Greening of the Arctic:
A “planet-to-plant” analysis of vegetation change

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Goals

1. Examine trends of vegetation, climate, and greening (NDVI) in relationship to sea ice trends along two transects through all 5 Arctic bioclimate subzones.

2. Link the remote sensing trends to ground observations at landscape and plant scales.

3. Education and outreach

Maximum NDVI as mapped by CAVM Team 2003.
Bioclimate subzones as mapped by CAVM Team 2003

Along the tundra bioclimate gradient:
- 10° C change in the MJT
- 10-fold change in zonal biomass
- 10-fold change in productivity
- 5 to 10-fold change in vascular-plant diversity

<table>
<thead>
<tr>
<th>Sub-Zone</th>
<th>MJT</th>
<th>Shrubs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1-3 °C</td>
<td>none</td>
</tr>
<tr>
<td>B</td>
<td>3-5 °C</td>
<td>prostrate dwarf-shrubs</td>
</tr>
<tr>
<td>C</td>
<td>5-7 °C</td>
<td>hemi-prostrate dwarf shrubs</td>
</tr>
<tr>
<td>D</td>
<td>7-9 °C</td>
<td>erect dwarf-shrubs</td>
</tr>
<tr>
<td>E</td>
<td>9-12 °C</td>
<td>low-shrubs</td>
</tr>
</tbody>
</table>

Arctic bioclimate gradient

Bioclimate subzones as mapped by CAVM Team 2003
Approach

1. Division of the Arctic by ocean basins and land floristic provinces

2. Examined trends in sea-ice (Comiso & Nishio 2008) within 50-km of each coastline.

3. Examined trends in summer AVHRR-derived land surface temperatures (Comiso 2003) using the summer warmth index (SWI).

4. Used new GIMMS 3g NDVI data set (Pinzon et al. in prep) corrected previous discontinuity in the High Arctic.

Circumpolar changes to early summer coastal sea ice, and summer land temperatures (1982-2008)

- **Coastal sea ice**: strongly decreasing throughout the Arctic except coastal areas of the Greenland Sea and parts of the Bering Sea. The strongest most significant trends are in the E. Siberian to Chukchi, and E. Kara regions (-40 to -44%).

- **Summer warmth**: increasing most strongly in the Canadian High Arctic and Greenland and in the Beringian region between the E. Siberian Sea and the E. Chukchi (40-70%).

- Relatively small increases are seen between the Kara and Laptev seas.

Greening patterns based on the Normalized Difference Vegetation Index (NDVI)

- NDVI = (NIR-R)/(NIR + R).
- The difference between the reflectance in the NIR and R portions of the spectrum is a measure of the photosynthetic capacity of the surface.
- The difference is divided by the sum of the reflectances to adjust for variations in the index due to slope and shadows.
Arctic wide: +5% increase in MaxNDVI

Much greater change in North America (+9%) than in Eurasia (+3%).

Largest increases (10-15%) in northern Canada and Greenland and Alaska areas.

Other analyses (not shown) revealed strong positive correlations between NDVI and land temperatures and strong negative correlations with the percentage of coastal sea ice.

Circumpolar Analysis of NDVI and Arctic transects

- North America NDVI strongly controlled by temperature and glacial history.
- Yamal NDVI shows surprisingly little trend with temperature compared to the circumpolar Arctic (mostly substrate (sand vs. loams) and disturbance (erosion and landslides) controlled.

USGS 1-km AVHRR data set used for the CAVM.

Raynolds. 2009. UAF Ph.D.

Epstein et al. 2010, NASA Science Team Meeting, Bethesda MD
The Yamal

Typical of the sorts of changes that are likely to become much more common in tundra areas of Russia and the circumpolar region within the next decade.

• Large undeveloped Arctic landscapes with few roads, but...
  • large-scale gas and oil potential,
  • extraordinarily sensitive permafrost environment
• traditional hunting and pasturelands for the indigenous people...
  in a time of rapid climate change.
Analysis of Yamal MaxNDVI with Landscape Units

• Most variation of uplands is related to soil texture. Loamy uplands (with abundant willows) have high NDVI.

• 1-km data is not fine enough to resolve the greening patterns within the highly eroded upland areas.

