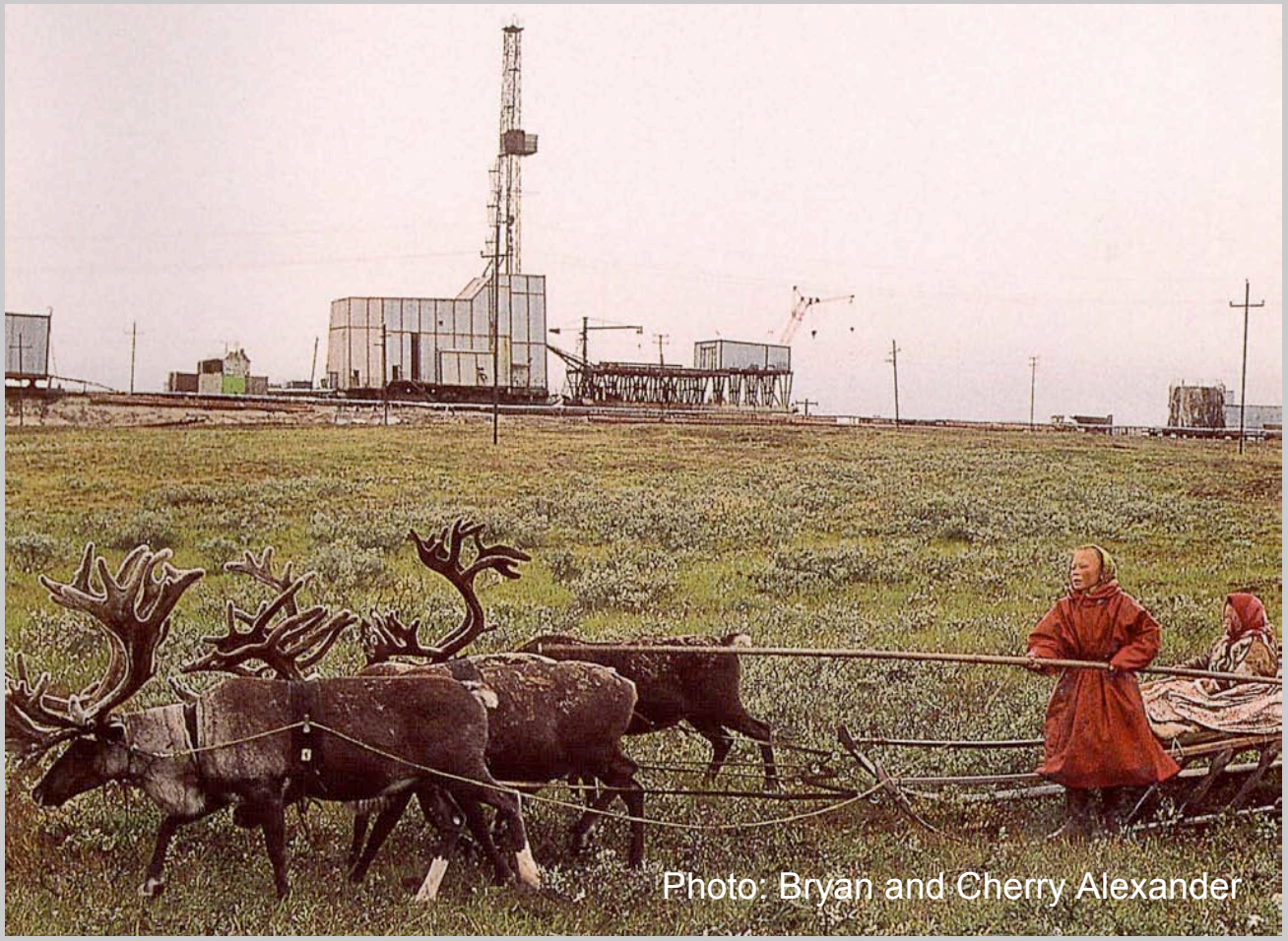
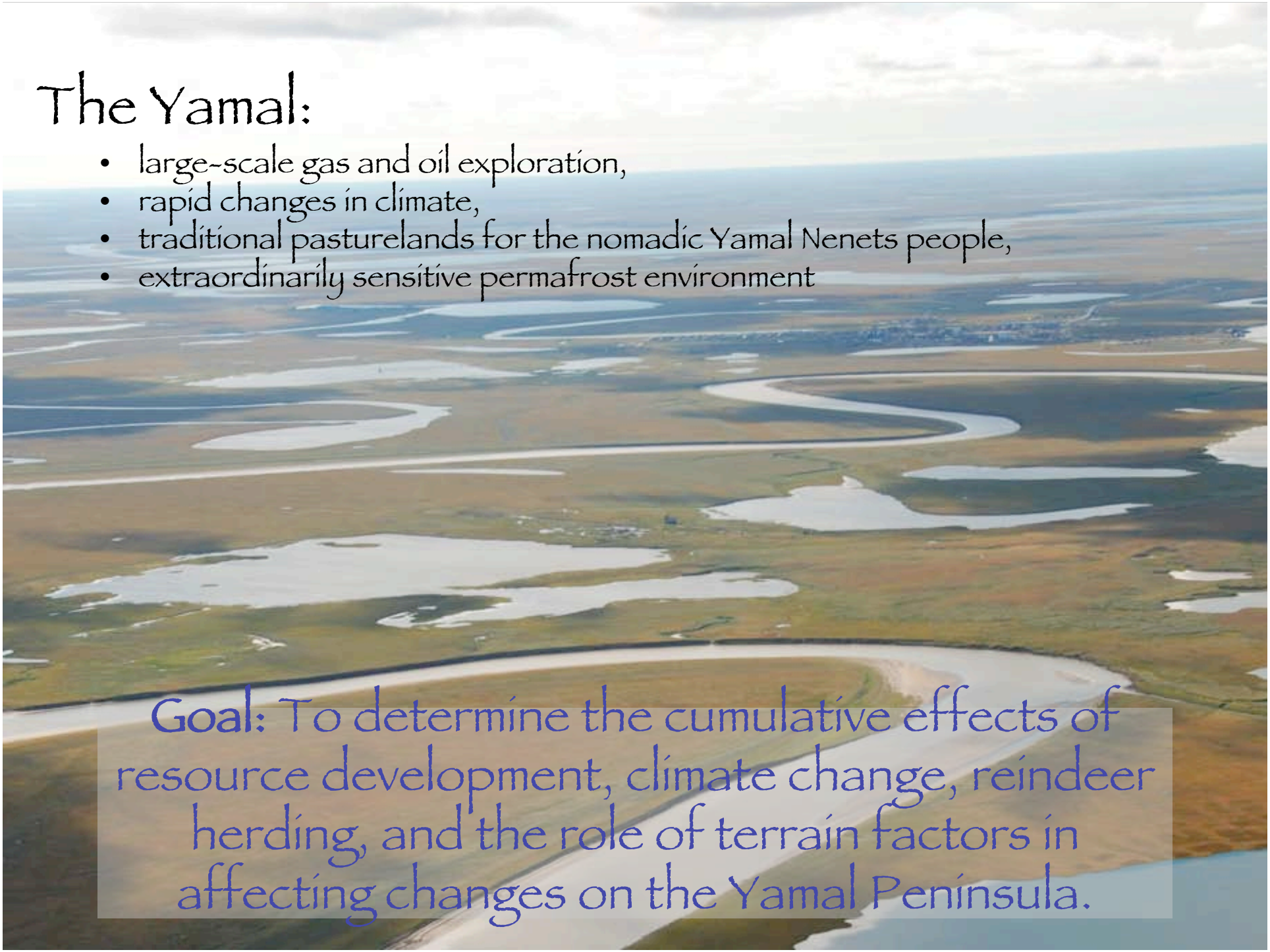
Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia



D. A. (Skip) Walker, University of Alaska Fairbanks,
and many colleagues

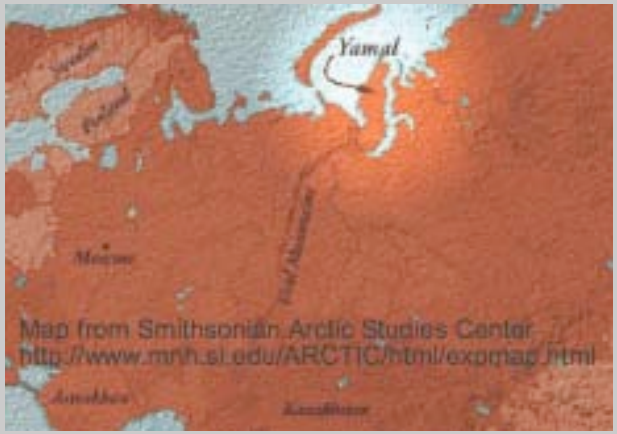


The Yamal:

