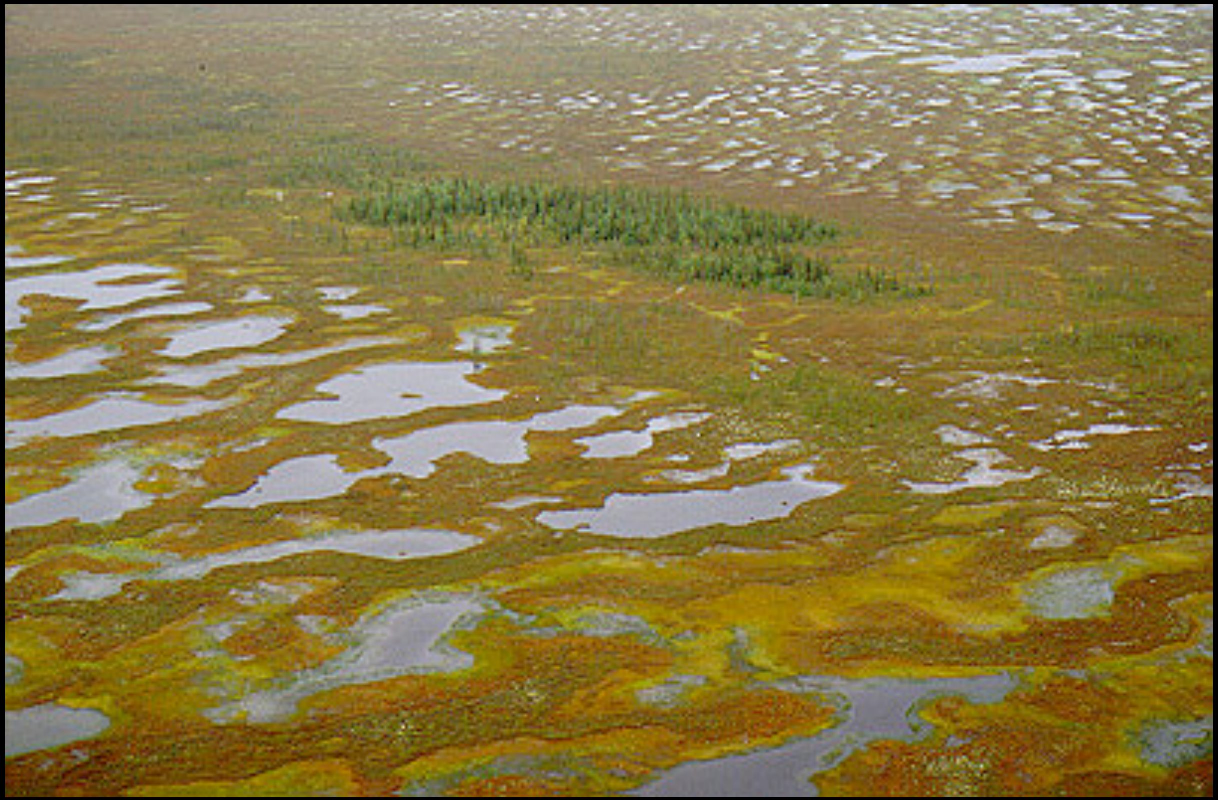
Ignatius Rigor video 1979-2009 multi-year sea ice

- http://dotearth.blogs.nytimes.com/2010/03/22/new-light-shed-on-north-pole-ice-trends/

Lesson 6
Greening of the Arctic: Climate change and circumpolar Arctic vegetation



A review of some current approaches to look at long-term tundra changes

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

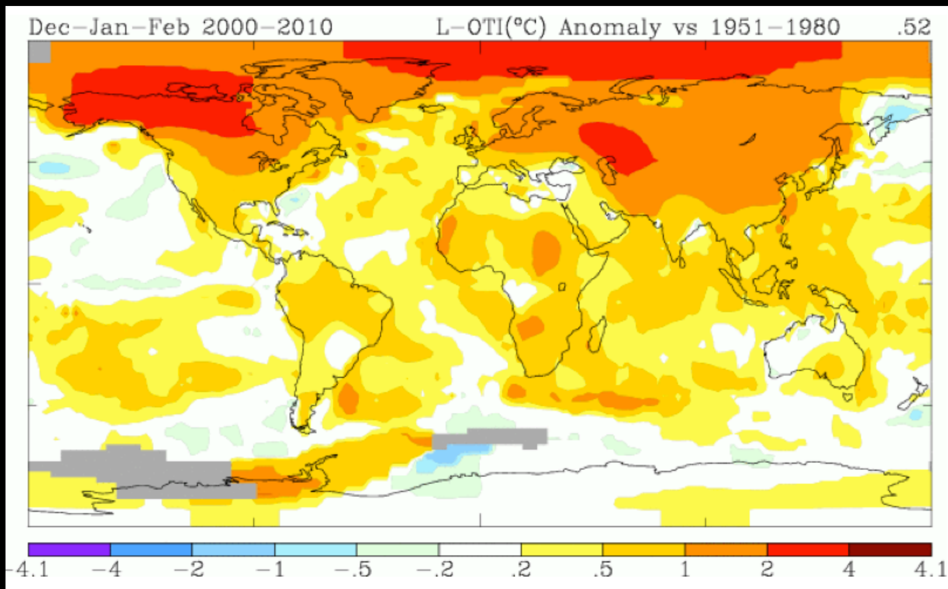
Fulbright Lectures by: D.A. Walker
at Masaryk University, Spring Semester, 2011

Overview of lecture

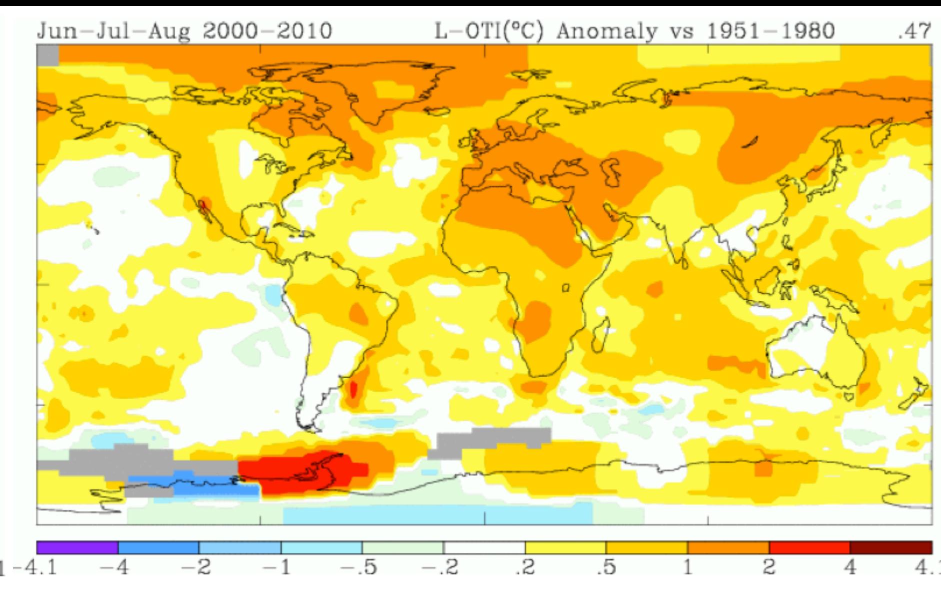
- Overview of trends in Arctic temperatures and sea ice.
- Global trends in in near-shore open water, land-temperatures and vegetation greenness observed from space (Bhatt et al. 2010, Walker et al. 2011).
- Review of remote sensing and ground observation methods.
- Examples of change from repeat photographs (Tape et al. 2006).
- The preliminary results from the Canadian International Tundra Experiment (ITEX; Henry 2010).
- Examples from the Back to the Future (BTF) observations (Webber 2010, Daniels 2011).
- Summary

Trend in surface temperatures

Dec-Feb Anomalies (2000-2010)



Jun-Aug Anomalies (2000-2010)



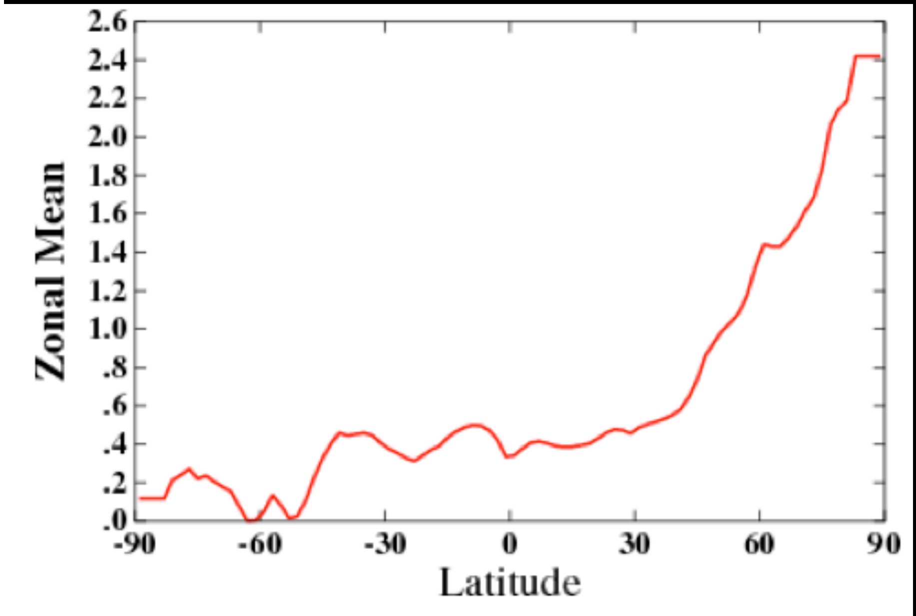
Courtesy of NASA: http://data.giss.nasa.gov/cgi-bin/gistemp/

Land-surface temperatures of North America north of 60° N rose at rate of 0.84± 0.18 ° C per decade since 1978 and 2006 (Comiso 2006).

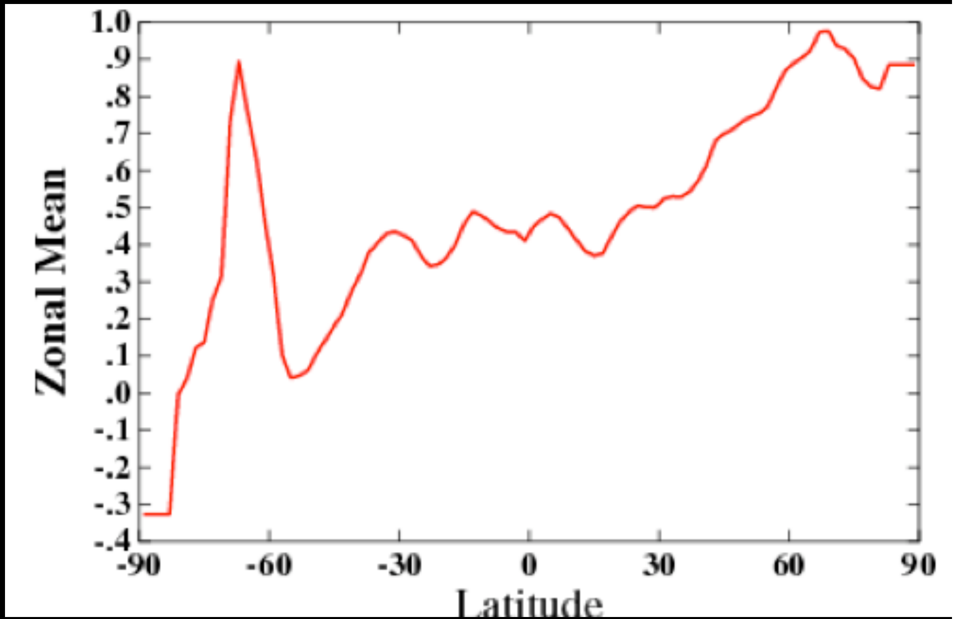
Arctic plant biomass and diversity are strongly related to total amount of available summer warmth, so changes in surface temperatures will likely result in increased biomass over much of the Arctic.

Mean anomalies by latitude

Dec-Feb (2000-10)

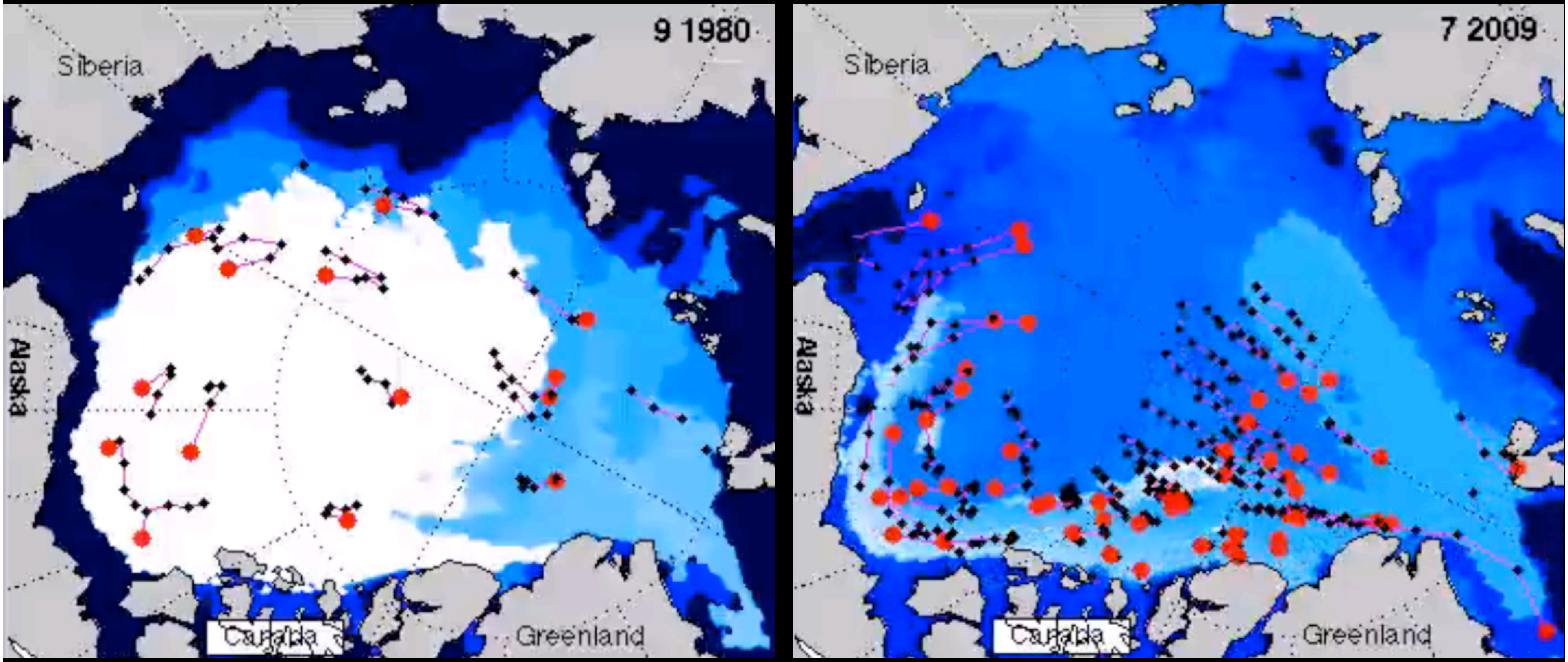


Jun-Aug (2000-10)



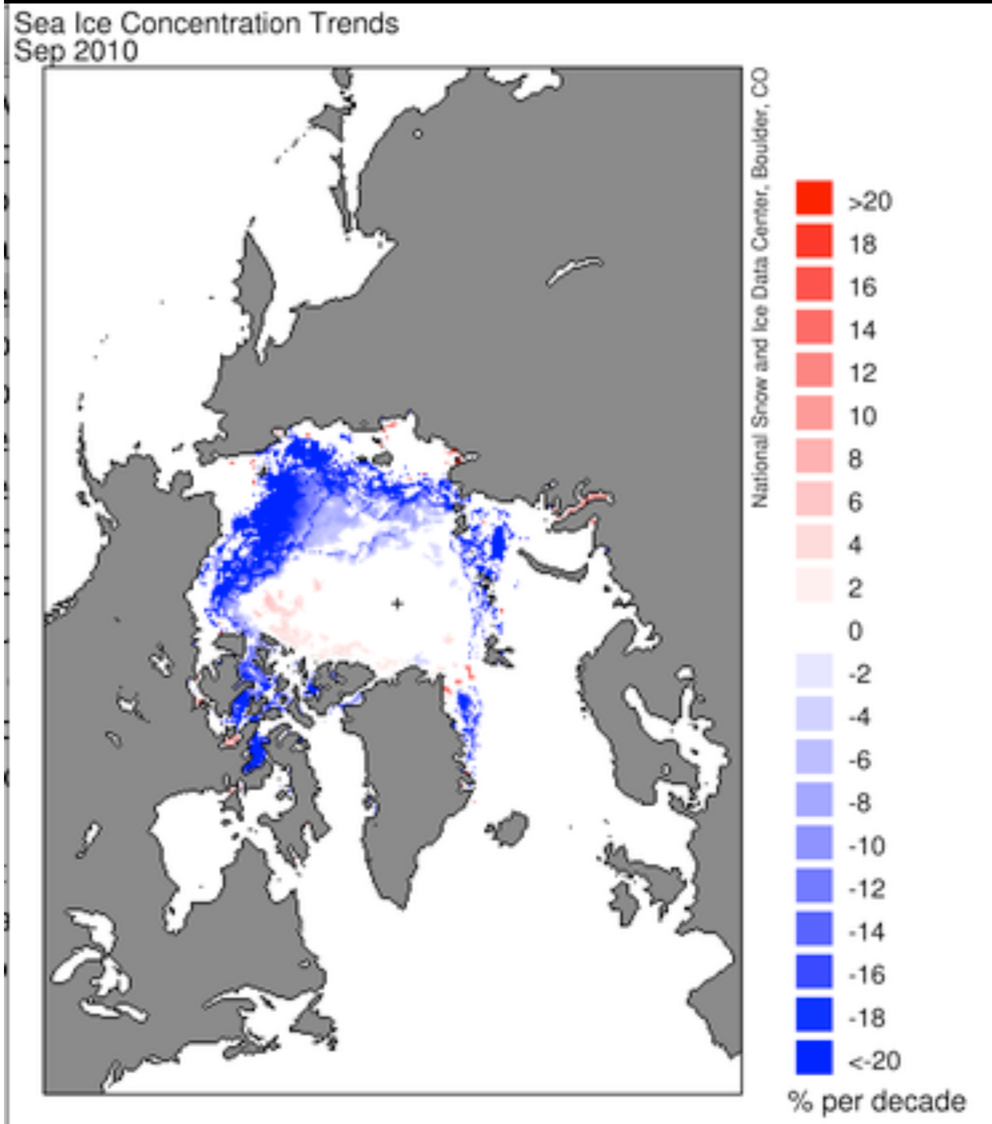
Winter anomalies north of 60˚N are 1.5-2.5 ˚C.
Summer anomalies north of 60˚ N are 0.8-1.0 ˚C.
Note negative anomalies in Antarctica except

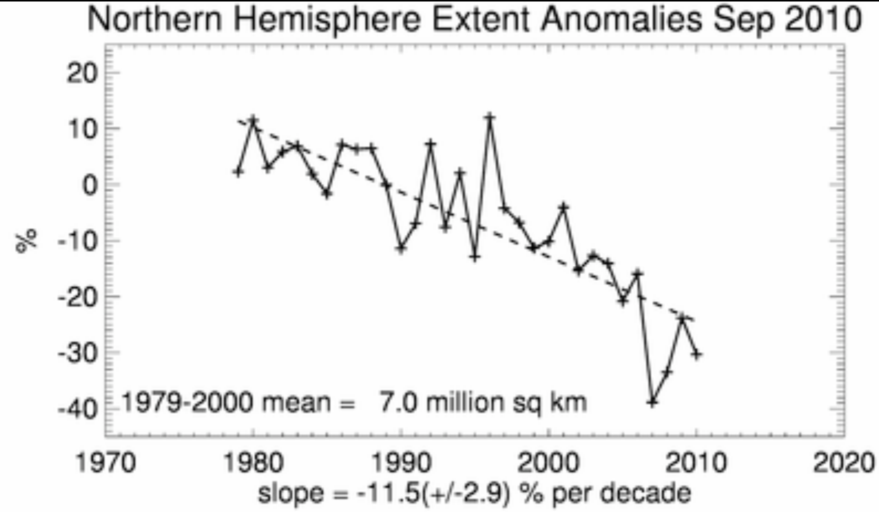
Change in multi-year sea ice



Rigor and Wallace 2004, updated to 2009

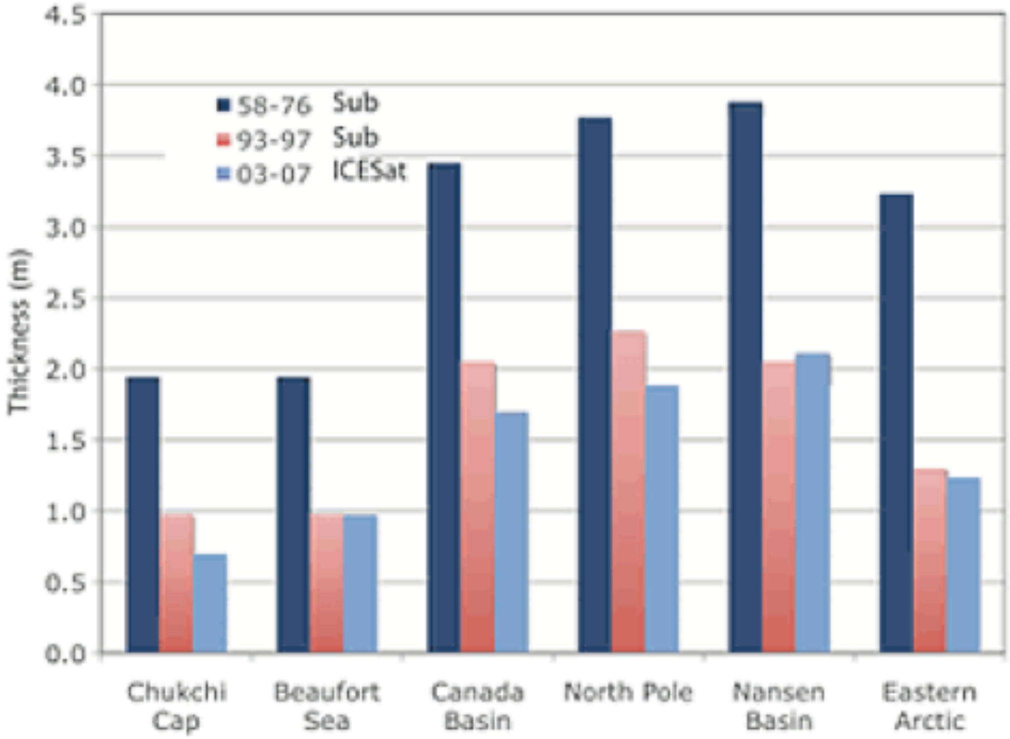
Sept 2010 Sea Ice concentration, change %/decade

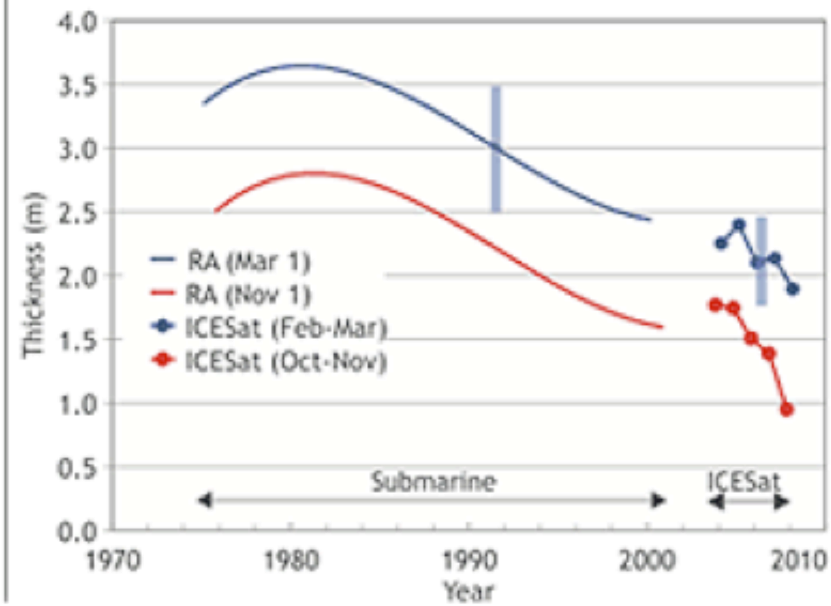




Courtesy of NOAA: ftp://sidads.colorado.edu//DATASETS/NOAA/

Ice thickness measured with submarine sonar and ICESat



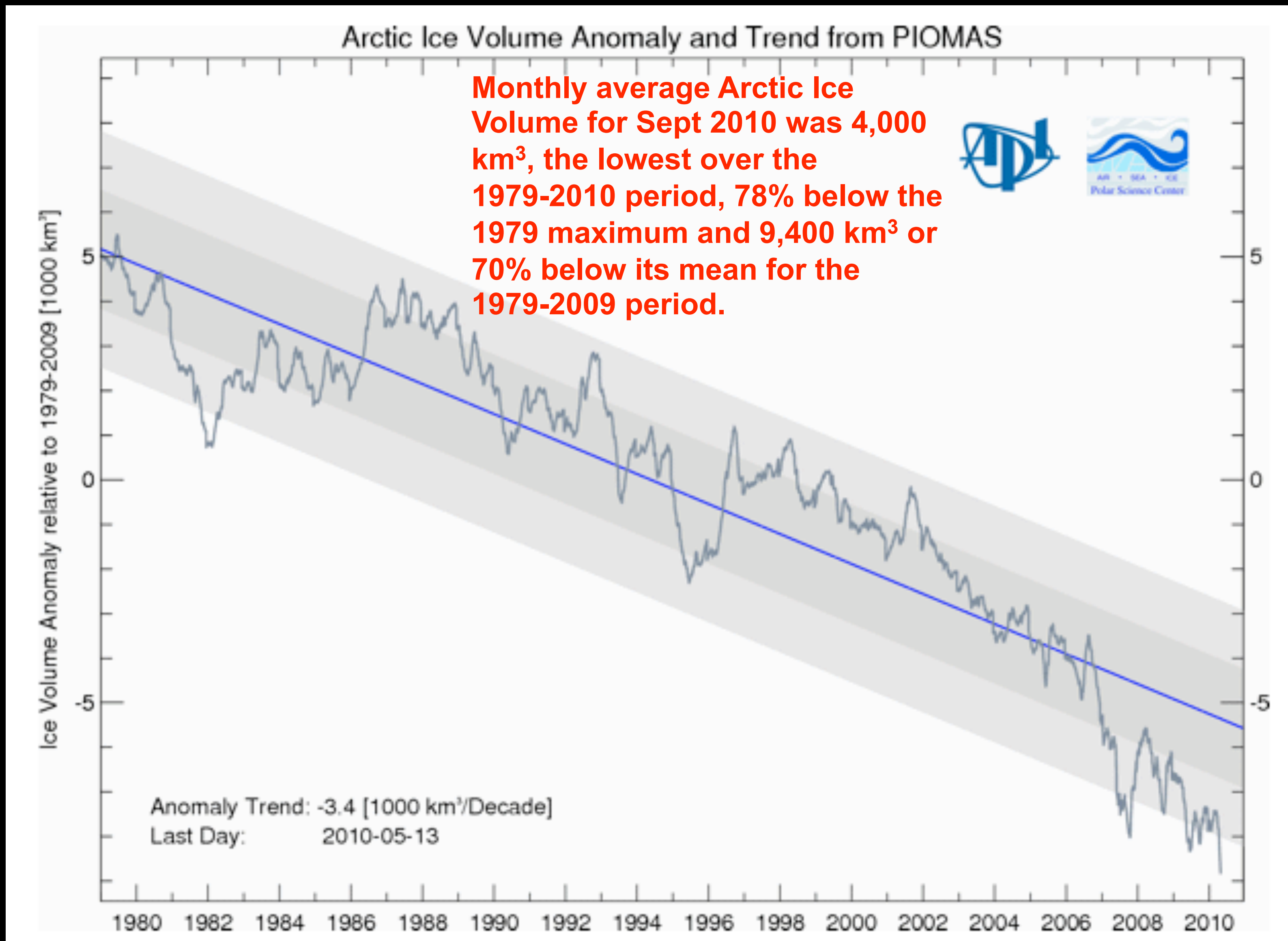


Thickness in different ocean basins. Two internvals with submarine sonor (58-76 and 93-97) and one with ICESat (03-07).

Minimum mean sea ice thickness (Nov, red lines) declined from 2.8 m in early 1980s to less than 1.0 m in 2009.

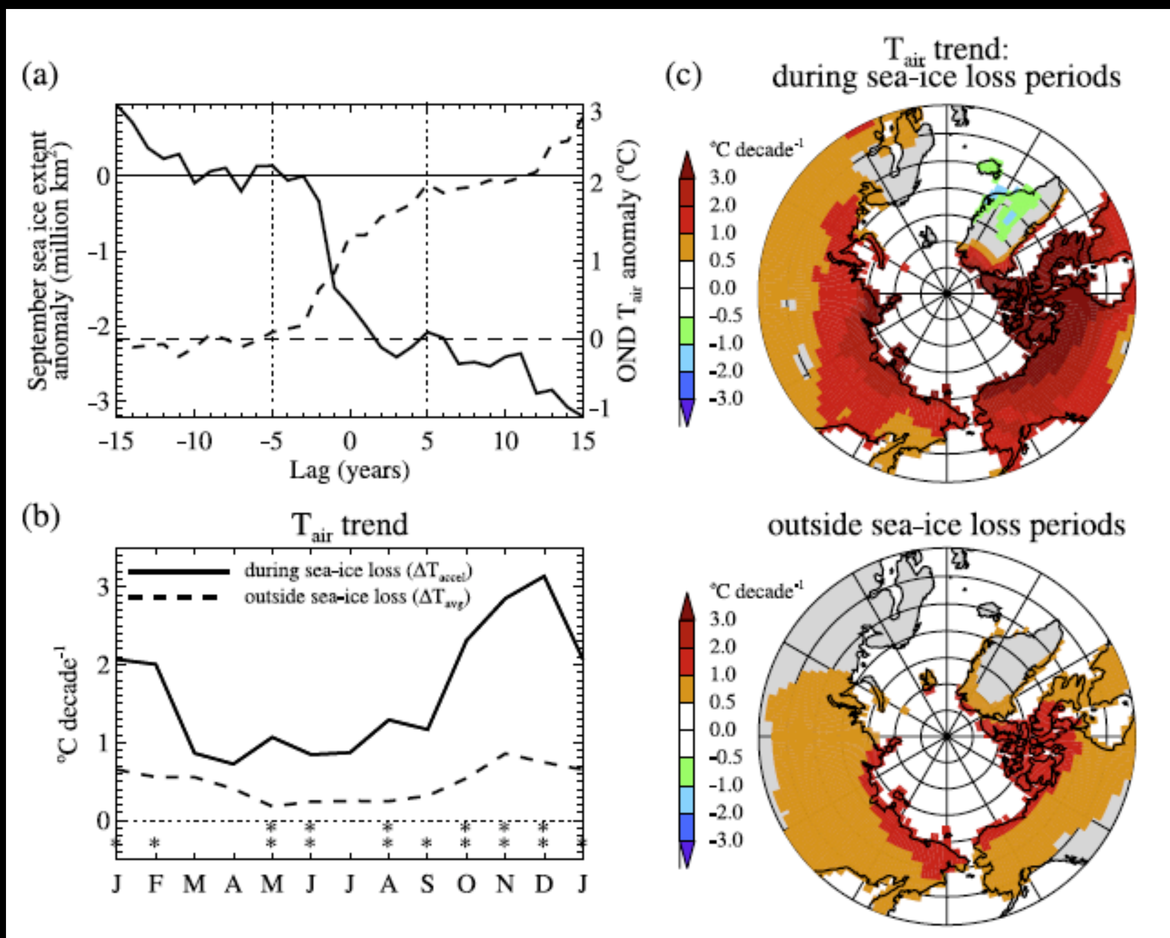
Kwok and Rothrock 2009

Ice volume



Arctic Ice Volume Anomaly and Trend from PIOMAS
Monthly average Arctic Ice Volume for Sept 2010 was 4,000 km³, the lowest over the 1979-2010 period, 78% below the 1979 maximum and 9,400 km³ or 70% below its mean for the 1979-2009 period.
Ice Volume Anomaly relative to 1979-2009 [1000 km³]
5
0
-5
Anomaly Trend: -3.4 [1000 km³/Decade]
Last Day: 2010-05-13
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010

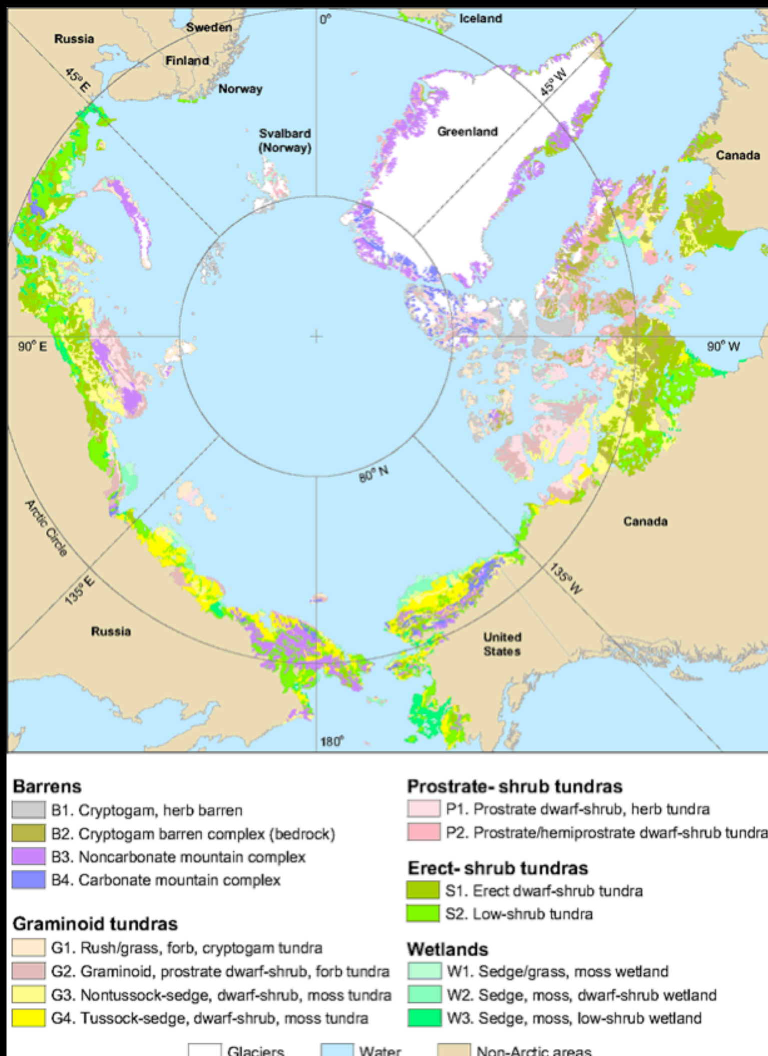
Modeled projected effect of melting sea ice on land surface temperatures



- Land warming trends during rapid sea ice loss are 3.5 times greater than secular 21st century climate-change trends.
- The warming signal penetrates up to 1500 km inland and is apparent throughout most of the year, peaking in autumn.

Lawrence and Slater 2008, GRL

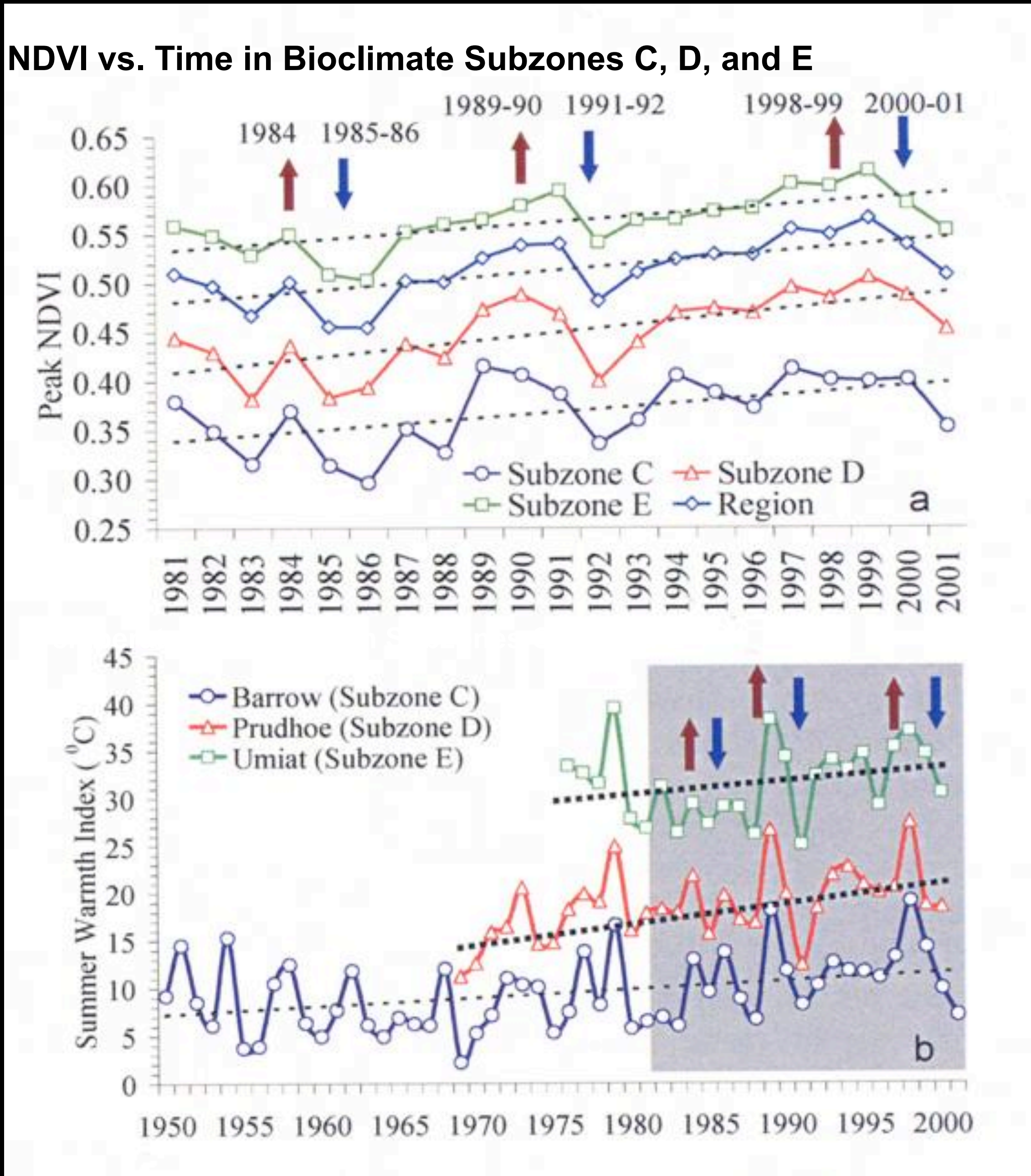
The Arctic tundra is a maritime biome



Walker, D. A., 2005. The Circumpolar Arctic Vegetation Map. Journal of Vegetation Science.

Map by Hilmar Maier.

- 61% of the tundra is within 50 km of sea ice (blue buffer).
- 80% is within 100 km (magenta and blue buffers).
- 100% is within 350 km (all colors).
- Changes in the Arctic ocean sea ice will very likely affect terrestrial ecosystems.

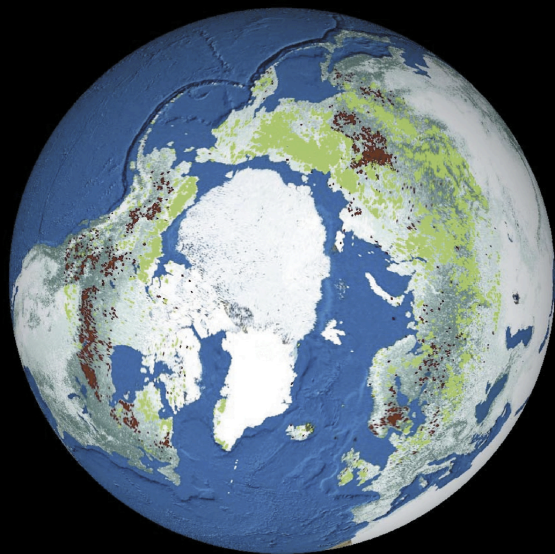


Jia et al. 2003 *Geophysical Research Letters.* 30: 2067.

What caused the concern: Time series of peak NDVI for northern Alaska (1981-2001)

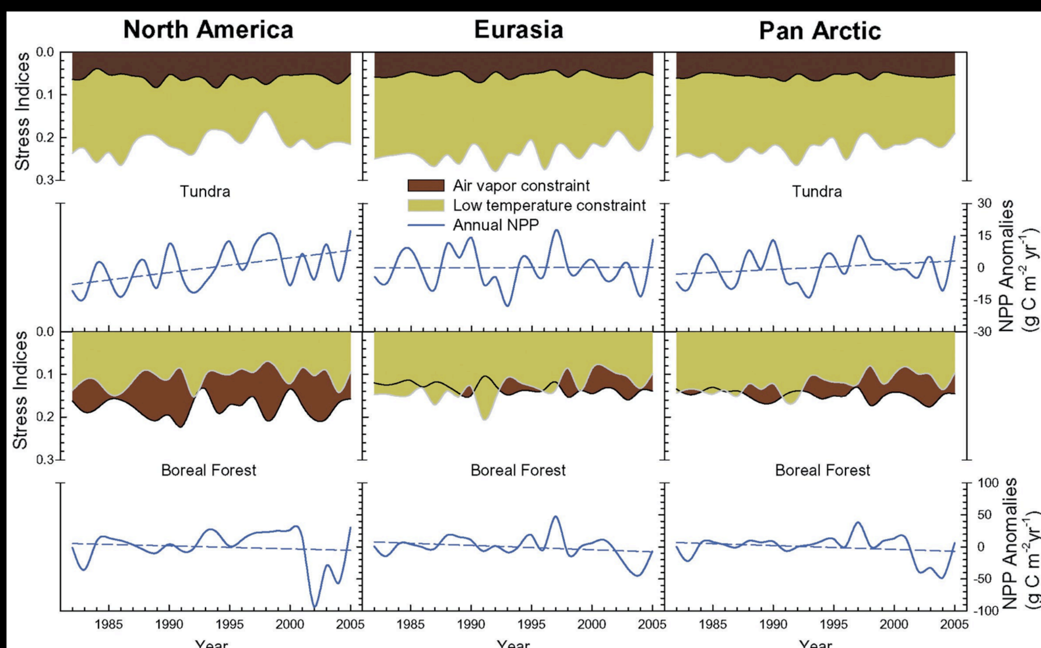
- 17 ± 6% increase in peak NDVI from 1981-2001.
- Available biomass data indicate that this increase in NDVI corresponds to about a 150 g m-2 increase in biomass.
- Changes in NDVI show a long term increase and also some correspondence to yearly fluctuations in temperature.

