Panarctic linkages between greening of Arctic tundra, sea ice decline, and summer land temperatures

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Main Point

Question: Is sea ice linked to observed trends and variability in tundra greenness?
Answer: Yes, it is linked and is most likely a primary driver of these changes.
Solar radiation absorbed by plants depends strongly on frequency

- Green plants have low albedo in 0.4-0.7 micron range
- Green plants have higher albedo in the near infrared
- NDVI index is a proxy for vegetation activity.

Normalized Vegetation Difference Index
NDVI = (NIR-R)/(NIR+R)

[Hartmann 1994]
NDVI & SWI trends/variability similar

Ground measured biomass follows NDVI

NDVI on the Arctic Slope for this period is greater than that reported for the northern latitudes as a whole \[Zhou et al., 2001; Lucht et al., 2002\]. Zhou et al. [2001] has indicated heterogeneous changes in NDVI in North America from 1981–1999, and even slight decreases in parts of Alaska and boreal Canada. However, our results show clearly a trend of increase in NDVI in the region. The highest peak NDVI increases occurred for Subzone D (0.082 ± 0.028, 18.7%), followed by Subzone E (0.069 ± 0.022, 12.6%) and Subzone C (0.056 ± 0.032, 15.1%). The increases in NDVI correspond to a general pattern of increasing temperature within all subzones (Figure 2b). The warming trend on the Arctic Slope is expressed by a summer warmth index (SWI) increase of 0.09–0.19°C/yr over the past 22–50 years and 0.16–0.34°C/yr over the time of the NDVI record, with the greatest increase occurring in Subzone D. Generally, years with greater NDVI values coincide with warm temperatures, and drops in NDVI correspond with cold summers, as shown by arrows in Figure 2.

The 1-km data showed similar general temporal patterns as the 8-km data. Both Peak NDVI and Time-integrated NDVI (TI-NDVI) have the lowest decadal mean values for moist sandy tundra and the highest values for shrub tundra. Peak NDVI from 1990–2000 and TI-NDVI from 1991–2000 increased for all vegetation types, with an interruption in 1992 due to the eruption of Mt. Pinatubo in late 1991. The data also showed differences in trends among the vegetation types. Peak NDVI generally increased by 0.061 (or 13.6%) for the 11-year period. The greatest increase in Peak-NDVI occurred for MNT (0.073), followed by MAT (0.059), shrub tundra (0.052) and sandy tundra (0.043). TI-NDVI increased by 0.526 (or 17.7%) for the 10-year period (Figure 3). Both MNT and MAT had high increases in TI-NDVI, whereas sandy tundra had a relatively low increase (0.23). Nearly all of our results suggest that the greatest changes in NDVI have occurred in moist nonacidic, graminoid-dominated tundra, which currently has relatively low shrub cover. Slight changes in shrub cover within this type may cause relatively large changes in NDVI compared to the other types (Figure 4). The relatively lower increase rates for shrub-dominated tundra may also be a result of saturating values of NDVI. These hypotheses are supported by spatial NDVI and biomass analyses at both local and regional scales. Slight increases in shrub biomass for MNT can lead to a strong NDVI increase, while similar increases in shrub biomass for shrub tundra only yield slight NDVI increases. For the whole area, TI-NDVI and Peak NDVI are highly correlated (r² = 0.82), showing that much of variation in TI-NDVI is related to the change of Peak NDVI.

There is evidence from the International Tundra Experiment (ITEX) and other studies showing the increase of shrub growth on the Arctic Slope and other areas [Arft et al., 1999; Sturm et al., 2001; Hobbie and Chapin, 1998]. A substantial increase in shrub abundance has been reported in the Alaskan Arctic over the past 50 years [Sturm et al., 2001], which is believed to have contributed to increased productivity in some areas. Others have studied the effects of aerosols on NDVI [Lucht et al., 2002; Hope et al., 2003] and vegetation productivity [Gu et al., 2002] following the Mt. Pinatubo eruption in 1991, but these effects appear to be transitory, and NDVI continued to increase after aerosol concentrations returned to pre-Pinatubo levels.

The temporal-spatial series of both Peak-NDVI and TI-NDVI showed positive relations with SWI. TI-NDVI had a stronger relation with SWI than Peak-NDVI (r² = 0.69 vs. r² = 0.51, p < 0.01). After separating the sites into subzones and vegetation types, the relationship between SWI and NDVI became less strong. However, the correlations between TI-NDVI and SWI were still greater (r² = 0.40–0.54) than those between Peak-NDVI and SWI (r² = 0.15–0.38). The NDVI increase in Subzone D and MNT were significantly greater than other subzones and vegetation types (t-tests, p < 0.05), and the greatest correlations...
Mean Tundra Vegetation Linked to Sea Ice

Circumpolar Arctic Vegetation Map

- 80% of the Arctic tundra (3.2 million km²) < 100 km from ocean
- Subzone A (mosses) to Subzone E (low shrubs)
Mean Tundra Vegetation Linked to Sea Ice

Are these Arctic tundra vegetation changes forced by changes in sea-ice?
Remote sensing data & methods

Data: 1982-2007 (26 yrs, weekly) at 25-km resolution

- Passive Microwave Sea Ice Concentration
- AVHRR Land Surface Temperature
- Gimms NDVI (maximum and integrated)

- Divided Arctic Ocean (Treshnikov, 1985) to examine trends and variability in 50-km land-ocean coastal domains
Pan-Arctic Trends (82-07) Vary Regionally

- SWI and Ice trends same sign & consistent
- TI-NDVI and MaxNDVI trends vary in sign
Pan-Arctic Trends over Tundra Vary

