Pan-Arctic climate dynamics in relationship to sea ice, land-surface temperatures and NDVI: focus Yamal region & comparison with North America

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Yamal Land-Cover Land-Use Change Workshop
28-30 January 2008, Moscow, Russia

Main Results

- Summer Warmth Index over land increases (decreases) as adjacent sea ice decreases (increases)
- Direct relationship between sea ice and tundra greenness not established, yet.
- Details of the climate relationships vary with region in the Arctic.

Remote Sensing Suggests Increasing Trend in Arctic Tundra Biomass

Normalized Vegetation Difference Index

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

NIR (Near Infra-red): spectral reflectance in near-infrared band (0.725-1.1 μm) & R (Red): red chlorophyll absorbing portion of spectrum (0.58-0.68 μm)

Summer Warmth Index

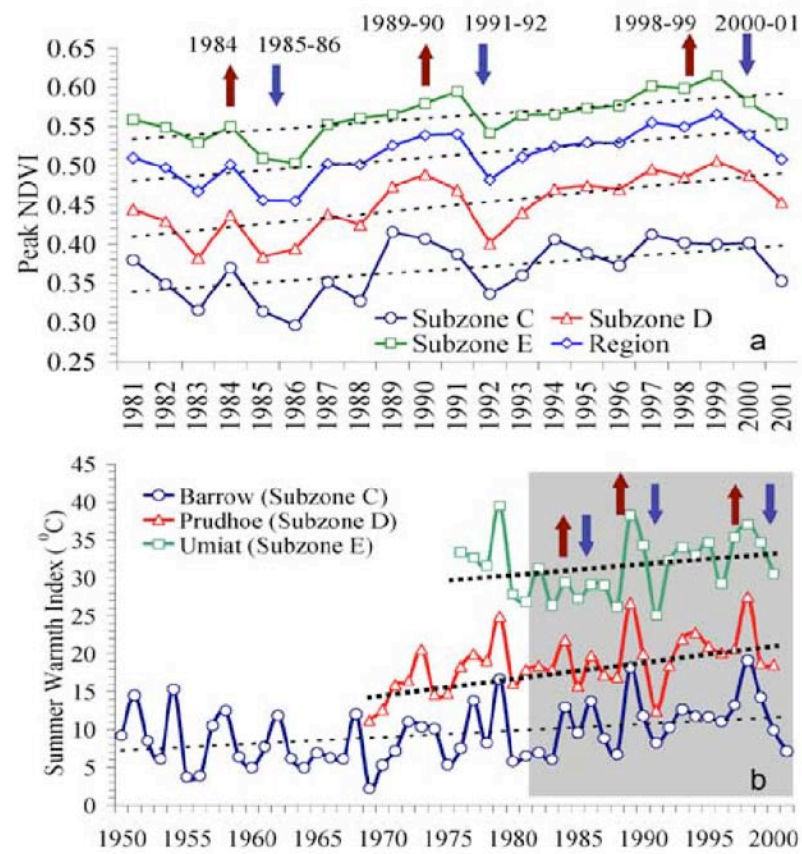


Figure 2. Time series of peak NDVI derived from 8-km resolution AVHRR data from 1981 to 2001 (a) and SWI over the past 22–50 years (b) among bioclimate subzones. Dashed lines are linear regressions. The shaded area highlights the period of SWI covered by NDVI data.

[Jia et al. 2003]

Project Hypothesis

Graminoid Tundras of the type tussock-sedge, dwarf-shrub, & moss tundra. Subzone E

- **80% of the Arctic tundra (3.2 million km^2) is within 100 km of ocean**
- **Positive trend in NDVI identified over Alaska N. America & the Arctic, suggests enhanced photosynthesis (i.e. increased tundra biomass).**
- ***Are these Arctic tundra vegetation changes associated with (forced by) changes in sea-ice? How?***

Hypothesis: Earlier ice melt leads to increased summer warmth and higher NDVI and enhanced greenness (plant biomass & change in vegetation).

Data Information

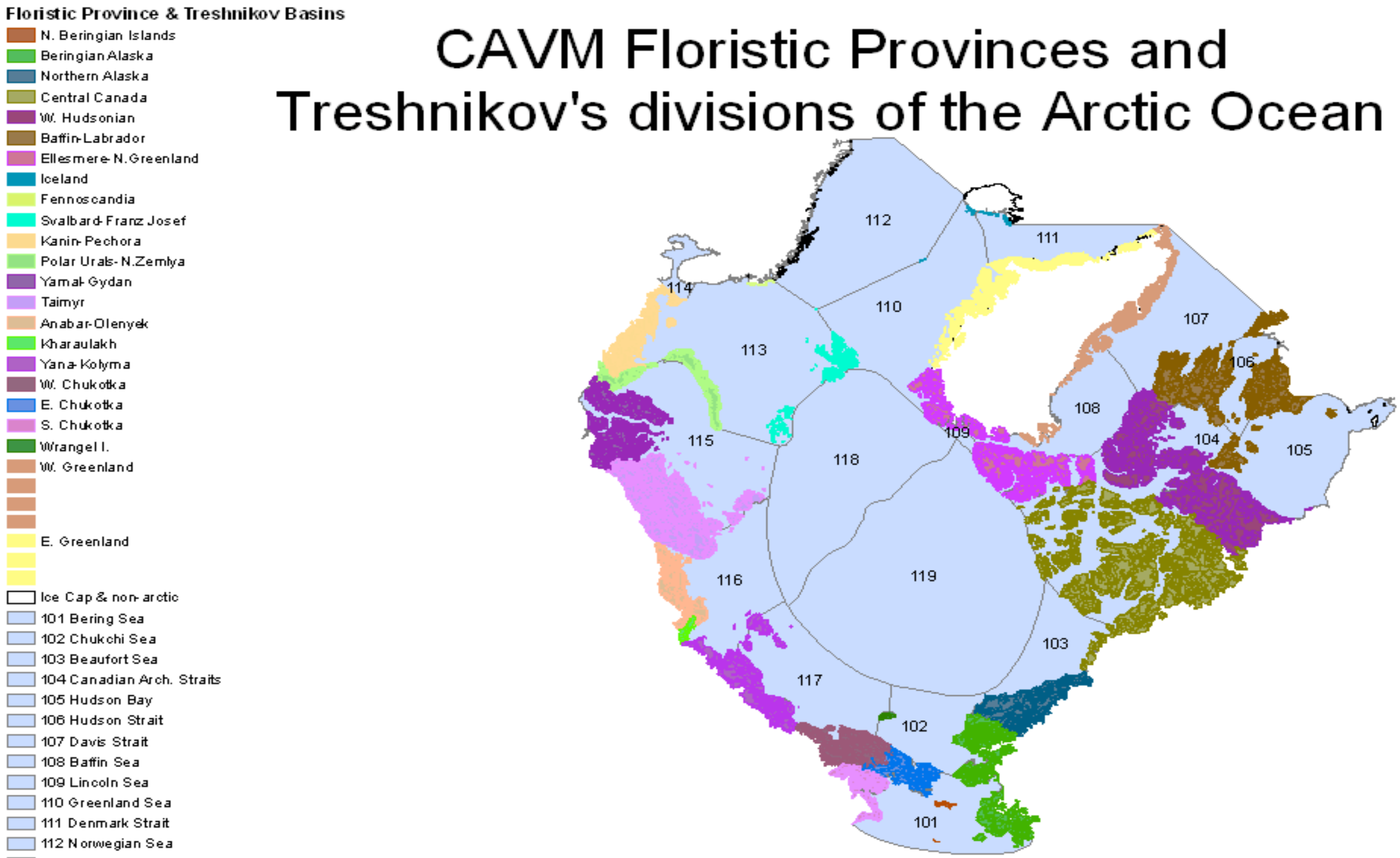
DATA: Use 25 km resolution SSMI passive microwave Bootstrap Sea Ice Concentration (SIC) and AVHRR Surface Temperature (T_s).

TIME: January 1982 to December 2005 (24 years, monthly & weekly) (2006 and 2007 being added)

AREA AVERAGING: Construct indices of SIC & T_s for total & 50 km buffer areas over land and ocean regions.

ANALYSIS: Examine the variability and trends at the site, regional and pan-arctic scales.

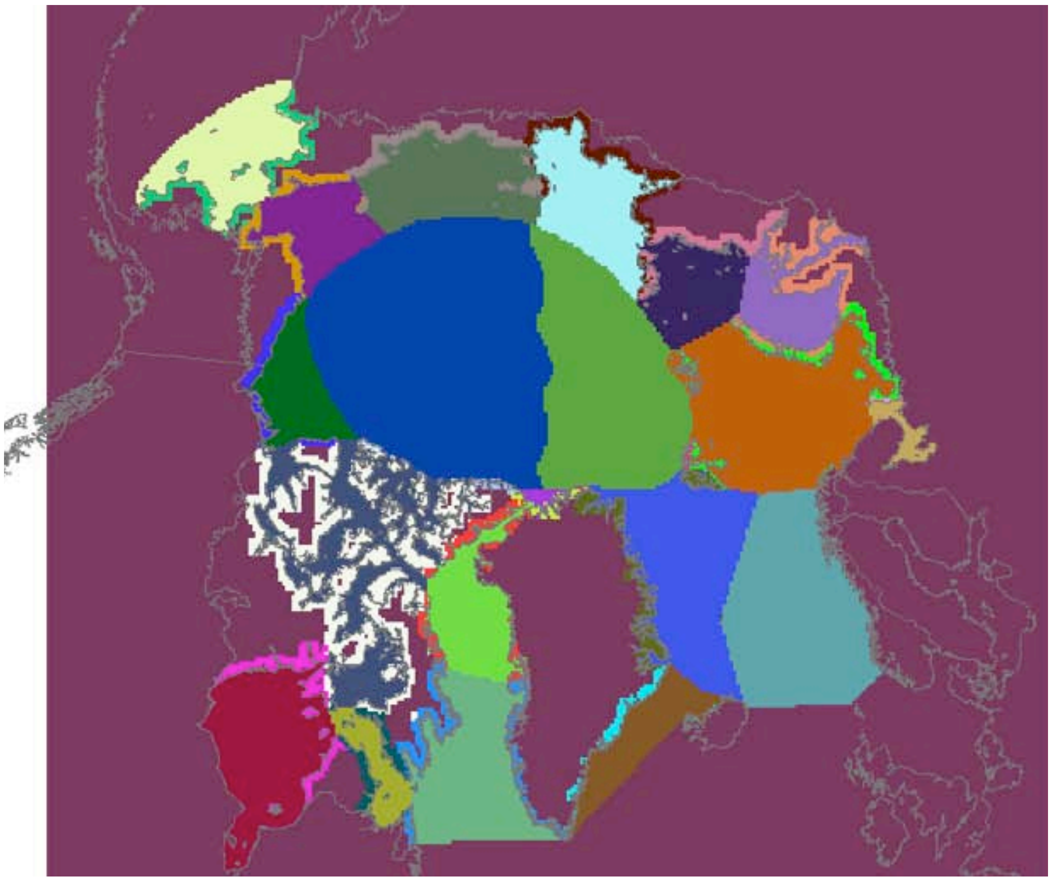
Division of the Arctic



50 km Buffer Zones

[Martha Raynolds]

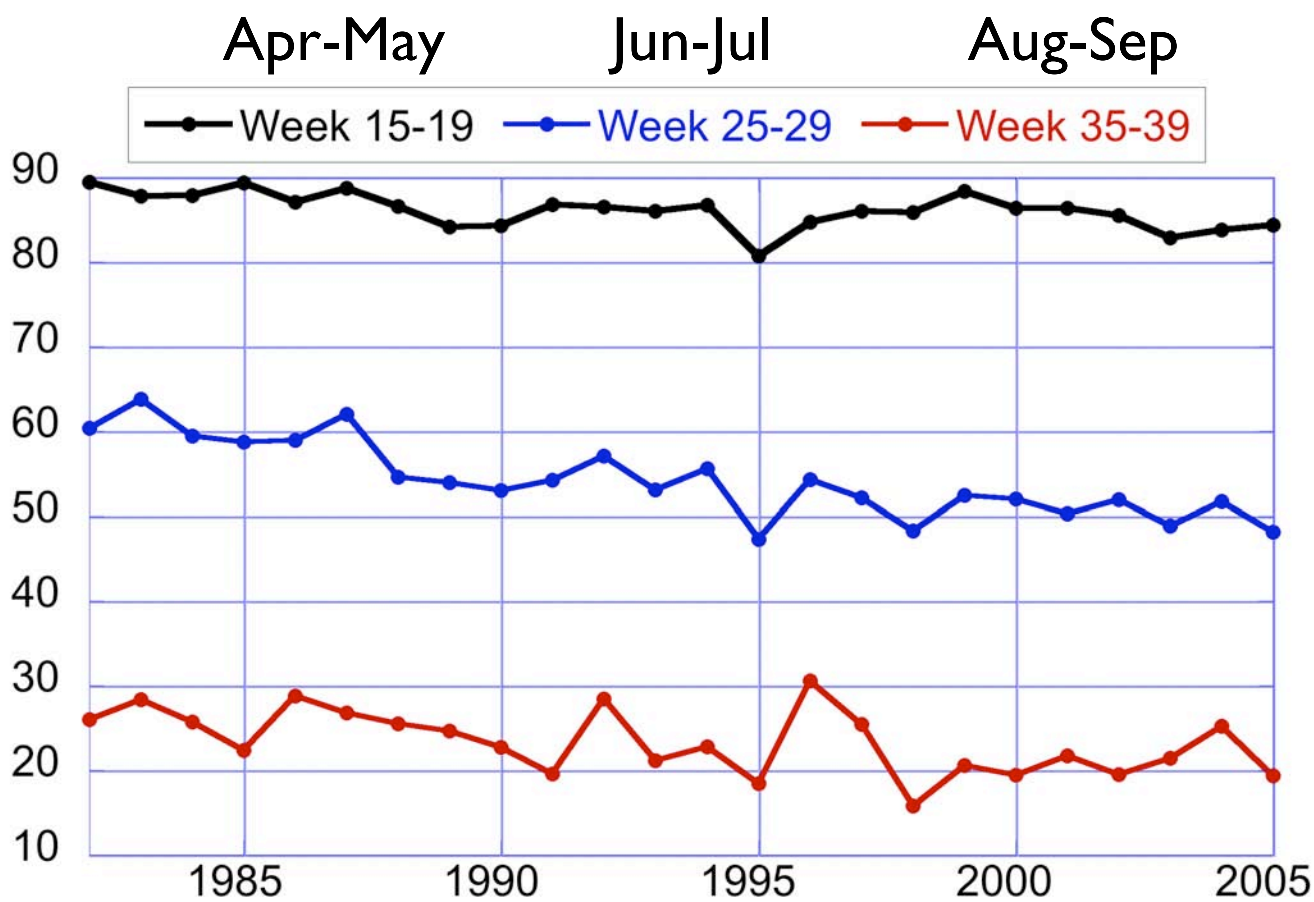
50-km land & ocean domains used in analysis