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



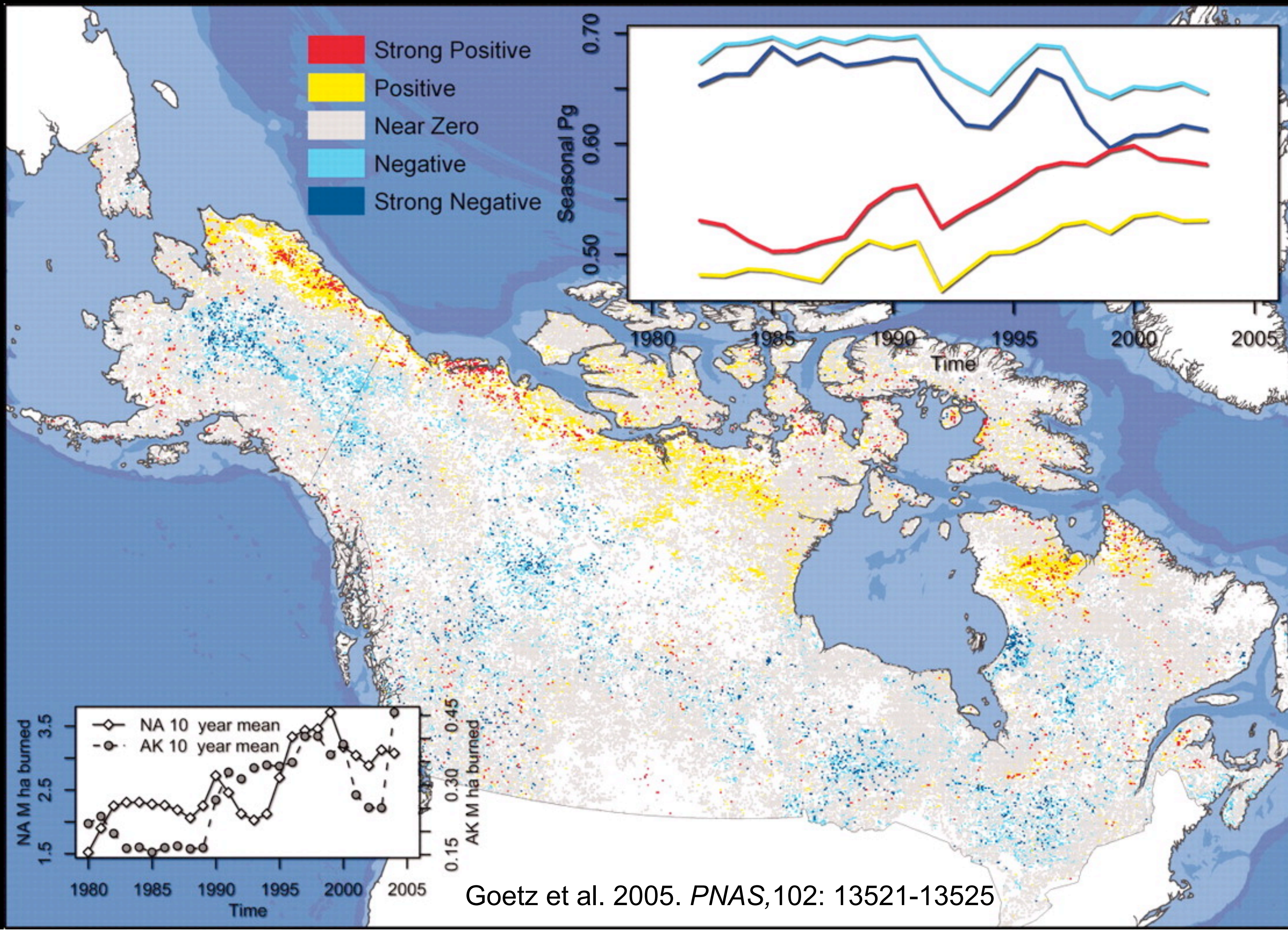
Green: increasing NDVI
Red: decreasing NDVI
White: no trend

- 88% of the region is shows no significant trends in NDVI. 3% have decreasing trends, and 9% have increasing trends.
- Most of the positive changes are in tundra areas, particularly in North America.
- Forest areas are showing an overall decline in NDVI.



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

1981-2003 Trends in NDVI across Canada and Alaska



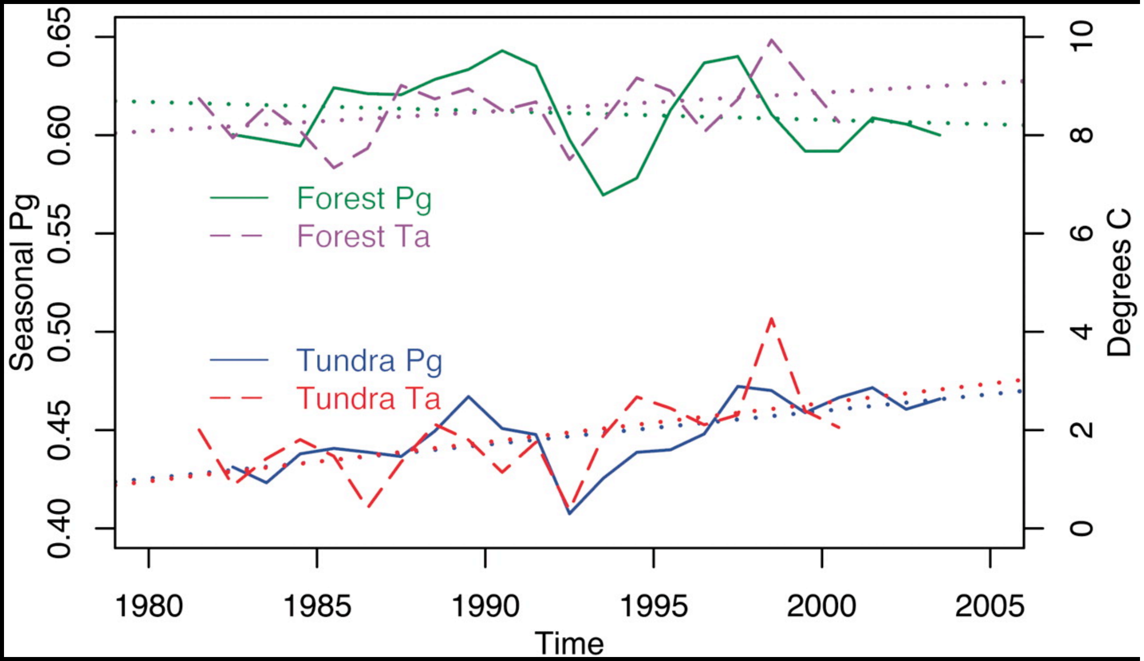
Goetz et al. 2005. *PNAS,*102: 13521-13525

Trends in temperature and NDVI in the forest and tundra

- Temperature has increased in both the forest areas and the tundra.

- NDVI has declined in the forest and increased in the tundra following the Pinatubo eruption in 1991.

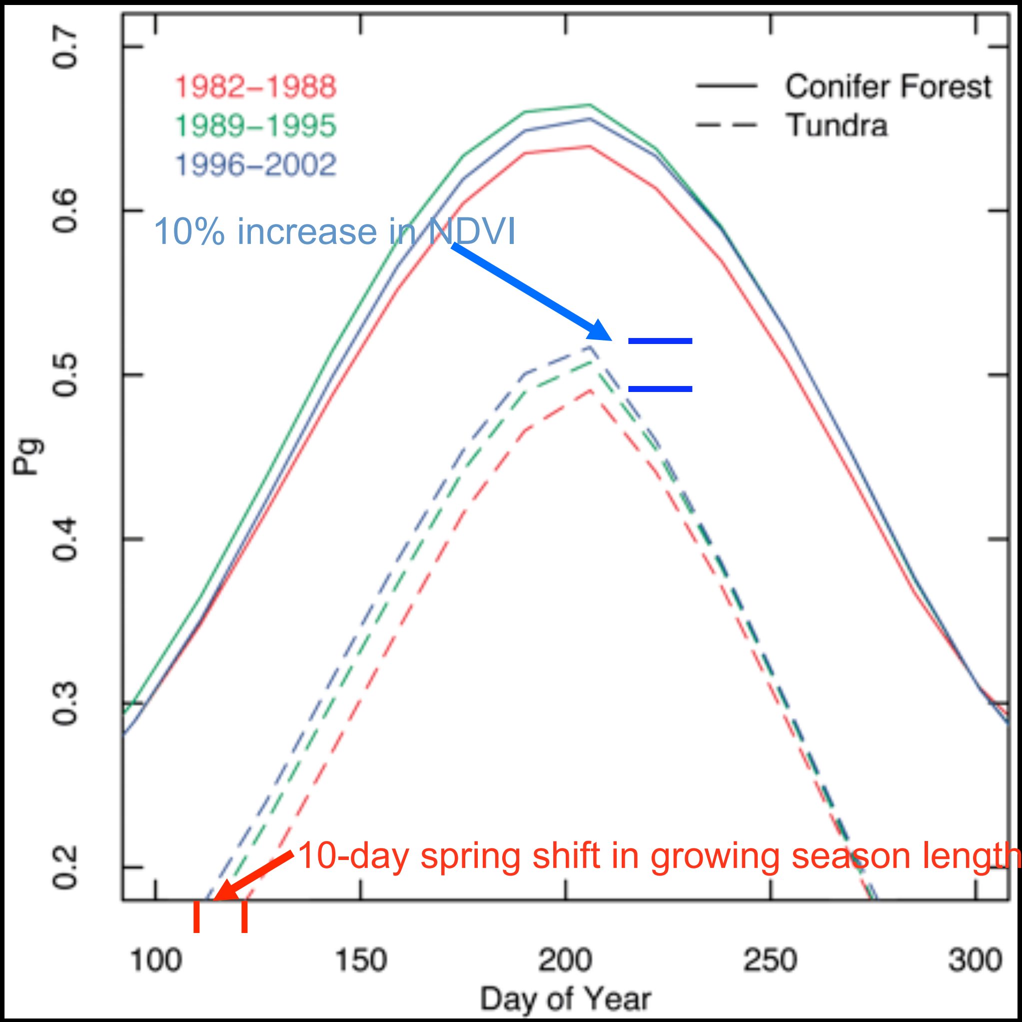
- Decline in the forests may be due to drought stress.



Goetz et al. 2005. *PNAS,*102: 13521-13525

The spring season has started earlier and max NDVI has increased

- NDVI trends for the forested and tundra regions, broken down by six-year intervals.
- The forested areas show a recent decline in the maximum Pg.
- Tundra regions have shown a continued increase in Pg and a marked 10-day shift toward earlier onset of greening.
- There is no corresponding shift in the cessation of the greening period.



Goetz et al. 2005. *PNAS,*102: 13521-13525

Why changes to the vegetation are important

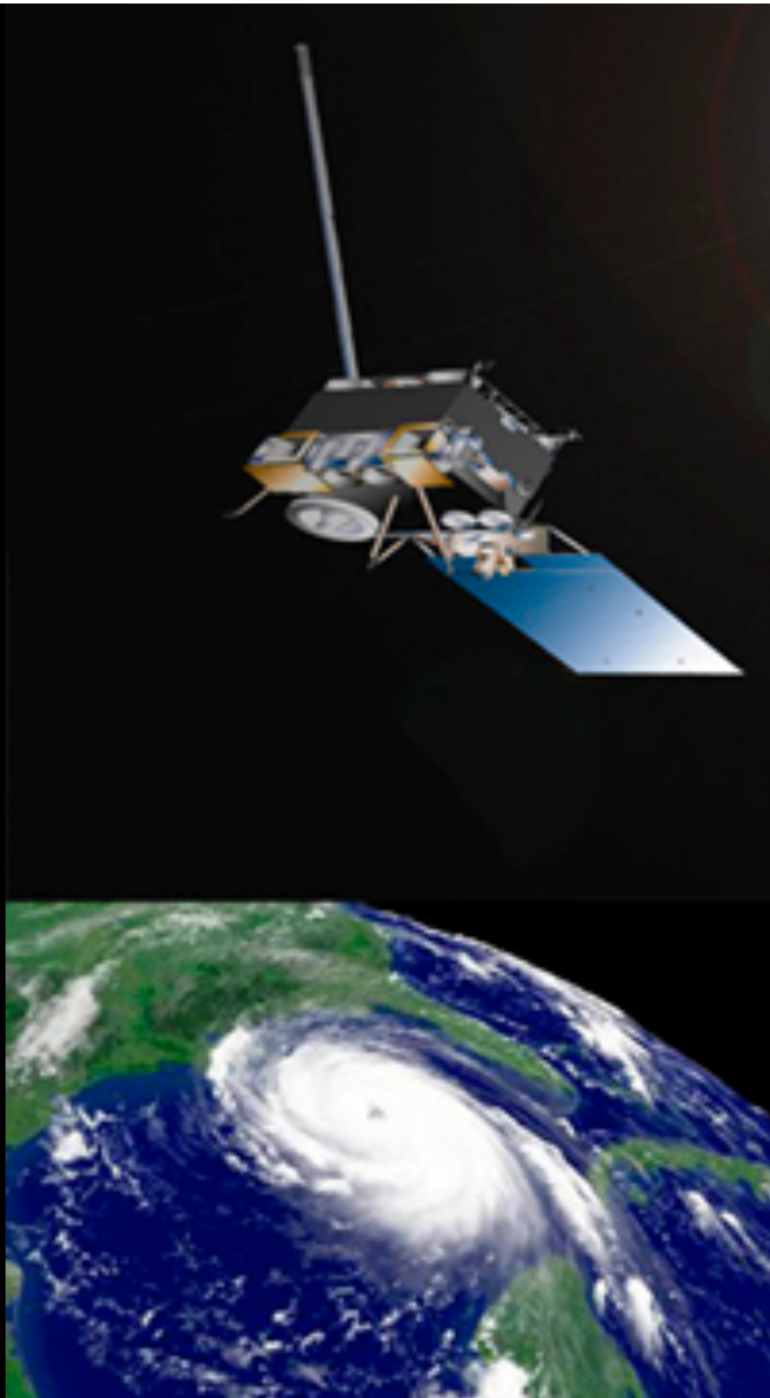
- Vegetation changes have major implications for the
  - carbon cycle (McGuire et al. 2000, Shaver et al. 2000, 2001; Oechel et al. 2000)
  - active layer (Nelson et al. 1987, Walker et al. 2003),
  - snow distribution (Sturm et al. 2001, 2005),
  - hydrology (Hinzman et al. 2005),
  - soils (Ping et al. 2004),
  - wildlife (Griffith et al. 2003),
  - trace-gases (Oechel et al, 2000, 2001; Reeburg et al. 1998; Eugster et al. 2005).
  - and albedo feedbacks to the climate system (Chapin et al. 2005),
  - …ultimately to people living in the Arctic and to the planet as a whole (ACIA, 2004, Sturm et al. 2003; Serreze et al. 2000; Overland et al. 2004, Overpeck et al. 2005, Hinzman et al, 2005).

There are many complex feedbacks between vegetation and all of these factors.

Changes to the above-ground carbon pool will have profound effects on nearly all Arctic system properties

Greater above-ground biomass will:

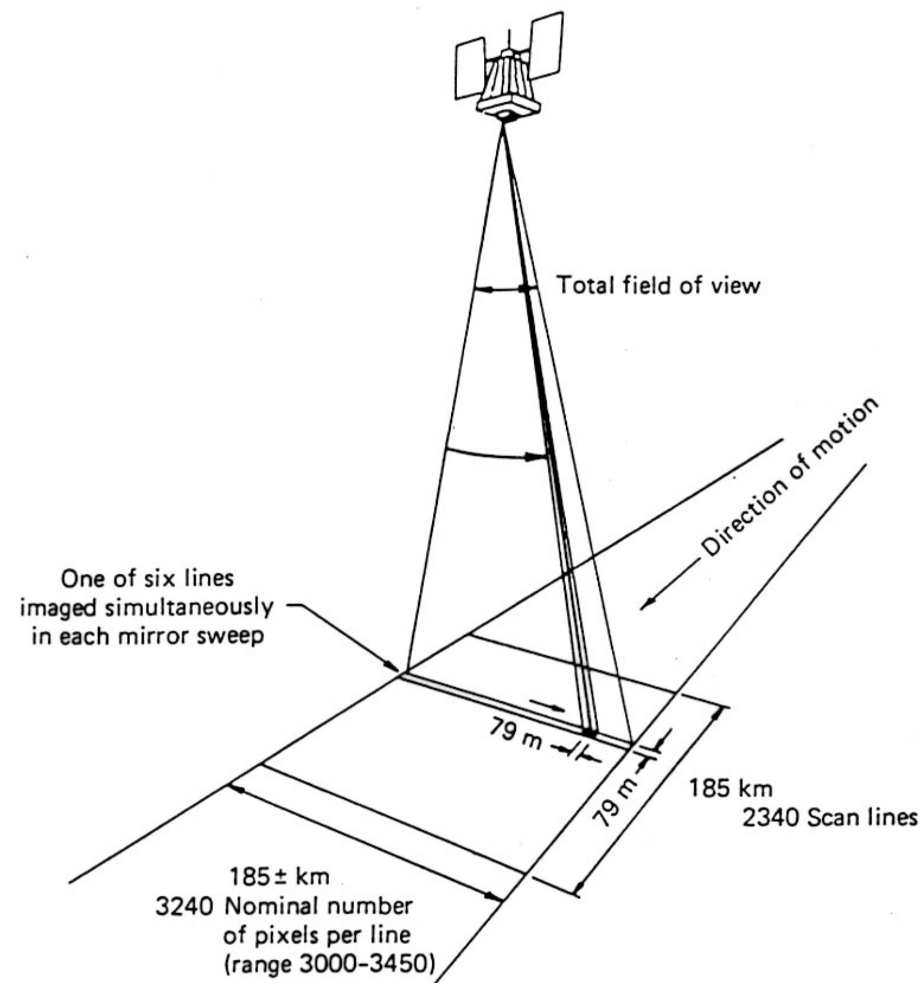
- Increase below-ground carbon reserves
- Reduce heat flux to the soils
  - Lower soil temperatures
  - Decrease active layer depths
  - Permafrost temperatures unaffected
- Trap more snow and water
  - Increase flux of moisture to the atmosphere
  - Decrease run-off of fresh water to the Arctic ocean
- Paludify the High Arctic to look more like the Low Arctic



First a review of remote sensing of Arctic vegetation and ground observation methods

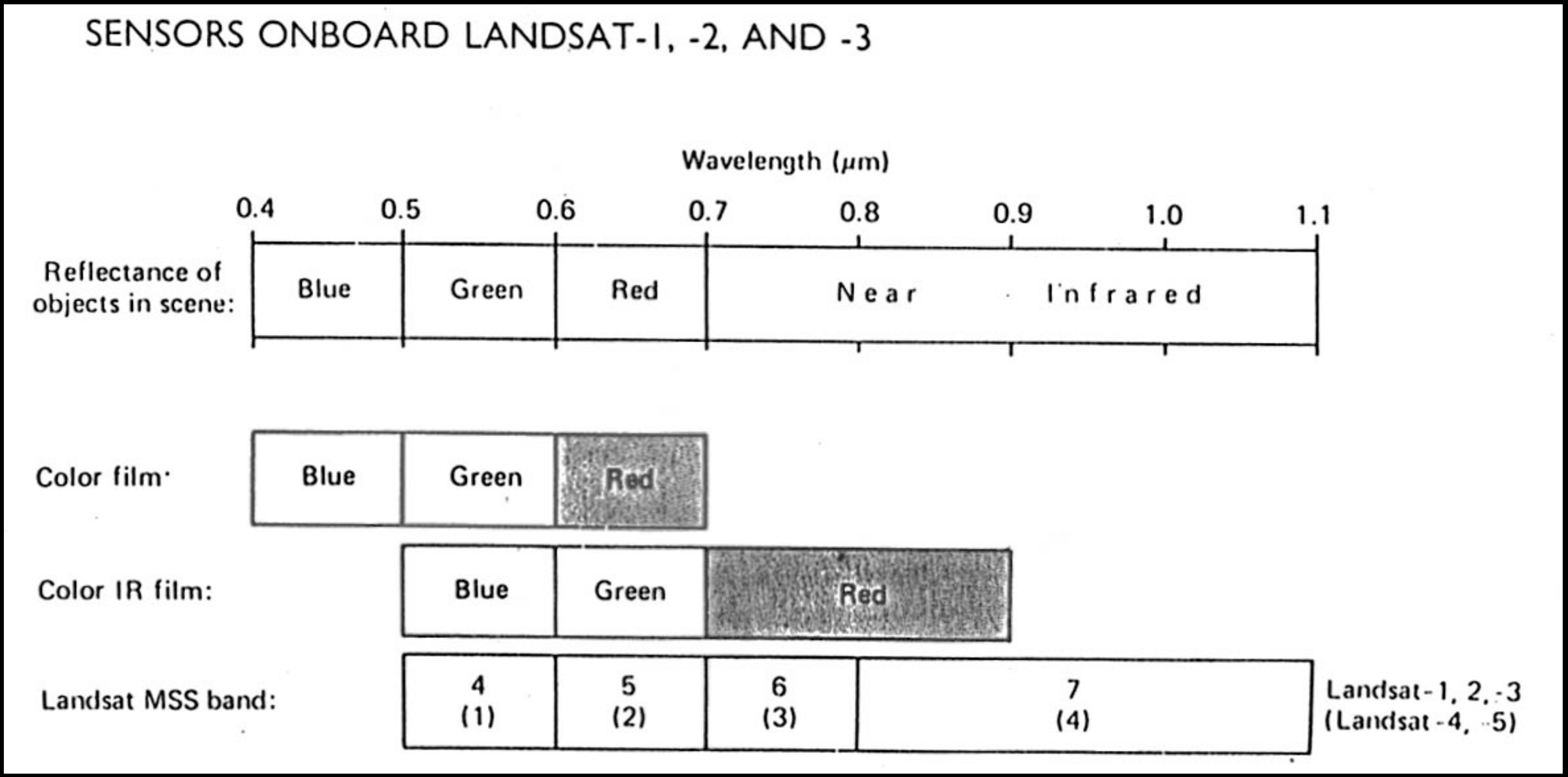
Landsat Multi-spectral sensor (MSS)

- The Multispectral scanner detects the spectral reflectance of the surface in several discreet bands of the spectrum.
- This is done for individual picture elements (pixels), whereby the reflectance in each band is recorded for an square area (in this case a 79 m x 79 m area).
- The scanner has mirror that rapidly moves back and forth along scanning lines consisting of many pixels. In this case each scanning line consists of 3240 pixels and there are 2340 scan lines per Landsat image.



From Lillisand and Kiefer 1987

Satellites measure reflectance in discreet bands or channels



Channels for the major Landsat satellites:

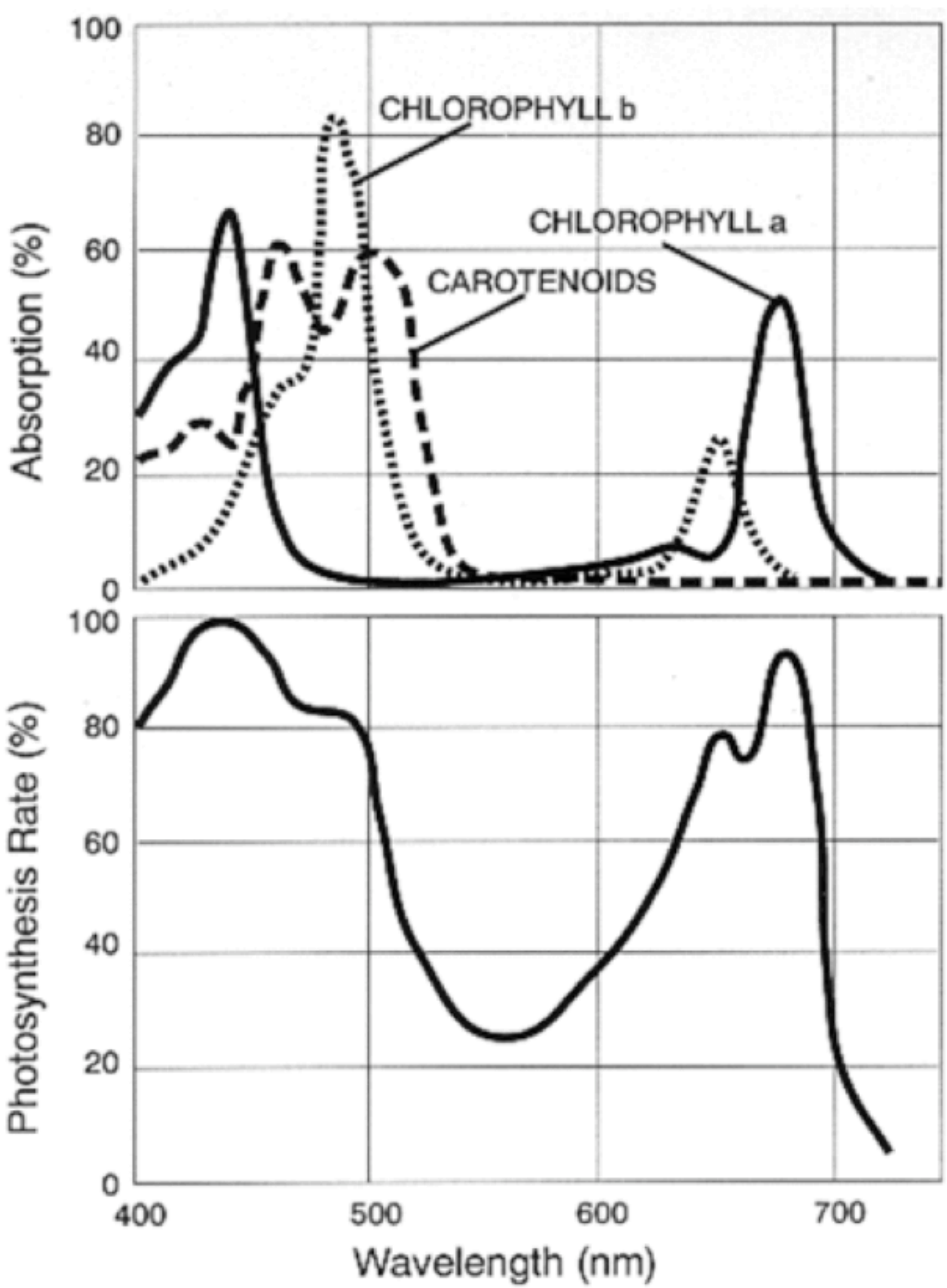
- **Instead of measuring the entire spectrum, most satellites average the reflectance across regions (bands or channels) of the spectrum.**
- **The Landsat satellites were designed to monitor the earth's surface, particularly the vegetation component. So two of the four bands are in regions of the spectrum that are sensitive to differences in the amount of chlorophyll, the red and near infrared regions.**

Band	Wavelength (µm)	Nominal spectral location	Principal applications
1	0.45–0.52	Blue	Designed for water body penetration, making it useful for coastal water mapping. Also useful for soil/vegetation discrimination, forest type mapping, and cultural feature identification.
2	0.52–0.60	Green	Designed to measure green reflectance peak of vegetation (Figure 1.10) for vegetation discrimination and vigor assessment. Also useful for cultural feature identification.
3	0.63–0.69	Red	Designed to sense in a chlorophyll absorption region (Figure 1.10) aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76–0.90	Near-infrared	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination.
5	1.55–1.75	Mid-infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.
6[a]	10.4–12.5	Thermal infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.
7[a]	2.08–2.35	Mid-infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.

[a]Bands 6 and 7 are out of wavelength sequence because band 7 was added to the TM late in the original system design process.

Thematic Mapper (TM) Sensor bands on Landsat 4 and 5 satellites

- More channels in the infrared region, corresponding to water absorption bands.
- For monitoring vegetation, soil moisture separating clouds from snow and ice.



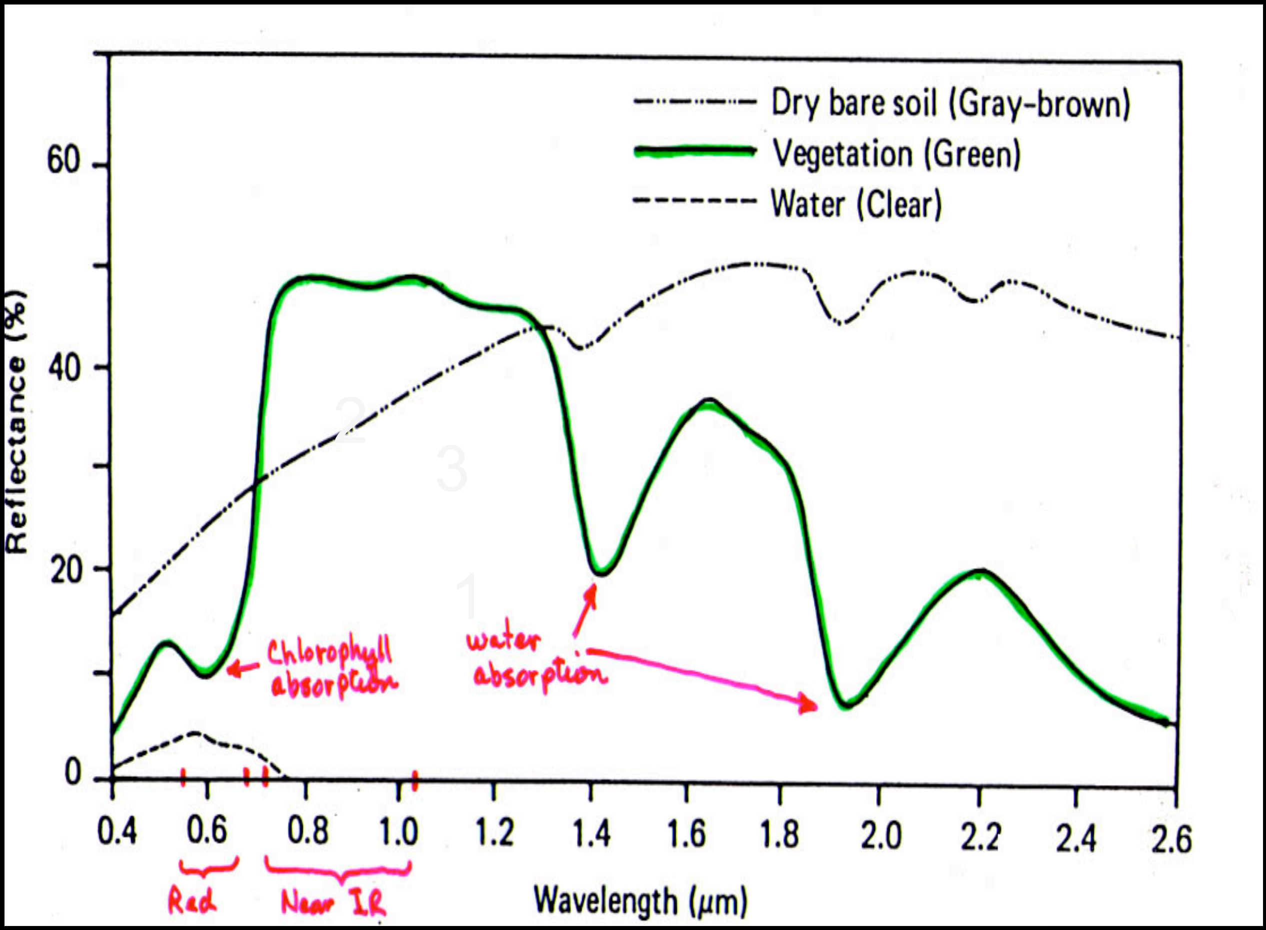
Absorption spectra for different plant pigments and photosynthetic response

The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 μm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 μm).

Reflectance spectra for typical components of the Earth's surface

1. Water is a very good absorber in nearly all portions of the spectrum, and very little energy is reflected from water surfaces.

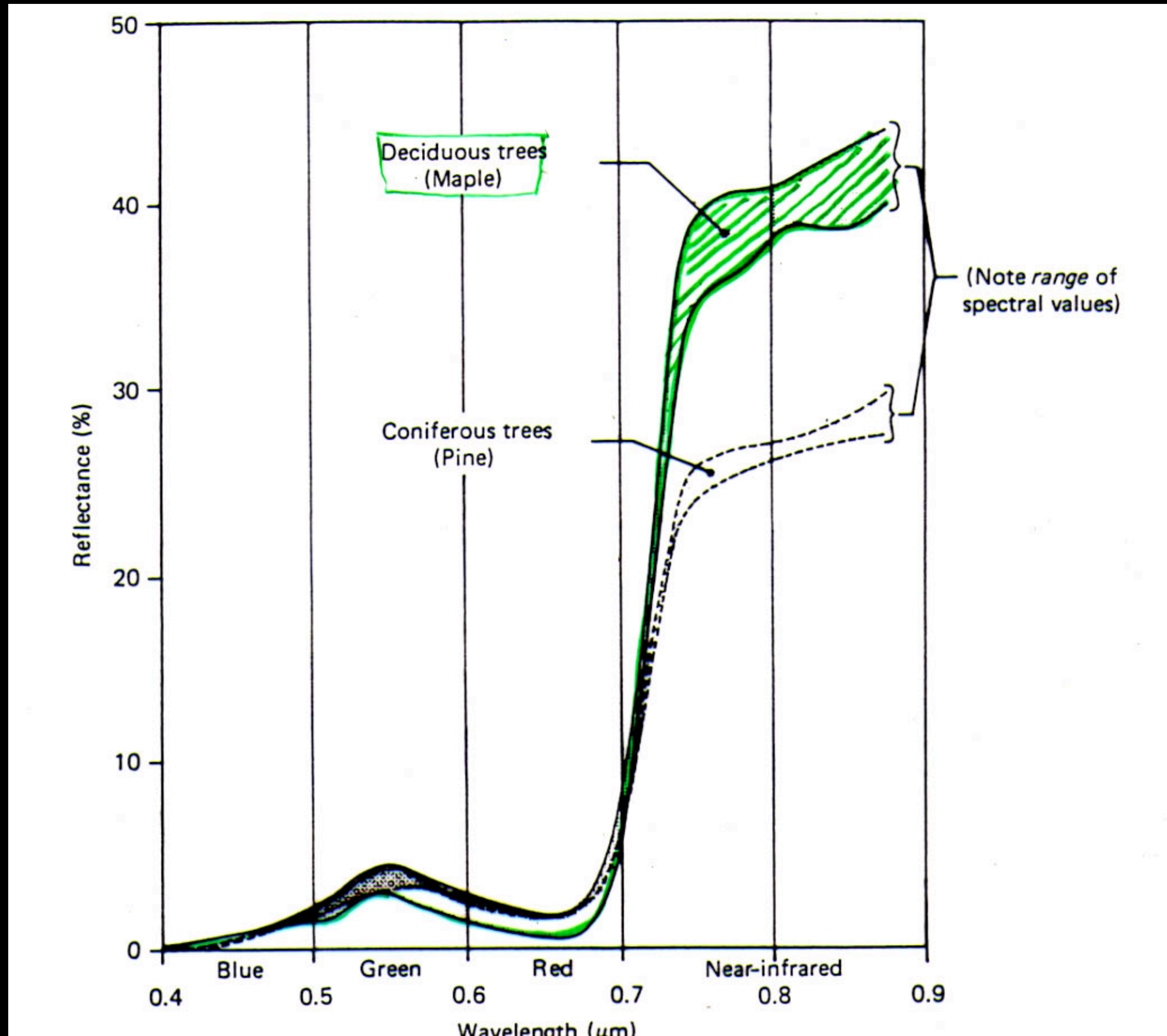
2. Soil has a reflectance spectrum that is nearly linear through the UV, visible, and near infrared portions of the spectrum.



From Lillisand and Kiefer 1987

Different vegetation types have different reflectance spectra

The greater the difference between the reflectance in the R and NIR portions of the spectrum the more chlorophyll is in the vegetation canopy.



From Lillisand and Kiefer 1987

Vegetation indices

- Vegetation indices are based on the principle that visible, VIS, wavelengths (near 0.4-0.7μm) are absorbed by chloroplasts and mesophyll, while near infrared, NIR, wavelengths (0.7-0.9μm) are reflected.

- If the NIR reflectance is much larger than the red reflectance, then presumably there is a considerable amount of green vegetation present.

- In general, for many ecosystems, the vegetation indices are proportional to IPAR (intercepted phytosynthetically active radiation) and to LAI and biomass.

Normalized Difference Vegetation Index: an index of greenness

NDVI = *(NIR-VIS)/(NIR+VIS)*

NIR **= spectral reflectance in the near-infrared band (0.725 - 1.1µm), where light scattering from the canopy dominates,**

VIS **= reflectance in the visible, chlorophyll-absorbing portion of the spectrum (0.04 to 0.68µm).**

Hand-held spectroradiometer for ground-level measurement of spectral reflectance

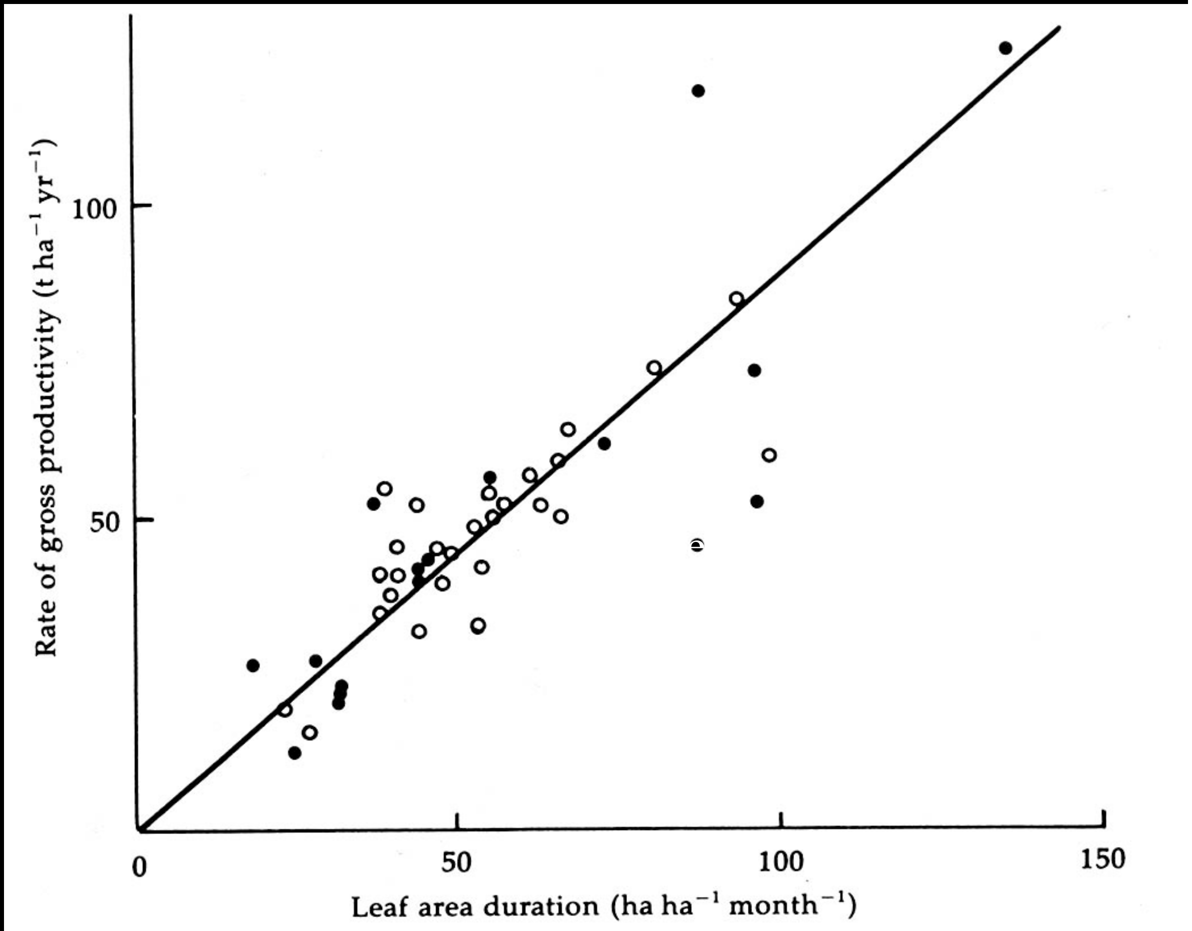
- There are several brands of hand-held radiometers that mimic the sensors in satellites.
- Some have four sensors that can be set to sense the same band widths as common satellite sensors.
- Most of the newer ones have large numbers of channels (ASD instruments have 256 channels).

Leaf Area Index (LAI)

- The ratio of the area of leaves and green vegetation in the plant canopy per unit area of ground surface
- The only way to get true leaf area is to strip all the leaves off the plants and measure their area. All other methods provide an "index" of this value (e.g. inclined point frame, LICOR-2000).
- Regression methods are used to relate biomass to leaf area.

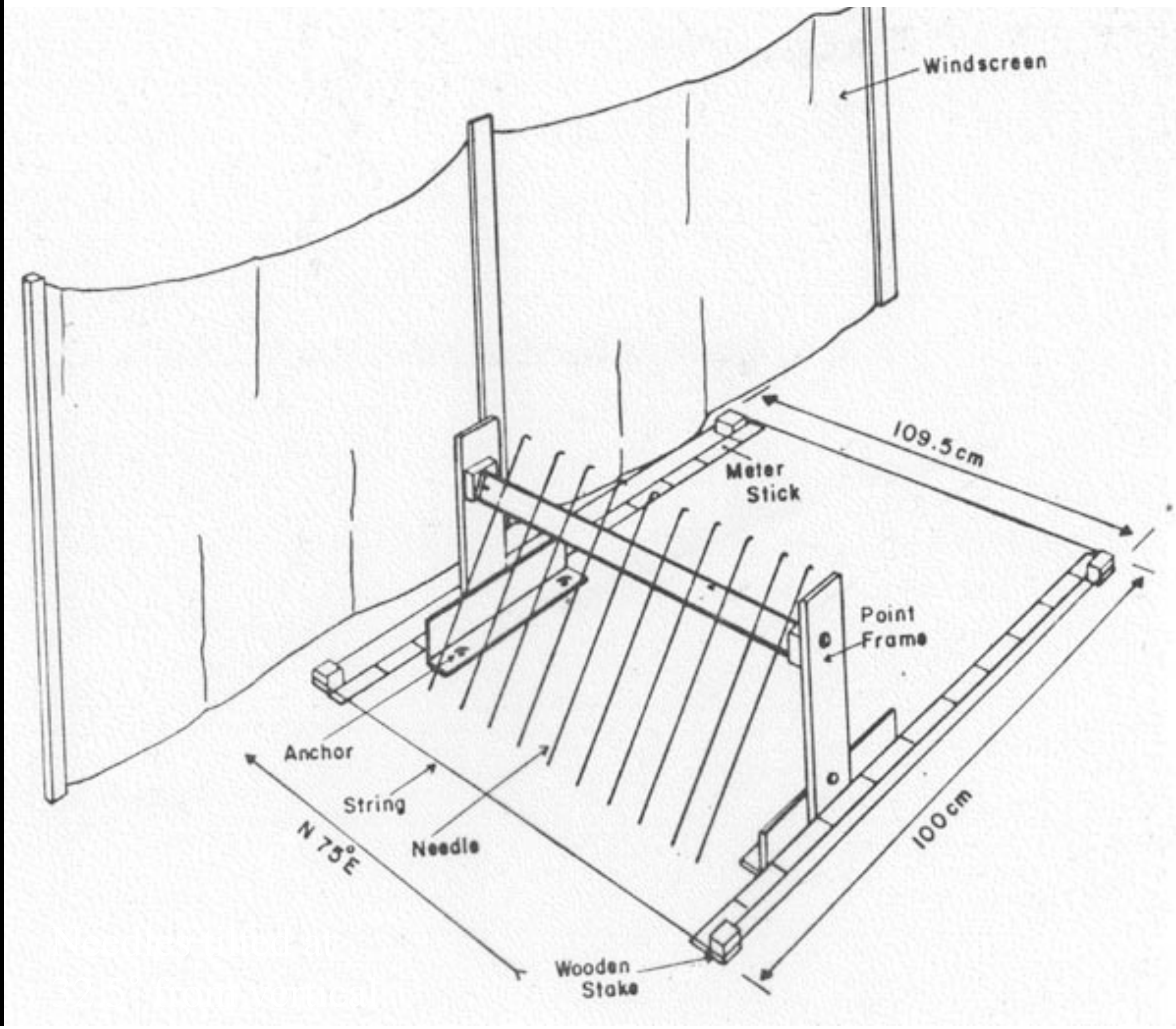
Relationship between leaf area duration and gross productivity

- Total production is a function of the leaf area and the length of time that the leaves remain on the trees.
- Leaf area duration (LAD) is the LAI times the length of the growing season in months. So a combination of high LAI and long growing season will result in the highest productivity.