• Broad river channels have highest NDVI despite large amount of lakes in the valleys.

M.K. Raynolds. 2010. Yamal LCLUC Workshop. Rovaniemi, FI
Ground observations:

- **Transects**
  - NDVI and LAI
  - Species cover
  - Active layer depth

- **Plots**
  - Cover abundance, site factors
  - Biomass
  - N-factor

- **Soils**
  - Soil pit profile
  - Soil chemical and physical analyses

- **Observations from other studies**
  - Arctic Centre: ENSINOR

Back to the Future

Biocomplexity
Results from Transects:

North American Arctic Transect

Biocomplexity of Arctic Tundra Ecosystems

9 papers in Walker et al. 2008, JGR + many others

Yamal Transect

THE 2009 YAMAL EXPEDITION TO OSTROV BELY AND KHARP, YAMAL REGION, RUSSIA

DATA REPORT


Alaska Geobotany Center, Institute of Arctic Biology, University of Alaska Fairbanks, AK 99775

December 2009
Funded by NASA Grant No. NNG05GE00A


North American Arctic Transect

- Yamal transect examined biomass trends on zonal (loamy) and sandy sites.
- Little variation in zonal sites, except in forest-tundra transition.

Yamal Transect

- NAAT examined biomass trends on disturbed sites (patterned ground features, PFG) and adjacent zonal sites (bPGF).
- Clear trends with temperature.

Walker et al. 2008. JGR
Yamal has somewhat higher total biomass in relationship to summer temperature, lower LAI, lower vascular plant biomass, and higher moss biomass.

Grazing pressure on the Yamal is much higher.
Relation of NDVI to vegetation and environmental variables

Ordination analysis shows the relationship of the study plots to each other based on floristic similarity.

- And with respect to environmental and plant variables (cover, biomass, NDVI)

JJ Frost et al. 2010, Yamal LCLUC Workshop
Disturbance has major effect on NDVI patterns but it is hard to partition the various effects.

Effects of reindeer:

- Entire peninsula is heavily grazed but effects on NDVI are unknown at present because of lack of control areas (exclosures) to study the effects.
- Potential major effect in sandy areas.

Photos: Bruce Forbes.
Landslides and cryogenic erosion

- Large effect on patterns of greenness in many areas.
- Quantitative measures of frequency of slides are needed to determine effects on regional greening trends.
- Need temporal series of high-resolution satellite images and/or photos in landslide areas to assess the rate of change.

Strong greening on landslide slopes cover extensive areas of the Yamal.

• Large effect on patterns of greenness in many areas.
• Quantitative measures of frequency of slides are needed to determine effects on regional greening trends.
• Need temporal series of high-resolution satellite images and/or photos in landslide areas to assess the rate of change.

Biomass

Before landslides

After landslides

Low-willow shrublands develop on landslides during 200-yr succession, greatly changing biomass and NDVI.

Photos D.A. Walker

Education and outreach

- Arctic Geobotanical Atlas

- Links to human dimension studies

http://www.arcticatlas.org/
The changes in willow growth are affecting reindeer management on the Yamal.

Nenets camp on Yamal in Salix low shrub tundra

Reindeer grazing Salix thickets in Nenets Okrug. If they grow over ≈ 2 m high, herders can lose sight of animals.

Forbes et al. 2009 PNAS, ENSINOR project
Changes in infrastructure are accelerating.

Table: Land use changes in Bovanenkovo

<table>
<thead>
<tr>
<th>Category</th>
<th>Bovanenkovo 2004</th>
<th>Bovanenkovo 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanently changed area</td>
<td>9.3 km²</td>
<td>17.4 km²</td>
</tr>
<tr>
<td>- buildings &amp; yards</td>
<td>2.1 km²</td>
<td>4.4 km²</td>
</tr>
<tr>
<td>- roads length</td>
<td>70 km</td>
<td>154 km</td>
</tr>
<tr>
<td>- roads area</td>
<td>2.9 km²</td>
<td>5.4 km²</td>
</tr>
<tr>
<td>- sand quarries</td>
<td>4.3 km²</td>
<td>6.6 km²</td>
</tr>
<tr>
<td>Pipeline, length</td>
<td>16 km</td>
<td></td>
</tr>
<tr>
<td>Off road tracks, length</td>
<td>2400 km</td>
<td></td>
</tr>
<tr>
<td>Off road tracks, area</td>
<td>24 km²</td>
<td></td>
</tr>
<tr>
<td>Total affected area</td>
<td>4.48 km²</td>
<td>550 km²</td>
</tr>
</tbody>
</table>
Yamal land-use changes: Impacts of gas development on reindeer rangelands

- Potential large effects on reindeer access to rangelands.
- Locally important effects on NDVI but still relatively small extent.
- Need development scenario models to help predict and plan for expansion of road networks.