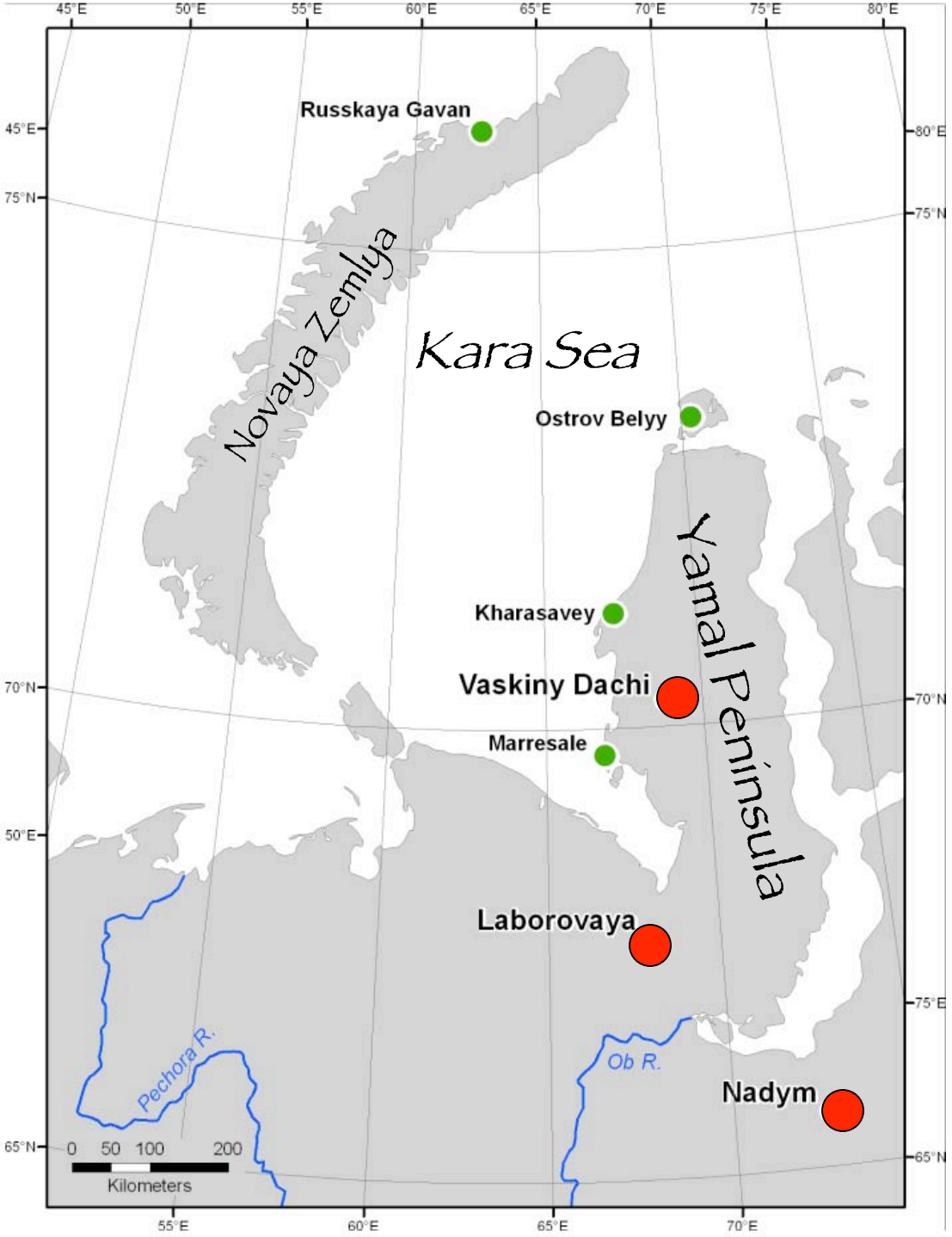
- large-scale gas and oil exploration,
- rapid changes in climate,
- traditional pasturelands for the nomadic Yamal Nenets people,
- extraordinarily sensitive permafrost environment

Goal: To determine the cumulative effects of resource development, climate change, reindeer herding, and the role of terrain factors in affecting changes on the Yamal Peninsula.

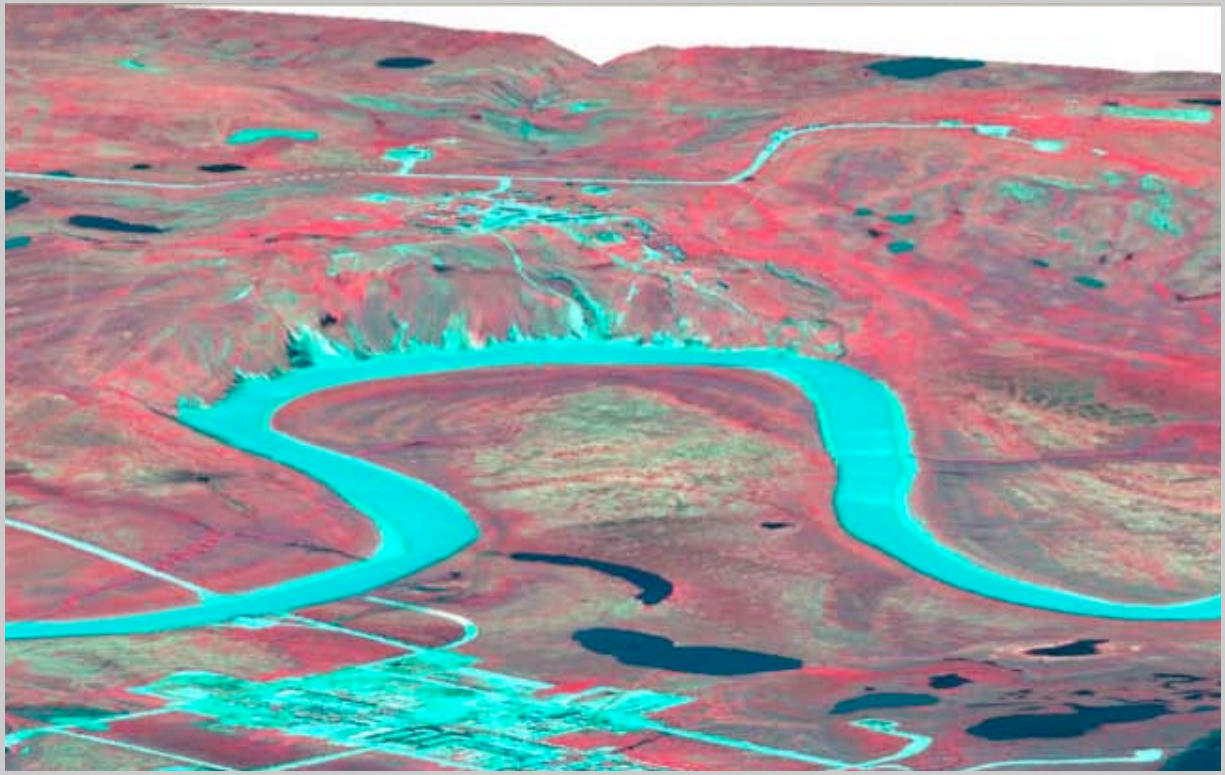
The Yamal Peninsula



- 2007 Yamal Expedition
  - Nadym
  - Laborovaya
  - Vaskiny Dachi
- Planned 2008-2009



Effects of resource extraction:



- Use of remote sensing and GIS to inventory direct and indirect effects of the Bovanenkovo Gas Field.

T. Kumpula: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Detectability of impacts with different sensors

- Quickbird best available sensor for most gas field impacts.
- Better than ground surveys for detecting off-road vehicle trails.

Detectivity / Impact	Field survey	Quickbird-2 Panchromatic	Quickbird-2 Multispectral	ASTER TERRA VNIR	Landsat TM	Landsat MSS
Soil contamination, oil & chemicals	x	–	–	–	–	–
Removal of top soil and vegetation	xxx	xxx	xxx	xx	x	x
Quarries	xxx	xxx	xxx	xxx	xx	x
Garbage						
- metal	xx	–	–	–	–	–
- glass	x	–	–	–	–	–
- concrete	xxx	x	x	–	–	–
- wood	xxx	x	–	–	–	–
Pipelines	xxx	xx	x	–	–	–
Powerlines	xxx	xx	x	–	–	–
Roads	xxx	xxx	xxx	xxx	x	x
Offroad tracks	xx	xxx	xx	xx	x	x
Winter roads	xx	xx	xx	xx	x	–
Drill towers	xxx	xxx	xx	x	–	–
Barracks	xxx	xxx	xx	x	–	–
Trucks/Vehicles	xxx	xx	x	–	–	–
Changes in hydrology	xxx	xxx	xx	xx	x	x

T. Kumpula: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

GIS and remote sensing approach to catalog impacts

Bovanenko gas field

Petroleum exploration related activity

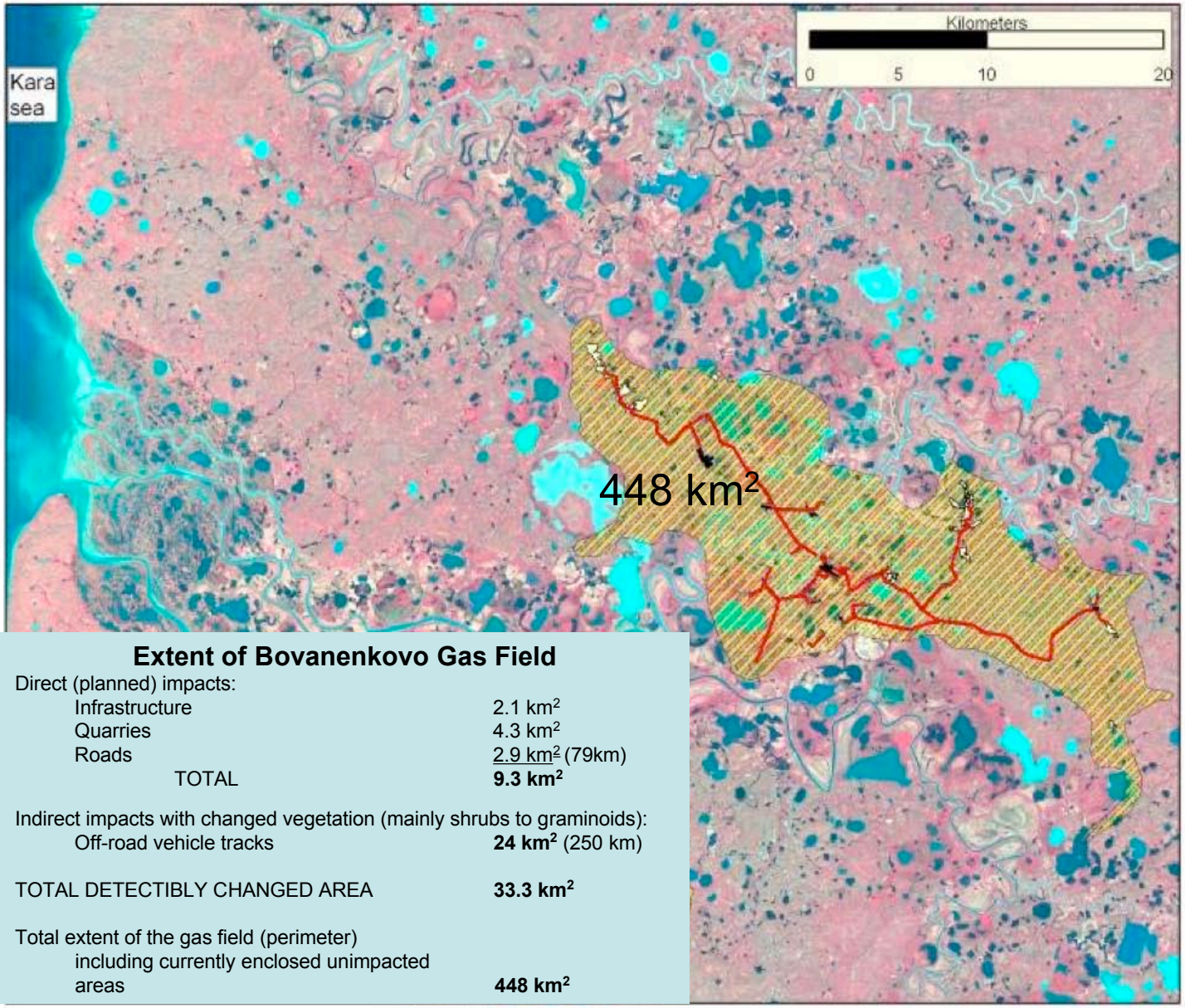
- Main road network
- Zone of effected area
- Sand quarries
- Active infrastructure

