The Greening of the Arctic IPY Project:
Changes in Arctic vegetation observed from space are linked to retreating sea-ice and warmer land temperatures

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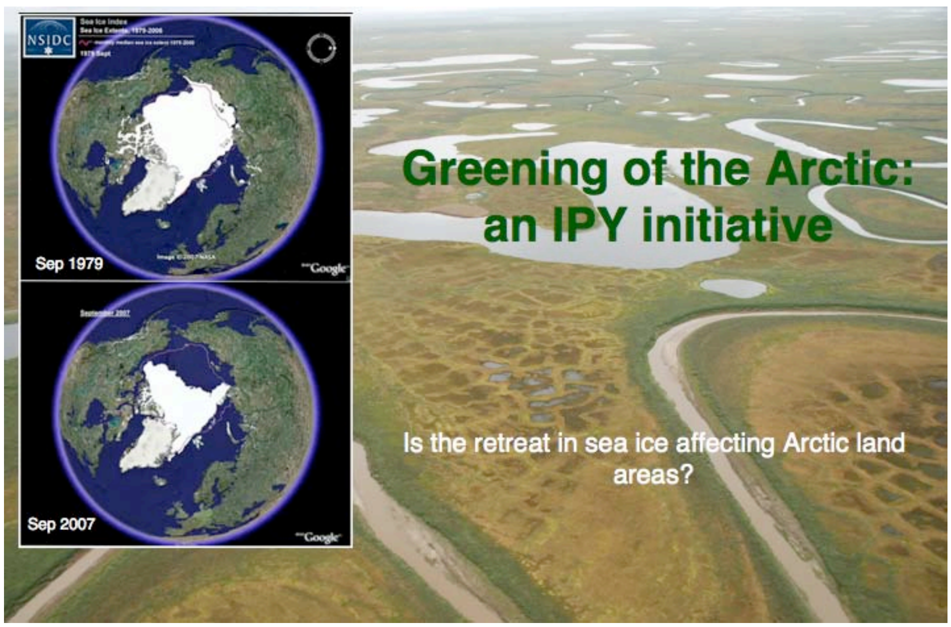

Summary statements:

- **From 1982 to 2007, late-spring coastal sea ice declined and summer land temperatures increased along all Arctic seacoasts.**
- **The productivity of Arctic tundra vegetation is coupled to summer land temperatures and late-spring sea-ice concentrations.**
- **The strongest greening has occurred in northern Alaska and Canada.**
- **Coldest ecosystems will vanish if summer sea ice goes away.**

Longer Abstract with references:

Models have predicted that the retreating sea ice should affect the temperature and ecosystems of adjacent lands (e.g., Lawrence et al. 2008). Our study examines the observed patterns of sea-ice, land temperatures, and an index of greening during the period 1982-2007, within a 50-km band along the coastlines of 14 Arctic seas (Fig. 1).

Coastal sea ice declined along all coasts (average of 27% for the northern hemisphere as a whole; (Bhatt et al. 2008a, b; Fig. 1, bottom blue bar). The largest declines were along the northern Beringia region including the W. Chukchi, E. Chukchi, and E. Siberia seas (-48%, -47%, and -49% respectively). This portion of the Arctic saw large areas of ice retreat in 2005 and 2007. The smallest decline was in the Greenland Sea (-4%) where the eastern coast of Greenland receives ice that is flushed out of the Arctic basin by the Trans-Polar drift.

Land temperatures as measured by the summer warmth index (sum of the monthly mean temperatures that are above freezing) increased 13% for the northern hemisphere as a whole. However, the coastal areas of the North America Arctic have experienced 19% increase in land temperatures while Eurasia experienced only a 4% increase. The largest increases occurred in the Beringia region (E. Siberia +35%, W. Chukchi +68%, W. Bering +39%, and E. Chukchi +39%) and in the Greenland, and Baffin Island regions (Greenland Sea +74%, Baffin Bay +64%, and Davis Straight 60%). The smallest increases were seen along the northern coast of Russia (Laptev Sea +2%, E. Kara Sea, +3%, and W. Kara Sea +4%.

