# Yamal LCLUC Synthesis

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

NASA-LCLUC All-Scientist Meeting, Bethesda, MD, 18-19 April 2016

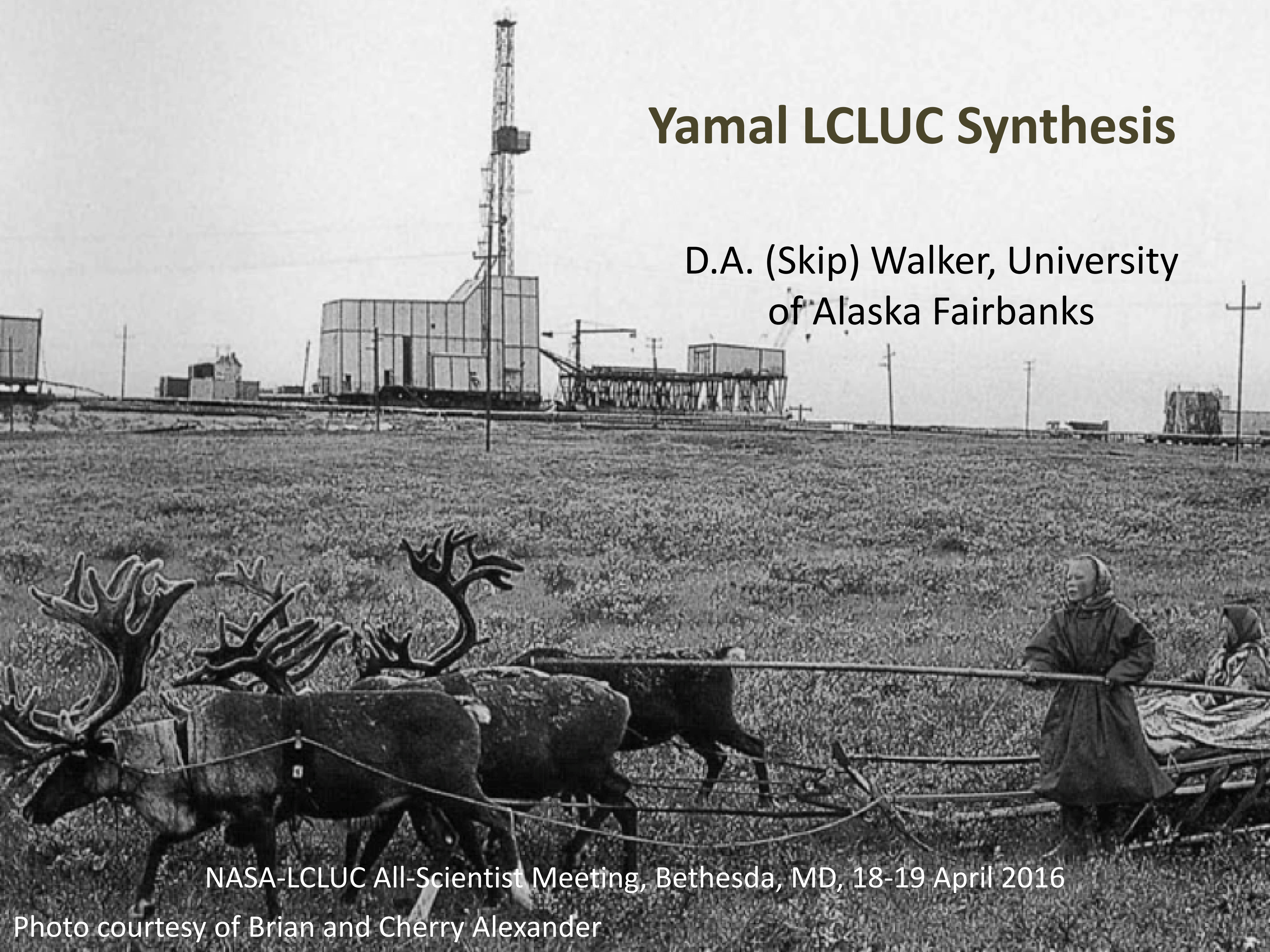
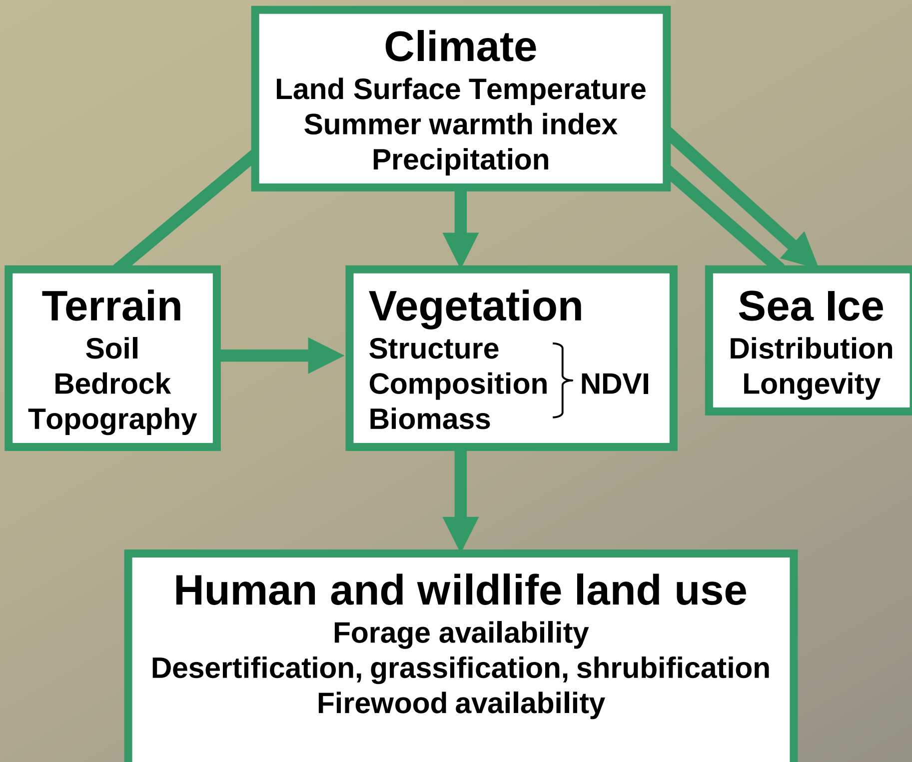
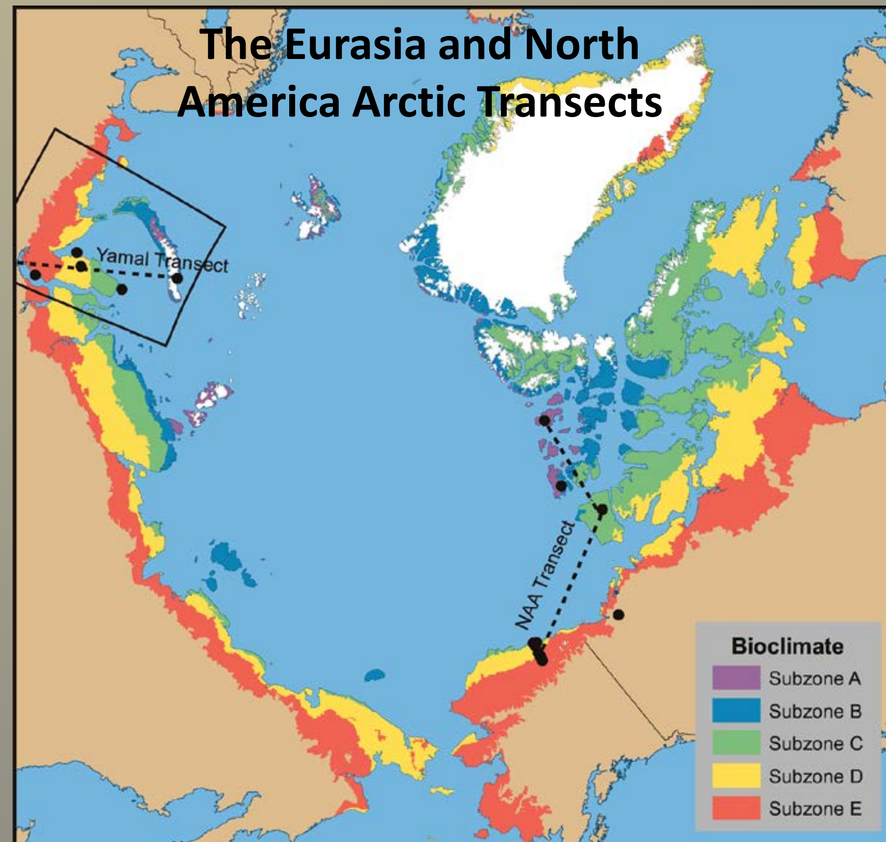


Photo courtesy of Brian and Cherry Alexander

# Yamal LCLUC began as the IPY 2007-2008 Greening of the Arctic project




Two Arctic transects to examine sea-ice, land-temperature, vegetation, human interactions

# Why the Yamal?

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

- Great transect through the full Arctic bioclimate zone
- Large-scale gas development plans
- Well-studied socio-ecological system of the Yamal Nenets people
- Extraordinarily sensitive but well-studied permafrost environment
- Rapid changes in near-shore sea ice and climate

- **Opportunity to compare and contrast with similar development at Prudhoe Bay oil field, AK and bioclimate along the NAAT.**

**Goal**: Develop tools using remote sensing and modeling to better predict the cumulative effects of climate change, resource development, traditional land use, and the role of terrain factors in affecting changes in tundra regions.

