# Vegetation greenness on the Yamal Peninsula, Russia: Disturbance–climate-change interactions


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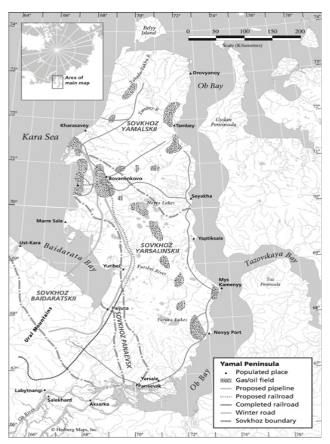
## Introduction

We use the AVHRR-derived normalized difference vegetation index (NDVI), land-surface temperatures, and the extent of sea ice — supplemented with information from a regional geographic information system (GIS) and aerial and ground surveys — to better understand the spatial and temporal patterns of vegetation production in relationship to disturbance factors on the Yamal Peninsula, Russia. Here, we focus on the effects of difference in climate, terrain variables, and melting permafrost.

### *Location and statement of the problem*



Forbes, 1999.

**Fig. 1.** The Yamal region in northwest Siberia is a hot spot of Arctic land-cover change due to rapid resource development, rapid population growth of the indigenous Nenets people and their reindeer, very active geomorphic changes, and climate change. Previous presentations have focused on the nature and extent of the gas-development activities and the effects of the reindeer herds. Here we examine the spatial and temporal trends of vegetation change and focus on the interactions between climate and the effects of extensive landscape erosion. Disturbance to the thin protective blanket of vegetation can trigger landslides and retrogressive thaw slumps.

### *Zonal trend in greenness*


Modified from CAVM Team, 2003.

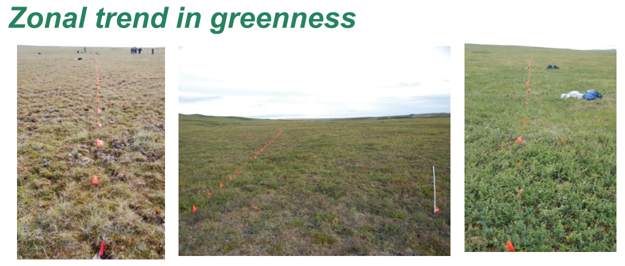


**Fig. 2. Left:** Study sites are distributed in each of the Arctic bioclimate subzones on the Yamal Peninsula. We are interested in how the present distribution of plant biomass as indicated by the NDVI conforms to the general circumpolar zonal pattern of decreasing NDVI with colder temperatures and other factors affecting the NDVI. **Above:** Zonal vegetation at Kharasavey (subzone C), Vaskiny Dachi (subzone D), and Laborovaya (subzone E). Note the increasing greenness with warmer temperatures toward the south. Photos: D.A. Walker