GIS database collection

- **Visual interpretation of impacts**
- **Develop digital elevation model from 1:100,000 maps**
- **Digitize boundaries**
  - **Roads**
  - **Pipeline network**
  - **Off-road vehicle trails**
  - **Infrastructure**
  - **Quarries**

Digitized from:
Quickbird-2 image 15.7.2004 (2.4 m resolution)
Aster Terra VNIR image 21.7.2001 (15 m resolution)

Background image:
Landsat TM 07.08.1988



Extent of Bovanenkovo Gas Field

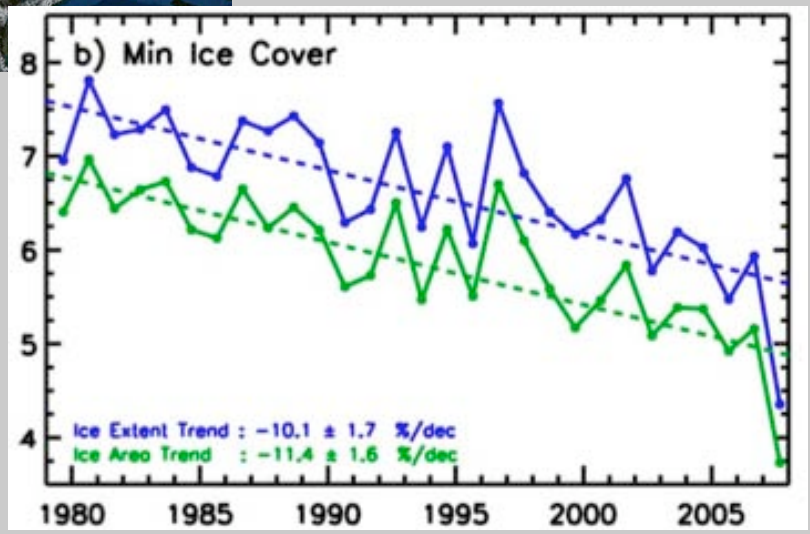
Direct (planned) impacts:	
Infrastructure	2.1 km²
Quarries	4.3 km²
Roads	2.9 km² (79km)
TOTAL	**9.3 km²**
Indirect impacts with changed vegetation (mainly shrubs to graminoids):	
Off-road vehicle tracks	**24 km²** (250 km)
TOTAL DETECTIBLY CHANGED AREA	**33.3 km²**
Total extent of the gas field (perimeter) including currently enclosed unimpacted areas	**448 km²**

Effects of climate change:
Analysis of sea-ice, land surface temperature and NDVI trends

Is the trend in sea-ice affecting Arctic vegetation ?

Since 1980, perennial sea ice extent in the Arctic has declined at the rate of 10.1% per decade.

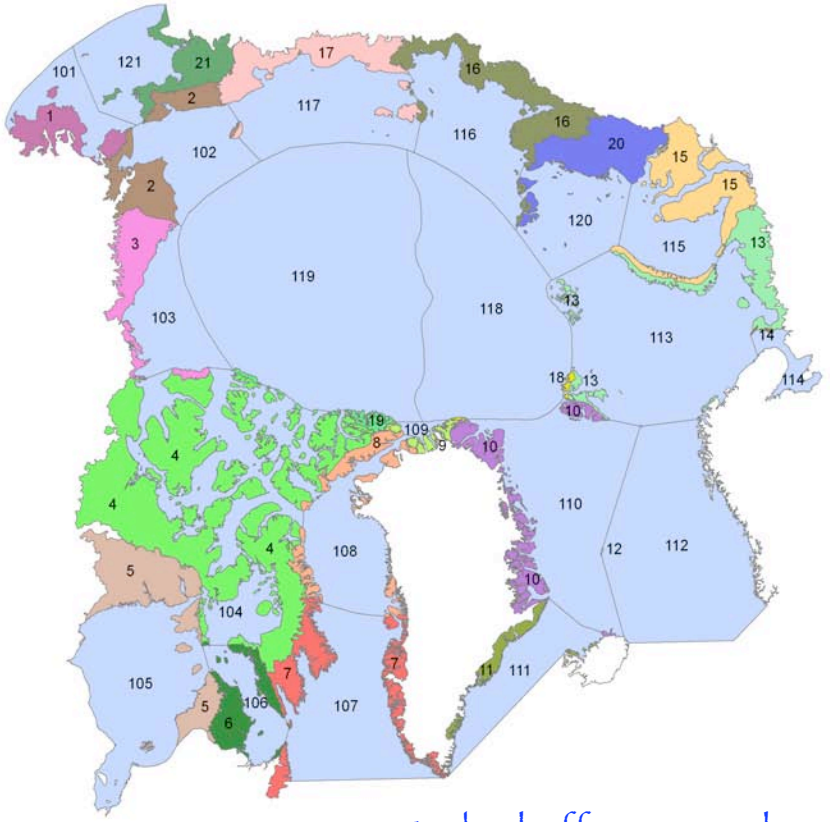
Comiso et al.: 2008, *Geophysical Research Letters*, 35: L01703.



Pan-Arctic variability of sea-ice concentration, land-surface temperatures, and vegetation greenness.

Division of Arctic Ocean and associated land masses according to Russian Arctic Atlas and Circumpolar Arctic Vegetation Map

101 & 1* East Bering Sea
102 & 2 Chukchi Sea
103 & 3 Beaufort Sea
104 & 4 Canadian Arch. Straits
105 & 5 Hudson Bay
106 & 6 Hudson Strait
107 & 7 Davis Strait
108 & 8 Baffin Sea
109 & 9 Lincoln Sea
110 & 10 Greenland Sea
111 & 11 Denmark Strait
112 & 12 Norwegian Sea
113 & 13 Barents Sea
114 & 14 White Sea
115 & 15* West Kara Sea
116 & 16 Laptev Sea
117 & 17 East Siberian Sea
118 & 18 Russian Arctic Basin
119 & 19 American Arctic Basin
120 & 20* East Kara Sea
121 & 21* West Bering Sea
*Treshnikov basin divided for purposes of this study



50-km buffer seaward and landward of coastline in each sea

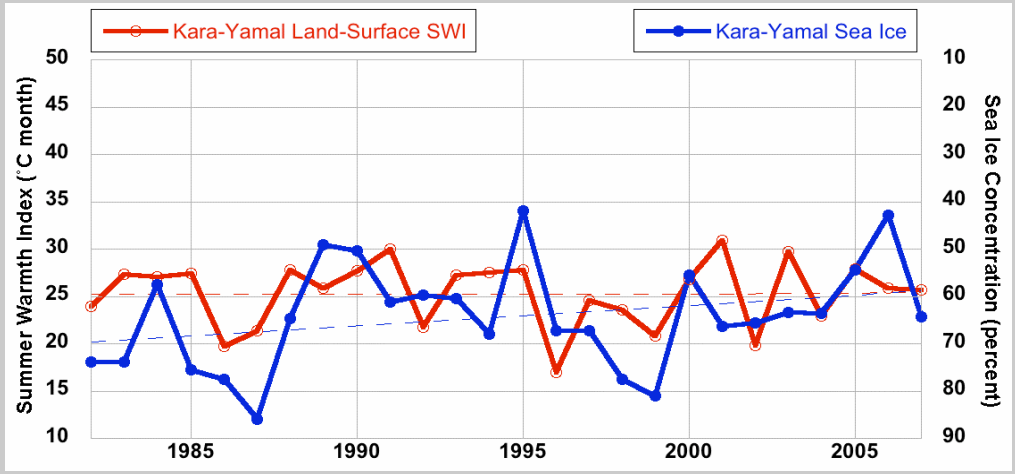
Polar stereographic projection (J. Comiso)
Map by M. Raynolds, March 2008

Bhatt et al.: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Sea-ice and temperature trends in Kara/Yamal region of Russia and Beaufort Sea