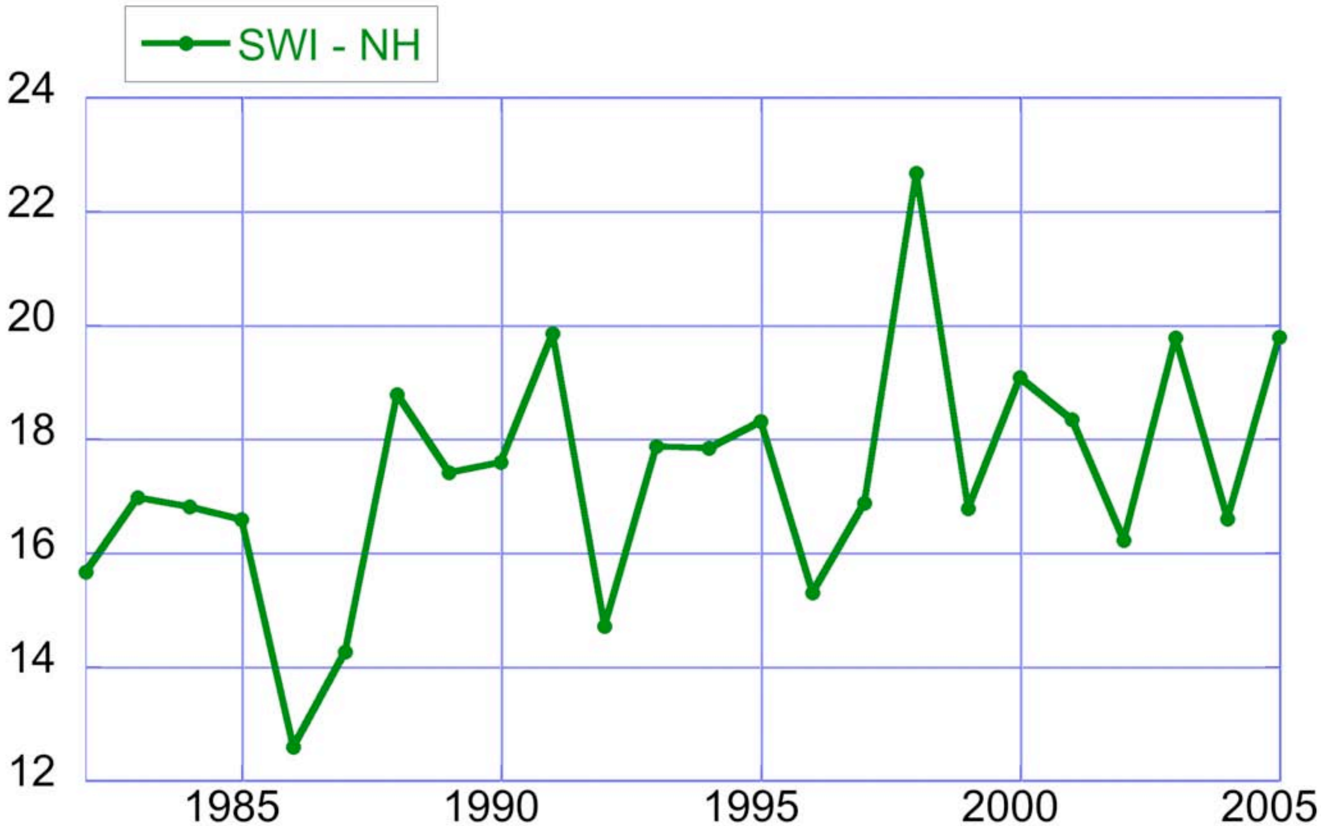
Example: Kara-Yamal Region 50 km land domains

Why? Tundra is in narrow land region along Arctic coast

Ice decreasing in Pan-Arctic 50-km zone

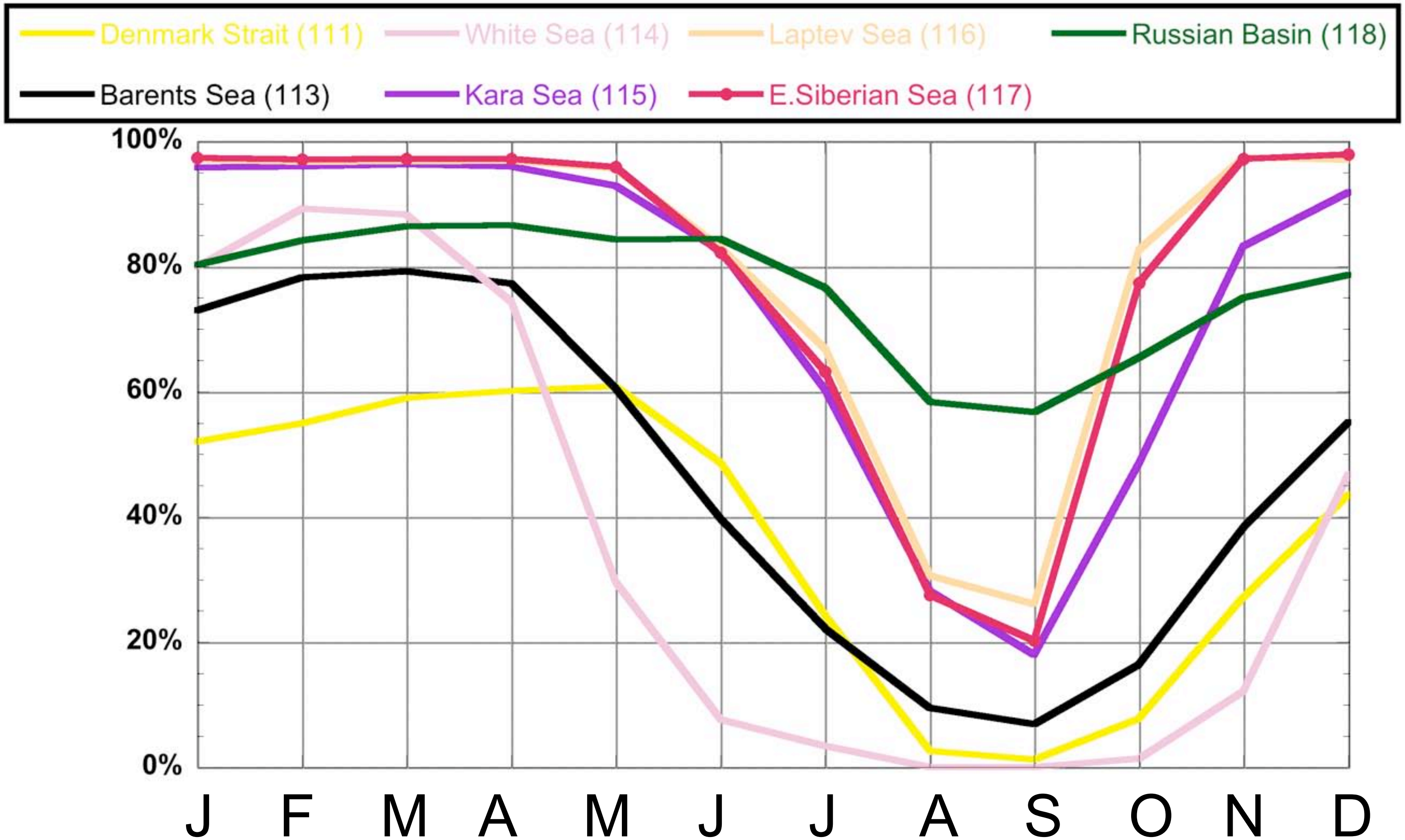


SWI increasing in Pan-Arctic 50-km zone

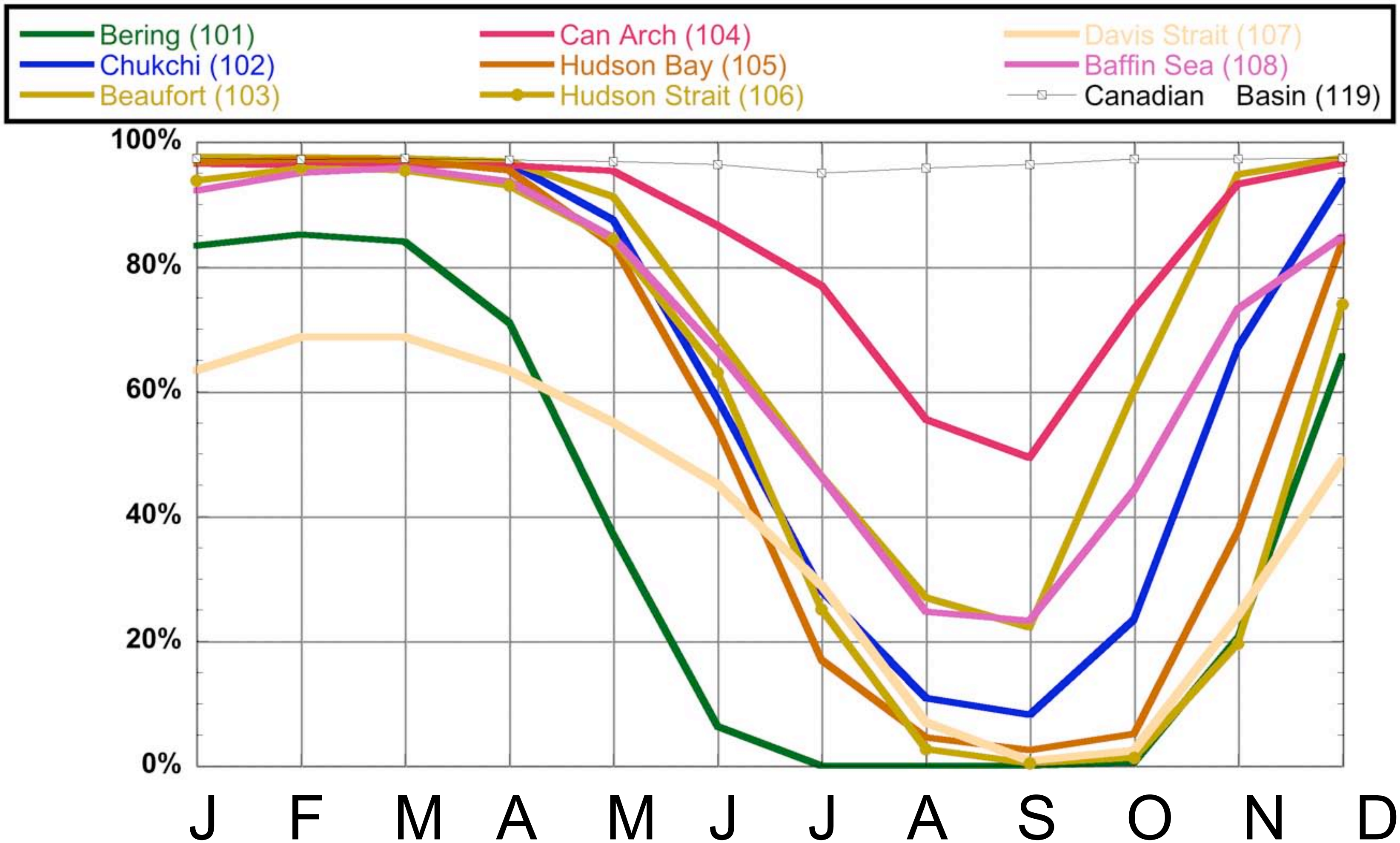


SWI & Sea Ice are correlated at -0.35, -0.65, and -0.77 for weeks 15-19, 25-29, and 35-39, respectively.

