Arctic Sea Ice, Arctic Vegetation Change and Lessons from 2007

D.A. (Skip) Walker

University of Alaska Fairbanks

Collaborators

Uma Bhatt, Gary Kofinas, Martha Raynolds, Vladimir Romanovsky, Skip Walker:
University of Alaska Fairbanks

Joey Comiso:
NASA Goddard

Howie Epstein:
University of Virginia

Jiong Jia:
REC-TEA, Chinese Academy of Science

Marina Liebman, Nataliya Moskalenko:
Earth Cryosphere Laboratory, Moscow, Russia

Bruce Forbes:
Arctic Centre, Rovaniemi, Finland

Funding

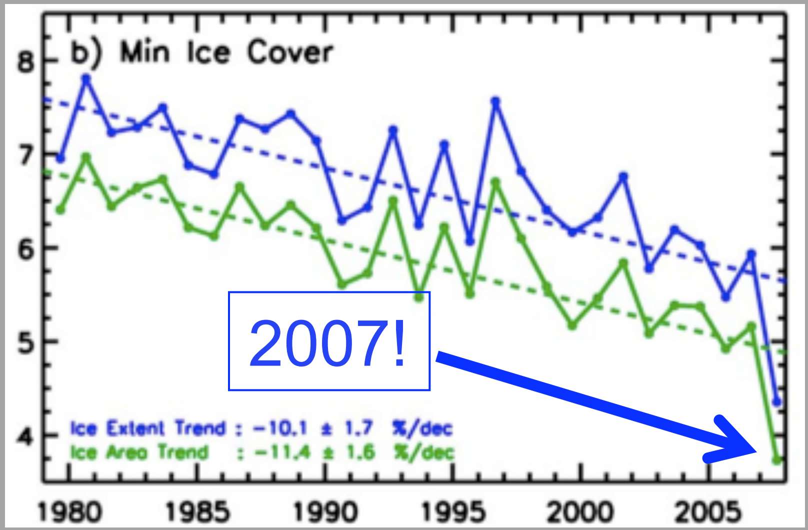
NSF: Synthesis of Arctic System Science initiative

NASA: Land Cover Land-Use Change program

Is the trend in sea-ice affecting Arctic vegetation ?

Since 1980, perennial sea ice extent in the Arctic has declined at the rate of 10.1% per decade, and area trend is -11.4% decade

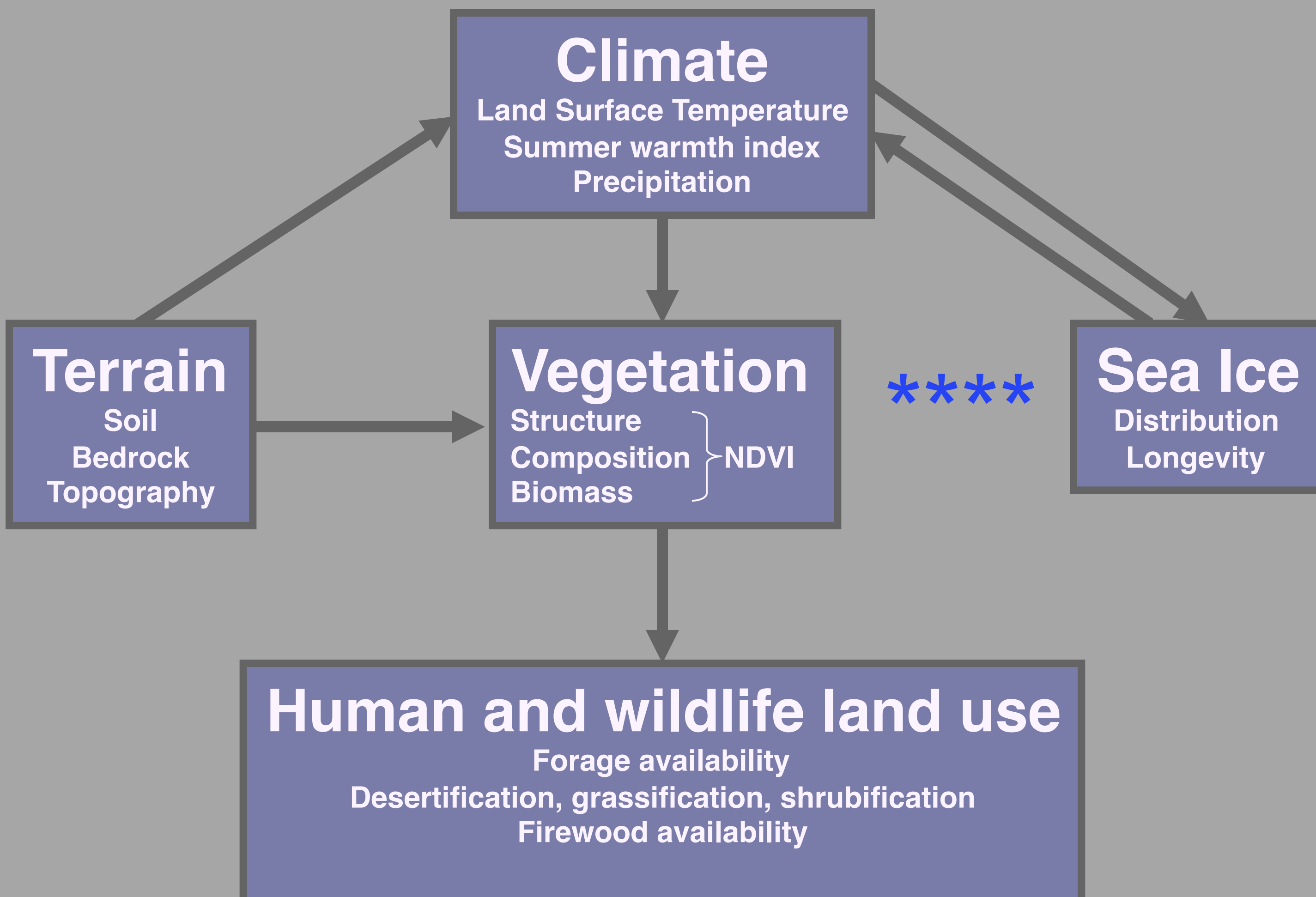
(Comiso et al. 2008, *Geophysical Research Letters* 35: L01703).



Outline

- *Connection between sea ice, summer land temperatures, arctic tundra greening and climate.*
- *Need for circumpolar terrestrial baseline representing entire bioclimate gradient.*
- *Special need for baseline in the perennial ice zones.*

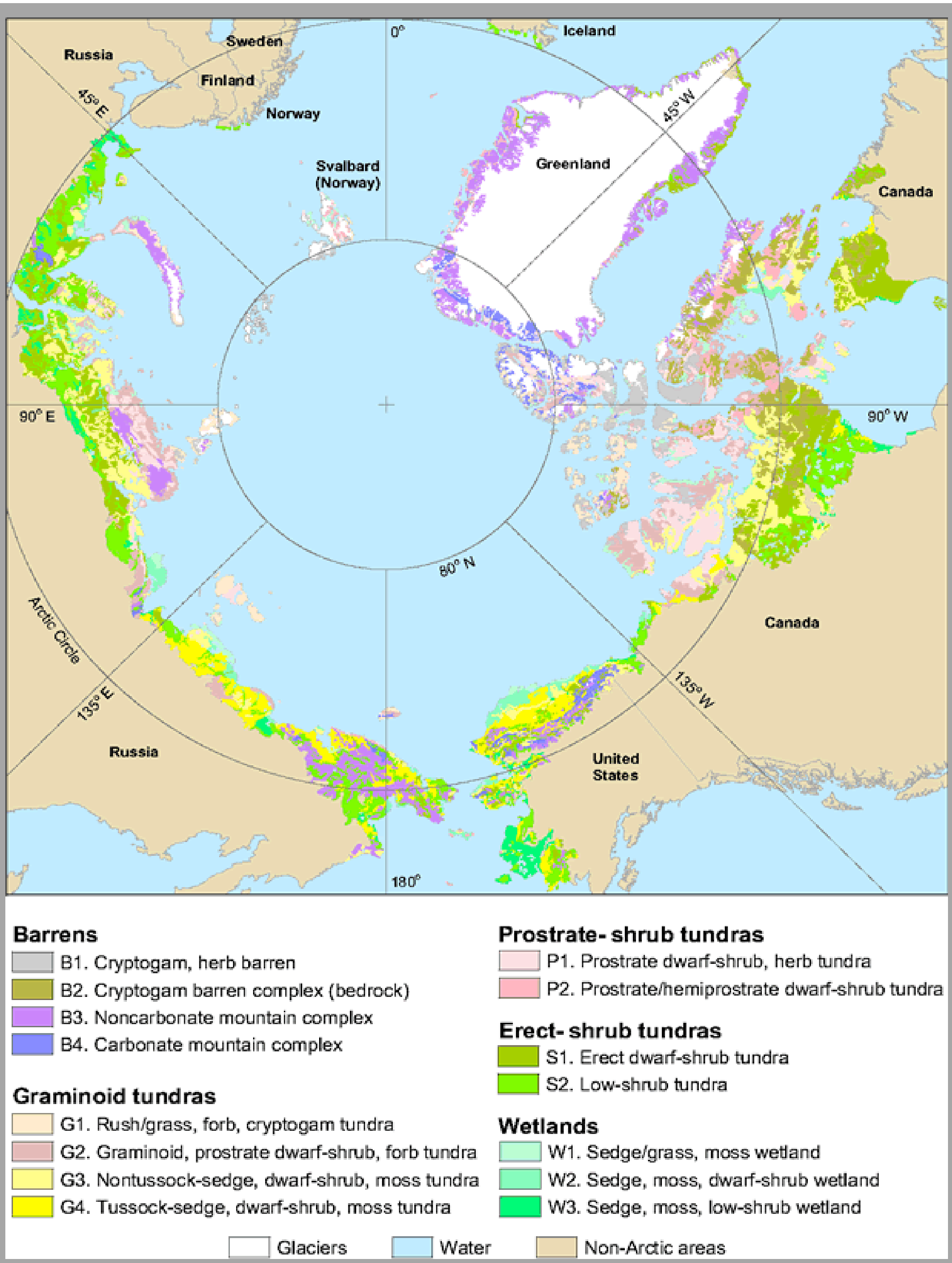
Although there is no direct link between sea ice and vegetation...



…the Arctic tundra is a maritime biome, that is largely defined by its proximity to sea ice.

- 80% of lowland tundra areas are is within 100 km of at least seasonally frozen oceans.

- **Changes in the Arctic ocean sea ice will very likely affect terrestrial ecosystems.**



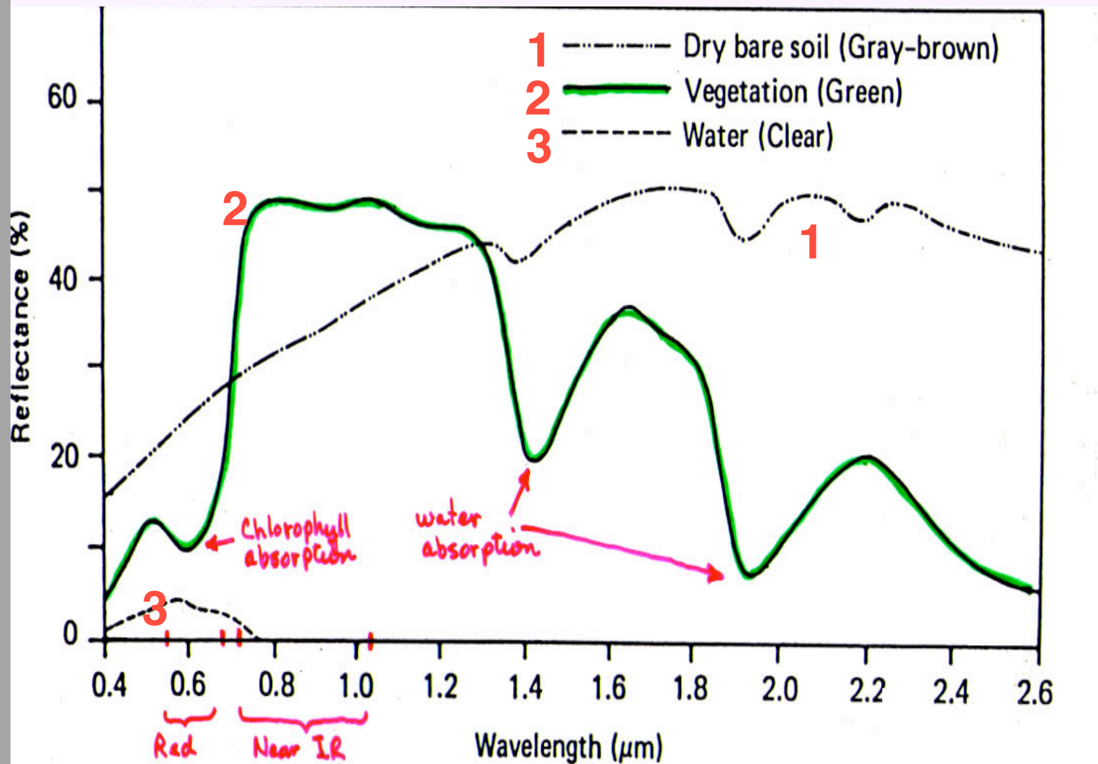
Walker, D. A., 2005. The Circumpolar Arctic Vegetation Map. Journal of Vegetation Science.