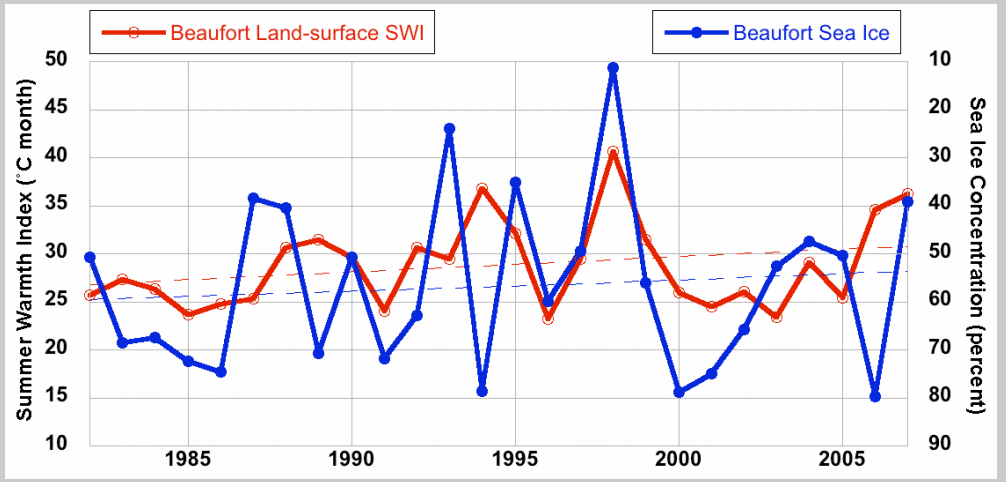
Kara/Yamal

- Negative sea-ice trend but nearly flat temperature trend



Beaufort

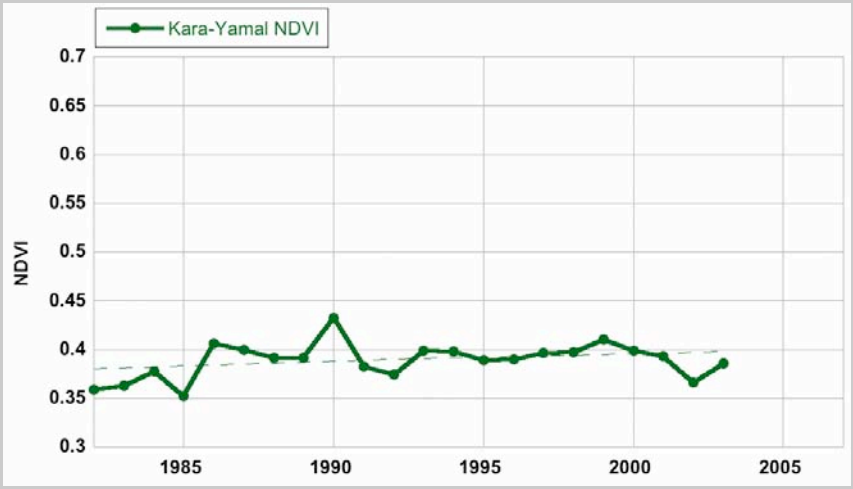
- High year-to-year variability
- Negative sea-ice trend correlated with positive temperature trend



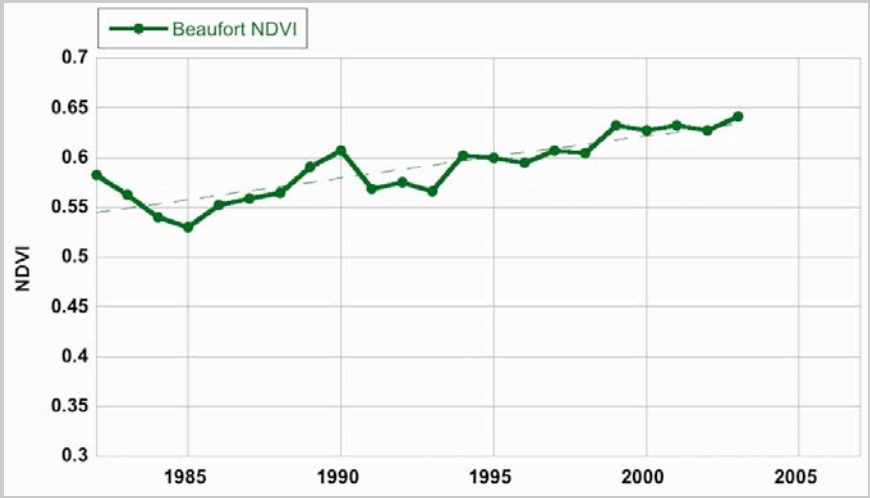
Bhatt et al.: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

NDVI trends in Kara/Yamal region of Russia and Beaufort Sea

Kara/Yamal



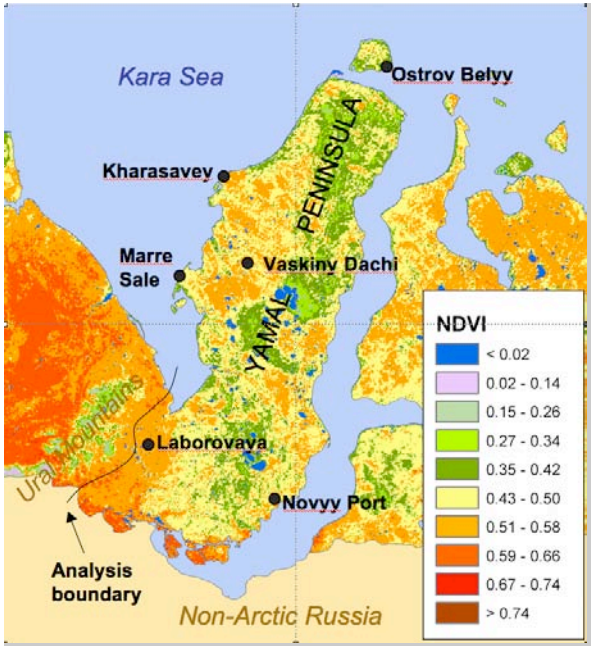
Beaufort

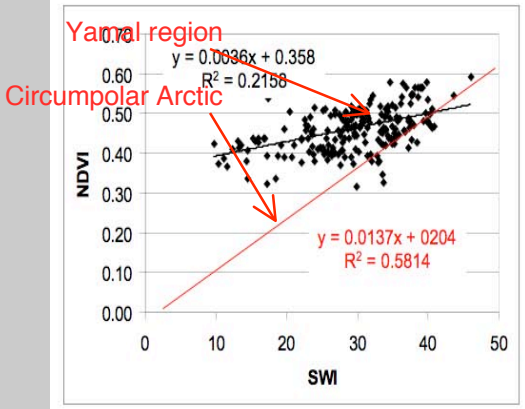


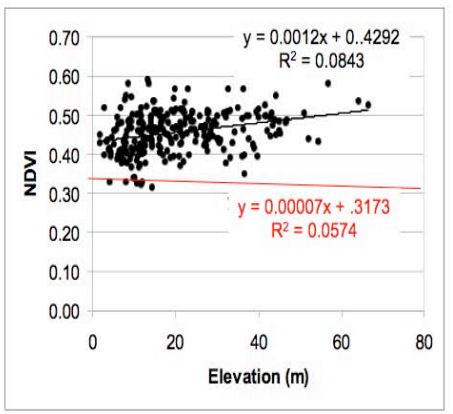
- Much lower NDVI on the Yamal is likely due to sandy wind-blown nutrient-poor soils, and grazing by reindeer.
- Greater change in Beaufort Region (+0.04 vs. +0.0085 NDVI units/decade) most likely due to more positive trend in ground surface temperatures in the Beaufort region during the period of record.

Bhatt et al.: EGU, Vienna, Proceedings, 2008.

