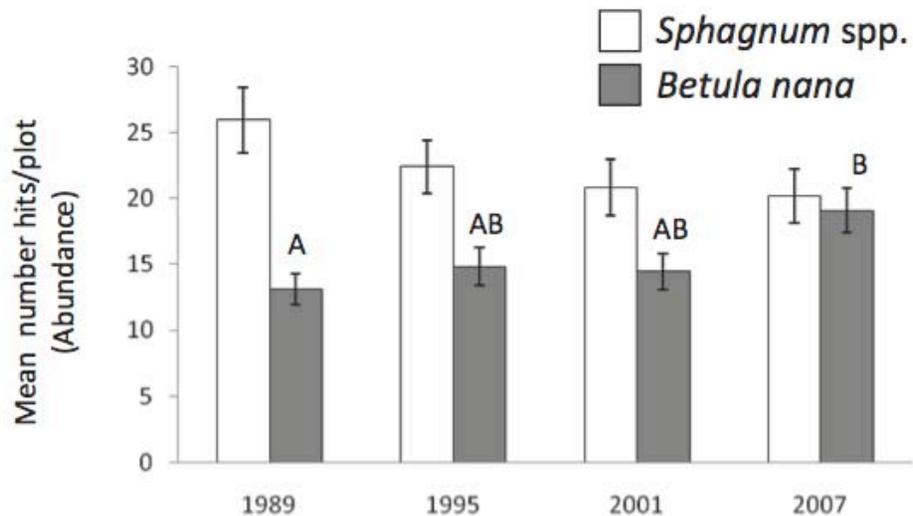


Growth form and species bottom of canopy

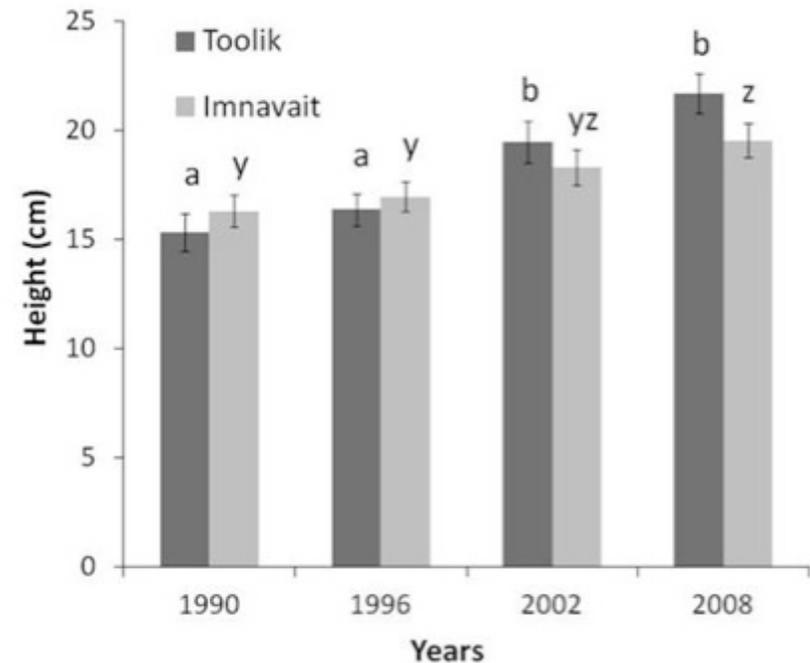


# 19 years of monitoring every 6-years at Toolik Lake and Imnavait Creek

## Changes in species abundance at Imnavait Creek



## Changes in canopy structure



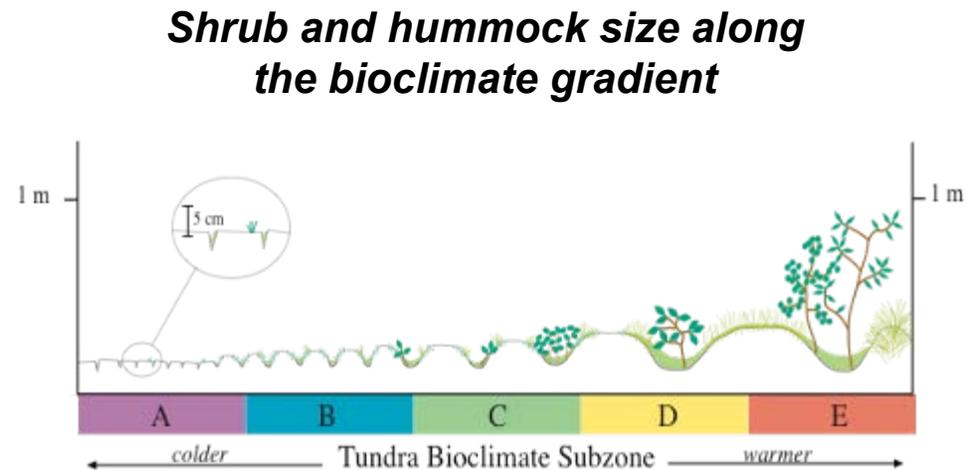
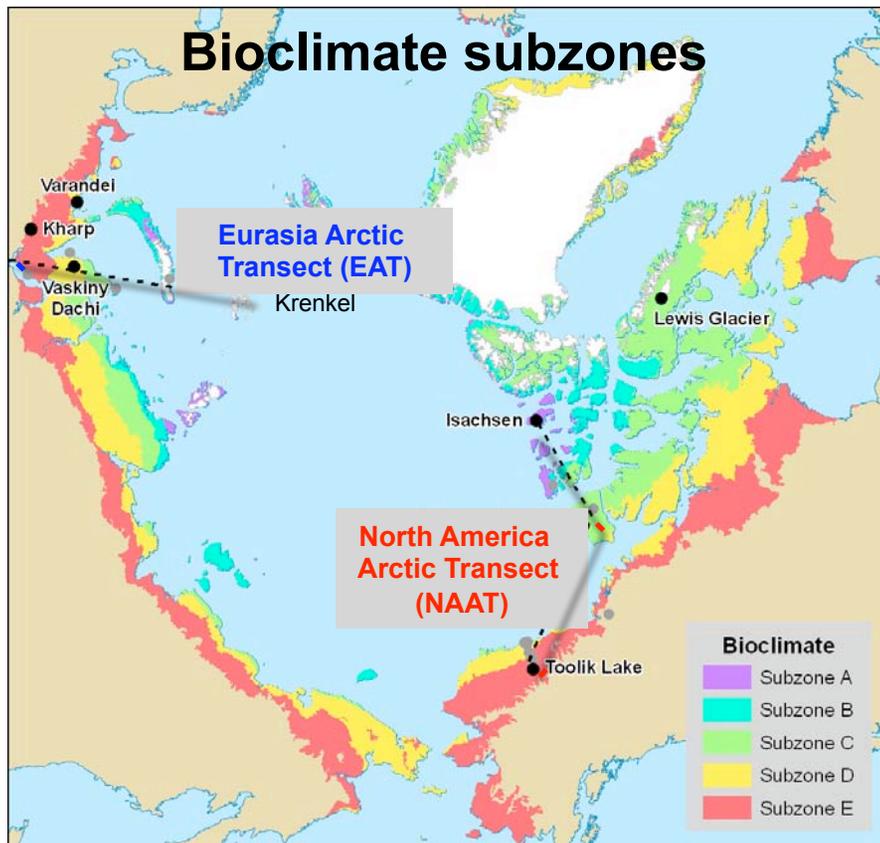
- **23% decline in relative abundance of *Sphagnum***
- **46% increase in relative abundance of *Betula nana***

- **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



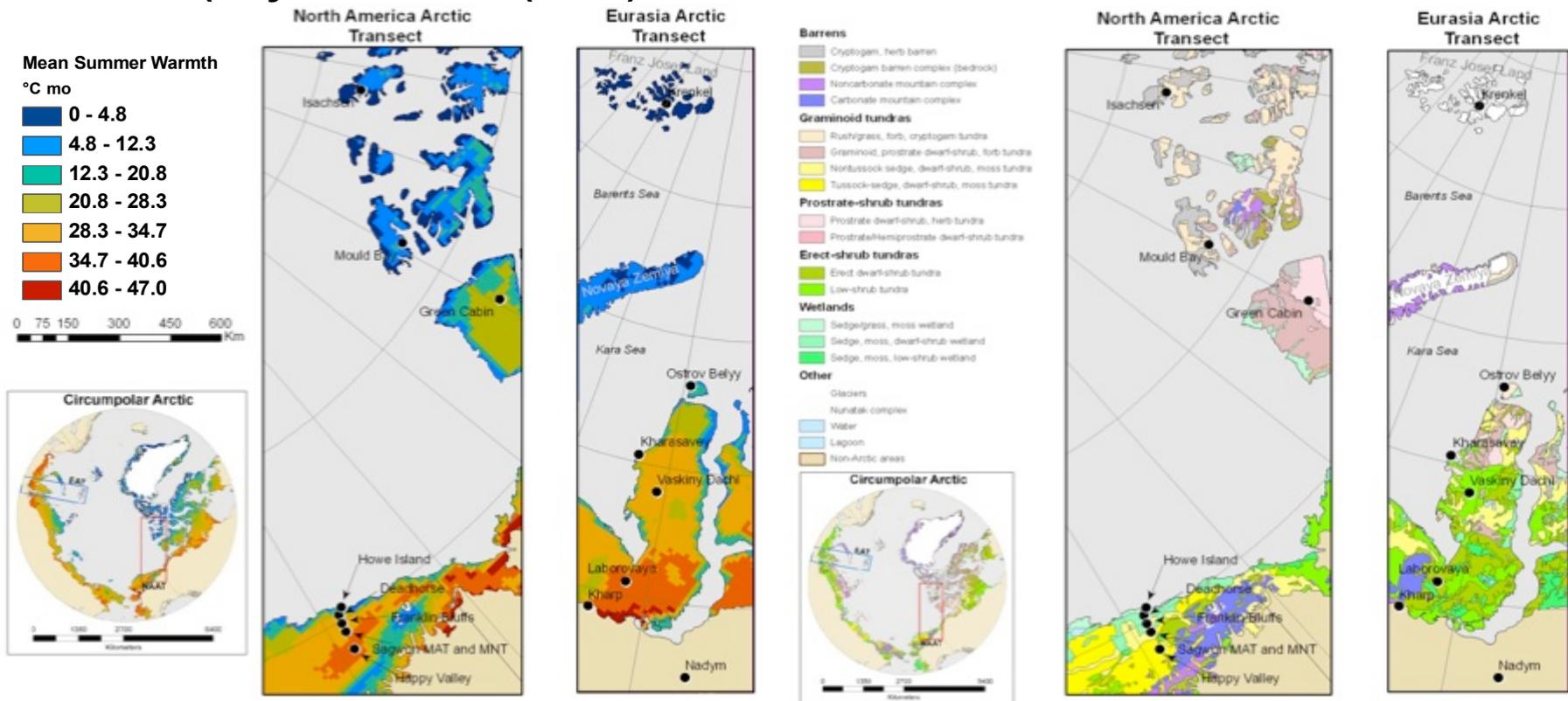
Subzone	MJT	Shrubs
A (Cushion forb)	1-3 °C	none
B ( <i>Dryas</i> )	3-5	prostrate dwarf (< 5 cm)
C ( <i>Cassiope</i> )	5-7	hemi-prostrate dwarf (< 15 cm)
D ( <i>Betula</i> )	7-9	erect dwarf (< 40 cm)
E ( <i>Alnus</i> )	9-12	low (40-200 cm)