# Thank you, Garik, Chris, and Pasha!

***LCLUC and NEESPI gave us the opportunity we were looking for.***

# Major Components of the Synthesis

1. **Eurasia Arctic Transect**
2. **Social-ecological effects of rapid infrastructure and climate changes**
3. **Modeling and remote sensing tools**

# Yamal Synthesis collaborating groups:

**USA**

***University of Alaska Fairbanks:***

Uma Bhatt (Co-PI, circumpolar climate, sea-ice, vegetation interactions)

Marcel Buchhorn (GIS, remote sensing, mapping)

Gary Kofinas (Co-PI, socio-ecological dimensions)

Martha Raynolds (Circumpolar vegetation remote sensing, GIS)

Vladimir Romanovsky (Co-PI, Permafrost)

Donald (Skip) Walker (PI, vegetation science and mapping)

*University of Virginia:*

Howard Epstein (Co-PI, modeling and ecosystem analysis)

Gerald (JJ) Frost (Ph.D. student, now at ABR, Fairbanks, Kharp alder studies, vegetation analysis

Qin Yu (Ph.D. student,now at George Washington U. ArcVeg Model)

***NASA Goddard:***

Joey Comiso (Arctic Sea Ice and land temperatures)

Jorge Pinzon (Arctic NDVI, GIMMS 3g data set)

Compton (Jim) Tucker

**Russia**

***Earth Cryosphere Institute, Tyumen and Moscow***

Dmitri Drosdov (ECI Director, Landschaft databases)

Marina Leibman (Permafrost, Russian lead PI)

Artuom Khomutov (Ph.D. student, active layer-landscape relationships)

***Lomonosov Moscow State University:***

George Matyshak (soil scientist)

***Komarov Botanical Institute, St. Petersburg***

Olga Khitun (Yamal flora)

**Finland**

***University of Eastern Finland, Joensuu***

Timo Kumpula (Finnish lead PI, Oil development impacts)

***Arctic Centre, University of Lapland, Rovaniemi***

Bruce Forbes (socio-ecological dimensions, vegetation, ENSINOR coordination)

**Germany:**

***Alfred Wegener Institute, Potsdam, Germany:***

Annett Bartsch (Remote Sensing, DUE GlobPerafrost)

Birgit Heim

**Major components of the synthesis**

# Component 1: The Eurasia Arctic Transect (EAT)


***Members of the 2010 Expedition to Hayes Island.***

*Marina Liebman, Artem Khomutov, Andrey Abramov, Dmitriy Drozdov, Elena Slagoda, G.V. (JJ) Frost, Pavel Orekhov, Ina Timling, Andrey Ermak, D.A. (Skip) Walker, Ivan Gameev, Grigory Matyshak*

# Five EAT expeditions

**2007**

- Nadym
- Laborovaya
- Vaskiny Dachi

**2008**

- Kharasavey

**2009**

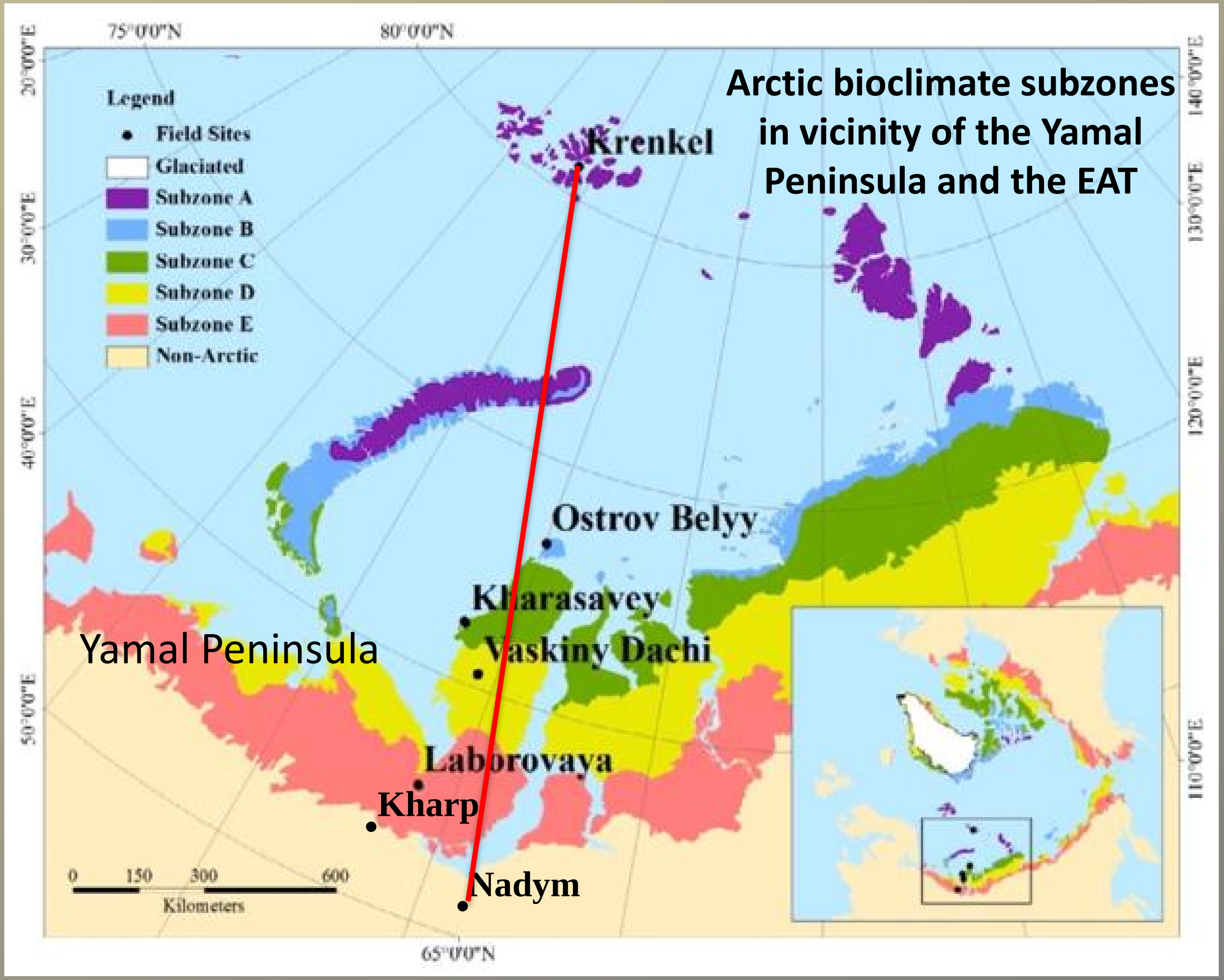
- Ostrov Belyy

**2010**

- Krenkel, Franz Jozef Land

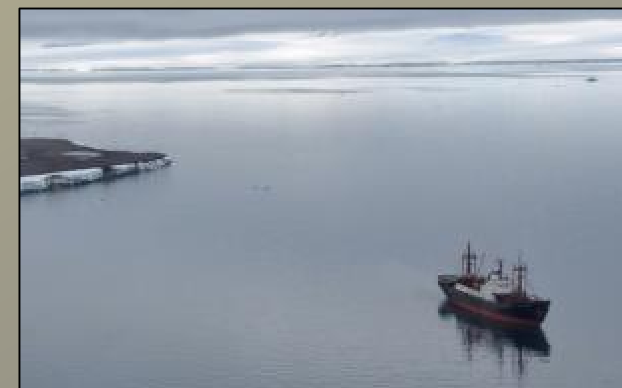
**2011**

- Kharp

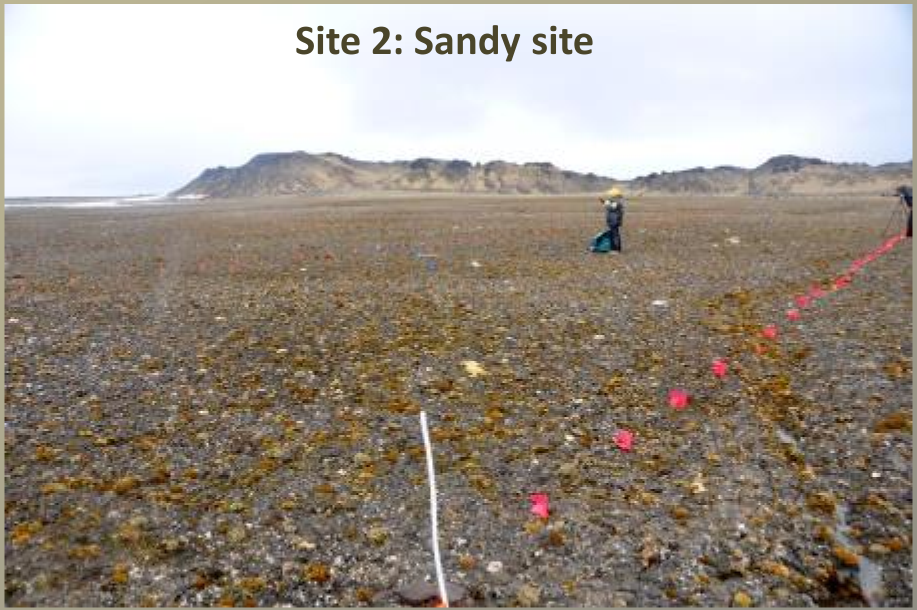


# Utilized capabilities of the Earth Cryosphere Institute, Moscow and Tyumen

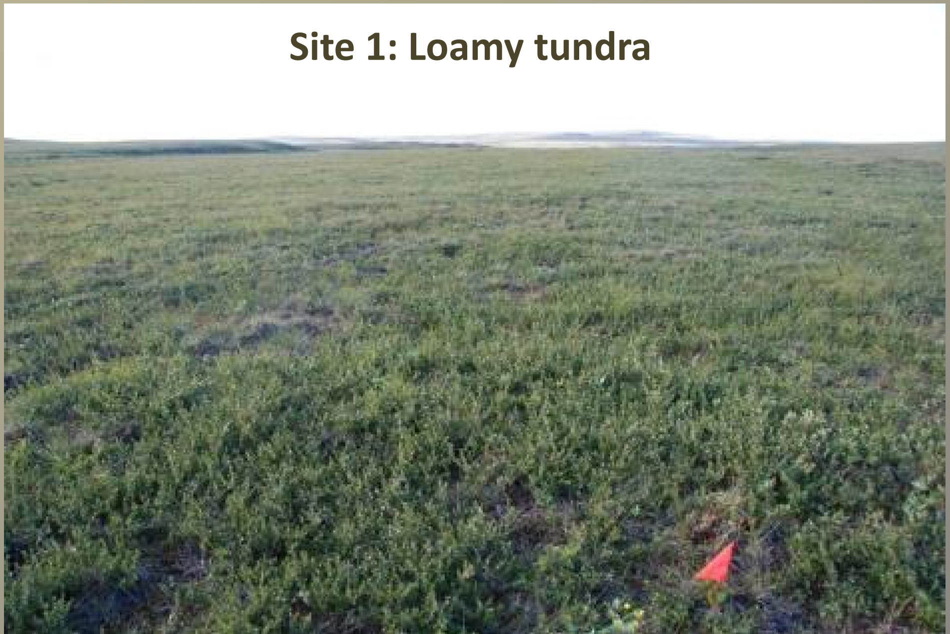
## Impossible logistics?…no problem.