Best evidence of widespread change comes from satellites using an index of greenness.

Green vegetation has the unique property of absorbing strongly in the visible (particularly red light) portion of the spectrum and reflecting strongly in the near infra-red portion.

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

Reflectance spectra of common ground-cover types

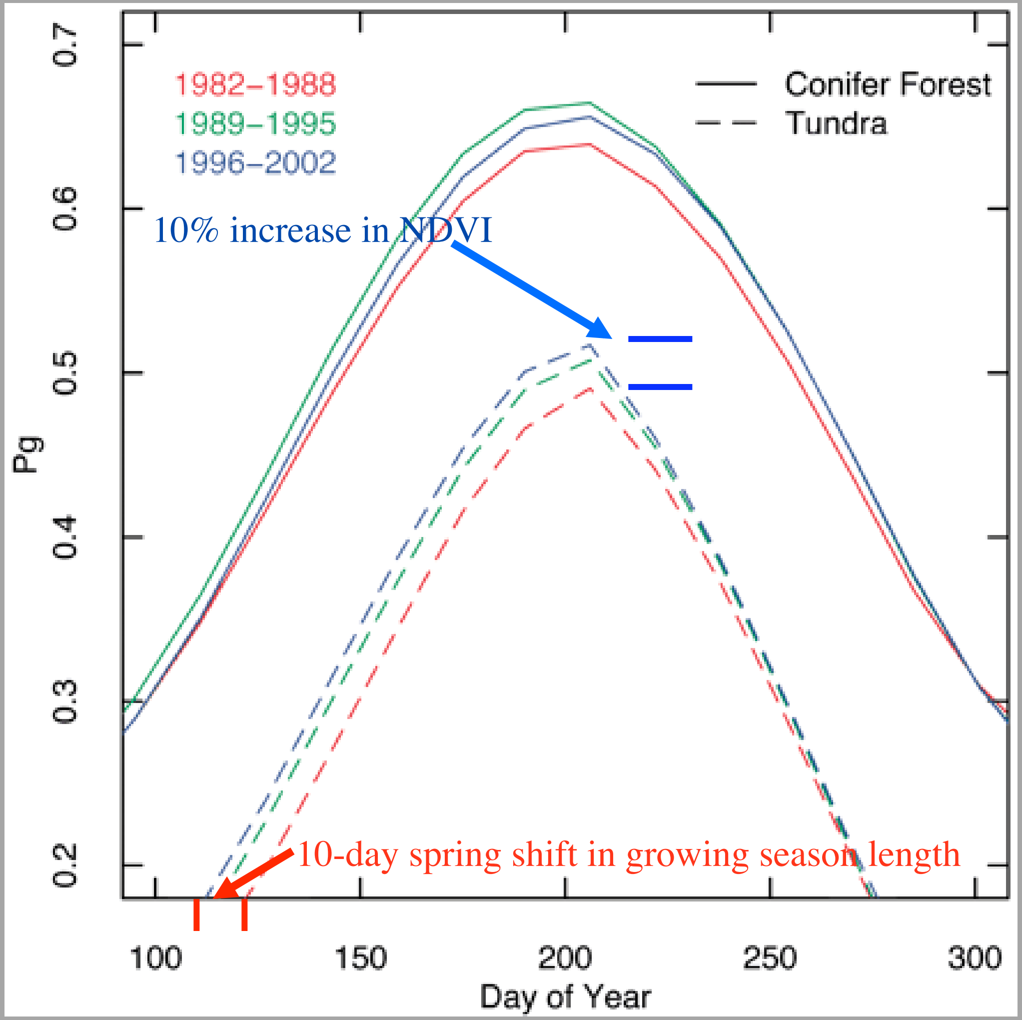


NDVI = (NIR-R) / (NIR+R)

From Lillisand and Kiefer 1987

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.



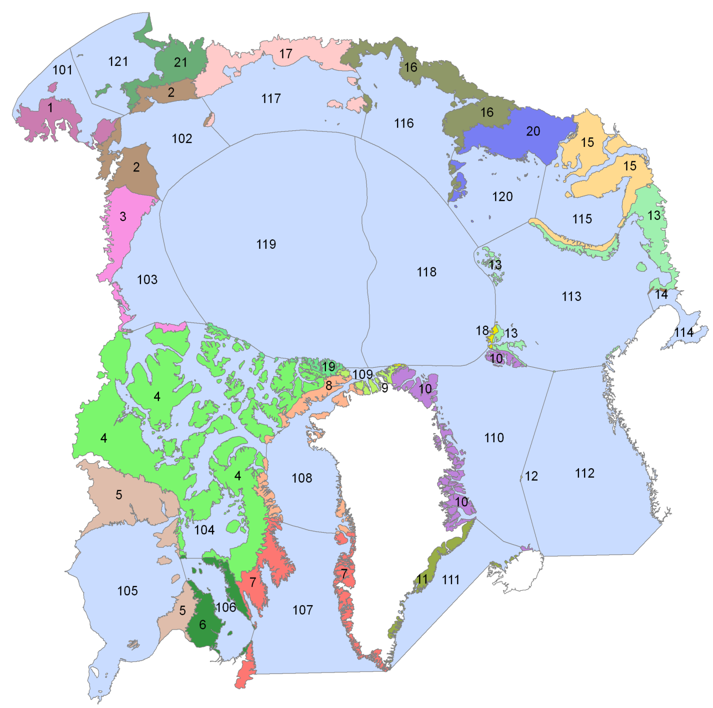
Goetz et al. 2005. *PNAS*,102: 13521-13525

Analysis of sea-ice, land surface temperature and NDVI trends: Arctic seas and associated land masses

Division of Arctic Ocean and associated land masses according to Russian Arctic Atlas

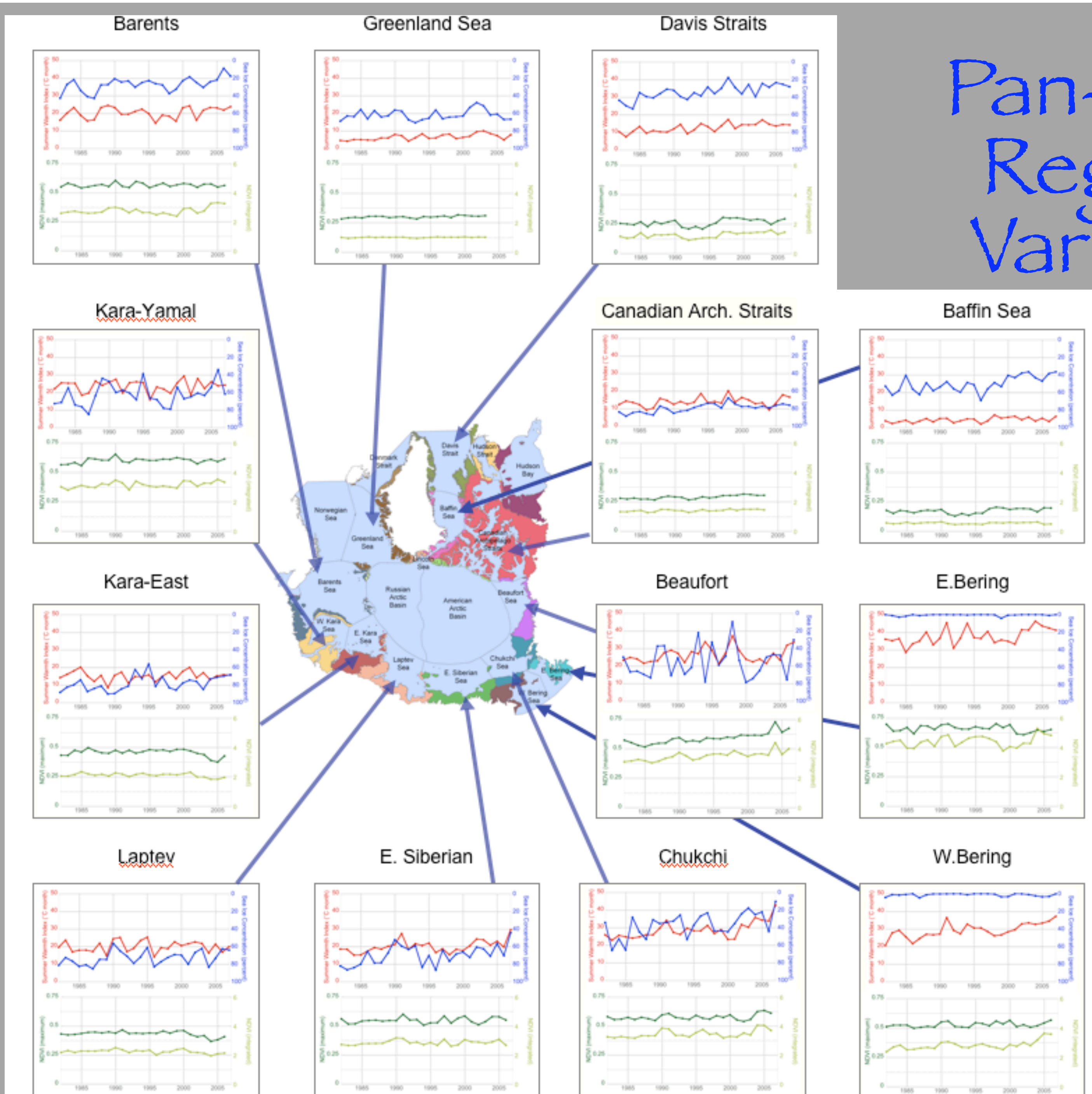
101 & 1* East Bering Sea
102 & 2 Chukchi Sea
103 & 3 Beaufort Sea
104 & 4 Canadian Arch. Straits
105 & 5 Hudson Bay
106 & 6 Hudson Strait
107 & 7 Davis Strait
108 & 8 Baffin Sea
109 & 9 Lincoln Sea
110 & 10 Greenland Sea
111 & 11 Denmark Strait
112 & 12 Norwegian Sea
113 & 13 Barents Sea
114 & 14 White Sea
115 & 15* West Kara Sea
116 & 16 Laptev Sea
117 & 17 East Siberian Sea
118 & 18 Russian Arctic Basin
119 & 19 American Arctic Basin
120 & 20* East Kara Sea
121 & 21* West Bering Sea