Old method for measuring LAI: Inclined Point Frame

Warren Wilson, J. 1959. Analysis of the distribution of foliage area in grassland. In: J. D. Ivins (Ed.), *The measurement of grassland productivity*. Butterworths Scientific Publications, London, pp. 51-61.



- Needles are lowered through the plant canopy and the species of each 'hit' is recorded.
- This design shows 10 needles spaced at 10-cm intervals.
- After lowering the 10 needles, the frame is moved 10 cm and the needles are again lowered. This is repeated so that a total of 100 needles are lowered through the canopy within a 1 m^2 area. The leaf area of each species is the total number of its hits divided by 100.
- The needles are tilted at 32.5˚ as the opitmum angle for sampling both erectophillic and planophillic leaves.

New method: LAI-2200 Plant Canopy Analyzer

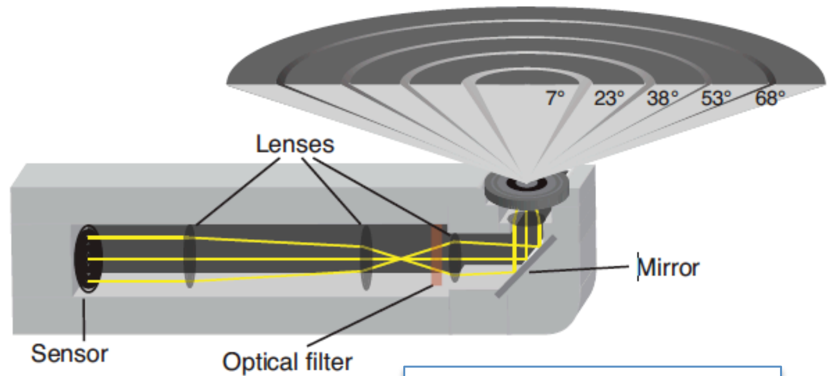
- Very rapid method of obtaining field LAI.
- Provides only total LAI, and cannot distinguish components of individual species nor of woody vs. foliar fraction.
- Not useful for very low growing vegetation (moss and lichen mats) because the height of the sensor is above most moss and lichens (about 2.5 cm).

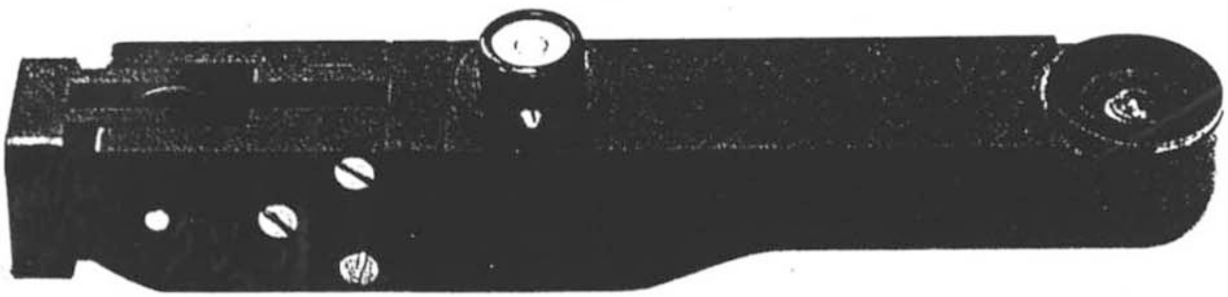
- Reference reading is taken above the plant canopy.

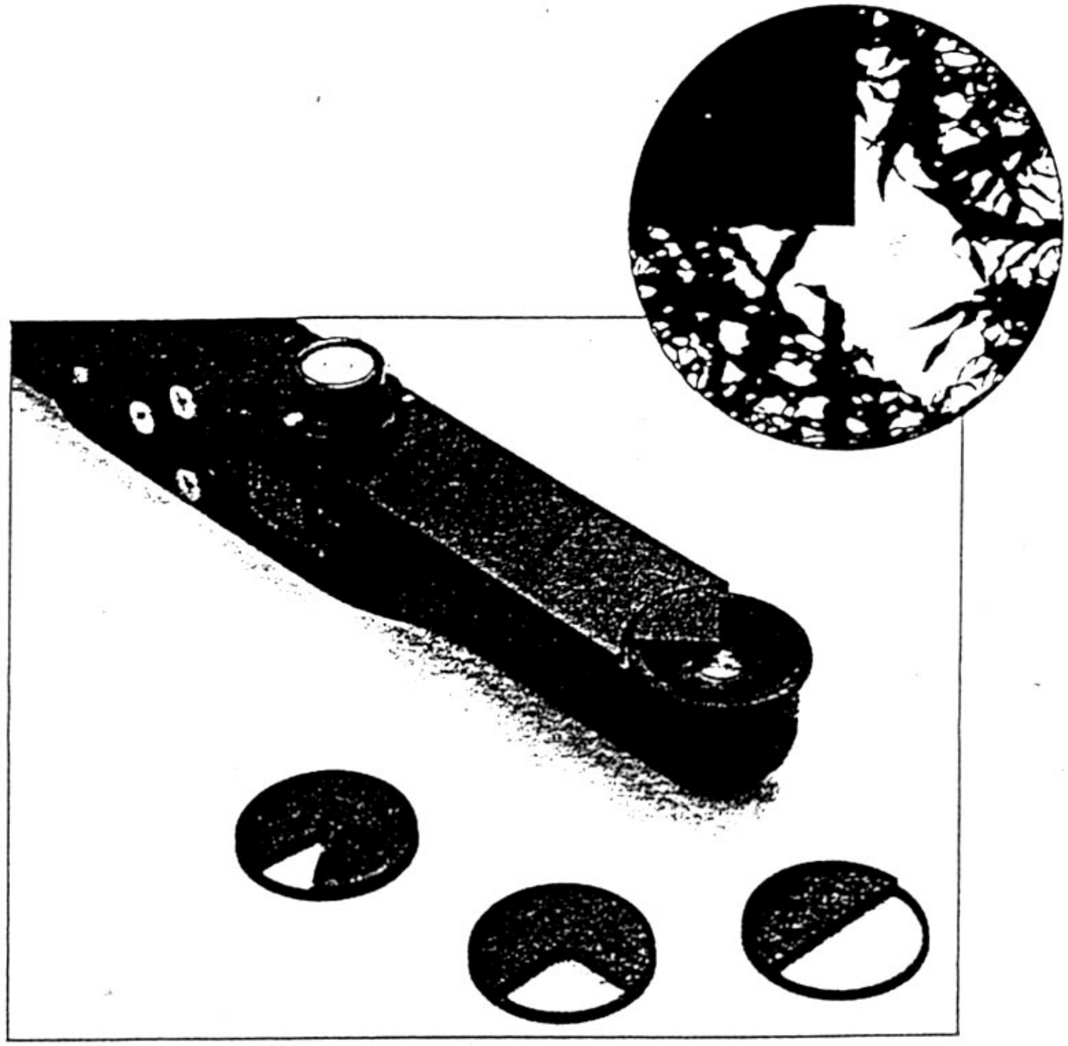
- Below the canopy measurement is then taken and the instrument records the difference in the two readings of light as the LAI.

LAI-2000 optical sensor

The heart of the LAI-2000 is the unique design of the LAI-2050 Optical Sensor. The LAI-2050 uses a "fish-eye" lens with a hemispheric field-of-view (zenith cutoff angle = 74°) to project radiation onto the detector. The use of a lens with a "fish-eye" field-of-view assures that LAI calculations are based on a large sample of the foliage canopy.

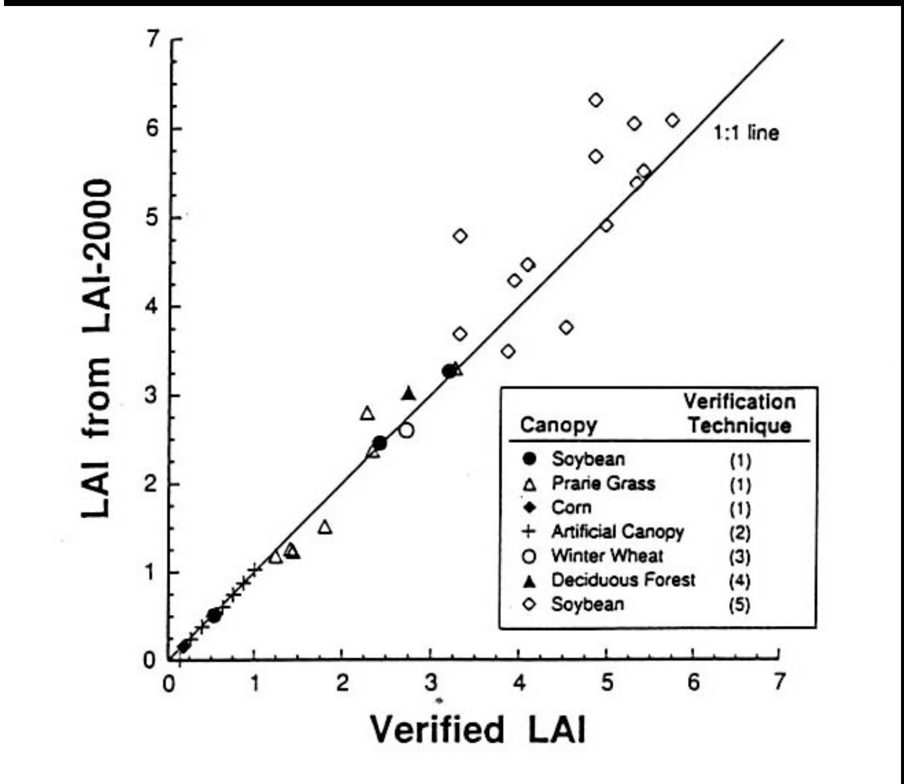


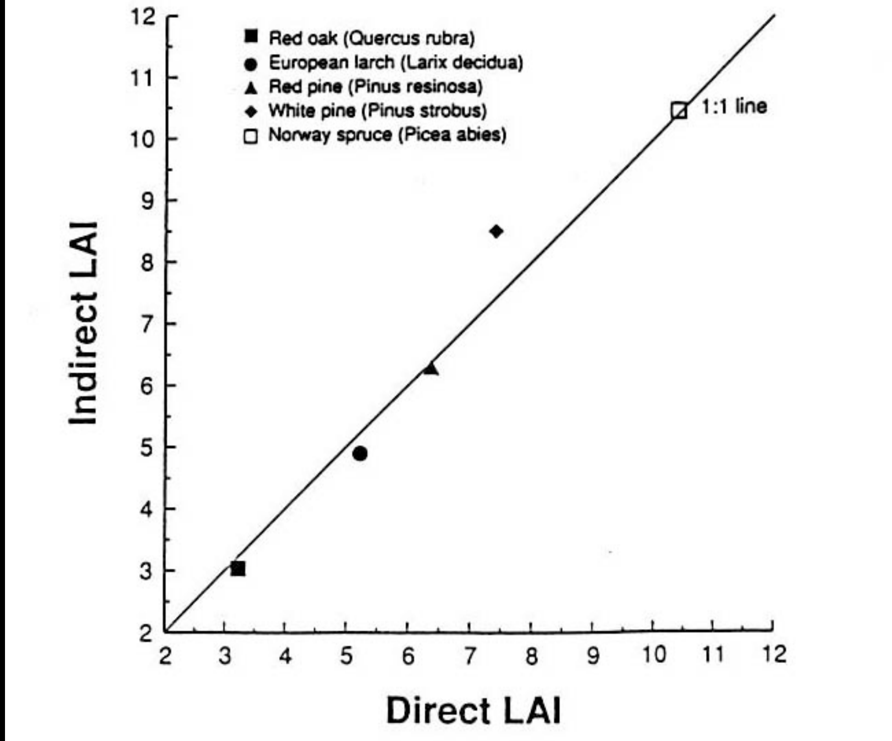




LAI-2050 Optical Sensor with view caps for the lens. The 270° view cap (shown installed on the optical sensor) is often used to mask the operator as simulated in the fisheye photo above.

Correlation between actual leaf area and LAI-2000





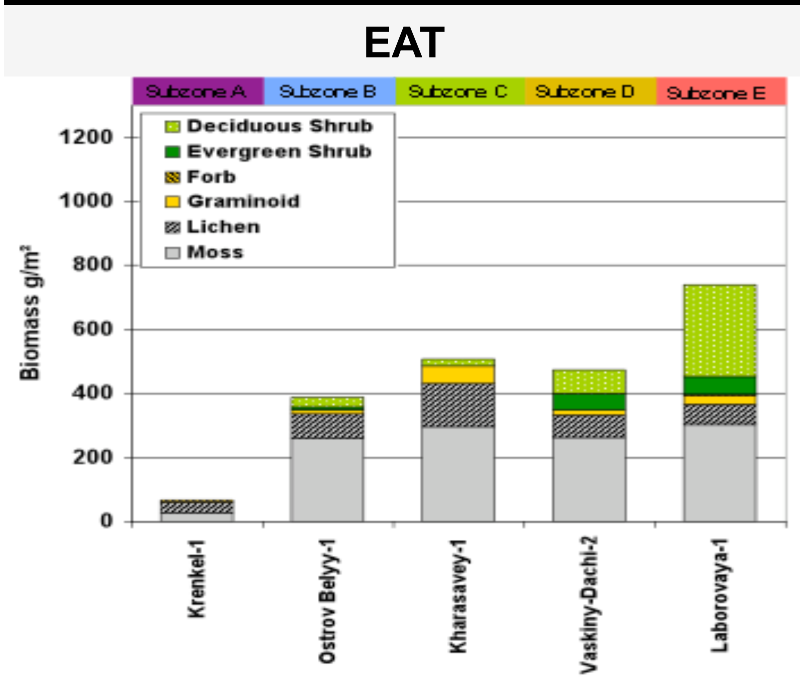
(From Gower, S.T., and Norman, J.M. (1990). Rapid estimation of leaf area index in forests using the LI-COR LAI-2000. Submitted to Ecology.)

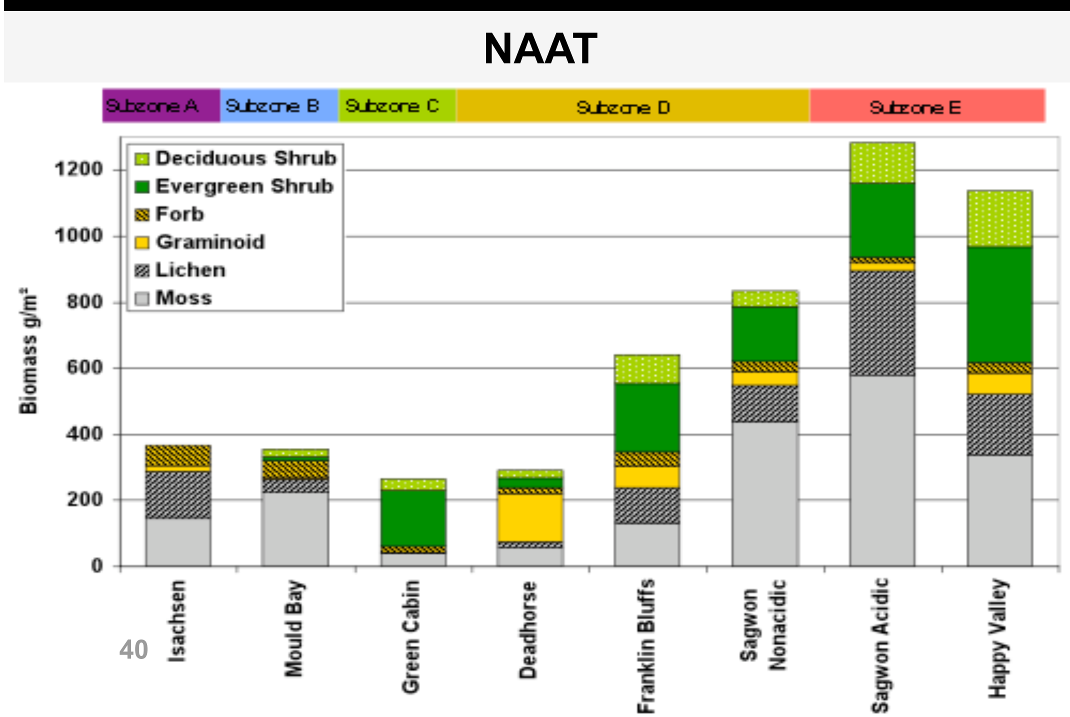
Biomass collection

Biomass sorting according plant functional types

Plant functional type sorting categories

- Deciduous shrubs
  - Woody stems
  - Foliar
    - Live
    - Dead
- Evergreen shrubs
  - Woody stems
  - Foliar
    - Live
    - Dead
- Forbs
    - Live
    - Dead
- Graminoids
    - Live
    - Dead
- Lichens
    - Live
    - Dead
- Mosses
    - Live
    - Dead
- Litter





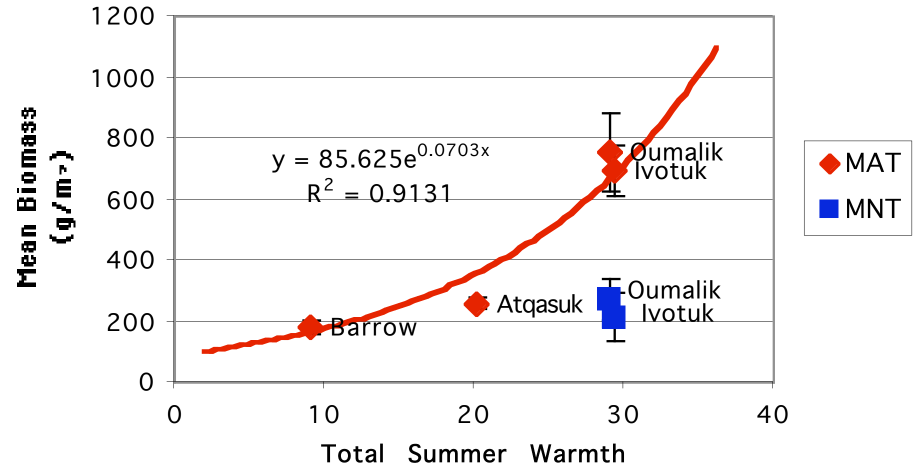
Plot-level biomass trends along EAT and NAAT

Major differences. Compared to NAAT, EAT has:

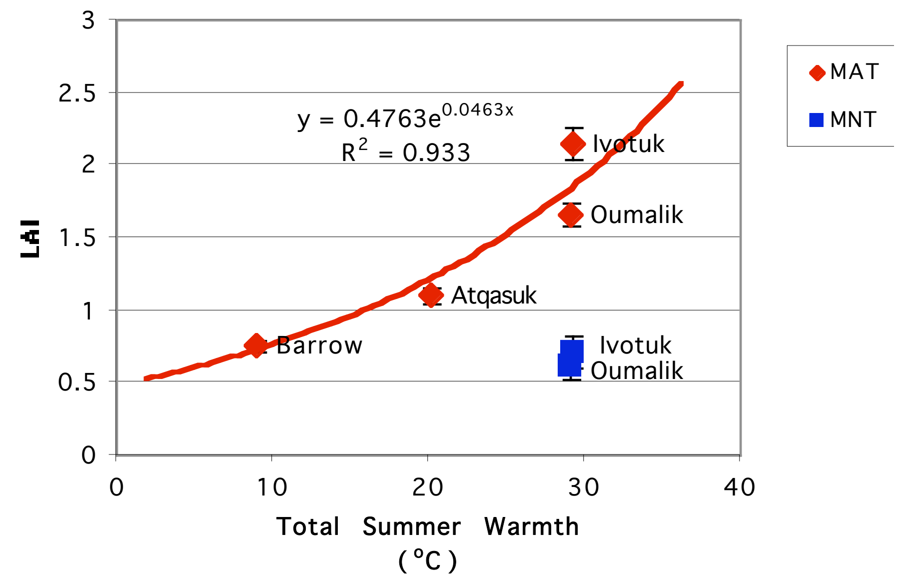
- Less biomass in subzone A (Wetter, much colder).
- More biomass in subzone C, (Wetter, unglaciated landscape along the EAT.)
- Much more biomass in subzone E (grazing effect).

Application to northern Alaska: Biomass and LAI vs. total summer warmth index

Biomass

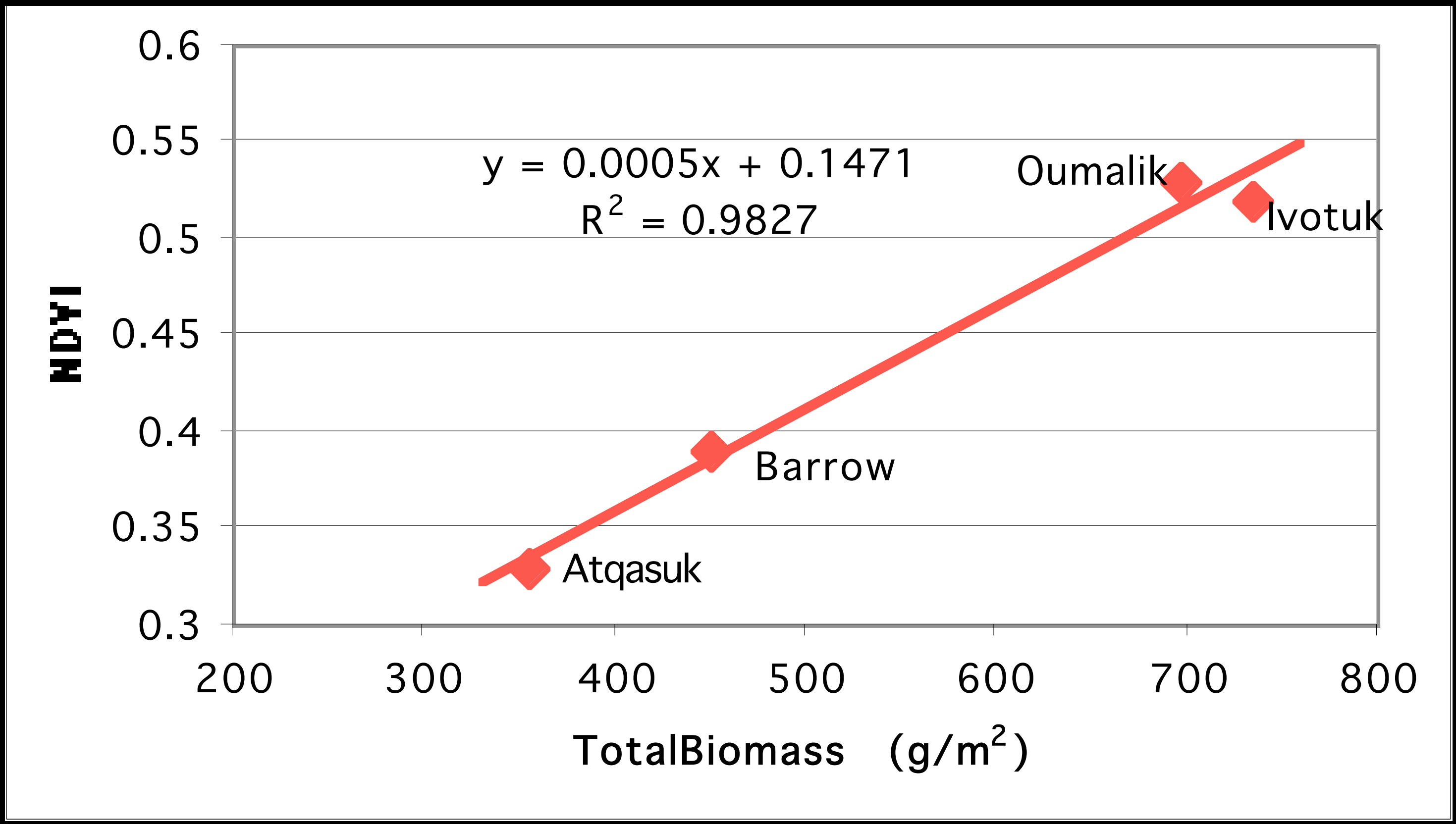


Leaf Area Index (LAI)



Total summer warmth = sum of monthly mean temperatures > 0 ˚C

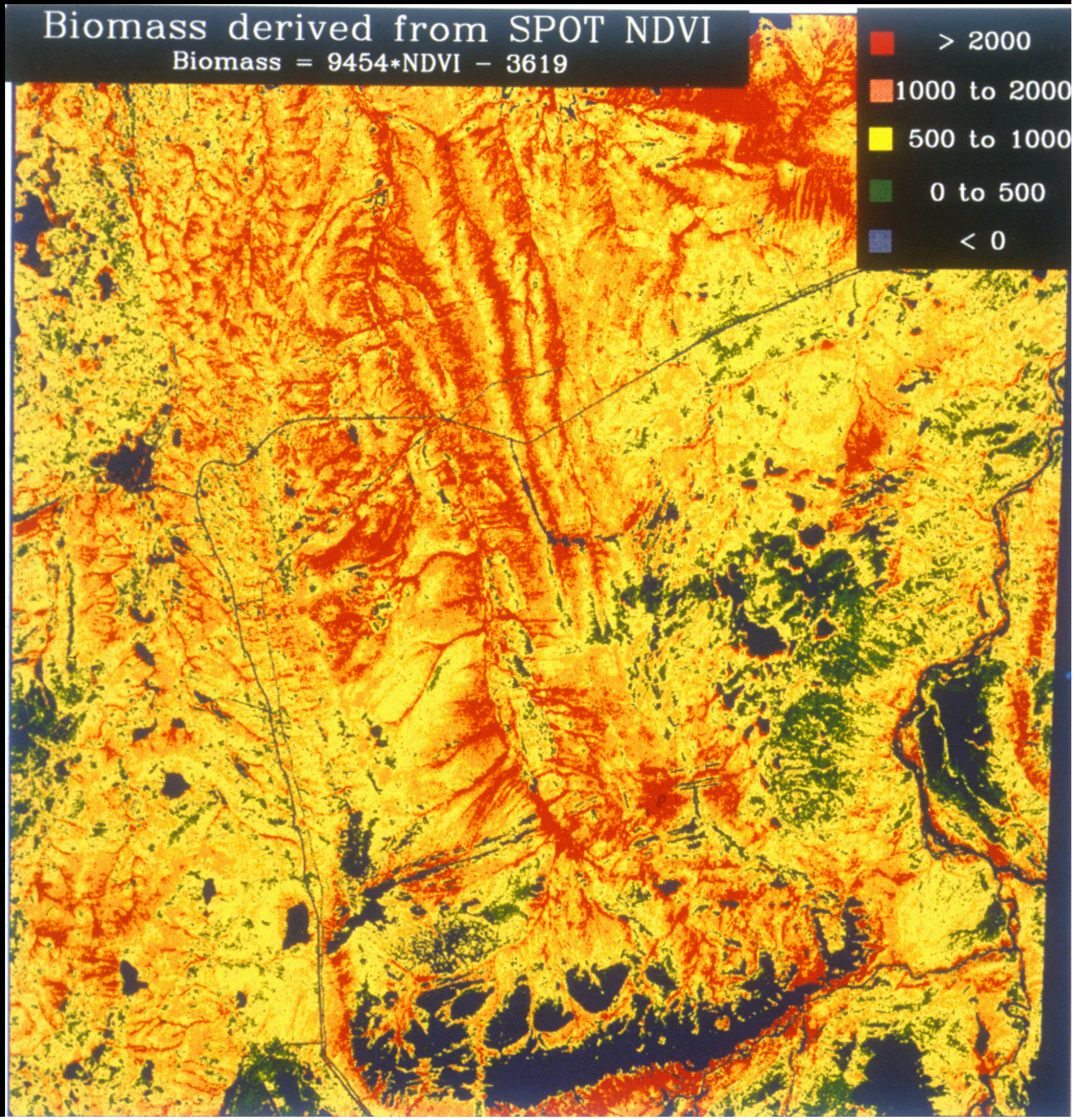
NDVI vs. total aboveground biomass



Biomass map of the Toolik Lake region derived from SPOT NDVI values (Shippert 1995)

- If the relationship between NDVI and biomass is strong, it is possible to develop biomass maps based on satellite images.

- It is also possible to develop maps that portray other biophysical properties of ecosystems (e.g. PAR, LAI, CO_2 flux, NH_4 flux).



Linkage of spatial and temporal trends of NDVI observed on AVHRR satellite images to ground observations along two Arctic transects

- Climate
- Vegetation
- Soils
- Permafrost
- Spectral properties

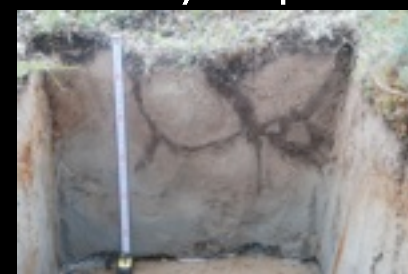

NDVI and LAI


Plant species cover


Active layer depth


Site characterizatiion


Biomass


Soil characterization


N-factor


Permafrost boreholes

Zonal vegetation along both transects

Eurasia Transect

A - Hayes Island

B - Ostrov Belyy

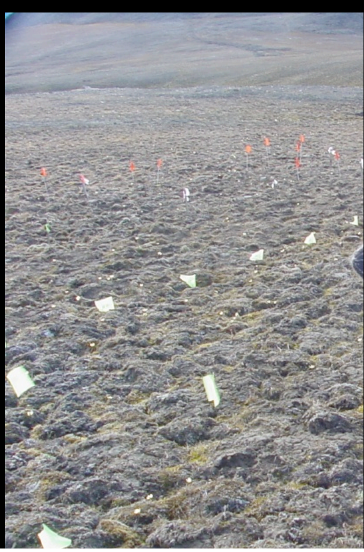
C – Kharasavey

D - Vaskiny Dachi

E - Laborovaya

North America transect

A - Isachsen



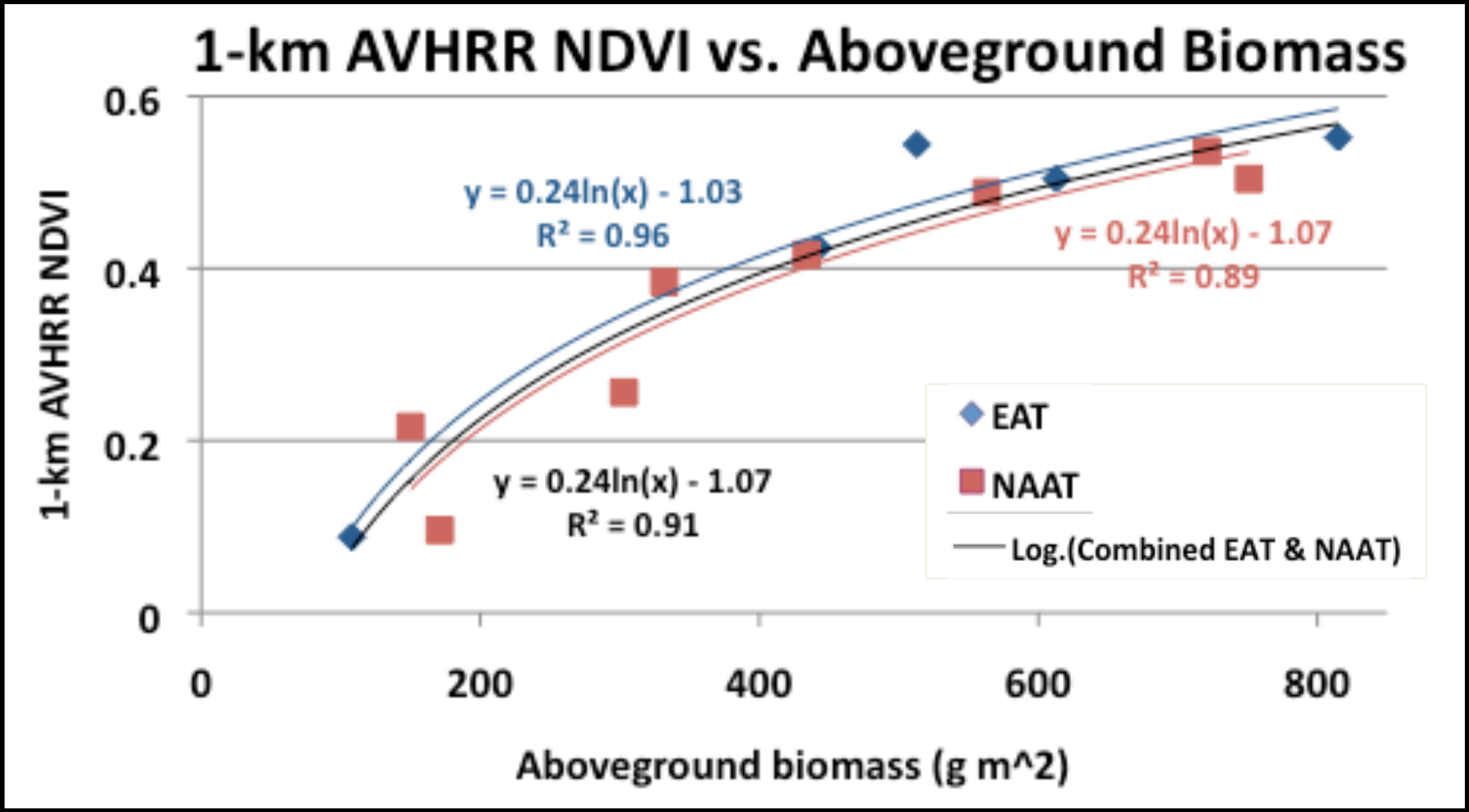
B- Mould Bay

C - Green Cabin

D - Sagwon MNT

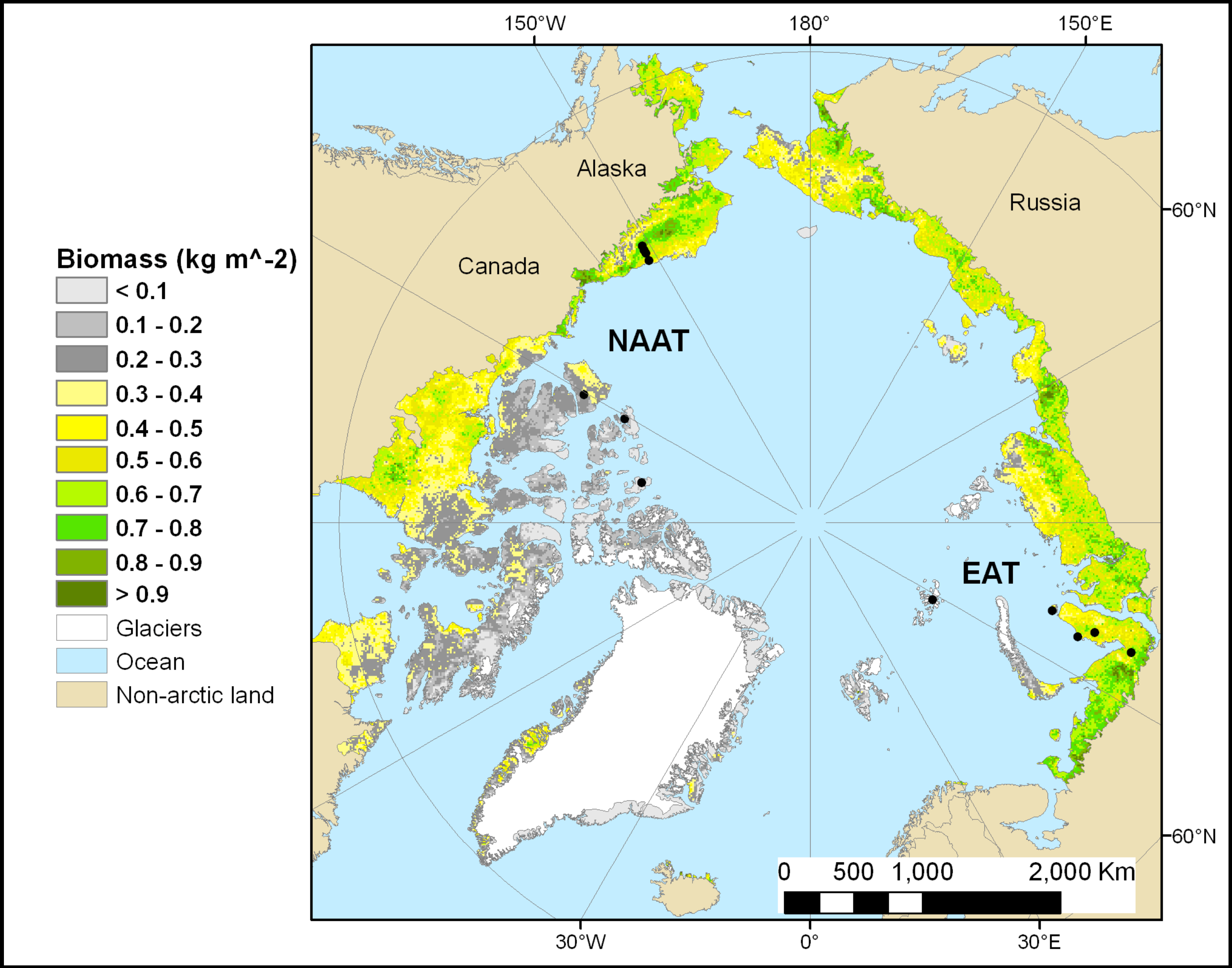
E - Happy Valley

Comparison of EAT and NAAT: 1-km AVHRR NDVI and zonal landscape-scale biomass



- Very strong correlation between AVHRR NDVI and biomass along both transects and for combined data set.

Circumpolar aboveground biomass derived from NDVI



Raynolds et al. 2011 submitted, Geophysical Research Letters

Greening of the Arctic:
Spatial and temporal (1982-2010) variation of biomass and NDVI along two Arctic transects

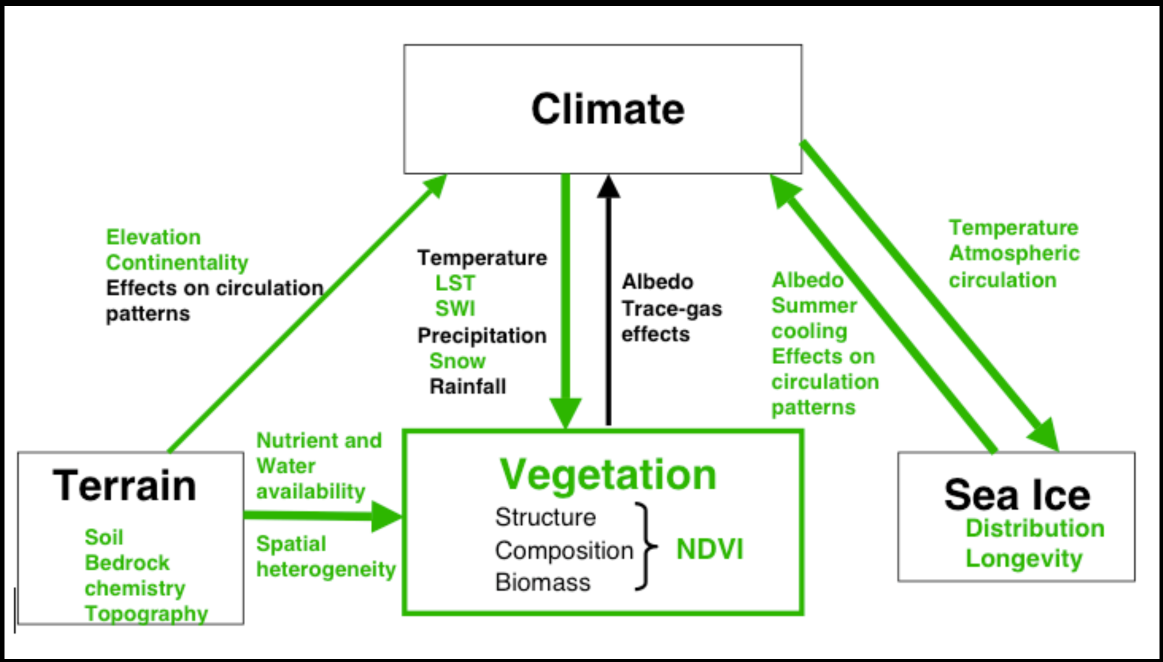
D.A. Walker[1], H.E. Epstein[2], U.S. Bhatt[1], M.K. Raynolds[1], G.J. Frost[2], G.J. Jia[3], J. Comiso[4], J. Pinzon[4], C.J. Tucker[4]

[1] University of Alaska Fairbanks, [2] University of Virginia, [3] RCE-TEA, Institute of Atmospheric Physics, Beijing, China, [4] NASA-Goddard, Greenbelt MD

An International Polar Year initiative

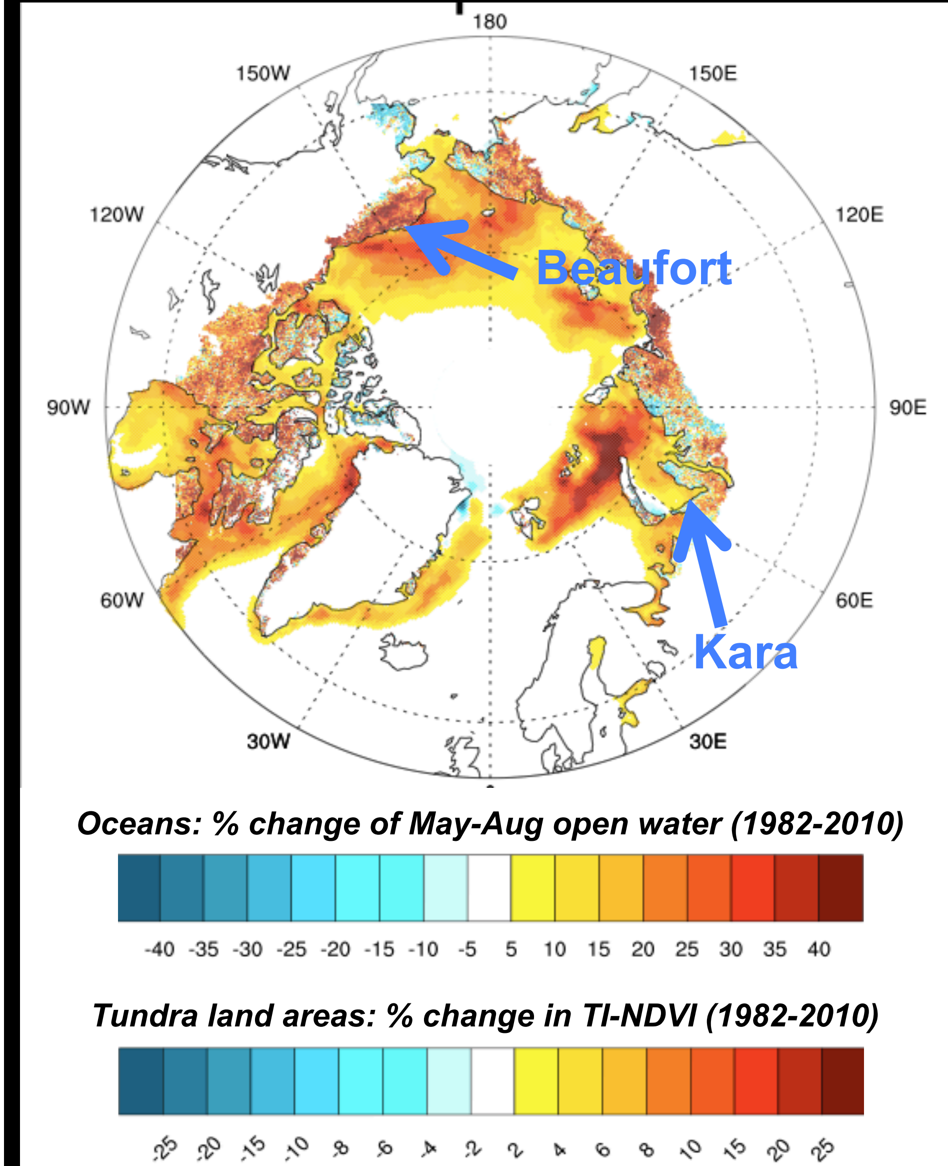
Oral presentation GC53B-01, AGU Fall meeting, 13-17 Dec 2010, San Francisco, CA

Greening of the Arctic Study



- Detailed examination of the 29-year record of greenness across the entire circumpolar Arctic as measured by the normalized difference vegetation index (NDVI) using satellite imagery (AVHRR and MODIS).
- Document trends in the NDVI ,sea-ice distribution & land-surface-temperatures (LSTs), snow-cover, bioclimate subzones, vegetation type, glacial history, and other variables in a circumpolar GIS database.