# Northern end of Tundra Bioclimate Zone, Subzone A, Hayes I.

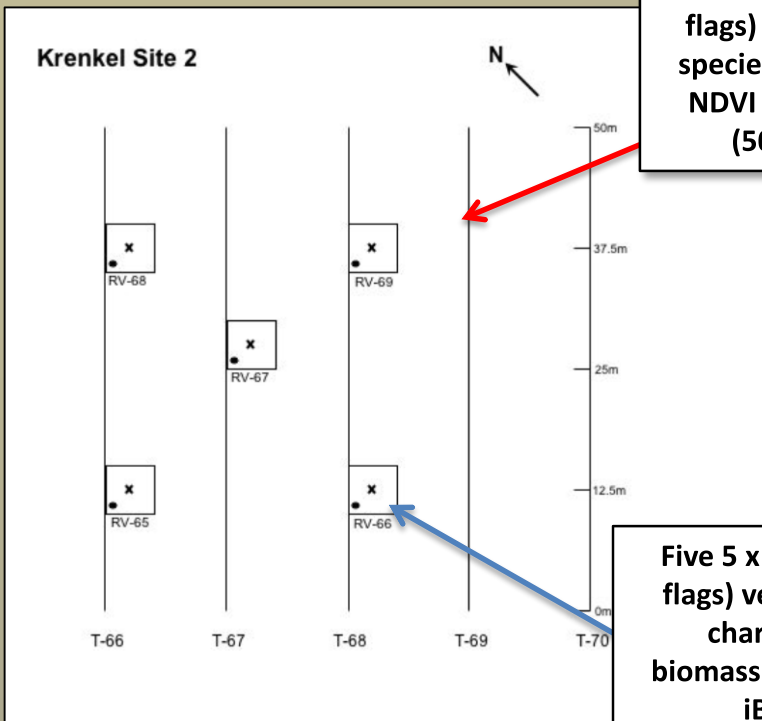




# Southern end, Subzone E, Laborovaya



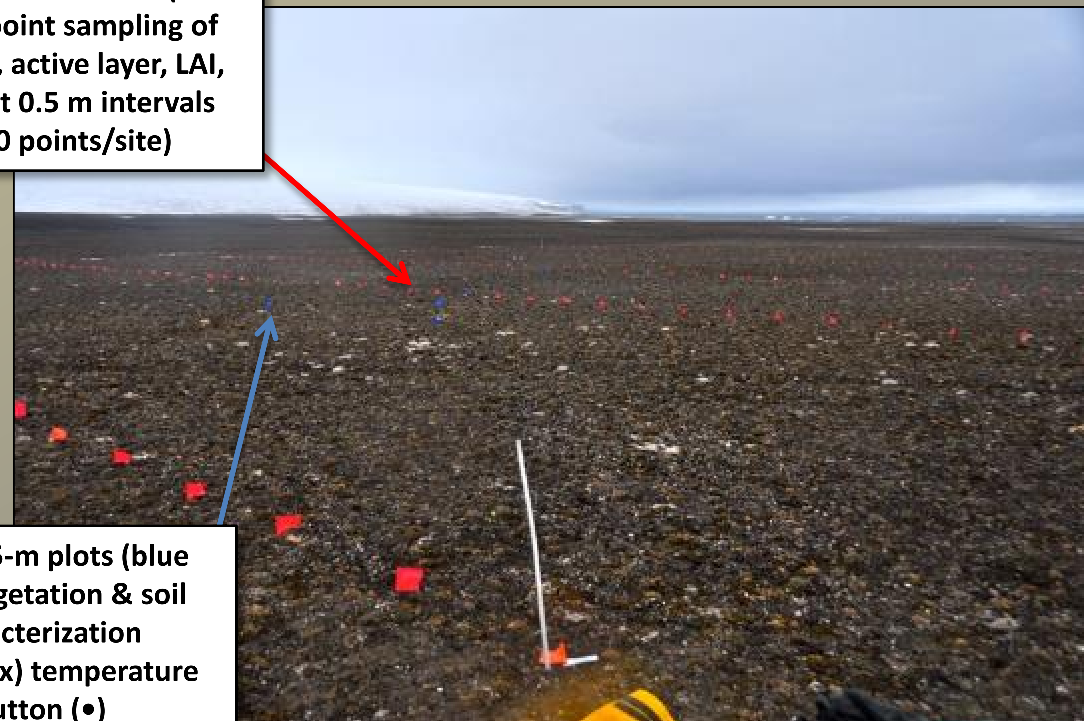

# Characterization of study sites

- 1-2 study locations in each bioclimate subzone
- 17 study sites




**Five 50-m transects (red flags) point sampling of species, active layer, LAI, NDVI at 0.5 m intervals (500 points/site)**

**Five 5 x 5-m plots (blue flags) vegetation & soil characterization biomass (x) temperature iButton (•)**



**Typical 50 x 50 sample site, Krenkel Site 2.**

# Ground-based studies at each study site


Soils


Vegetation

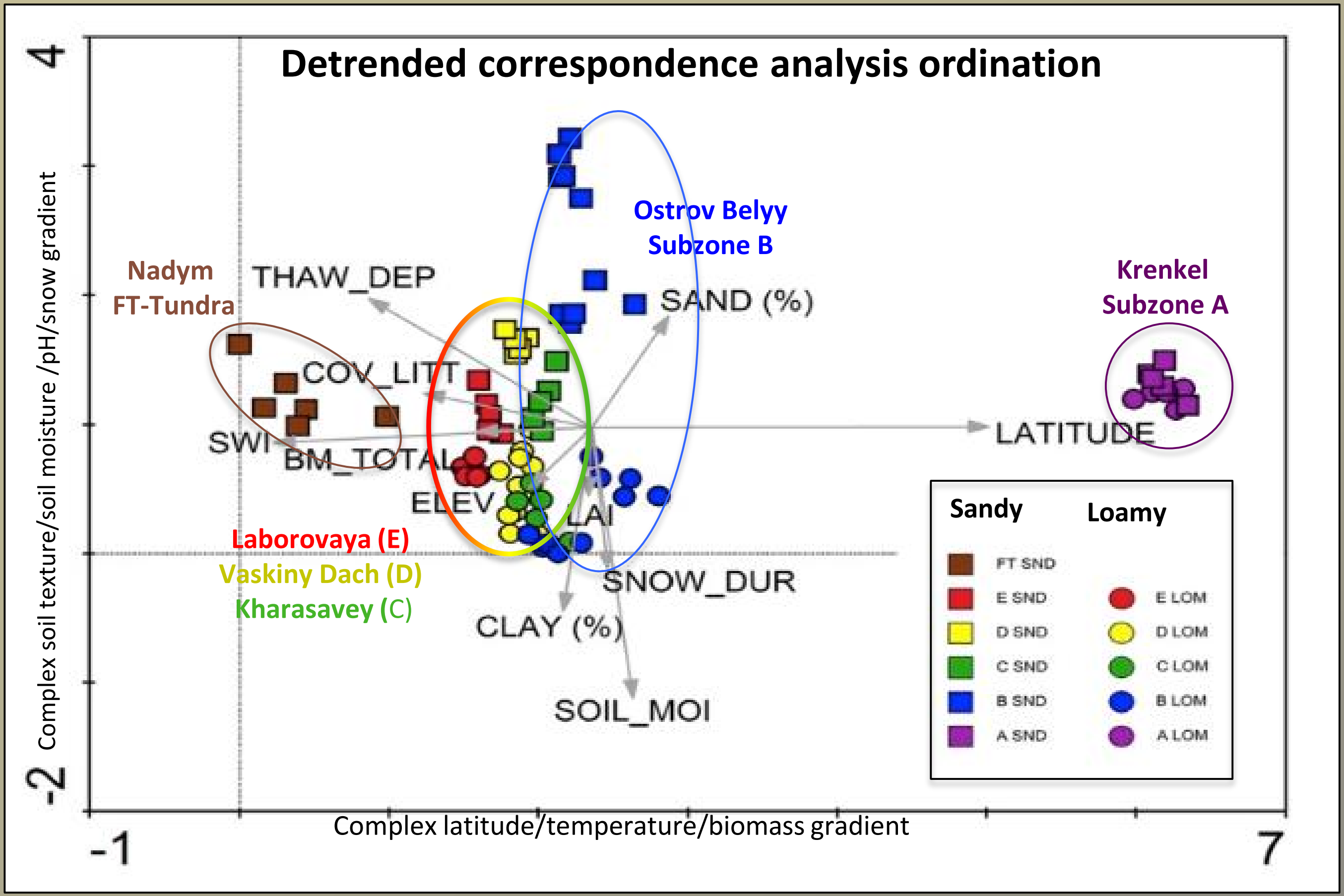

NDVI & LAI


Ground temperatures


Active layer


Plant Biomass

# Cluster analysis of vegetation along the EAT




- Data are grouped according to floristic similarity into clusters that correspond to Braun-Blanquet classes.

- Ordination of plots reveals their relationships to primary environmental gradients.

**Courtesy of Silvia Chasnikova**

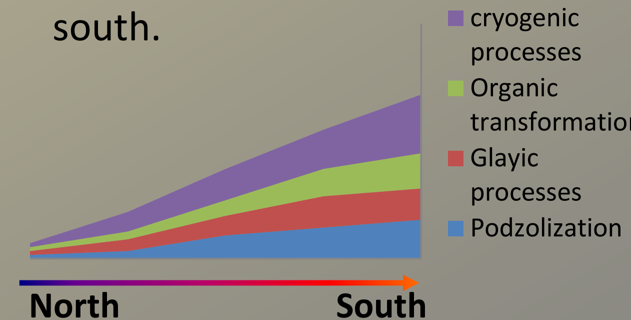
North → South

Mesic → Dry

# Soils along the EAT

By George Matyshak

- Vertical and horizontal sections of soils display the influence of cryoturbation and pattern-ground processes.
- The main processes of soil formation happen in all soils, but their intensity increases to the south.

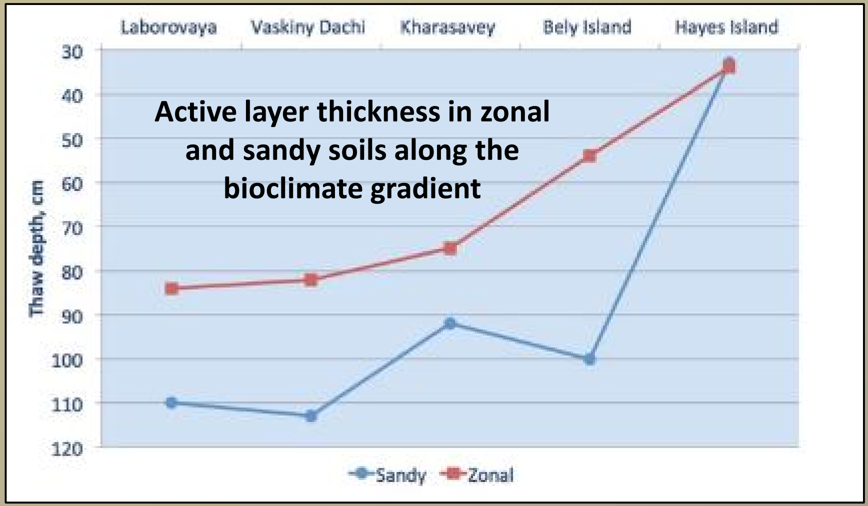



Soils have generally low biological activity, but there was about a 3x increase in $CO_2$ flux from north to south.