*Treshnikov basin divided for purposes of this study



Polar stereographic projection (J. Comiso)
Map by M. Raynolds, March 2008

Pan-Arctic Regional Variability



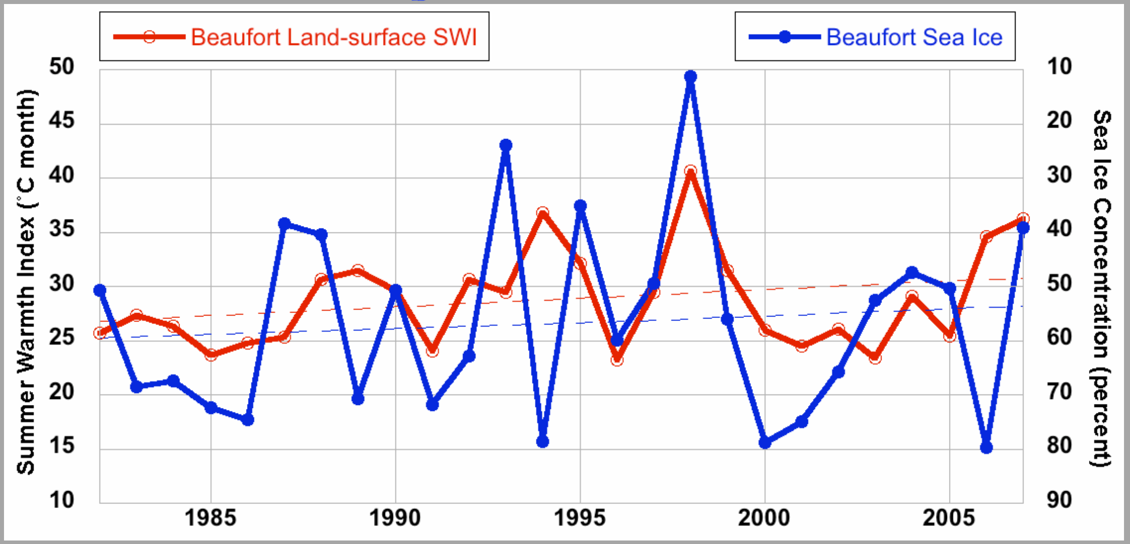
- **Summer warmth index (SWI)**
- **Mid July Sea Ice percentage cover**
- **Max NDVI**
- **Integrated NDVI**

Bhatt, Walker, Raynolds, Comiso, In prep.

Sea-ice and temperature trends in Beaufort Sea and Kara/Yamal region of Russia

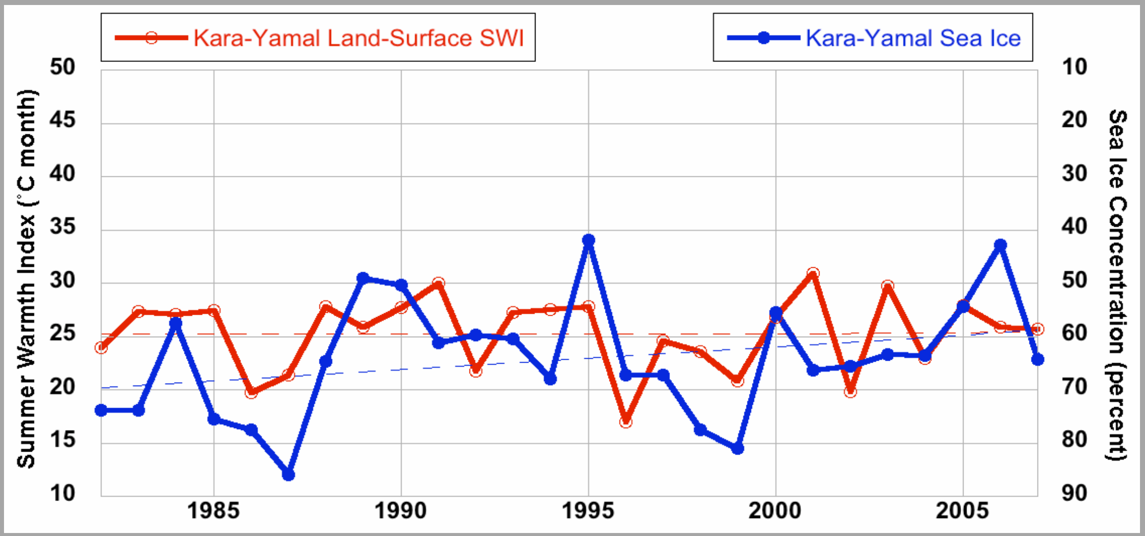
Beaufort

Negative sea-ice trend correlated with positive temperature trend



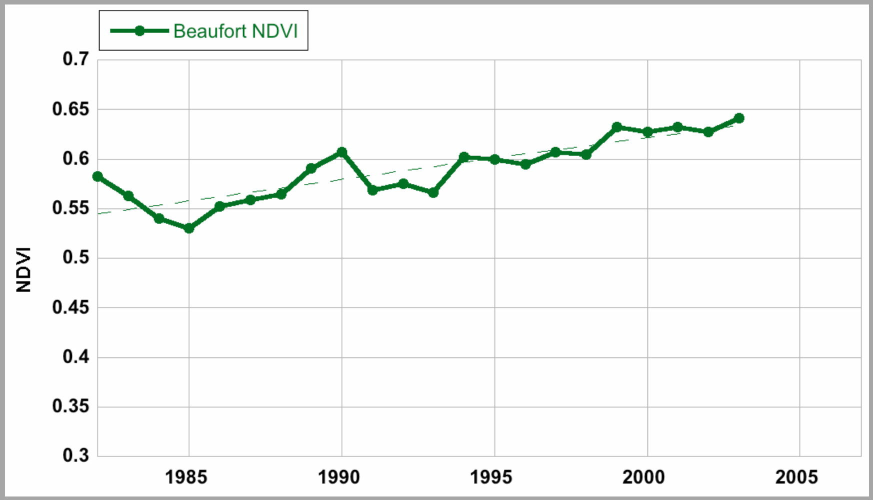
Kara/Yamal

Negative sea-ice trend but nearly flat temperature trend

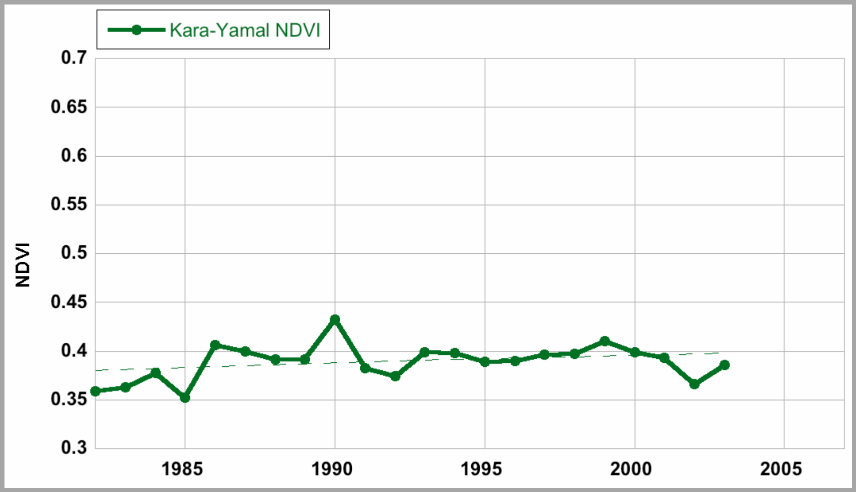


NDVI trends in Beaufort Sea and Kara/Yamal region of Russia

Beaufort



Kara/Yamal



- Much lower NDVI on the Yamal is likely due to sandy wind-blown nutrient-poor soils, and grazing by reindeer.
- Greater change in Beaufort Region (+0.04 vs. +0.0085 NDVI units/ decade) most likely due to more positive trend in ground surface temperatures in the Beaufort region during the period of record (Bhatt et al. 2007).

General trends

- Year to year variation in summer land surface temperature (SWI) is strongly correlated with mid-July ice cover within 50-km of the coast.

- Maximum and integrated NDVI are strongly correlated with the trend in SWI, but not to yearly variation in sea-ice.

Correlations between climate indices SWI, sea ice, & int. NDVI

50-km zones with climate indices during preceding winter (DJFM)

Bold values indicate significance at 90% level or greater

Correlation	SWI				Sea Ice				Integrated NDVI			
	NAO	AO	PDO	NPI	NAO	AO	PDO	NPI	NAO	AO	PDO	NPI
Barents	**0.38**	0.3	0	.14	-0.2	-0.3	**0.42**	-.20	.11	0.20	-.24	.23
Kara-Yamal	0.27	.12	0	.14	**-.54**	**-.57**	**0.48**	**-.34**	0	.14	-.29	**.40**
Kara-East	- 0.2	**-.40**	-.14	-.2	0	0	0	0	0	-.13	0	.16
Laptev	0.33	.19	-.31	.15	**-.56**	**-.53**	**0.43**	-.17	**0.60**	**0.41**	**-.41**	.27
E.Siberian	0.14	.33	**-.43**	.32	-.27	**-.56**	**0.49**	-.26	0.19	**0.45**	**-.63**	**.49**
Chukchi	-0.1	.12	-.28	**.37**	.19	-.26	0.20	-.11	-.17	0	-.26	.25
W. Bering	0.0	0	-.26	.13	-.11	-.24	0.14	0	0	0	-.22	0
E. Bering	0.0	0	-.11	.22	0	-.25	0.10	0	0	0	0	.15
Beaufort	**0.48**	**.40**	0	.11	0	0	-.27	.16	-.12	0.10	-.25	.22
Canadian Arch	0.19	.13	0	0	.14	0	0	0	0	.14	-.16	.15
Davis Straits	-0.2	0	0	.15	.18	0	0	-.11	-.31	0	0	.10
Baffin Sea	0.0	0	-.15	.16	0	0	0.15	-.17	0	0	0	.24
Grnland Sea	-0.1	.14	-.10	.19	**.43**	0.26	0	0	.13	0	0	0