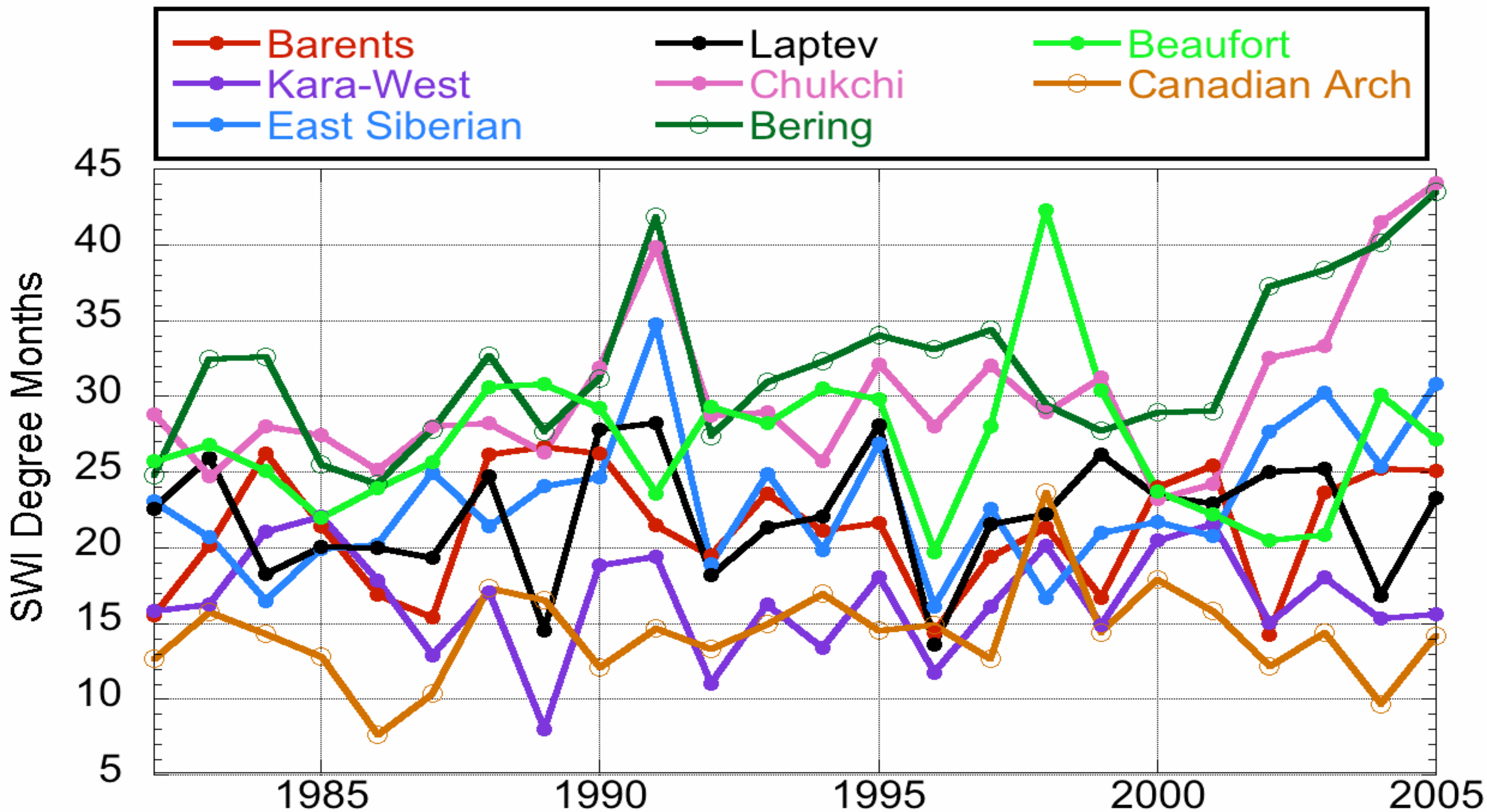
Annual Cycle of Sea Ice in 100-km Coastal Buffers Varies Regionally: Euro Arctic



Annual Cycle of Sea Ice in 100-km Coastal Buffers Varies Regionally: NA Arctic

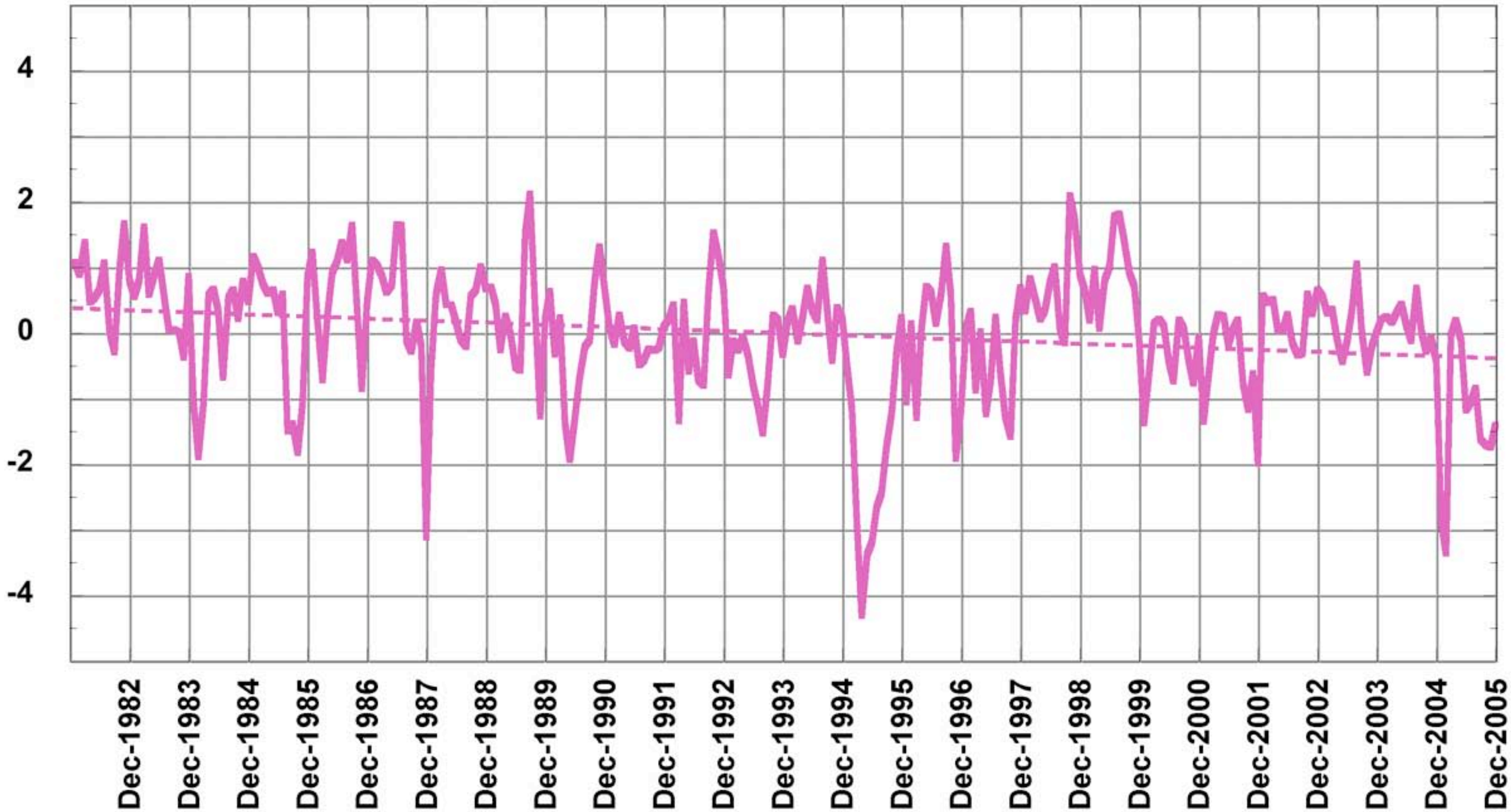


SWI Variability in 50-km Coastal Land Zones is Highly Variable, Some Trends



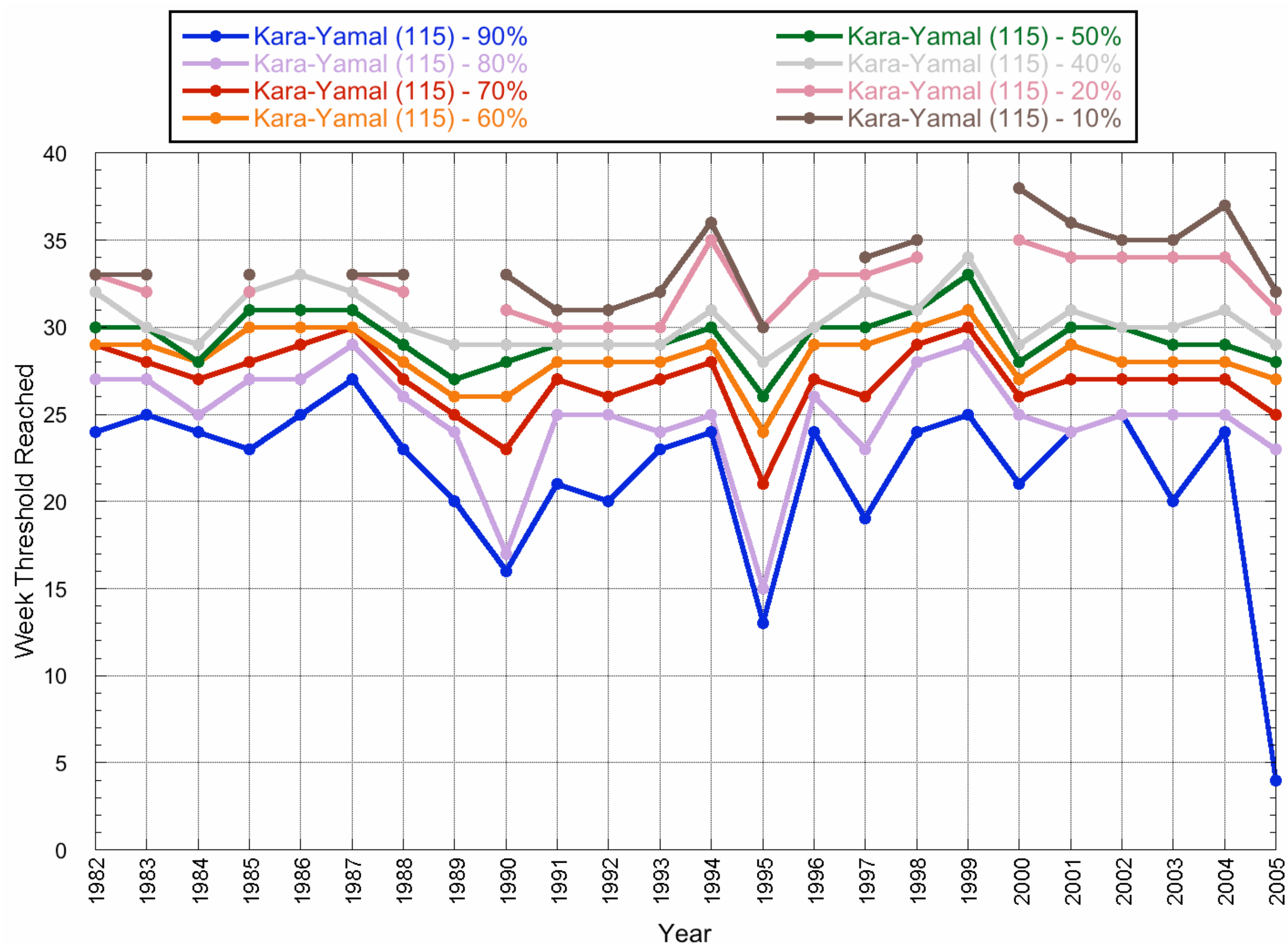
Chukchi and Bering display largest positive trend in SWI

Sea Ice Variability in 100-km Coastal Kara Sea



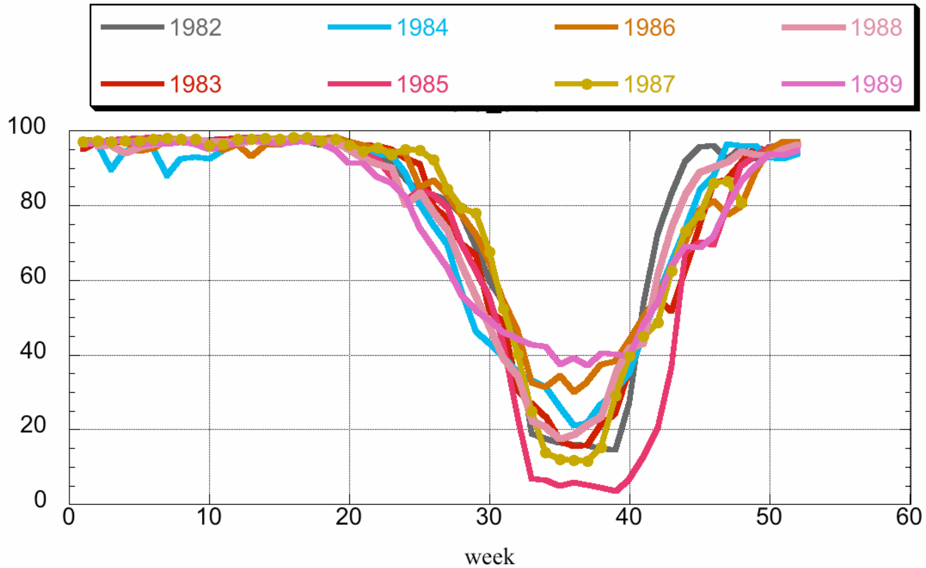
Displayed as normalized ice concentration anomalies