Prudhoe Bay land-use changes: 1968-2001

Direct impacts in 2001:
- Gravel roads (km) 400
- Pipelines (km) 450
- Powerlines (km) 219
- Production pads 115
- Airstrips 4
- Culverts 1395
- Bridges 17

Gravel area (km^2) 37.5
Gravel mines 25.7
Off-shore gravel 0.6
Other impacted areas 7.1

Total directly impacted area: 70.2 km^2

National Research Council 2003
Links to other IPY projects: Back to the Future

**Webber and Tweedie 2009:**

- High Arctic Arctic change at the plot level. Rapid vegetation succession in polar desert near the Barnes Ice Cap

- Repeat photographs of permanent vegetation 46 years after the initial studies.

- Vegetation is increasing most strongly along ponds and streams (where there is water and nutrients).

- Helps explain the very large percentage NDVI changes seen especially in ice-marginal areas in northern Canada and Greenland.

Webber and Tweedie 2009 Back to the Future project
Hudson and Henry 2009:

- Rapid High Arctic change in zonal sites at Alexandra Fiord (1981-2008). First study to detect significant change in total aboveground biomass.

- Vegetation change accompanies increase in length of growing season and summer temperature.

- High Arctic appears to be responding more rapidly than Low Arctic, possibly due to more open plant canopies.
Walker and Maier 2008:

- Hierarchy of geobotanical maps used to detect change with remote sensing at Toolik and Imnavait Creek.
- Imnavait Grid plots used to detect species and cover changes.

Toolik Area Change Analysis 1985-99 using Landsat data.

- Upland water tracks; likely related to shrub advance.
- Vicinity of intensive research site at Toolik Field Station; large number of research plots and human activity.
- Dust disturbance, roadside thermokarst.
- Roadside areas of the Dalton Highway; enhanced shrub growth.
- Alluvial fan of the Atigun river; possible draining and revegetation of an old river channel.

Links to other IPY projects: ITEX at Toolik Lake

**Plant Canopy Height**

![Graph showing mean canopy height (cm) for Toolik and Imnavait Creek from 1990 to 2008.](image)

**Cover of Plant Growth Forms**

![Graph showing cover of plant growth forms for Toolik and Imnavait Creek.](image)

**Gould and Mercado 2008:**

- First demonstration of long-term changes in low-arctic zonal plant communities.

Gould, Mercado et al. (2009 in progress), ITEX project.
Multiple lines of evidence from many studies are needed to help explain observed NDVI changes.

1. NDVI is affected most directly by changes to the plant canopy (e.g. species composition, vegetation structure, phenology, plant health).

2. Arctic plants respond most directly to changes to their immediate plant environment (summer temperature, moisture, and nutrients, site stability).

3. Multiple, often interrelated, disturbances are often associated with changes in the plant environment.

4. Furthermore, the causes of the disturbance can be linked to complexes of social factors affecting land-use changes.

Vegetation change models can help to unravel the effects of various types of disturbance.

Epstein et al. ArcVeg Model:

- Used to examine effects of multiple interacting factors on plant productivity of the Yamal transect.

- Grazing suppresses vegetation response to warming.

- Herbivory has greater effect in loamy (nutrient-rich) sites.

Credits

* NSF: Biocomplexity in the Environment (BE) initiative; ARCSS: Synthesis of Arctic System Science and Seasonality initiatives
* NASA: Land Cover Land Use Change (LCLUC) program
* Northern Eurasia Earth Science Partnership Initiative (NEESPI)
* Russian Academy of Science, Earth Cryosphere Institute
* Arctic Centre (Finland): Environmental and Social Impacts of Industrialization in Northern Russia (ENSINOR) project