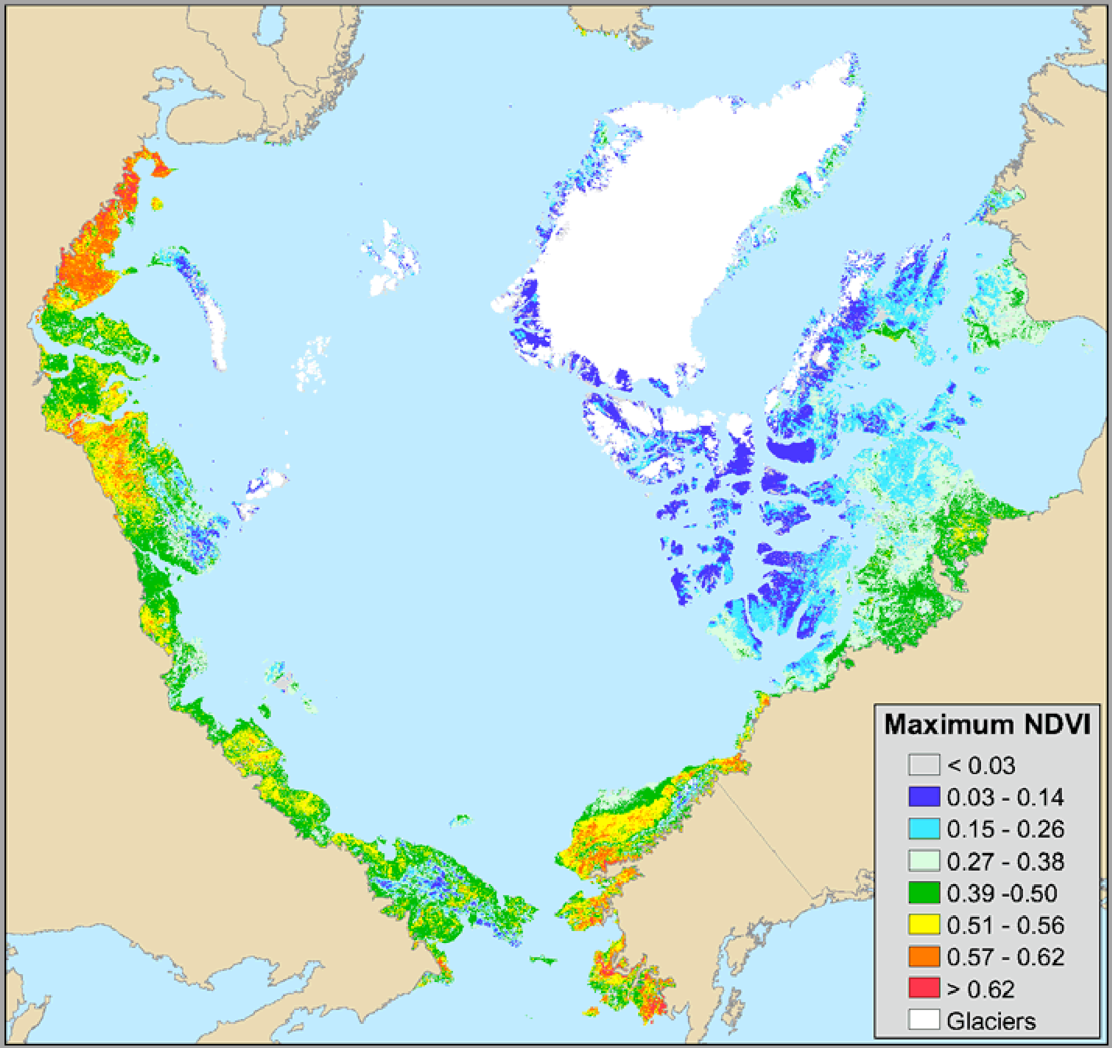
General trends

- The positive phase of NAO or NAM is consistent with a warmer winter Arctic, reduced summer sea ice (-), increased SWI (+) and increased integrated NDVI (+).
- Strongest climate-driver for sea ice and NDVI correlations are in the Laptev and East Siberian seas.
- Correlations require more thought in terms of mechanisms. Analysis of wind correlations with NDVI and SWI are in progress.

Circumpolar pattern of NDVI

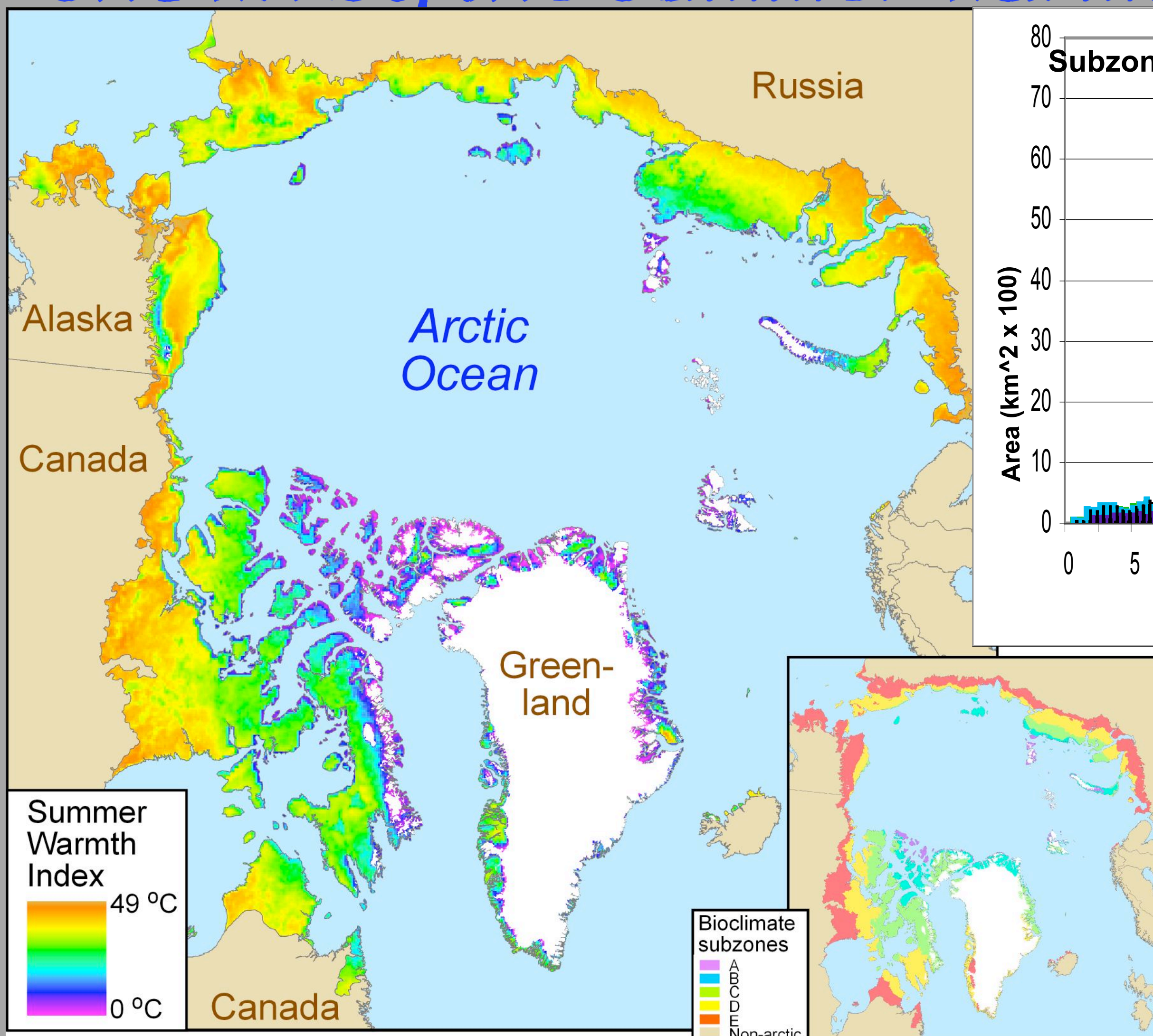
Primary controls at pan-Arctic scale:

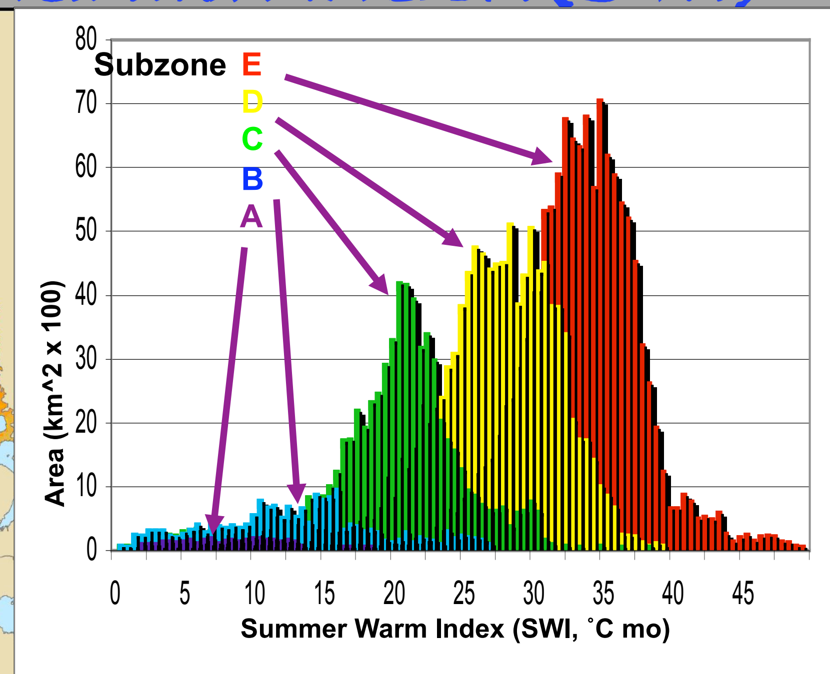
- Summer temp
- Lake cover
- Glacial history
- Soil type



CAVM Team. 2003

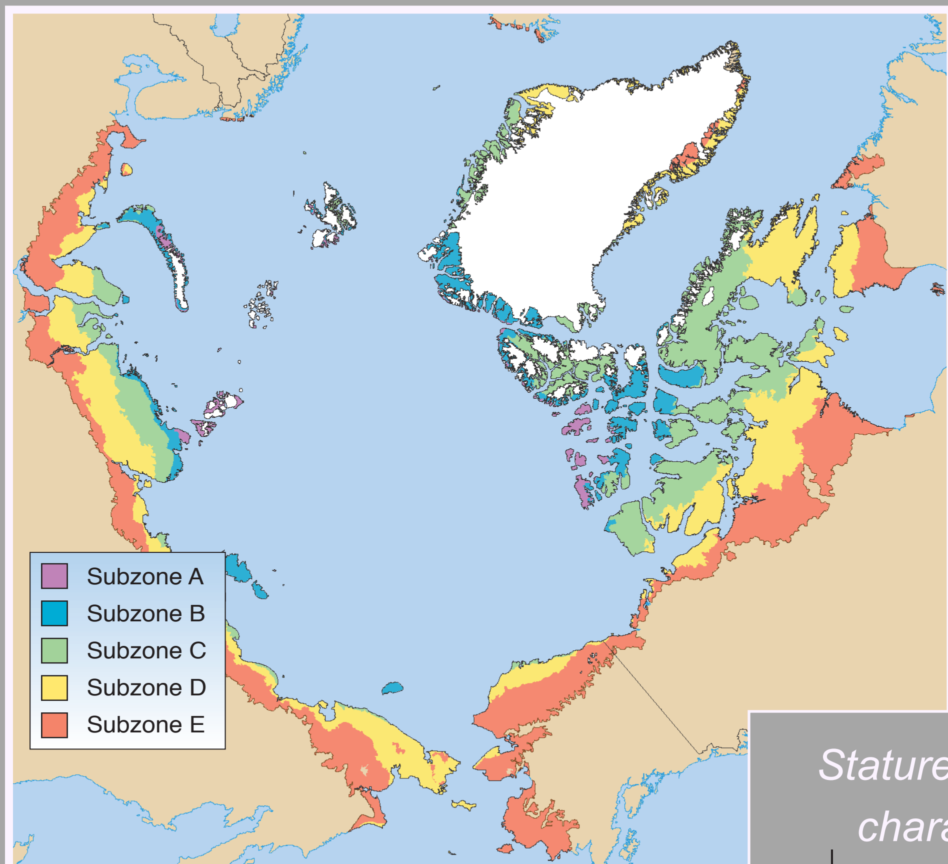
Summer land-surface temperature as shown by the summer warmth index (SWI)





SWI derived from 20-yr mean AVHRR thermal data (Raynolds et al. 2008 Rem. Sens. Envir.)

Arctic bioclimate subzones



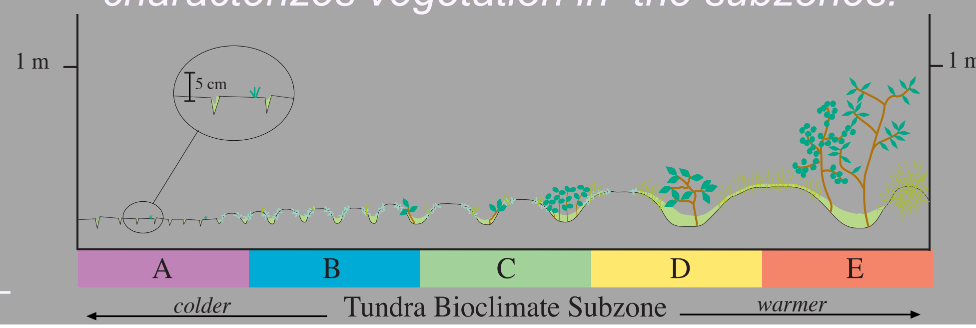
5 subzones spaced at approximately 2˚C mean July temperature intervals.