Other effects on NDVI







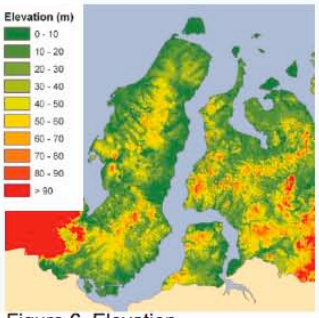


Figure 6. Elevation

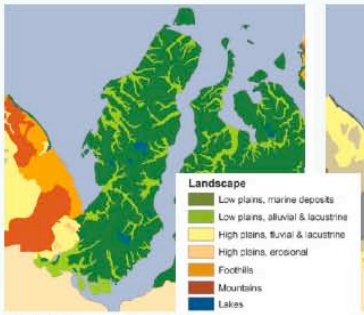


Figure 7. Landscape

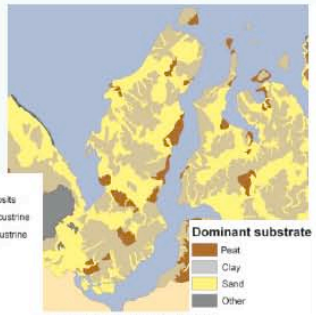


Figure 8. Substrate

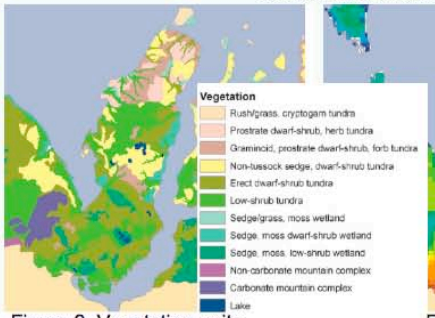


Figure 9. Vegetation units

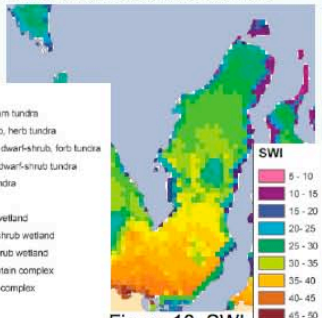


Figure 10. SWI

Figure 11. Percent Lake Cover

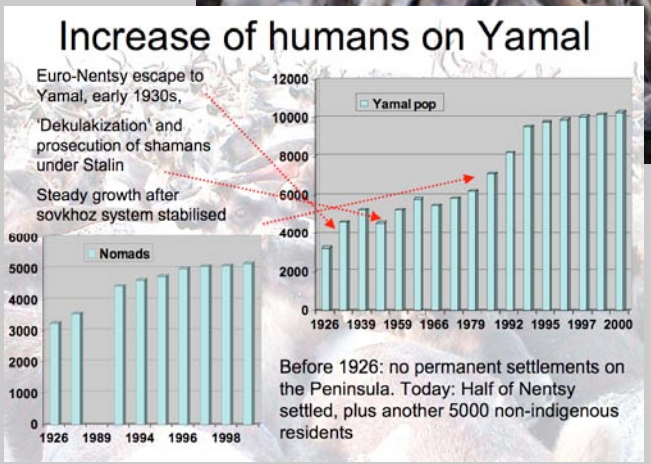
Results from General Linear Model

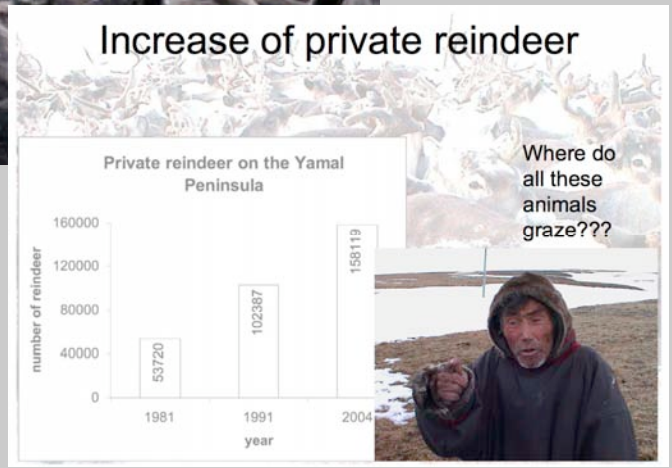
	Df	Deviance	Residual Df	Residual Deviance	% Deviance accounted for	Signi-ficance
Null			280	2.06516		
Elevation	0.60322	0.60322	279	1.46194	**29.21**	< 2e-16 ***
Land-schaft	0.40732	0.40732	278	1.05462	**19.72**	< 2e-16 ***
Lithology	0.10083	0.10083	277	0.9538	**4.88**	2.91e-07 ***
Veget-ID	0.08868	0.08868	276	0.86512	**4.29**	3.50e-06 ***
SWI	0.03856	0.03856	275	0.82655	**1.87**	1.12e-04***
Lake area	0.03245	0.03245	274	0.7941	**1.57**	9.34 e-04***
TOTAL					**61.55**	

- Weak correlation between SWI and NDVI on Yamal compared to circumpolar.
- Summer warmth explains only 2% of the regional spatial variation of NDVI on the Yamal!
- Elevation, landscape type, vegetation type, and substrate explain 58%.

Raynolds et al.: 2008, Yamal LCLUC Workshop, Moscow.

Impacts of and to the Nenets people and their reindeer





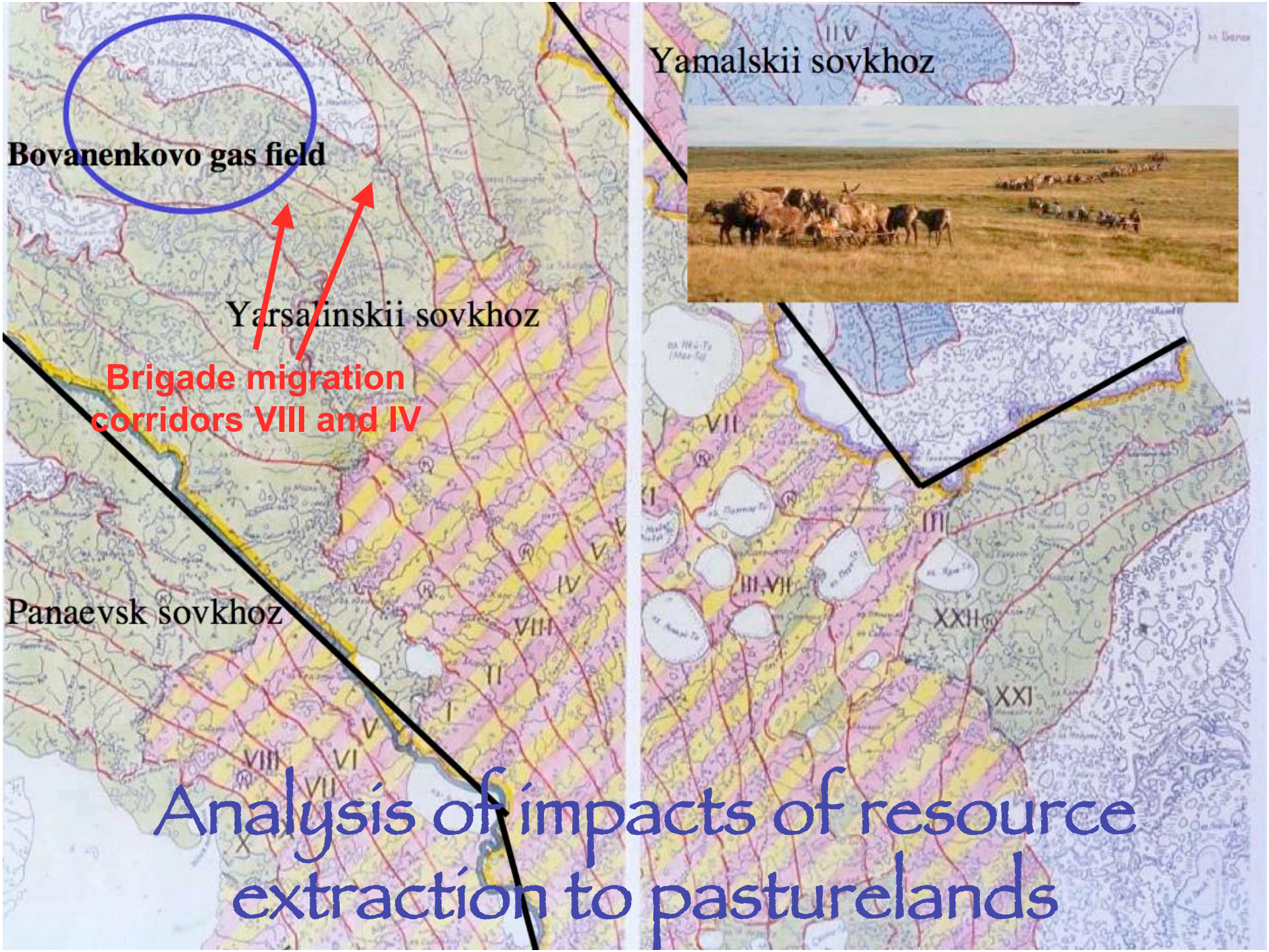
Florian Stammler: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Effects of reindeer herding

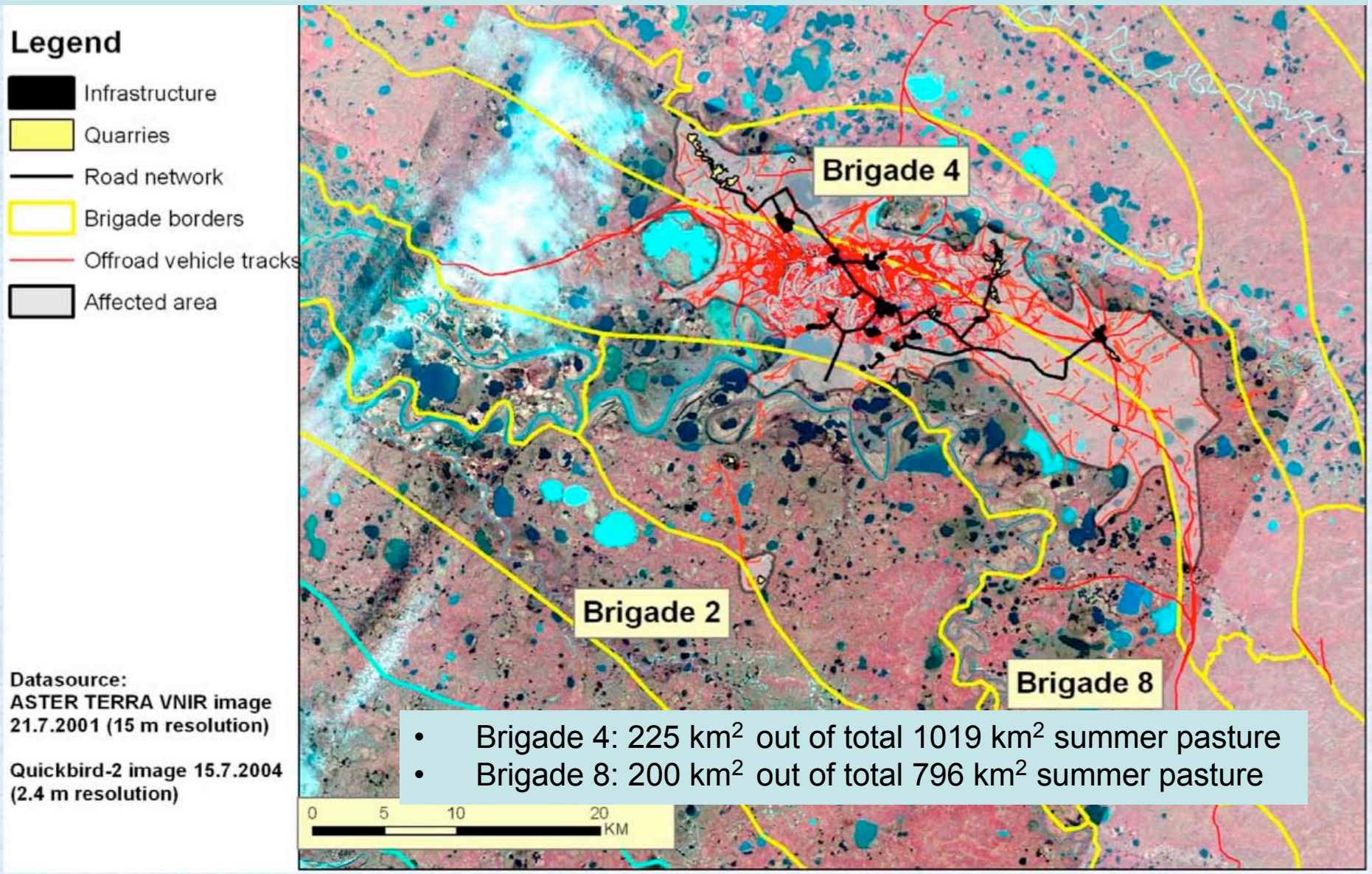
- Overgrazing
- Trampling
- Grassification
- Wind erosion

Photos: Bruce Forbes.