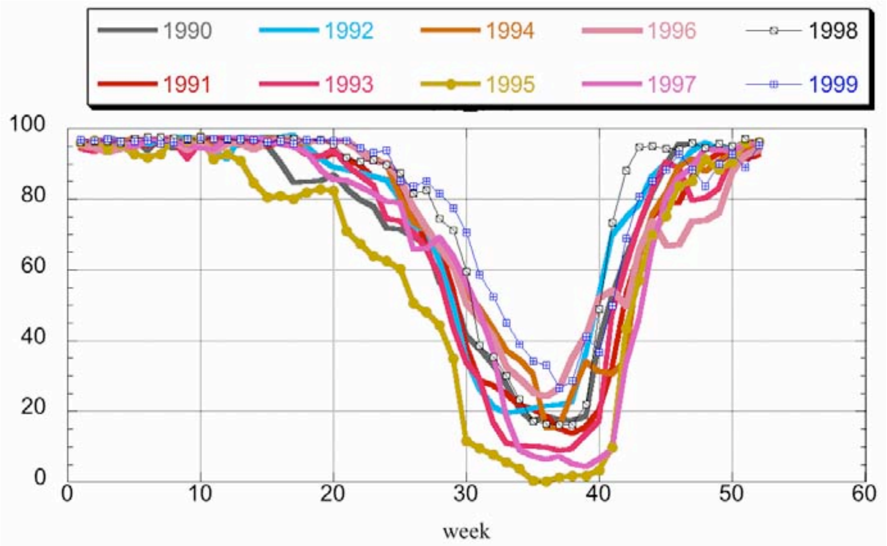
Sea Ice Thresholds Vary Similarly

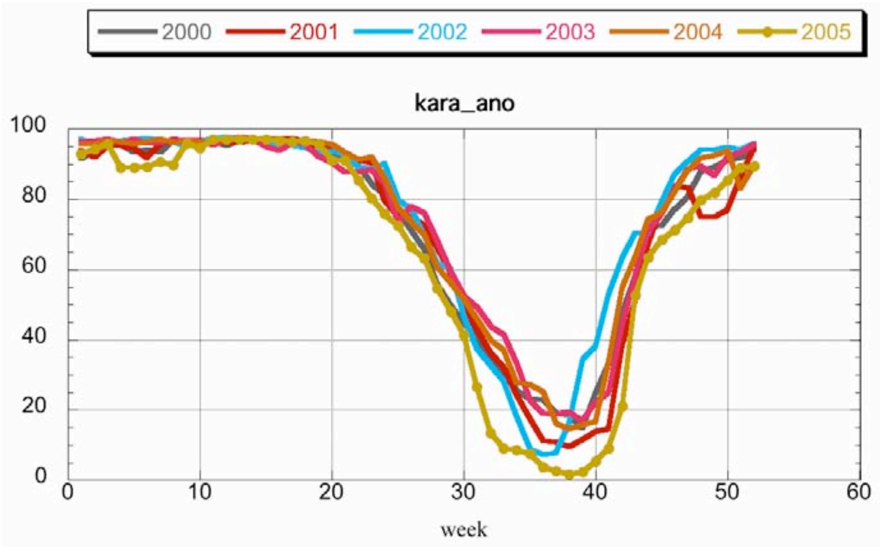


No point shown if threshold not reached

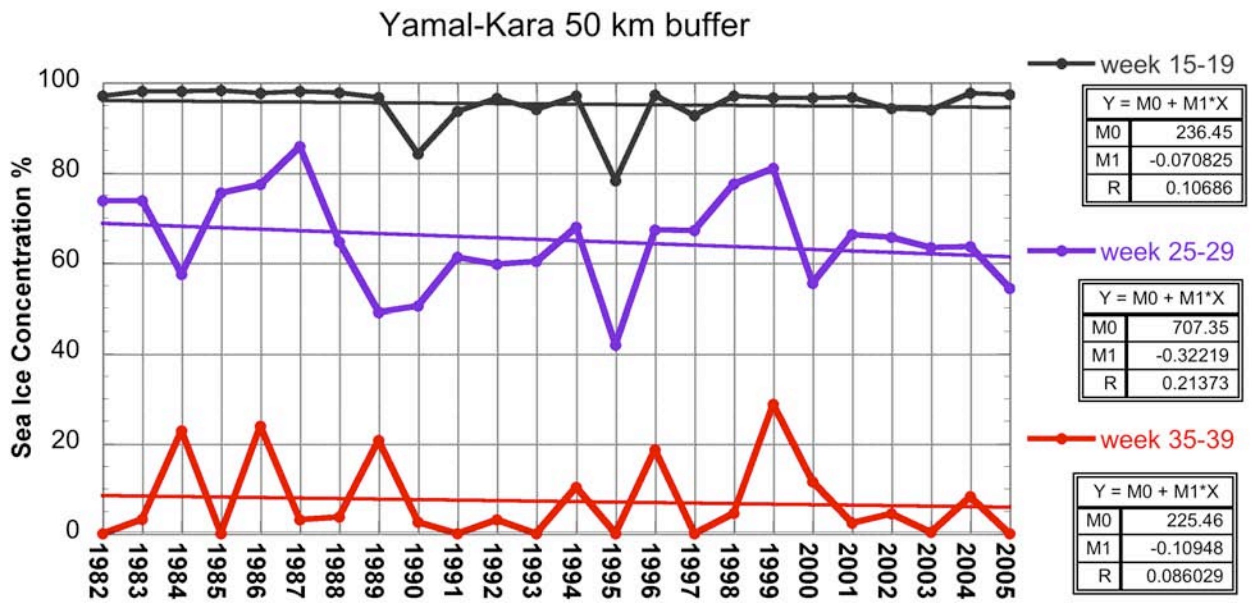
Annual Cycle Yamal-Kara Sea Ice







Sea Ice Concentration in Yamal-Kara

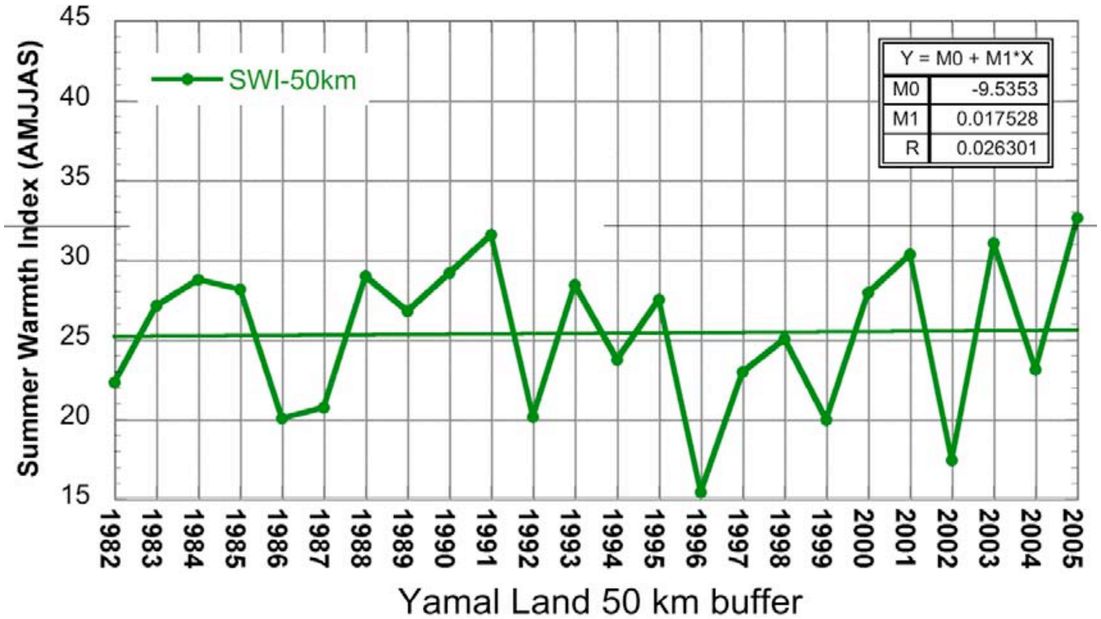


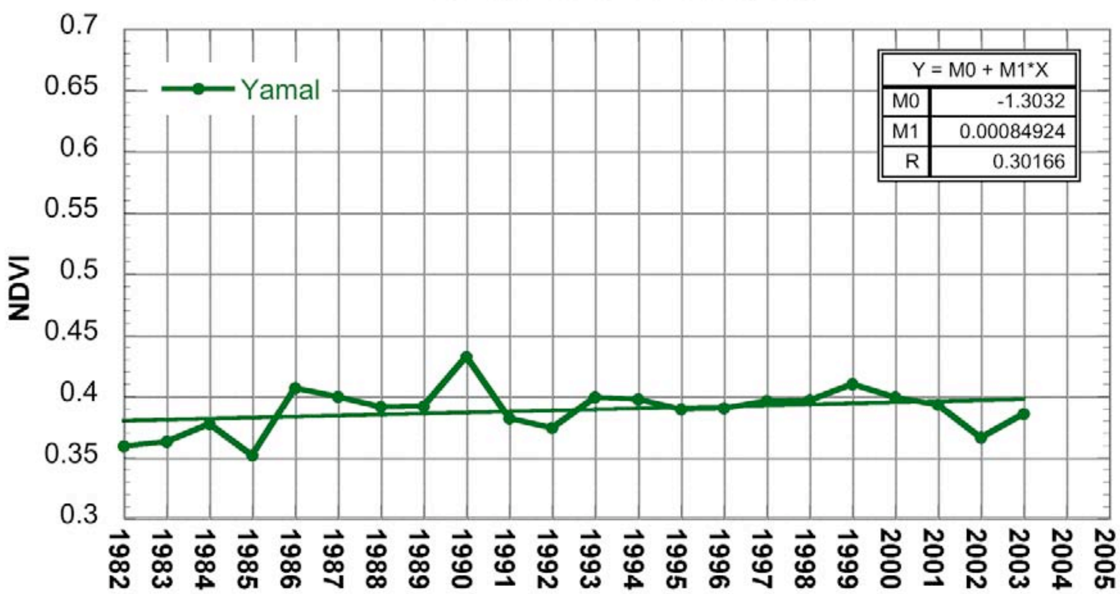
Apr-May

Jun-Jul

Aug-Sep

Yamal Region SWI & NDVI: small increase





Kara-Yamal

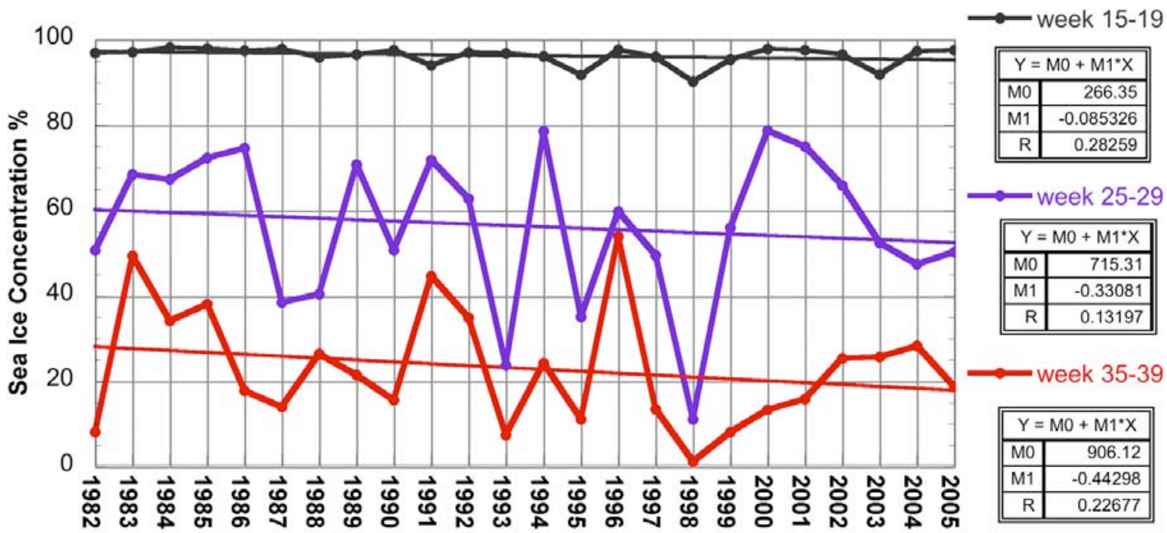
Decreasing Ice

SWI Variable

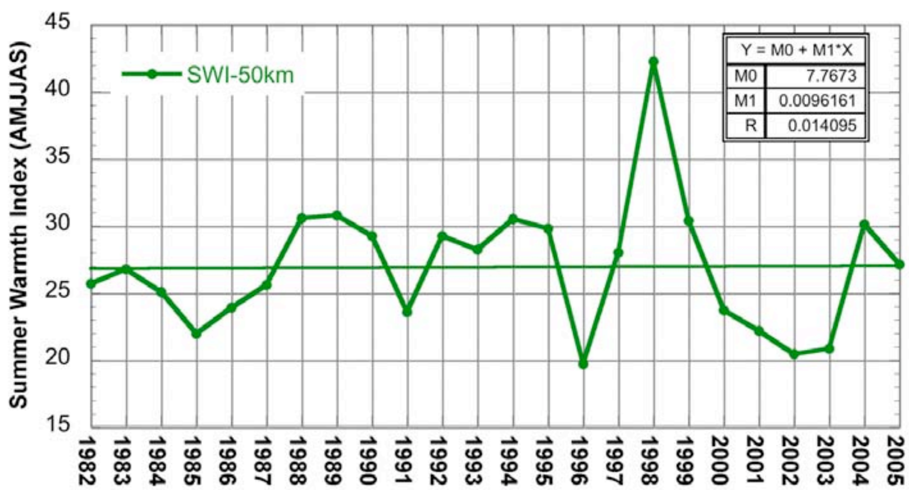
NDVI small trend

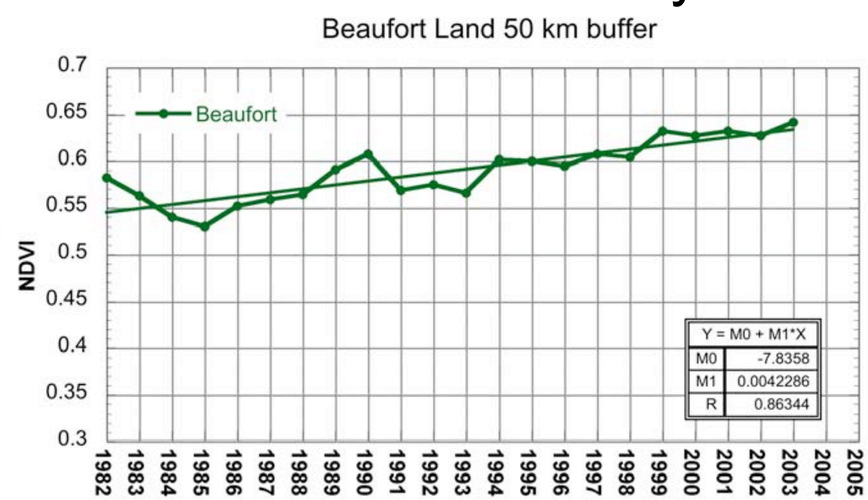
- SWI negatively correlated with sea ice
- NDVI not correlated to ice or SWI
- Correlated with NAO variability