CAVM Team 2003

# 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**

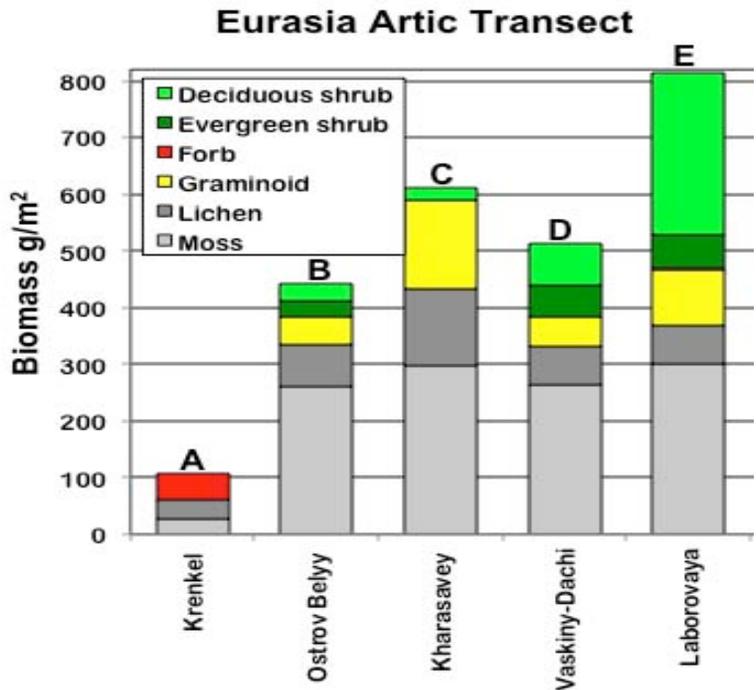
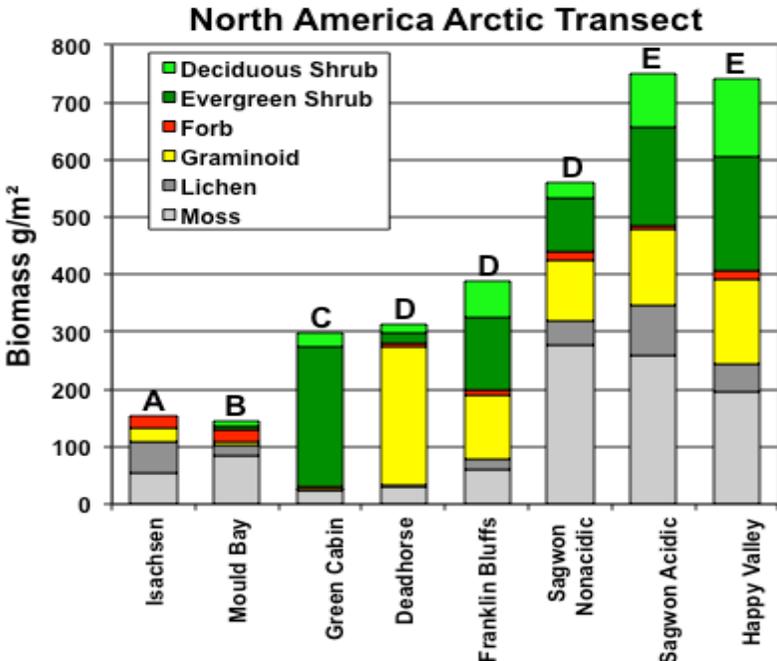


**N-factor**



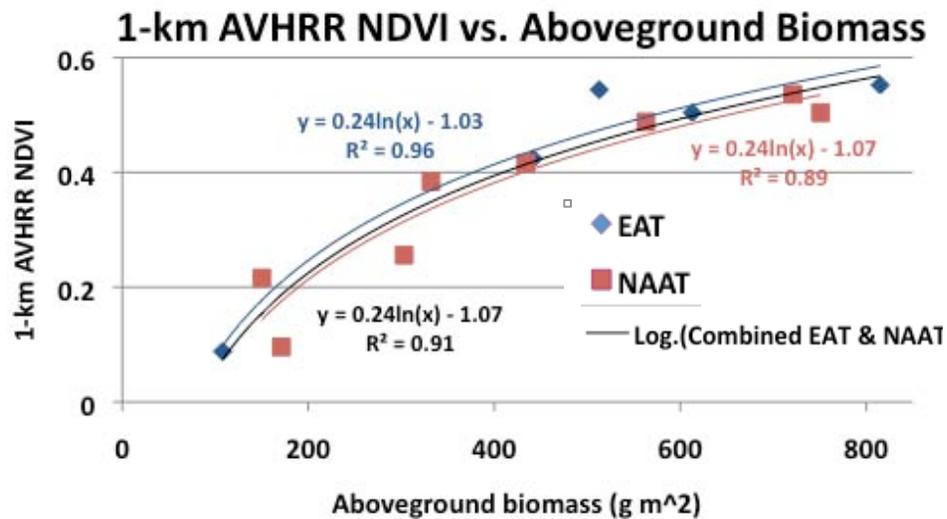
**Permafrost boreholes**

# Biomass differences between the NAAT and EAT

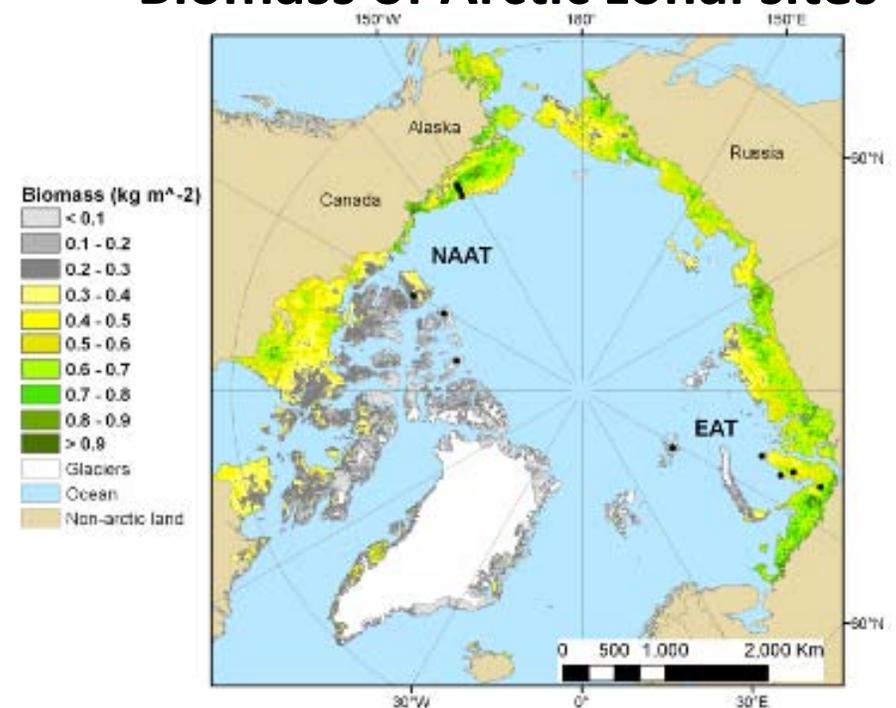


- More evergreen shrubs along the NAAT, due mostly to substrate difference (abundant *Dryas* on nonacidic soils of NAAT).
- More mosses and biomass in subzones B, C, D of the EAT (moister climate, older landscapes of EAT in subzones particularly in B and C).

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.