Quantification of wind deflated areas with satellite imagery: T. Kumpula: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008


Bovanenkovo gas field
Yamalskii sovkhoz
Yarsalinskii sovkhoz
Brigade migration corridors VIII and IV
Panaevsk sovkhoz
Analysis of impacts of resource extraction to pasturelands

Impacts of Bovanenkovo gas field to summer pasture of Brigades 4 and 8



- Brigade 4: 225 km^2 out of total 1019 km^2 summer pasture
- Brigade 8: 200 km^2 out of total 796 km^2 summer pasture

2007 Expedition to Yamal Peninsula Region, Russia

Goals:

- Collection of ground observations to support remote-sensing climate-change studies on the Yamal and circumpolar region.
- Learn about environmental controls on primary production in the region.

Members of the Expedition:

Nadym

Laborovaya and Vaskiny Dachi

Logistics:

Data collected:

Soils

Plant Cover

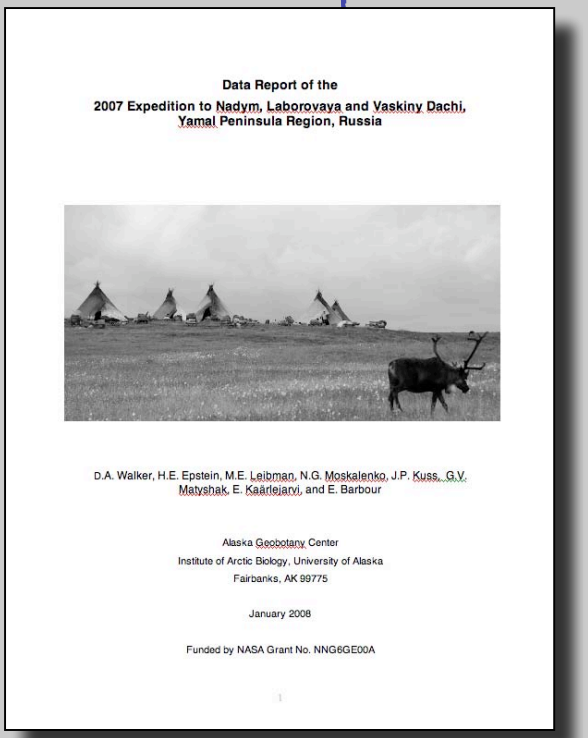
NDVI & LAI

Ground temperatures

Active layer

Plant Biomass

Data Report



Data Report of the
2007 Expedition to Nadym, Laborovaya and Vaskiny Dachi,
Yamal Peninsula Region, Russia

D.A. Walker, H.E. Epstein, M.E. Leibman, N.G. Moskalenko, J.P. Kuss, G.V. Matyshak, E. Kaärlejarvi, and E. Barbour

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

January 2008

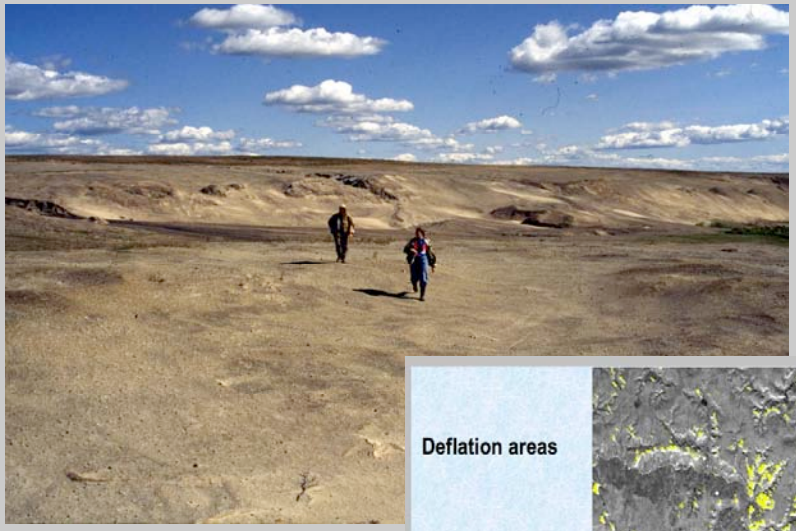
Funded by NASA Grant No. NNG6GE00A

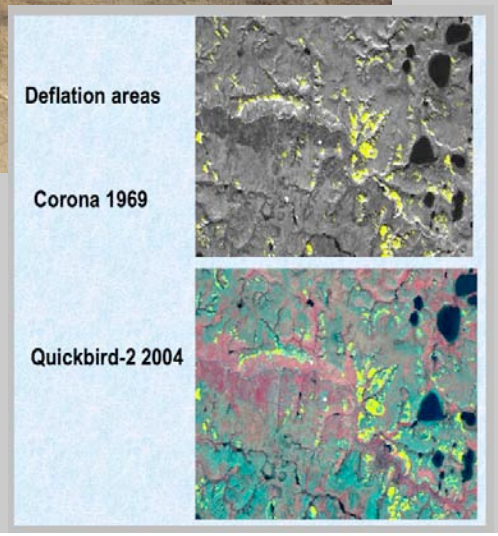
http://www.geobotany.uaf.edu/yamal/documents/yamal_2007_dr080211

Terrain factors that make the Yamal region so sensitive to terrain disturbance

Sandy nutrient poor soils:

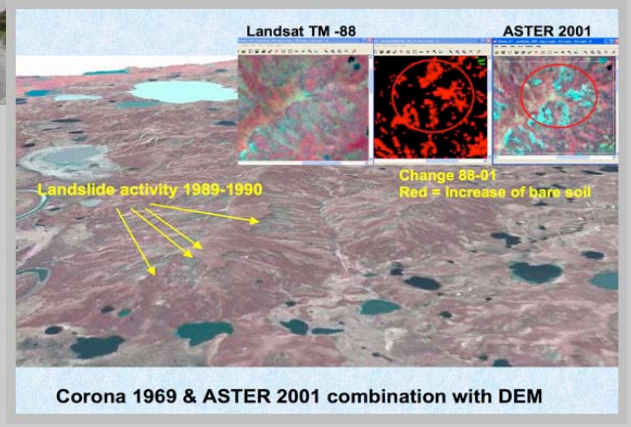
- Highly susceptible to wind erosion.
- Poor plant production, low plant diversity, slow recovery.





Extreme massive ground ice conditions:

- Extreme ice-rich permafrost makes the region very susceptible to landslides.



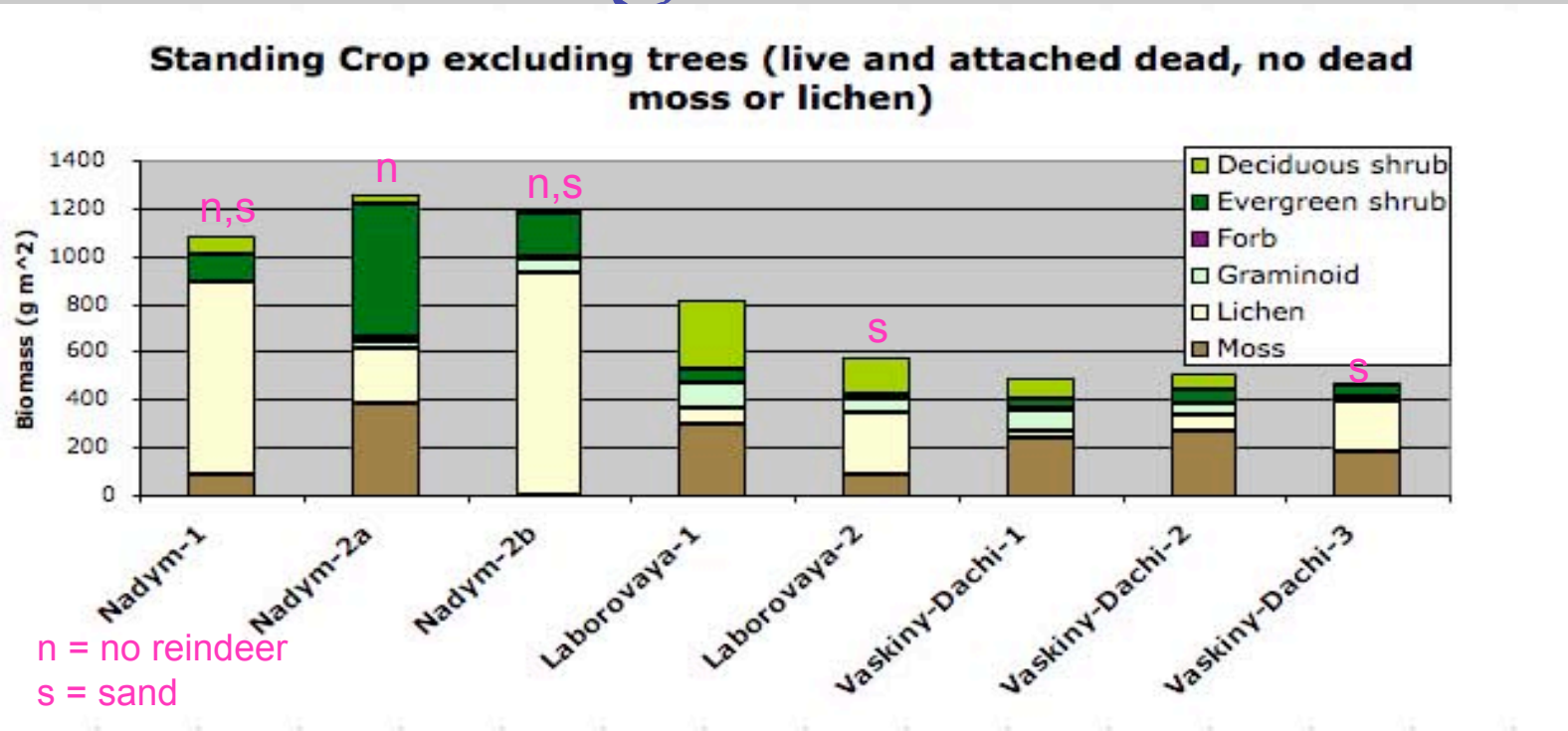
T. Kumpula:
Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Vaskiny Dachi: Unique vegetation successional sequences related to Quaternary history, massive ground ice, landslides and soils

- Dense willow thickets develop on old landslides after leaching of salts from clayey marine sediments.