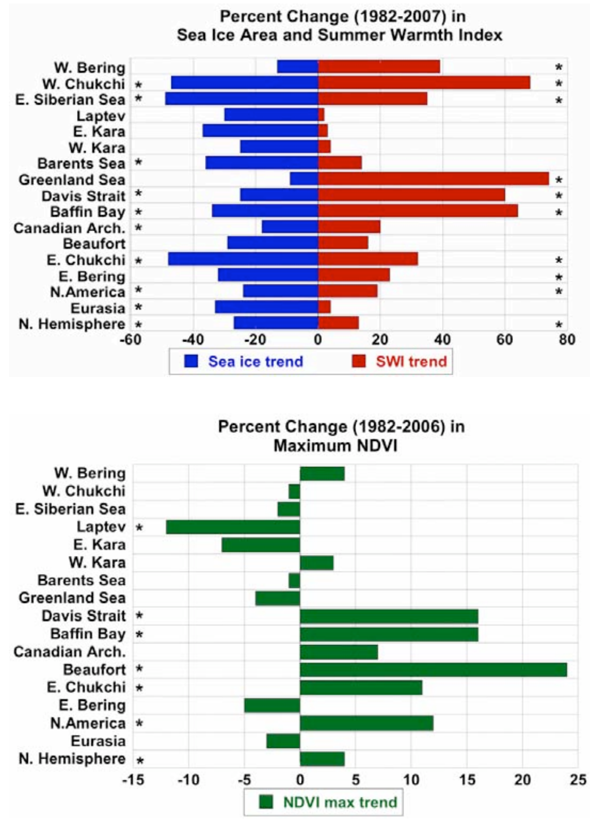

Fig. 1. Top left: Percentage change in sea-ice area in late spring (when the long term mean 50% concentration is reached) during 1982-2007 along the 50-km-seaward coastal margin in each of the major seas of the Arctic using 25-km resolution SSMI passive microwave Bootstrap sea-ice concentration data (Comiso and Nishio 2008). Top right: Percentage change in the summer land-surface temperature as measured by the summer warmth index (SWI = sum of the monthly mean temperatures above freezing (˚C mo)) based on AVHRR surface-temperature data (Comiso 2003). Bottom: Percentage change in greenness as measured by the maximum Normalized Difference Vegetatin Index (NDVI) based on biweekly GIMMS NDVI (Tucker et al.,2001). Asterisks denote significant trends at $p < 0.05$. Based on Bhatt et al. 2008.

Greenness was determined using the MaxNDVI, an index of the maximum greenness of the vegetation each summer that is derived from earth's reflectance in the visible (VIS) and near infrared (NIR) portions of the spectrum (NDVI = (NIR -

VIS)/(NIR + VIS)). MaxNDVI increased 4% for the coastal Arctic as a whole (Fig. 1, bottom green bar), but was variable. The largest increases were in Alaska and Canada (Beaufort Sea +24%, Baffin Bay 16%, Davis Strait 16%, E. Chukchi Sea 11%), and declines occurred mainly in northern Russia (Laptev Sea -12%, E. Kara Sea -7%, E. Siberian Sea -2%, W. Chukchi -1%) and along the Greenland Sea (-4%). Temporal analyses of these trends (not shown) generally show that within each region, periods of lower sea-ice concentration are correlated with warmer land-surface temperatures and higher NDVI values. Variations in this pattern may be due to different wind regimes, for example, on-shore vs. off shore wind regimes, or other unique conditions that are not explained by our data.

The NDVI changes are in general agreement with ground observations. For example increased shrub cover has been observed in northern Alaska and elsewhere (Tape et al. 2006), and biomass clearly increases on zonal sites along north-south bioclimate transects in North American and Russia (Walker et al. 2008a, Epstein et al. 2008). It is, however, uncertain what the remarkable changes in greenness, particularly in Alaska, mean with respect to changes in plant biomass. Ground studies of NDVI-biomass relationships suggest that over 100 g m^{-2} of plant biomass have been added to the tundra of northern Alaska within the past 25 years, but quantitative observation of temporal changes in tundra biomass are needed to corroborate the observations from space, as well as a clearer understanding of other variables affecting tundra NDVI at circumpolar scales (Raynolds et al. 2008). Such information is crucial for modeling studies to predict future changes to the Arctic tundra in response to climate warming (Epstein et al. 2007).

If the Arctic continues to warm over the next few decades as predicted by most models, large changes in vegetation biomass are expected and will have important consequences to many components of the Arctic system including the status of the permafrost, depth of the thaw layer, snow patterns, the distribution of patterned ground, hydrological cycles, wildlife, and human use of arctic landscapes. There will also be important feedbacks to climate through changes in albedo and carbon fluxes.

We are particularly concerned about the unique ecosystems that occur in the extreme northern, coldest bioclimate subzone of the Arctic (Subzone A of the Circumpolar Arctic Vegetation Map, Walker et al. 2005). This bioclimate subzone is currently surrounded by perennial summer sea ice, and the NDVI of this region is also increasing (Jia 2008 submitted). This subzone is most sensitive to increases in temperature, and the entire bioclimate subzone is endangered if the perennial sea-ice vanishes.

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Web pages:

***Greening of the Arctic IPY overview*:** **http://www.geobotany.uaf.edu/goa/.**

***NSF-funded Synthesis of Arctic System Science project, Greening of the Arctic: Synthesis and models to examine pan-Arctic vegetation change: climate, sea-ice, and terrain linkages*:** **http://www.geobotany.uaf.edu/goa/sass/.**

***NSF-funded Biocomplexity in the Environment project (the North American Arctic Transect*):** **http://www.geobotany.uaf.edu/naat/.**

***NASA-funded Land-Cover Land-Use Change project*:** Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia **(the Yamal Russia Transect), http://www.geobotany.uaf.edu/yamal/.**

***NSF-funded Arctic Geobotanical Atlas*: http://www.arcticatlas.org/.**

AGU Fall Meeting Talks:

1. **U23F-05 (invited), Tue 1340, MC 3016, Walker, D.A., Bhatt, U.S., Epstein, H.E. The Greening of the Arctic IPY Project.**
2. **C21C-0559 (poster), Tue 0800 MC Hall D, Jia, G.J., Epstein, H.E., Walker, D.A., Wang, H. Decadal changes of phonological patterns over Arctic tundra biome.**
3. **GC52A-07, Fri 1020 am, MC2007, Walker, D.A. Leibman, M.O., Forbes, B.C., Epstein, H.E. Cumulative effects of rapid climate and land-use changes on the Yamal Peninsula, Russia.**