### *NDVI: A simple greenness index that integrates many factors affecting vegetation change*

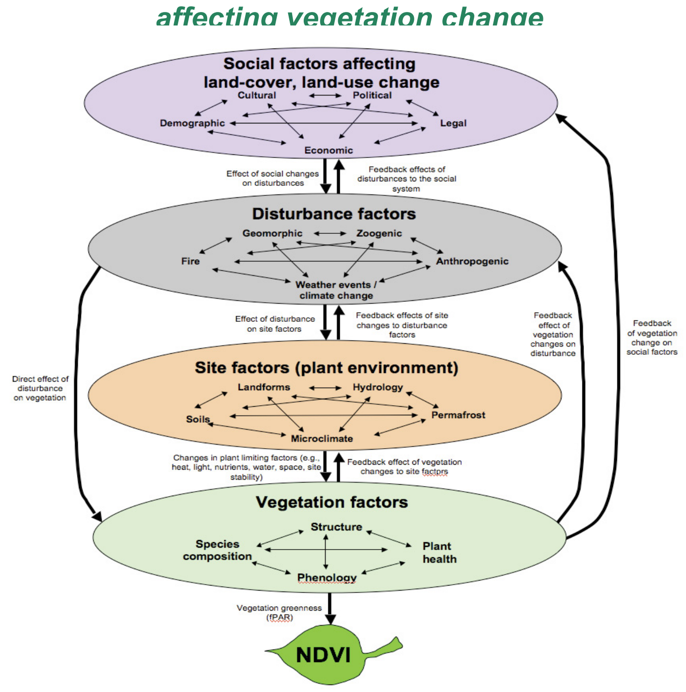



**Fig. 3.** The observed spatial and temporal changes in greenness represent changes in the fraction of photosynthetically active radiation (fPAR) that is absorbed by the plant canopy. **NDVI = (NIR - R) / (NIR + R),** where NDVI is the normalized difference vegetation index, NIR = reflectance in the near-infrared channel, and R is the reflectance in the red channel, the primary wavelengths of light that are absorbed by chloroplasts for photosynthesis.The observed changes in NDVI occur at the cellular level but are a result of complex interactions between social factors, disturbance factors at numerous scales, site factors, and the thin layer of vegetation.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## Spatial analysis of greenness patterns: Influence of the climate gradient and terrain factors

### *NDVI and summer warmth*

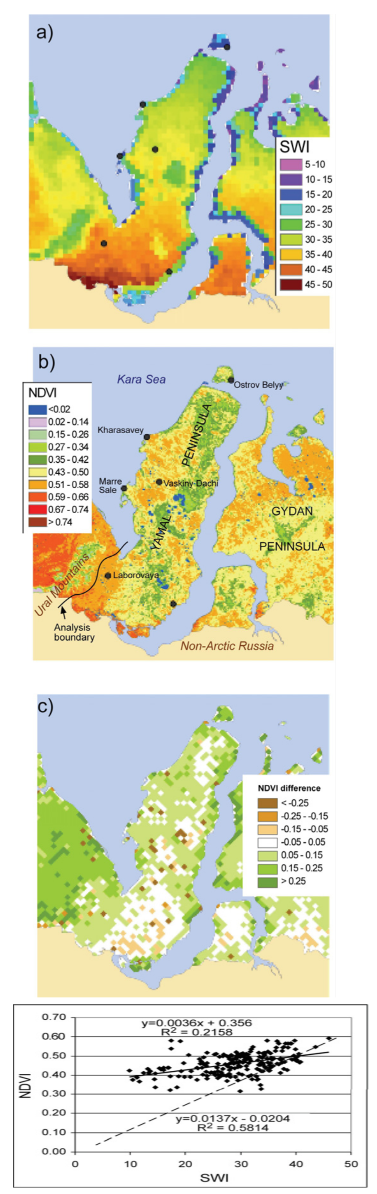
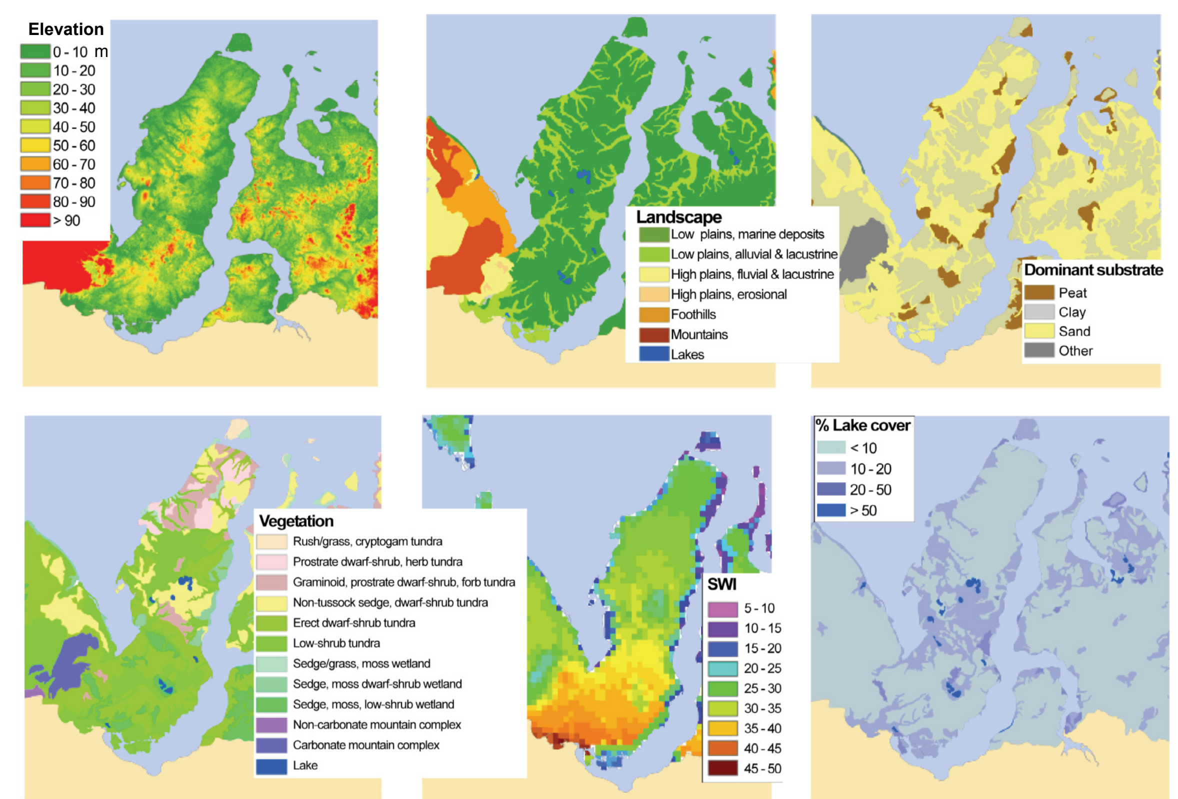