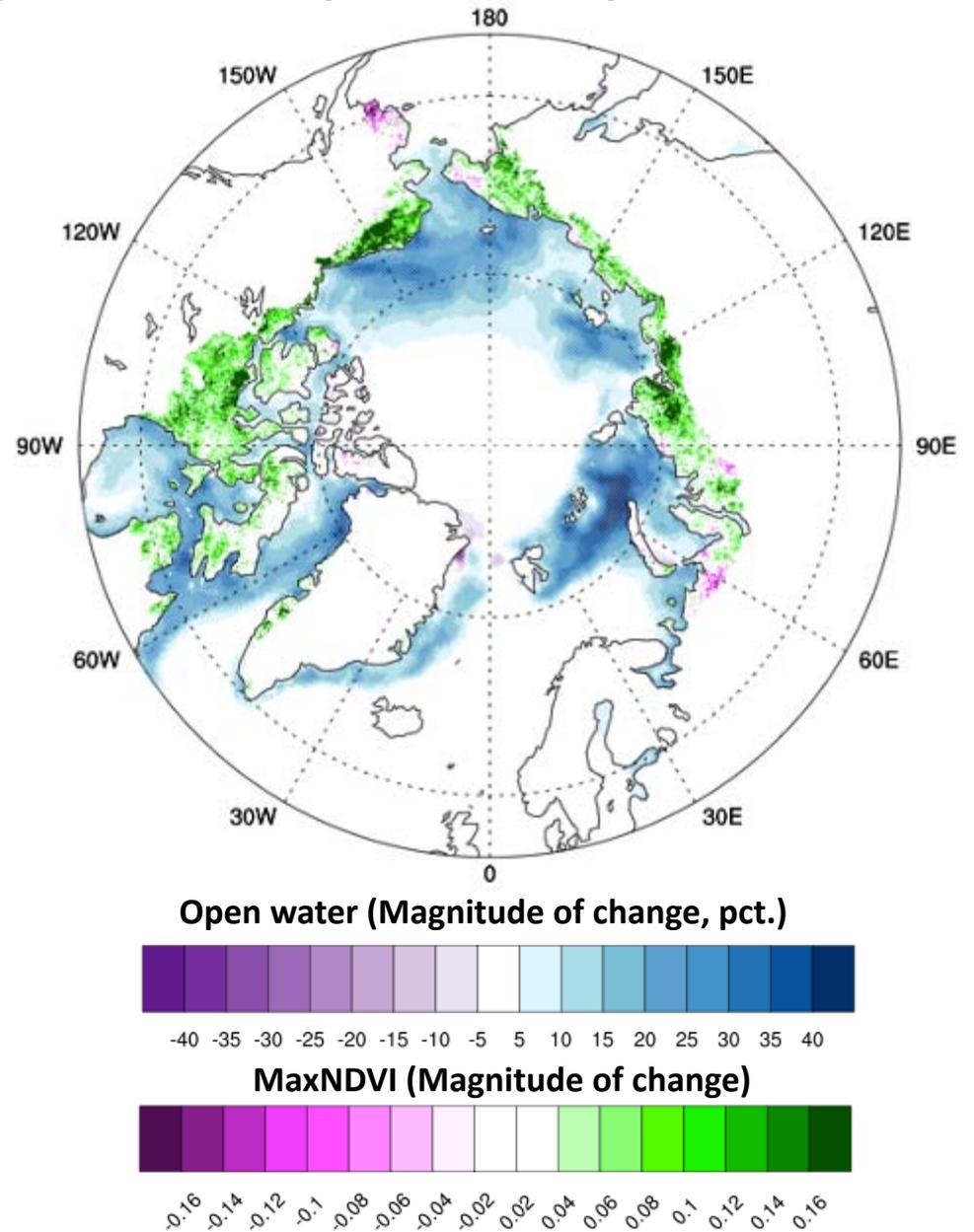
### Biomass of Arctic zonal sites



Raynolds et al. 2012, *Remote Sensing Letters*

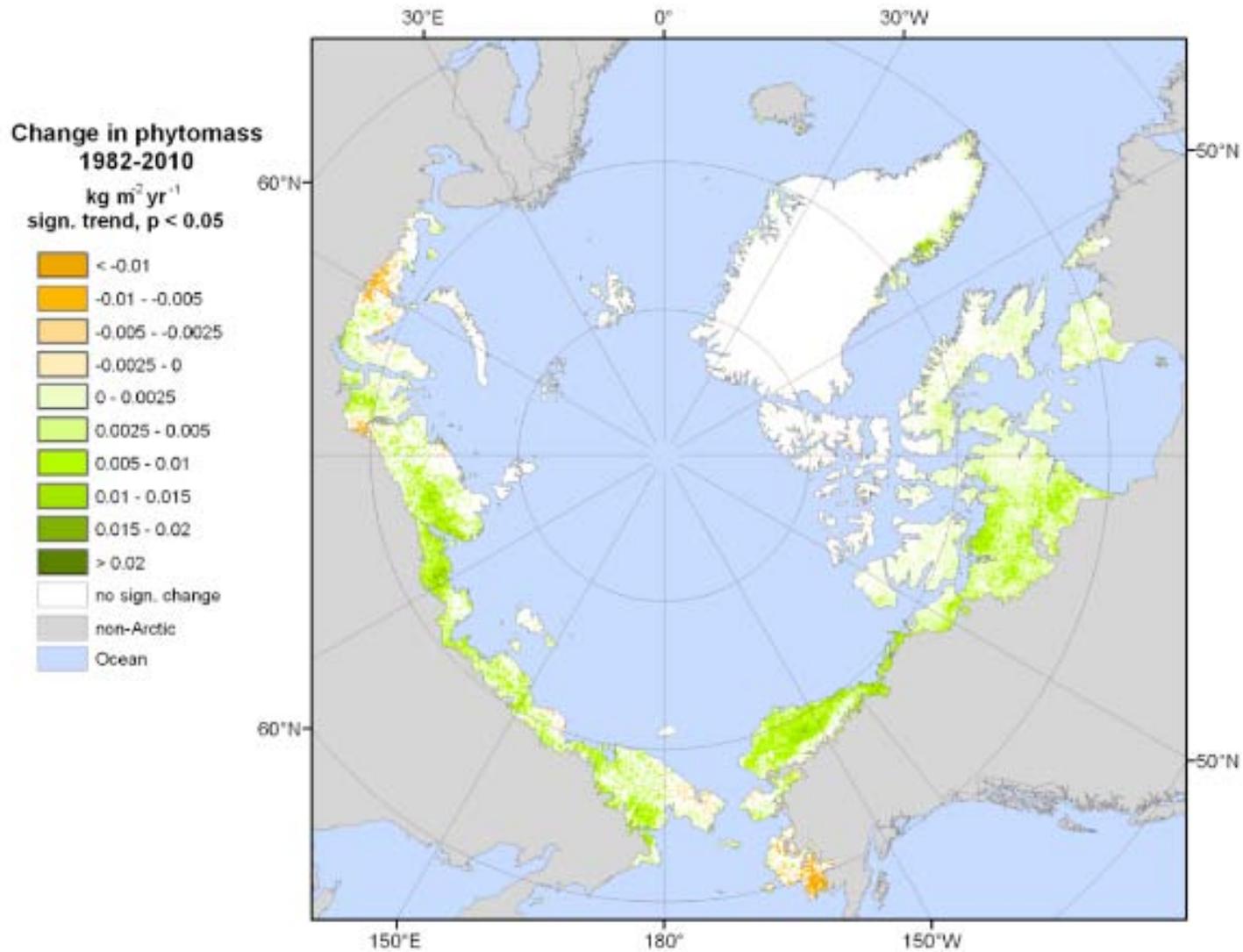
# Changes in maximum tundra greenness (MaxNDVI) 1982-2010

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.



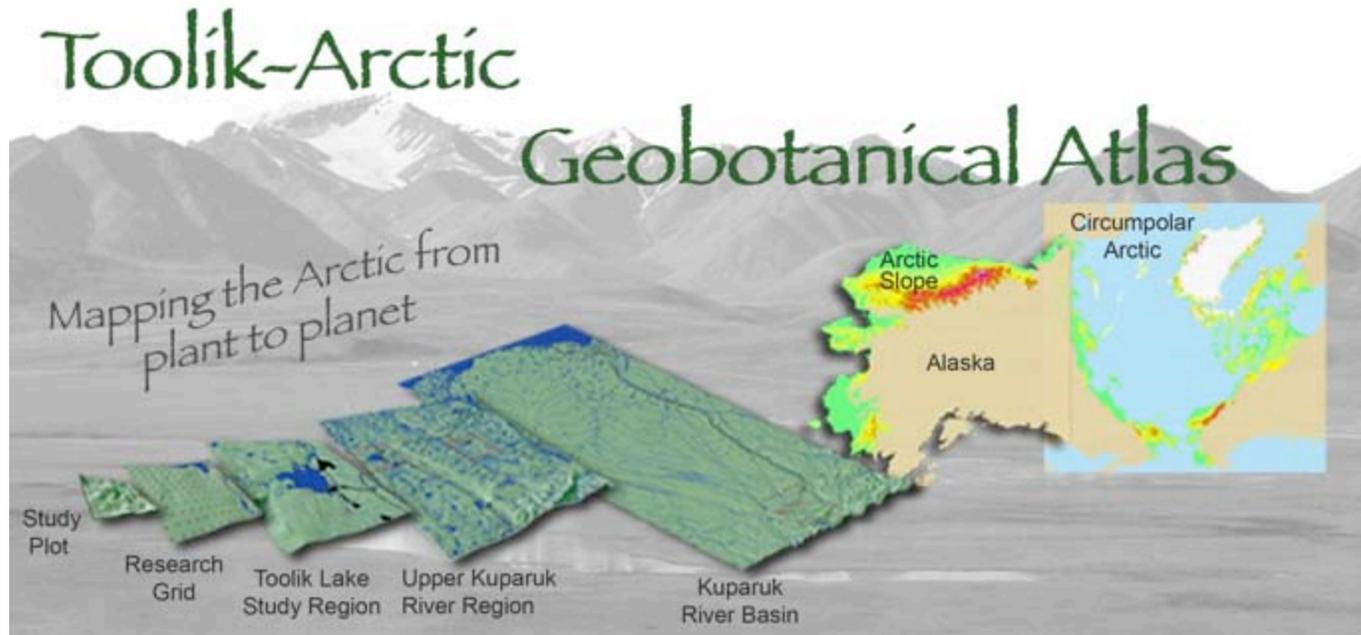
Updated from Bhatt et al. 2010

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



Epstein et al. submitted. *Environmental Research Letters*

# Hierarchy of maps in the Toolik-Arctic Geobotanical Atlas

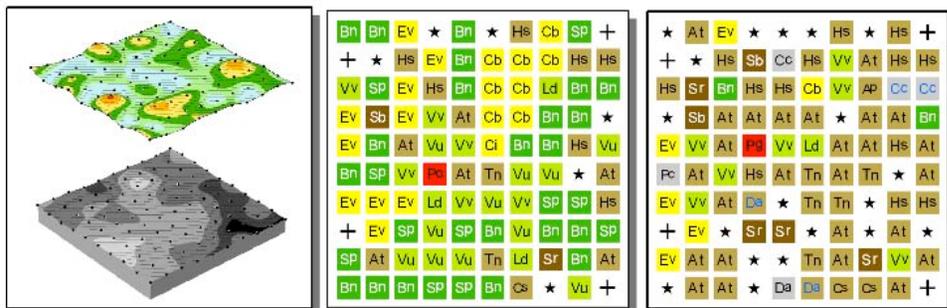


- Global-level(circumpolar) maps
- Regional-level maps
- Landscape-level maps
- Plot-level maps