Modeling studies will use the past trends in NDVI to predict future distribution of arctic vegetation using the BIOME4 model. Transient dynamics of the vegetation will be examined using the ArcVeg model.



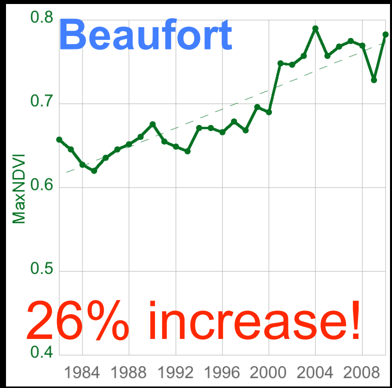
From Bhatt et al. 2010, *AGU Fall Meeting*

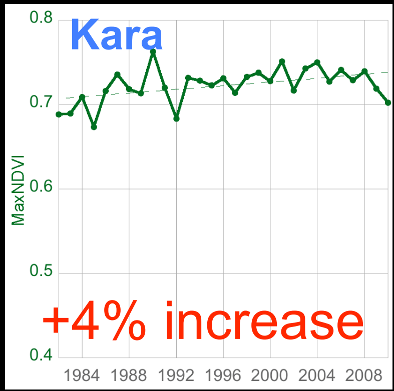
Temporal patterns of in NDVI in relationship to changes in area of summer open water

Bhatt et al. 2010. *Earth Interaction.*

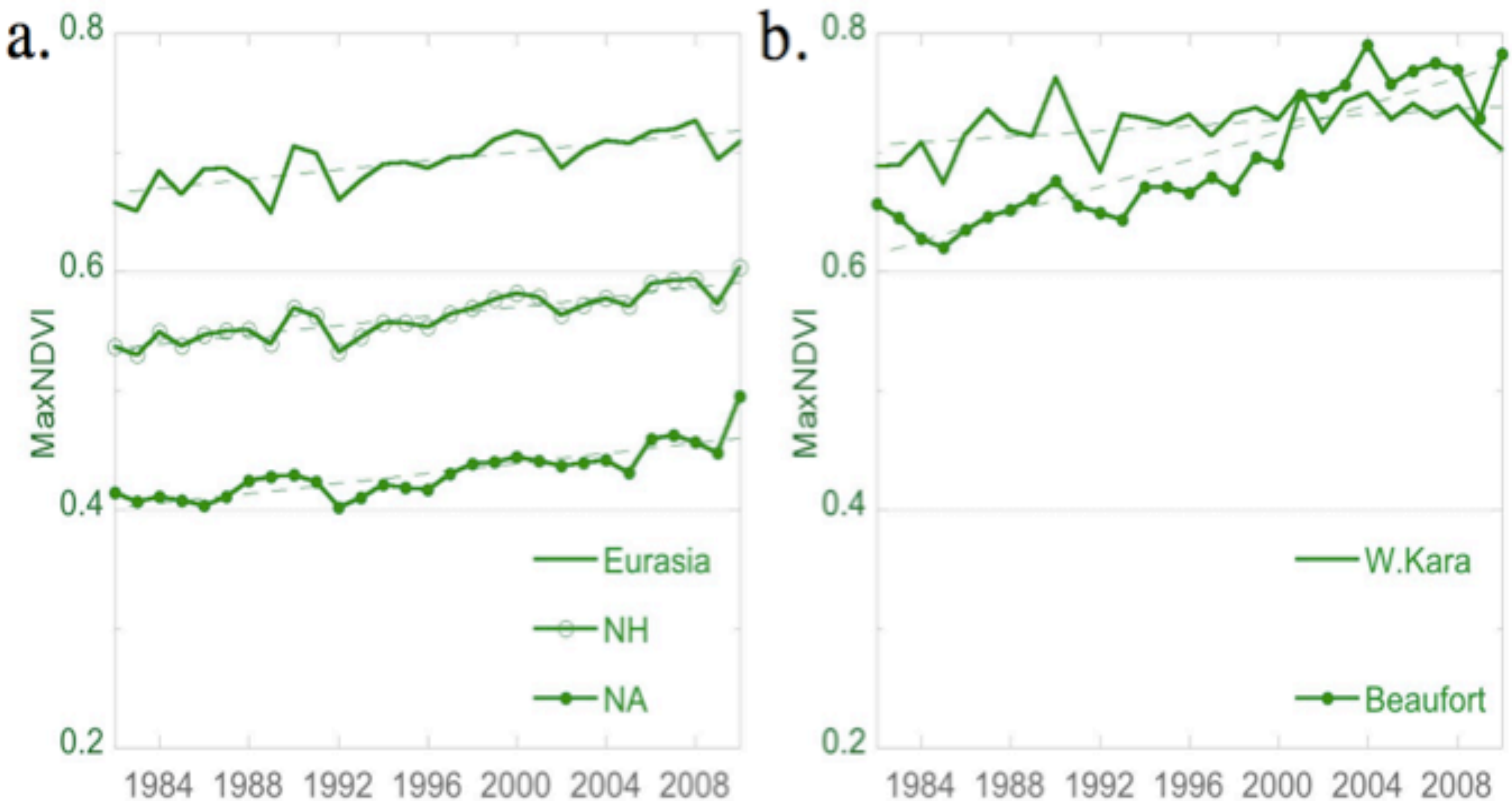
New analysis based on new GIMMS 3g AVHRR NDVI data by Pinzon et al. 2010 (in progress) and sea ice data by Comiso et al. 2010.

Pct. Change MaxNDVI (1982-2010)

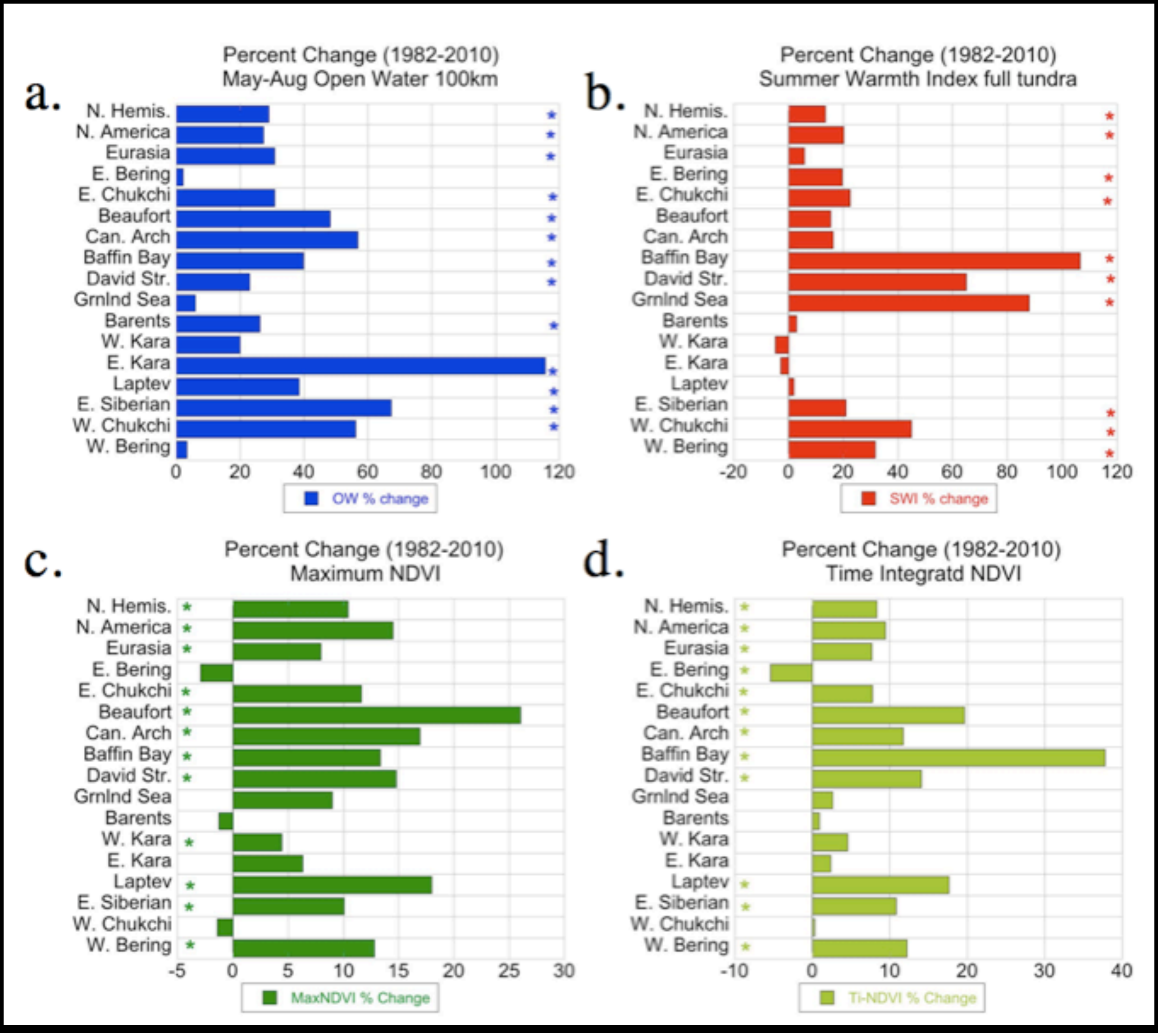




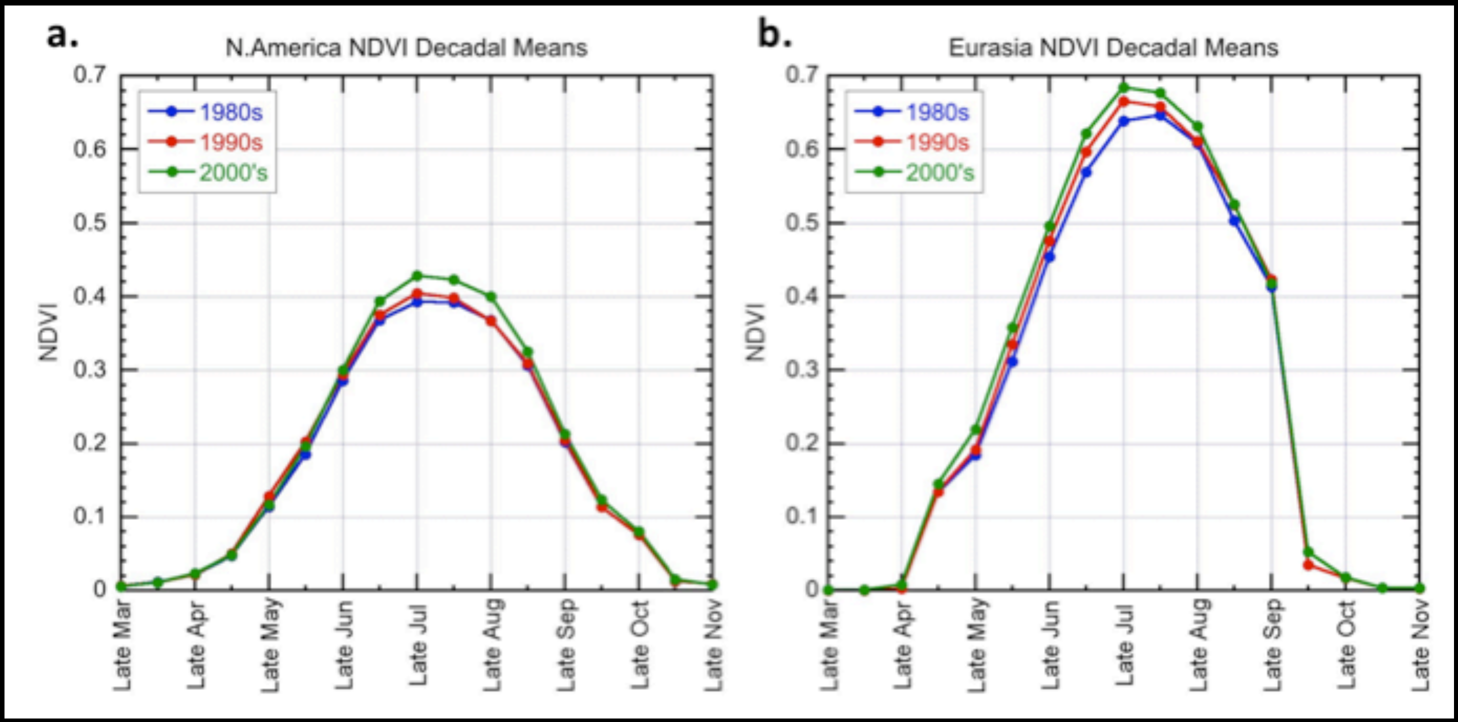
Long-term trends in MaxNDVI



Trends in the lands adjacent to the sea basins



Time-integrated NDVI



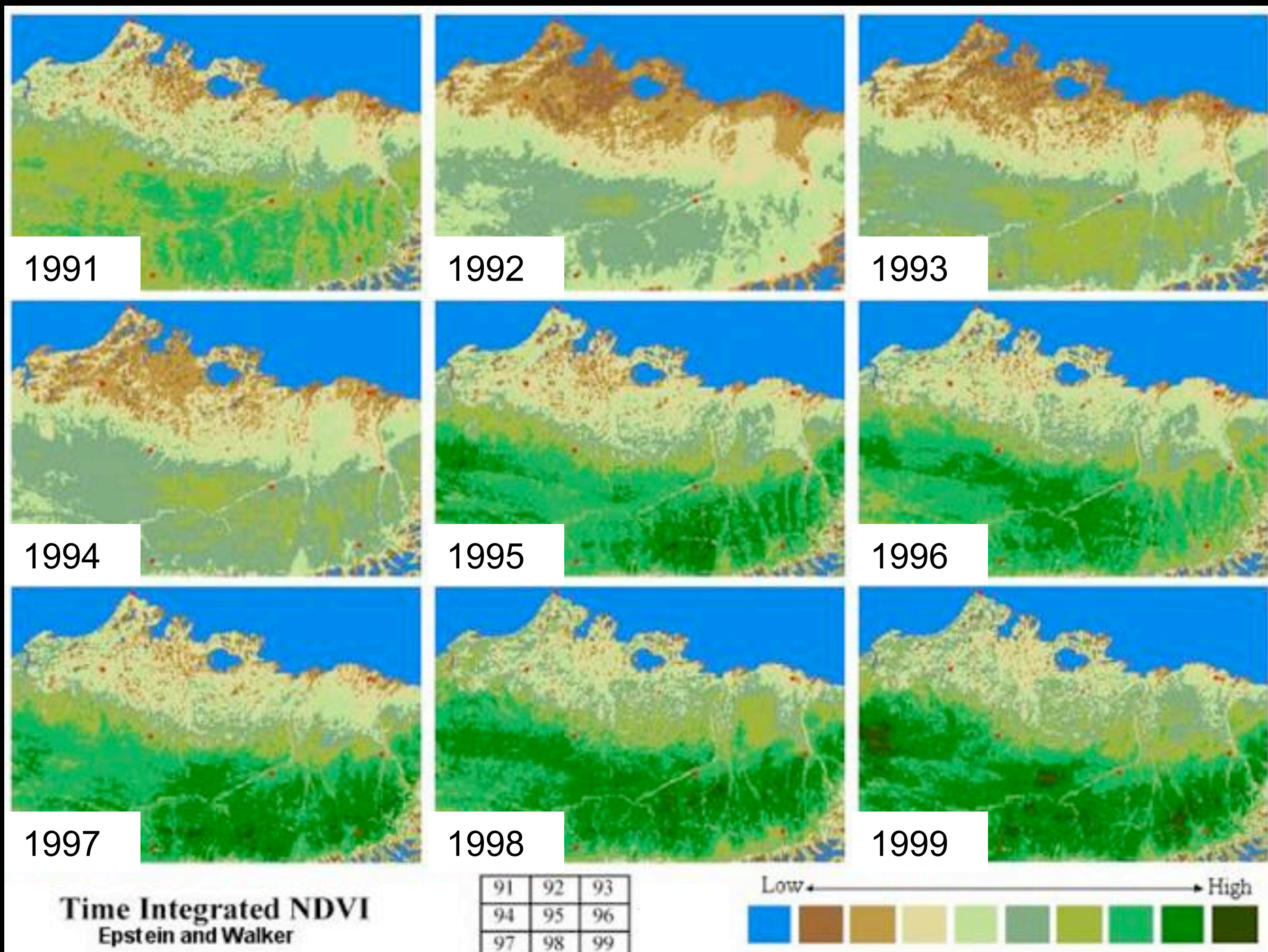
- ***Shift in timing of spring green-up in Eurasia but not North America.***
- ***Peak NDVI has increased in both areas.***

- **NDVI is measured twice daily for every spot on Earth.**
- **Cloud cover may prevent getting good NDVI values, so max value is taken from biweekly collection of data.**
- **This is done for the growing period.**

- **TI-NDVI = Sum of the biweekly maxNDVI values.**

Trend of increased Time-Integrated NDVI in northern Alaska 1981-1999

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$



TI-NDVI is the annual sum of the bi-weekly NDVI measurements.

From a series of papers by Jia, Epstein and Walker that document changes in the NDVI in Northern Alask

(Jia et al. 2003)

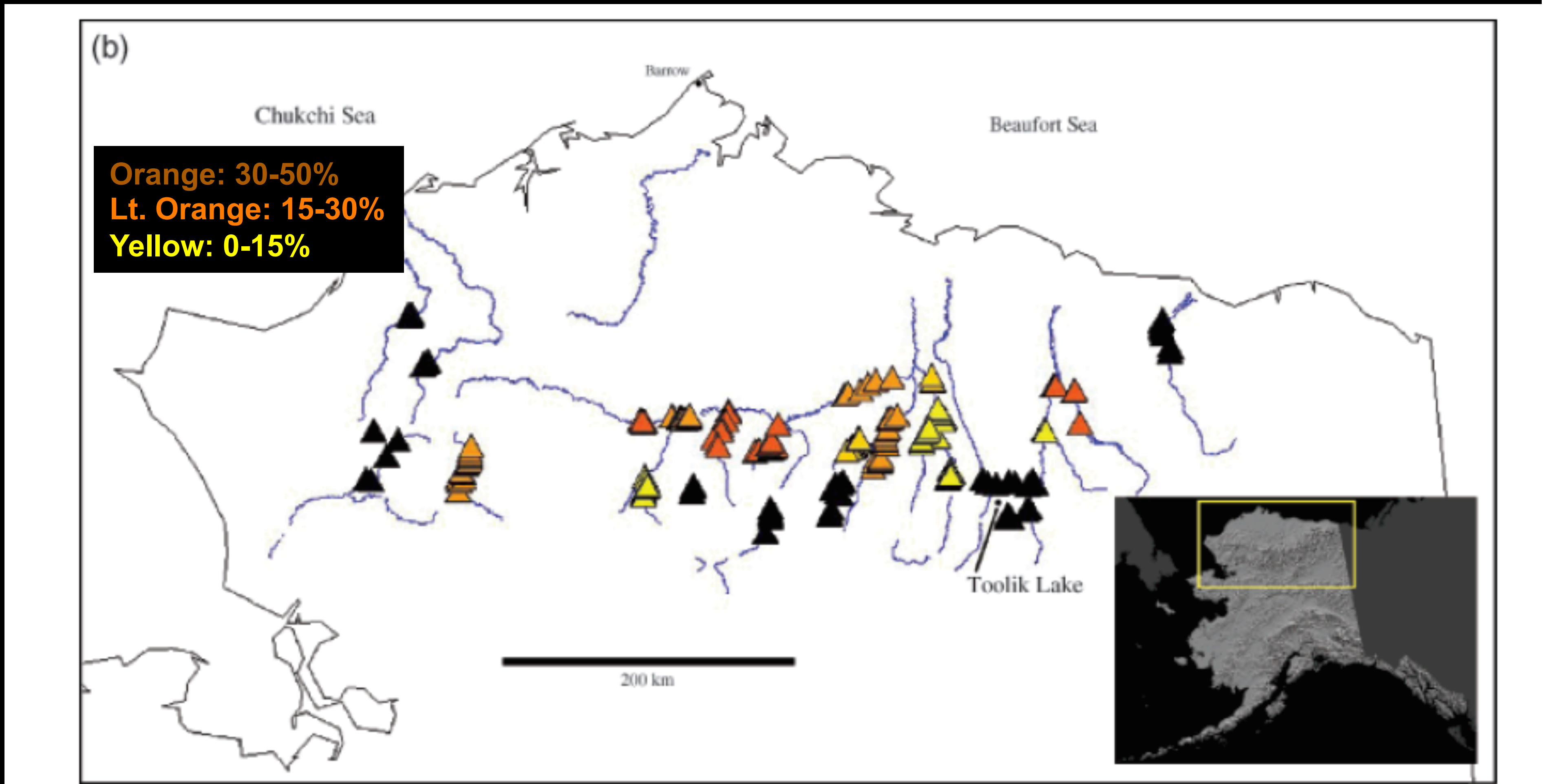
What is the present evidence for change in Arctic vegetation?

Photo – M. K. Raynolds

Changes in shrub cover, northern Alaska 1950-2003

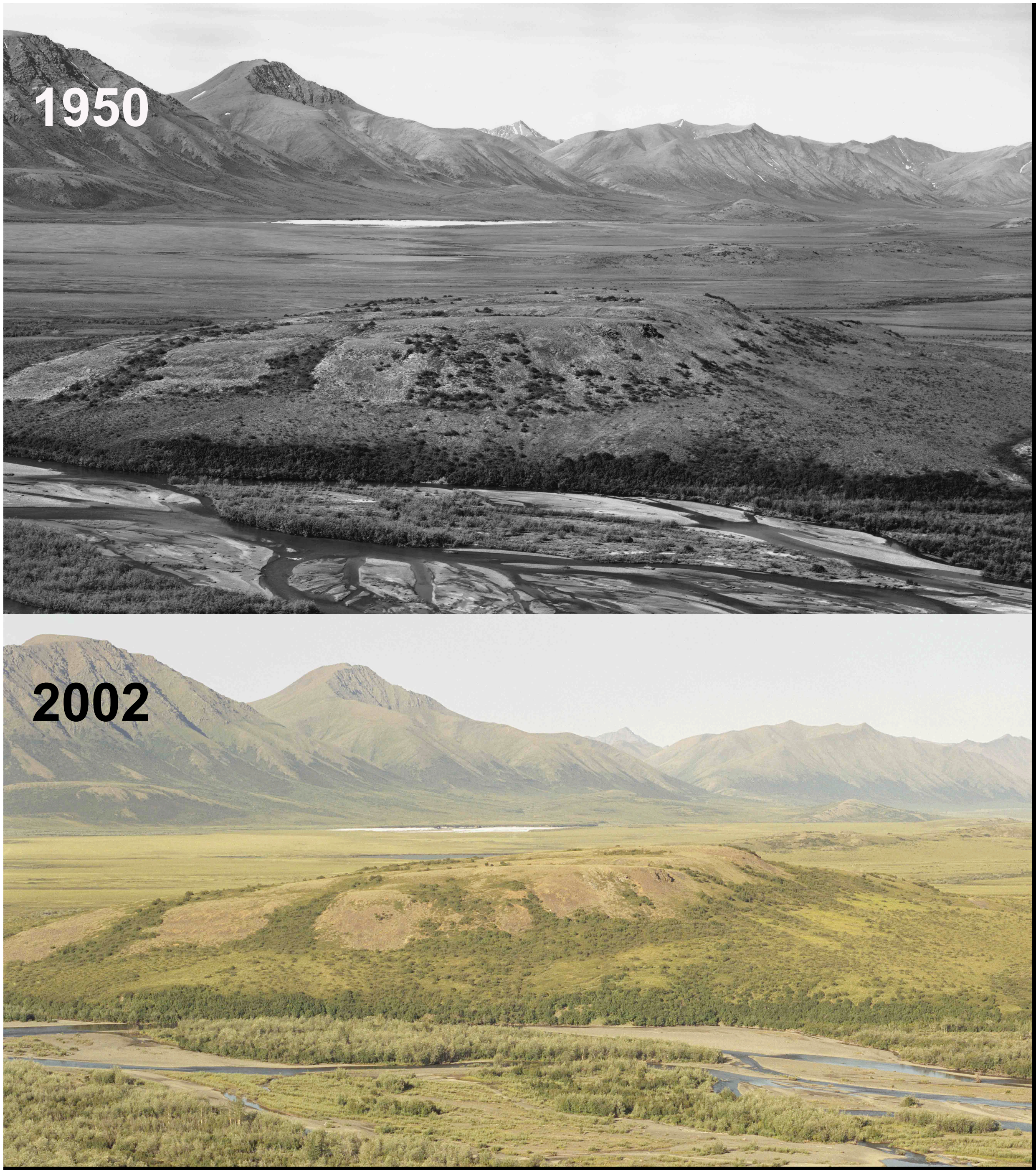
Increased shrub abundance is apparent in photographs of areas photographed by the U.S.Navy in 1950 and then rephotographed in 2002 by Ken Tape. A total of 202 pairs of photos have been examined from northern Alaska, mainly in the Arctic Foothills (Sturm and Racine 2005; Sturm et al. 2001a, b)

Locations of shrub photos and estimated percentage change since 1950



Tape, K., Sturm, M., and Racine, C., 2006, The evidence for shrub expansion in Northern Alaska and the Pan-Arctic: Global Change Biology, v. 12, p. 686-702.

Paired aerial photographs



Photos: Courtesy of Ken Tape

Paired ground photographs

Photos: Courtesy of Ken Tape

- Over 30% increase in alders on stable valley slopes in Subzone E.
- Dramatic increase in shrub cover on river terraces.
- More vegetation and less bare sand and gravel in river floodplains.

Local Knowledge: The Nentzy, reindeer and vegetation change

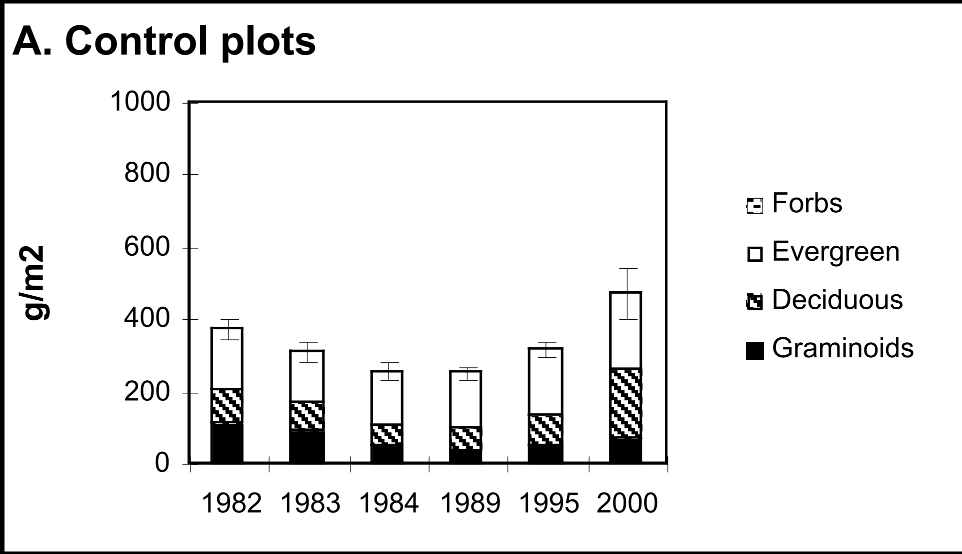
"The average brigadier is in his 50's and has lived his whole life on the tundra… they collect shrubs (mainly *Salix*)…all along the migration route for firewood. Of course, *Salix* is also one of the most important fodder species for the reindeer. So for these reasons they pay pretty close attention to the ecology of this particular genus in the landscape. In more southerly areas, they have noticed that some stands of Salix have gotten so big that the reindeer can now disappear into them. This is not good because if they lose sight of the animals during the migration when they are moving quickly, breaking camp once every 24 hours, the animals can get left behind. So, they have begun to make efforts to steer around the growing *Salix* patches to avoid losing animals.."

--Bruce Forbes

Very few long-term biomass studies

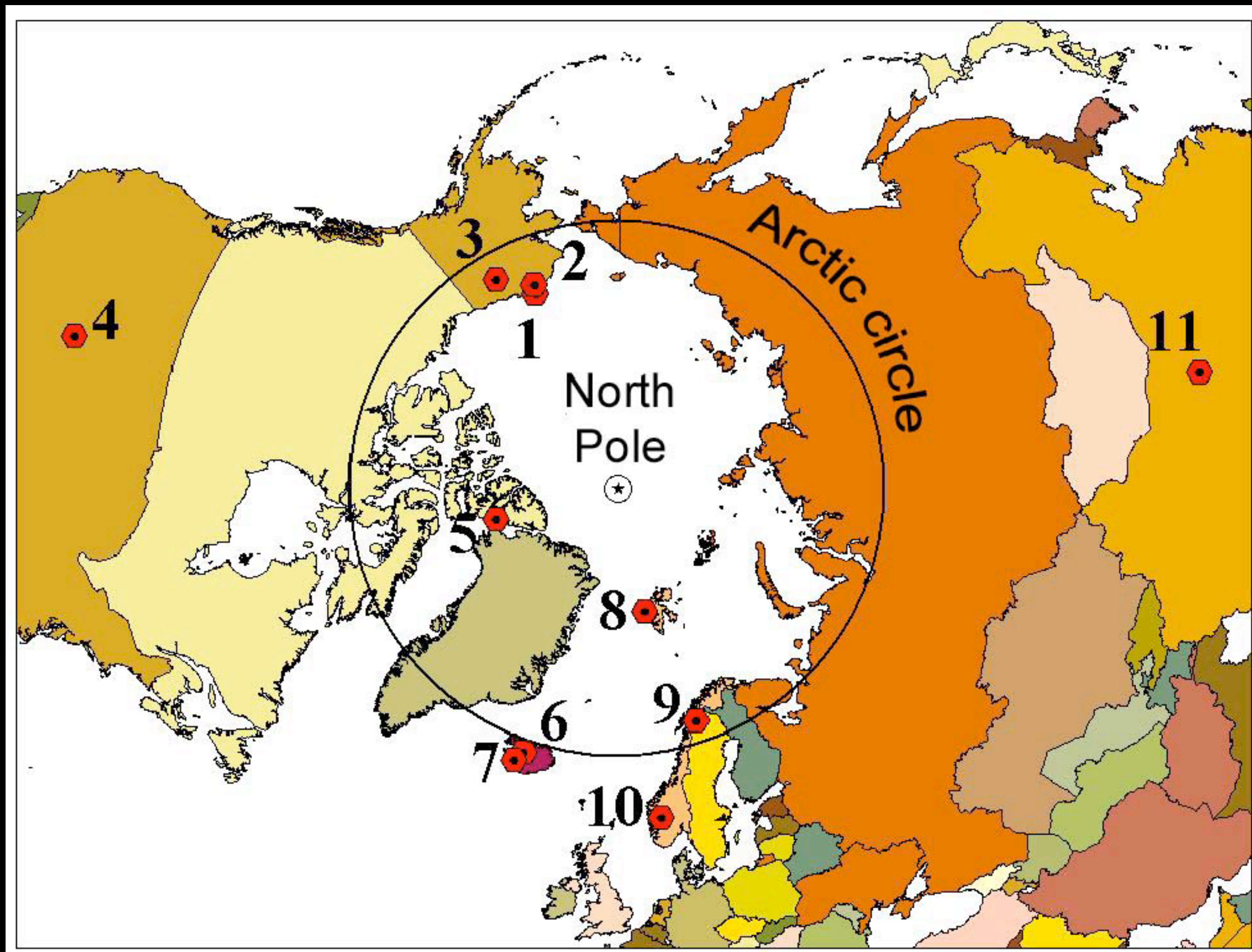
"…although the 2000 harvest occurred after 20 years of climate warming, we still cannot say for sure whether the greater total ANPP and the greater productivity of deciduous shrubs in 2000 is the result of warming or is within the "normal" range of ANPP."

Shaver et al. 2001. Ecology 82: 3163-3181).



For purposes of monitoring change to circum-Arctic vegetation, it is essential to have replicated sampling of biomass in conjunction with NDVI measurements using standard protocols for collecting and reporting biomass data.

International Tundra Experiment (ITEX) synthesis



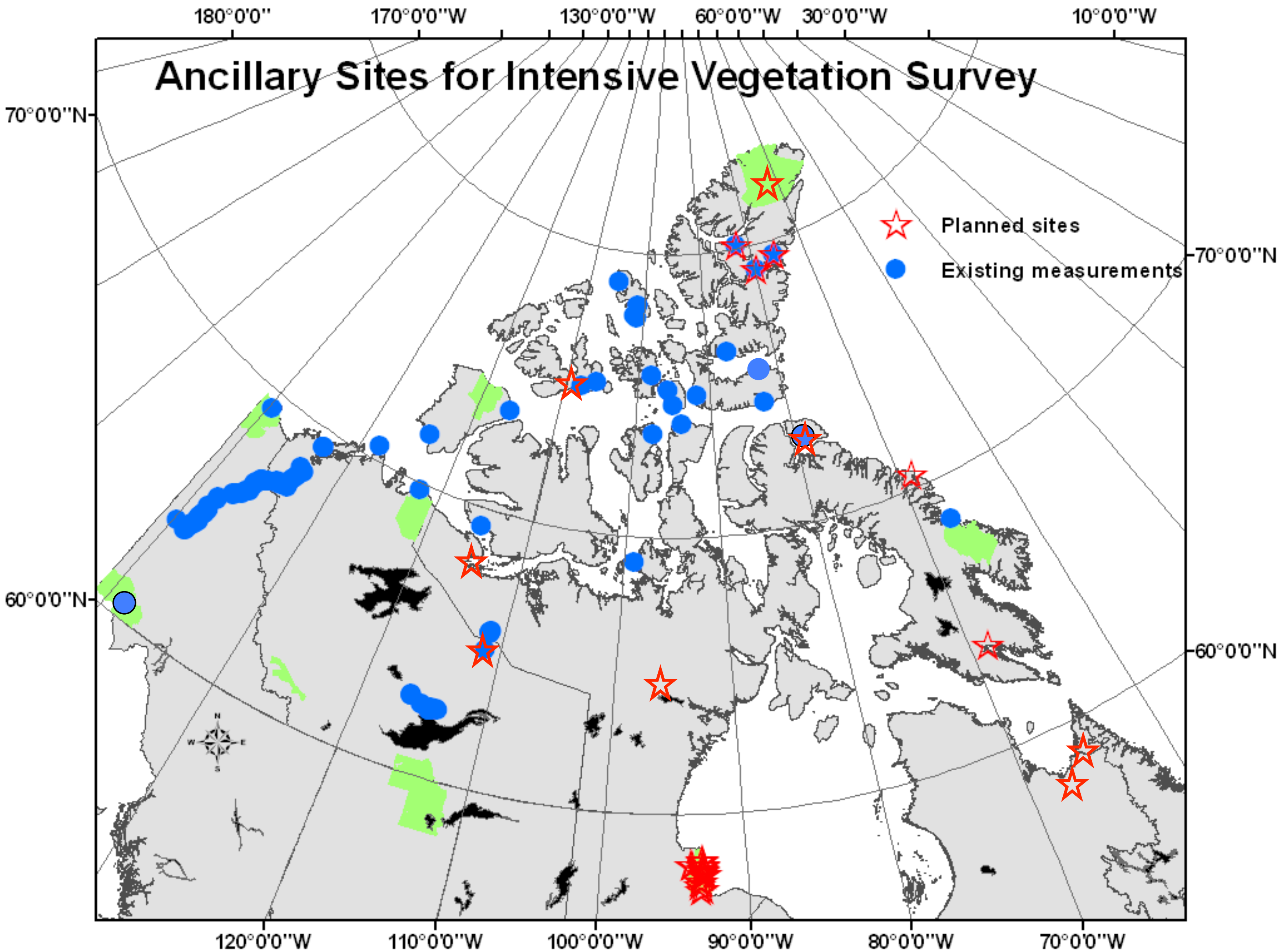
Walker, M. D., C. H. Wahren, R. D. Hollister, G. H. R. Henry, et al. 2005 in review. Plant community responses to experimental warming across the tundra biome. Proceedings of the National Academy of Science.

Canadian IPY project linked to ITEX Core Project 188

Slides provided by Greg Henry from his talk in Vancouver, May 2010

CiCAT Objectives

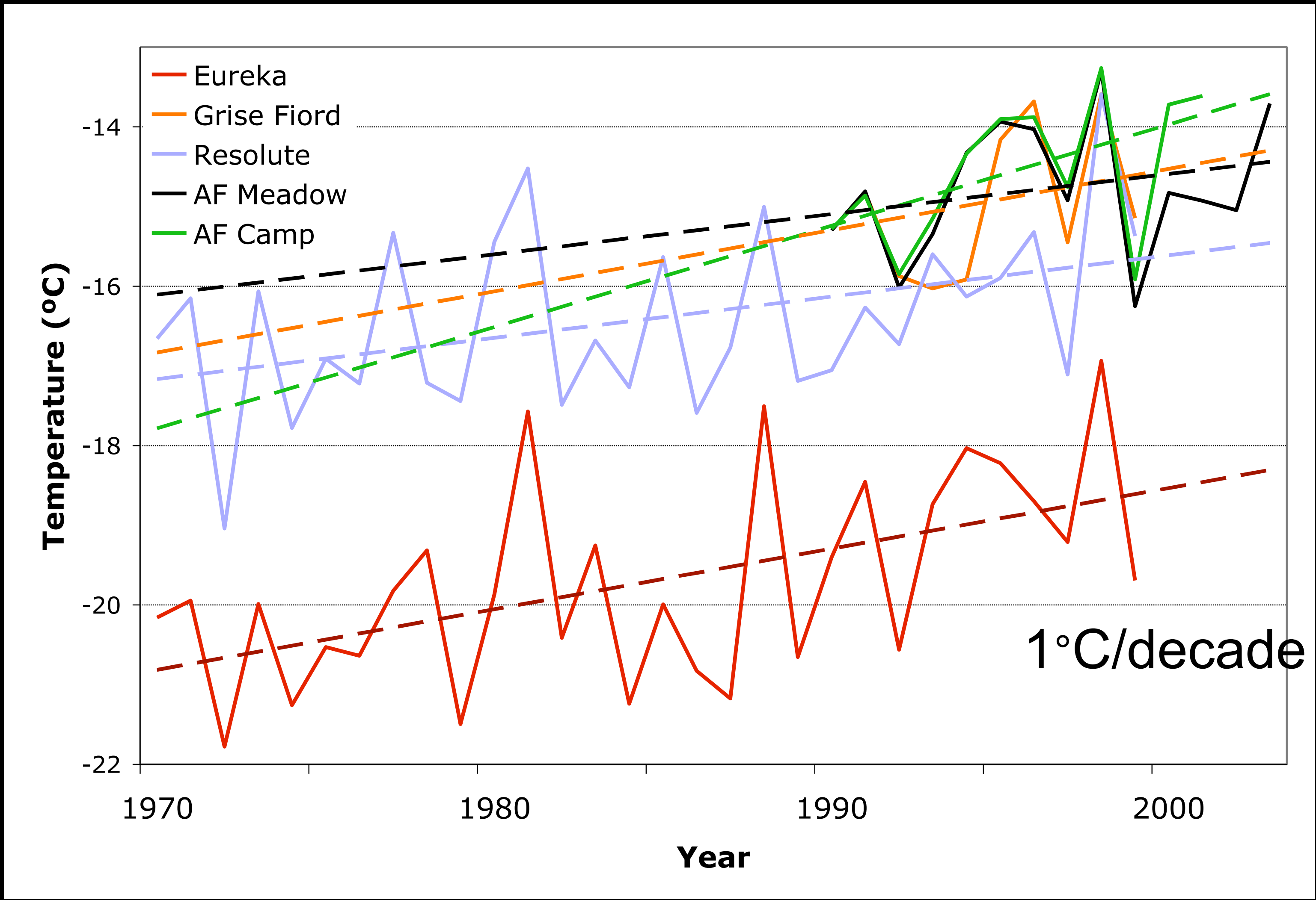
- *"To assess the past, present and future impacts of climate changes on Arctic tundra ecosystems in Canada and the consequences of changes in tundra systems for northern communities, Canada and the planet."*
- **Conduct interdisciplinary research at a variety of scales: molecules to satellites**

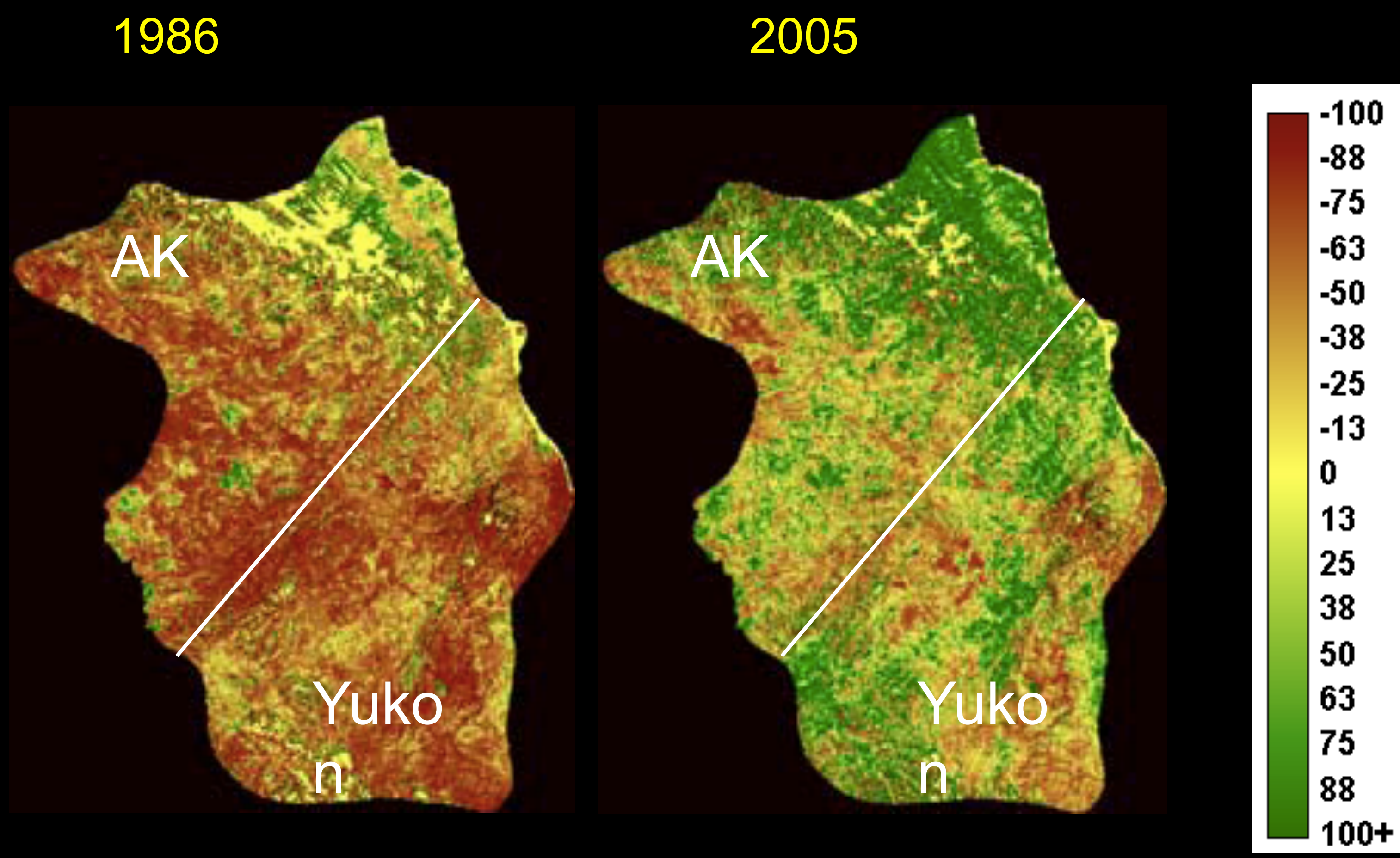

Ancillary Sites for Intensive Vegetation Survey
Planned sites
Existing measurements
180°0'0"
170°0'0"W
130°0'0"W
60°0'0"W
30°0'0"W
10°0'0"W
70°0'0"N
60°0'0"N
120°0'0"W
110°0'0"W
100°0'0"W
90°0'0"W
80°0'0"W
70°0'0"W