**Fig. 4. (a)** Summer land surface temperatures expressed as summer warmth index (**SWI** = sum of the monthly mean temperatures > 0 ˚C). **(b)** Maximum NDVI. **(c )** Difference between Yamal NDVI and expected NDVI based on circumpolar patterns. **Graph:** Regression between NDVI and SWI for the Yamal (**solid line**) and circumpolar region (**dashed line**).

### *GIS of terrain variables*




GIS data from Melnikov (1988) and Raynolds et al. (2008).

### *Landscape factors control NDVI patterns.*

Although global patterns of NDVI are highly correlated with summer land temperatures (SWI), the correlation is weak on the Yamal (**Fig. 4**). Less than 2% of the total variation in NDVI on the Yamal is explained by SWI (**Table 1**).

Landscape factors such as the distribution of marine terraces and eroded valleys and the distribution of soil and vegetation types exert a much stronger control.

### *Table 1. General linear model of climate & landscape effects on NDVI*

| GIS variable | Deviance | Residual deviance | % deviance accounted for | Significance |
|---|---|---|---|---|
| Null | | 2.065 | | |
| Elevation | 0.603 | 1.462 | 29.21 | <0.000000 |
| Landscape | 0.407 | 1.055 | 19.72 | <0.000000 |
| Substrate | 0.101 | 0.954 | 4.88 | <0.000000 |
| Vegetation | 0.088 | 0.865 | 4.29 | 0.000004 |
| Land temp | 0.039 | 0.827 | 1.87 | 0.000012 |
| Lake area | 0.032 | 0.794 | 1.57 | 0.000934 |
| TOTAL | | | 61.55 | |


Melnikov, E. S. 1998. Uniting basis for creation of ecological maps for the Russian cryolithozone. Pages 719-722 in Proceedings of the Seventh International Conference on Permafrost, Yellowknife, Canada.

Raynolds, M. K., D. A. Walker, and J. C. Comiso. 2008. Spatial patterns of land surface temperature and NDVI and their relation to vegetation distribution on the Yamal Peninsula. Pages 23-25 in Yamal Land-Cover Land-Use Change Workshop Abstracts, Moscow, Russia, 28-30 May 2008. Alaska Geobotany Center, University of Alaska Fairbanks.