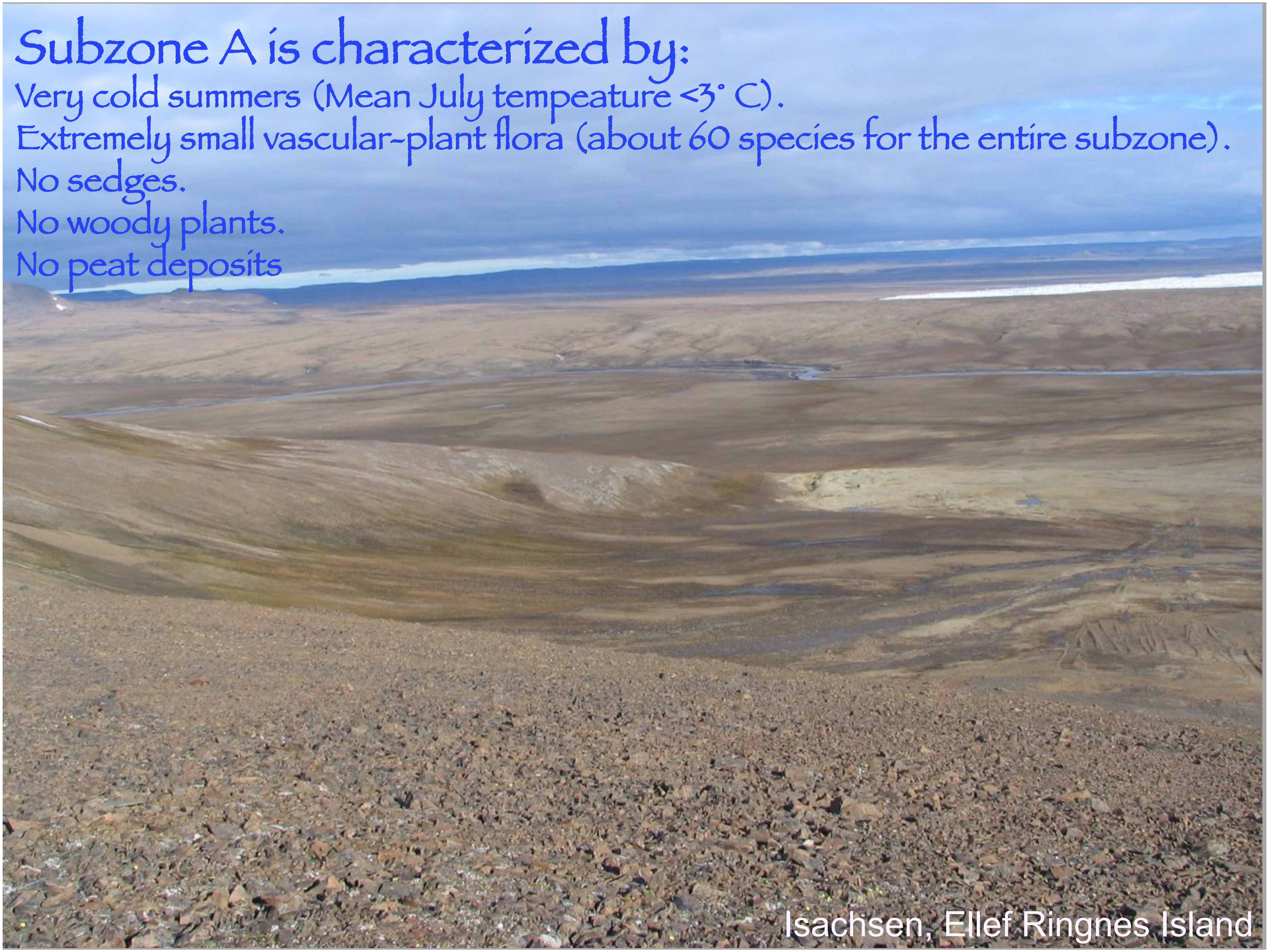
Bioclimate Subzone	Mean July Temp		Area (km^2 x 10^6)
A	1-3˚ C		.114 (2%)
B	3-5˚ C		.450 (6%)
C	5-7˚ C		1.179 (17%)
D	7-9˚ C		1.564 (22%)
E	9-12˚C		1.840 (26%)
		Glaciers	1.975 (28%)
		Total Arctic	**7.111 (100%)**

Subzone A is a rare subzone.

A	No woody species
B	Prostrate dwarf shrubs, <5 cm tall
C	Hemi-prostrate dwarf shrubs, 5-15 cm
D	Erect dwarf shrubs, 15-40 cm
E	Low shrubs, >40 cm

Stature of woody plants is a primary factor that characterizes vegetation in the subzones.



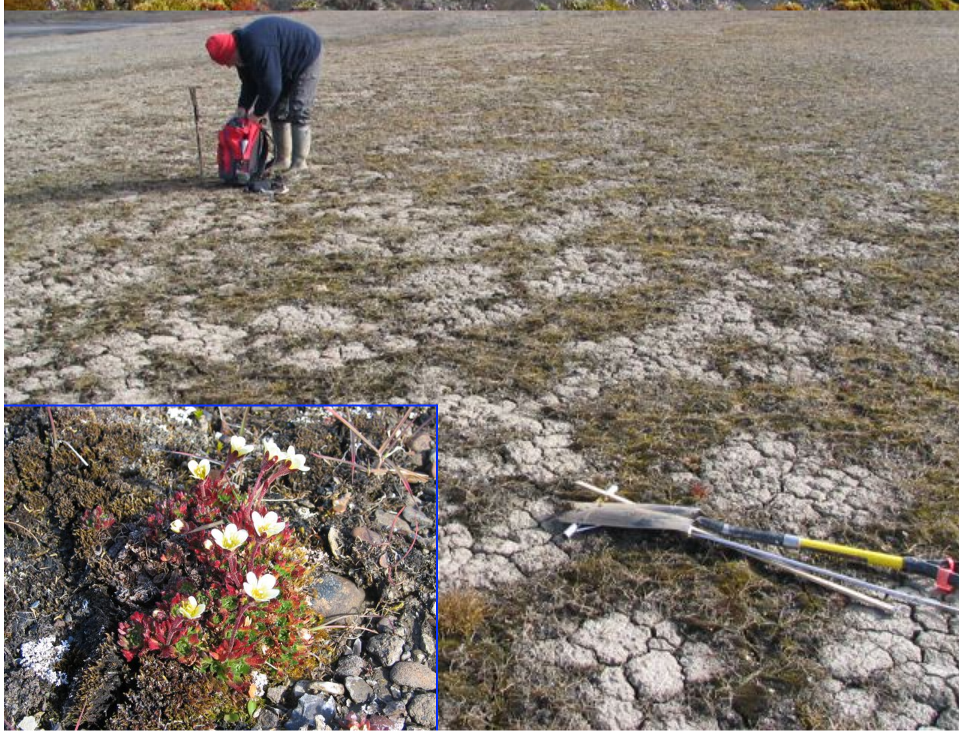

Subzone A is characterized by:
Very cold summers (Mean July tempeature <3° C).
Extremely small vascular-plant flora (about 60 species for the entire subzone).
No sedges.
No woody plants.
No peat deposits
Isachsen, Ellef Ringnes Island

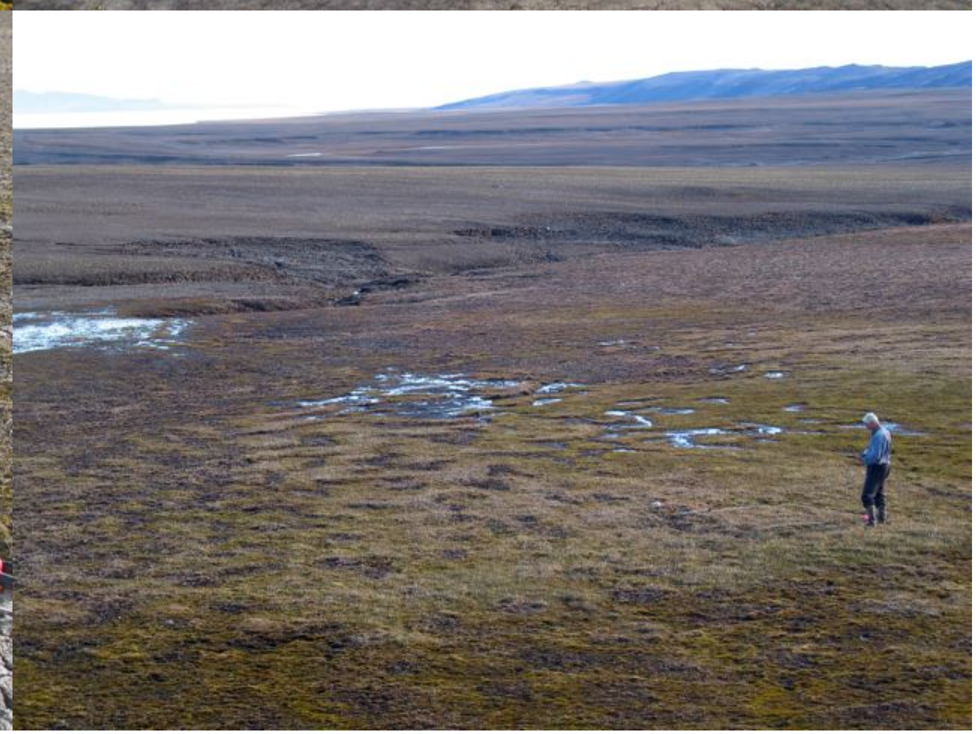
- In the Russian literature, subzone A is treated as an entirely separate bioclimate "Zone" -- the true "polar desert" of Gorodkov, Alexandrova and others.
- If the Tundra Zone is defined by its proximity to the Arctic Ocean, subzone A is defined by its proximity to perennial sea ice.

Isachsen, Nunuvut, Canada

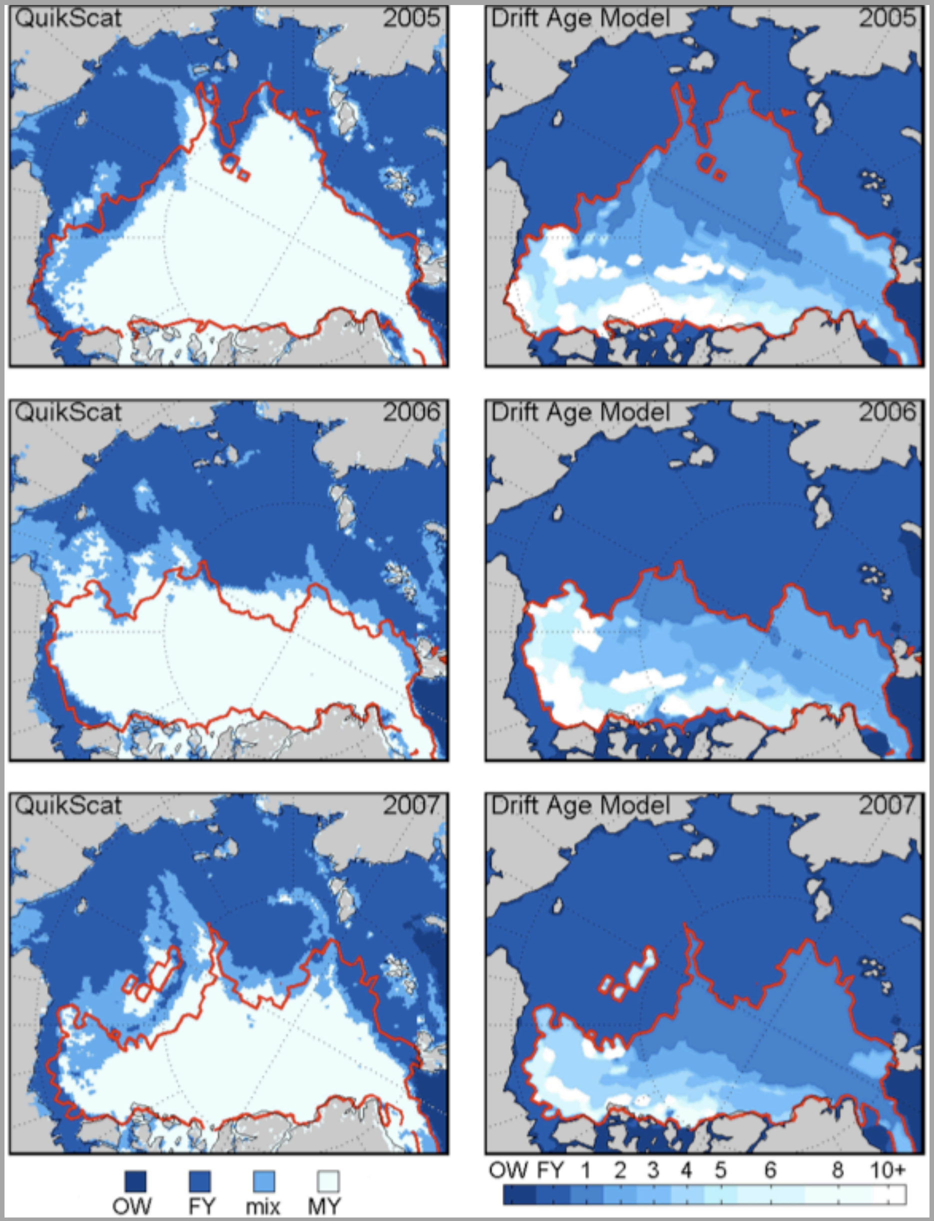
- In the Russian literature, subzone A is treated as an entirely separate bioclimate "Zone" -- the true "polar desert" of Gorodkov, Alexandrova and others.
- If the Tundra Zone is defined by its proximity to the Arctic Ocean, subzone A is defined by its proximity to <u>perennial</u> sea ice.