Highlights of Canadian ITEX observations

- Vegetation change from remote sensing – related to caribou habitat (Bathurst and Porcupine herds)
- Vegetation change over time in ITEX experimental warming and control plots
- Soils – carbon, microbial diversity, GHG flux
- NEP from tower sites across tundra + models
- Community based monitoring and research
  - Berry ecology, vegetation/environment change

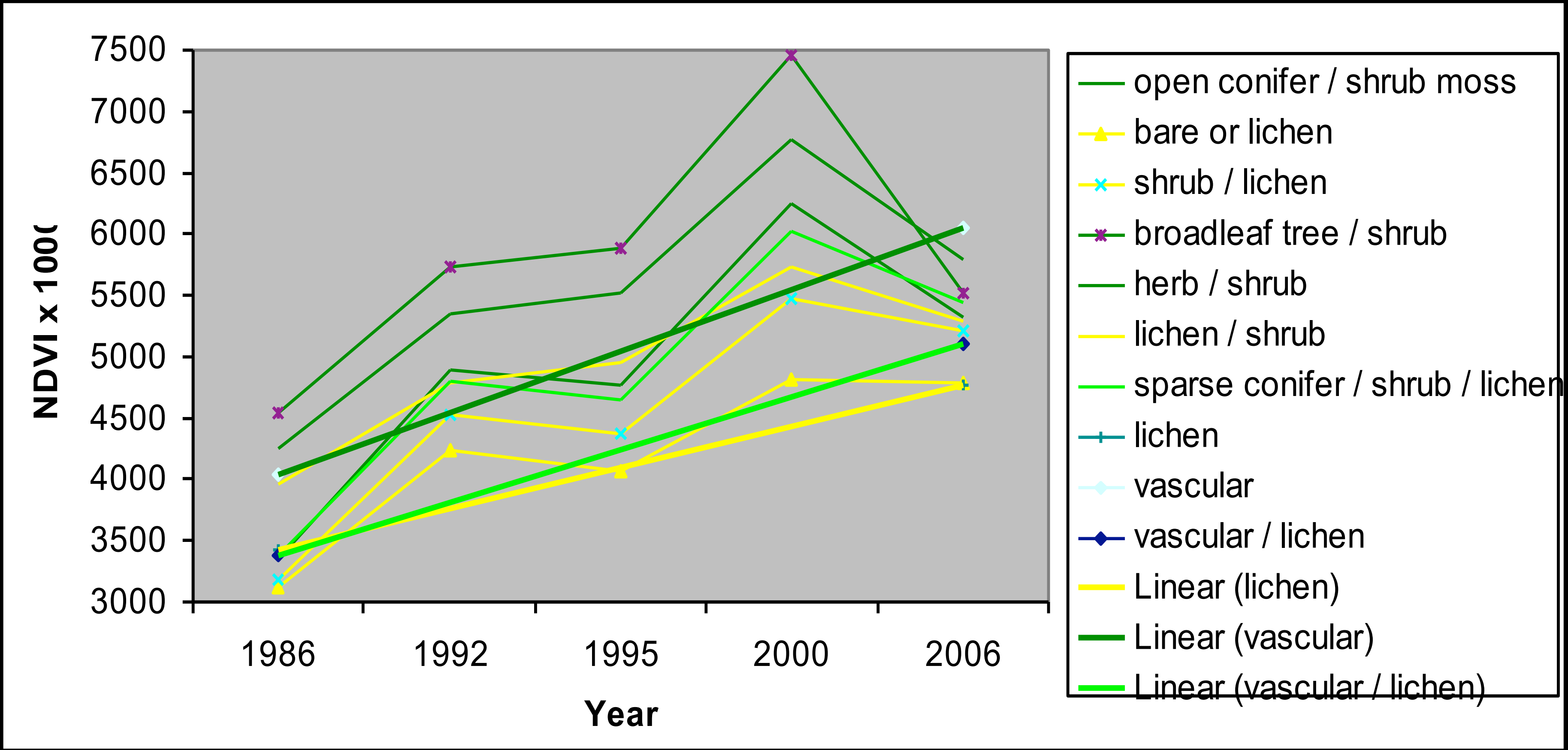
Mean annual temperature at key sites





Vegetation change (NDVI) in porcupine caribou habitat 1986 - 2005

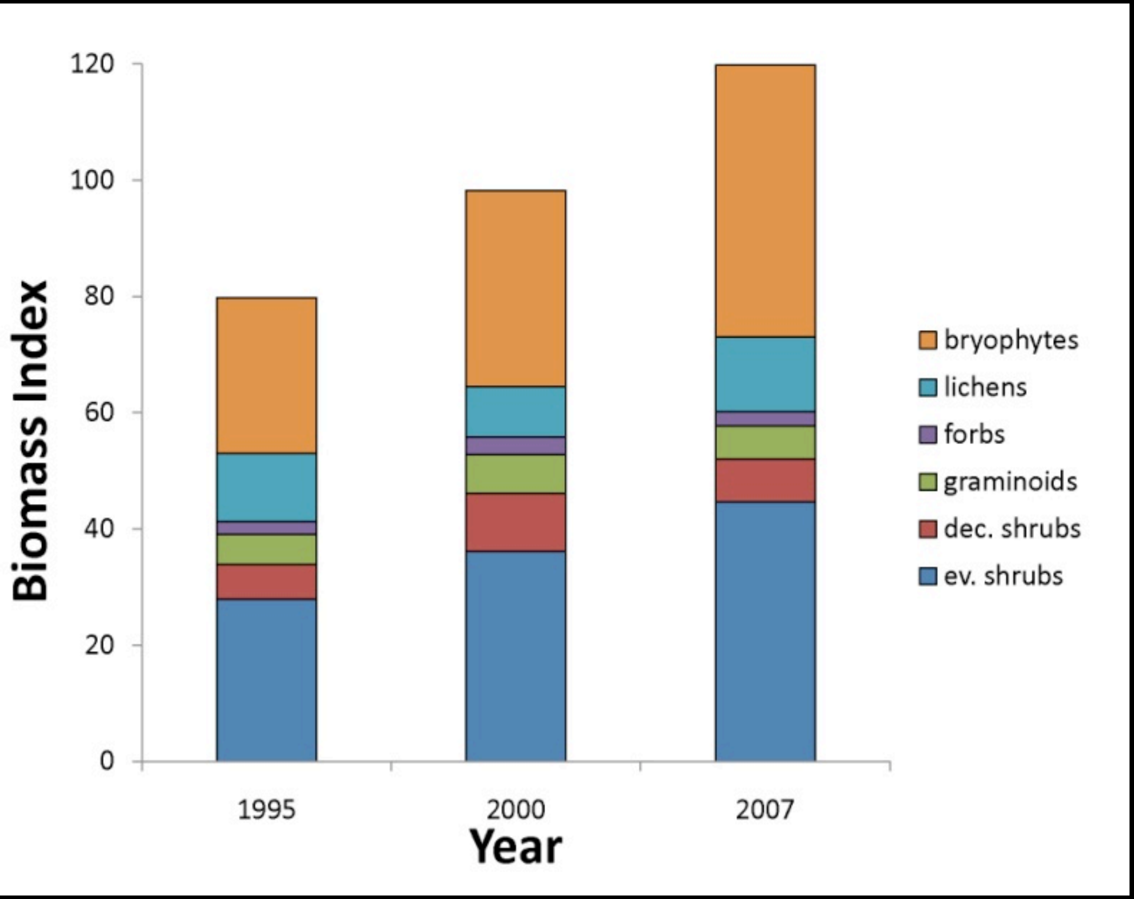
Chen et al. (in prep.)



NDVI trends by vegetation type: Northern Yukon

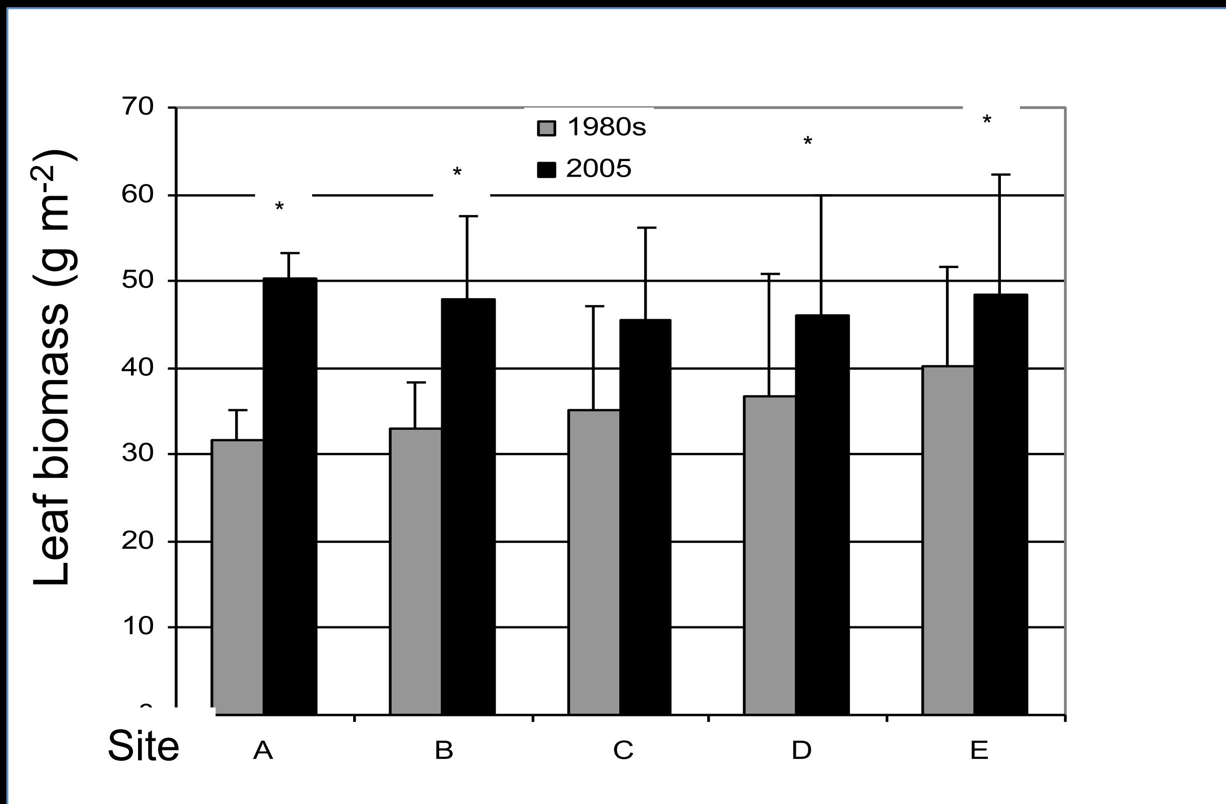
From Chen et al. (in prep.)

Changes in heath vegetation in ITEX control plots at Alexandra Fiord, Ellesmere Island



(Hudson and Henry, 2009)

Biomass change in wet sedge tundra over 25 years (no grazing pressure), Alexandra Fiord,

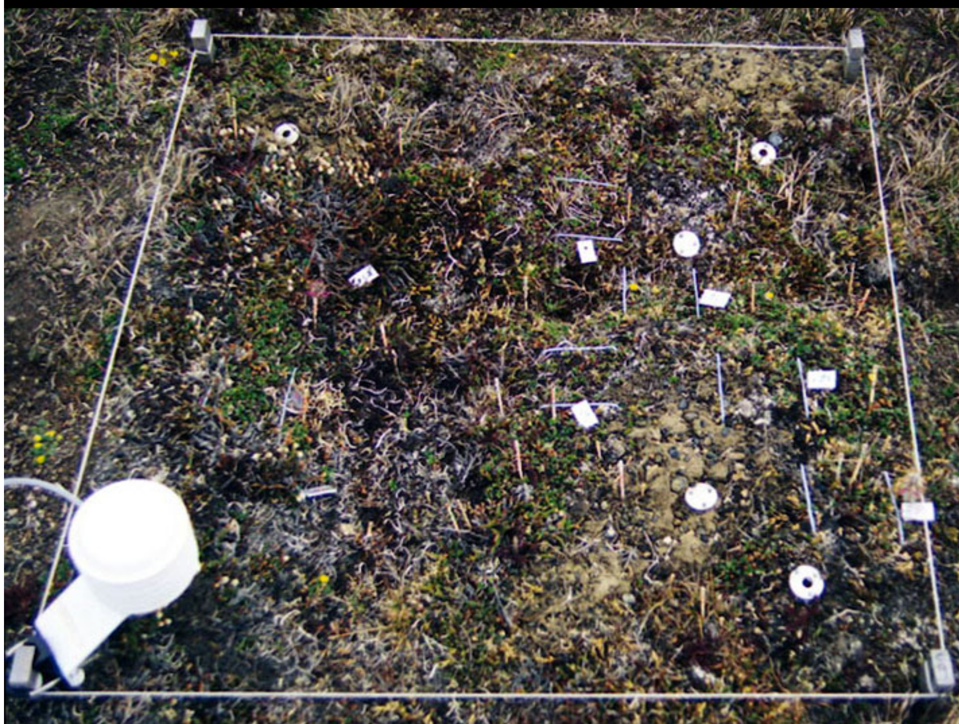


no grazing pressure,
Alexandra Fiord,

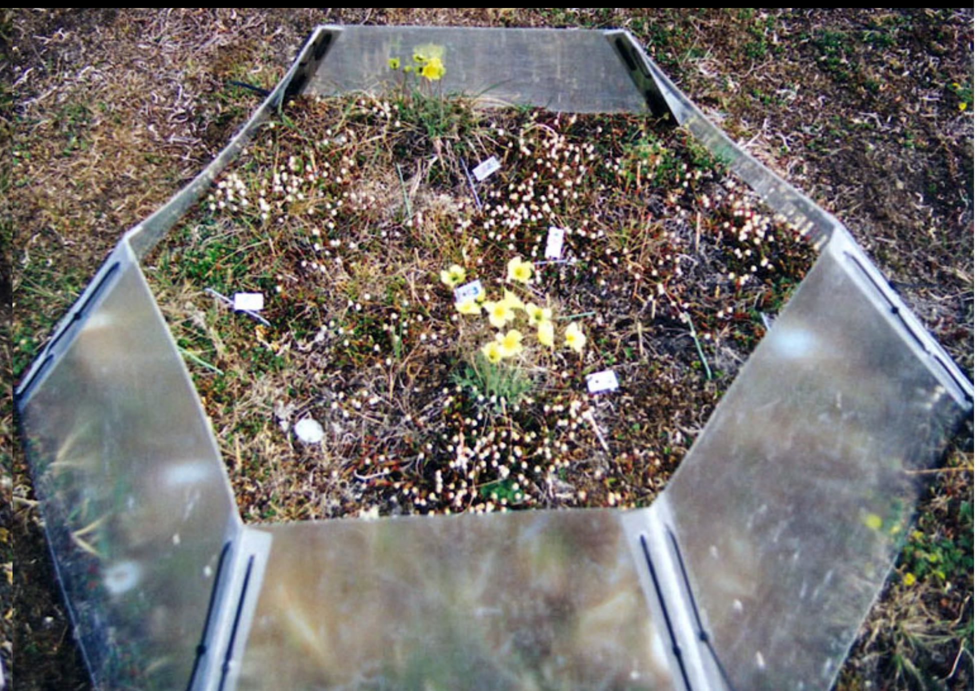
(Hill and Henry 2011)

ITEX
International Tundra Experiment

Core ITEX Experiment after 20 years
Small-scale greenhouse warming



Control



Open-top chamber

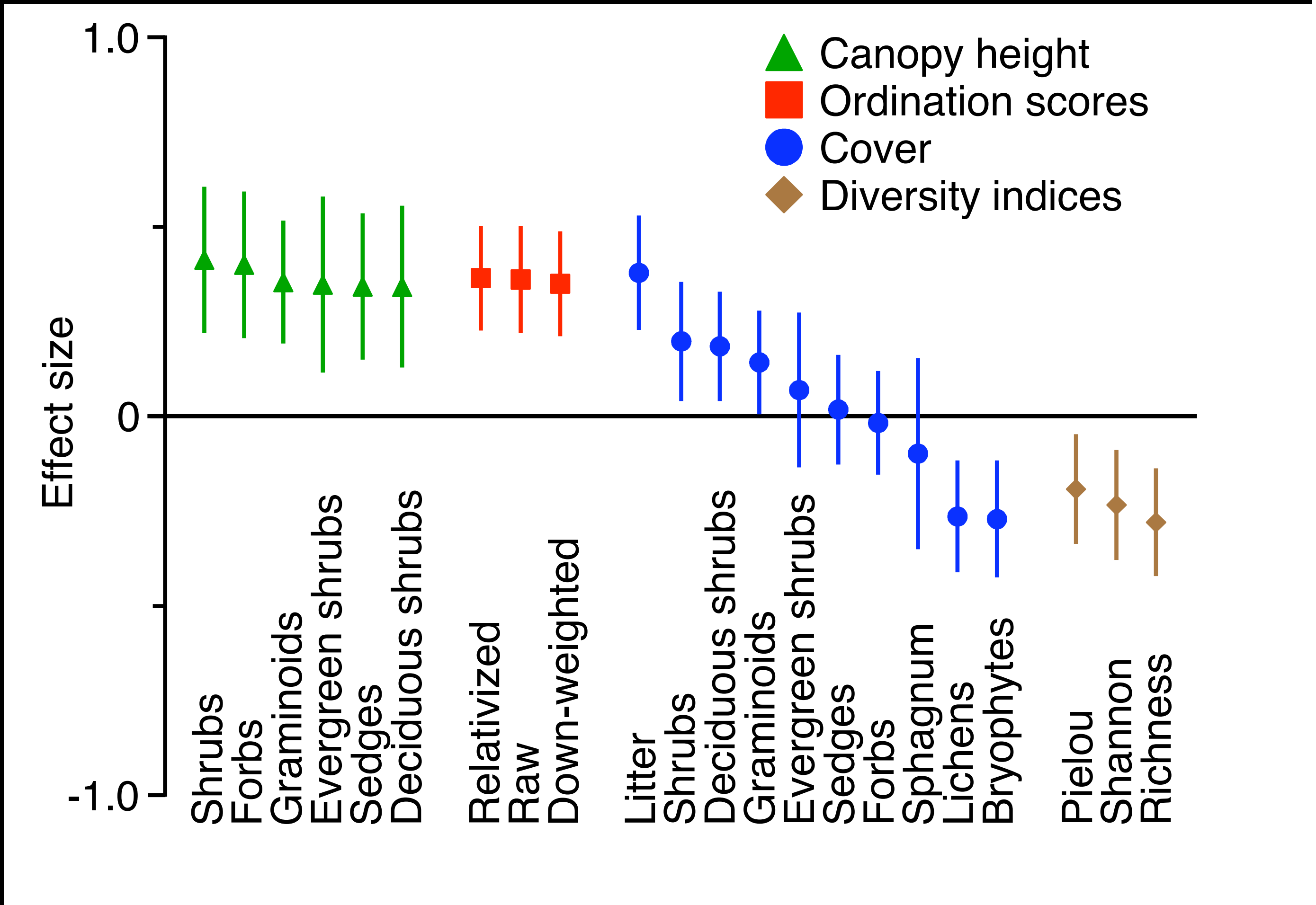
Experimental warming – metaanalysis of ITEX results in 2010

Warming increases:

- Vascular plant height,
- Cover of litter, deciduous shrubs, graminoids.

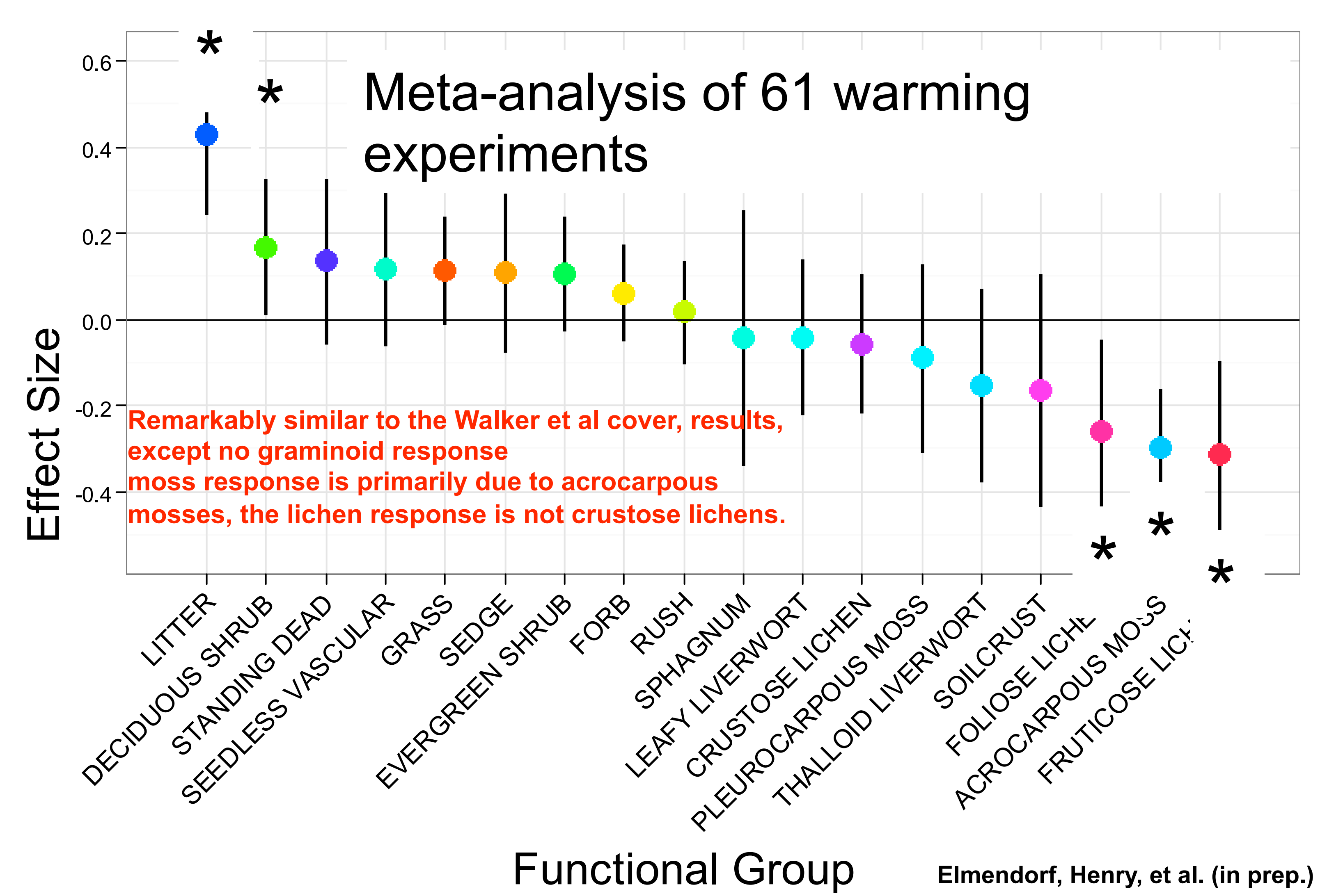
Decreases:

- cover of lichens and mosses
- diversity



M.D.Walker et al. 2006, PNAS

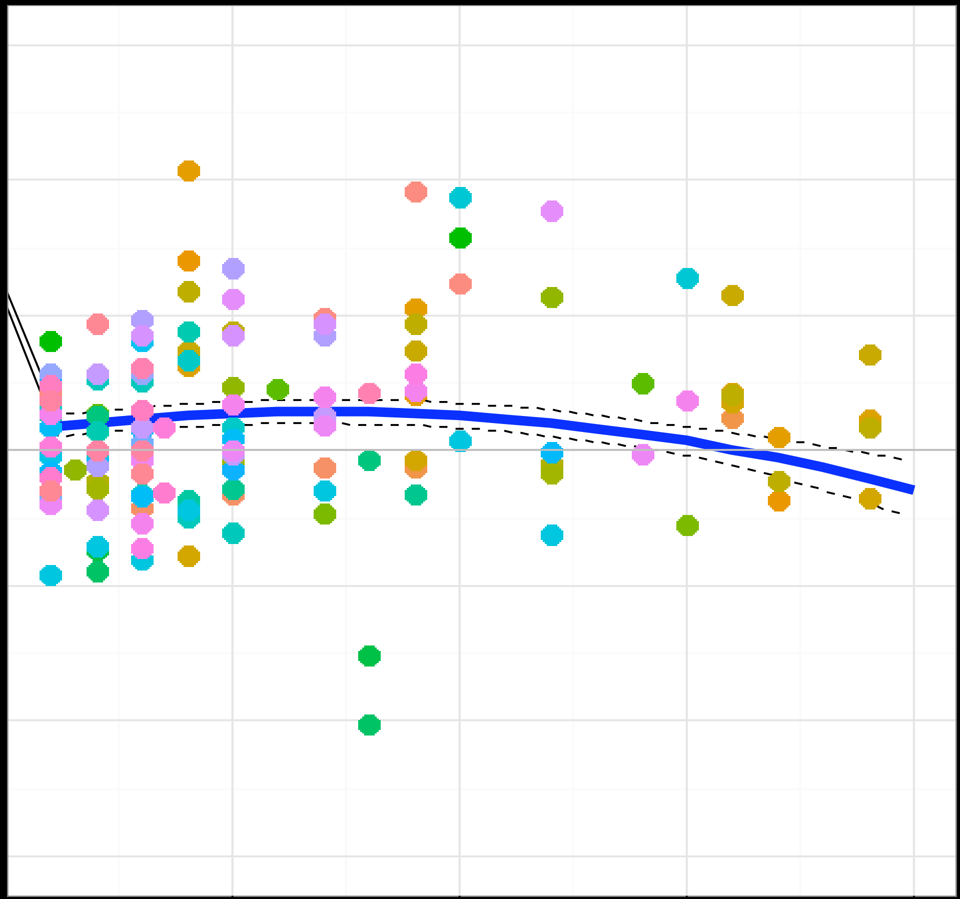
Repeat of the analysis in 2010: showing only affects on cover of tundra plant functional groups



Elmendorf, Henry, et al. (in prep.)

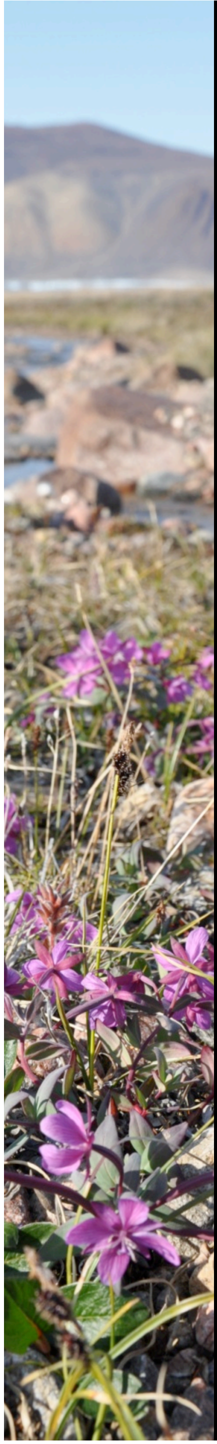
How do warming effects vary over time?

Deciduous shrub abundance positive effect but peaks after ~ 10 years of warming, then becomes negative



SHORT TERM ⟵⟶ LONG TERM

Elmendorf, Henry, et al. (in prep.)

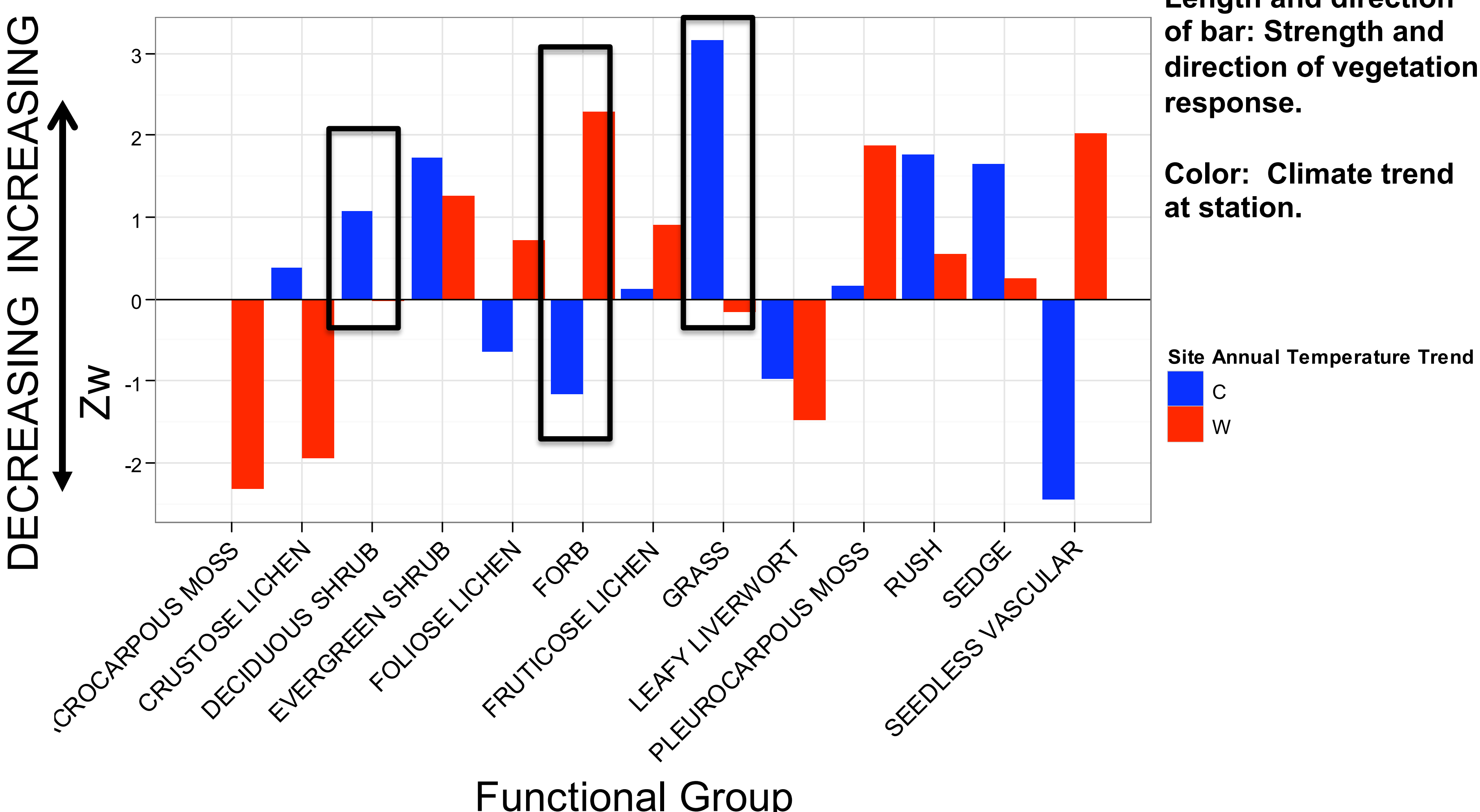


Part II. How is vegetation changing over time under ambient conditions?

OBSERVATIONAL DATASETS (min 2 sampling points at least 5 years apart in time)

- 50 Locations
- 190 Plots
- 13 years = Average duration of observational record (range 5-27)
- 4 = Average number of sampling years per plot
- 789 plot*YEAR combinations

Somewhat variable responses – no clear relation with temperature change

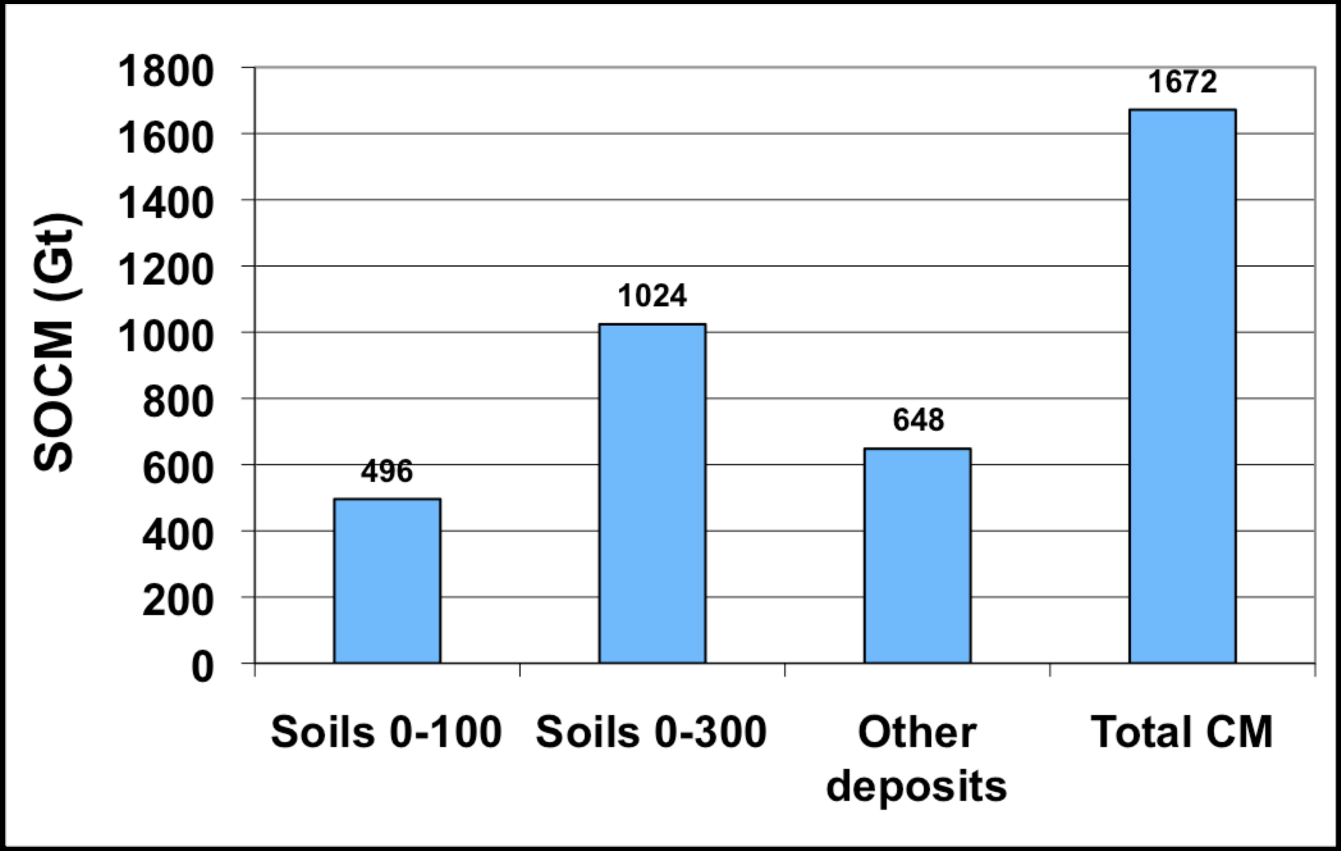


Length and direction of bar: Strength and direction of vegetation response.

Color: Climate trend at station.

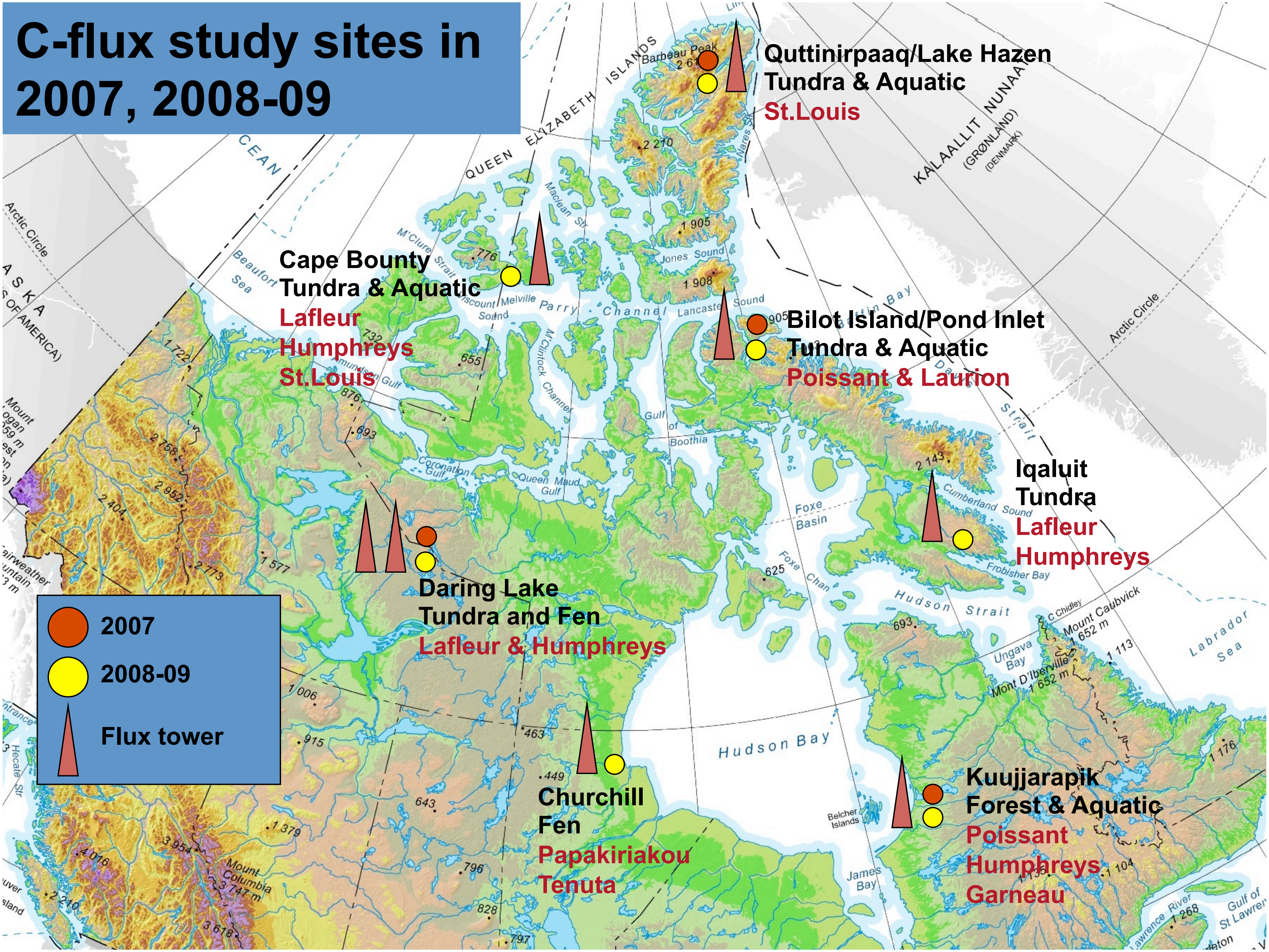
Elmendorf, Henry, et al. (in prep.)

Total Soil Organic Carbon Mass in the northern circumpolar permafrost region

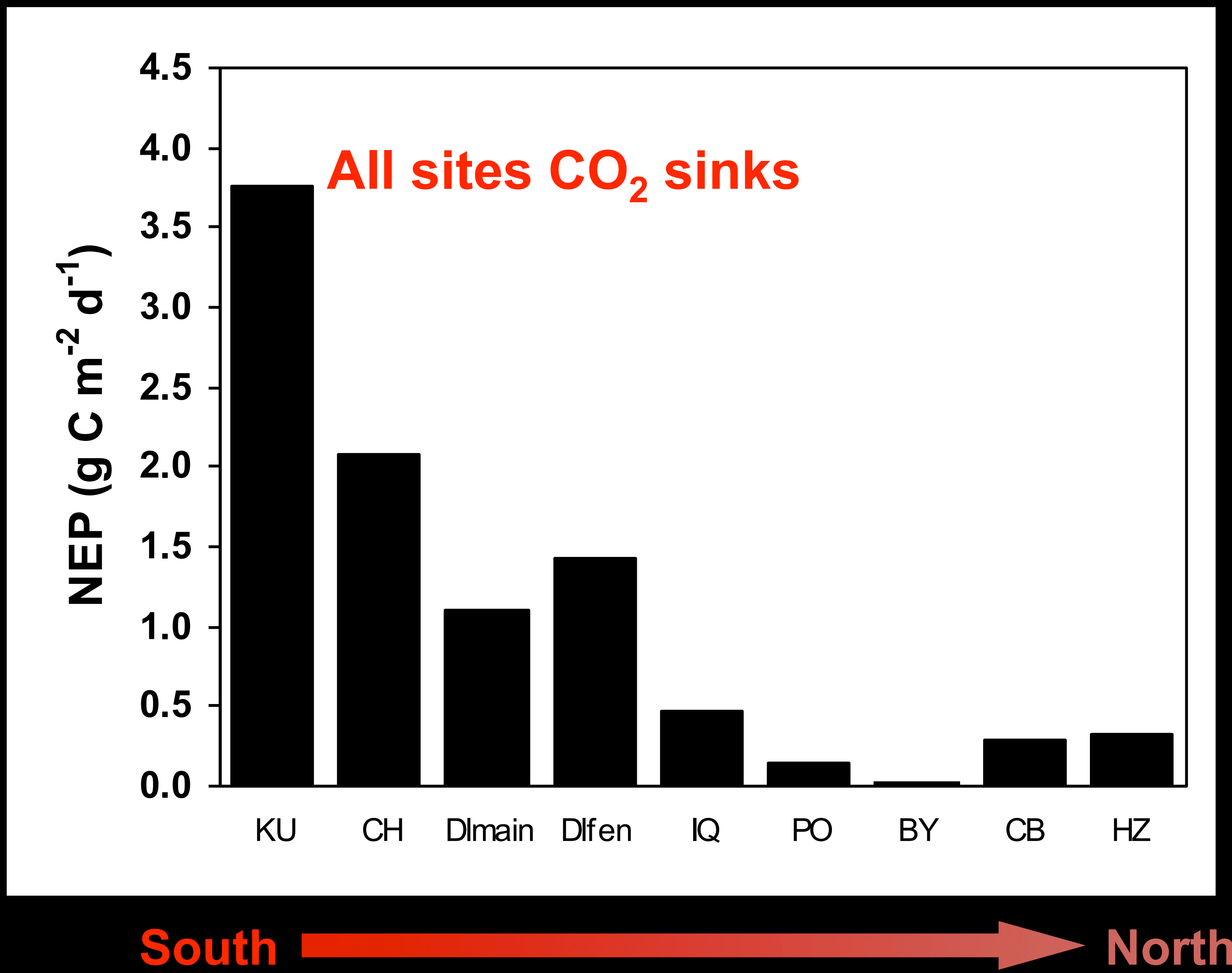


Total SOC mass is ca. 50% of the reported global belowground soil organic carbon pool.