***$CO_2$ flux along the Russian transect, August***

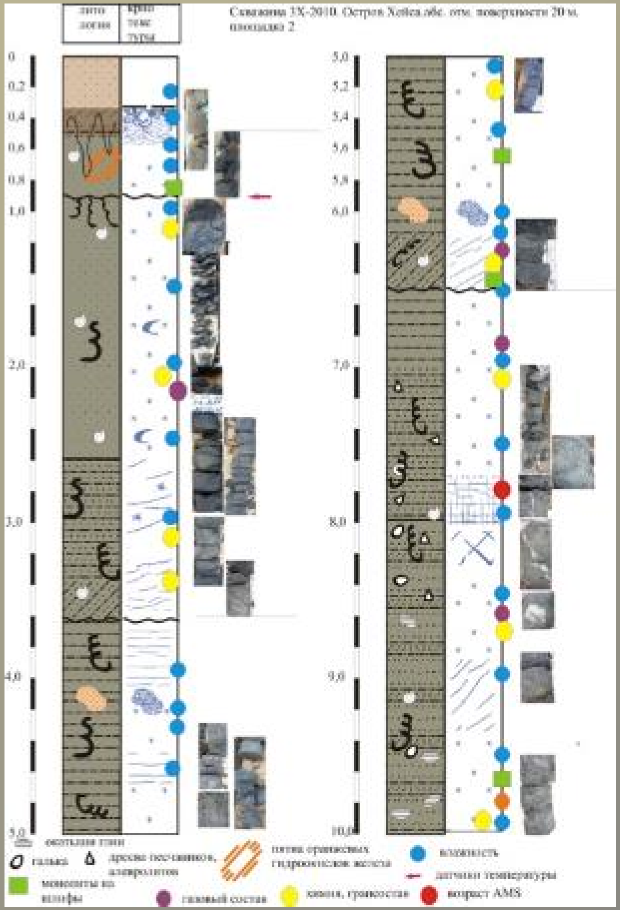
| *Location* | *Flux $CO_2$ mg/m$^2$ per h* | *number of cases* |
|---|---|---|
| **Krenkel** | 57.2 | 26 |
| **Ostrov Belyy** | 102.1 | 42 |
| **Nadym** | 138.1 | 300 |

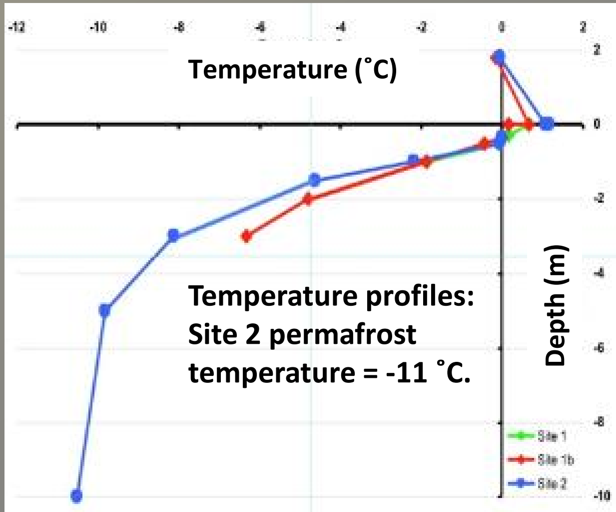
# Thaw depth and permafrost boreholes





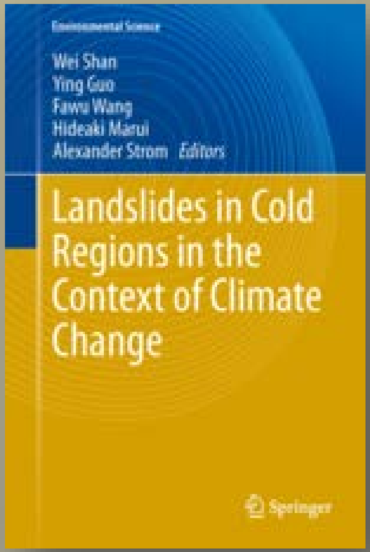
Hayes Island: Farthest north permafrost borehole





# Yamal landslides synthesis

**Four chapters in Shan et al. 2014 *Landslides in Cold Regions in the Context of Climate***




- Leibman M, Khomutov A and Kizyakov A . Cryogenic Landslides in the West-Siberian Plain of Russia: Classification, Mechanisms pp 143–162.
- Ukraintseva N, Leibman M, Streletskaya I and Mikhaylova T 2014 Geochemistry of plant-soil-permafrost system on landslide-affected pp 107–131
- Khomutov A and Leibman M O Assessment of landslide hazards in a typical tundra of central Yamal, Russia pp 271-290
- Gubarkov, A. Leibman M O Andreeva Cryogenic landslides in paragenetic complexes of slope and channel processes in the central Yamal Peninsula pp 291-308


# Pan-Arctic ice-wedge degradation synthesis

- Continued ice-wedge melting leads to increased trough connectivity and an overall draining of the landscape.
- Melting at the tops of ice wedges over recent decades and subsequent decimetre-scale ground subsidence is a widespread Arctic phenomenon.
- Ice-wedge degradation and the hydrological changes associated with the resulting differential ground subsidence will expand and amplify in rapidly warming permafrost regions.

*Pan-Arctic synthesis of ice-wedge degradation (Anna Liljedahl et al. 2016)*


INFRASTRUCTURE-THERMOKARST-SOIL-VEGETATION INTERACTIONS AT LAKE COLLEEN SITE A, PRUDHOE BAY, ALASKA

AGC 15-01

*Prudhoe Bay, thermokarst analysis. (Walker et al. 2015)*

## Major components of the synthesis

# Component 2: Social-ecological effects of rapid infrastructure and climate changes:

Photos: D.A. Walker

# Environmental and Social Impacts of Industrial Development in Northern Russia (ENSINOR)

Bruce Forbes, Arctic Centre, Rovaniemi, PI of the ENSINOR Project.

Timo Kumpula, Finnish lead on the Yamal LCLUC Synthesis project

Photo: Bruce Forbes

Florian  Stammler interviewing members of a Nenets brigade. Combining remote sensing and traditional knowledge.

Photo: Bruce Forbes

# Mutual coexistence: rhetoric vs. reality

**Nenets SESs have adapted to a variety of pressures from oil & gas extraction in recent decades. There are cultural aspects of resilience that have helped them to persist.**

Forbes (2013) *Ecology and Society*

Forbes, B. C. 2013. Cultural resilience of social-ecological systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: a focus on reindeer nomads of the tundra. *Ecology and Society* **18**(4): 36.
http://dx.doi.org/10.5751/ES-05791-180436

F&S

*Research*, part of a Special Feature on Heterogeneity and Resilience of Human-*Rangifer* Systems: A CircumArctic Synthesis

## Cultural Resilience of Social-ecological Systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: A Focus on Reindeer Nomads of the Tundra

Bruce C. Forbes[1]

ABSTRACT. Empirical data on resilience in social-ecological systems (SESs) are reviewed from local and regional scale case studies among full-time nomads in the neighboring Nenets and Yamal-Nenets Autonomous Okrugs, Russia. The focus is on critical cultural factors contributing to SES resilience. In particular, this work presents an integrated view of people situated in specific tundra landscapes that face significantly different prospects for adaptation depending on existing or planned infrastructure associated with oil and gas development. Factors contributing to general resilience are compared to those that are adapted to certain spatial and temporal contexts. Environmental factors include ample space and an abundance of resources, such as fish and game (e.g., geese), to augment the diet of not only the migratory herders, but also residents from coastal settlements. In contrast to other regions, such as the Nenets Okrug, Yamal Nenets households consist of intact nuclear families with high retention among youth in the nomadic tundra population. Accepting attitudes toward exogenous drivers such as climate change and industrial development appear to play a significant role in how people react to both extreme weather events and piecemeal confiscation or degradation of territory. Consciousness of their role as responsible stewards of the territories they occupy has likely been a factor in maintaining viable wildlife populations over centuries. Institutions administering reindeer herding have remained flexible, especially on Yamal, and so accommodate decision-making that is sensitive to herders' needs and timetables. This affects factors such as herd demography, mobility and energetics. Resilience is further facilitated within the existing governance regimes by herders' own agency, most recently in the post-Soviet shift to smaller, privately managed herds that can better utilize available pastures in a highly dynamic environment experiencing rapid socio-economic, climate and land use change.

Key Words: *Climate change; Hydrocarbon extraction; Nomadism; Rangifer tarandus; Siberia; Stewardship; West Siberian Tundra*