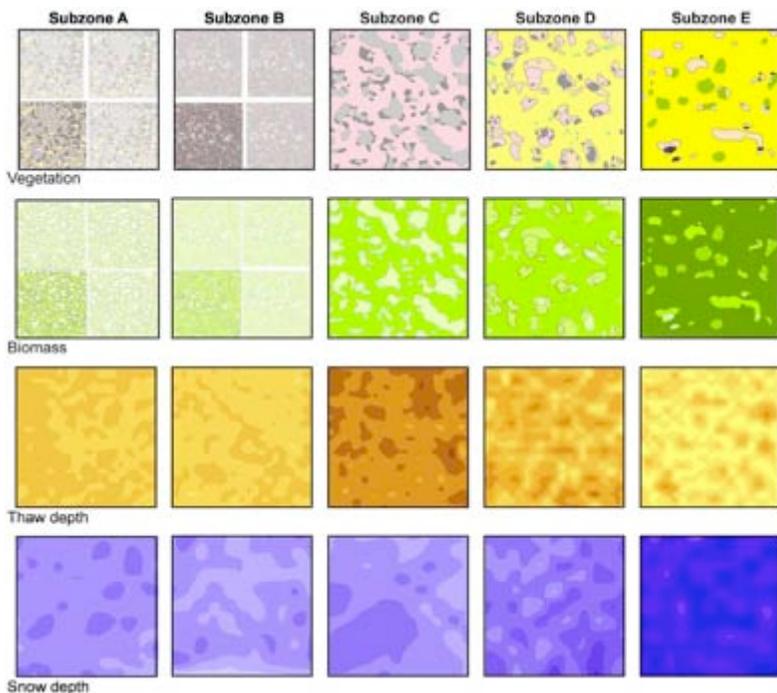
# A. Plot maps

## 1. 1x1m maps at Toolik Lake

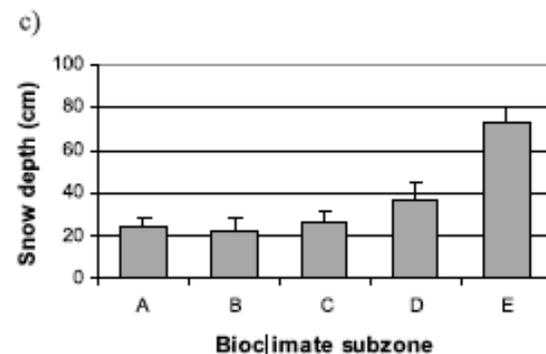
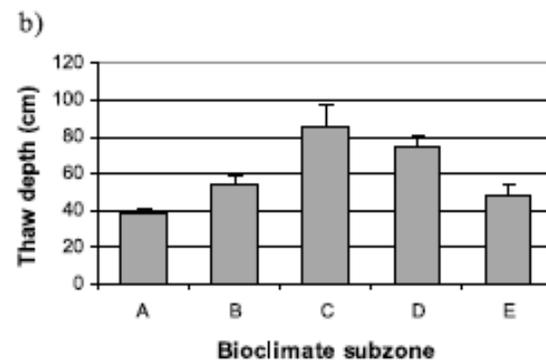
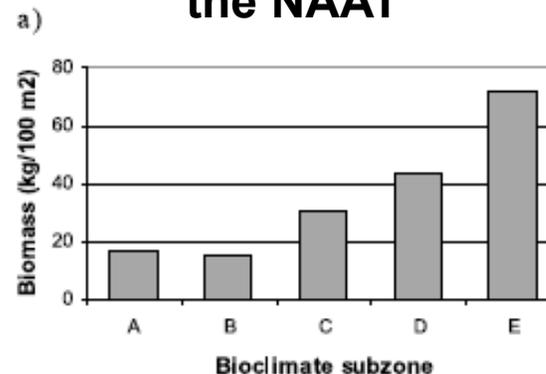


Walker et al. 2010, *Viten*

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

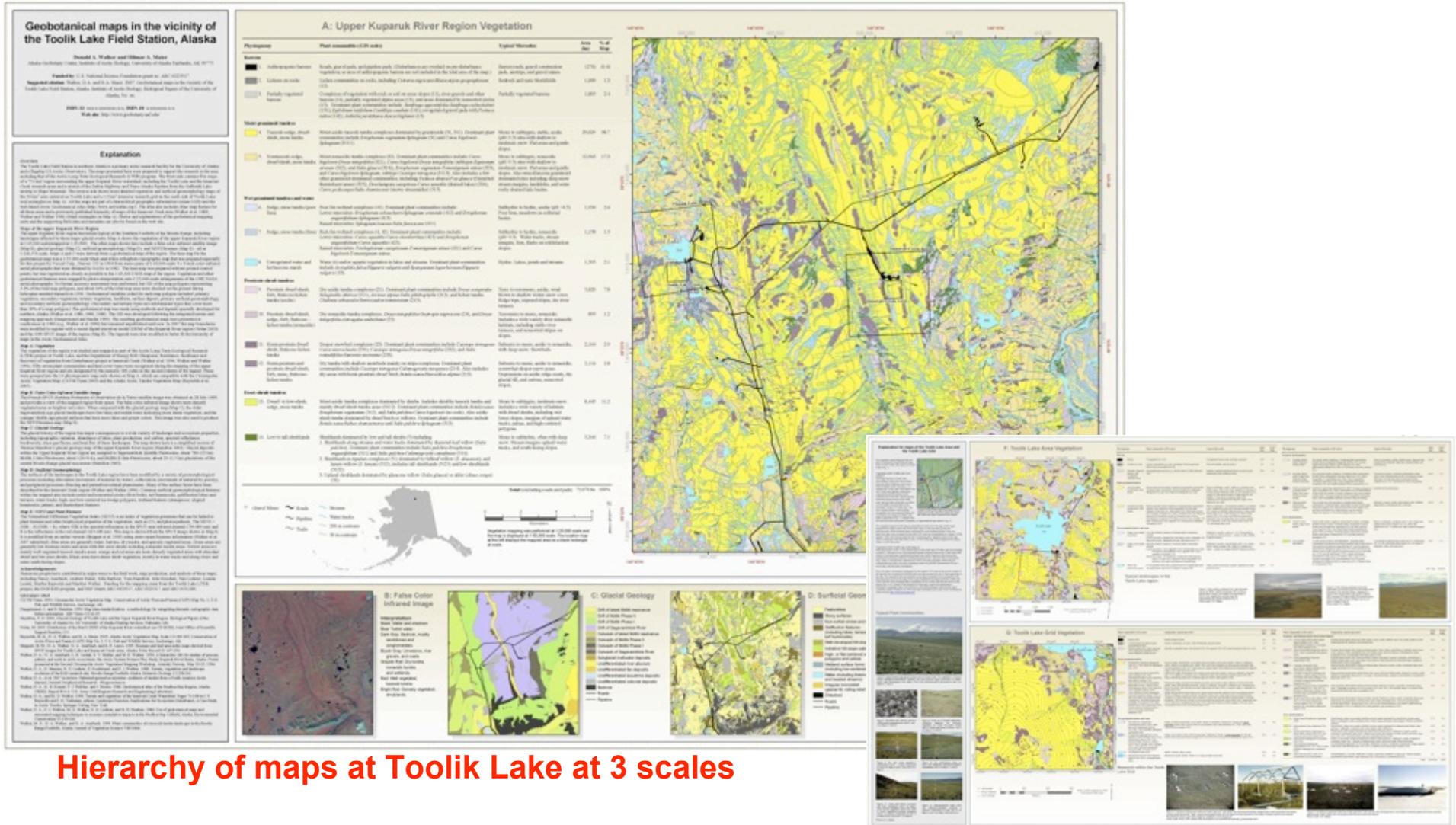


## 2b. Trends of key variables along the NAAT



Raynolds et al. 2008,  
*Journal of Geophysical Research*

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



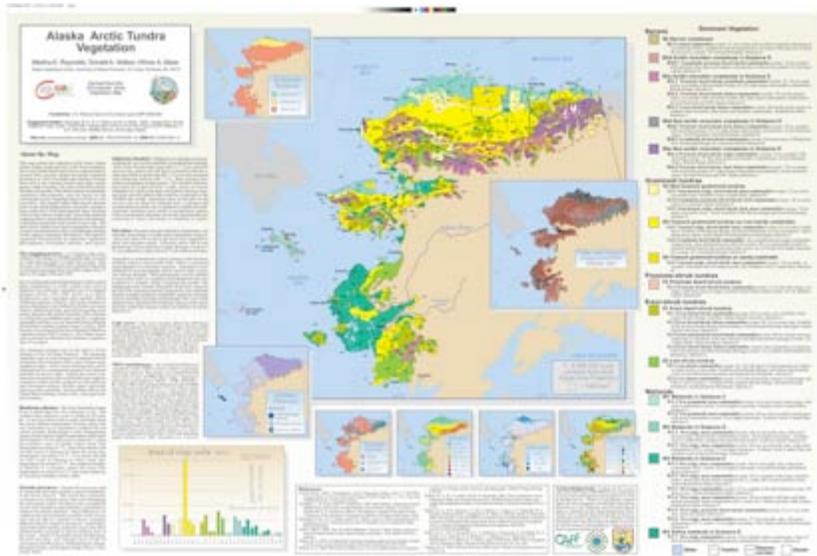
**Hierarchy of maps at Toolik Lake at 3 scales**