Contrast to Beaufort Region Sea Ice, SWI & NDVI

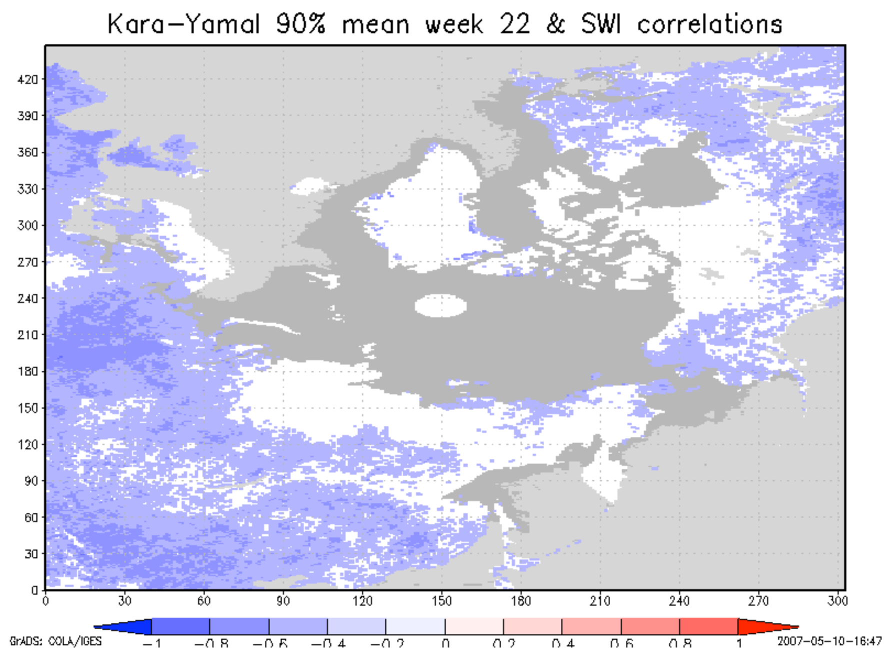


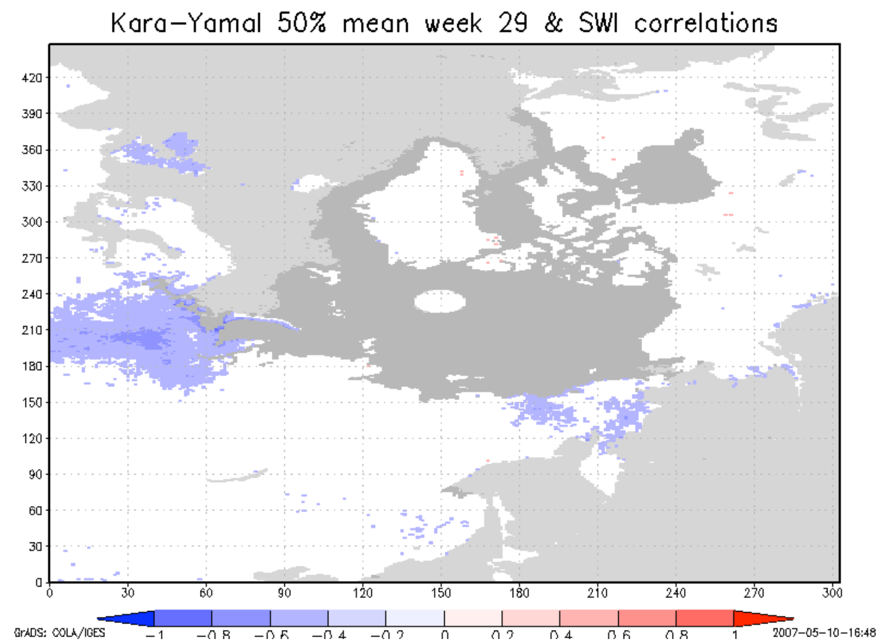
Decreasing Ice
SWI Variable
NDVI increasing
SWI negatively correlated with sea ice
NDVI not correlated to ice or SWI
Correlated to Pacific Variability





Correlations Between Ice & SWI
Kara-Yamal

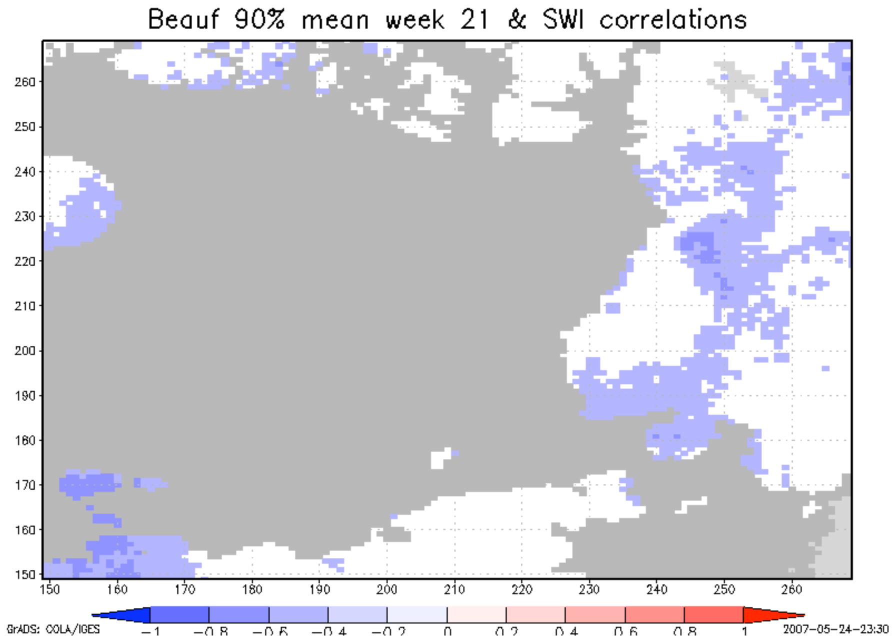




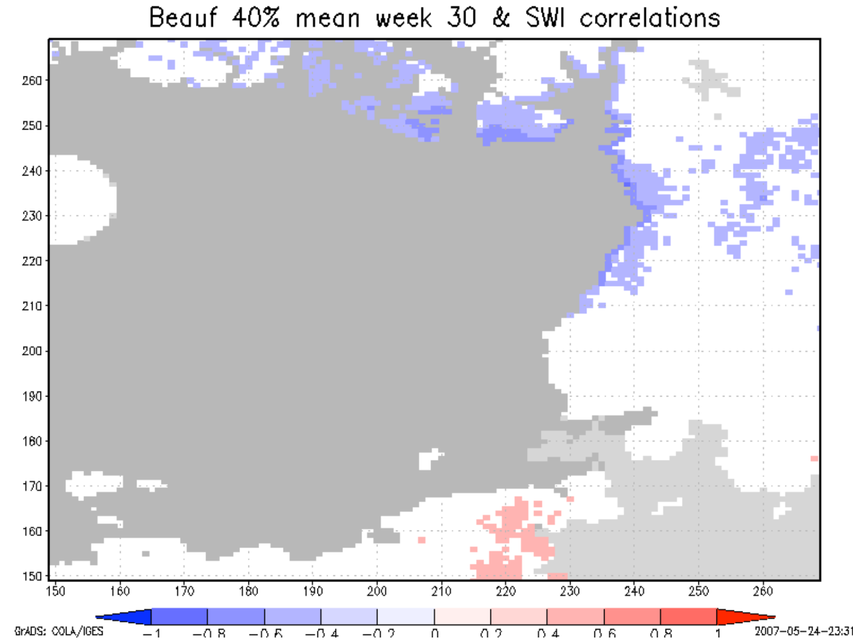
- **Circulation influences are more hemispheric in early summer (early June) and then more local in late July**

Western Arctic Region

Late May



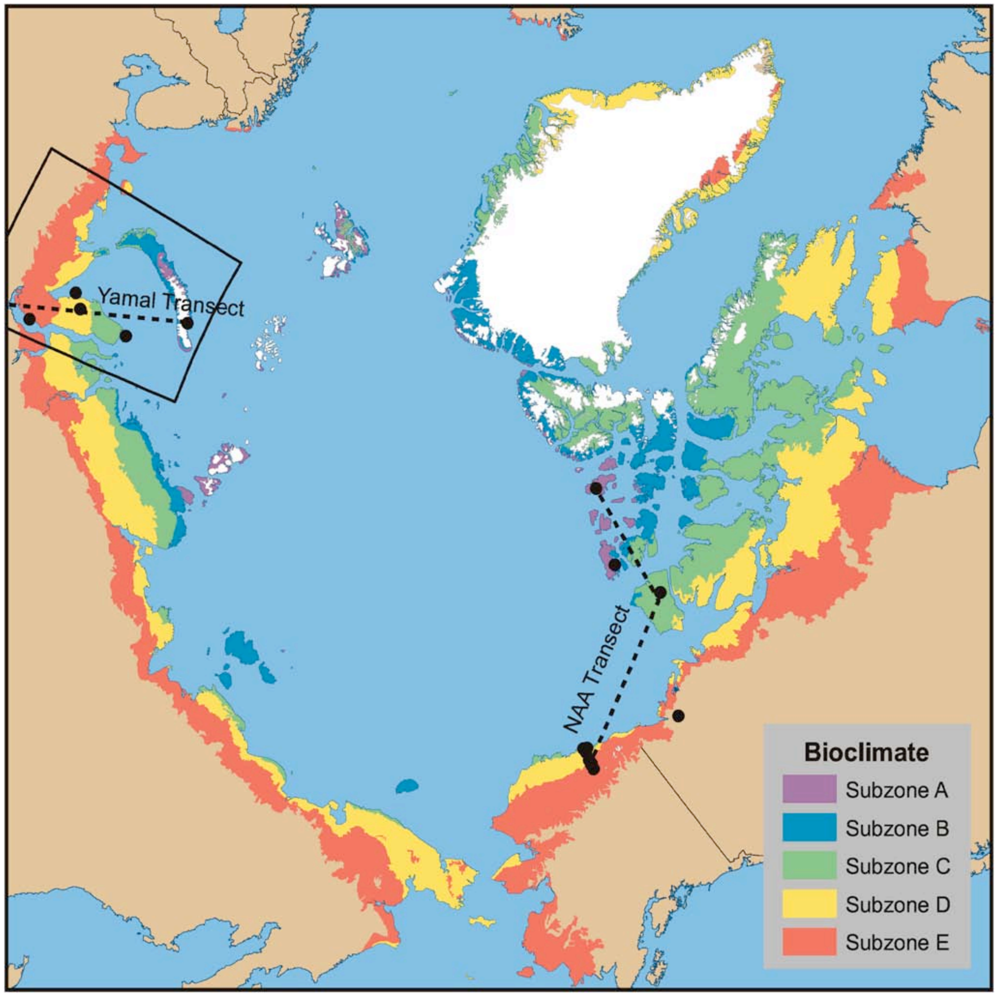
Late July



DJFM indices	Sea ice Week 25-29 avg	SWI	NDVI
NAO	-----	**0.43** (95%)	-----
NAM	-----	0.30	0.30
NPI	-----	-----	0.12
ENSO	**-0.51** (99%)	0.37	-0.12
Siberian High	0.23	-0.27	**-0.43** (95%)
PDO	-0.26	-----	-0.33
Summer Indices			
SWI	**-0.60** (99%)	X	
Ice	X		
NDVI	-----	-----	X

- **Previous winter ENSO index negatively correlated with early summer ice**
- **SWI is negatively correlated with early summer ice (i.e. Less ice is associated with a warmer growing season)**
- **Max NDVI and SWI were not directly related to each other but are with SH & NAO, respectively.**