### INTRODUCTION

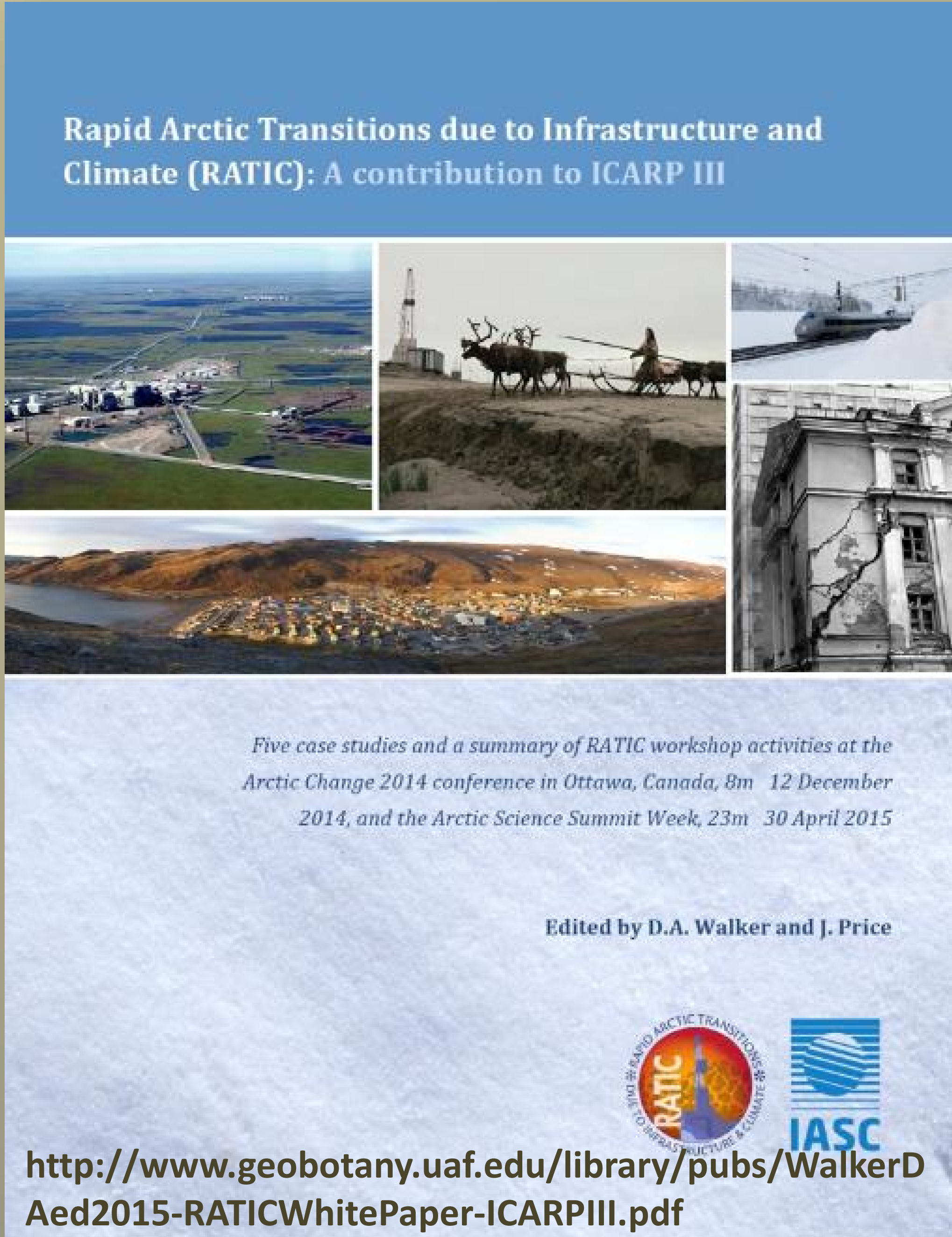
Tundra Nenets nomadism is well known within and outside Russia for both the high quality of the intensive or 'close' reindeer herding (*sensu* Ingold 1980) techniques used and the iconic imagery of a long-distance migratory lifestyle that has all but vanished from most other sectors of the circumpolar Arctic (Stammler 2005*a*). Nenets reindeer herding within the tundra zone straddles the Polar Ural Mountains, its rangelands encompassing >70% of the Nenets Autonomous Okrug (NAO) of the East European Arctic and the Yamal-Nenets Autonomous Okrug (YNAO) of West Siberia (Stammler 2005*a*, Rees et al. 2008). As neighboring federal districts they share key common characteristics. These include the presence of large semidomestic reindeer herds managed by the indigenous Nenets, ongoing large-scale hydrocarbon development and climate warming in the past few decades (Rees et al. 2008, Forbes et al. 2009). Other indigenous peoples practice reindeer herding on the tundra pastures of these regions, such as Komi-Izhemtsy and Khanty in YNAO and Komi-Izhemtsy in NAO, but the present analysis will be limited to tundra Nenets. Ecological drivers are certainly important, and there is evidence for extensive terrestrial and freshwater degradation across these regions from anthropogenic disturbance. Specifically, there has been a shift from shrub- to graminoid-dominated tundra that is persistent over sizable areas in the vicinity of active and abandoned oil and gas infrastructure (Forbes et al. 2009, Kumpula et al. 2011, 2012). At the same time the availability of fish, a critical source of protein for herders during summer migration, has decreased. This is a result of direct and indirect impacts from road, railway, and bridge construction combined with increasing competition from new workers, who fish in rivers and lakes during their free time (Forbes et al. 2009). Symptoms of warming air temperatures commented on by herders in recent years include earlier break up of rivers and lakes in the spring, later freeze up in autumn, more frequent and intensive rain-on-snow events in winter, and hotter summers with a greater degree of insect harassment (Rees et al. 2008, Forbes and Stammler 2009, Forbes et al. 2009, Bartsch et al. 2010).

Observers have often commented on the apparent flexibility of the Nenets when faced with a wide range of exogenous forces during the Soviet and post-Soviet eras (Golovnev and Osherenko 1999, Stammler 2002, Tuisku 2003, Zenko 2004). The Yamal Nenets social-ecological system (SES), in particular, has stood out as being resilient in the face of extreme shocks and pressures in the past 20-30 years (Forbes et al. 2009) and its tundra nomads are generally considered by other herding cultures within modern Russia to be the 'real' reindeer

[1]Arctic Centre, University of Lapland, Finland

# Comparison of two Nenets' Social-Ecological-Systems (Forbes 2013)

- An integrated view of two groups of Nenets situated in specific tundra landscapes that face significantly different prospects for adaptation..
- Some factors contributing the Nenets' generally positive attitude toward adaptation:
  - Intact nuclear families with high retention among youth.
  - Accepting attitudes toward climate change and industrial development.
  - Consciousness of their role as responsible stewards of the territories.
  - Russian institutions administering reindeer herding accommodate decision-making that is sensitive to herders' needs and timetables.
  - Smaller, privately managed herds that can better utilize available pastures.



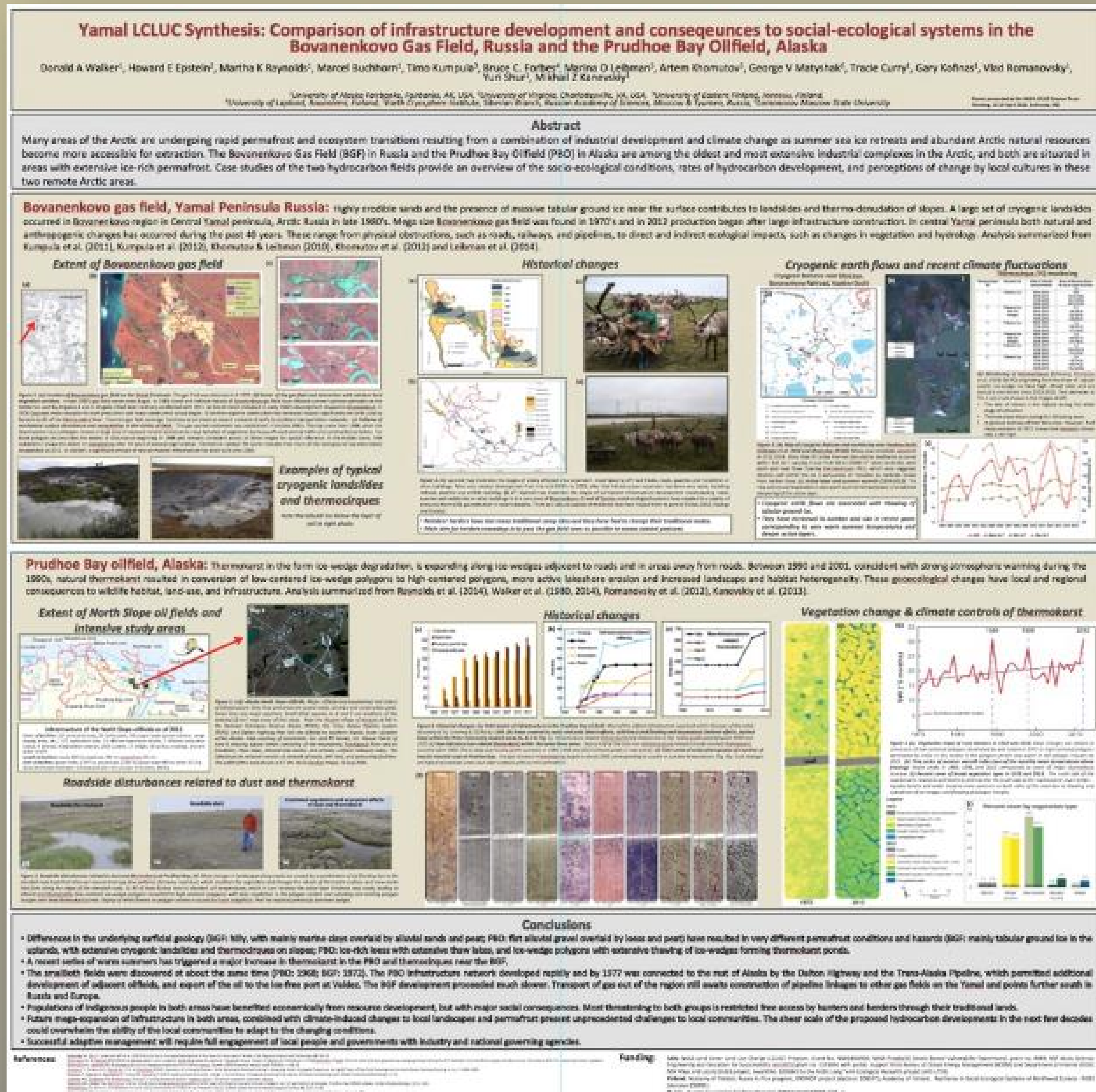

http://www.geobotany.uaf.edu/library/pubs/WalkerDAed2015-RATICWhitePaper-ICARPIII.pdf

RAPID ARCTIC TRANSITIONS DUE TO INFRASTRUCTURE & CLIMATE
RATIC

# White paper for the Third Conference on International Arctic Research Planning Process (ICARP III)

- *Five case studies presented at Arctic Change 2014 (Ottawa) and Arctic Science Summit Week 2015 (Yohama).*
- *Conclusions*
- *Recommendations*

