Spatial analysis of glacial geology, surficial geomorphology and vegetation in the Toolik Lake region: Relevance to past and future land cover changes

Corinne Munger, Donald A. Walker, Hilmar A. Maier (Institute of Arctic Biology, University of Alaska Fairbanks), Thomas D. Hamilton (USGS, Anchorage)

Based on C.A. Munger (2007) M.S. thesis research
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Plant cover is an insulative mat that strongly affects the thermal properties of the ground surface

- n-factor
- Active-layer thickness
- Permafrost temperatures.
With multi-spectral satellite data we can measure the photosynthetic activity of the land surface and get a first approximation of the plant biomass using the normalized difference vegetation index.

Vegetation greenness (NDVI) is based on satellite-derived data.
Study area

- Located in the northern foothills of the Brooks Range in northern Alaska.
1:25,000-scale GIS database of the Toolik Lake/Upper Kuparuk Region region

Walker and Maier. 2008. NICOP.
Research questions

- How do glacial history, surficial geomorphology, and elevation affect patterns of vegetation?
- How is the pattern of vegetation greenness affected by terrain variables?
- How have the patterns changed during the satellite record?
Simplified Glacial Geology Map
Based on Hamilton (2003)

Sagavanirktok age
(middle Pleistocene
Deglaciated by 125,000 y BP)

Itkillik I age
(late Pleistocene
Deglaciated by 53,000 y BP)

Itkillik II age
(late Pleistocene
Deglaciated by 11,500 y BP)

Other surfaces
- Bedrock, colluvium, alluvium,
  thermokarst
- Water
Vegetation

- Barren (roads and pads)
- Lichens on rocks
- Partially vegetated barrens, and revegetated disturbed areas
- Tussock sedge, dwarf-shrub, moss tundra
- Non-tussock sedge, dwarf-shrub, moss tundra
- Miscellaneous graminoid, dwarf-shrub, forb communities
- Sedge, moss tundra (poor fen)
- Sedge, moss tundra (fens)
- Water and deep-water herbaceous marsh
- Prostrate dwarf-shrub, forb, fruticose-lichen tundra, acidic
- Prostrate dwarf-shrub, forb, fruticose-lichen tundra, non-acidic
- Hemi-prostrate and prostrate dwarf-shrub, forb, moss, fruticose-lichen tundra
- Hemi-prostrate dwarf-shrub, fruticose-lichen tundra
- Dwarf-shrub, sedge, moss tundra
- Dwarf- to low-shrub, tundra
- Low to tall shrublands (riparian south-facing slopes)
Characteristic vegetation types

Lichens barrens

Rich fen wetland

Moist nonacidic graminoid tundra

Dry acidic tundra

Shrub tundra
Surficial Geomorphology
Information derived from digital elevation model (Nolan et al. 2003)

Slope angle

- Flat (< 2°)
- Gentle (2-5°)
- Moderate (5-10°)
- Steep (>10°)

Aspect

- Flat (water)
- North
- East
- South
- West

Elevation (m)

- 550-600
- 600-650
- 650-700
- 700-750
- 750-800
- 800-850
- 850-900
- 900-950
- 950-1000
- 1000-1050
- 1050-1100
- 1100-1150
- 1150-1200
- 1200-1250
- 1250-1300
- >1300
Acidic tussock tundra (dark yellow) covers less of the younger landscapes. (61% cover of tussock tundra on the oldest surfaces, 38% on the intermediate-age surfaces, and 24% on the youngest surfaces).

Nonacidic tundra (tan color) is more abundant on the younger surfaces (39% cover on the youngest surfaces, 17% on the intermediate-age surfaces, and 2% on the oldest surfaces).

Younger surfaces also had more lakes, more area of dry tundra, fewer wetlands, and fewer shrublands.
Relationship between elevation and vegetation

- Increase in barren and sparsely vegetated types with elevation.
- Decrease shrubby vegetation types.
Characteristics of the glacial surfaces

Sagavanirktok surfaces:
• Few glacial lakes
• Gentle slopes
• Few glacial erratics
• Continuous loess cover
• Broad solifluction slopes
• Abundant watertracks
• Predominantly acidic tussock tundra and well-developed colluvial basins with acidic mires

Itkillik surfaces:
• More lakes but fewer wetlands
• Stony blockfields
• Abundant sorted and nonsorted stripes and circles
• Few watertracks
• Covered predominantly in nonacidic tundra vegetation
Vegetation biomass of the region was interpreted using the Normalized Difference Vegetation Index (NDVI)

Reflectance spectra of vegetation

The greater the difference between the reflectance in the R and NIR portions of the spectrum, the more chlorophyll is in the vegetation canopy.