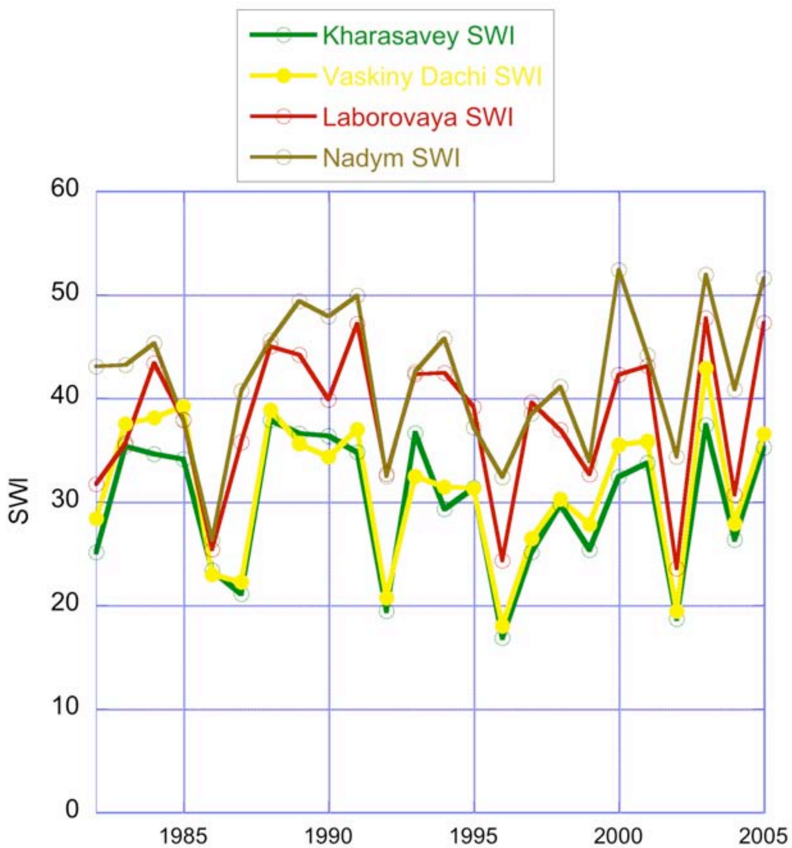
Tundra Vegetation Divisions in Arctic



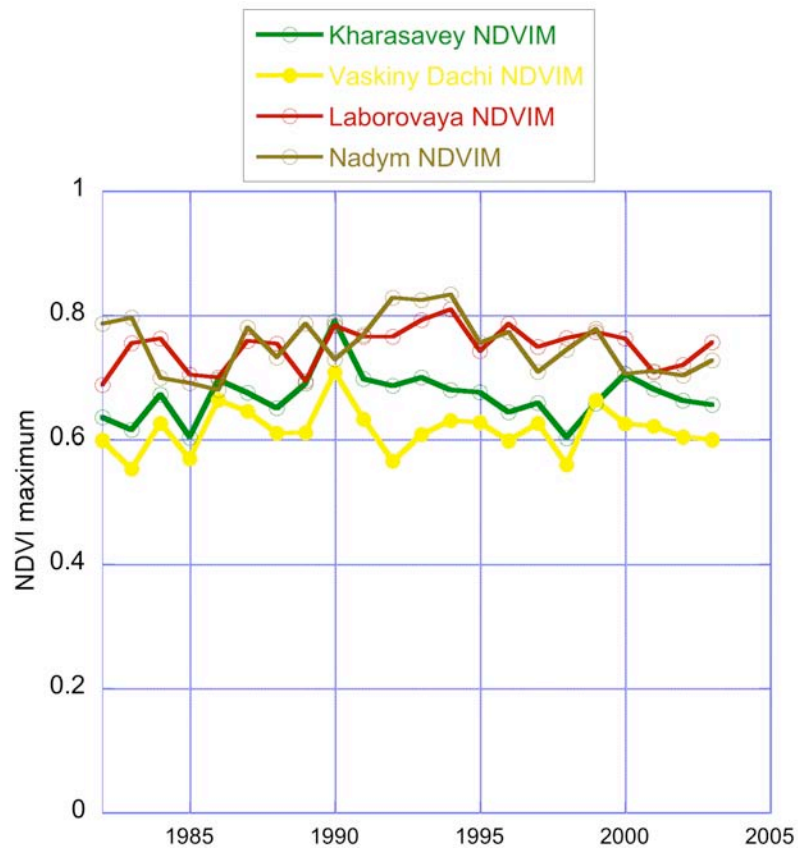
Subzone A: Cushion forbs, mosses, lichens
Subzone B: Prostrate dwarf shrubs
Subzone C: Hemi-prostrate dwarf shrubs, sedges
Subzone D: Erect dwarf shrubs, sedges, mosses
Subzone E: Low shrubs, tussock sedges, mosses

Bioclimate Subzone Map showing transects where ground observations taken

Yamal-Kara Site SWI & NDVIM

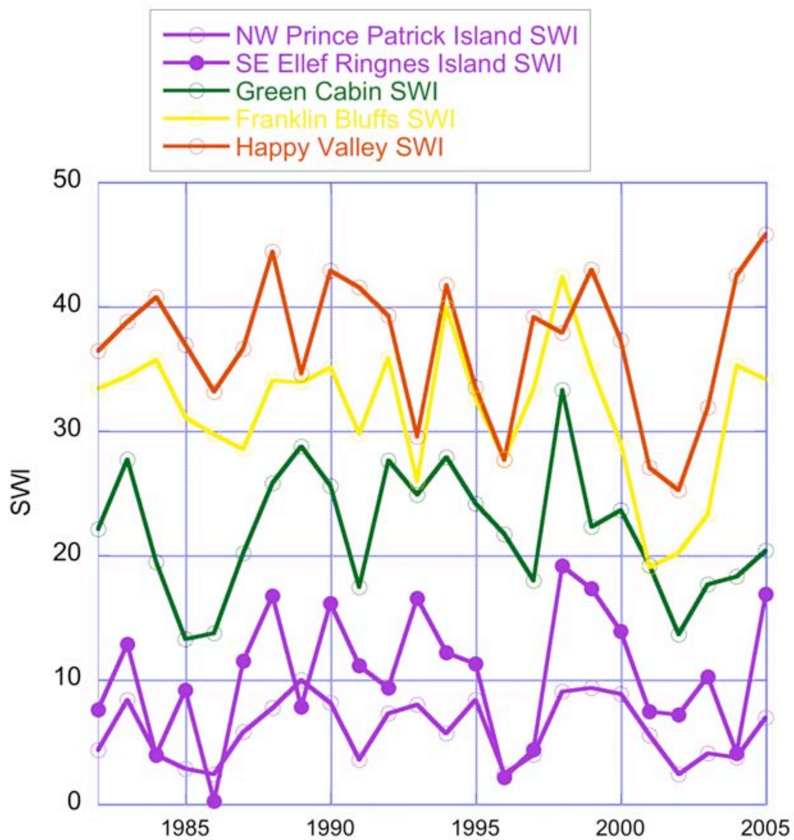


Summer warmth index

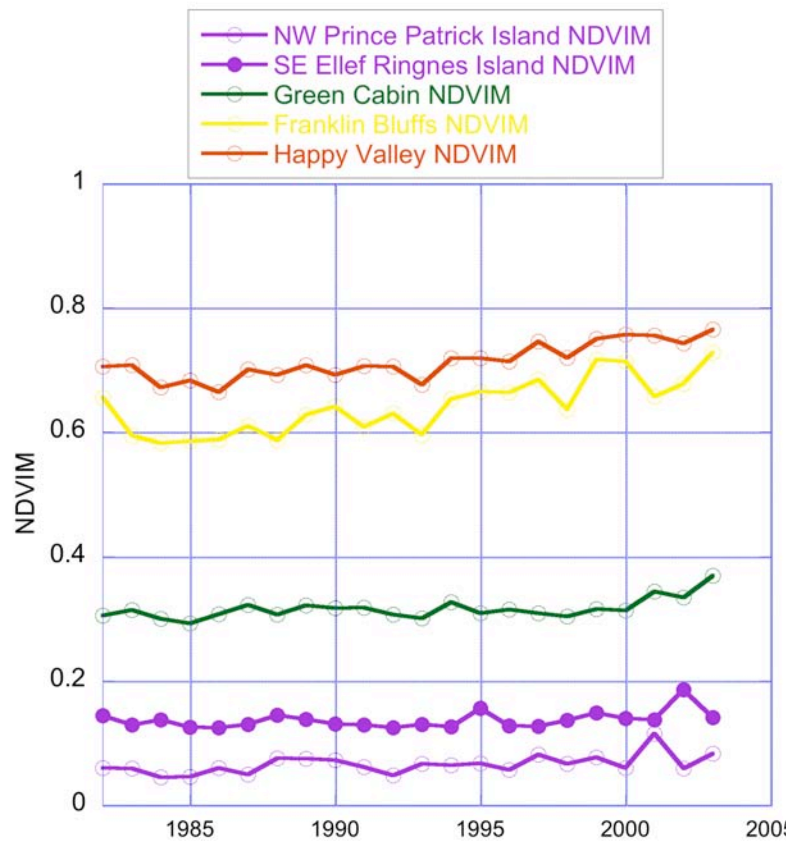


NDVI maximum

N. American Transect Site Analysis Shows Larger Gradients



Summer warmth index

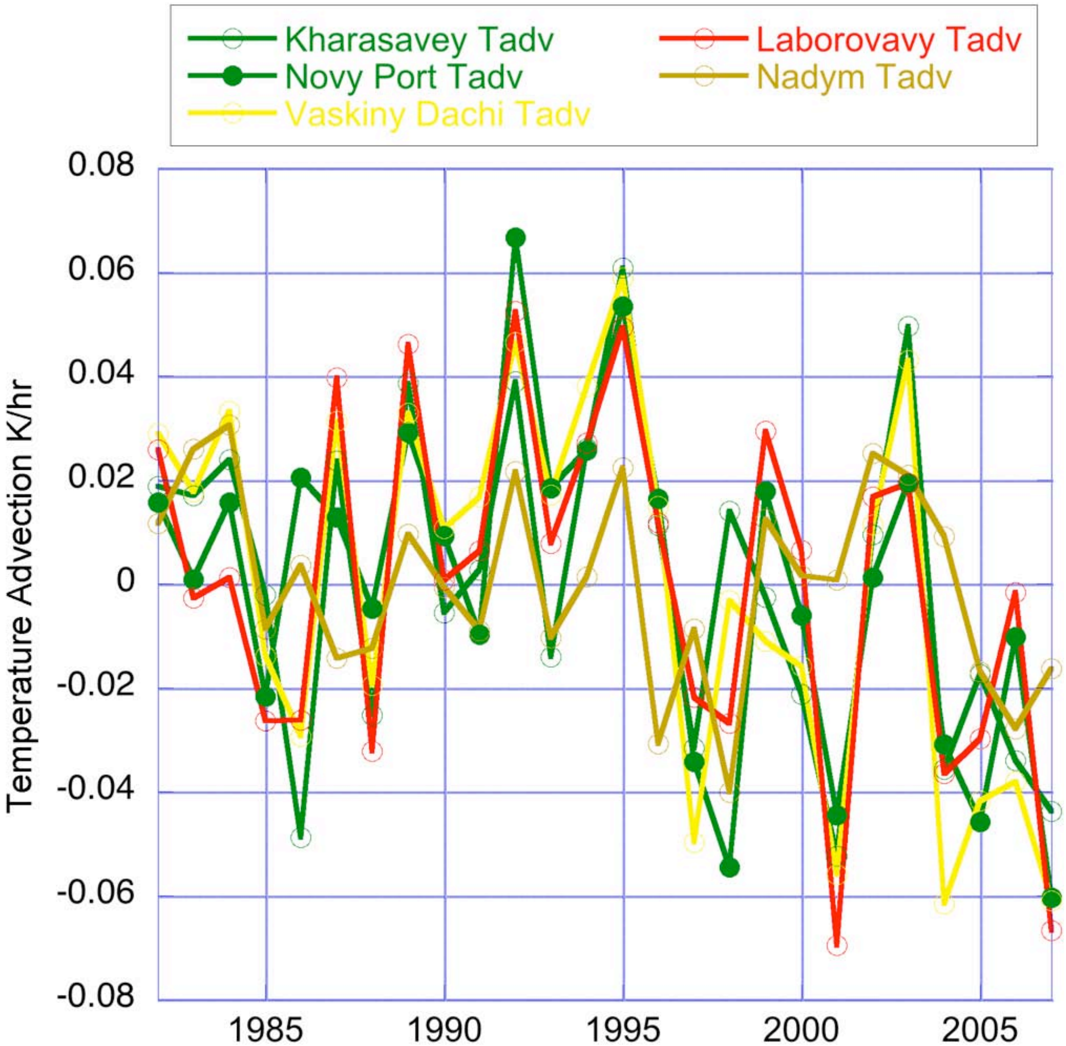


NDVI maximum

Summary Site Analysis

- Ice decreasing in both regions but NDVI increasing only in Beaufort
- June 18-Jul 22 **sea ice is negatively correlated to SWI** at each station. Less ice means warmer overall summer.
  Significant correlations **-0.42 Nadym**, **-0.43 Laborovaya**, & **-0.42 Kharasavey** in Yamal & **-0.46 Ellef Ringnes** in NA Transect.
- Ice and NDVI are not significantly correlated (Need to examine this in more creative ways!)
- SWI and NDVI are not significantly correlated (Seasonality may be confounding a simple interpretation).

