Greening of Arctic tundra is linked to warming summer land temperatures and sea-ice declines

Uma Bhatt[1], Donald A. Walker[2], Martha Raynolds[2], Josefino Comiso[3], Howard Epstein[4], Jiong Jia[5], & Rudiger Gens[6]

[1] Geophysical Institute & Dept. Atmospheric Sciences at U. Alaska Fairbanks (UAF), [2]Institute of Arctic Biology at UAF, [3]NASA Goddard Space Flight Center, [4]Dept. of Environmental Sciences at University of Virginia, [5]START Regional Center for Temperate East Asia, Institute of Atmospheric Physics, Beijing China, [6]Alaska SAR Facility & Geophysical Institute at UAF

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Main Results

- **Declining sea ice trends are found with generally increasing NDVI and increasing Summer Warmth Index (SWI)**
- **Correlations indicate that below normal sea ice is found with above normal integrated NDVI and SWI**
- **As sea ice declines and the land warms, the future of the coldest bioclimate subzone vegetation is in question**

Motivation & Methods

GOAL: Understand tundra-climate relationships

- **80(60)% of the Arctic tundra (3.2 million km²) is within 100(50) km of ocean**
- **Positive trend in NDVI identified over Alaska, N. America & the Arctic, suggests enhanced photosynthesis. Are these Arctic tundra vegetation changes associated with (forced by) changes in sea-ice?**

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

NDVI = (NIR-R)/(NIR+R) NIR: spectral reflectance in near-infrared band (0.725-1.1 µm) & R: red chlorophyll absorbing portion of spectrum (0.58-0.68 µm)

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

TIME: January 1982 to December 2007 (25 years, monthly & weekly) with NDVI to 2006.

AREA AVERAGING: Construct indices of SIC & T_s for 50 km regions in Bioclimate Subzones (see reference 2) and Treshnikov divisions.

ANALYSIS: Examine the variability and trends regionally and on pan-arctic scales. Correlate detrended time series.

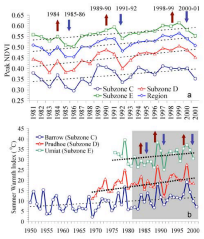


Figure 1 Time series of peak NDVI derived from 8-km resolution AVHRR data from 1981 to 2001 (a) and SWI over the past 22–50 years (b) among bioclimate subzones. Dashed lines are linear regressions. The shaded area highlights the period of SWI covered by NDVI data.

[Jia et al. 2003, Reference 1]

NDVI trends are positive (weak) in N. America (Eurasia) as sea ice declines and land temperatures warm

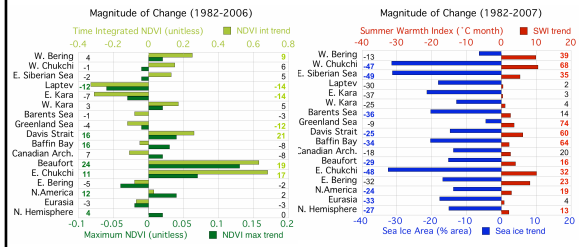
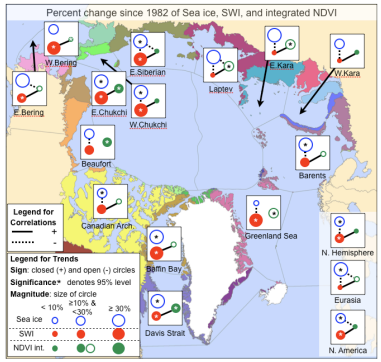


Figure 2. Magnitude of maximum NDVI (dark green), integrated NDVI (light green), sea ice concentration (blue), and SWI (red) trends from 1982-2007 in 50-km coastal zones of Arctic. Sea ice trends are based on a three-week period centered on the week when mean concentrations are 50%, the timing of which varies regionally. Percent trends numbers over the 1982-2007 period are shown for each region and all four variables. Statistically significant trends are identified by colored bold percent trend values.

- Large sea ice declines throughout Arctic with a -9 to -49% decline over the 1982-2007 period.
- SWI increases are variable from 2-74% between 1982-2007.
- Beaufort and E. Chukchi display largest positive Max NDVI and TI-NDVI trends. Laptev and E. Kara display largest negative Max NDVI and TI-NDVI trends.