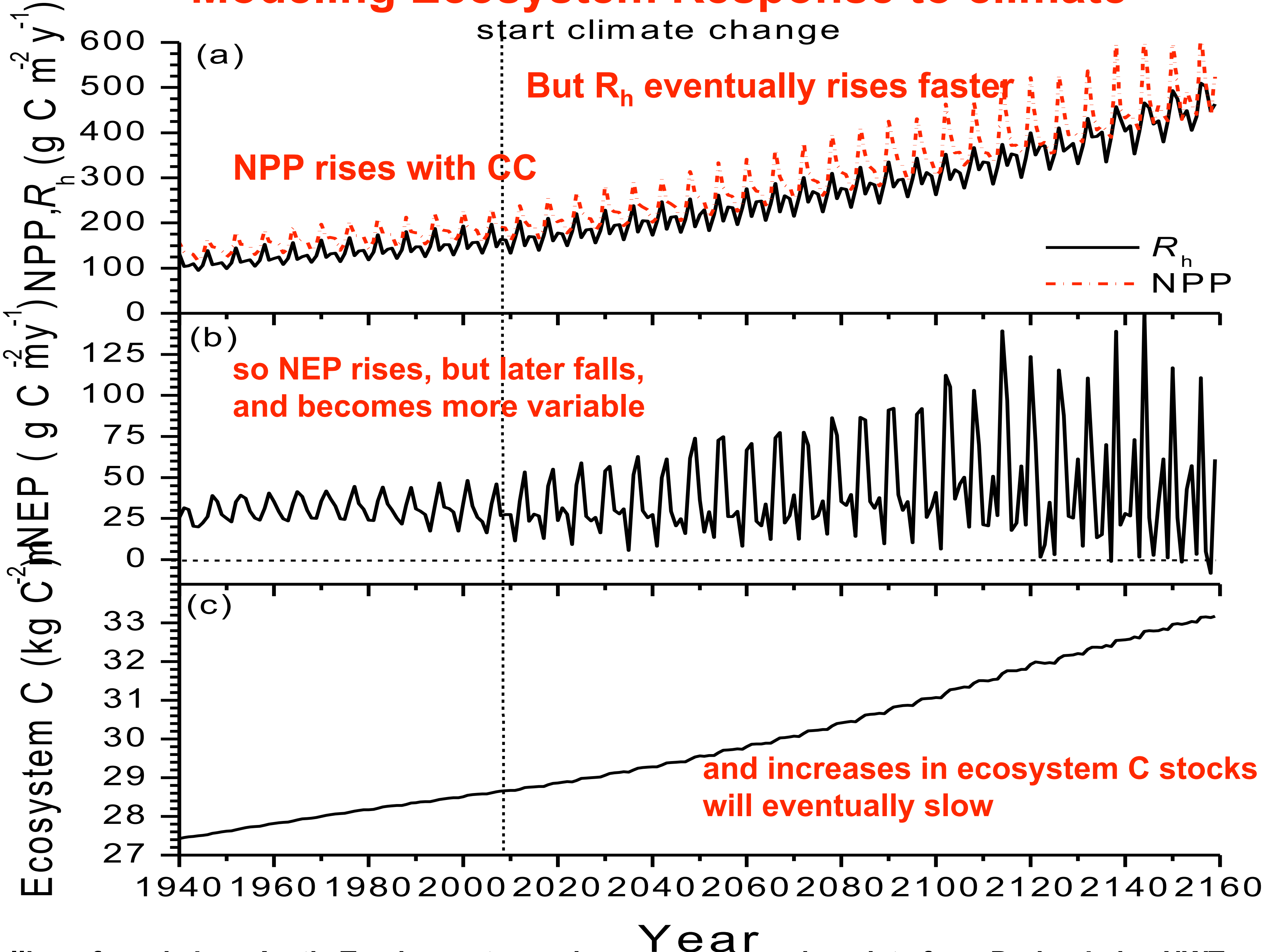
C-flux study sites in 2007, 2008-09



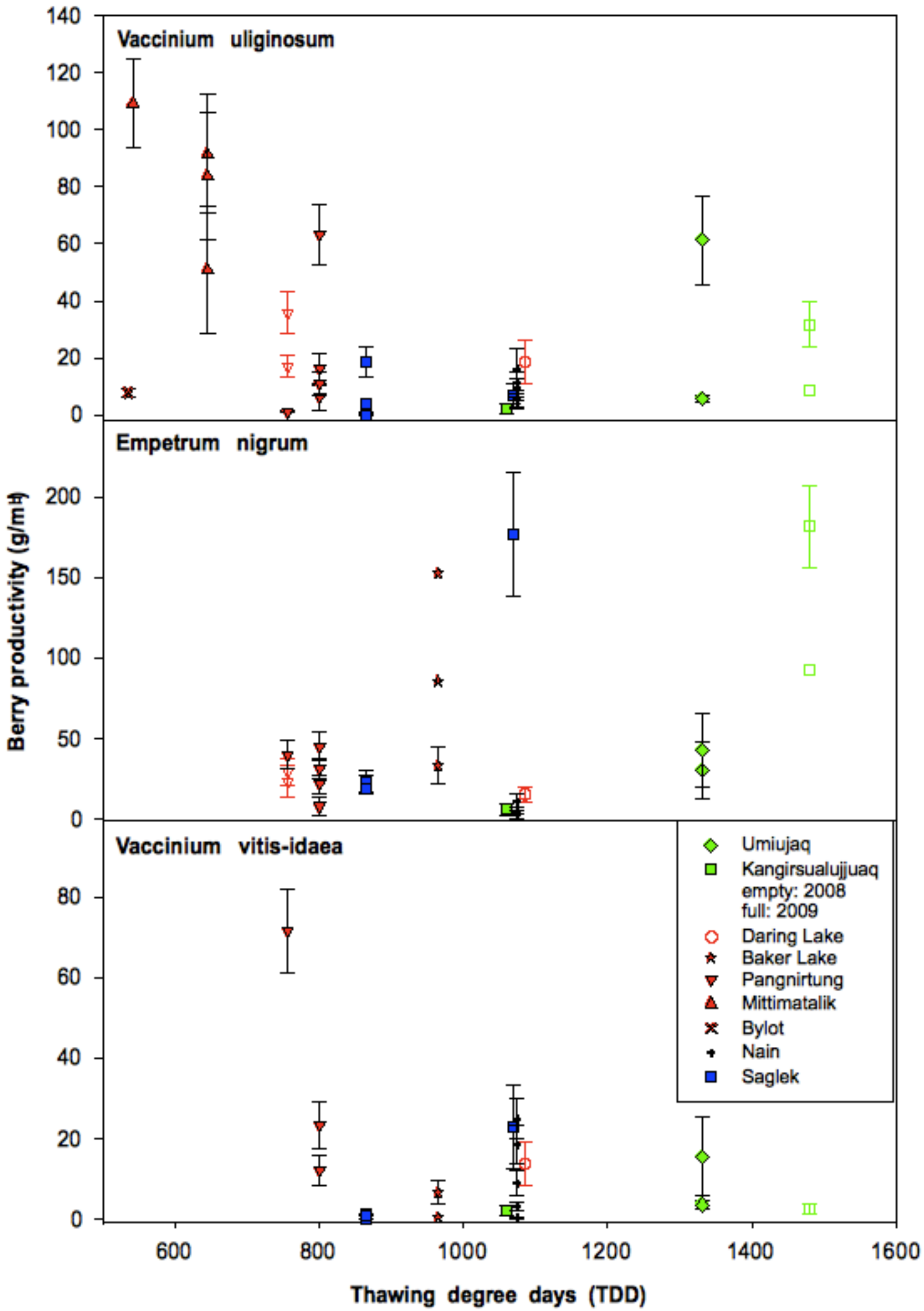
Mean Daily NEP, July 2008



Modeling Ecosystem Response to climate



Modelling of mesic Low Arctic Tundra system using *ecosys*, based on data from Daring Lake, NWT.
From: Grant et al. (in prep.)



Preliminary results of community-based research on berry production across nine communities/sites in the Canadian Arctic.

Berry productivity across CiCAT sites in relation to thawing degree days (TDD)

Berry production appears to be higher in northern (cooler) sites for *Vaccinium uliginosum* and *V. vitis-idaea*.

CiCAT Results: Summary

- Tundra ecosystems are responding to warming of the past 30+ years
  - Increased biomass / productivity
  - Increased cover of shrubs
- Tundra soils
  - Permafrost soils hold huge stores of carbon
  - emit substantial amounts of N_2O and CH_4
  - have similar microbial diversity as other soils
- CiCAT sites are currently sinks for CO_2
  - Will this continue? Modelling indicates yes.

CiCAT Results: Summary

- Berry production varies greatly across the Canadian Arctic
- Our network of sites in communities allows combination of science and LTEK to be used for monitoring and education
- Legacy of sites, data, and inspired and dedicated researchers
- Ongoing syntheses within sub-projects

Back to the Future Studies: Long-term observations on old arctic study sites

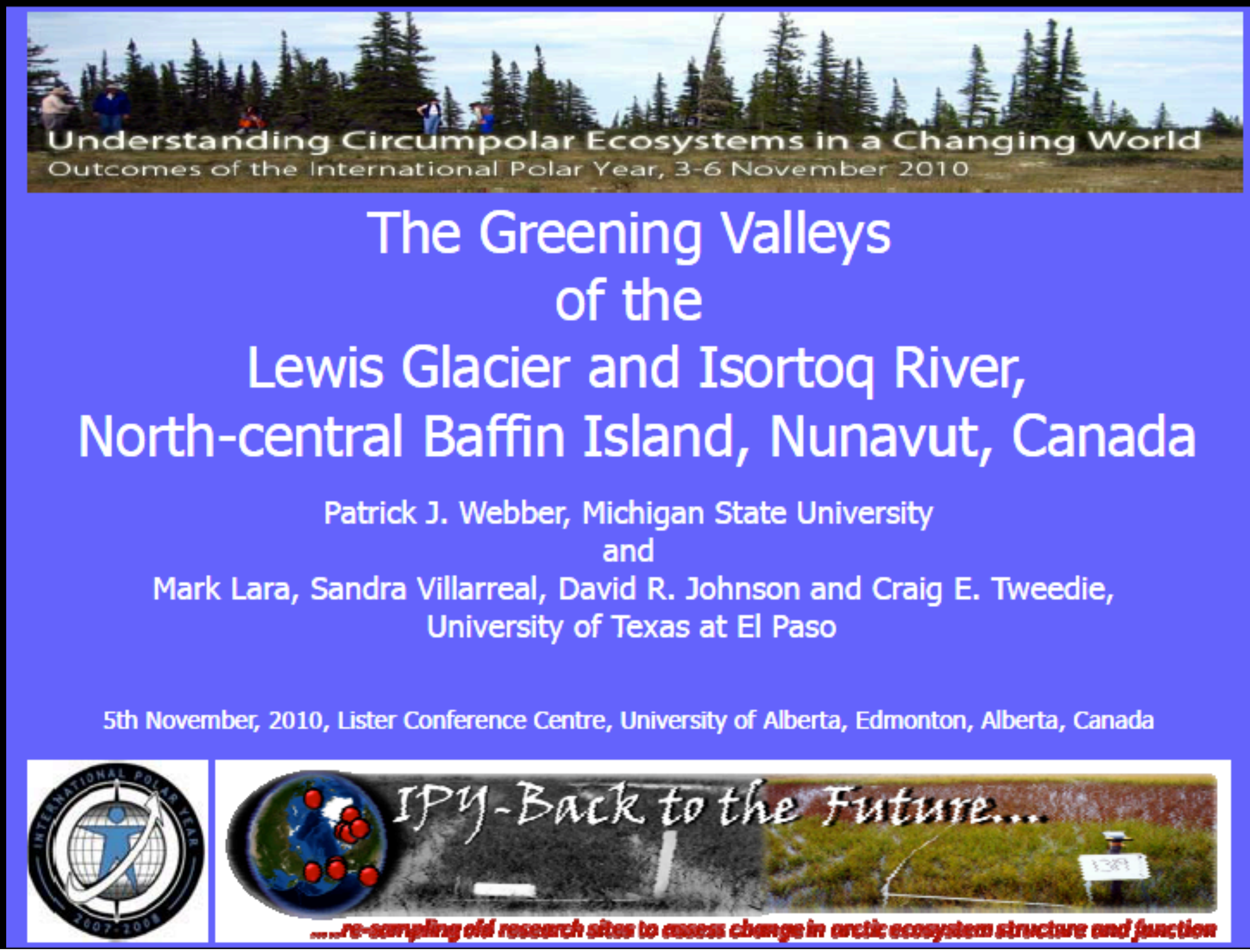
IPY Endorsed Project 512

Retrospective and Prospective Vegetation Change in Polar Regions: Back to the Future (BTF)

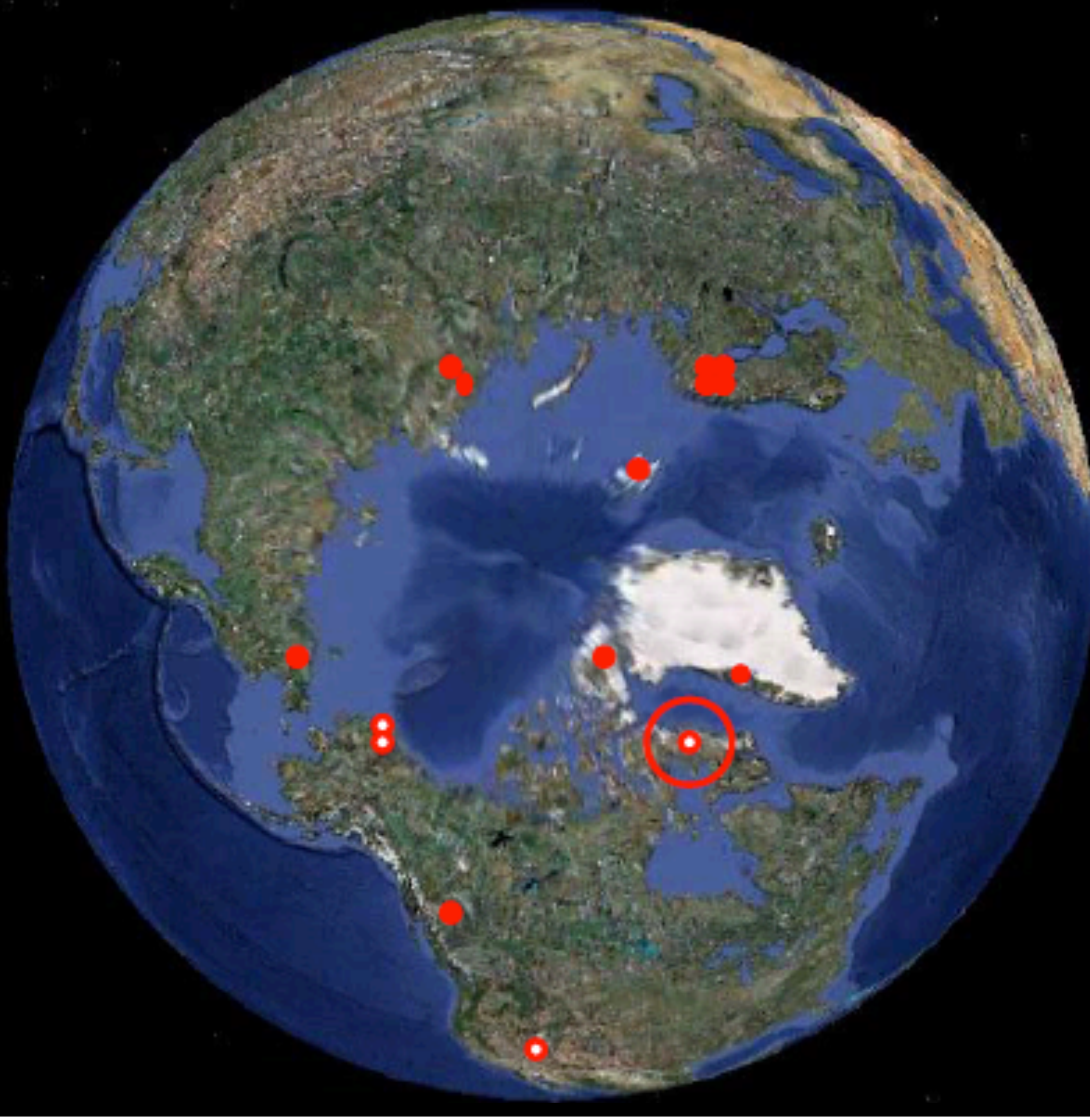
Leader TV Callaghan – SWE
Co-Leader CE Tweedie - US

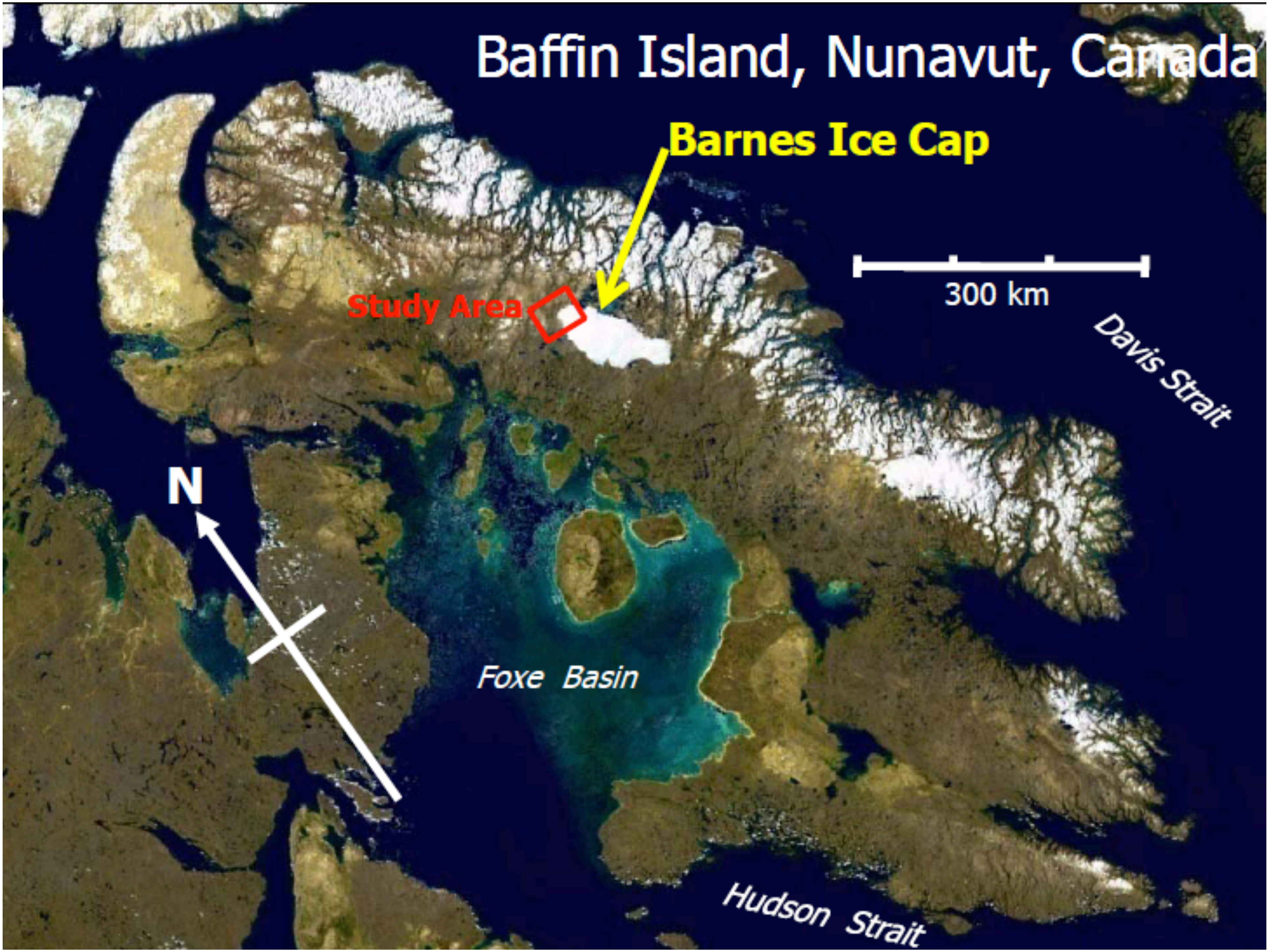
- The old **geological adage:** "the present is the key to the past". James Hutton, 1726–97, Scottish geologist
- The **paleoecologists' adage**: "the past is the key to the future".
- BTF takes advantage of the IPY opportunity, historic data sets and sites, **aging PIs, a pool of talented young scientists and students** and contributes to an IPY database.

Study site on Baffin Island: 46 years after initial observations

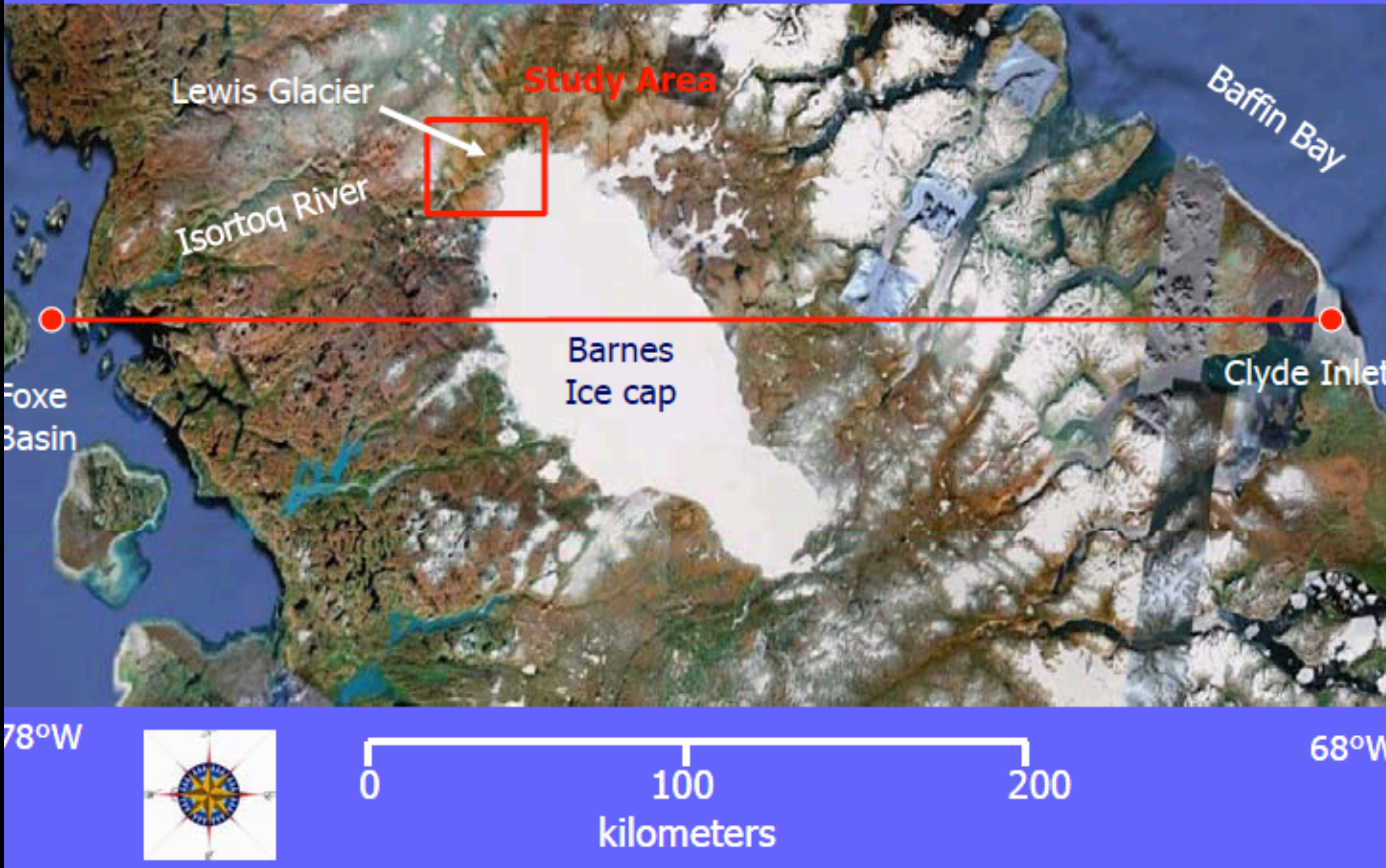


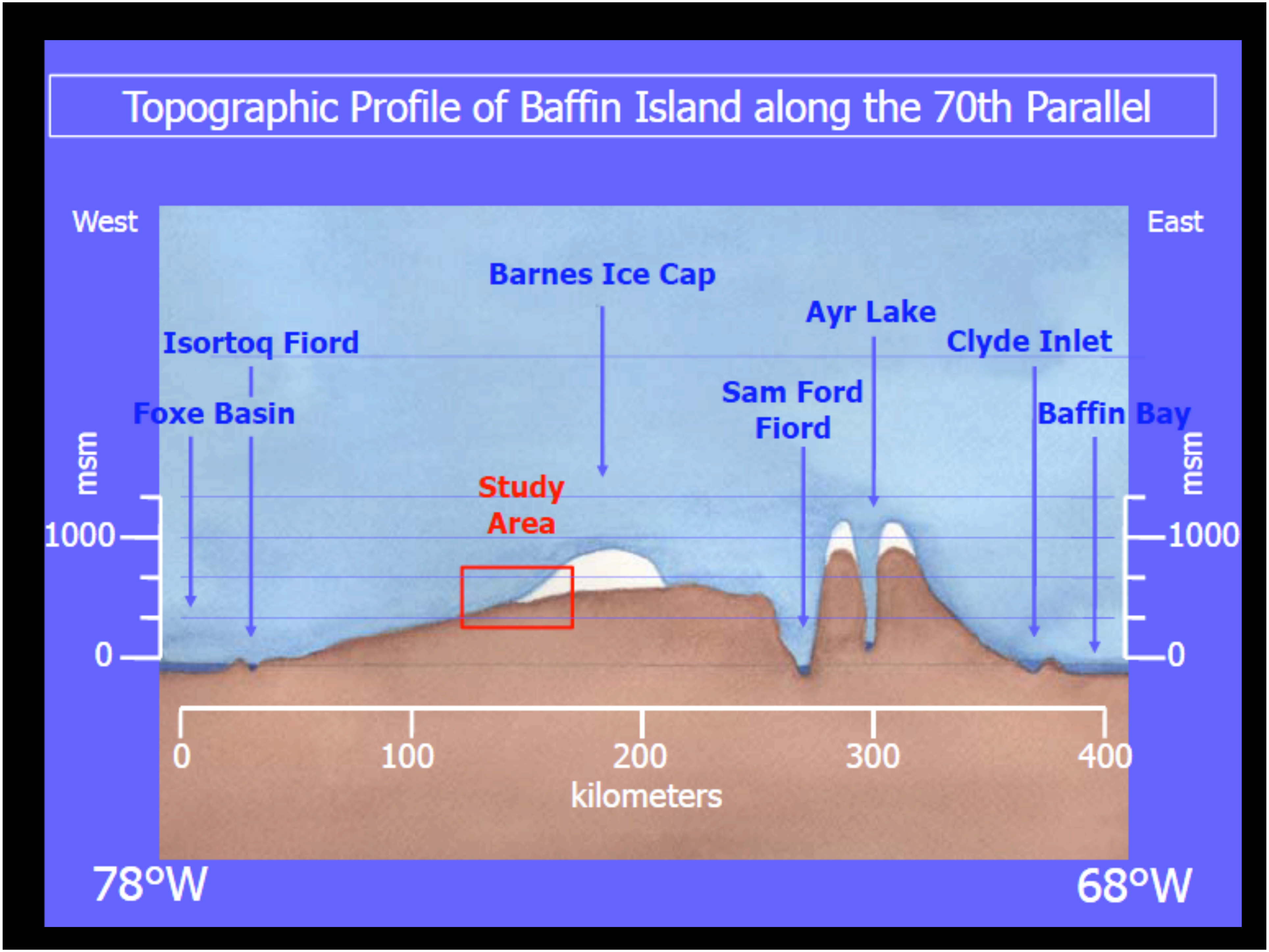
Lewis Glacier location and other BTF sites

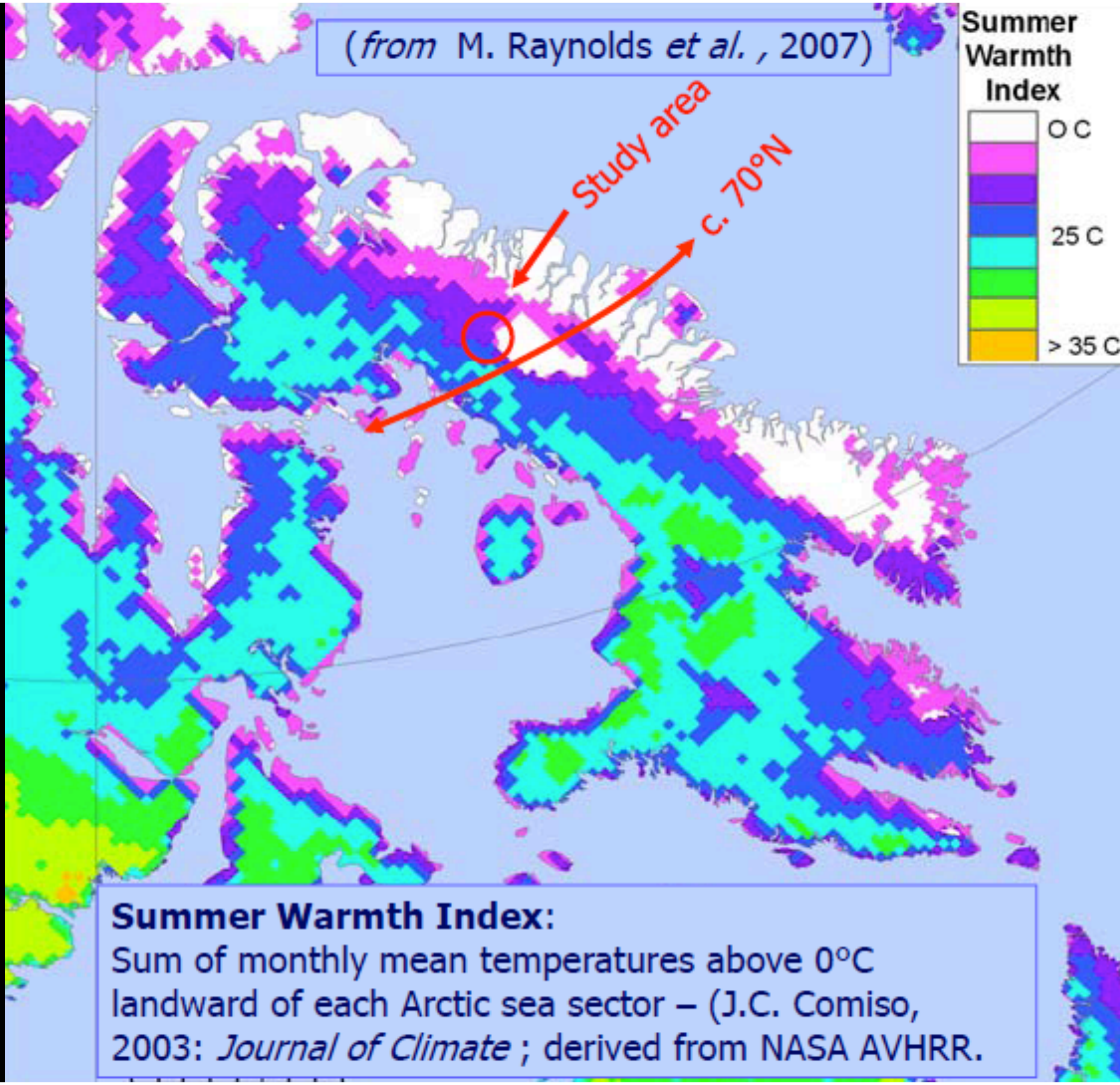


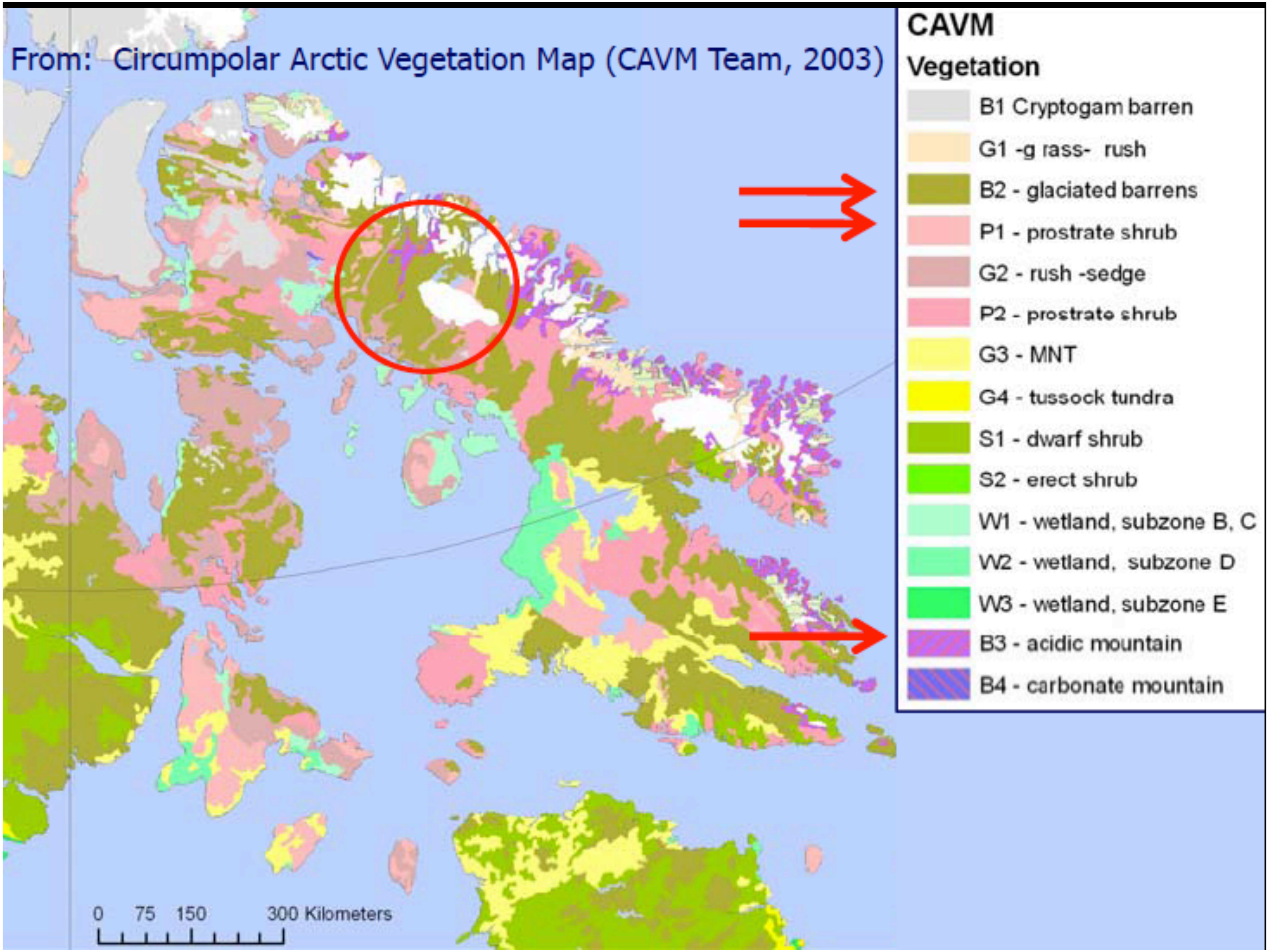

Baffin Island, Nunavut, Canada
Barnes Ice Cap
Study Area
300 km
Davis Strait
N
Foxe Basin
Hudson Strait

Lewis Glacier and Isortoq River BTF Study Area and the Topographic Profile along the along the 70th Parallel

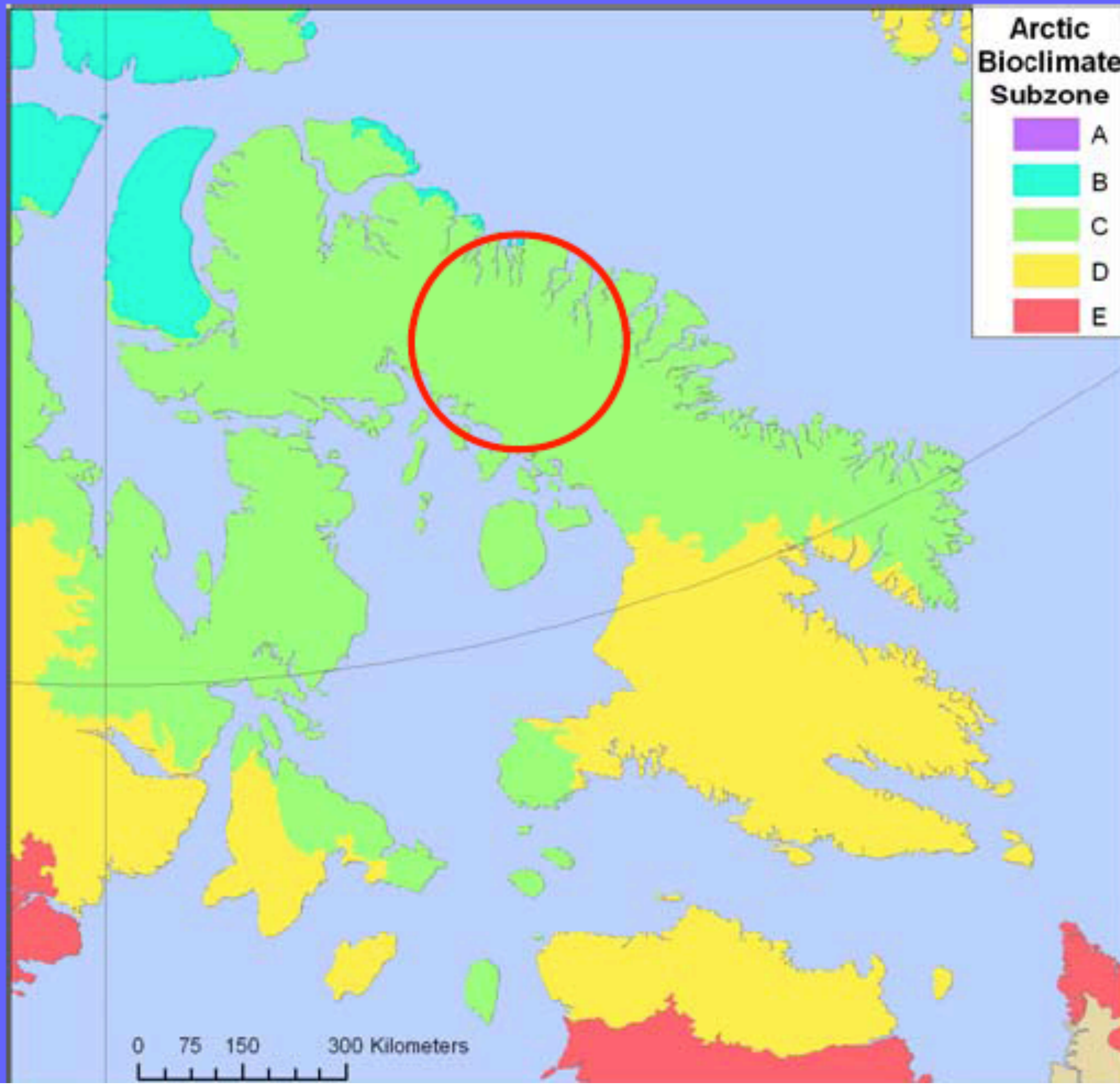



Topographic Profile of Baffin Island along the 70th Parallel
West
East
Barnes Ice Cap
Ayr Lake
Isortoq Fiord
Clyde Inlet
Sam Ford Fiord
Foxe Basin
Baffin Bay
msm
msm
Study Area
1000
1000
0
0
0
100
200
300
400
kilometers
78°W
68°W


(*from* M. Raynolds *et al.* , 2007)
Study area
c. 70°N
Summer Warmth Index
0 C
25 C
> 35 C
Summer Warmth Index:
Sum of monthly mean temperatures above 0°C
landward of each Arctic sea sector – (J.C. Comiso,
2003: *Journal of Climate* ; derived from NASA AVHRR.