Ukraintseva and Liebman: 2007, 1st North American Landslide Conference, Vail, CO.

Biomass along the Yamal transect

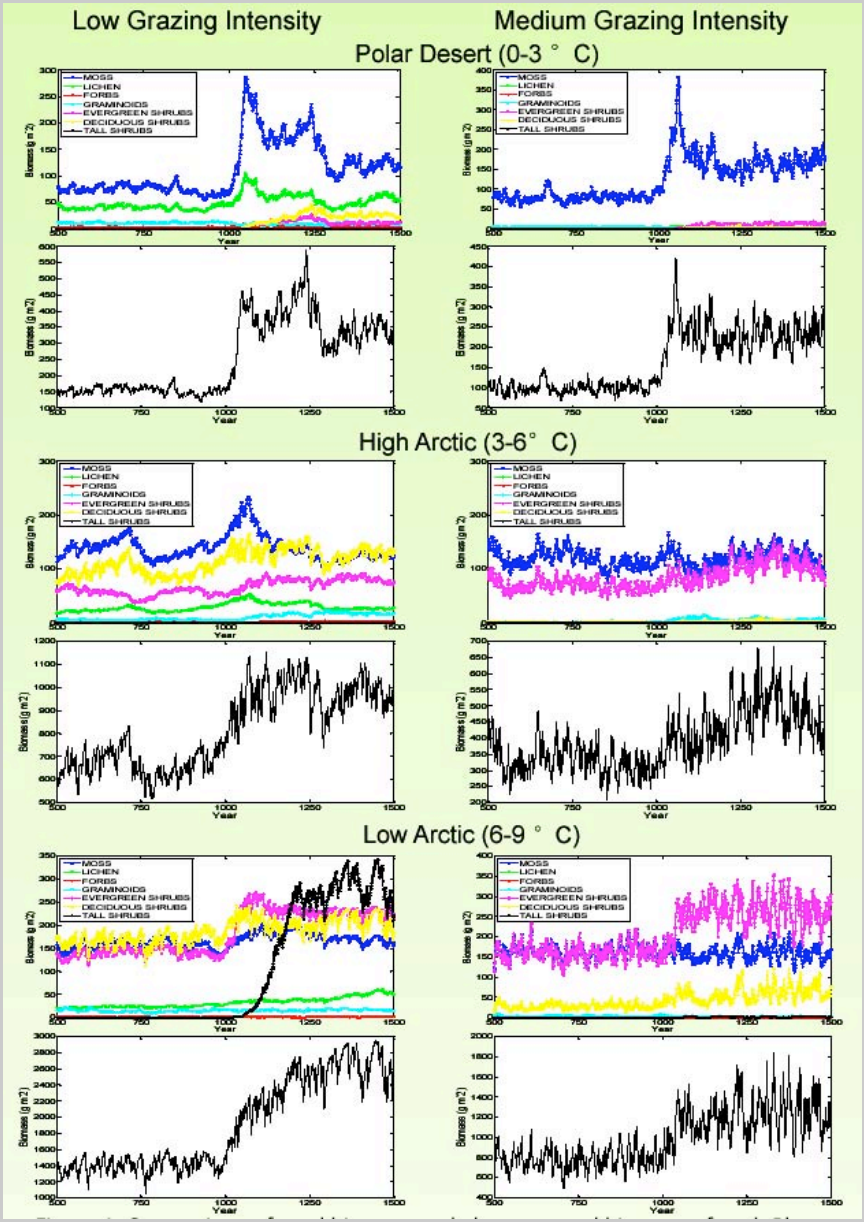


Climate trend:
2000–2300 g m^{-2} at Nadym to about 1000–1300 g m^{-2} at Vaskiny Dachi.

Effect of sandy soils:
- Sandy soils have 250–350 g m^{-2} less biomass than comparable clayey sites
- Much more lichen biomass and less mosses and graminoids.

Effect of reindeer:
- Ungrazed sandy areas near Nadym – over 1000 g m^{-2}
- Less than 250 g m^{-2} in sandy areas where reindeer grazing has occurred annually.

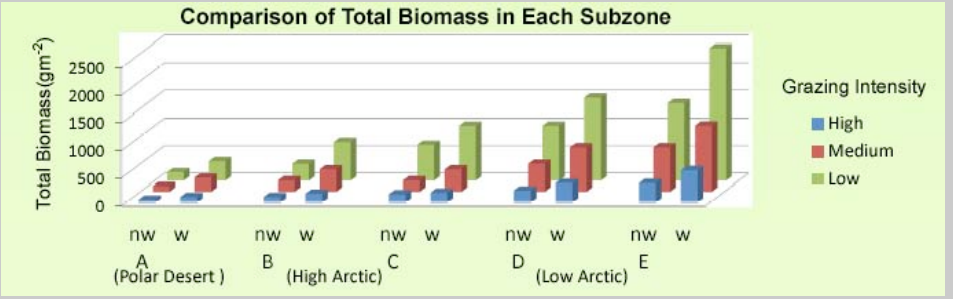
Walker et al:
Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.
Epstein et al:
EGU Vienna Proceedings 2008.

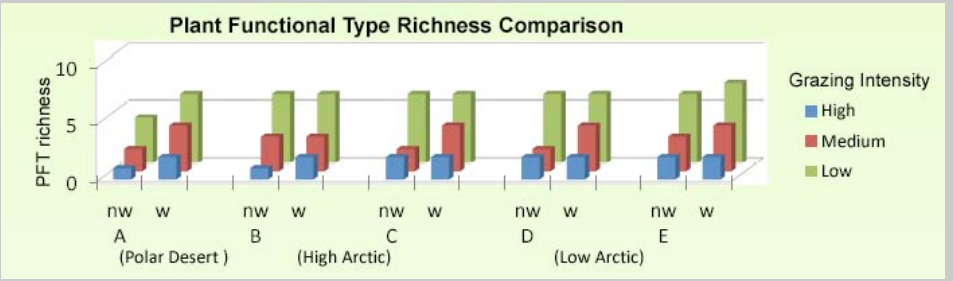


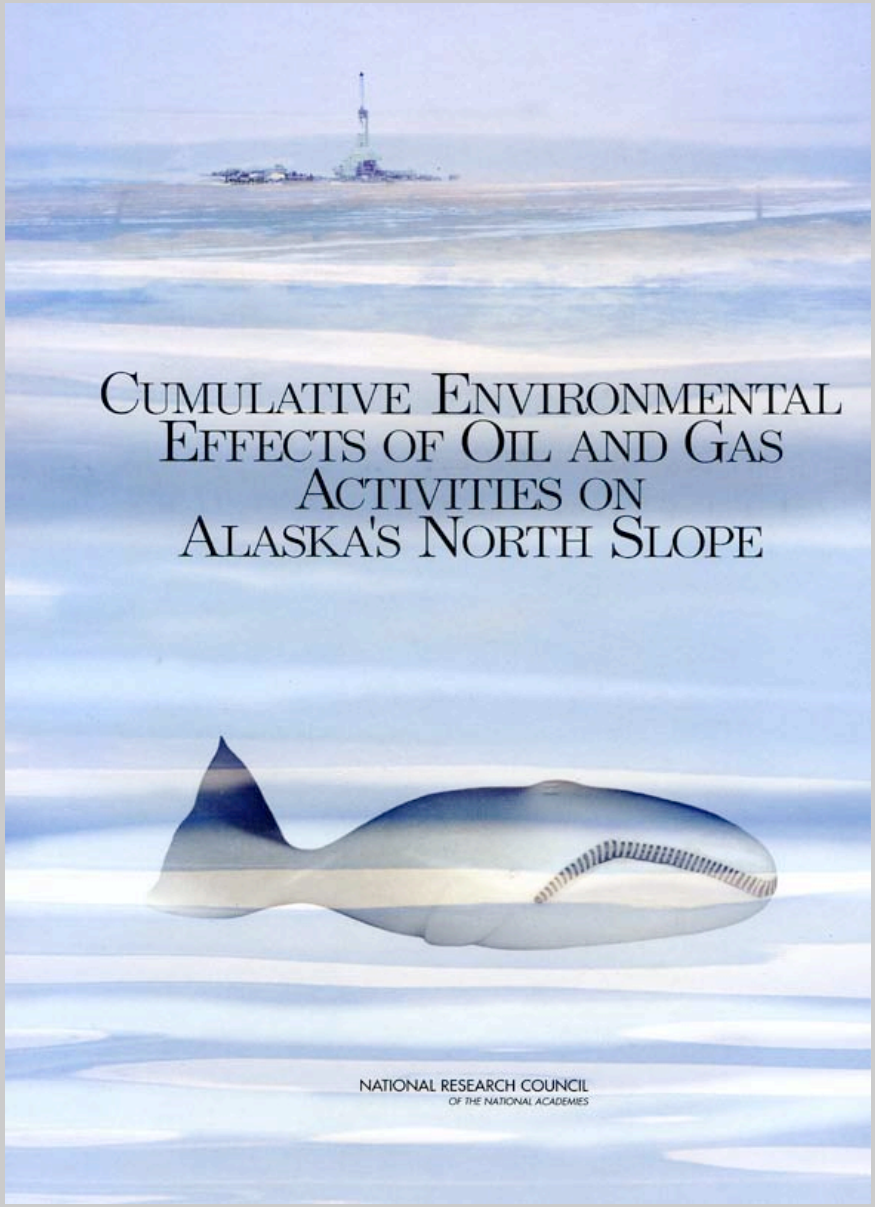
Yu and Epstein: 2008, EGU conference.