Isachsen, Nunuvut, Canada







Nghiem et al. 2008.

Lessons from 2007:

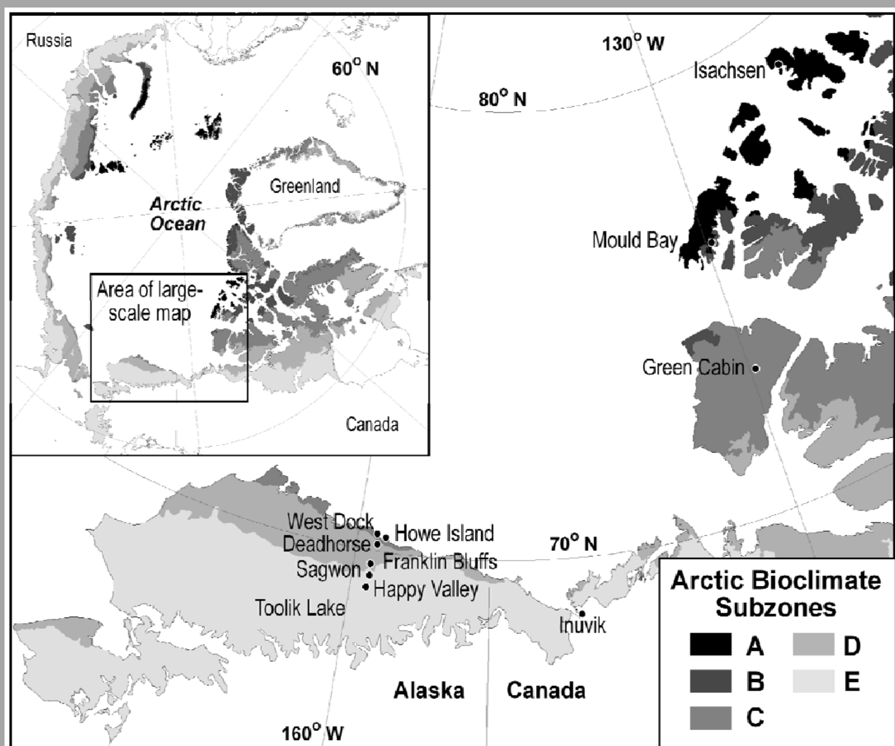
Recognition that Bioclimate Subzone A is in the region of heaviest multiyear ice along the western Canadian Archipelago, N. Svalbard and Arctic Russian Islands.

If summer arctic ice vanishes, so does Subzone A.

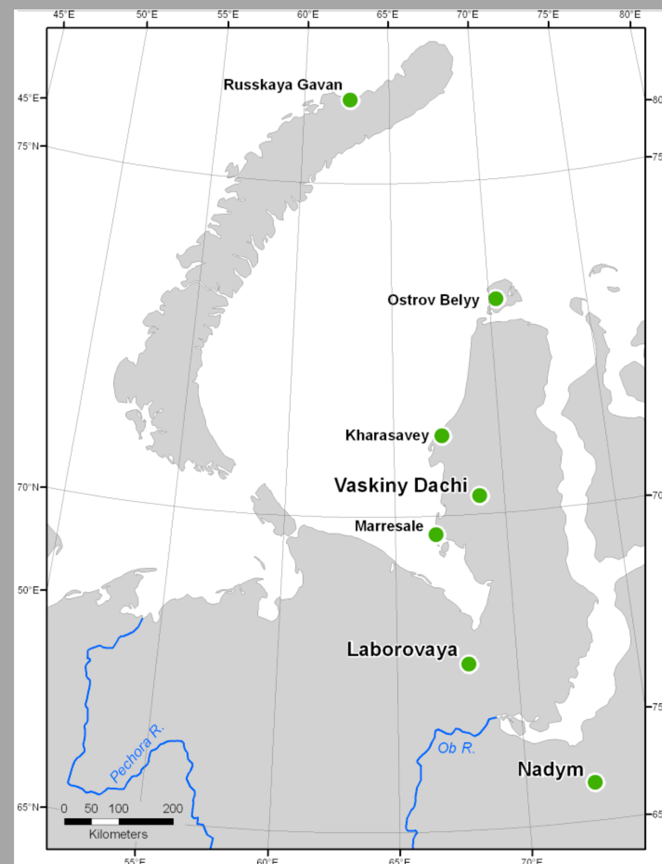
Subzone A is a rare and <u>endangered</u> bioclimate subzone!

Ground and satellite observations along the complete Arctic bioclimate gradient: 2 transects

North America



Yamal Russia



Summary

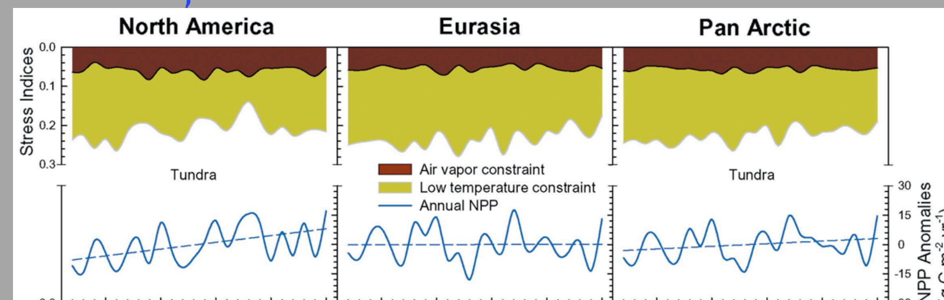
- Critical need for baseline studies in Subzone A and B (Isachsen and Mould Bay).

- Will require close coordination with Canadians (Arctic Net) and inclusion of other terrestrial monitoring programs, including CBMP, CALM, TSP and flagship observatories (Toolik, Barrow, Zachenburg, etc.), as well as ocean and sea ice studies.

- Step in developing standardized protocols at a network of sites for a coordinated Circumpolar Terrestrial Ecosystem Baseline along the complete arctic bioclimate gradient.

Numerous studies have shown a general trend of increased NDVI in the Arctic, but…

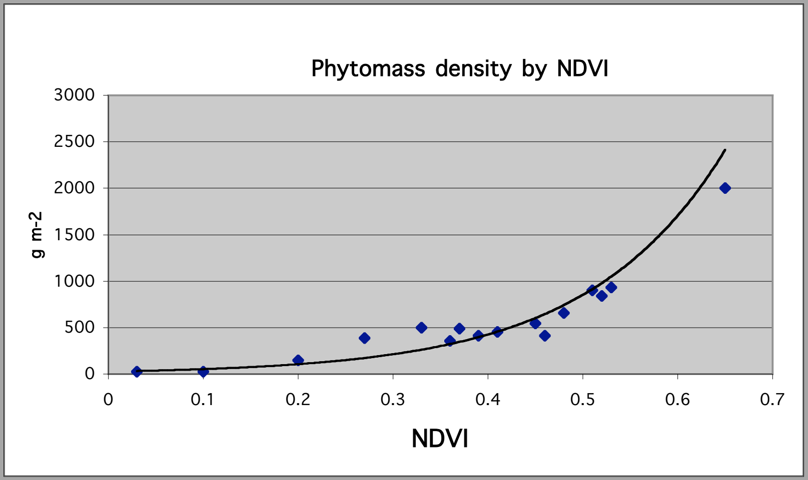
Bunn et al. 2007, Eos, 88: 333-334.



"Should we believe in the NDVI trend? There are no "ground truth" measurements of photosynthesis at northern high latitudes over the same period, and so the accuracy of the trend cannot be established unambiguously." (Inez Fung, 1997)

Great need for consistent Arctic-wide ground data

- Links to satellite information.



- Time series at intensive research sites to document change.

Important aspects of an Arctic Terrestrial Vegetation Baseline

- Network of permanent sites with baseline databases, and standard protocols for ground-based time-series observations of:
  - Biomass
  - Species diversity.
- Observations along the complete climate gradient.
- Observations at several relevant scales (plots to planet).
- Close coordination with other terrestrial baselines (soils, active layer, permafrost, snow).

Data collected

Transects

- Species cover (Buckner sampler)
- Leaf area index (LAI-2000)
- NDVI (PSII)
- Active layer thickness (thaw probe)

Study plots (relevés)

- Species cover (all species, cover estimates)
- Site descriptions (vegetation structure, photos, geolology, thaw depth,soil descriptions and collection, etc.)
- LAI and NDVI
- Biomass (harvest, 20 x 50-cm plots)
- Soil descriptions and analysis

Cover (Buckner sampler)

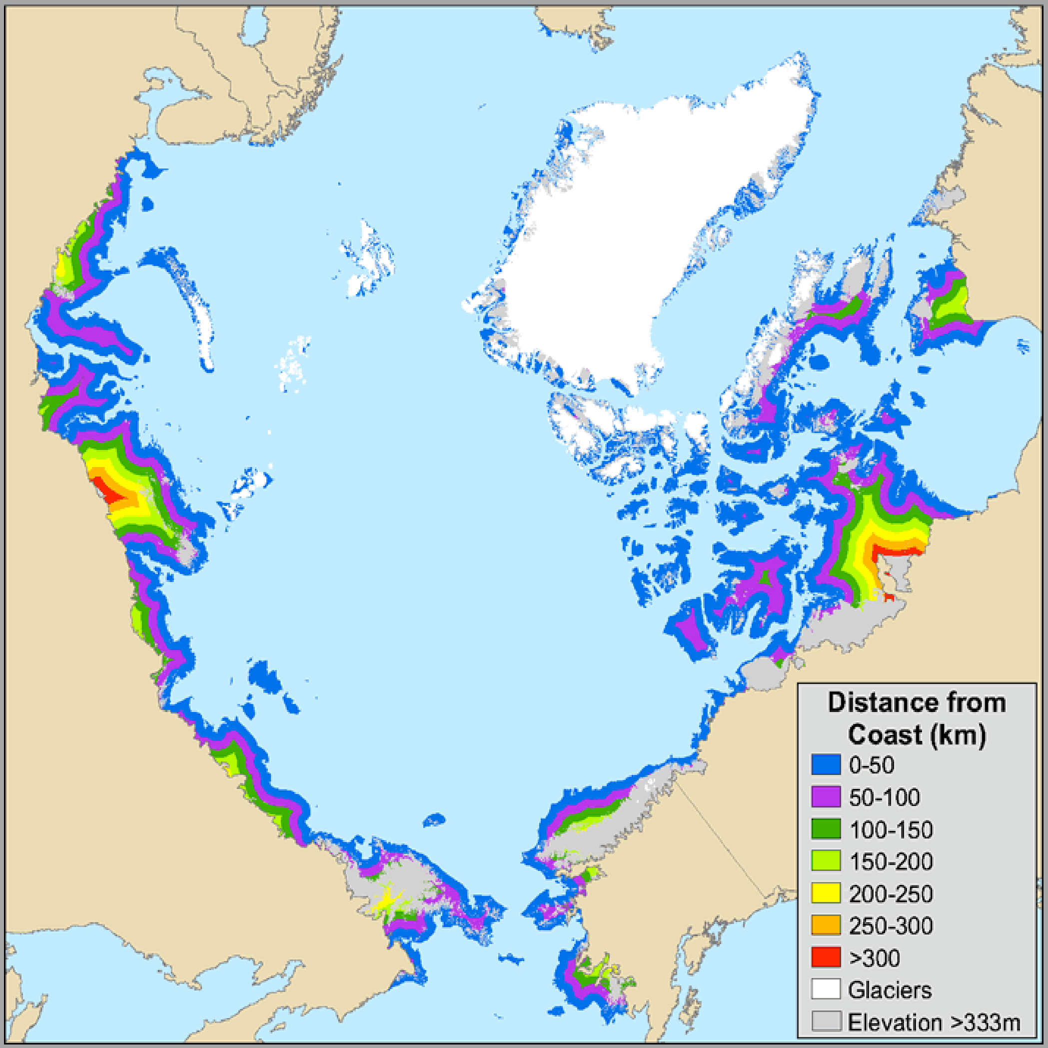
NDVI (PSII)