## Temporal analysis of greenness patterns: Influence of changing sea ice and land temperatures

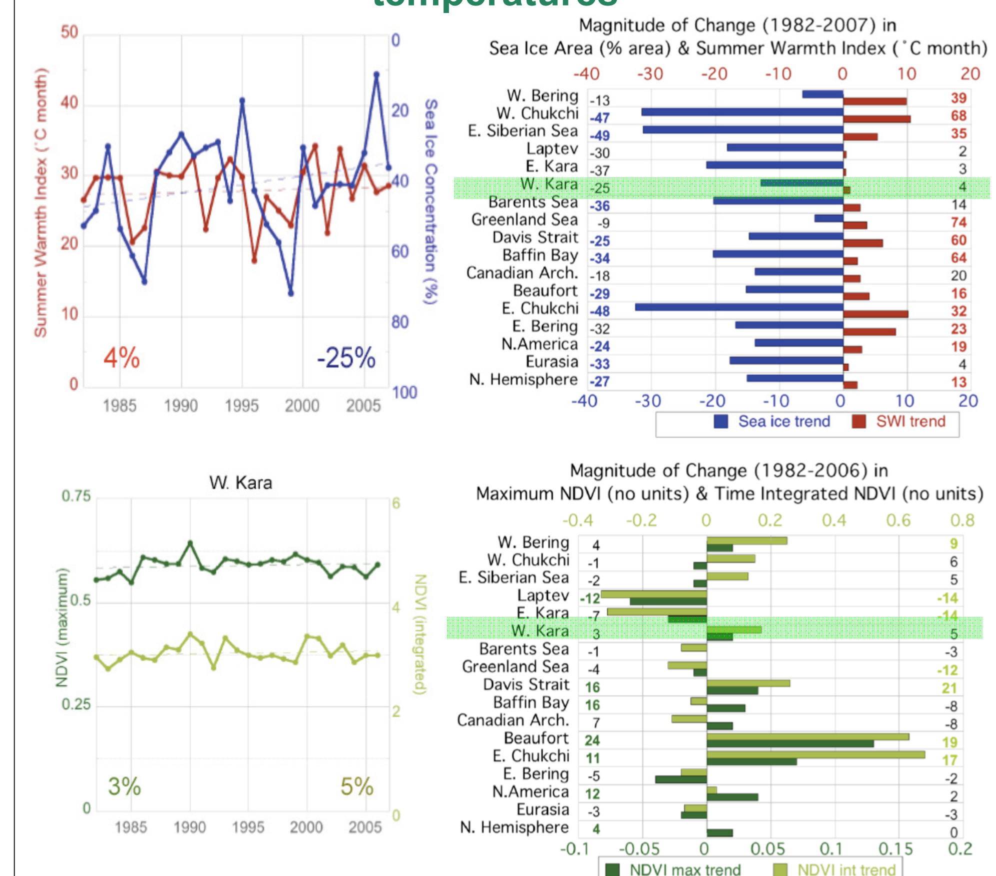



**Fig 5. Left:** Trends in sea ice,land temperatures and NDVI in the W. Kara Sea/ Yamal region from 1982 to 2007. **Blue line:** Sea ice concentration, (% area,, -4.3% cover / decade, -25% overall change) is based on the climatological 50% concentration period, which is 9-29 July for the W. Kara. **Red line**: Summer warmth index (SWI, +0.22 ˚C mo / decade, 4% change) is the sum of mean monthly temperatures above freezing (˚C month). **Dark green line**: Maximum NDVI (0.01 units / decade, 3% change. L**ight green line:** Integrated NDVI (+0.13 units / decade, 5% change) derived from AVHRR satellite data. Percent change in each variable from 1982 to 2007 (2006) for each trend. None of the trends are significant at p = 95%. **Right:** Magnitudes of 1982-2007 change for sea ice (**blue bar**), SWI (**red bar**), maximum NDVI (**dark green bar**) and integrated NDVI (**light green bar**) trends for 50-km coastal strips of the 14 Arctic seas. 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 over the 1982-2007(6) period are shown for each region and all four variables. Statistically significant trends are identified by colored bold percent trend values. The W. Kara / Yamal bars are highlighted. Bhatt et al. 2009 (submitted).