# Poster focusing on infrastructure and human dimension at Bovanenkova and Prudhoe Bay



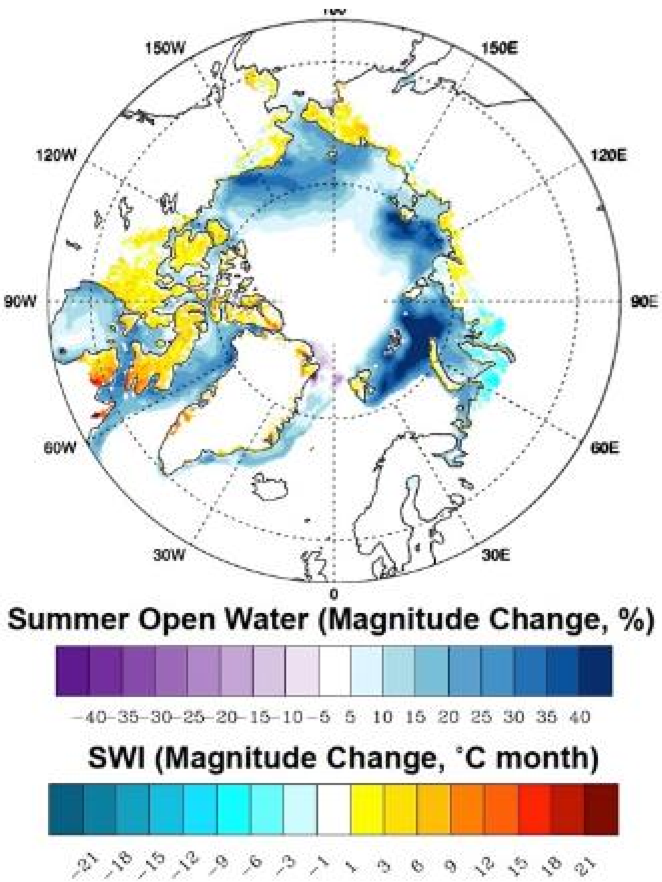
Major components of the synthesis

# Component 3:

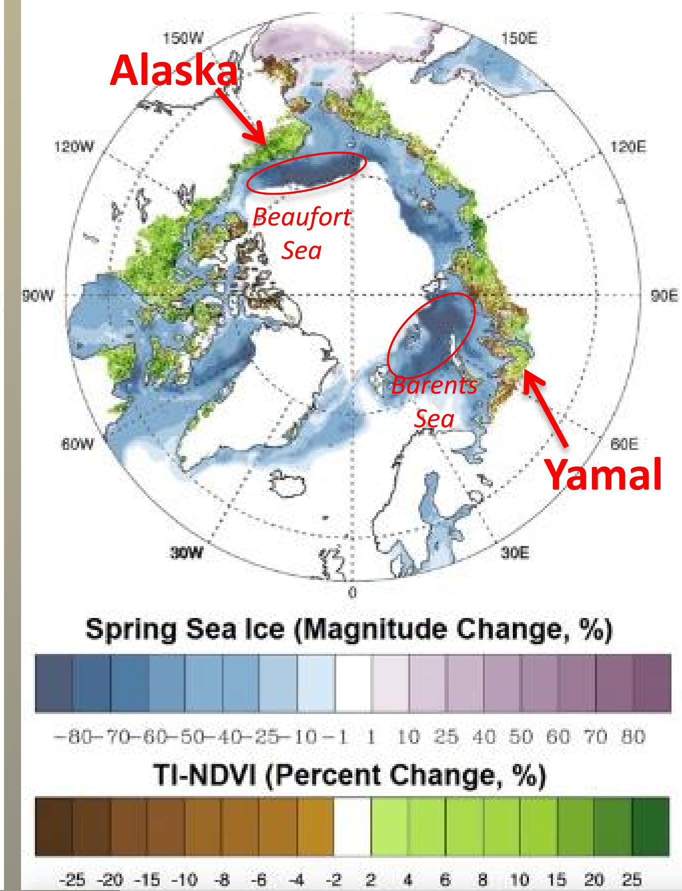
# Remote-sensing, modeling, and visualization tools:

# Circumpolar changes in sea ice, land temperatures, & vegetation greening

**Fall open water and summer land temperature trends**




**Spring sea-ice and summer greening trends**

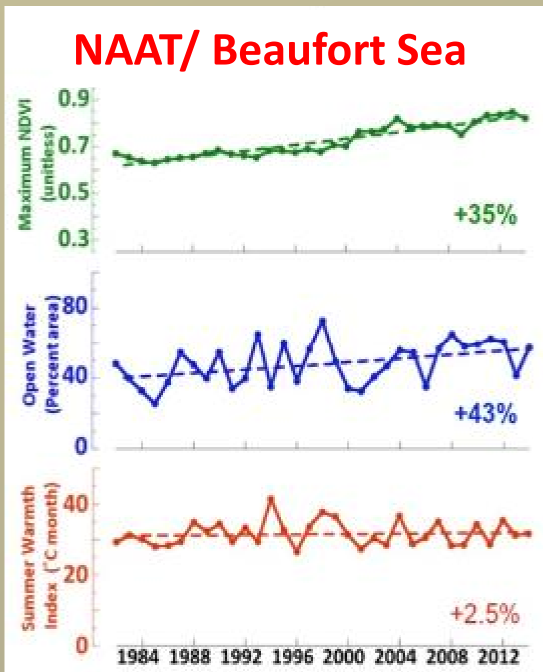


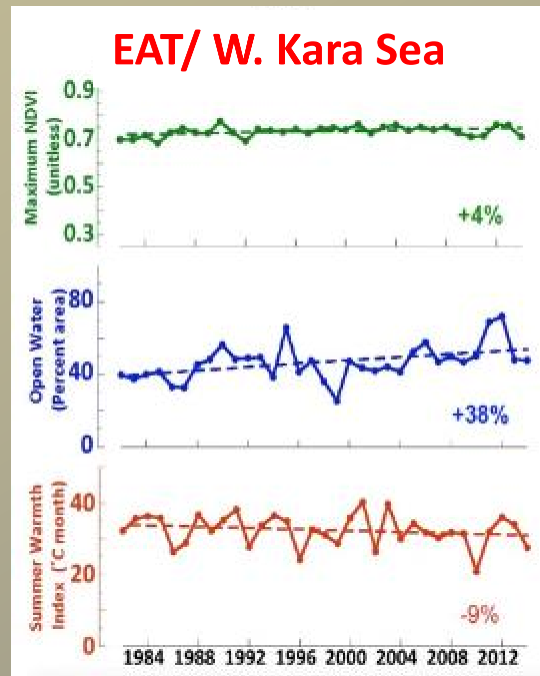

- Positive open water and negative sea-ice trends in most areas of the Arctic basin.
- Summer temperatures increasing in most areas except the Yamal and NW Siberia.
- Greening is occurring in most areas of the Arctic except NW Siberia, Canadian Archipelago, and Y-K delta.

*Bhatt et al. 2010 updated to 2014.*

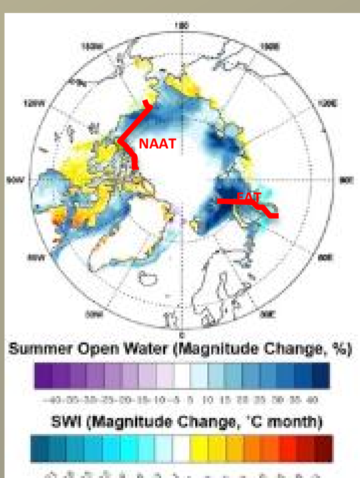
The NAAT and EAT are well situated to examine two areas of the Arctic that are most strongly affected by rapid sea-ice changes in the Beaufort and Barents seas.

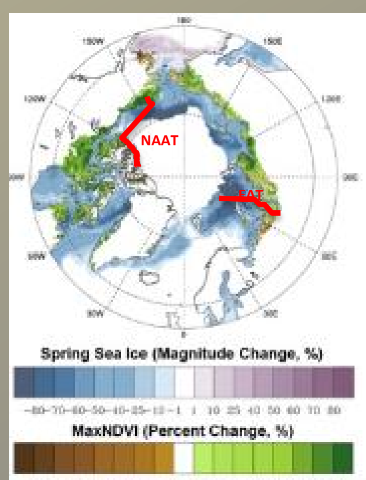
# Comparisons along the NAAT and EAT




- Similar levels of sea ice retreat (blue trend lines) within 100 km coast along the Beaufort and W. Kara seas.
- Decline in summer land temperatures (red trend lines) on the Yamal vs. a small increase along the Beaufort coast.
- NDVI (green trend lines) has increased along the W. Kara Sea and strongly increased along the Beaufort.




The cooling summer temperature and muted NDVI response in NW Siberia may be linked to midsummer cloudiness and cooling associated with much more open water in the Barents and Kara Seas.

Bhatt et al. *Remote Sensing.* 2013

# Now a NOAA Arctic Report Card tool for annual monitoring of greening in the Arctic

**Arctic Report Card:** ***Update for 2015***

*Tracking recent environmental changes*

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HOME
Executive Summary

**VITAL SIGNS**

- Air Temperature
- Terrestrial Snow Cover
- Greenland Ice Sheet
- Sea Ice
- Sea Surface Temperature
- Ocean Primary Productivity
- Tundra Greenness

**INDICATORS**

- River Discharge
- Walruses

**FROSTBITES**

- Borealization of the Fish Community
- Community-based Observing in the Arctic
- Greenland Ice Sheet Surface Velocity: New Data Sets

## Tundra Greenness

**H. E. Epstein[1], U. S. Bhatt[2], M. K. Raynolds[3], D. A. Walker[3], P. A. Bieniek[2], C. J. Tucker[4], J. Pinzon[4], I. H. Myers-Smith[5], B. C. Forbes[6], M. Macias-Fauria[7], N. T. Boelman[8], S. K. Sweet[8]**

[1]Department of Environmental Sciences, University of Virginia, Charlottesville, VA, USA
[2]Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK, USA
[3]Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK, USA
[4]Biospheric Science Branch, NASA Goddard Space Flight Center, Greenbelt, MD, USA
[5]School of GeoSciences, University of Edinburgh, Edinburgh, UK
[6]Arctic Centre, University of Lapland, Rovaniemi, Finland
[7]School of Geography and the Environment, University Oxford, Oxford, UK
[8]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA

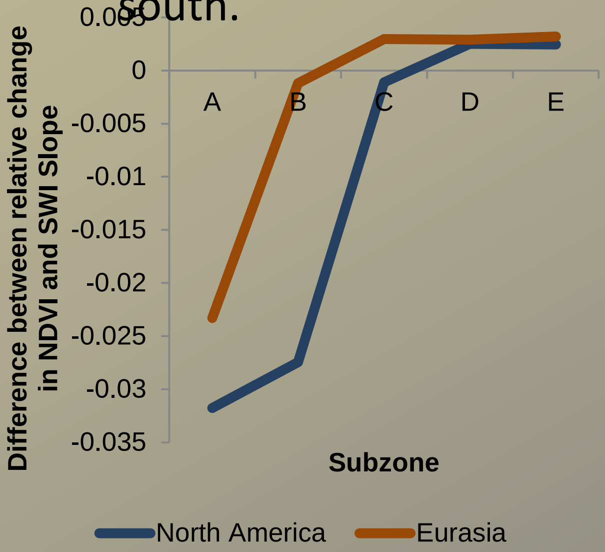
November 17, 2015

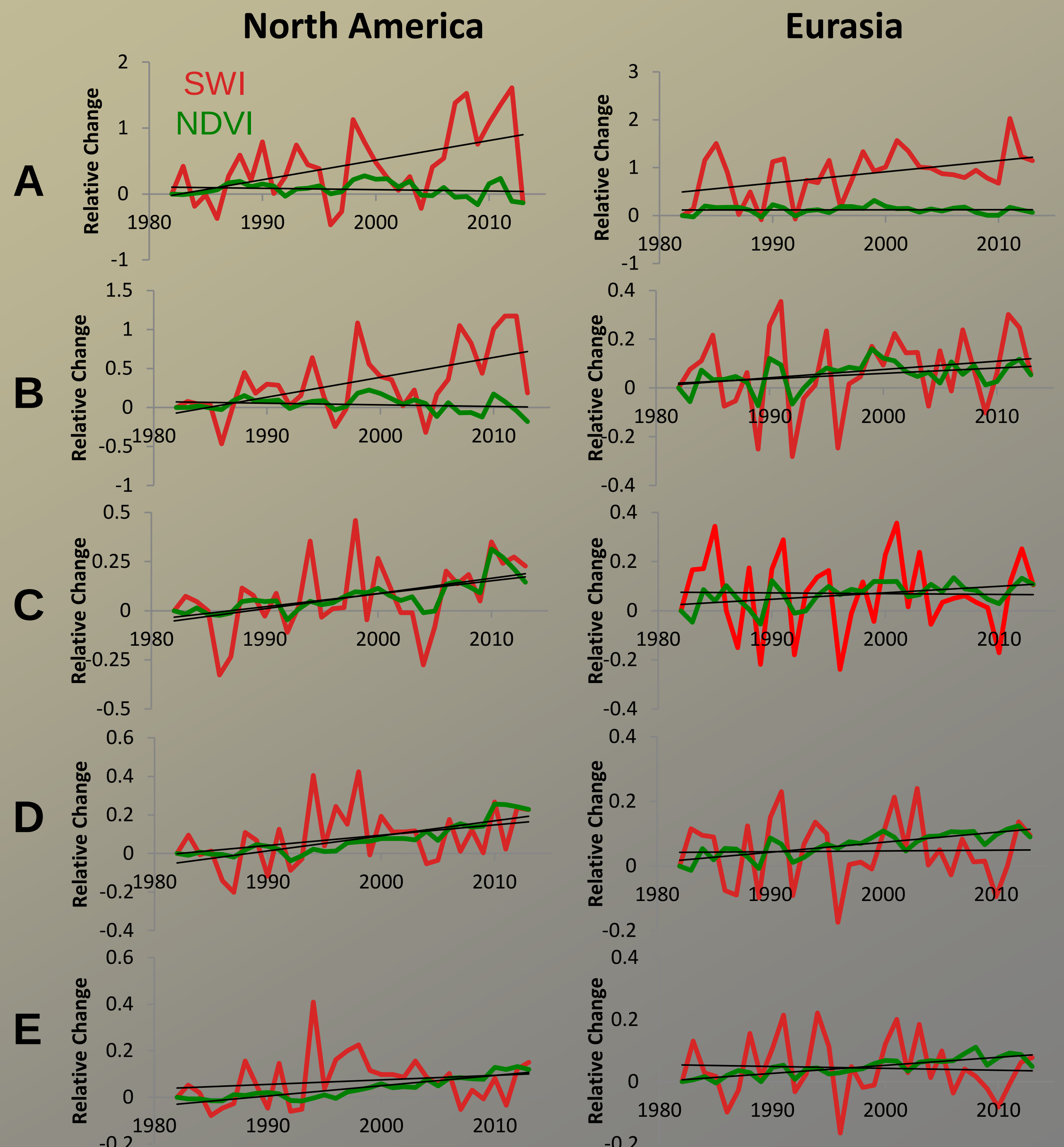
### Highlights

- Following a general increase over nearly three decades, tundra greenness, derived from remote sensing data, has been declining consistently for the past 2-4 years throughout the Arctic.
- MaxNDVI in 2014 in the Eurasian Arctic and the Arctic as a whole was below the 33-year (1982-2014) average. Temporally-integrated greenness (TI-NDVI) in 2014 had the lowest value on record for Eurasia and the second lowest value for the Arctic as a whole.
- Long-term MaxNDVI and TI-NDVI trends (1992-2014) show tundra "browning" extending over larger areas.
- In contrast to remote sensing observations, field monitoring and experimental studies continue to report increased tundra shrub growth in response to rising air temperatures.

# Examination of summer warmth (SWI) and NDVI trends by subzone and continent

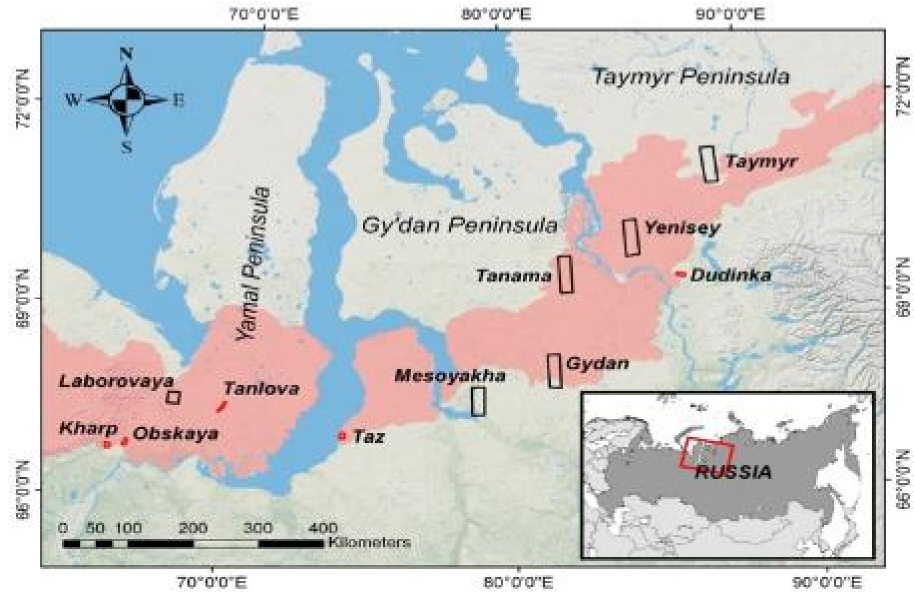
SWI is increasing faster than NDVI in the north, and NDVI is increasing somewhat faster than SWI in the south.



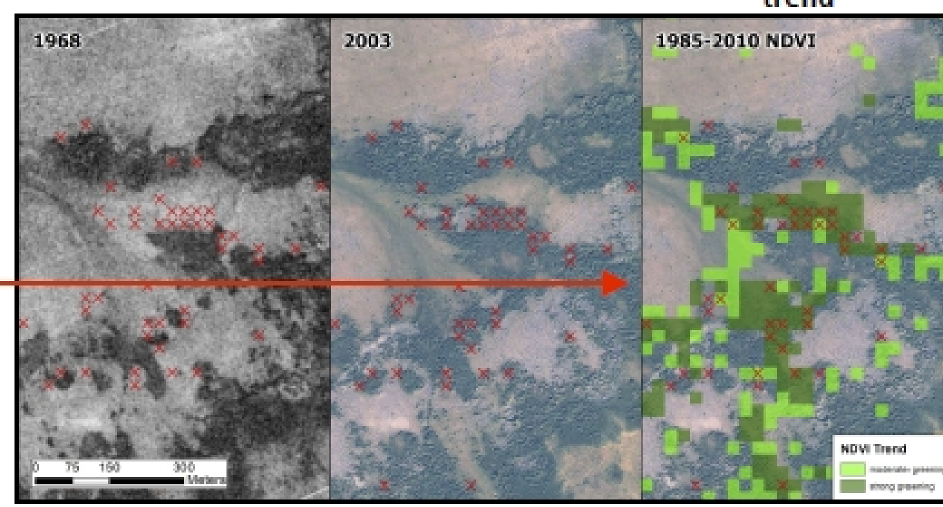

Epstein and Reichle, in prep.

**The greening documented at the regional scale in northern Russia is also documented in the hi-res satellite record is reflected in landscape-scale patterns of greening in Landsat time-series across northwestern Siberia.**


**High-resolution imagery from two eras of satellites reveal broad patterns of greening.**

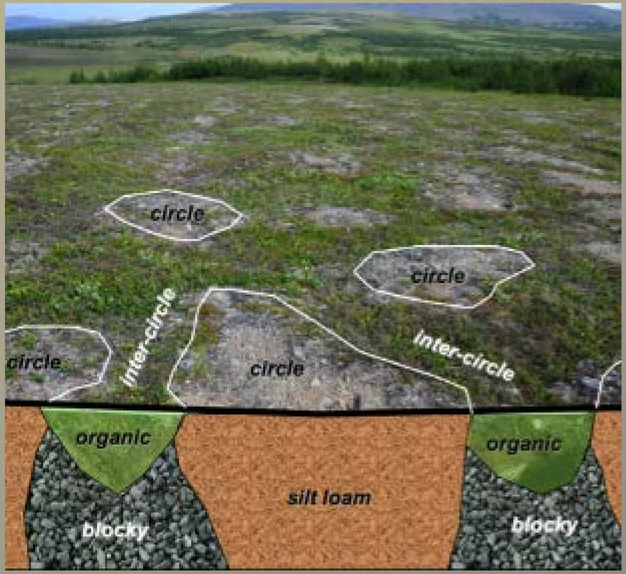
Corona 1968 | Quickbird 2003 | Quickbird with 1985-2010 Landsat trend

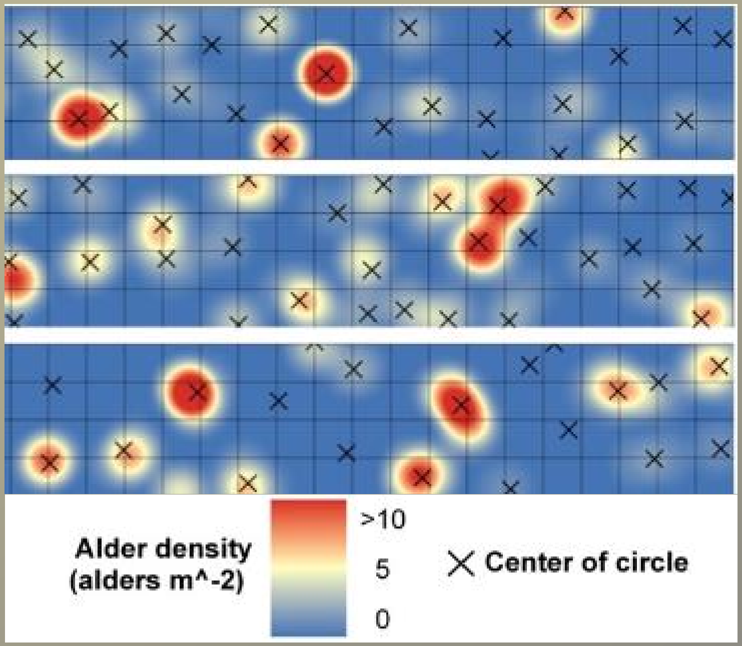



*Frost et al. 2014, Environmental Research Letters*

X grid points with new alder cover since 1968.