- Trends of 50% average sea ice cover
- SWI shows cooling over Yamal, Taymyr (consistent with station data)
- TI-NDVI decreasing Seward Peninsula, Taymyr & Canadian Archipelago (Data issue concern)
Percent change since 1982 of Sea ice, SWI, and TI-NDVI

Legend for Correlations
- +

Legend for Trends
Sign: closed (+) and open (-) circles
Significance: * denotes 95% level
Magnitude: size of circle
- <10%
- ≥10% & <30%
- ≥30%

Sea ice
SWI
TI-NDVI

N. Hemisphere
Eurasia
N. America

W. Bering
E. Bering
W. Chukchi
E. Chukchi
Beaufort
E. Siberian
Laptev
W. Kara
E. Kara
Barents

Sea ice correlated with SWI & NDVI
## Correlations larger in 50-km coastal zone

<table>
<thead>
<tr>
<th></th>
<th>Week of 50% ice conc.</th>
<th>sea ice &amp; SWI</th>
<th>SWI &amp;TI-NDVI</th>
<th>sea ice &amp; TI-NDVI</th>
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<tbody>
<tr>
<td>Northern Hemisphere</td>
<td>July 16-22</td>
<td>-0.48 (-0.23)</td>
<td>0.52 (0.51)</td>
<td>-0.38 (-0.38)</td>
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<tr>
<td>Eurasia</td>
<td>July 9-15</td>
<td>-0.57 (-0.45)</td>
<td>0.52 (0.51)</td>
<td>-0.56 (-0.51)</td>
</tr>
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<td>N. America</td>
<td>July 23-29</td>
<td>-0.58 (0 )</td>
<td>0.54 (0.53)</td>
<td>-0.43 (-0.32)</td>
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<tr>
<td>E. Bering</td>
<td>April 30 - May 6</td>
<td>-0.20 (0)</td>
<td>0.64 (0.54)</td>
<td>-0.52 (-0.43)</td>
</tr>
<tr>
<td>E.Chukchi</td>
<td>June 11-17</td>
<td>-0.18 (0)</td>
<td>0.66 (0.63)</td>
<td>-0.42 (-0.36)</td>
</tr>
<tr>
<td>Beaufort</td>
<td>July 16-22</td>
<td>-0.41 (-0.26)</td>
<td>0.35 (0.29)</td>
<td>-0.19 (-0.21)</td>
</tr>
<tr>
<td>Canadian Archipelago</td>
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<td>-0.48 (-0.49)</td>
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<tr>
<td>Baffin</td>
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<td>-0.37 (-0.39)</td>
<td>0.54 (0.38)</td>
<td>-0.37 (-0.18)</td>
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<tr>
<td>Davis Strait</td>
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<td>0.45 (0.51)</td>
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<tr>
<td>Greenland</td>
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<td>-0.43 (-0.42)</td>
</tr>
<tr>
<td>Barents</td>
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<td>0.72 (0.60)</td>
<td>-0.51 (-0.45)</td>
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<tr>
<td>W. Kara</td>
<td>July 16-22</td>
<td>-0.41 (-0.39)</td>
<td>0.62 (0.60)</td>
<td>-0.36 (-0.38)</td>
</tr>
<tr>
<td>E. Kara</td>
<td>August 13-19</td>
<td>-0.41 (-0.26)</td>
<td>0.50 (0.51)</td>
<td>-0.11 (-0.16)</td>
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<tr>
<td>Laptev</td>
<td>July 23-29</td>
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<tr>
<td>W. Chukchi</td>
<td>July 2-8</td>
<td>-0.52 (-0.44)</td>
<td>0.67 (0.65)</td>
<td>-0.42 (-0.38)</td>
</tr>
<tr>
<td>W. Bering</td>
<td>May 14-20</td>
<td>0 (0)</td>
<td>0.65 (0.52)</td>
<td>0 (0)</td>
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</tbody>
</table>
Contrasting Trends: Laptev vs Beaufort

Laptev

Sea Ice Concentration (%)

-13% -12%

MaxNDVI

-13% -12%

Beaufort

Sea Ice Concentration (%)

16% -29%

MaxNDVI

23% 21%
Sea ice decline ==> SWI & NDVI increase

- Modeling evidence (Fixed sea ice GCM experiments)
  - Lawrence et al. 2008
  - Bhatt et al. 2008
- Observational Evidence
  - Rouse 1991
  - Haugen and Brown 1980
- Mean NDVI map =========>

- Another option is that the forcing from comes from the south(??)
Beaufort greens up earlier than W. Kara

- Seasonality of ice different in these regions
Correlations between ice and SWI are more local in summer: Beaufort

- Negative correlation less ice ==> warmer growing season
- More localized later in summer, when winds are typically onshore
Ecological consequences of perennial ice declines: Impacts to Subzone A

Northern Canada has shown little decrease thus far but if coastal ice declined then Subzone A would be impacted as new species move in.

Typical subzone A zonal vegetation at Isachsen, Ellef Ringnes Island, Nunuvut, Canada. Yellow flowers are *Papaver polaris*. Photo: D.A. Walker.
Conclusions

- Arctic NDVI trends are more heterogenous than previously thought.
  - E. Siberian to Beaufort vs Taymyr peninsula
- Coastal sea ice correlated with land temperatures and Time Integrated NDVI.
  - Correlations plus other evidence suggest ice is a key driver of the terrestrial changes
- Regional differences are likely linked to seasonality of air-sea-land parameters & atmospheric circulation
Acknowledgments

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Thank you for your attention