- 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

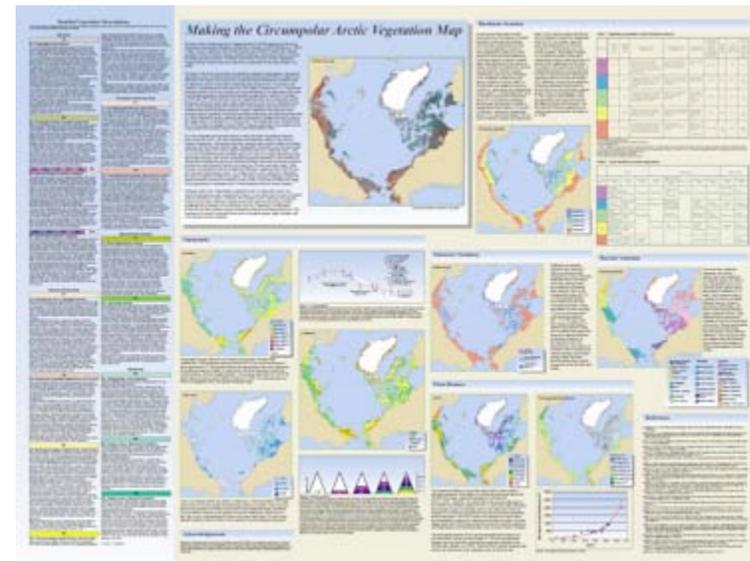


## Circumpolar Arctic



**Dominant arctic Alaska plant communities**

Community	Code	Color	Characteristics	Vegetation	Soil	Water	Shrub	Tree	Notes
1	1	Yellow	Open tundra	Low shrubs	Well-drained	Low	None	None	
2	2	Green	Wet tundra	Low shrubs	Wet	Low	None	None	
3	3	Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
4	4	Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
5	5	Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
6	6	Red	Wet tundra	Low shrubs	Wet	Low	None	None	
7	7	Light Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
8	8	Dark Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
9	9	Light Green	Wet tundra	Low shrubs	Wet	Low	None	None	
10	10	Dark Green	Wet tundra	Low shrubs	Wet	Low	None	None	
11	11	Light Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
12	12	Dark Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
13	13	Light Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
14	14	Dark Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
15	15	Light Red	Wet tundra	Low shrubs	Wet	Low	None	None	
16	16	Dark Red	Wet tundra	Low shrubs	Wet	Low	None	None	
17	17	Light Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
18	18	Dark Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
19	19	Light Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
20	20	Dark Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
21	21	Light Green	Wet tundra	Low shrubs	Wet	Low	None	None	
22	22	Dark Green	Wet tundra	Low shrubs	Wet	Low	None	None	
23	23	Light Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
24	24	Dark Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
25	25	Light Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
26	26	Dark Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
27	27	Light Red	Wet tundra	Low shrubs	Wet	Low	None	None	
28	28	Dark Red	Wet tundra	Low shrubs	Wet	Low	None	None	
29	29	Light Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
30	30	Dark Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
31	31	Light Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
32	32	Dark Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
33	33	Light Green	Wet tundra	Low shrubs	Wet	Low	None	None	
34	34	Dark Green	Wet tundra	Low shrubs	Wet	Low	None	None	
35	35	Light Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
36	36	Dark Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
37	37	Light Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
38	38	Dark Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
39	39	Light Red	Wet tundra	Low shrubs	Wet	Low	None	None	
40	40	Dark Red	Wet tundra	Low shrubs	Wet	Low	None	None	
41	41	Light Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
42	42	Dark Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
43	43	Light Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
44	44	Dark Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
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46	46	Dark Green	Wet tundra	Low shrubs	Wet	Low	None	None	
47	47	Light Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
48	48	Dark Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
49	49	Light Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
50	50	Dark Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
51	51	Light Red	Wet tundra	Low shrubs	Wet	Low	None	None	
52	52	Dark Red	Wet tundra	Low shrubs	Wet	Low	None	None	
53	53	Light Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
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57	57	Light Green	Wet tundra	Low shrubs	Wet	Low	None	None	
58	58	Dark Green	Wet tundra	Low shrubs	Wet	Low	None	None	
59	59	Light Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
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63	63	Light Red	Wet tundra	Low shrubs	Wet	Low	None	None	
64	64	Dark Red	Wet tundra	Low shrubs	Wet	Low	None	None	
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68	68	Dark Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
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71	71	Light Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
72	72	Dark Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
73	73	Light Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
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75	75	Light Red	Wet tundra	Low shrubs	Wet	Low	None	None	
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87	87	Light Red	Wet tundra	Low shrubs	Wet	Low	None	None	
88	88	Dark Red	Wet tundra	Low shrubs	Wet	Low	None	None	
89	89	Light Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
90	90	Dark Purple	Wet tundra	Low shrubs	Wet	Low	None	None	
91	91	Light Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
92	92	Dark Blue	Wet tundra	Low shrubs	Wet	Low	None	None	
93	93	Light Green	Wet tundra	Low shrubs	Wet	Low	None	None	
94	94	Dark Green	Wet tundra	Low shrubs	Wet	Low	None	None	
95	95	Light Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
96	96	Dark Yellow	Wet tundra	Low shrubs	Wet	Low	None	None	
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98	98	Dark Orange	Wet tundra	Low shrubs	Wet	Low	None	None	
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100	100	Dark Red	Wet tundra	Low shrubs	Wet	Low	None	None	

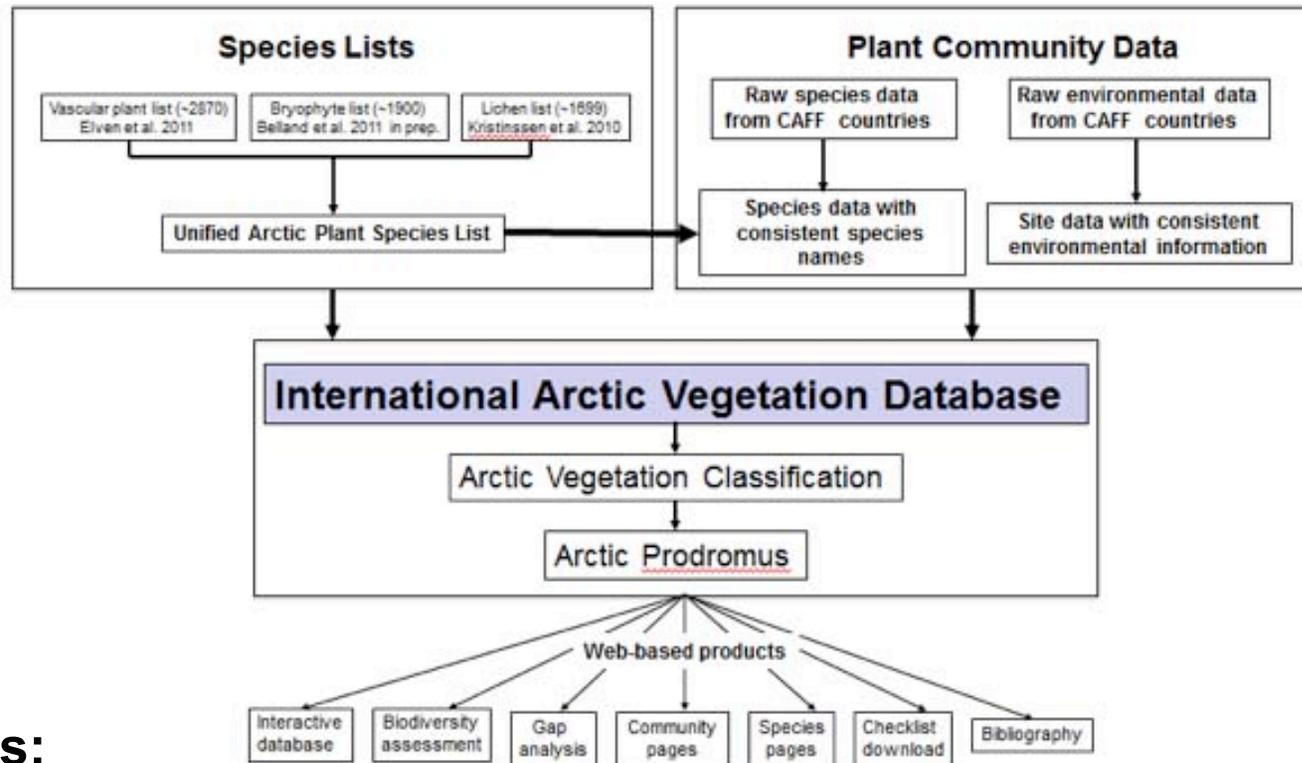


## ***Needs for mapping and classification***

- 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*



## Plant Lists:

Vascular plants: Elven et al. 2011

Lichens: Kristinsson 2011

Mosses: Balladin in prep.

Walker and Raynolds, 2011 draft

**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

Introduction: The nature of vegetation data

The need for an Arctic-wide vegetation database

Some history

Two approaches to vegetation classification

Is the Arctic an appropriate region for such a database?

How the Arctic Vegetation Database fits within the CAFF mandate

Conceptual framework of the Arctic Vegetation Database

The Arctic Flora Database

The Arctic Vegetation Database

How will the Arctic Vegetation Database be created?

Using the internet to make the data easily available to users

Funding

Appendix. Preliminary survey of available Arctic Relevés

International Partners

References

Photo: M.K. Raynolds

## **IV. Multi-scale satellite-based monitoring**

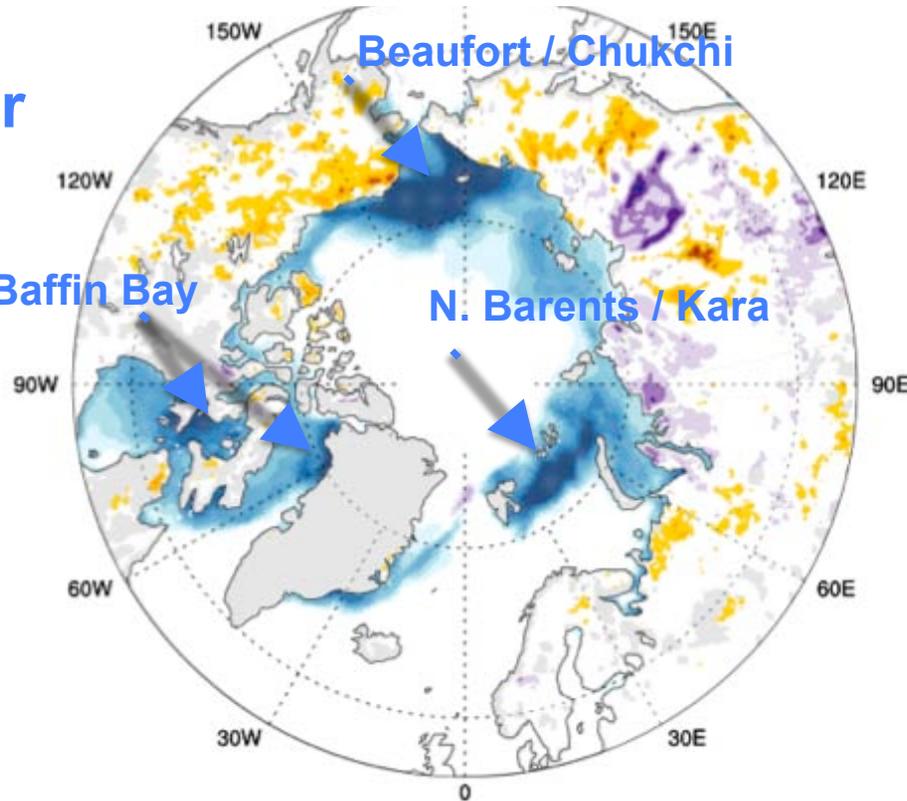
### ***A. Global-scale 1 to 25 km resolution***

- 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

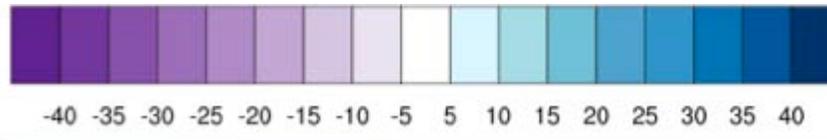
Oct-Nov 1982-2010



Sea Ice / open  
water / snow water  
equivalent  
concentrations  
Passive microwave  
sensors