Next Calculation: Working on To Understand the Climate Dynamics



Role of Temperature advection: What type of air mass does the wind directions bring? Warm or cold? How does this change with reduced sea ice? *Seasonal Evolution*

Summary & Conclusions

- **Sea ice opening up earlier is correlated with a warmer summer and this is likely due in part to large scale climate circulation anomalies from previous the winter as well as *local effects*.**
- **Kara-Yamal is more closely associated with the NAO/NAM while the Beaufort (large amplitude during 1998) with ENSO .**
- **Site scale and regional scale analysis are similar but indicate variations within a region.**

Acknowledgments

- NSF through the Arctic Synthesis
- NASA through land use and land change

Extra Slides

Positive (Negative) Productivity trend over tundra (boreal forest)

- **Trends from 1981-2005 in photosynthetic activity**
- **Green is positive and Rust is negative**
- **Increased moisture stress is impacting boreal forests**

- Goetz et al. 2005

[Bunn et al. 2007]

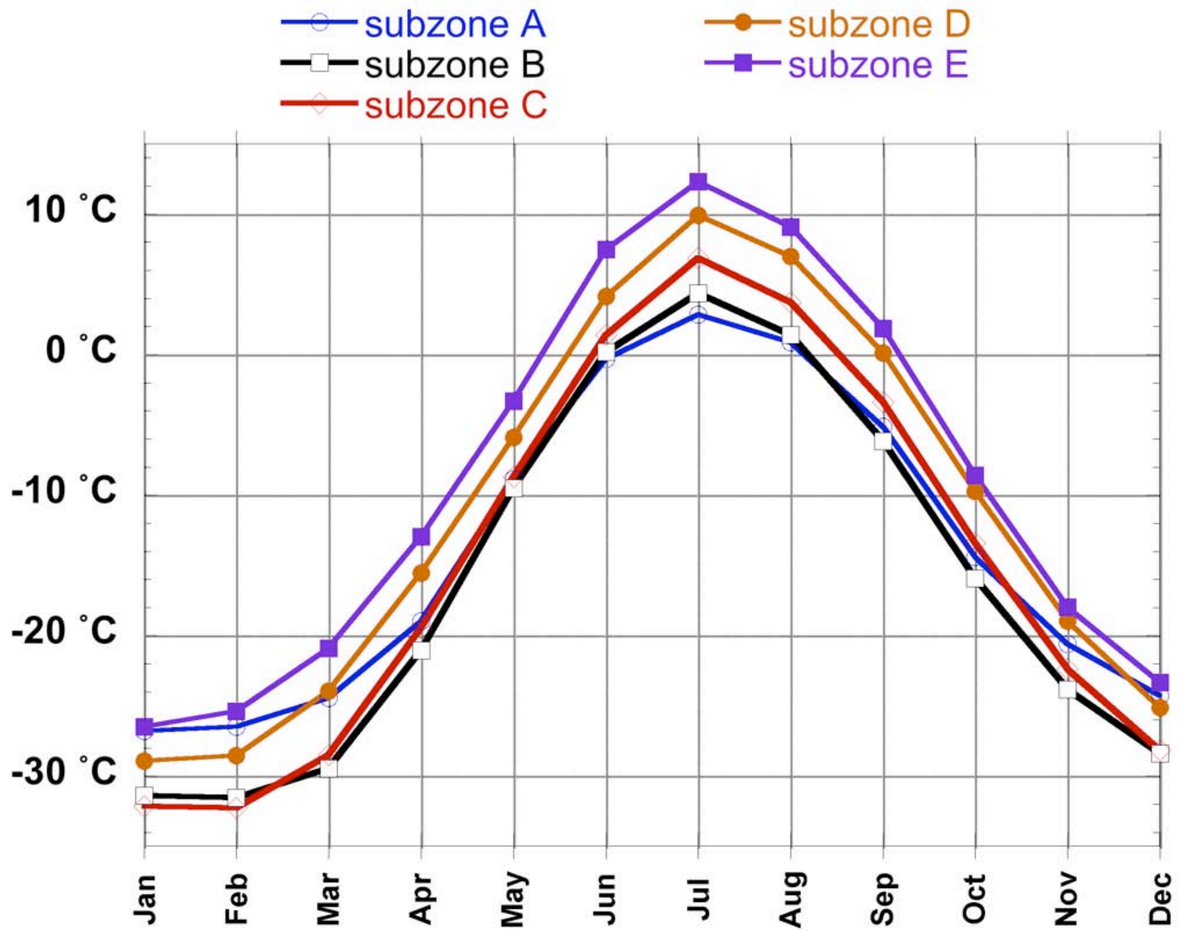
Sea Ice displays correlations

DJFM indices	Sea ice Week 25-29 avg	SWI	NDVI
NAO	**-0.50** (99%)	0.25	0.15
NAM	**-0.56** (99%)	-----	0.23
NPI	-0.35	-----	-----
ENSO	0.13	-----	-0.16
Siberian High	-----	0.15	-0.24
PDO	**0.48** (99%)	-----	-0.12
Summer Indices			
SWI	**-0.47** (98%)	X	
Ice	X		X
NDVI		-----	

- **Previous winter climate indices are negatively correlated with early summer ice (i.e. Positive phase of NAO/NAM implies less ice)**

- **SWI is negatively correlated with early summer ice (i.e. Less ice is associated with a warmer growing season)**
- **Max NDVI and SWI are not directly related to climate indices or each other**

T_S Climatology in Pan-Arctic Subzones



Summer Warmth Index (SWI) is the sum of degree months above 0˚C between April and September.

Relationship to Sea Ice

- Ice in the Yamal buffer zone (June 18-Jul 22) is negatively correlated to SWI at each station. **Less ice means warmer overall summer.**
  - -0.42 Nadym, -0.43 Laborovaya, & -0.42 Kharasavey
- Ice and NDVI are not significantly correlated
- SWI and NDVI are not significantly correlated

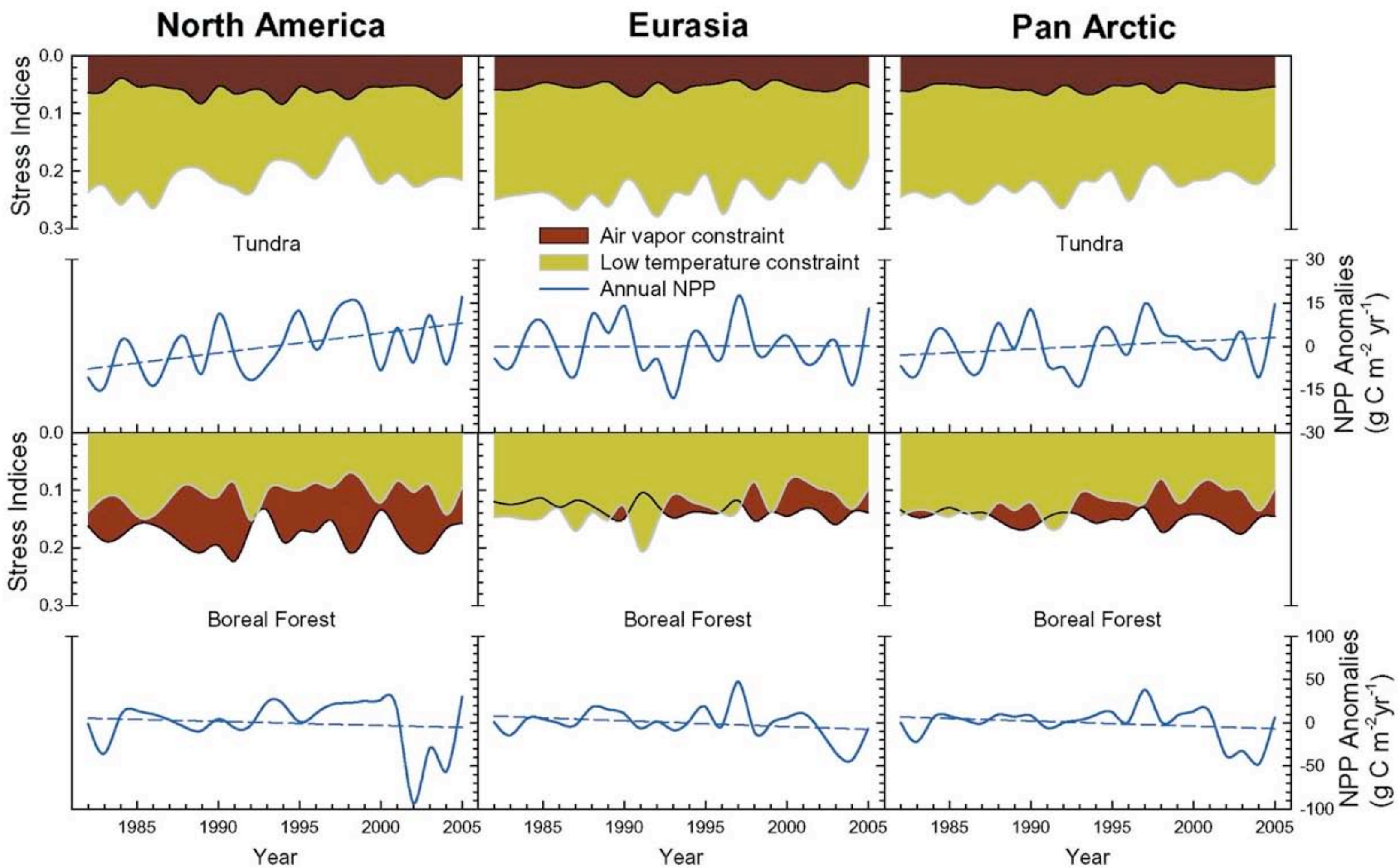
Relationship to Sea Ice

- Ice in the Beaufort buffer zone (June 18-Jul 22) is negatively correlated to SWI at each station. Similar to Yamal.
  Less ice means warmer overall summer.
  - -0.46 Ellef Ringnes (only significant cor)

Observations suggest less early summer ice means warmer but late summer less ice means cloudy and cooler.

- Ice and NDVI are not significantly correlated.
- SWI and NDVI are not significantly correlated

Consistent with Bunn et al. 2007



[Bunn et al. 2007]

Plants display strong shift with frequency in absorption

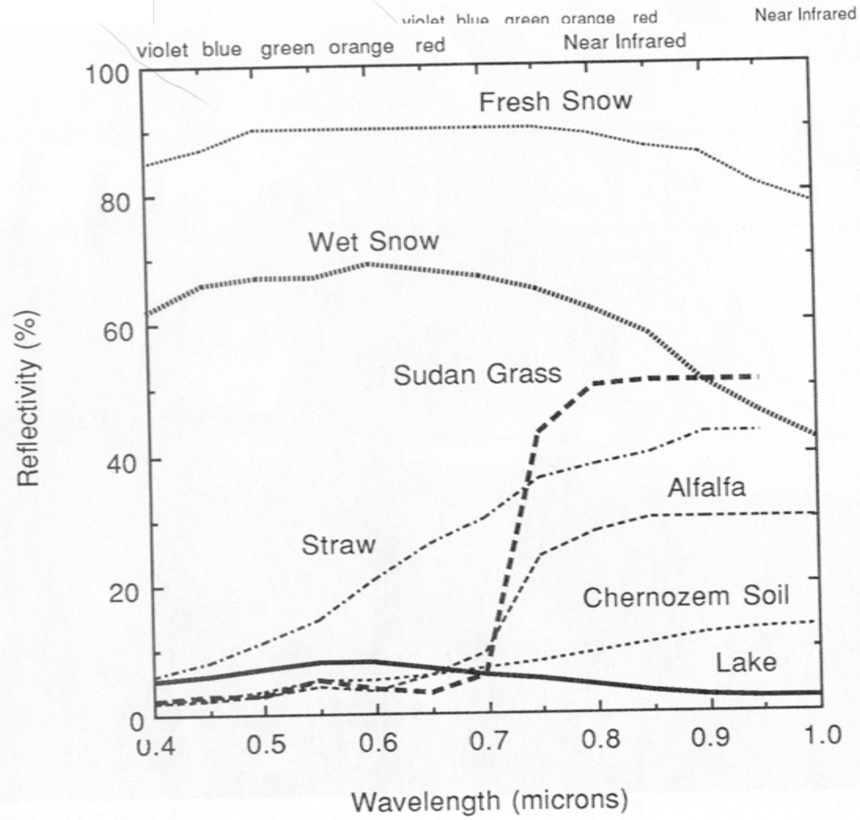


Fig. 4.5 Surface reflectivity as a function of wavelength of radiation for a variety of natural surfaces. Human eyesight is sensitive to wavelengths from 0.4 μm (violet) to 0.7 μm (red). Alfalfa and sudan grass appear green because their albedo is higher for green light (~0.55 μm) than for other visible wavelengths. [Data from Mirinova (1973).]

- **Green plants have low albedo in .4-.7 micron range where they are photosynthetically active**

[Hartmann 1994]

The Nentzy, reindeer and LCLUC

Vegetation change (shrubification):

Positive effects:

- Collect willows for firewood, tools, etc.
- Important fodder species for the reindeer.

Negative effects:

- In the south, the willows have gotten so big that the reindeer can now disappear into them and get left behind during migration.