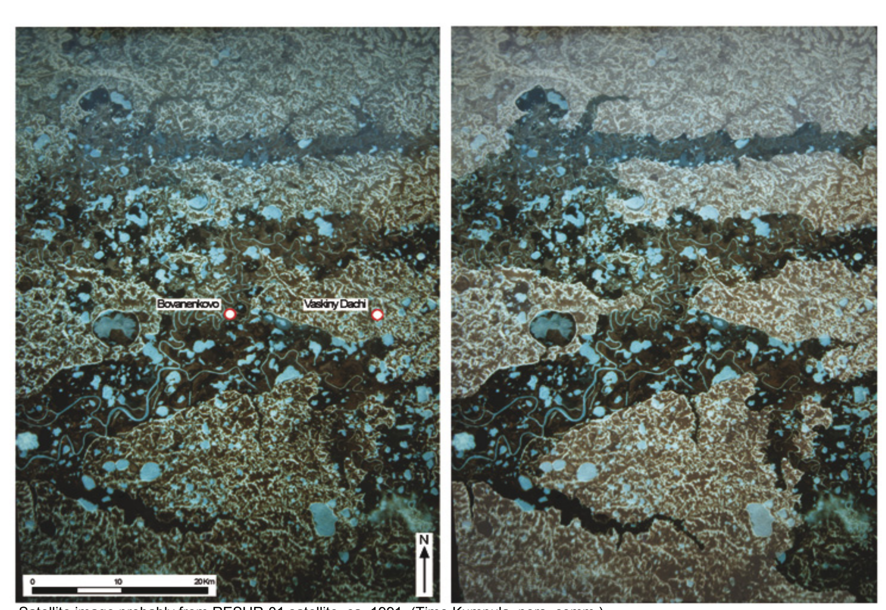
### *Despite only slight warming on the Yamal, NDVI has increased.*

Coastal sea ice has declined 25% over the 24-yr record of satellite observations, and land surface temperatures have increased (+4%).

There have been moderate increases in both the maximum NDVI (+3%) and the integrated NDVI (+5%) — the only such increases along the Eurasian coast between Laptev and Barents seas — indicating that factors other than climate change are influencing the changing greenness patterns.


Bhatt, U. S., D. A. Walker, M. K. Raynolds, J. Comiso, H. E. Epstein, J. Jia, and R. Gens. 2009 In prep. Panarctic linkages between greening of Arctic tundra, summer land temperatures and sea-ice decline.


## Ground observations: Influence of melting permafrost




Satellite image probably from RESUR-01 satellite, ca. 1991, (Timo Kumpula, pers. comm.).

**Fig. 6.** Early-summer Russian satellite image of the Bovanenkovo and Vaskiny Dachi region. Note the broad valleys, up to 10 km wide, with meandering rivers and numerous thaw lakes. The rivers have eroded away the marine terraces that compose the uplands (lighter brown areas), which are highly dissected by mazes of small streams that trap abundant snow in the narrow valleys. The deep snow provides summer water that further promotes the erosion, and landslides occur on the slopes of these small channels (**Fig. 7**). The upland areas on the right hand image are enhanced to provide more contrast between the broad alluvial valleys and the uplands.

**Fig. 7.** Massive tabular ground ice underlies most of the marine terrace uplands. Thermal erosion of this ice is causing rapid expansion of drainage networks, creating valleys that are much greener than the residual terrace surfaces. The present rates of erosion are unknown.

Photos: D.A. Walker and M.O. Leibman

**Fig. 8.** Vegetation succession on landslides (upper two photos) and retrogressive thaw slumps (middle left) results in bright green wet meadows and willow shrublands in about 200 years that are quite unlike the original uplands and persist indefinitely.

## Conclusions

- Despite a strong climate gradient on the Yamal, vegetation production shows only a weak correlation with land temperatures.
- The West Kara Sea/ Yamal region stands out as the only part of the Russian Arctic coastline between the Laptev Sea and Barents Sea where the NDVI values have increased during the past 24 years.
- One possible explanation for the increased NDVI in this region may be interaction with other forms of disturbance, including the rapid thermal erosion of the massive tabular ground ice that underlies the upland surface deposits. Landslides on nearly all hill slopes expose nutrient-rich marine sediments that underlie the ice and eventually develop vegetation that is much greener than the adjacent uplands.
- Satellite images taken in late spring during snow-melt reveal highly dissected uplands that collect deep snow in the valleys. The summer-long supply of water provided by late-melting snow banks further enhance plant productivity, causing the much greener vegetation in the valleys.
- There is high potential for extensive landscape degradation due to the cumulative effects of climate change interacting with other forms of disturbance. The extremely ice-rich permafrost near the surface is particularly vulnerable.
- Ground-based baseline studies are currently in progress that will provide further baseline information on plant species composition, biomass, NDVI, active layer depths and soil properties.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