Modeled productivity of PFTs on the Yamal

- ArcVeg model (Epstein et al. 2002)
- Examines succession of biomass for seven Arctic plant functional types.
- Five climate scenarios.
- Warming vs. non-warming treatments.
- Three grazing intensities.
- Next steps will incorporate soil type and disturbance regimes (dust and complete removal of vegetation), relate to NDVI and develop regional extrapolations.







National Research Council 2003

Comparative study with Alaska oil and gas development

Examination of Similarities and Dissimilarities:

- Resource development effects
- Traditional land-use effects
- Climate change

Comparison of Cumulative Effects

- Development of predictive biomass models
- Lessons learned in both regions,
- Development of generalities for application in other new areas of developments

Walker et al.: in progress, in Gutman et al. LCLUC book.

Greening of the Arctic
An IPY Initiative

Authors

D.A. Walker, U.S. Bhatt, V.E. Romanovsky, G.P. Kofinas, M.K. Raynolds, University of Alaska, Fairbanks, AK, USA,
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B.C. Forbes, F. Stammler, E. Karlejäarvi: Arctic Centre, Rovaneimi, Finland,
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J.C. Comiso: NASA Goddard, USA,
J.P. Kuss: Institute of Plant Science, University of Bern, Switzerland
G.J. Jia: REC-TEA, Chinese Academy of Science, Beijing, China,
J.O. Kaplan: Swiss Federal Institute for Forest, Snow &. Landscape Research, Lausanne, Switzerland
G. Matyshak: Faculty of Pedology, Moscow State University,Russia

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NASA Land Cover Land Use Change Initiative, Grant No. NNG6GE00A
NSF Grant No. ARC-0531180, part of the Synthesis of Arctic System Science initiative.
Finnish participation came from the Russia in Flux program of the Academy of Finland (Decision #208147).

The project is part of the Greening of the Arctic project of the International Polar Year and the Northern Eurasia Earth Science Partnership Initiative (NEESPI).

General sea-ice, NDVI, climate trends

- Summer land-surface temperature, winter sea-ice concentrations, and integrated NDVI are correlated at all spatial scales.
- Preseason large-scale climate forces the sea ice while local circulation patterns play a larger role during the summer.
- Although there is a correlation between NDVI and the summer temperature, summer temperature accounts for only a small proportion of the total variation in NDVI on the Yamal. Other factors such as substrate, vegetation type, and major physiographic boundaries play a much larger role than temperature.

Conclusions

Resource development:

- Direct (planned) impacts less extensive than indirect impacts.
- Roads and pipelines: serious barriers to migration corridors.
- Effects will increase as new field are developed.

Reindeer herding:

- Land withdrawals by industry, increasing Nenets population, and larger reindeer herds are all increasing pressure on the rangelands.
- Herders view: Threats from industrial development much greater than threats from climate change,but they generally view the gas development positively because of increased economic opportunities.

Climate change:

- Climate change effects are currently hard to document because of lack of long-term ground observations.
- Satellite data suggest that there has been only modest summer land-surface warming and only slight greening changes across the Yamal during the past 24 years.
- Summer temperature controls only small amount of total variation in NDVI on Yamal. Terrain factors are more important.

Landscape factors and terrain sensitivity:

- High potential for extensive landscape effects due to unstable sandy soils, and extremely ice-rich permafrost near the surface.

Comparison with North American Arctic hydrocarbon development:

- Useful insights regarding generality of Yamal observations and lessons to be learned for other areas of Arctic developments.

AVHRR 1980-2007 Trends

- Mid July Sea Ice percentage cover
- Summer warmth index (SWI)
- Max NDVI
- Integrated NDVI

Bhatt, Walker, Raynolds, Comiso: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008, and EGU 2008.

Correlations between climate indices SWI, sea ice, & integrated NDVI

50-km zones with climate indices during preceding winter (DJFM)

Showing bold values with significance at 90% level or greater

Correlation	Sea Ice			Summer Warmth			Integrated NDVI		
	NAO	AO	PDO	NAO	AO	PDO	NAO	AO	PDO
Barents	-0.38	-0.34	0.26	**0.45**	0.28		0.16		-0.15
Kara-Yamal	**-0.41**	-0.31	0.32	0.28	0.11		0.11		-0.22
Laptev	**-0.52**			0.38	0.23	-0.30	**0.56**	**0.47**	**-.52**
E.Siberian	**-0.50**	**-0.59**	**0.42**	0.37	0.38	-0.36		**0.49**	**-.60**
Beaufort		-0.14	-0.28	**0.52**	**0.33**				-0.15

- Throughout the Arctic including the Yamal, the general trend is positive summer warmth and NDVI with positive phases of the North Atlantic Oscillation and Arctic Oscillation, and negative correlations with positive phases of the PDO.

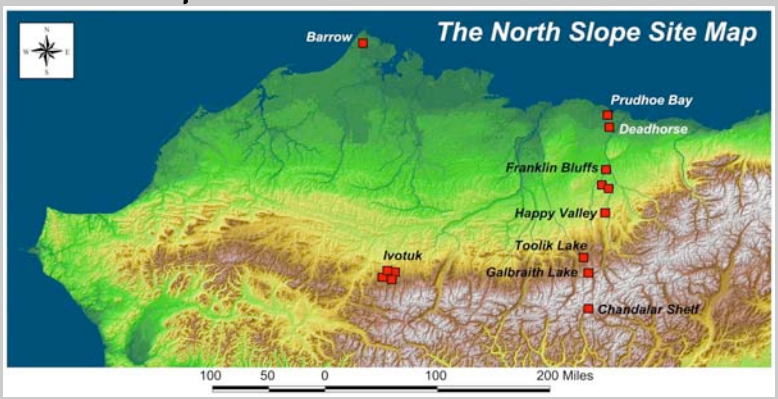
Combining remote sensing and traditional knowledge

"…in addition to taking part in daily life and seeing with our own eyes exactly how the animals are managed we … do more formal semi-structured interviews. Some of these are recorded on either digital tape or film, or both. In these cases we have medium or very high resolution satellite imagery of the areas we are discussing to focus on specific places and features that the herders can recognize easily."

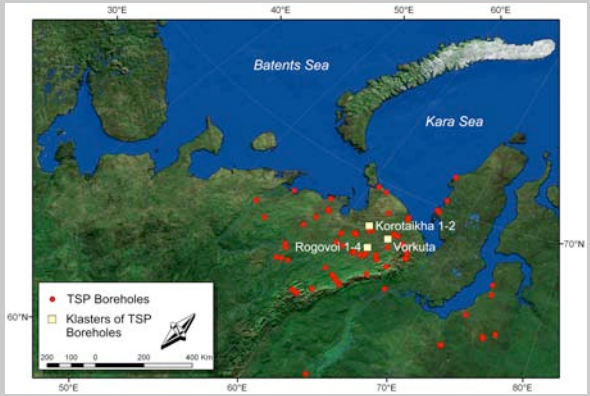
Photo and quote: Bruce Forbes

Permafrost temperatures

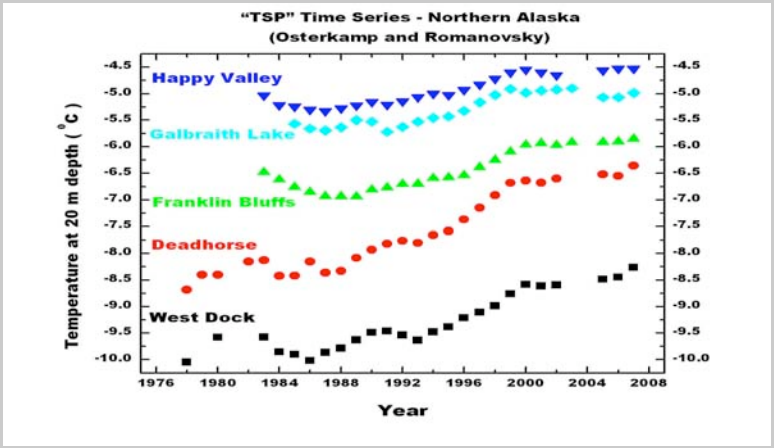
North Slope, Alaska

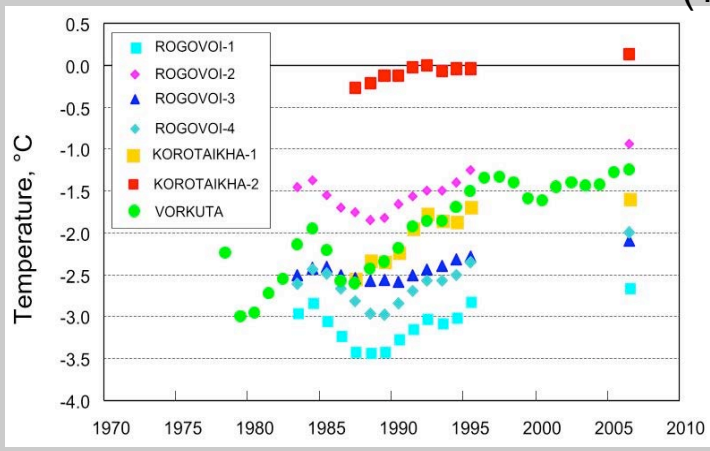


Yamal Region, Russia



- Cooling mid-1980s
- Warming to late 1990s
- Stable 2000 to present
- Strongest warming near the Beaufort coast (+1.5 – +2.0 ˚C)





Russia data from N. Oberman, MIREKO

Romanovsky et al.: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.