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

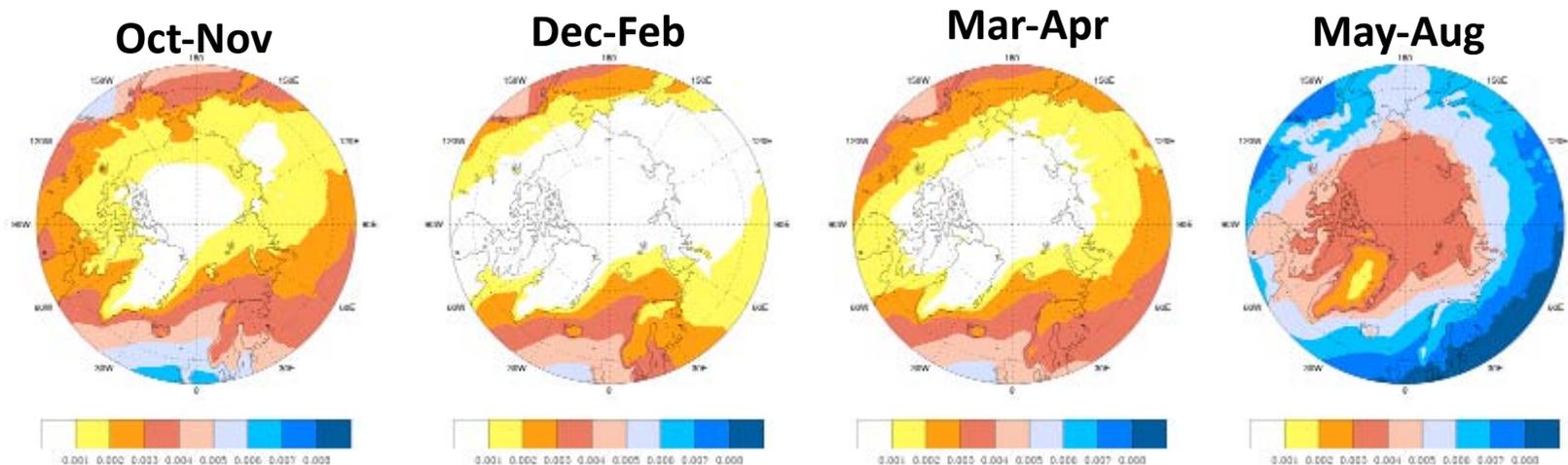
Open Water Magnitude of Change (pct.)



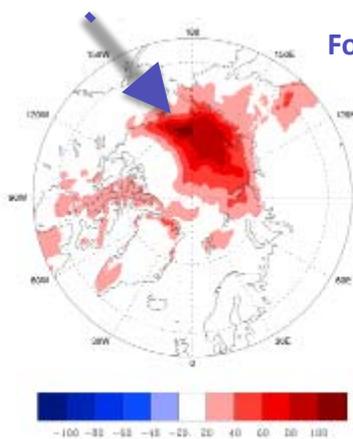
Bieniek, Bhatt, et al., in progress

# Humidity seasonal means and trends

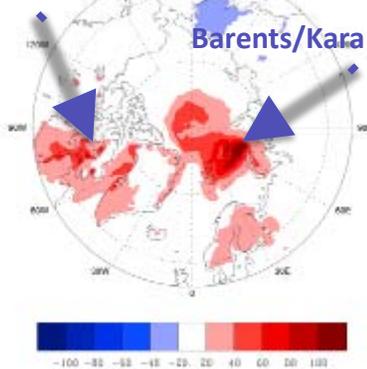
Average specific humidity ( $q$ , kg water/kg air)



Beaufort/Chukchi

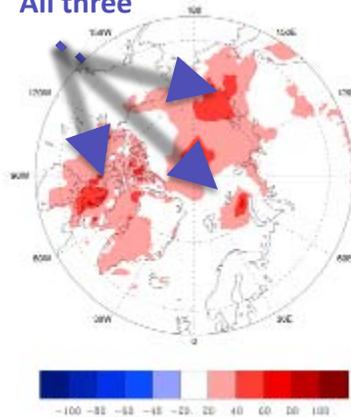


Foxe Basin/ Baffin Bay

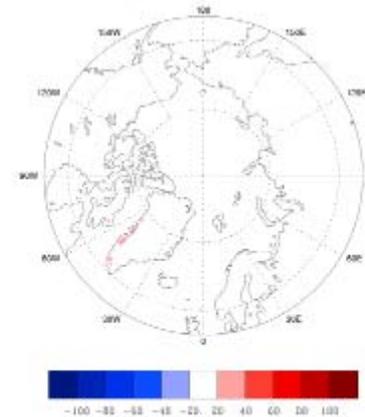


Percent Change 1979-2010

All three



Barents/Kara



Beaufort - Chukchi change occurring mainly in Fall.

Barents - Kara mainly in winter.

Fox Basin/Baffin Bay - winter and spring.

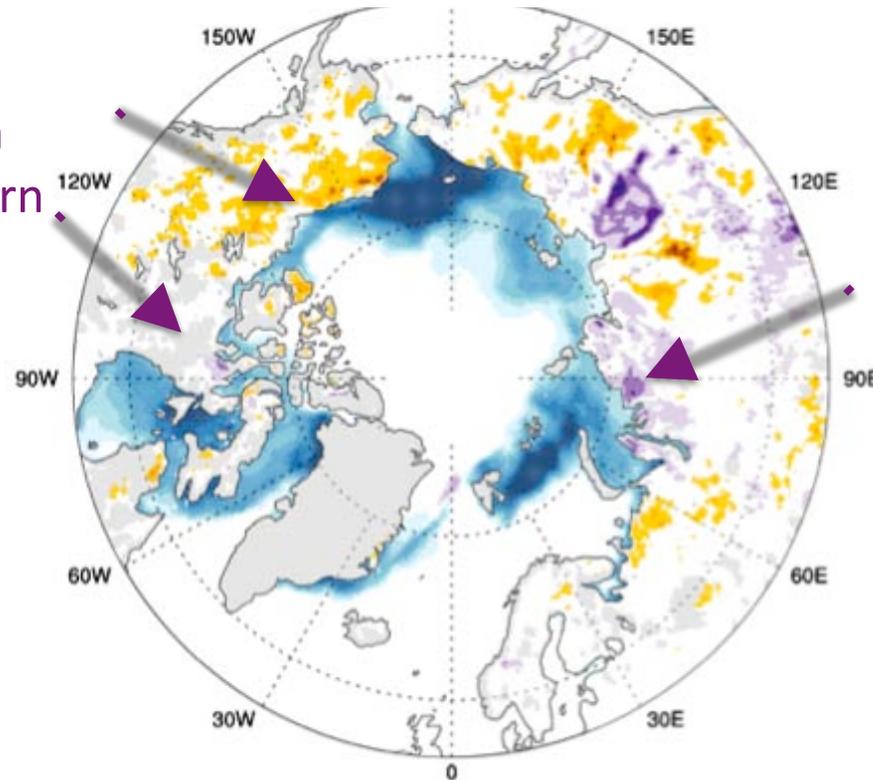
Humidity & Winds: CFSR (Coupled Forecast System Reanalysis)

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)

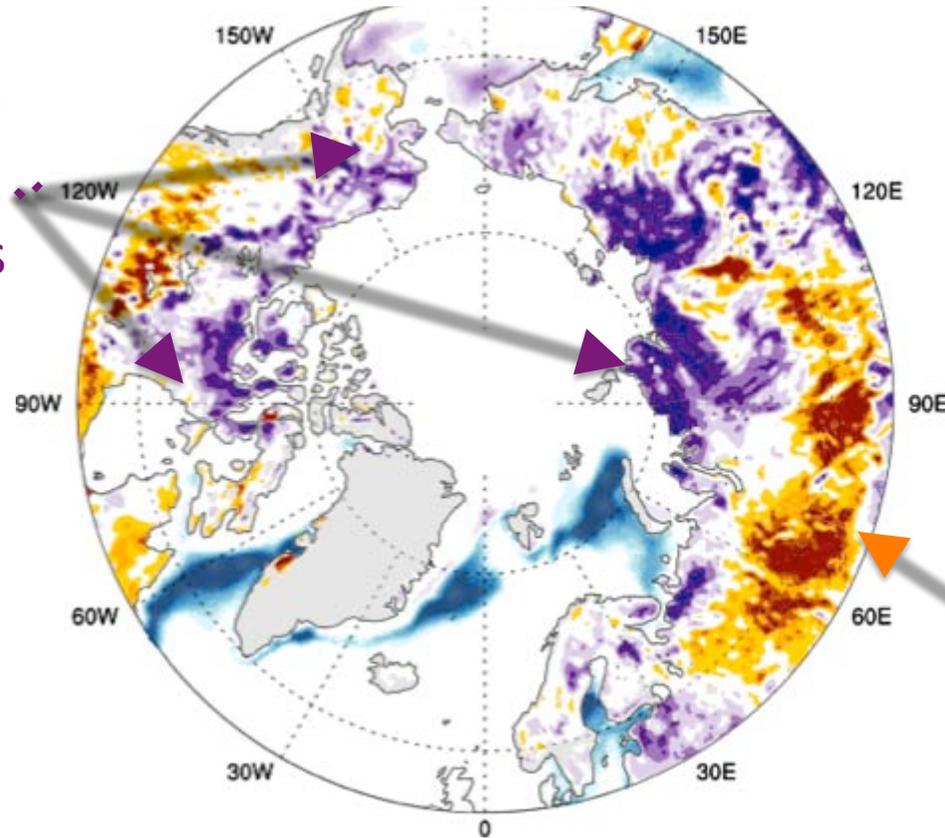


Bieniek, Bhatt, et al., in progress

# Spring Snow Trends

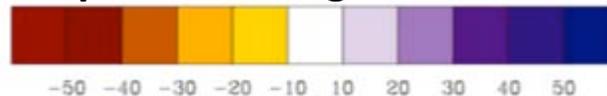
Mar-Apr 1982-2010

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.