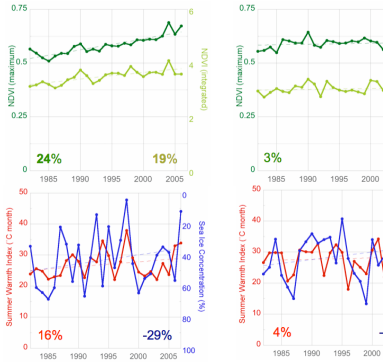
Variability: Lower than normal sea ice is found with above average SWI & TI-NDVI



- Linearly detrended correlations identify covariability between sea ice, SWI, and TI-NDVI.
- Correlations vary in strength but are of the same sign for all regions.
- Spring sea Ice negatively correlated with SWI & TI-NDVI.
- SWI and TI-NDVI significantly positively correlated in most regions.
- Sea ice link to SWI stronger than to TI-NDVI.

Figure 3. Regional trends of sea ice concentration, SWI, and integrated NDVI shown as percent change since 1982. Regions are delineated according to floristic provinces and Arctic sea boundaries in 50-km zones along the land-ocean interface. SWI and NDVI trends are shown for the May-September period. Sea ice trends are based on a three-week period centered on the week when mean concentrations are 50%, the timing of which varies regionally. Significant correlations are shown by solid (+) and dashed (-) lines. Sea ice concentration has decreased and SWI increased throughout the Arctic. NDVI trends vary, but in general have been increasing (decreasing) in the North America (Eurasia).

Beaufort and W. Kara display large contrasts



- Large sea ice declines in both regions (-29% & -25%).
- NDVI increasing in Beaufort much faster than in W. Kara.
- Beaufort SWI trend is larger than W. Kara SWI trend.
- Why the different NDVI responses when ice losses are similar?

Figure 4. Trends in sea ice, land temperatures and NDVI in the Beaufort (left), and W. Kara (right) from 1982 to 2007. Sea ice concentration, (% area, blue lines) is based on the climatological 50% concentration period, which is 2-22 July for the Beaufort, and 9-29 July for the W. Kara. Summer warmth index (SWI, red lines) is the sum of mean monthly temperatures above freezing (˚C month). Maximum NDVI (dark green) and integrated NDVI (light green) are unit-less greenness indexes derived from AVHRR satellite data. Percent change in variable from 1982 to 2007 (2006) is shown by the numbers in the plots, where trends significant at the 95% level or greater are in bold.

Coldest bioclimate subzone will diminish as sea ice declines & SWI increases

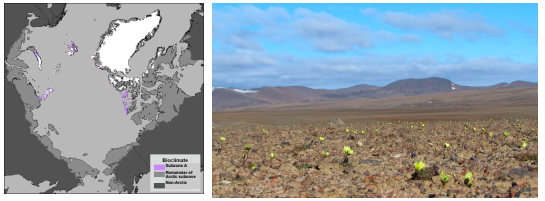


Figure 5. (a) Location of bioclimate subzone A within the circumpolar Arctic (Arctic Geobotanical Atlas: http://www.arcticatlas.org/atlas/cavm/cavmbz/bza.shtml, 2 March 2009. (b) Typical subzone A landscape at Isachsen (Photo D.A. Walker).

- The coldest subzone (A) covers about 2% of the Arctic and is confined to areas where the mean July temperature is less than 2-3 ˚C. These low summer temperatures are linked to the presence of near-shore sea ice.
- Ground truth needed to map baseline measurements of biomass in the Arctic. Field work is also necessary in order to understand the complex relationships between climate and vegetation and to validate remotely sensed data.

Conclusions

- **Correlations ≠ causality: However, our correlations are consistent with observational studies that document the well-known major cooling effect of sea ice on adjacent land masses[3].**
- **Sea ice has declined throughout Arctic, summer land surface temperatures have warmed to varying degrees and vegetation has generally become greener but there are exceptions.**
- **Trends and correlations are consistent between sea ice, NDVI and SWI.**

References

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