Biomass harvest

Soils

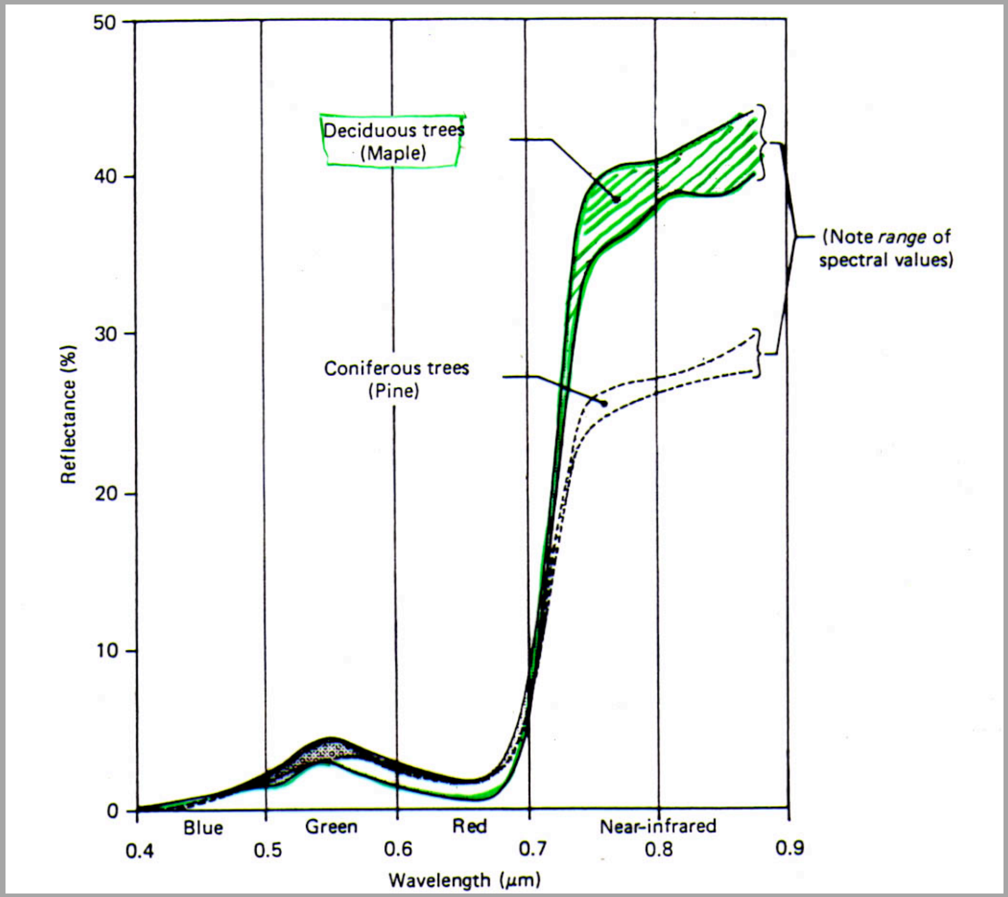
Proximity of lowland tundra areas to sea ice

- 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.
- **Changes in the Arctic ocean sea ice will very likely affect terrestrial ecosystems.**



Different land cover types have different NDVI

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



NDVI = (NIR-R) / (NIR+R)

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

R **= reflectance in the red, chlorophyll-absorbing portion of the spectrum (0.58 to 0.68µm).**

NDVI has generally increased in the Arctic in the past 25 years.

- Green areas have increased NDVI from 1982-2005.
- Red areas have decreased NDVI.

Bunn et al. 2007, *Eos* 88: 333-334.

Why should we care about changes to the vegetation?

Summer warming is changing the whole system.

If summer sea-ice totally melts, we could very well lose the entire northern-most bioclimate subzone (Subzone A), and shrink the total area of the Arctic to a fraction of its present extent.

Changes to the vegetation will have profound effects on nearly all aspects of Arctic systems:

Wildlife: Amount of forage (biomass, Griffith et al. 2003). More importantly: types of forage (changes in species composition, animals only eat certain parts of the available biomass,).

Heat budgets: Vegetation is the insulative blanket that affects surface melting in summer (Nelson et al. 1987, Walker et al. 2003, Romanovsky et al. 2008, Walker et al. 2008); decreased albedo of trees of trees and shrubs (Chapin et al. 2005),

Snow distribution and character: Shrub-snow interactions (Sturm et al. 2001).

Carbon budgets: Increase above and below-ground carbon reserves (McGuire et al. 2000, Shaver et al. 2000, 2001, Oechel et al. 2000, Kimball et al. 2006);

Trace-gas fluxes: CO_2, CH_4, H_2O (Oechel et al, 2000, 2001; Reeburg et al. 1998; Eugster et al. 2005),

Water budgets: Changes of flux of moisture to the atmosphere and runoff of water to the Arctic Ocean and snow distribution (Hinzman et al. 2005; Sturm et al. 2001),

…ultimately **people** living in the Arctic and 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).

Many problems with existing biomass data

- Mostly collected during IBP in 1960s and 1970s.
- Often impossible to replicate harvests.
- Sites were not georeferenced.
- Vegetation type unknown.
- Soil and site factor information missing.
- Harvest methods not documented.
- Amount of replication not documented.
- Not linked to NDVI, LAI, or other cover properties of the vegetation.
- Definitions of biomass components unclear.

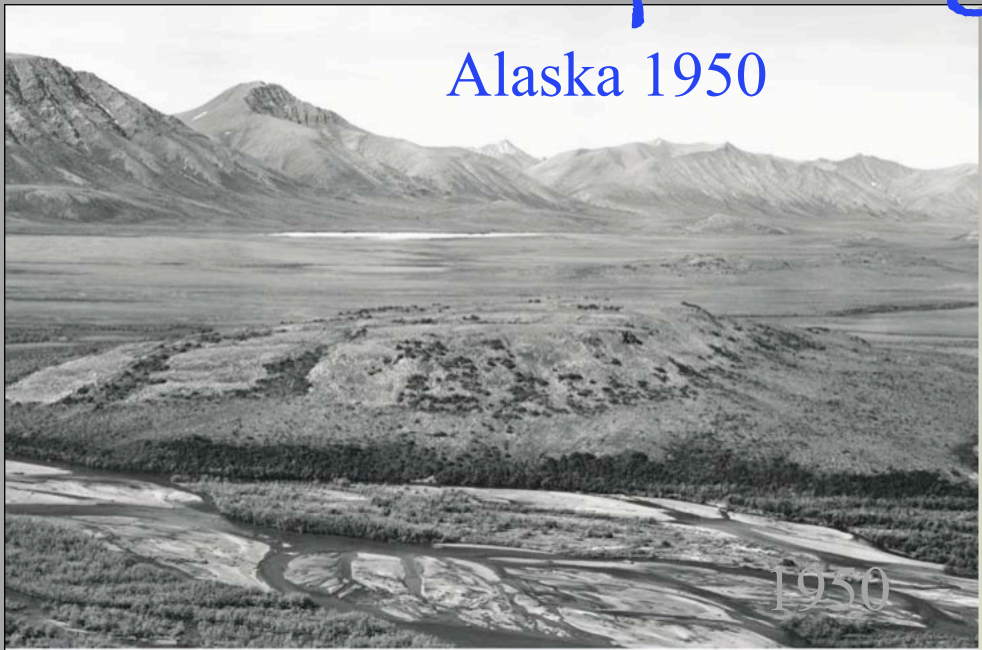
"What is above-ground biomass?"

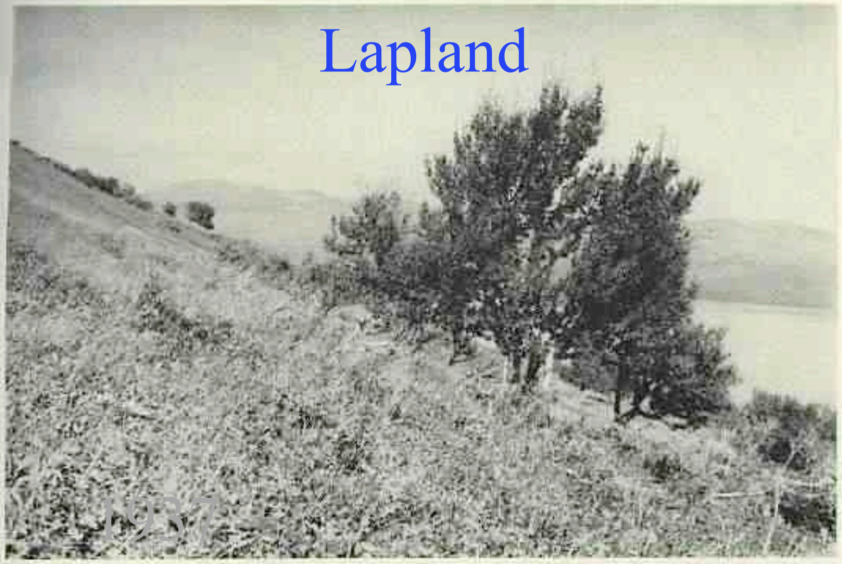
There is not a lot of quantitative evidence for change in natural Arctic vegetation.