Normalized difference vegetation index (NDVI)

$$NDVI = \frac{(NIR-R)}{(NIR+R)}$$
Uses of NDVI

NDVI has been used to estimate:
  - biomass
  - leaf area index
  - intercepted photosynthetically active radiation
  - other plant biophysical properties such as CO₂ and methane flux

Interannual variation in NDVI analysis can show
  - variability in plant phenology (timing of green-up and senescence)
  - changes in standing crop
  - ecosystem net primary production.

With respect to permafrost:
1. NDVI in the Arctic is a measure of biomass, which is an insulator reducing the heat flux to the permafrost. But the relationships are not simple.

2. Several other studies are trying to work out the relationships between plant biomass, plant functional types, the n-factor and R values of the vegetation.

Our analysis also examined the relationship between NDVI and surficial geomorphology, including many periglacial features (e.g., non-sorted circles, stripes, high- and low-centered polygons).
Older surfaces have higher values of NDVI than younger surfaces.

Older surfaces have greater cover of shrub-rich tussock tundra and shrub-filled water tracks, whereas younger surfaces have more dry, well-drained sites, stony areas, and irregular microrelief.
Hillslope watertracks had the highest NDVI values.

Water and stony surfaces had the lowest values.
Shrubby vegetation types and tussock tundra had the highest NDVI values.

Tussock sedge areas tended to be greener than areas of non-tussock sedge.
Landsat NDVI at different elevations

- The lowest elevation band (550-600) had relatively low NDVI values, likely due to water cover.

- The highest elevation bands have low NDVI, likely because of steep slopes, adiabatic cooling, and exposed areas.
16.9% ($\pm$5.6%) increase in peak vegetation greenness across Arctic Alaska.

Corresponds to simultaneous warming.

8-km resolution of AVHRR data does not provide information on where greening is occurring within landscapes.

Jia, Epstein, Walker (2003), *GRL*
AVHRR vs. Landsat-TM

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Temporal resolution</th>
<th>Spatial resolution</th>
<th>Date of first launch</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR</td>
<td>Daily</td>
<td>1.1-km pixels</td>
<td>1981</td>
</tr>
<tr>
<td>Landsat-TM</td>
<td>16 days</td>
<td>30-m pixels</td>
<td>1982</td>
</tr>
</tbody>
</table>

- AVHRR has great temporal coverage, but coarse spatial resolution. Good to examine year-to-year variations in NDVI and for global analyses.

- Landsat-TM has poor temporal coverage (16 days), but greater spatial resolution. Good for examining details of greening patterns within local areas.
Temporal analysis of Landsat-derived “Max” NDVI
30-m resolution, 4 mid-summer scenes

Landsat images were acquired during the time of peak greenness (early August) except 2002, which was acquired 10-14 days earlier, and appears to have been at an earlier phenological stage than the other scenes.
Temporal changes in summer warmth, AVHRR NDVI, and Landsat-TM Max NDVI
Change in Landsat NDVI for each 30-m pixel between 1985 and 1999

- **Negative change in NDVI**
- Below 1 standard deviation of the mean change in NDVI
- Within 1 standard deviation above/below the mean change in NDVI
- Above 1 standard deviation of the mean change in NDVI
Areas of greatest change between 1985 and 1999

1. Upland watertracks; likely related to increased shrubs.

2. Roadside areas of the Dalton Highway; enhanced shrub growth, dust disturbance, thermokarst; also changes along underground gas pipeline just north of the road.

3. Alluvial fan of the Atigun river; possible draining and revegetation of an old river channel.

4. Vicinity of intensive research site at Toolik Field Station; may be related to the large number of research plots and human activity in the area.
Conclusions

- Analyses of vegetation-terrain relationships show that different aged glacial surfaces all have characteristic geomorphology and vegetation, suggesting that over time, plant succession in the Arctic trends towards peaty, acidic, wetter upland surfaces and the infilling of lakes in lowland sites.

- The highest NDVI values occur in portions of the landscape with abundant shrubs, such as water tracks, on moderate slopes, and on older glacial surfaces.

- Greening occurred heterogeneously across the landscape during the 14 years of comparable data, with the most rapid change occurring in well-vegetated areas such as tussock tundra and shrubby areas, on areas of nonsorted circles, and at lower elevations.

- Analysis of four areas of greatest change indicated that a variety of factors were involved, including shrub advance in upland water tracks, road effects along the Dalton Highway, intensive research and human activity near the Toolik Lake research station, and on an alluvial fan of the Atigun River.

- The Landsat analysis is based on only three temporally comparable image acquisitions (1985, 1995, 1999) and will require more data points to confirm the locations and magnitude of the land-cover change trends.