From: Circumpolar Arctic Vegetation Map (CAVM Team, 2003)
CAVM
Vegetation
B1 Cryptogam barren
G1 -g rass- rush
B2 - glaciated barrens
P1 - prostrate shrub
G2 - rush -sedge
P2 - prostrate shrub
G3 - MNT
G4 - tussock tundra
S1 - dwarf shrub
S2 - erect shrub
W1 - wetland, subzone B, C
W2 - wetland, subzone D
W3 - wetland, subzone E
B3 - acidic mountain
B4 - carbonate mountain
0 75 150 300 Kilometers

Climate Subzones (from: CAVM Team, 2003)



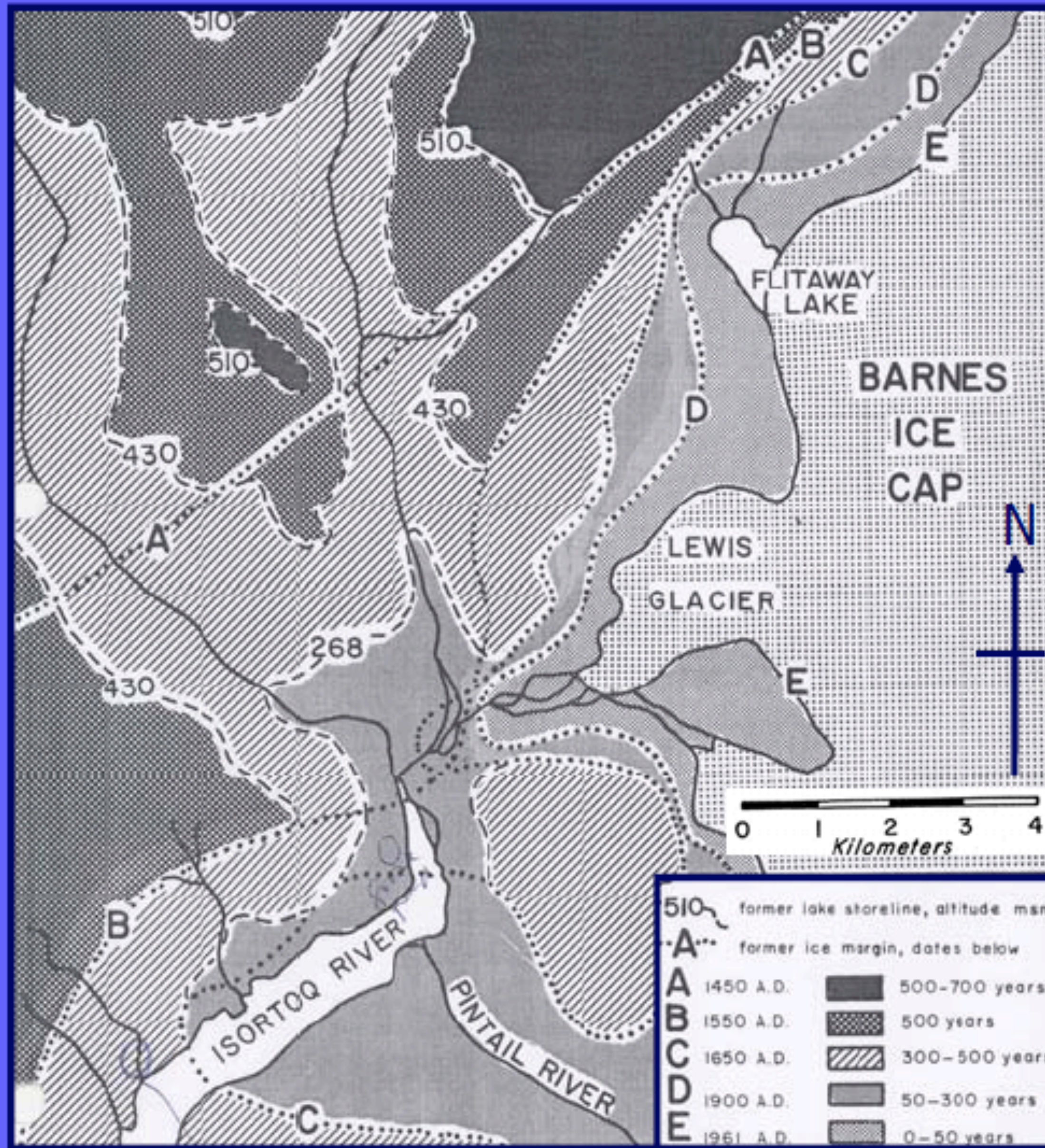
Circumpolar Arctic Vegetation Map (CAVM) Bioclimate Subzone Characteristics (*after* Raynolds *et al.* 2006)

* Summer Warmth Index: The sum of the monthly mean temperatures above 0°C; it corresponds well NPP and NDVI

Bioclimate Subzone	Temperature		Dominant Plant Growth Forms on Zonal/Mesic sites	Number of Vascular Plants in Local Flora	Characteristic Species and Genera on Zonal/Mesic Sites
	Mean July Temperature	Summer Warmth Index*			
A	0-3°C	< 6°C	Cushion forbs, mosses and lichens. **Woody plants & sedges absent**	<50	***Papaver, Draba, Saxifraga , Stellaria, Minuartia , Cerastium,*** *Luzula, Juncus, Puccinelia, Phippsia*
B	3-5°C	6 - 9°C	Prostrate dwarf shrubs. **Erect shrubs lacking**	50-100	***Salix arctica, Dryas,*** *Saxifraga, Papaver radicatum, Luzula confusa, Alopecurus alpinus*
C	5-7°C	9-12°C	**Hemi-prostrate** shrubs (<15cm) and sedges	75-100	***Cassiope tetragona, Carex bigelowii, C. rupestris,*** *Epilobium latifolium, Astragalus alpinus*
D	7-9°C	12-20°C	**Erect shrubs** (<40cm), sedges and mosses	125-250	***Betula nana, Empetrum, Carex membranacea, Eriophorum vaginatum,*** *Salix richardsonii, Dryas integrifolia, Aulacomnium*
E	9-12°C	20-35°C	**Low shrubs**, tussock sedges, and mosses (40-200cm)	200-500	***Betula, Salix, Alnus,*** *Eriophorum,*

Young landscape

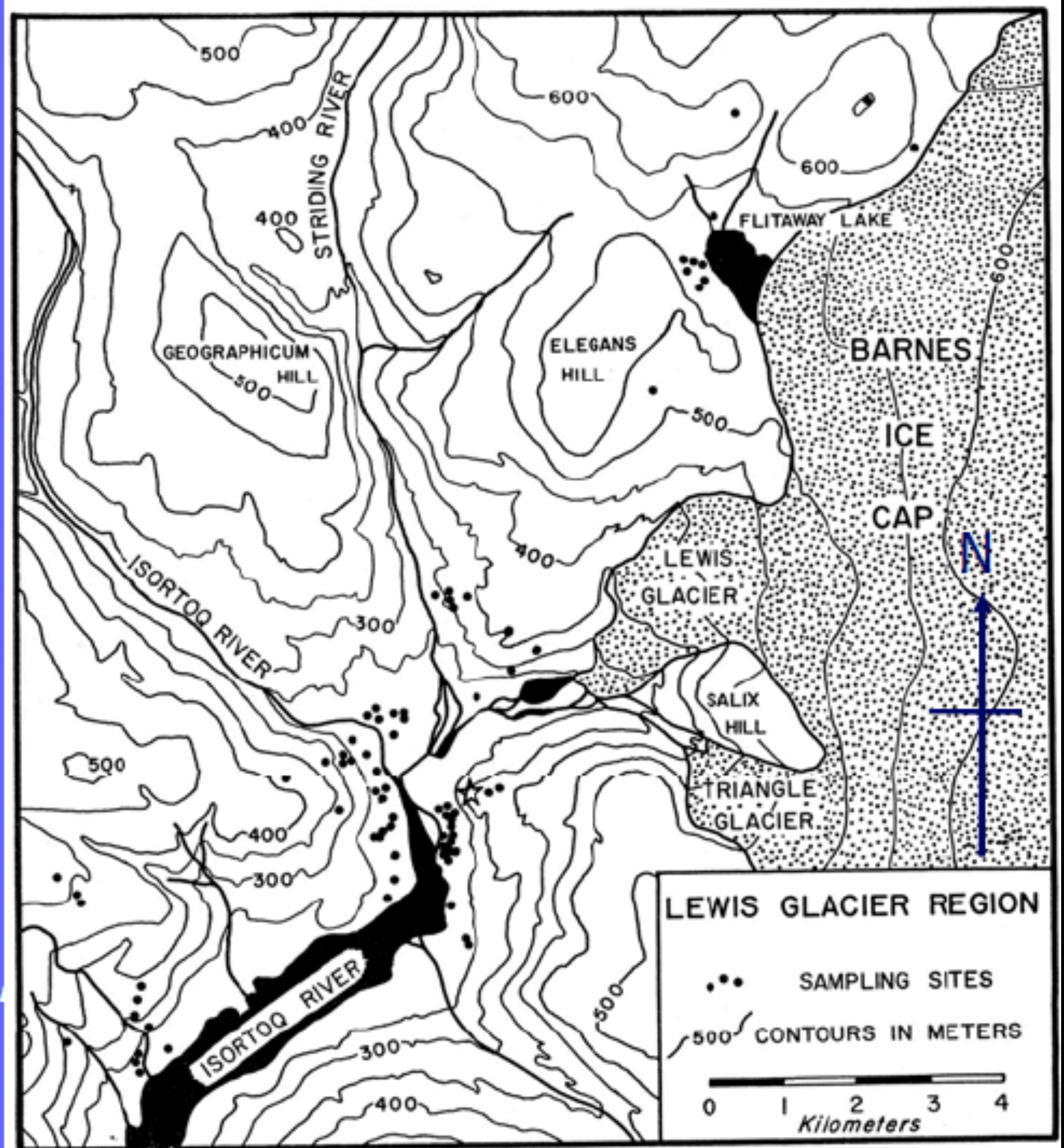
Surface ages in the study area derived from lichenometry, moraine positions and former proglacial lake shorelines. (from Webber 1967)



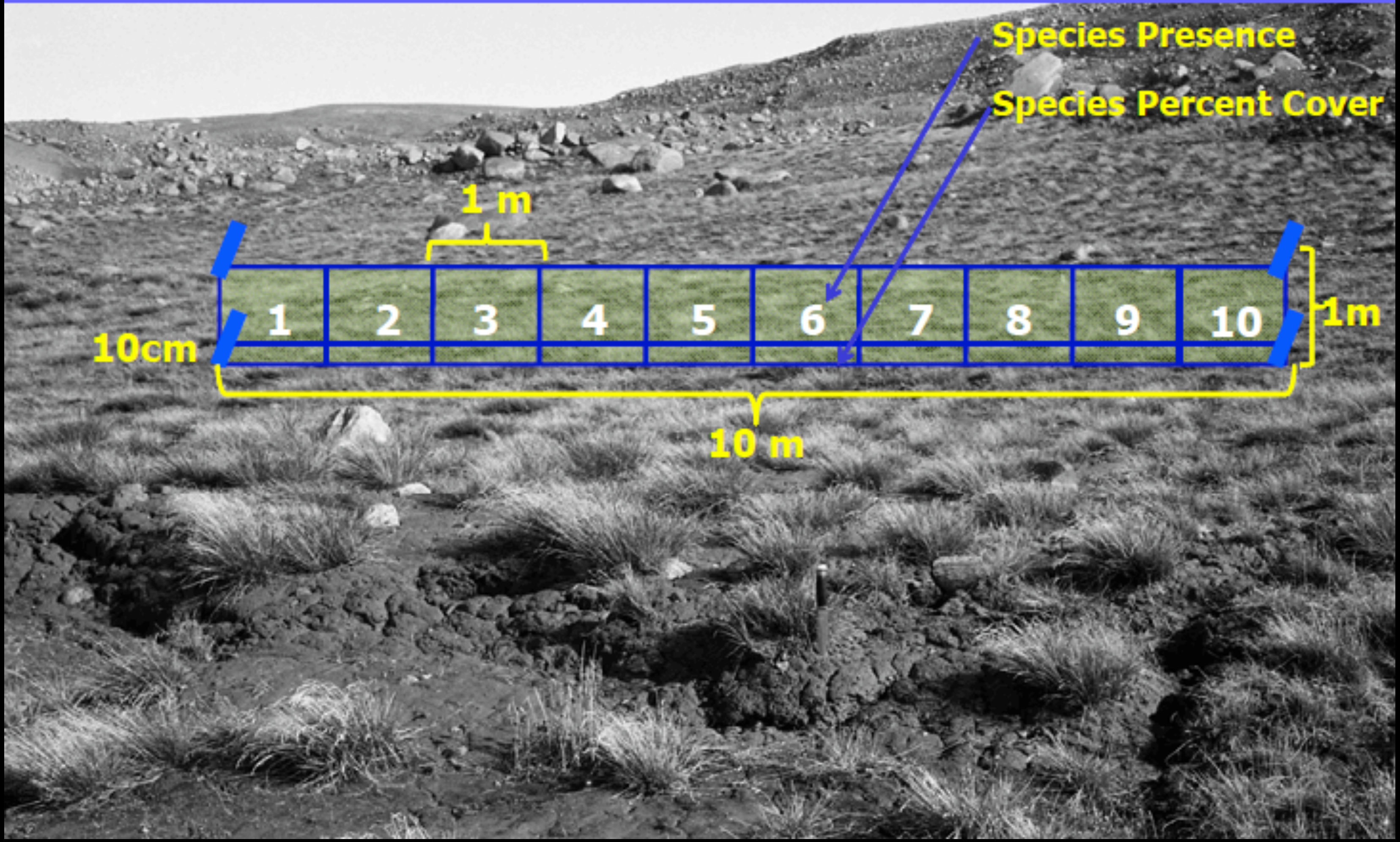
1964 Sampling

82 sampling and collection points for Webber's PhD dissertation study:

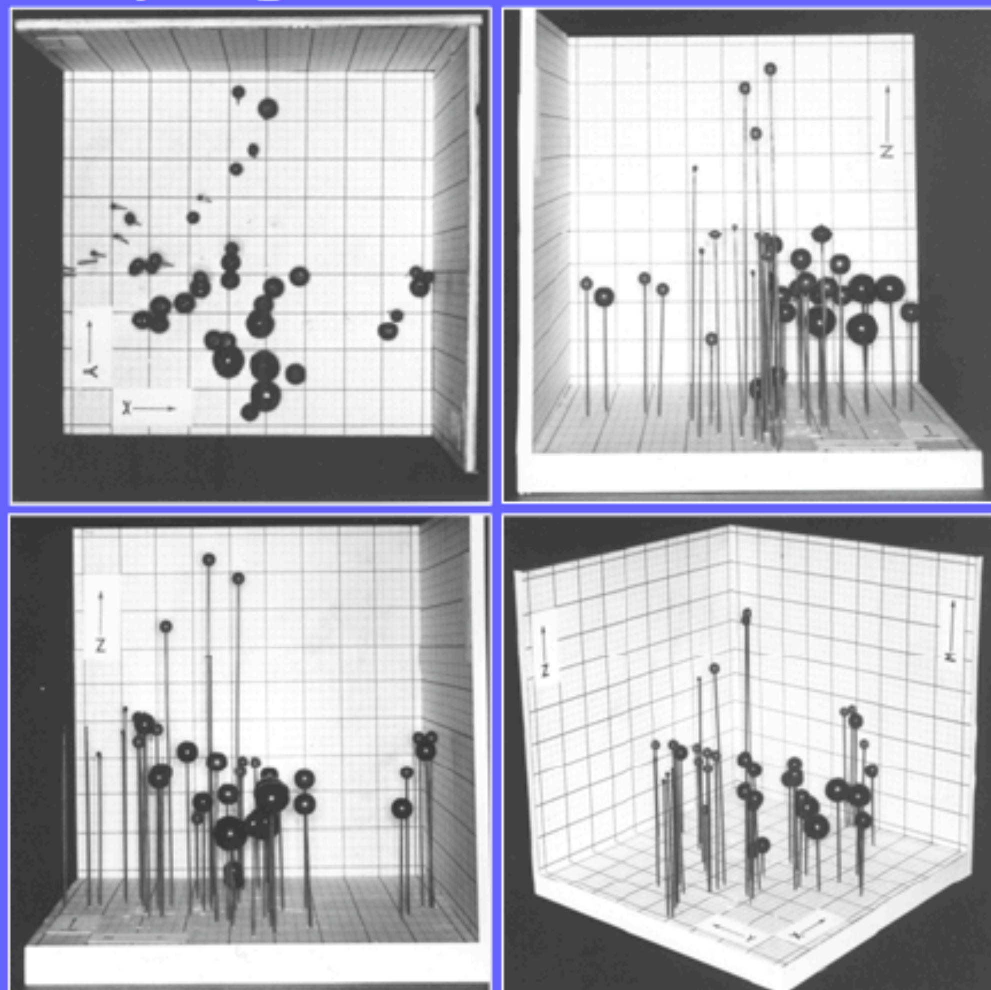
"Gradient analysis of the vegetation around the Lewis Valley, north-central Baffin Island, Northwest Territories, Canada"



Plot Design US/BTF sites: Baffin, Niwot, Barrow and Atqasuk (after Webber, 1967)



Bray and Curtis Polar Ordination from 1964 Sampling (*from* Webber, P.J, CBA June 1967)

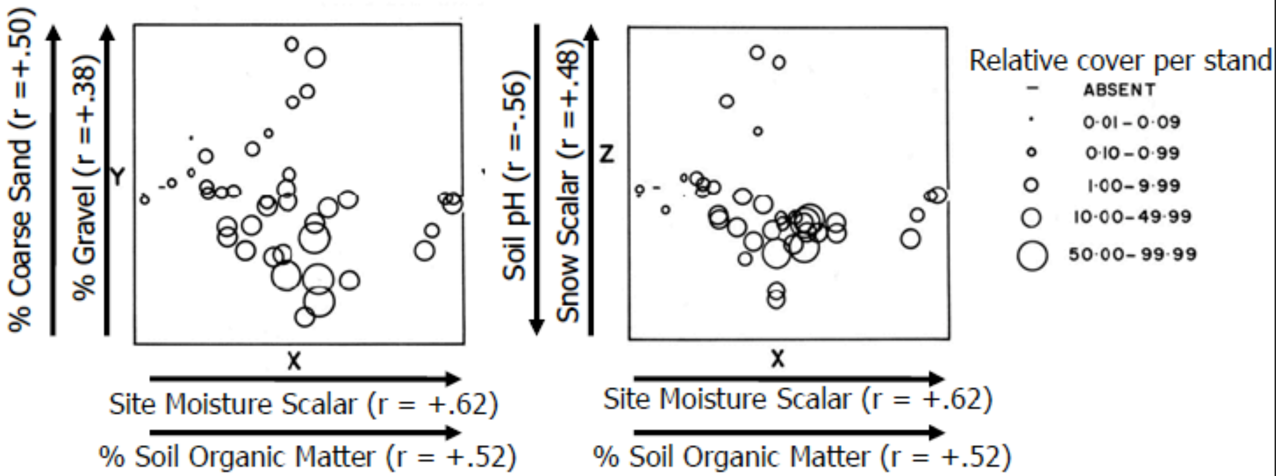


Salix arctica

Distribution of a common species occurring in most plots

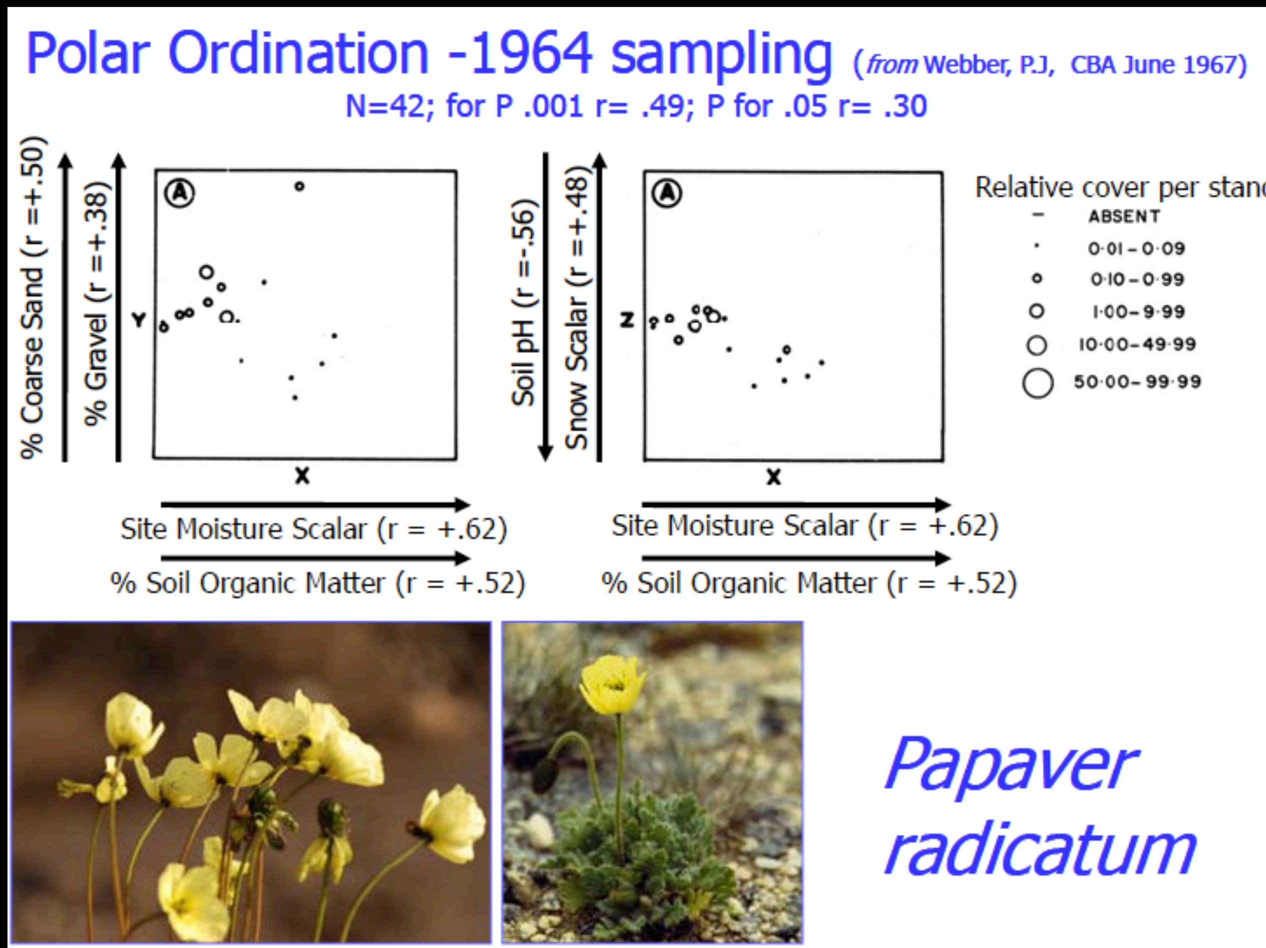
Polar Ordination -1964 sampling (*from* Webber, P.J, CBA June 1967)

N=42; for P .001 r= .49; P for .05 r= .30

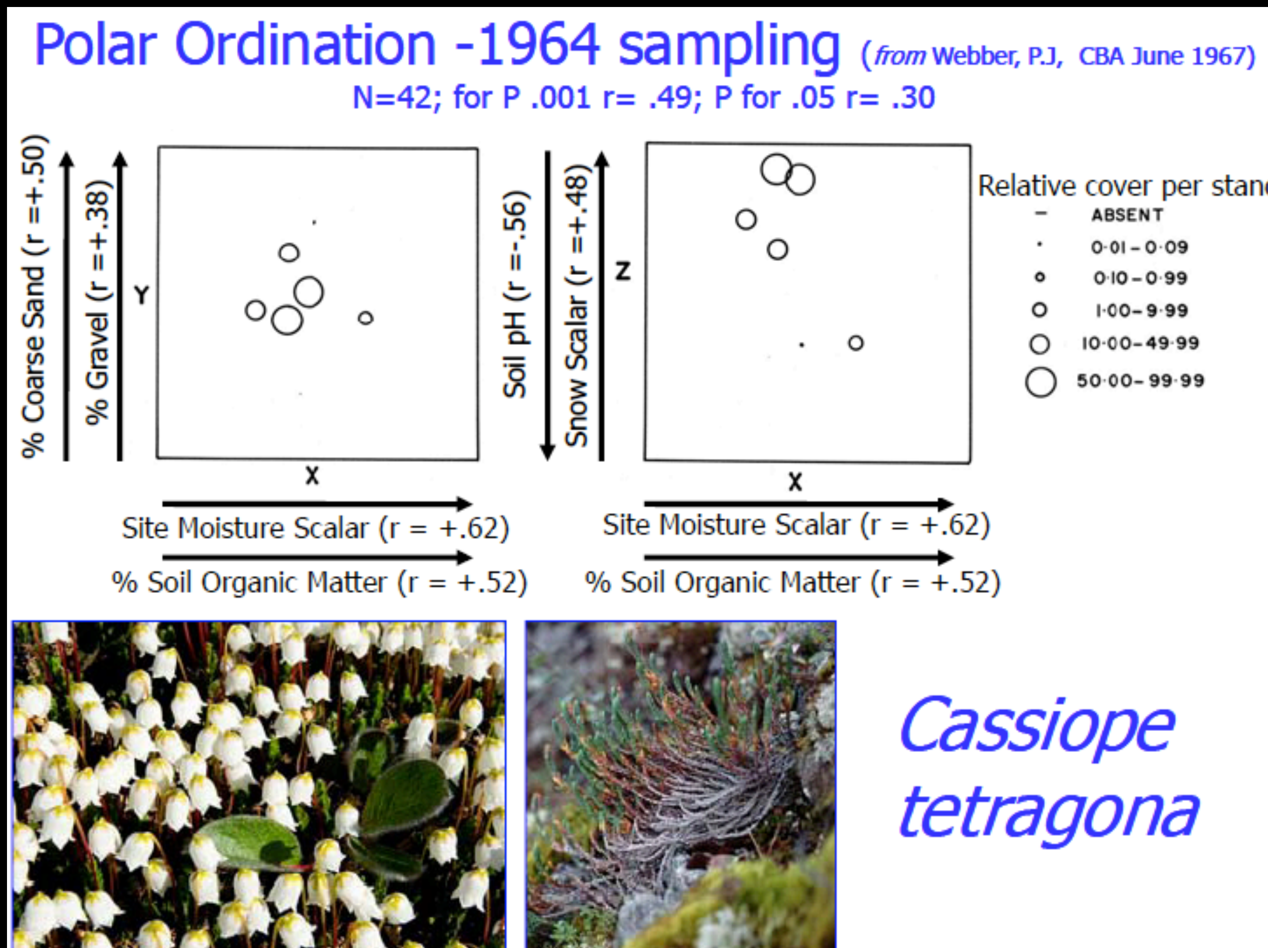


Salix arctica

Distribution of a common dry species

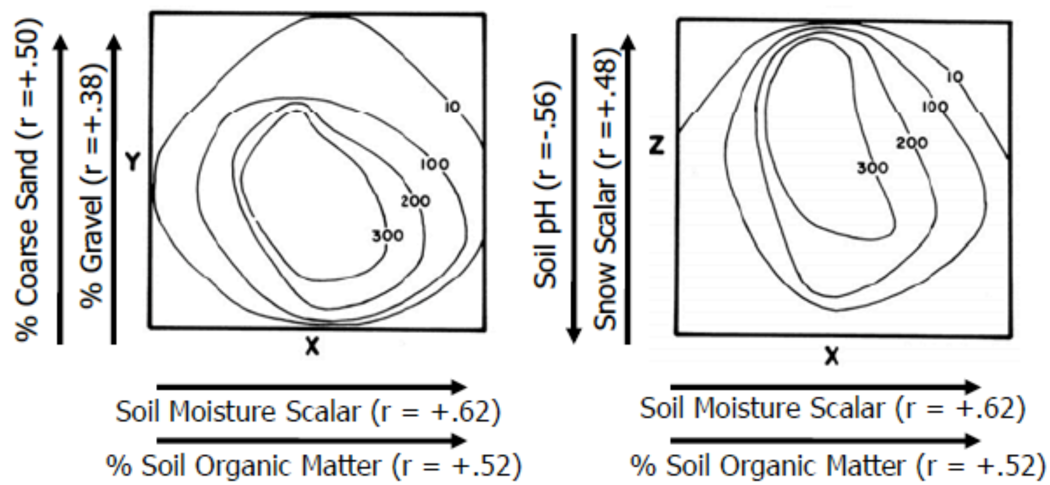


Distribution of a common snow-bed species



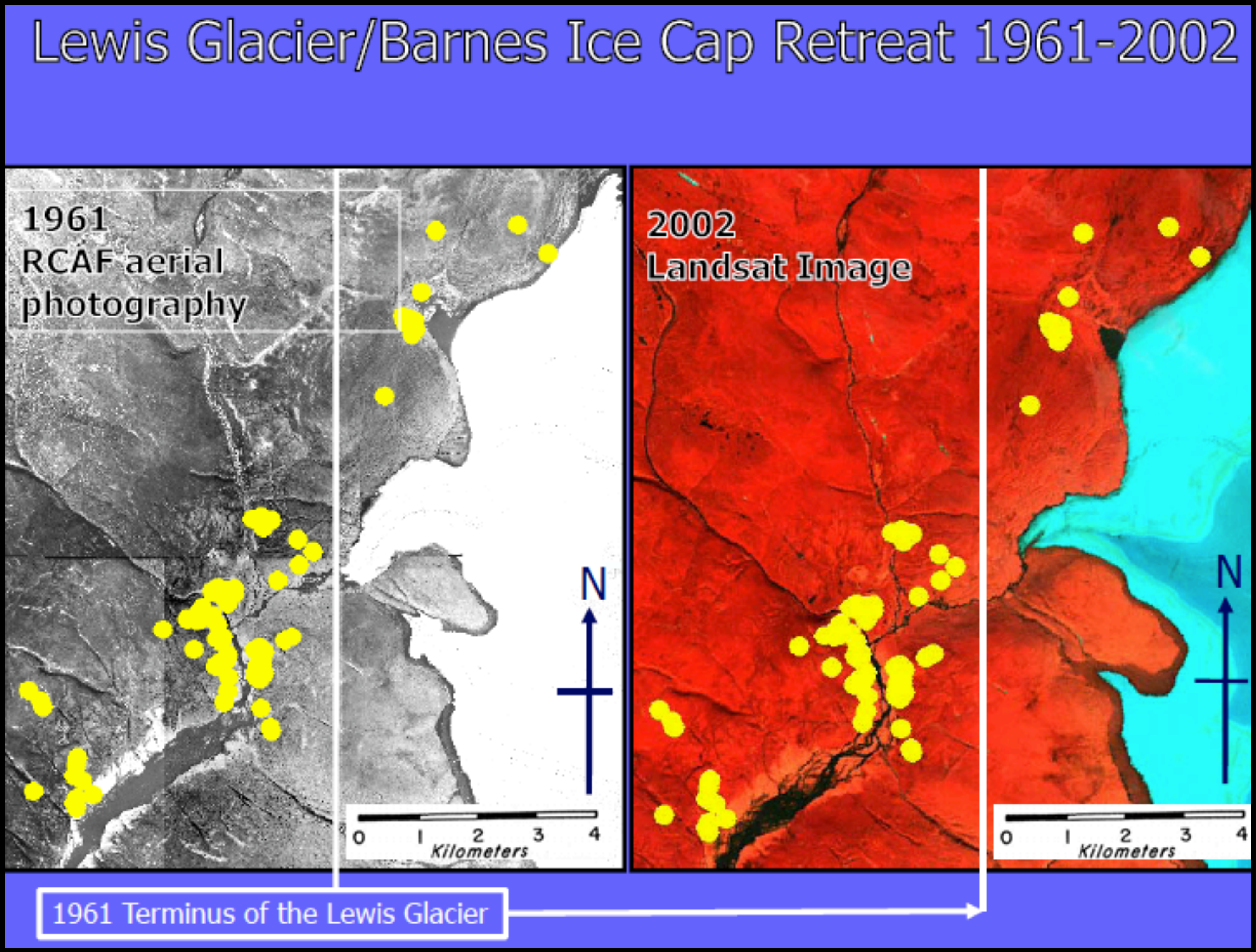
Distribution of biomass in the ordination space

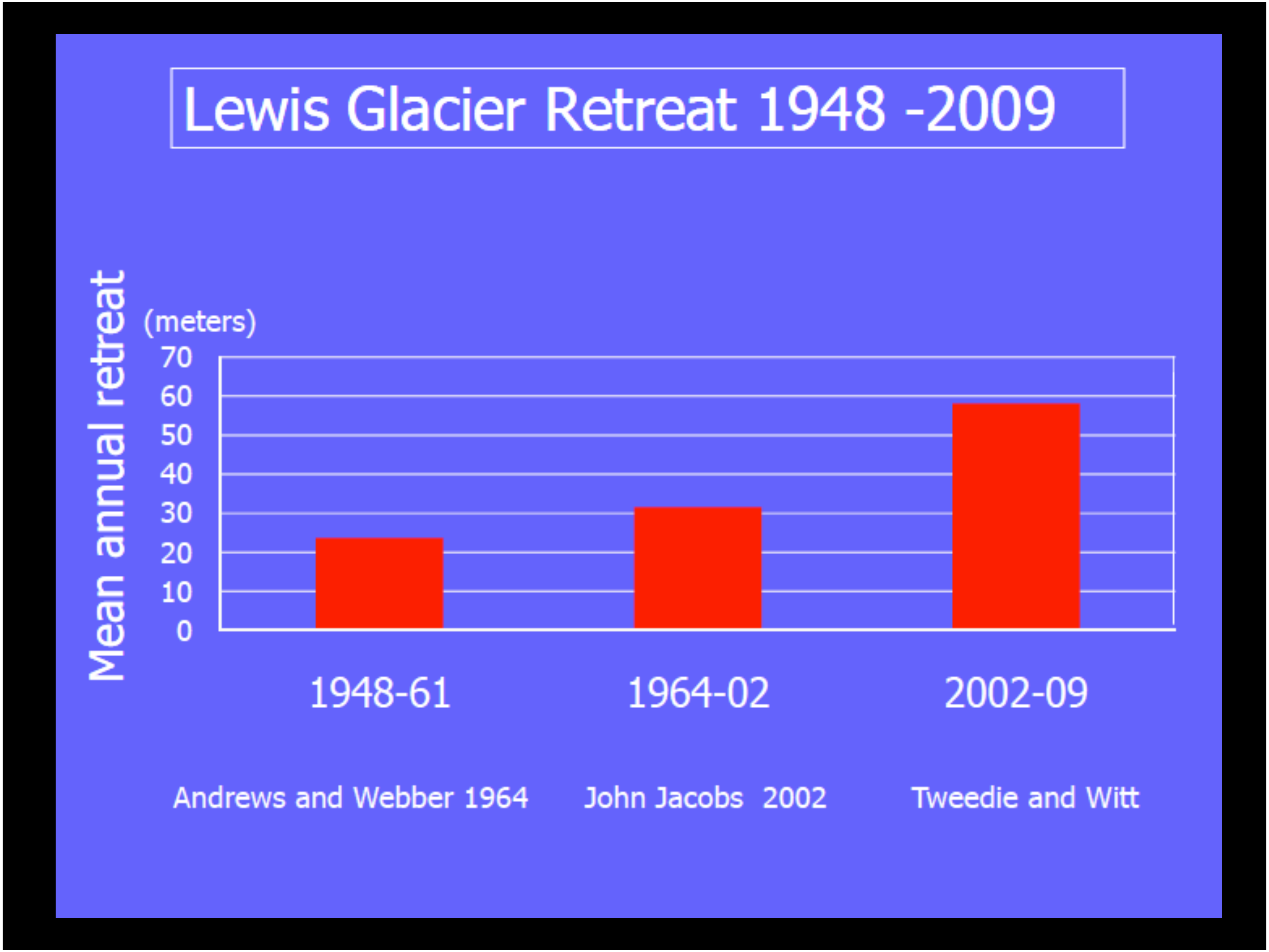
Polar Ordination -1964 sampling (*from* Webber, P.J, CBA June 1967)



Peak season standing crop
of above and belowground biomass (g dry weight/m²)

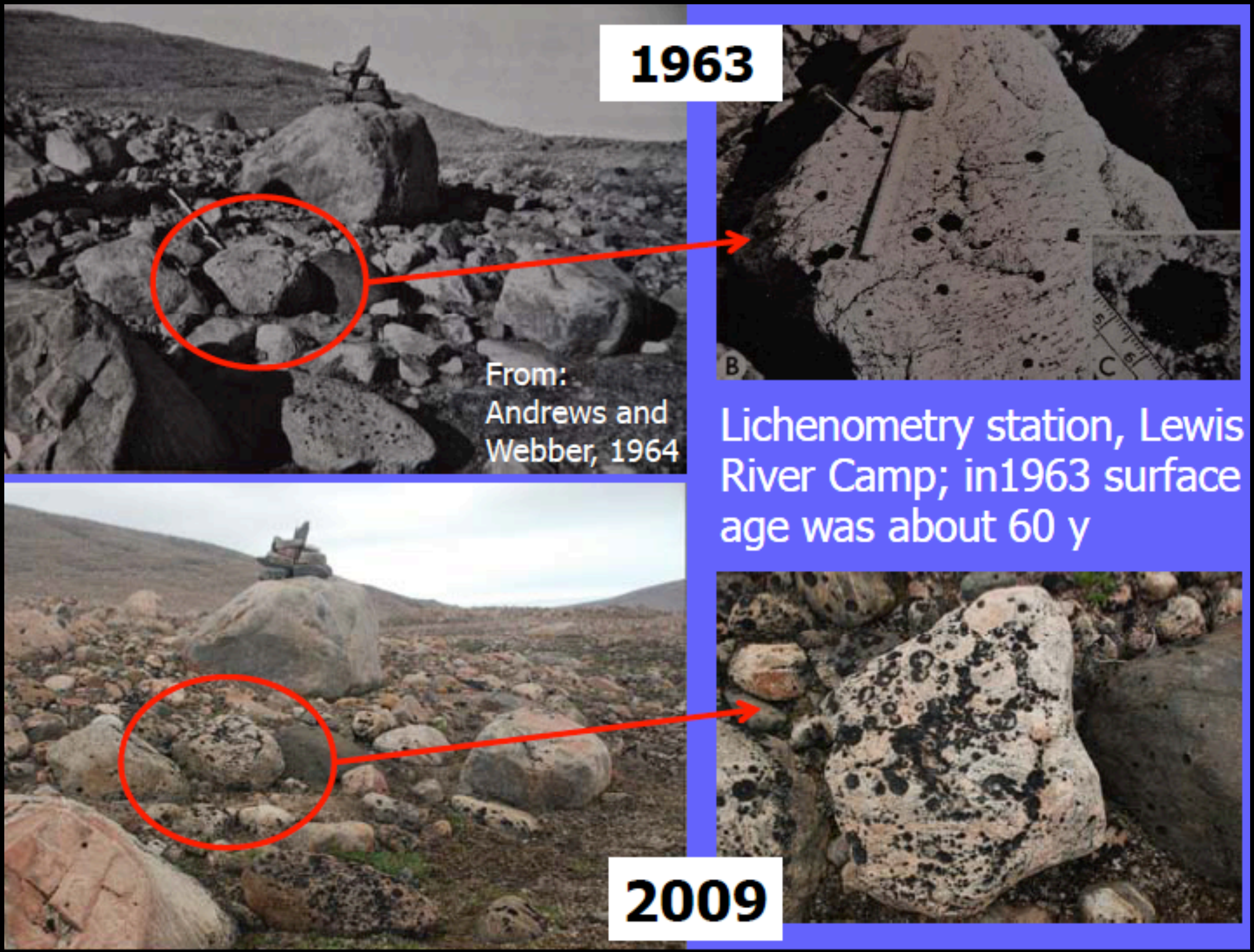
Changes in the position of the Lewis Glacier



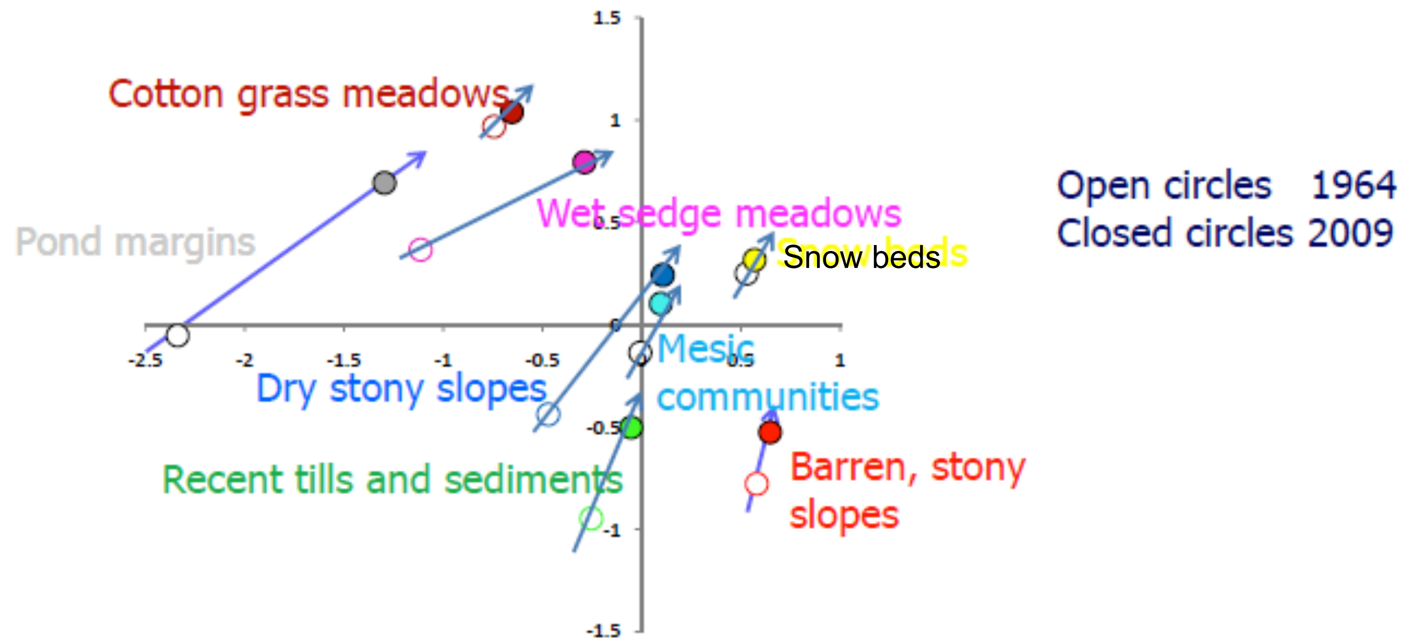


Lewis Glacier Retreat 1948 -2009
Mean annual retreat
(meters)
70
60
50
40
30
20
10
0
1948-61
1964-02
2002-09
Andrews and Webber 1964
John Jacobs 2002
Tweedie and Witt

Calibration of lichen growth for regional lichenometric studies

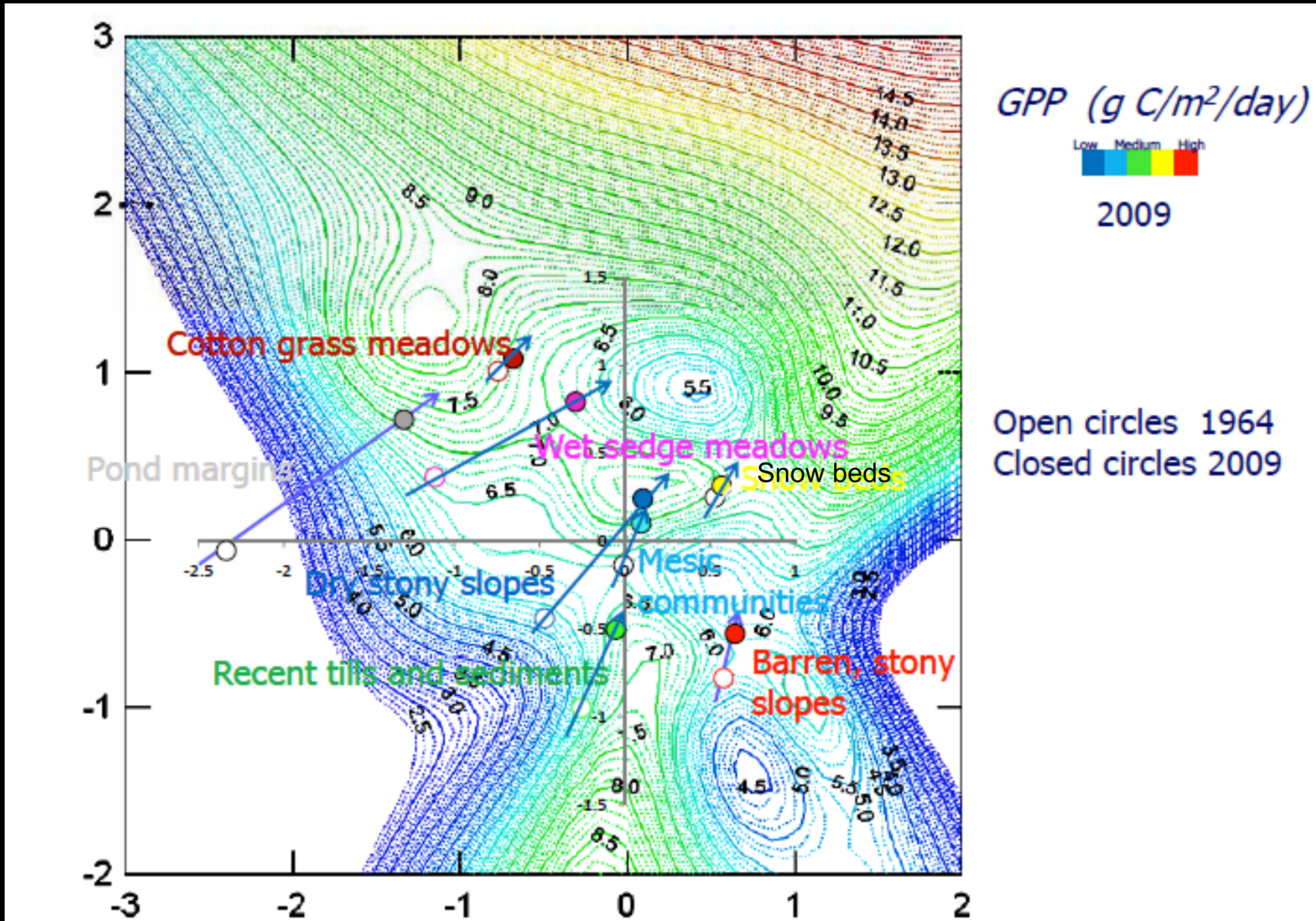


Ordination analysis of vegetation change in major plant communities



Non-metric multidimensional scaling (NMDS) combined ordination of seventy-nine 1964 and 2009 plots; the location of stand clusters for the two years is shown. A consistent direction of resultant cluster shifts is shown by arrows.

Ordination with respect to biomass gradient



Ordination with an overlay of gross primary production (GPP)

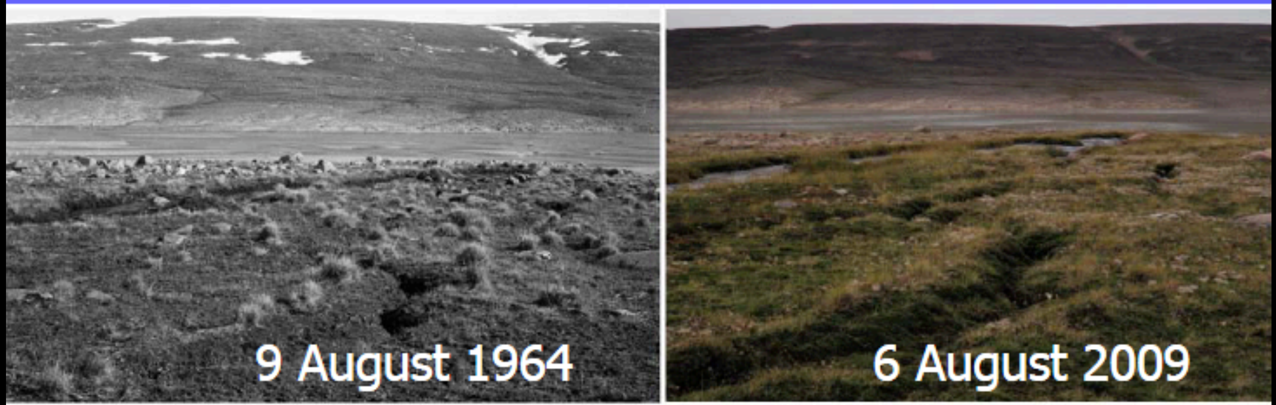
Causes of greening?