Snow Water Equivalent Magnitude of Change (mm)

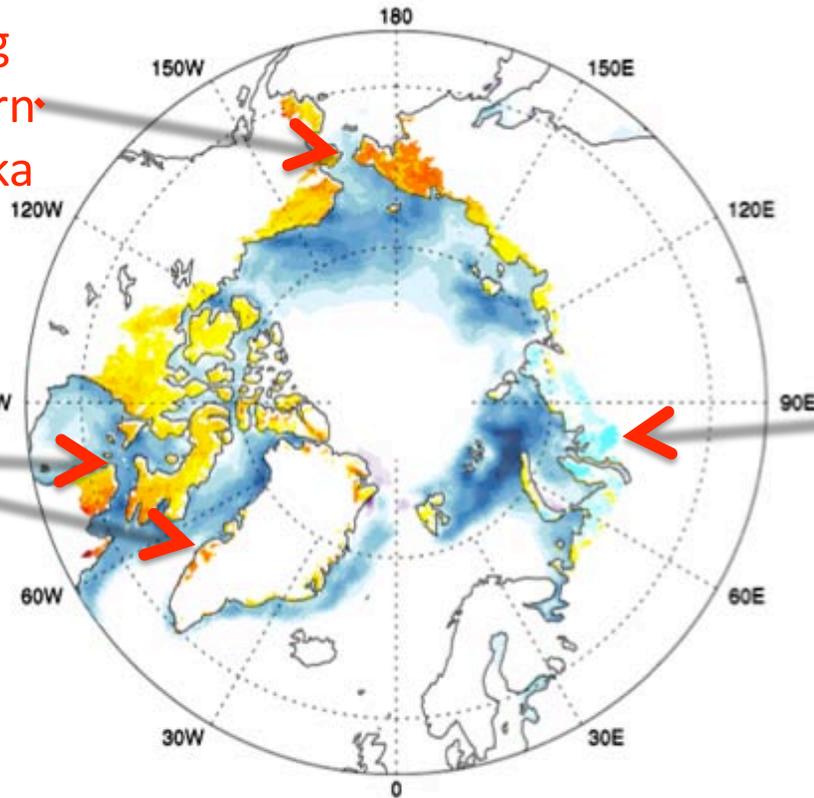


Bieniek, Bhatt, et al., in progress

# 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



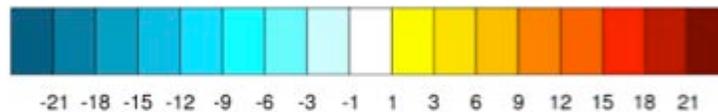
Cooling to neutral change in the Yamal/Taimyr region

**Land Temperatures:** AVHRR (25-km). SWI = sum of mean monthly temperatures above freezing ( $^{\circ}\text{C mo}$ ).

Open water (Magnitude of change, pct.)



Summer warmth index (SWI, magnitude of change,  $^{\circ}\text{C}$ )

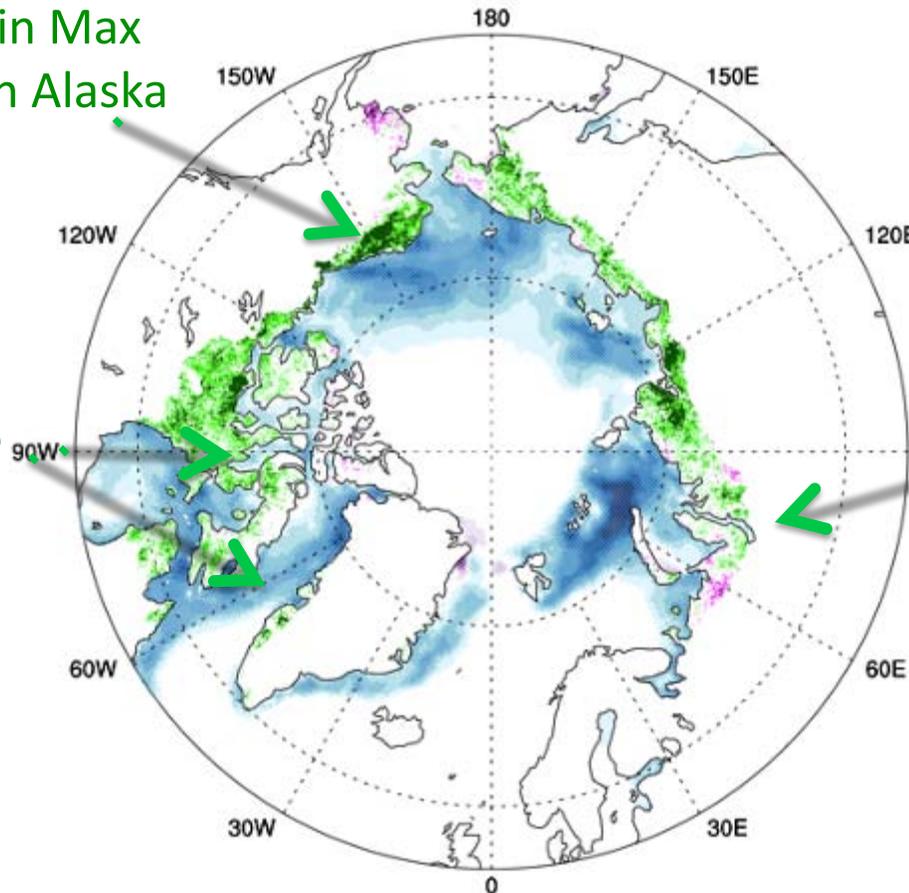


Updated from Bhatt et al. 2010

# Changes in maximum tundra greenness (MaxNDVI) 1982-2010

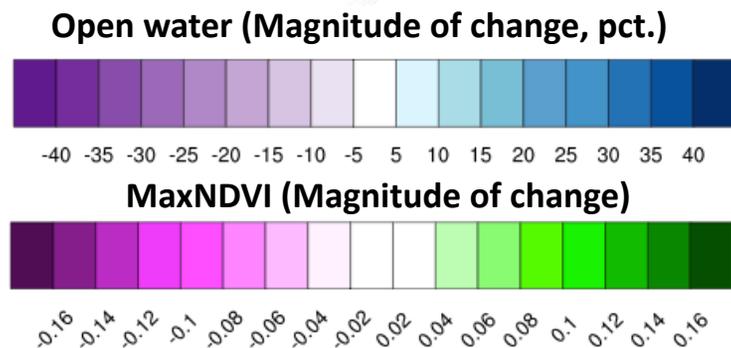
Strong increase in Max NDVI in northern Alaska and Chukotka

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

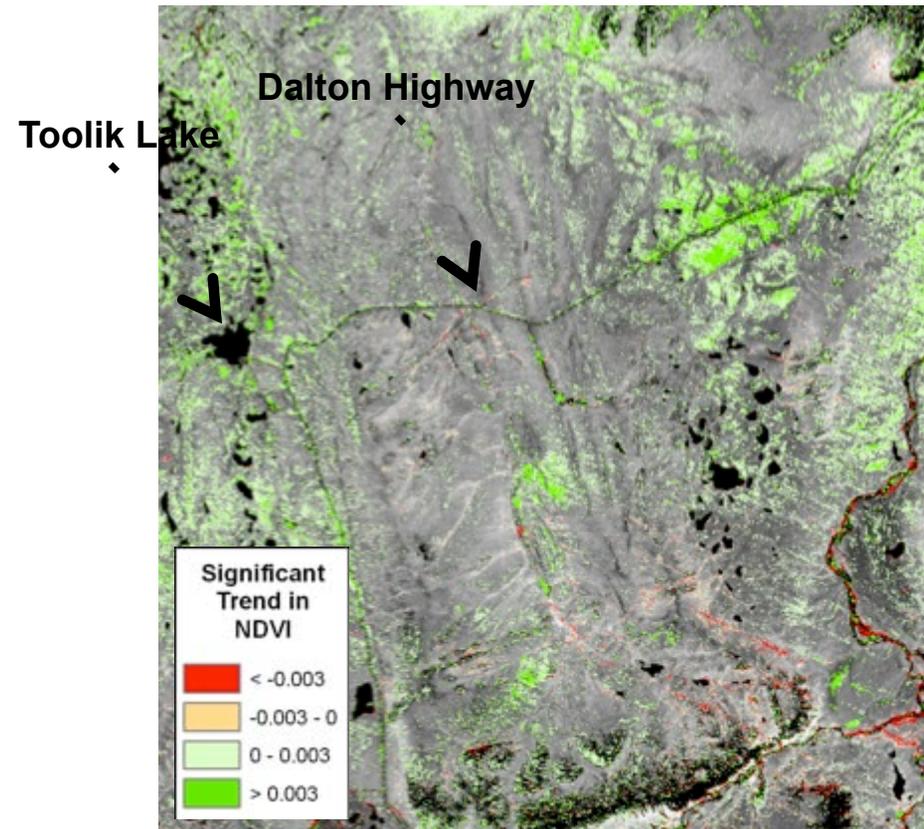
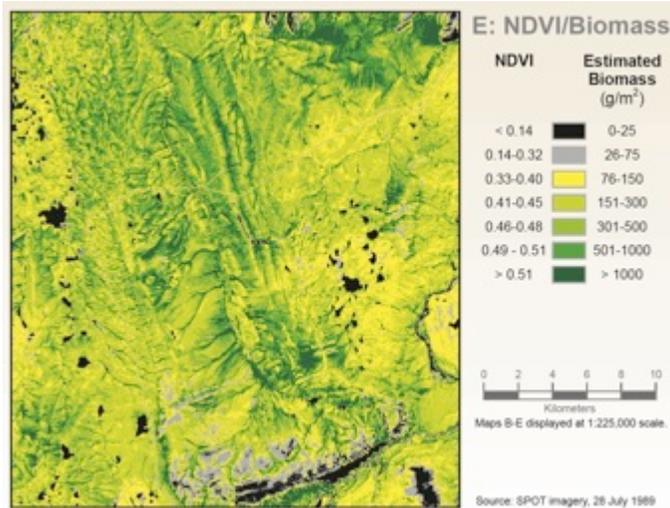


**Needed: 1) Plot-based evidence to support evidence from space.  
2) Explanations of mechanisms of change.**

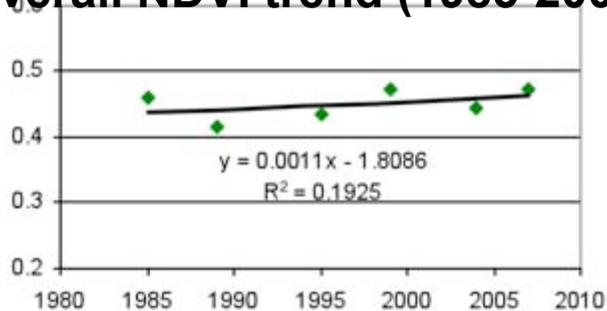
Photo: P. Kuhry, <http://www.ulapland.fi/home/arktinen/tundra/tu-taig.htm>:

## 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)



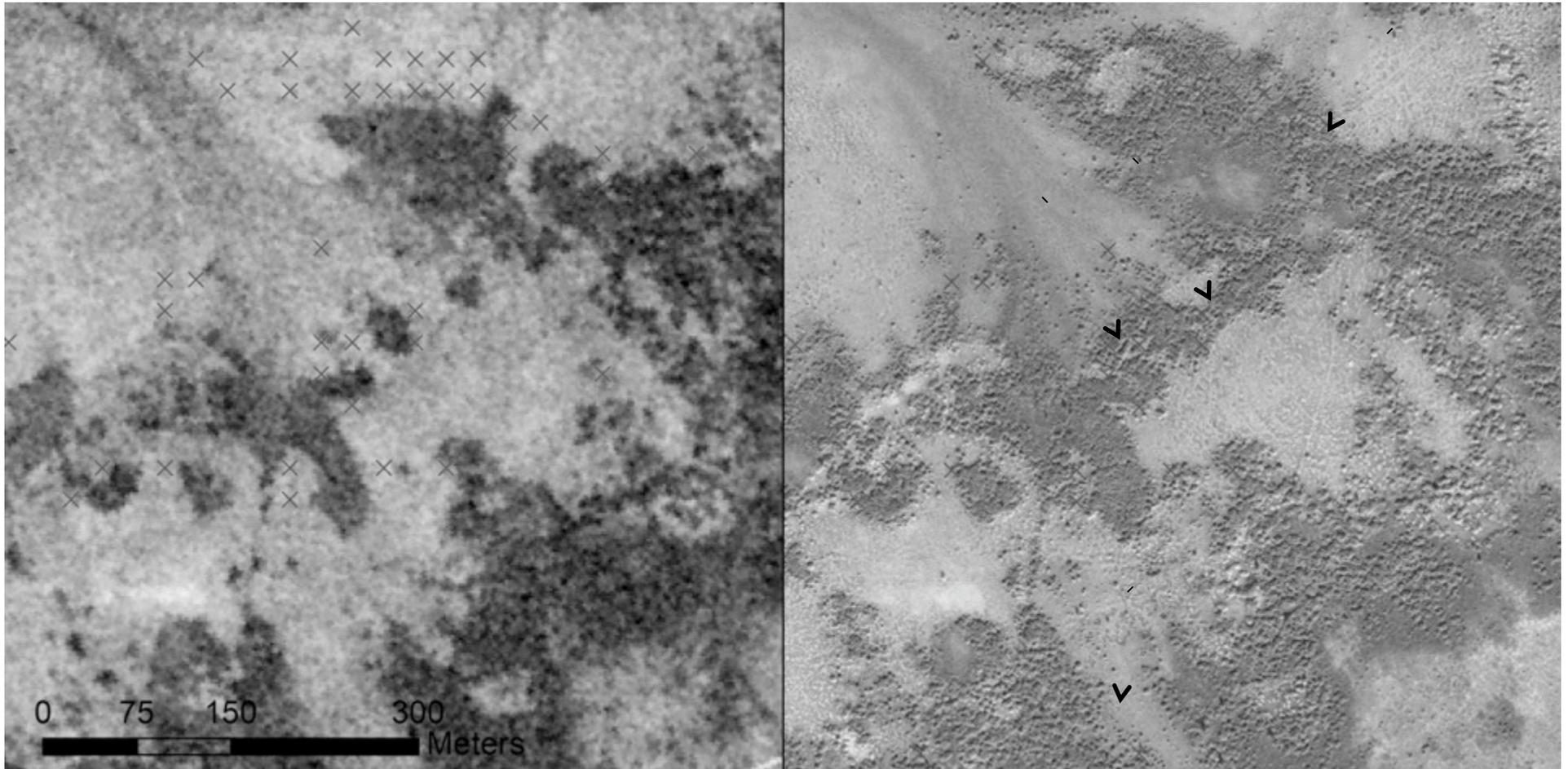
**+3.2% Landsat**  
**+13.8% AVHRR, GIMMS3g**

- 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.

# 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

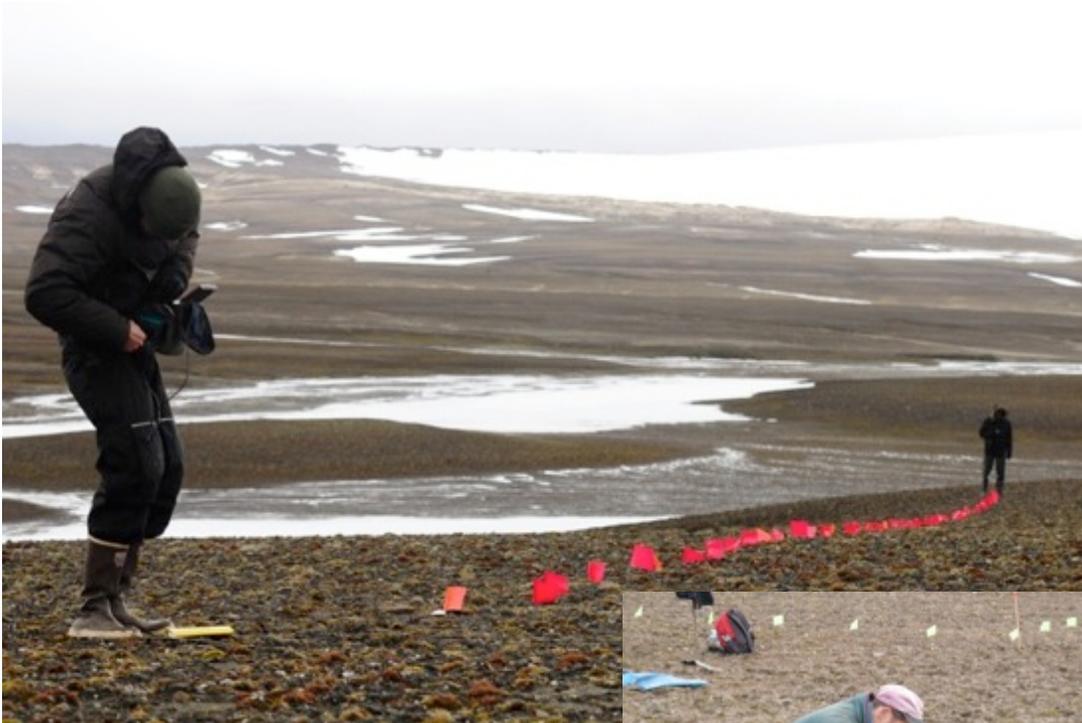
2003 Quickbird



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   ■ Biology   ■ Greenland  
■ Sea Ice   ■ Ocean   ■ Land

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



0:00 / 3:01

**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

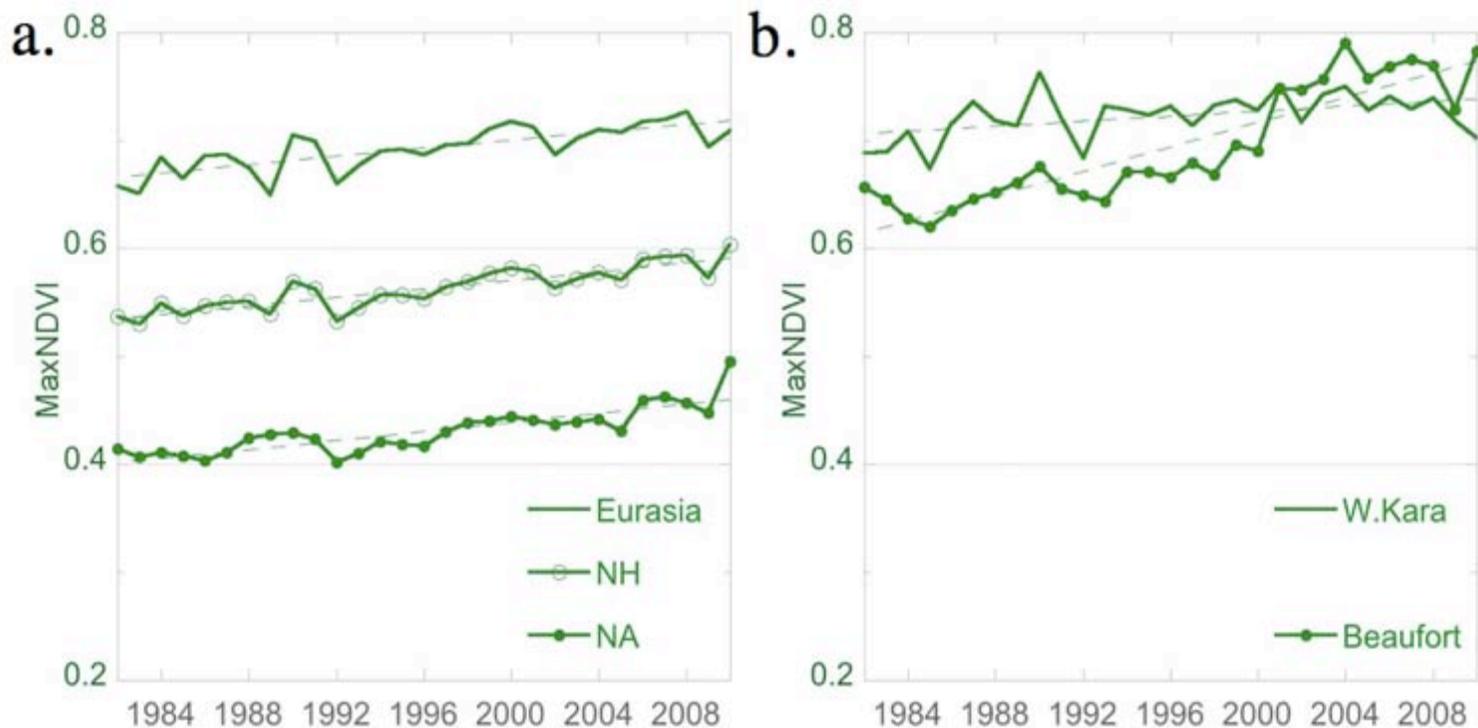
[About the Report Card](#)

[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.**