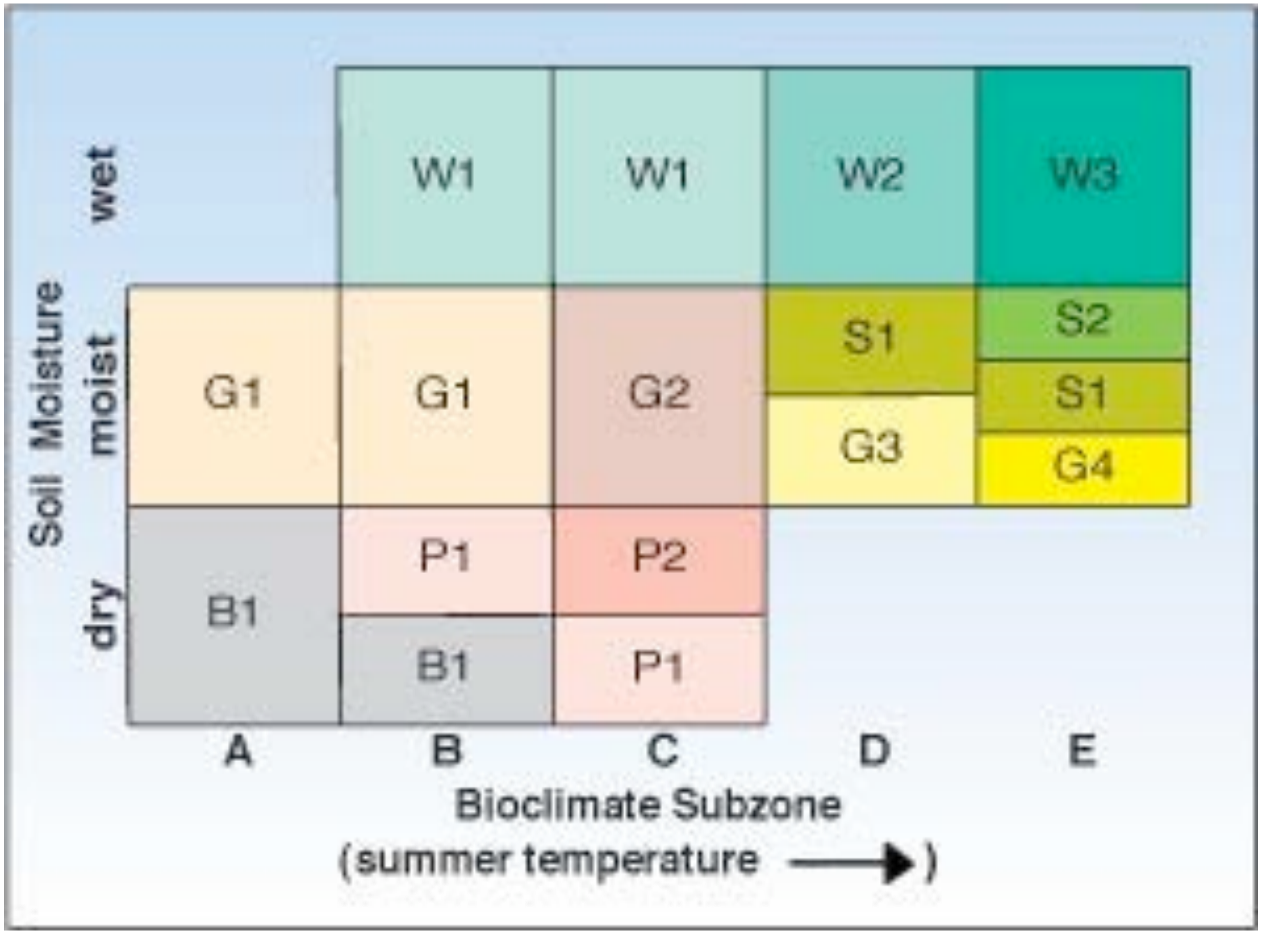
Other land-cover and land-use changes:

Interactions with extensive oil development infrastructure in the region.

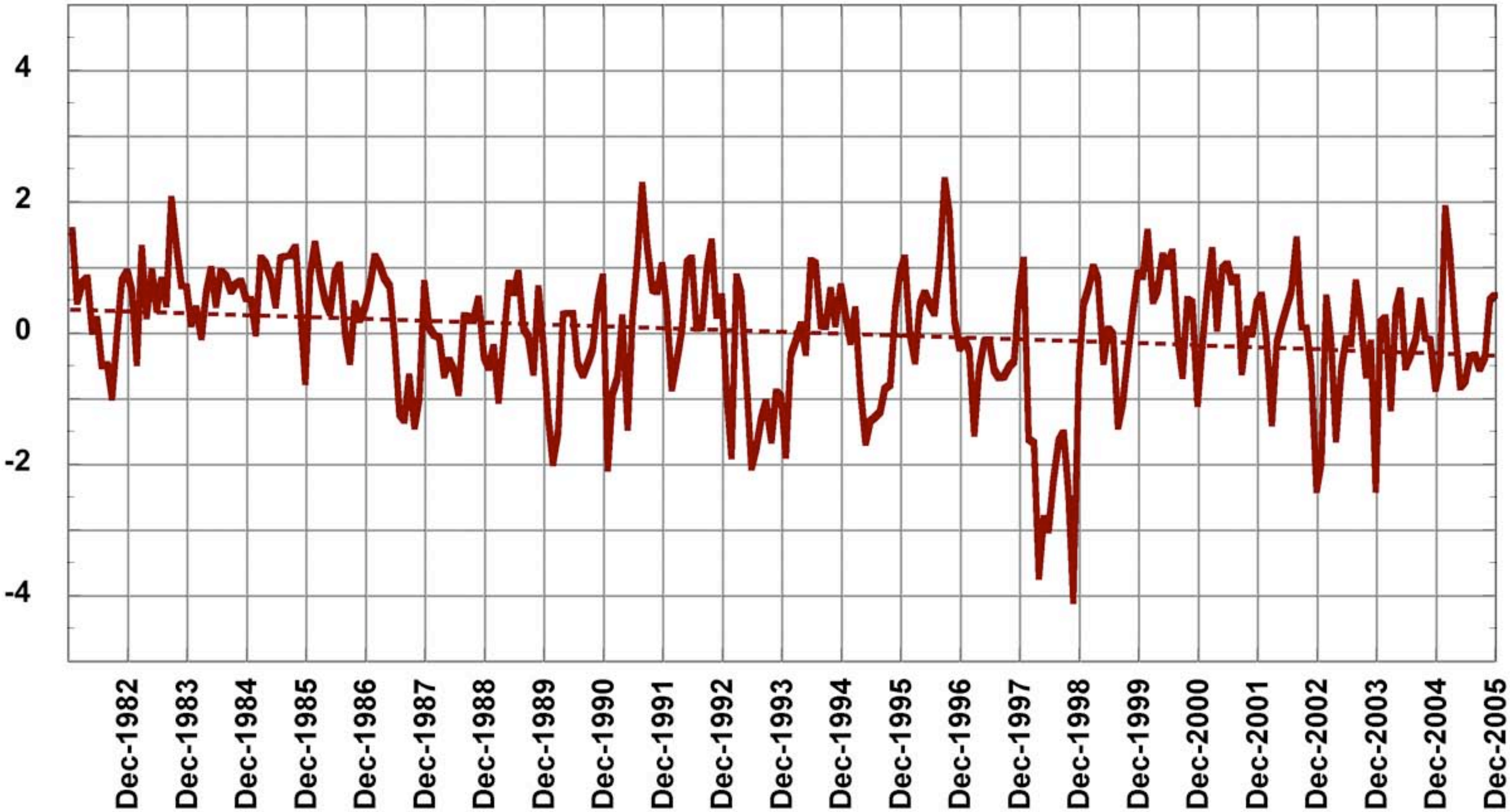
Restriction of forage to smaller regions, overgrazing, desertification, grassification.

Photos by Bruce Forbes

Within each Subzone there are variations due to moisture availability

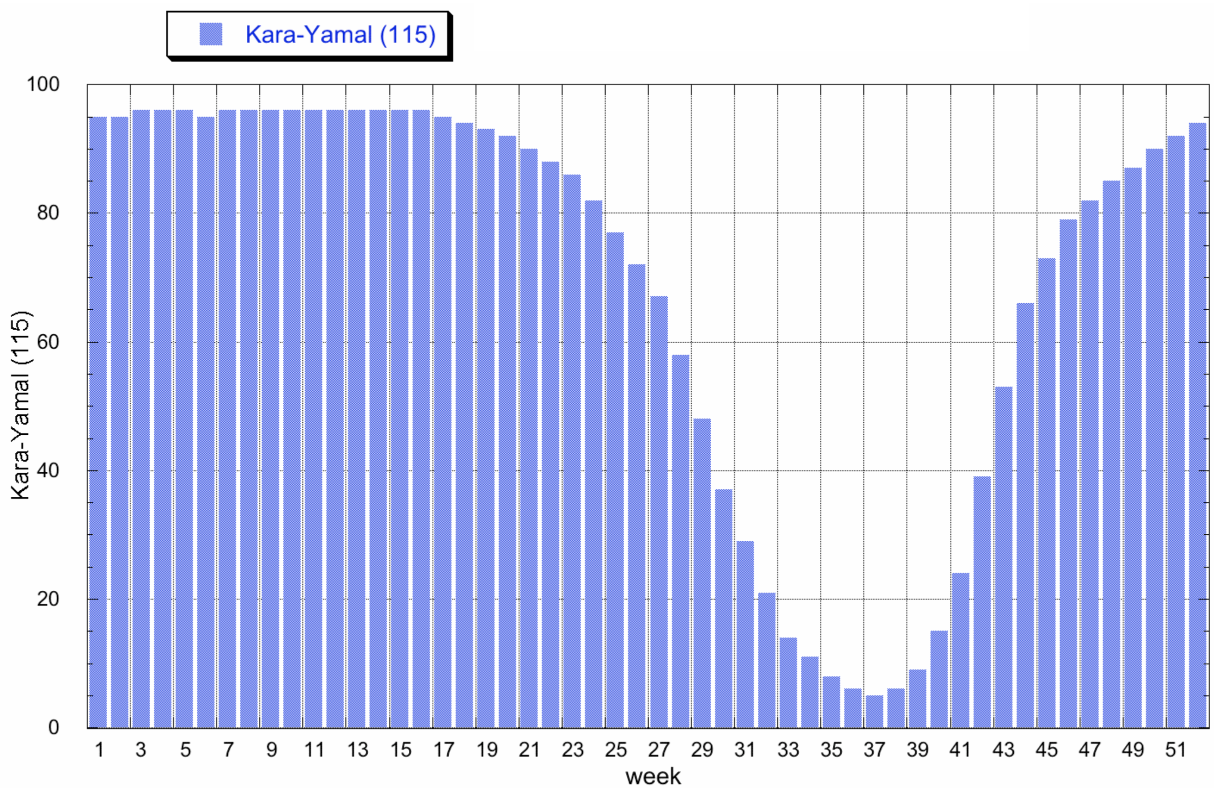


Sea Ice Variability in 100-km Coastal Beaufort Sea



Displayed as normalized ice concentration anomalies

Weekly Ice Climatology (1982-2005) in 50km Buffer of Yamal-Kara

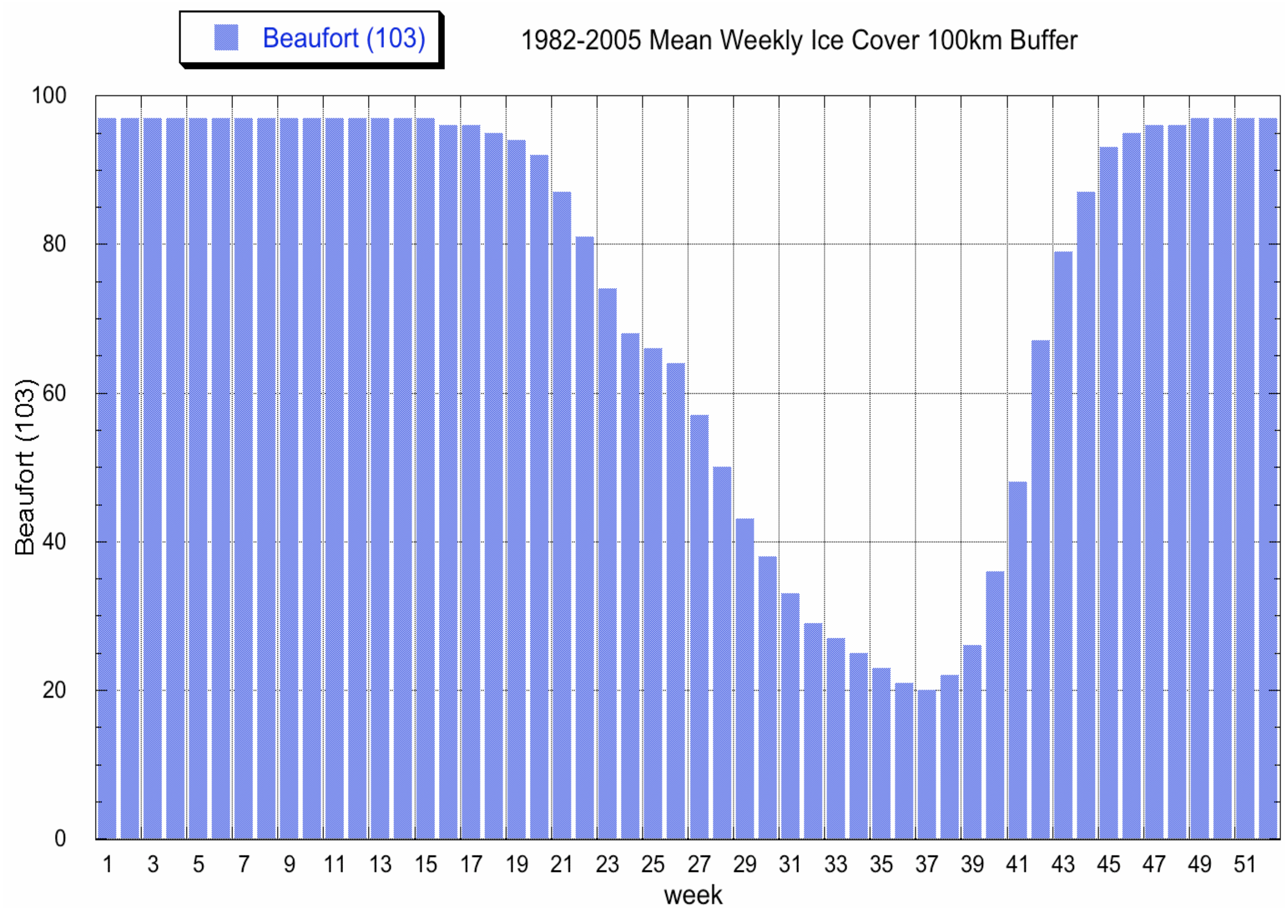


- Ice falls below 90% in week 21 and below 10% in week 35

17	**23-Apr**
18	**30-Apr**
19	**7-May**
20	**14-May**
21	**21-May**
22	**28-May**
23	**4-Jun**
24	**11-Jun**
25	**18-Jun**
26	**25-Jun**
27	**2-Jul**
28	**9-Jul**
29	**16-Jul**
30	**23-Jul**
31	**30-Jul**
32	**6-Aug**
33	**13-Aug**
34	**20-Aug**
35	**27-Aug**

Weeks for reference

Weekly Ice Climatology (1982-2005) in 50km Buffer of Beaufort



- Ice falls below 90% in week 21 and does not typically fall below 10%