July 15, 1964

Repeat photography of Plot 5 (*Carex stans* community). Note the increasing vegetation cover and vanished (distant) snow banks after 45 years. Surface age about 200 years in 1964. The vegetation changes are considered to be more than seasonal development or classical hydrosere succession over 45 years.

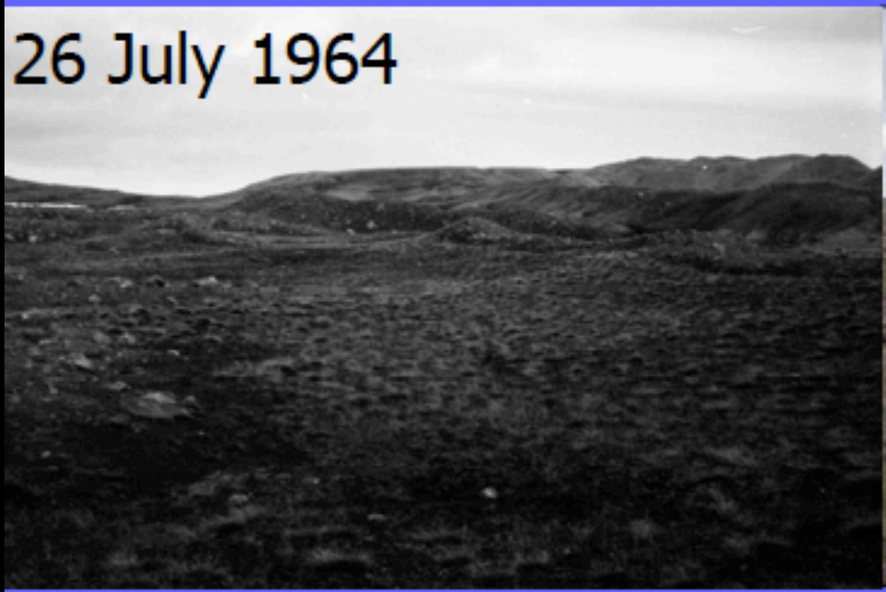
Plot 11 Cassiope (Nodum II). Looking towards the Isortoq from just west of the Striding Delta 1964. c. 400 y surface in 1964

Increasing vegetation cover and vanished snow banks after 45 years: Greening Valleys!



Repeat photography of a mesic surface in the Blockade Bend region above the Isortoq River. (Webber and Tweedie 2009, Walker *et al.*, 2010). Note the increased cover of vegetation and loss of previously perennial snow banks. The foreground was exposed around 1550 AD (Webber 1971). It is on the oldest mesic surfaces where one would look for evidence of change due to warming in the event of no physical disturbance. Note the disappearance of small ice-thrusted tussocks. There has been a general drying and deepening of the active layer.

Greening on dry sites with fine soils and moderate winter snow cover



Poa glauca dominated community typical of the dry clayey Glacial Lake Lewis sediments between the cross valley moraines. The proglacial lake drained about 550 years ago. Greater enlargement of the photographs show that by 2009 the *Poa glauca* tussocks are less pronounced , ground cover and species diversity has increased.

Significant Floristic Changes

Species that show significant matching directional change of both absolute cover (>30%) and frequency (>10%) from 1964 to 2009 in the 79 plots. Sequence is by 1964 rank of summed cover and overall DAFOR assignment. Recorded direction of change and heuristic prediction, by experts for a warming Arctic, are both shown as +, -, or 0 (gain, loss and no change).

Species ordered by absolute cover and DAFOR assessment	Growth Form	Significant cover and frequency sign matching	Heuristic cover sign prediction
ABUNDANT			
Campylium stellatum	Pleurocarpous Moss	-	0
Carex stans	Stolon Graminoid	+	+
Cassiope tetragona	Hemi-Prostrate Shrub	+	+
Dryas integrifolia	Hemi-Prostrate Shrub	+	+
FREQUENT			
Festuca brachyphylla	Tussock Graminoid	+	+
Stellaria monantha	Mat Forb	-	-
Juncus castaneus	Stolon Graminoid	+	0
Cerastium alpinum	Mat Forb	-	0
Saxifraga cernua	Erect Forb	-	0
OCCASIONAL			
Saxifraga nivalis	Rosette Forb	-	0
RARE			
Cetraria nivalis	Foliose Lichen	+	+
Salix richardsonii	Erect Shrub	+	+
Eriophorum vaginatum	Tussock Graminoid	+	+
Vaccinium uliginosum	Hemi-Prostrate Shrub	+	+
Astragalus alpinus	Erect Forb	+	+

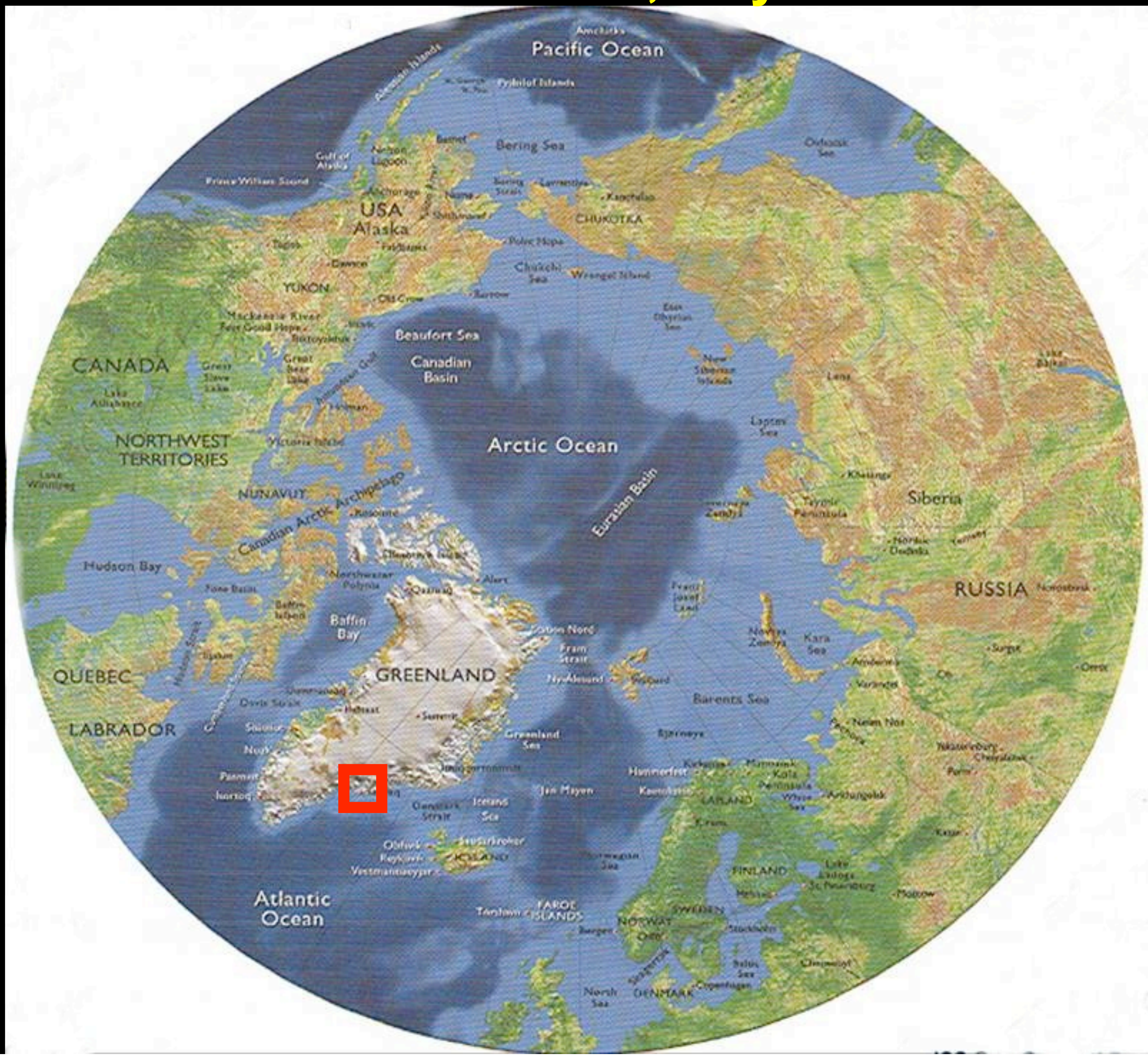
Summary & Conclusions

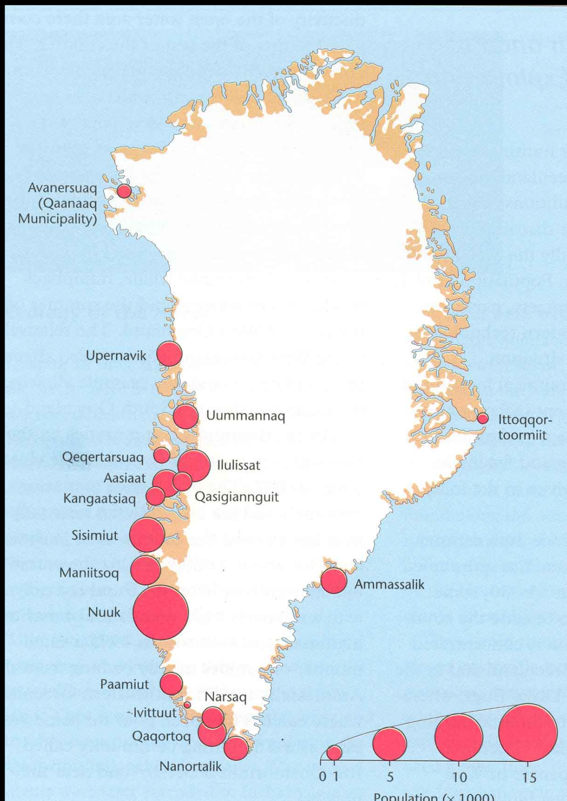
- The 2009 IPY expedition to the northwest margins of the Barnes Ice Cap was able to repeat many geobotanical measurements made 46 years previously by former Canadian Geographical Branch field parties.
- In this landscape, free of direct human disturbance and where surfaces range in age from 0 to 600y, dramatic changes to snow, ice and vegetation cover have occurred.
- Ice and snow cover has retreated exposing large areas for plant colonization. Moss, lichen and vascular plant cover and biomass have increased on both young and old surfaces.
- Plant cover has increased on average by 33% and primary production may have increased 3-fold. The land surface is greening.
- Some of this is due to the expected ecesis on recently exposed surfaces and maturing of pioneer communities.

Summary & Conclusions continued

- However, plant community composition on older surfaces has changed and some formerly rare species have become more frequent. Further, the cover of hemi-prostrate and erect shrubs has increased on older mesic sites.
- In terms of the CAVM Bioclimate Subzones the observed changes of plant cover, growth form and species on the older mesic sites suggest a shift from Subzone B toward C.
- A parsimonious, although possibly naïve, *raison d'être* for causality of the changes on the oldest surfaces suggests that there is a system response to the summer warming as projected from AVHRR satellite data.
- Such changes are similar to those reported in several recent studies by other authors and groups.
- Nevertheless, we are reminded that the Arctic is diverse in terms of geology, climate, flora and history and that there will not be a common response across the Arctic.

Story from Ammassalik, S.E. Greenland, Fred Daniëls, 40 years





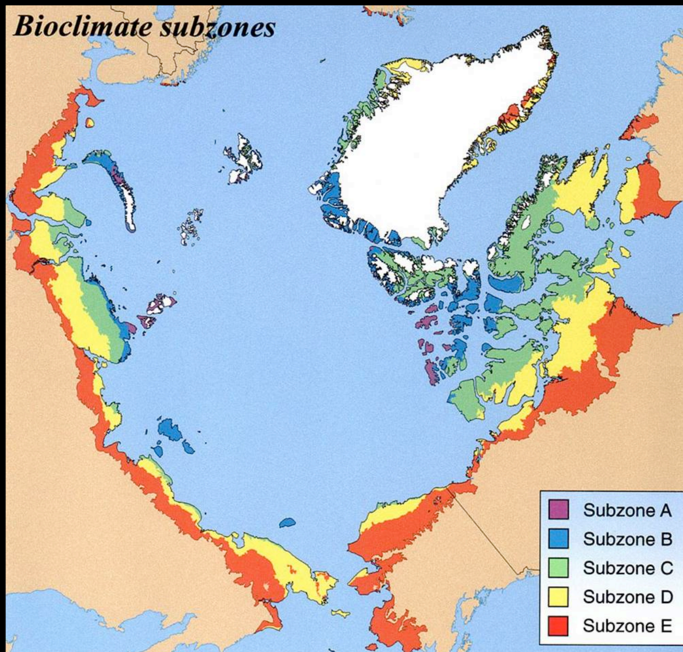
Towns in Greenland

Ammassalik 1968

Daniëls, F.J.A. 1982. Vegetation of the Angmagssalik District, Southeast Greenland, IV. Shrub, dwarf shrub and terricolous lichens. Meddelelser om Grønland, Bioscience 10:1–78.

Daniëls, F.J.A. and de Molenaar, J.G. 1976. Vegetation of the Angmagssalik District, Southeast Greenland, II. Herb and snowbed vegetation. Meddelelser om Grønland 198(2): 1–256.

Daniëls, F.J.A., Molenaar, J.G., Chytry, M., and Tichy, L., 2011, Vegetation change in Southeast Greenland? Tasiilaq revisited after 40 years: Applied Vegetation Science, v. 14, p. 230-241.



Subzone D: Southern arctic dwarf shrub Subzone

CAVM

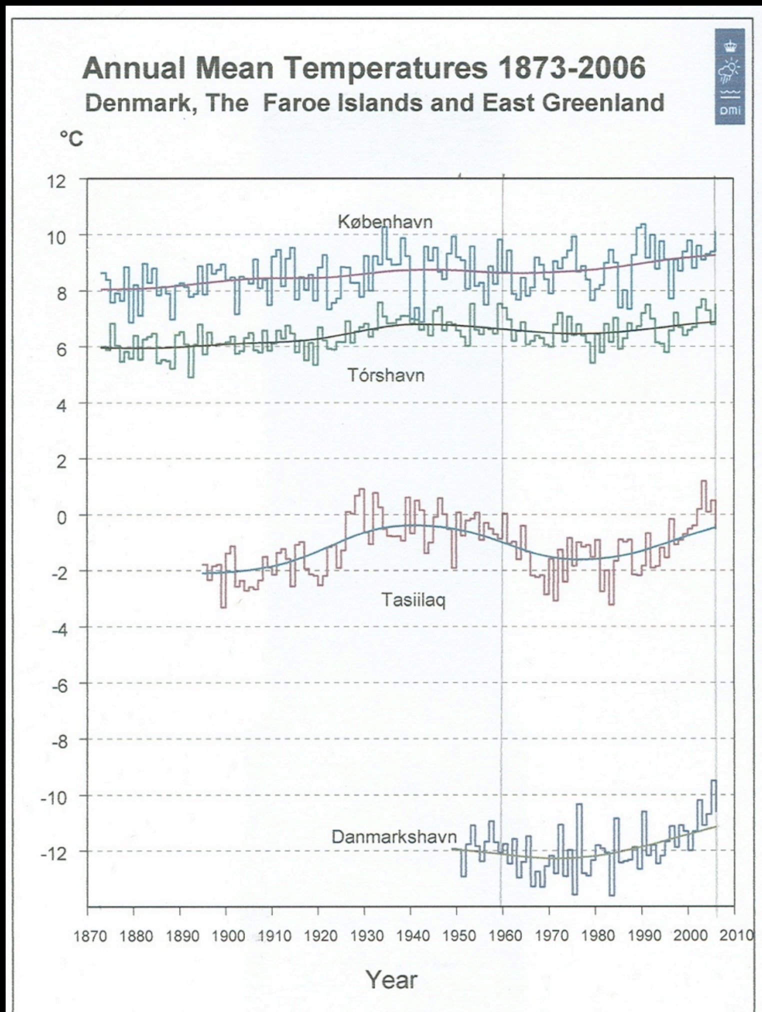
Subzone	Mean July Temp[1] (°C)	Summer warmth index[2] (°C)	Vertical structure of plant cover[3]	Horizontal structure of plant cover[3]	Major plant growth forms[4]	Dominant vegetation unit	Total phyto-mass[5] ($t\ ha^{-1}$)	Net annual production[6] ($t\ ha^{-1}\ yr^{-1}$)	Number of vascular plant species in local floras[7]
A	1-3	<6	Mostly barren. In favorable microsites, 1 lichen or moss layer <2 cm tall, very scattered vascular plants hardly exceeding the moss layer	<5% cover of vascular plants, up to 40% cover by mosses and lichens	b, g, r, cf, of ol, c	<3	Units 1 and 2	<0.3	<50
B	4-5	6-9	2 layers, moss layer 1-3 cm thick and herbaceous layer, 5-10 cm tall, prostrate dwarf shrubs <5 cm tall	5-25% cover of vascular plants, up to 60% cover of cryptogams	npds, dpds, b, ns, cf, of, ol	Unit 4	5-20	0.2-1.9	50-100
C	6-7	9-12	2 layers, moss layer 3-5 cm thick and herbaceous layer 5-10 cm tall, prostrate and hemi-prostrate dwarf shrubs <15 cm tall	5-50% cover of vascular plants, open patchy vegetation	npds, dpds, b, ns, cf, of, ol, ehds* * in acidic areas	Unit 5	10-30	1.7-2.9	75-150
D	8-9	12-20	2 layers, moss layer 5-10 cm thick and herbaceous and dwarf-shrub layer 10-40 cm tall	50-80% cover of vascular plants, interrupted close vegetation	ns, nb, npds, dpds, deds, neds, cf, of, ol, b	Units 7 and 9	30-60	2.7-3.9	125-250
E	10-12	20-35	2-3 layers, moss layer 5-10 cm thick, herbaceous/ dwarf-shrub layer 20-50 cm tall, sometimes with low-shrub layer to 80 cm	80-100% cover of vascular plants, closed canopy	dls, ts*, ns, deds, neds, sb, nb, rl, ol *in Beringia	Units 8 and 10	50-100	3.3-4.3	200 to 500

Vegetation features of the subzones of the Arctic (CAVM)

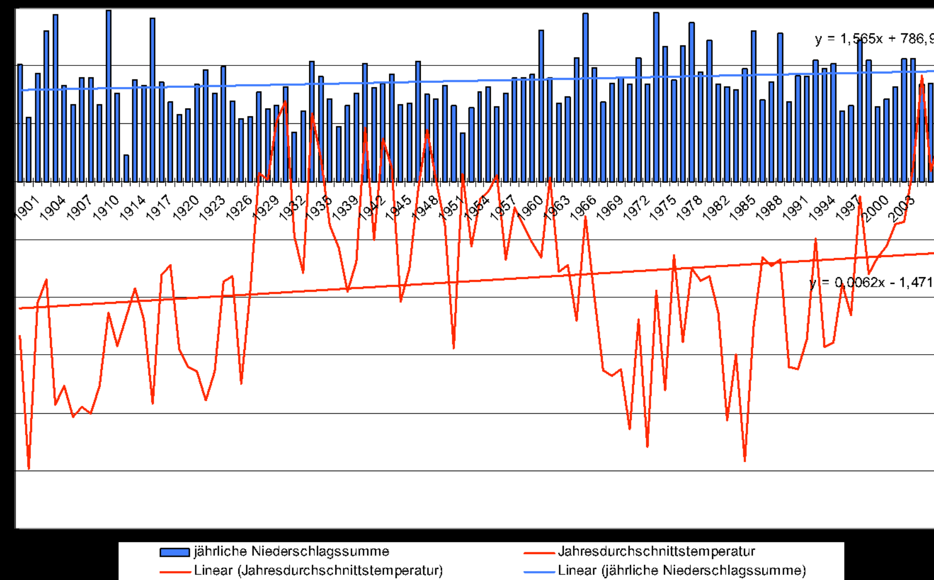
Changes 1968/69 - 2007

1. Loss of traditional skills, globalisation, increase inhabitants 700-1800
2. Increase tourism, traffic, 5000 tourists a year
3. Climate change

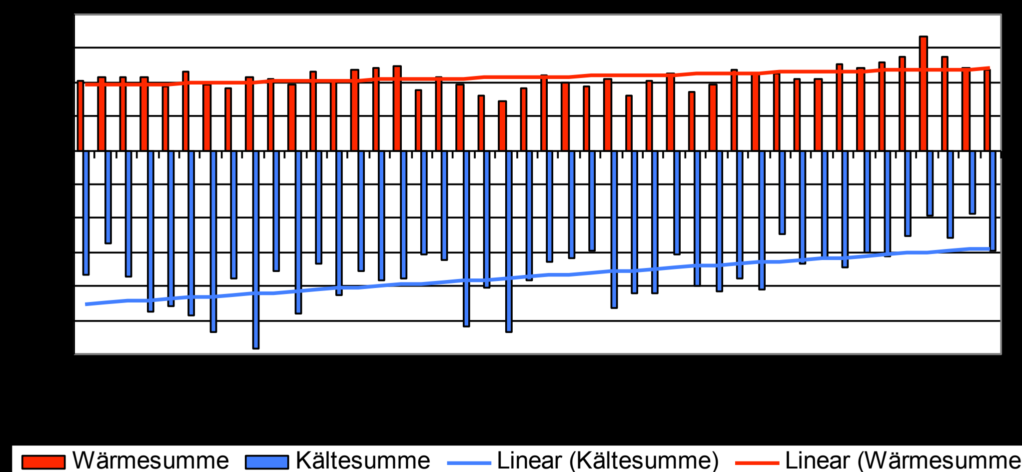
Near Ammassalik, 1969



Annual mean T (°C) and precipitation (mm) 1898-2006



Annual mean T (°C) 1873-2006



Summer warmth and winter coldness indices 1963 -2006

Cladonio-Viscarietum				
	FD		FD	
Year	6869		2007	
Number of releves	11		11	
Cladonia phyllophora	IV	+/1	V	+/2
Viscaria alpina	V	+/1	IV	+/1
Carex bigelowii	V	+/2	V	+/1
Cetraria islandica	V	+/1	V	+/1
Cladonia arbuscula ssp. mitis	V	+/3	V	1/5
Cladonia ecmocyna	V	+/2	V	+/2
Stereocaulon alpinum	V	+/5	V	1/5
Cladonia gracilis	V	+/1	V	+/1
Luzula spicata	V	+	V	r/1
Stereocaulon paschale	V	+/5	V	1/3
Campanula gieseckiana	V	+/1	V	+/2
Cladonia rangiferina	V	+/2	V	+/2
Cladonia uncialis	V	+/1	V	+/1
Cetraria ericetorum	V	+/1	V	+/1
Chamaenerion angustifolium	IV	+	V	r/1
Barbilophozia hatcheri	V	+/3	IV	+/2
Cerastium alpinum ssp. lanatum	IV	+	V	+/1
Juncus trifidus	IV	+/1	V	+/2
Dicranum scoparium	IV	+/2	IV	+/1
Peltigera malacea	IV	+/1	IV	r/1
Cladonia crispata	IV	+/1	IV	r/2
Salix herbacea	III	+/2	III	r/1
Cladonia macrophyllodes	III	+	III	+/1
Cladonia coccifera	III	+	II	r/+
Ptilidium ciliare	III	+/3	II	+/1
Lepraria neglecta s.l.	II	+	III	+/2
Poa arctica	II	+	II	+/1
Desmatodon latifolius	II	+	II	+/1
Drepanocladus uncinatus	II	+	I	+
Cephaloziella species	III	+		
Brachythecium species	II	+		
Cetrariella delisei	II	+		
Dicranum muehlenbeckii	II	+/1		
Rinodina species	II	+		
Hieracium alpinum	II	+/3	IV	r/1
Thymus drucei	II	+/1	IV	r/3
Trisetum spicatum	+	+	III	r/+
Empetrum nigrum ssp. hermaphroditum			II	r
Erigeron eriocephalus			II	r/1
Agrostis hyperborea			II	+
Veronica fruticans			II	r/1

Cladonio-Viscarietum Blomsterdalen

1969

2007

Xerophytic and thermophytic vascular plants slightly increased

Festuco-Salicetum				
	FD		FD	
Year	6869		2007	
Number of releves	12		11	
Salix glauca ssp. callicarpaea	V	4/6	V	5/6
Chamaenerion angustifolium	V	+/1	V	+/2
Carex bigelowii	V	+/2	V	r/2
Campanula gieseckiana	IV	+/2	V	r/1
Cerastium alpinum	IV	+/1	IV	r/+
Festuca rubra coll.	IV	+/1	IV	r/1
Thalictrum alpinum	IV	+/1	IV	r/1
Taraxacum croceum	III	+/1	IV	r/1
Empetrum nigrum ssp. hermaphroditum	III	+/4	III	1/3
Pyrola minor	III	+/1	III	r/3
Poa arctica	III	+/1	III	+/1
Polygonum viviparum	III	+/2	II	+/2
Cetraria islandica	III	+	II	+
Thymus drucei	II	+/1	II	r/2
Tortula ruralis	II	+	I	+
Rhodiola rosea	II	+	I	1/2
Coptis trifolia	II	+	I	+/1
Poa glauca	II	+	I	+
Luzula spicata	II	+	I	+
Stereocaulon species	III	+		
Cladonia species	II	+		
Cladonia chlorophaea s.l.	II	+		
Vaccinium uliginosum ssp. microphyllum	II	+/4		
Bryum species	II	+		
Poa alpina	I	+/1	III	+/1
Hieracium hyparcticum			II	+/1

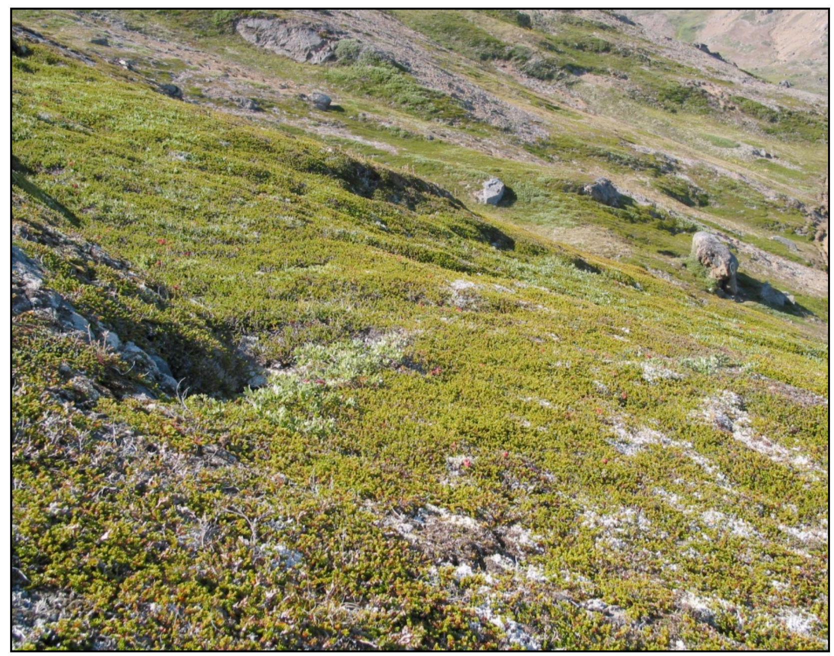
1969

2007

Slight increase in vascular plants

Empetrum-Vaccinium community				
	FD		FD	
Year	6869		2007	
Number of releves	10		10	
Empetrum nigrum ssp. hermaphroditum	V	4/6	V	4/6
Salix herbacea	V	+/2	V	+/1
Vaccinium uliginosum ssp. microphyllum	IV	2/4	III	+/4
Carex bigelowii	V	+/1	IV	+/1
Ptilidium ciliare	V	+/3	IV	+/4
Psoroma hypnorum	V	+/1	IV	+/2
Stereocaulon alpinum	IV	+/4	V	+/4
Drepanocladus uncinatus	IV	+/2	V	+/2
Polygonum viviparum	IV	+	V	+/1
Cladonia arbuscula ssp. mitis	IV	+/2	IV	+/1
Cladonia rangiferina	IV	+/2	IV	+/1
Barbilophozia hatcheri	IV	+/4	III	+/2
Cladonia gracilis	IV	+/2	II	+/1
Cladonia ecmocyna	III	+/1	IV	+/1
Dicranum scoparium	III	+/4	IV	+/2
Pohlia nutans	III	+/1	IV	r/1
Cetraria islandica	III	+/1	IV	+/1
Peltigera scabrosa	III	+/1	III	+
Cetraria ericetorum	III	+/1	III	+/1
Cetrariella delisei	III	+	II	+
Cladonia coccifera s.l.	II	+	II	+/1
Lophozia ventricosa	II	+	II	1/2
Cladonia crispata	III	+	I	+
Ochrolechia frigida	II	+	+	+
Cladonia uncialis	II	+	+	+
Dicranum fuscescens	II	+/4	IV	+/2
Salix glauca ssp. callicarpaea	I	+/1	III	+/3
Peltigera malacea	I	+	III	+
Solorina crocea			III	+
Peltigera aphthosa			III	+/1
Stereocaulon paschale	+	1	II	+/1
Juncus trifidus			II	r/+
Poa arctica			II	+
Silene acaulis			II	+
Polytricum alpinum			II	+

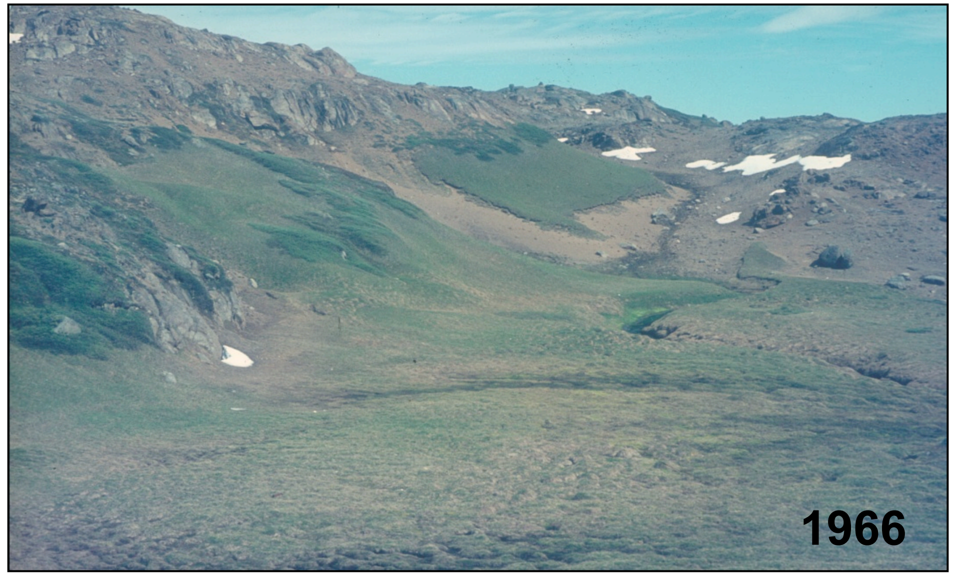
1968



2007 **Increase of *Salix glauca***

Caricetum bigelowii
12 relevés

Caricetum bigelowii	1968 1969		2007	
Carex bigelowii	V	3-5	V	3-6
Campanula gieseckiana	V	+-4	V	1-4
Cerastium alpinum	V	+-2	V	+-1
Taraxacum croceum	V	+-4	V	1-4
Chamaenerion angustifolium	IV	1-4	V	+-4
Cetraria islandica	IV	+-2	V	+-2
Bryum elegans	IV	+-1	V	+-1
Luzula spicata	IV	+-3	IV	+-3
Barbilophozia hatcheri	III	+-4	V	+-3
Dicranum scoparium	III	+-1	IV	+-3
Stereocaulon alp./paschale	III	+-2	IV	+-2
Cladonia mitis	III	+	IV	+-1
Erigeron uniflorus	II	+	III	+
Hieracium alpinum	II	+	III	+-2
Thymus drucei	II	1	III	+-4
Peltigera 'canina'***	II	+	III	+
Cladonia ecmocyna	II	+-2	III	+-1
Poa alpina	II	+-2	II	+-1
Salix herbacea	II	+-2	II	+-2
Polygonum viviparum	II	+-2	I	1-3
Phleum commutatum	I	+	II	+-1
Viscaria alpina	I	+-1	II	+-1
Veronica fruticans	I	3	II	+
Tortula norvegica	I	+	II	+-1
Thalictrum alpinum	III	+-4	I	2
Poa arctica	I	+	IV	+-1
Desmatodon latifolium	I	+	IV	+-3
Trisetum spicatum	I	+	III	+-1
Cetraria crispa	I	+-2	III	+-2
Cladonia chlorophaea	I	+	III	+-1
Cladonia phyllophora			III	+-1



Xerophytes (and thermophytes) slightly increase

Festuco-Salicetum, Cladonio-Viscarietum and Caricetum bigelowii on south-exposed slopes in Blomsterdalen,

Ammassalik

Hardly any changes in the thermo-and xerophytic Cladonio-Viscarietum, Festuco-Salicetum callicarpaeae and mesophytic zonal dwarf shrub vegetation, Empetrum-Vaccinium community

More changes in mire vegetation, Caricetum rariflorae and moist and wet snowbed communities such as Polygono-Salicetum, Hylocomio-Salicetum herbaceae and Alchemilletum glomerulantis.

Moist snowbed and mire vegetation beneath the slopes

Take home message from S.E. Greenland

1. The characteristic species combination and structure of the zonal dwarf shrub vegetation has not changed essentially.

2. The same applies to representative vegetation types in warm and dry habitats. However, xerophytes and thermophytes are more prominent now.

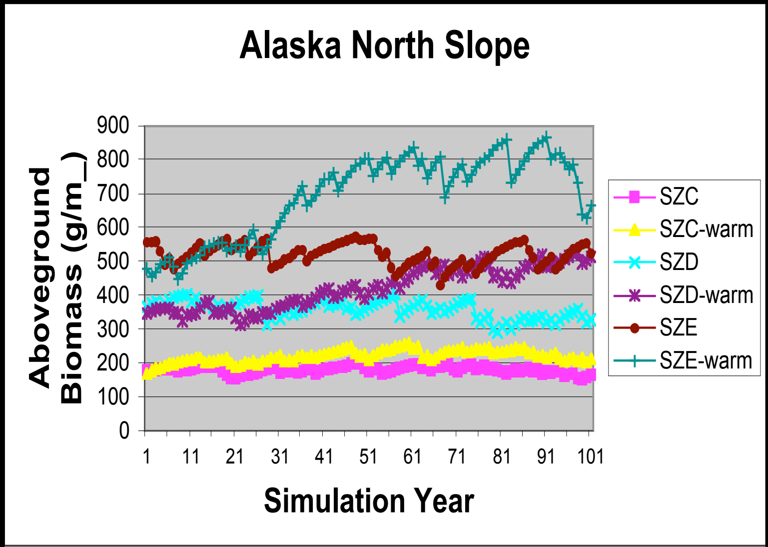
3. Vegetation of snow bed and mire habitats show more changes, probably due to the shorter and milder winter season with less snow allowing species of drier and less snow protected sites to increase/ invade.

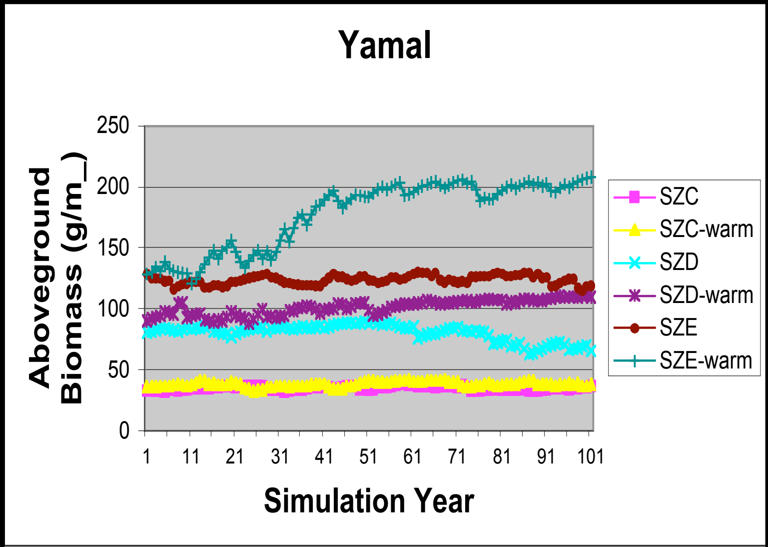
4. Direct human influence (disturbance by trampling) on the vegetation is evident, but restricted to the immediate vicinity of the town of Ammassalik.

Thus: no significant changes on the plant community type level of the investigated plant communities in the last 40 years!

All plant community types are still present. However some boreal species seem more common, such as *Salix callicarpaea*.

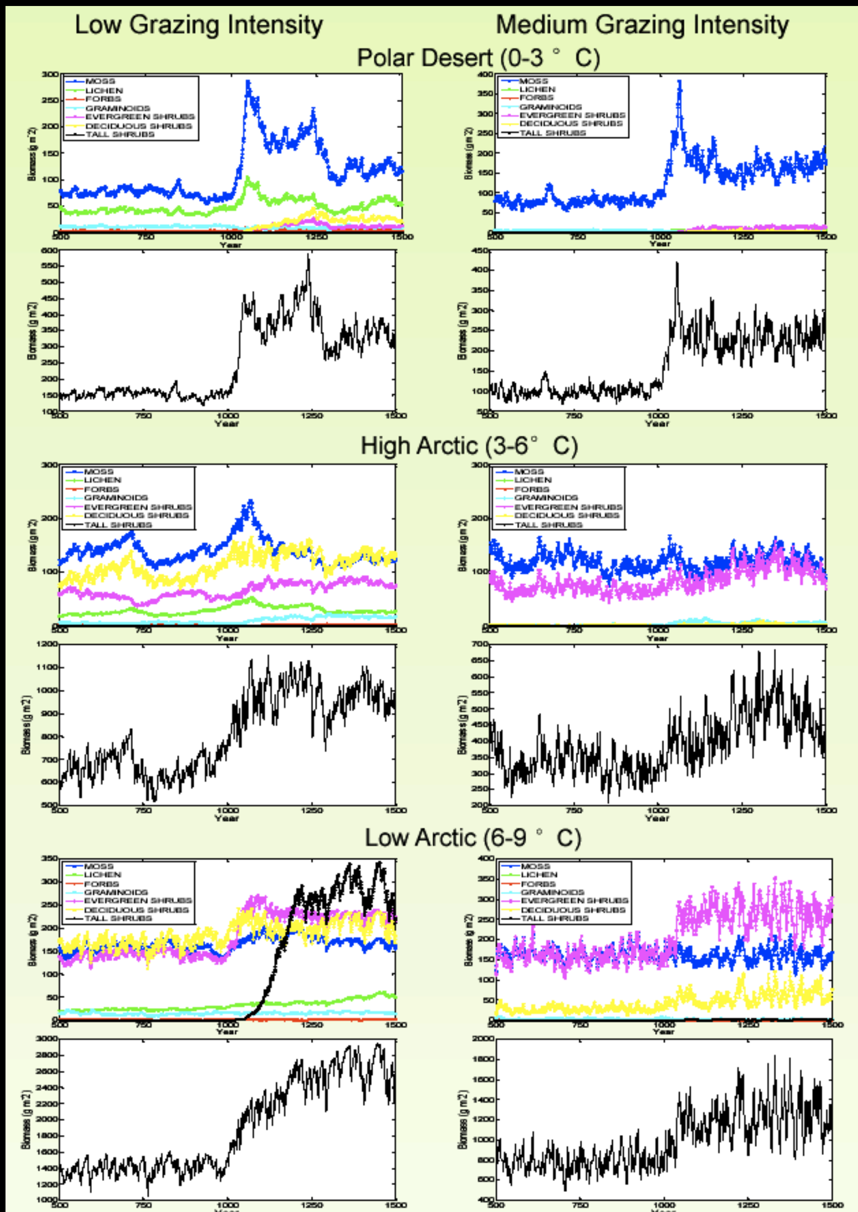
Modeling transient dynamics of the vegetation





- ArcVeg model (Epstein et al. 2001, 2004) examines soil nutrient effects on interannual changes in tundra.
- Simulates changes to plant functional types, with nitrogen being the key limiting nutrient, the availability of which is driven by climate and disturbance.
- Preliminary simulation shows the differences in production expected on the nutrient-rich soils of the Alaskan North Slope, vs the nutrient-poor soils of the Yamal.

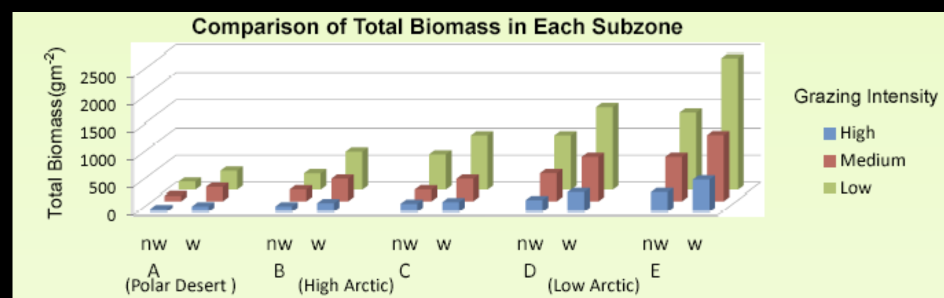
Courtesy of Howie Epstein

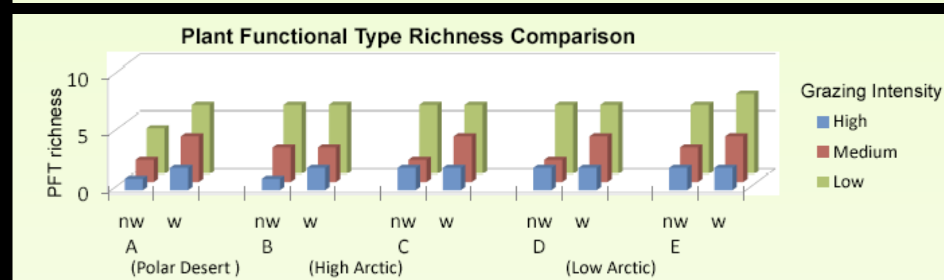


Yu and Epstein: 2008, NASA LCLUC conference.

Modeled productivity of PFTs on the Yamal

- ArcVeg model (Epstein et al. 2002)
- Examines succession of biomass for seven Arctic plant functional types.
- Five climate scenarios.
- Warming vs. non-warming treatments.
- Three grazing intensities.
- Next steps will incorporate soil type and disturbance regimes (dust and complete removal of vegetation), relate to NDVI and develop regional extrapolations.





Summary of evidence for change

- NDVI record indicates an increase in green plant cover in the Arctic over the past 29 years.
- Interannual variations in NDVI appear to be sensitive to yearly variations in temperature, increasing in years of warmer temperatures and declining in years of cooler temperatures.
- Repeat photography supports an increase in alders in the warmer parts of the Arctic over the past 50 years.
- ITEX experimental warming and greenhouse experiments have resulted in increased deciduous shrubs while understory plants have declined.
- One study from Alexandra Fiord (Hudson & Henry 2009) indicates an increase in biomass. There are no other repeat biomass studies to support or dispute the trends shown by NDVI.

- **Most observed changes appear to be linked to greater deciduous shrub biomass, particularly in warmer areas of the Low Arctic.**
- **Long-term repeat observations of species change on Baffin Island (Webber 2010) and Greenland (Daniëls and Molenaar 2011) indicate minor changes in species composition, but directional change in biomass. On Baffin I., this is likely due to a combination of the natural succession and response to climate change.**
- **Mechanisms of changed greenness are not fully known. The relative roles of interacting factors affecting present-day NDVI patterns (e.g., climate, sea-ice distribution, elevation, glacial history, substrate chemistry, water regimes) need to be better understood.**
- **Replicated long-term studies of tundra biomass and community composition are needed. Some of these studies have been initiated within ITEX and other projects, but a protocol is needed for standardized measurements across the Arctic.**
- **The best hope for predicting change in the future is a combination of continued long-term observations and improved modeling efforts.**