Photo – M. K. Raynolds

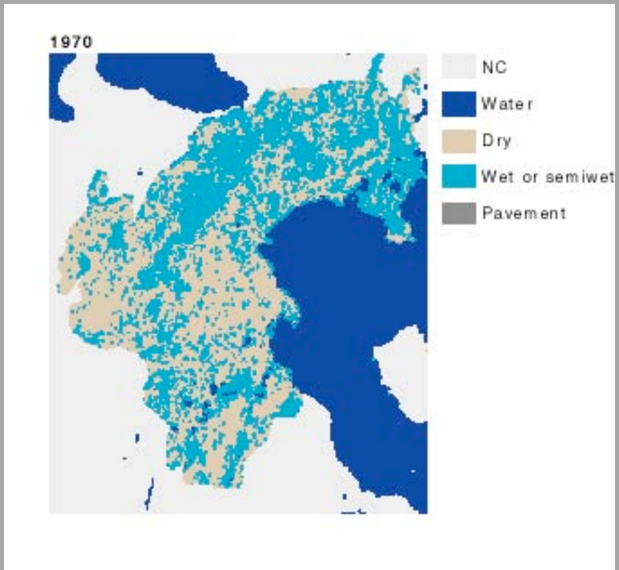
- **Mostly experimental evidence;**
  - Green-house experiments (Chapin et al.)
  - ITEX experiments
- **One long-term biomass study of Shaver at Toolik Lake that is suggestive of change but it is inconclusive.**
- **Photo record of shrub cover change in northern AK (Matthew Sturm, Ken Tape, and Chuck Racine):**

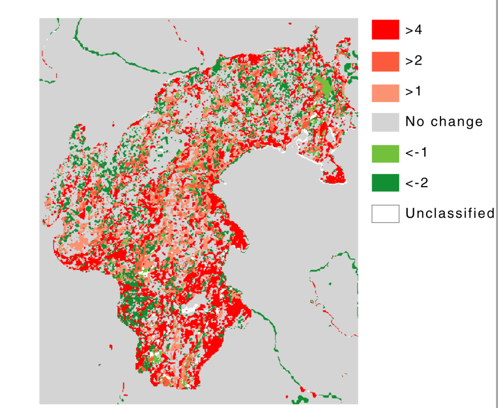
Shrubs are expanding in tundra regions



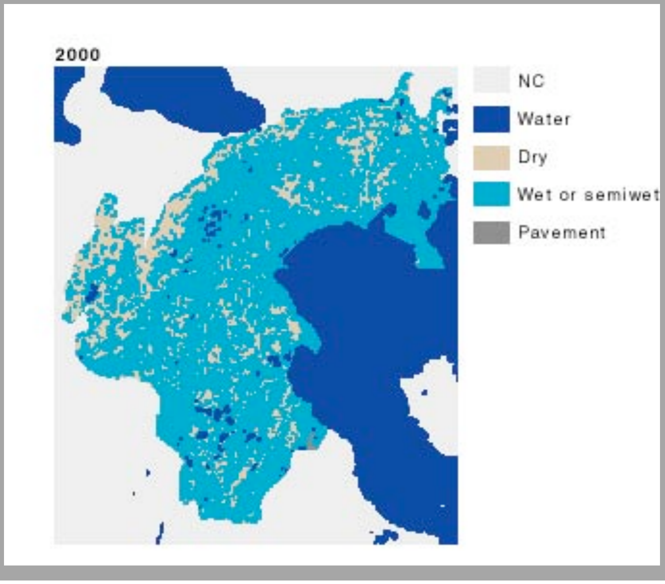


At Stordalen, Sweden, thawing of permafrost has led to waterlogging and loss of dry habitats

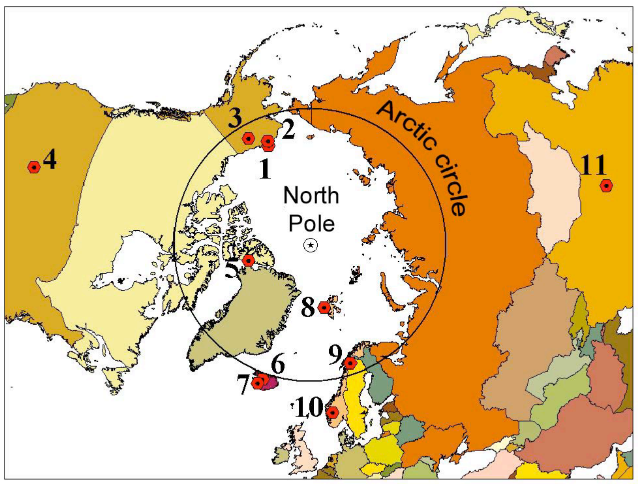


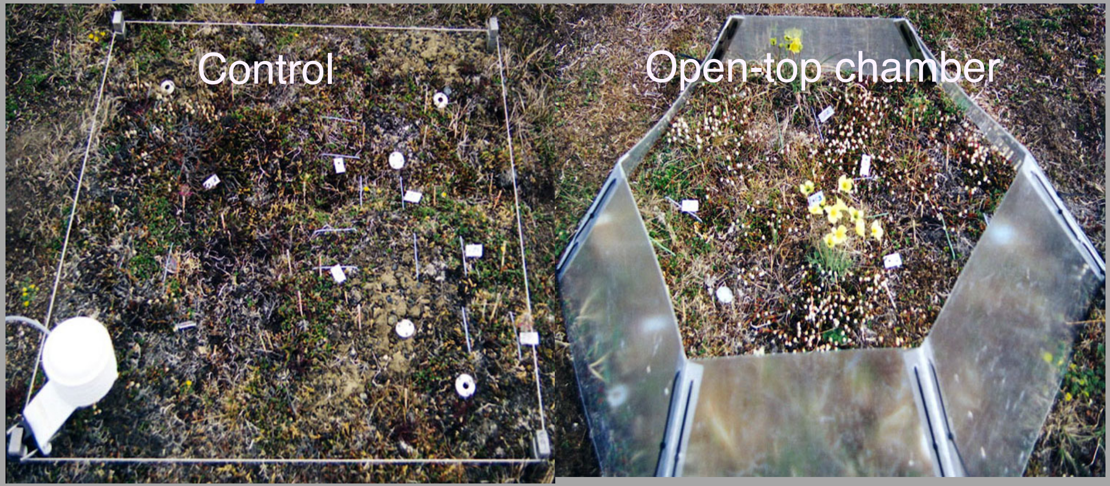


change in mg CH4/m2/hr



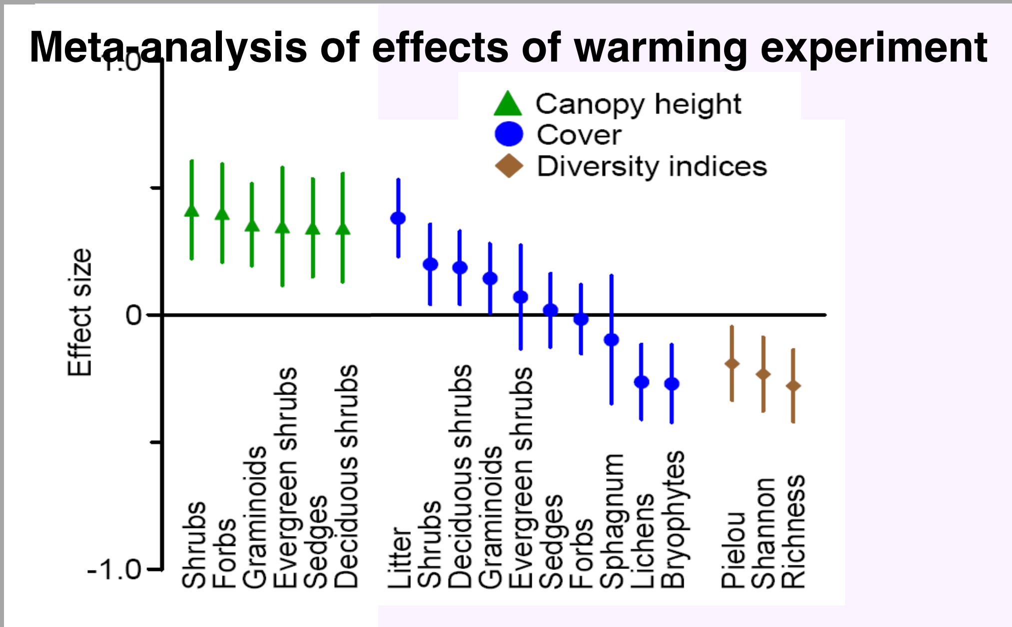
International Tundra Experiment (ITEX) synthesis





Warming:

- Increased shrubs, graminoids
- Decreased lichens, mosses, species diversity.



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

Consistent circumpolar baseline databases are critical

Plant species:

- **Local floras** complete floras vascular plants, mosses, and lichens for a network of Arctic terrestrial vegetation observatories
- ***Flora Arctica*** database derived from the CAFF Pan-Arctic Flora,

Plant communities:

- ***Arctic Prodromus*** (list of plant communities of the Arctic).
- **Pan-Arctic Vegetation Database** (with species cover)**,**

Biomass, NDVI, species cover:

- **GLORIA-style monitoring system** (Global Observation Research Initiative in Alpine environments) along elevation and latitudinal bioclimate gradients.

Local Floras

- Focus on premier Arctic Observatories where intensive surveys of at least vascular plants, mosses and lichens could be accomplished and repeated.

- New sites are needed in the very coldest two subzones (Subzones A and B).

- Follow the Russian concept whereby prescribed protocols are used to develop complete inventories of plants within 10 x 10 km areas with representative areas of regional habitats.

- 24-hour inventories (Bioblitzes) across a given taxonomic group or even all living organisms in a given area, could help achieve “Local flora” lists for at least the vascular plants, mosses, and lichens. Specialists could be gathered for intensive surveys.

Baselines at four different scales:

Circumpolar-level

- Satellite-derived baseline using global-scale sensors (AVHRR), NDVI, LST, phenology
- Global network of local floras
- Drivers at global scale, e.g. sea ice, changes in climate.

Regional-level

- Vegetation classification and mapping, habitat diversity (Beta-diversity).
- Analysis of landcover/land-use change using intermediate-scale satellite data (Landsat TM, MODIS).
- Identify "hot spots" of potential for change (e.g. Subzone A).
- Major drivers: fire, insect outbreaks, droughts, etc.

Landscape-level

- Toposequences (moisture gradients, small hill scales)
- Elevation gradients in mountains: adoption of GLORIA protocols
- Monitoring of landscape-scale changes in biomass, habitats using satellite data (Quickbird, SPOT)
- Major Drivers: Extreme events (floods, avalanche years, thermokarst, landslides); shrub expansion in drainage networks and on hill slopes

Plot-level

- Species lists (alpha-diversity scale) for vascular plants, mosses, and lichens
- Microflora and fauna (soil organisms)
- Standardized methodologies at plots
- Drivers: all the above plus micro-events, animal outbreaks, grazing, etc.

Sampling standards needed

International workshop needed to standardize vegetation sampling procedures.

Yamal Biomass procedures
August 2007
Skip Walker, Martha Raynolds

TUNDRA BIOMASS PROCEDURES

TABLE OF CONTENTS

PURPOSE
The goal of biomass sampling of vegetation is to quantify the amount of plant material in a given vegetation type, thus we sample all phytomass from a specified amount of surface area, so the values can be extrapolated over larger areas.

Phytomass is sorted into categories that are relevant to research questions. Phytomass includes three major categories: above-ground live phytomass, above-ground dead phytomass, and below ground phytomass. Phytomass is also commonly sorted by plant functional type, such as deciduous shrub or lichen. Finally, plant functional types can be sorted into plant parts, such as live leaves, dead leaves, stems, reproductive parts.

Most of the difficulties in obtaining good phytomass data come from inconsistencies in the clip harvest methods, and the sorting methods. This document is intended to make these methods as consistent as possible. It is based primarily with some modificatin on the methods used to collect biomass along the North American Arctic Transect (Walker et al. 2007 submitted; Epstein et al. 2007 submitted).

COLLECTING ABOVEGROUND BIOMASS
Equipment needed: Metal frame(s), pegs, serrated knife, clippers, scissors, gallon zip-lock plastic bags, indelible "Sharpie" markers, "write-in-the-rain" paper or Post-its

1. **Establish sample grids.** At each location (Nadym, Km-143, Vaskiny Dachi), we will establish 5 10x10-m grids with grid points spaced at 1-m intervals. These will be in replicated homogeneous areas of the zonal vegetation. Within each grid we

"What does NDVI really mean in tundra systems… particularly for reindeer and caribou?"

Some areas with low NDVI have high forage quality for reindeer.

Lichen-woodland at Nadym

Bright green areas may be dominated by species such as alder or dwarf-birch, which have abundant toxic secondary plant compounds that protect them from grazing.

Shrub tundra at Laborovaya

Collaboration and coordinations with other projects

IPY Arctic Observatory Network (AON) sites at Barrow, Toolik Lake, Zachenburg, Abisko, Svalbard, Thule, Cherski, SCANNET, CEON etc.

Other Specific IPY projects (BTF, COMAAR) including non-biological networks (e.g. CALM, TSP).

Coordination with mechanistic and experimental studies of change (ITEX, snow fences, greenhouses, etc.).