# And at the plot level: Alder recruitment is most commonly occurring on patterned-ground features

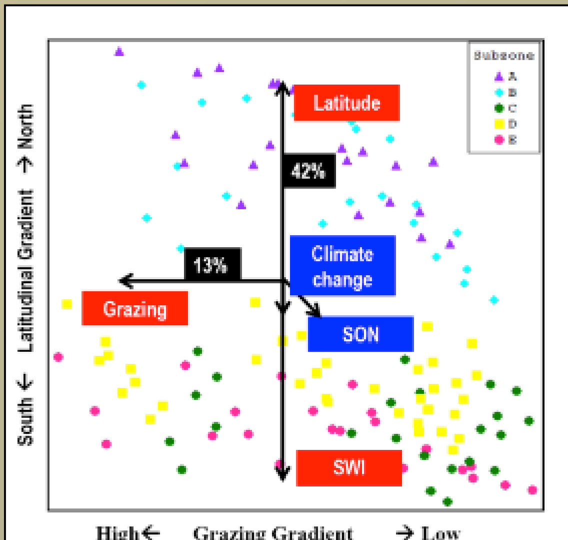


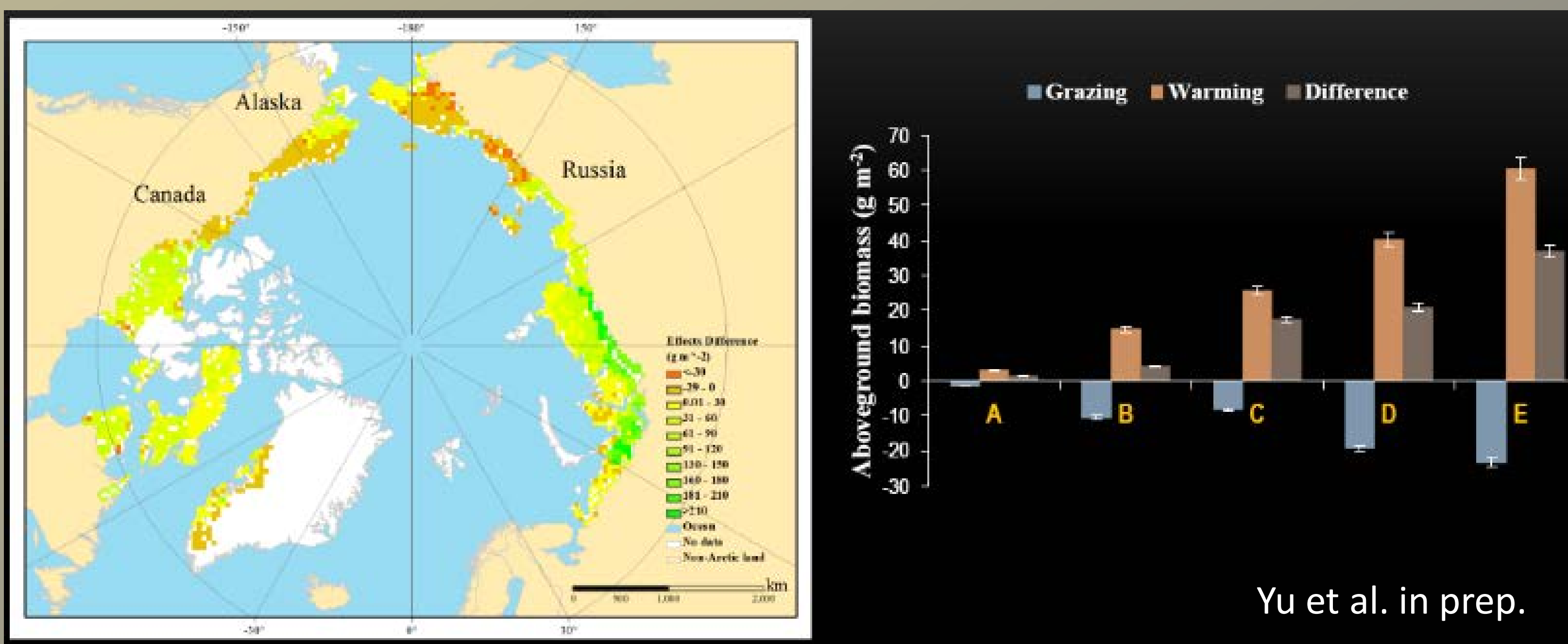

- Field studies showed that alder establishment is closely linked to disturbed mineral soils.
- The highest rates of shrub expansion were found in northwestern Siberia, where active frost boils are common.

*Frost et al. 2013, Environmental Research Letters*

# Use of the remote sensing and ground-based information from the transect to model circumpolar climate and grazing effects on greening



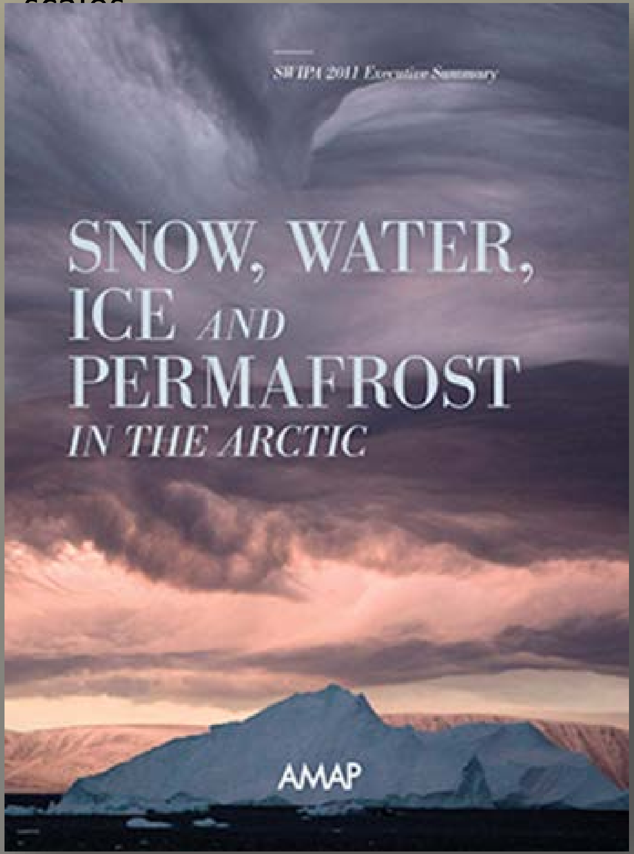

- Ordination of plant community composition (left) from 121 simulation runs of the ArcVeg model with varying latitude (SWI), soils, climate change scenarios, and grazing intensities (Yu et al. 2011)
- After latitude (SWI), which explained 42% of the variability, grazing explained the next greatest fraction of the variance (13%)
- Grazing led to decreased biomass overall, and decreased abundance of deciduous shrubs
- At the circumpolar scale (below), grazing can potentially reduce tundra “greening” by 25-75% (Yu et al. in prep.)




Yu et al. in prep.


# AMAP SWIPA Update

- **Greening cross-cutting chapter** (Mård, Walker, Bhatt, Epstein, Raynolds, Myers-Smith):
  – Changes in snow, water, ice and permafrost have strong implications for Arctic greenness patterns at all scales



# *Environmental Research Letters* Focus Issue

Environmental Research Letters

## Focus on Recent, Present and Future Arctic and Boreal Productivity and Biomass Changes

### Guest Editors

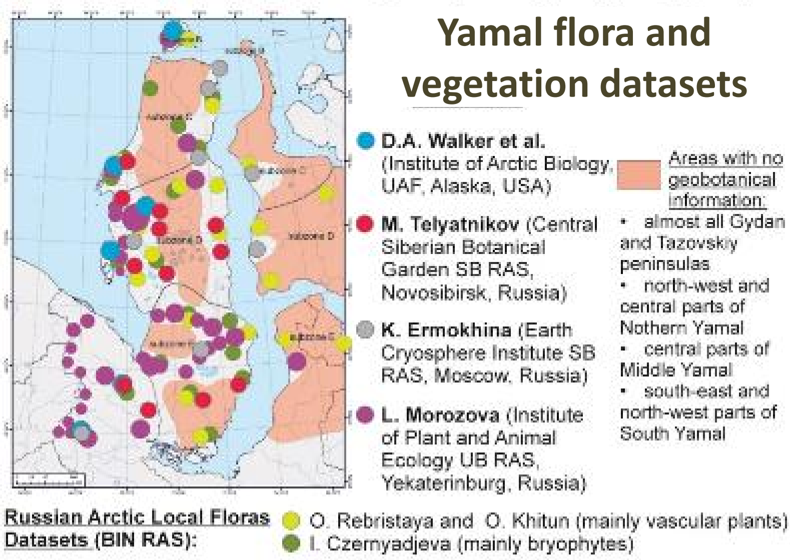
**Hans Tømmervik** Norwegian Institute for Nature Research
**Bruce Forbes** University of Lapland
**Donald Walker** University of Alaska Fairbanks
**Scott Goetz** Woods Hole Research Center

Credit: Bruce C Forbes, July 2014.

### Scope

- Recent changes in phenology, biomass and productivity and the mechanisms and drivers that control such changes, along with the consequences for local, regional and global scale processes. This includes impacts on vegetation, ecosystems and effects on human communities that are dependent on the resources in Arctic and Boreal regions.
- Changes in the physical environment over high latitude regions and associated ecological changes in Arctic/Boreal vegetation.
- Changes in phenology of Arctic vegetation. Actual and potential biomass change influenced by (local) climate, natural disturbances, human impacts (e.g. resource extraction) and impacts on humans (e.g. reindeer herders).
- Transformation of open tundra vegetation to a more shrub dominated landscape.
- Integration of in situ observations and manipulation experiments with remote sensing.

# Yamal Arctic Geoecological Atlas and Yamal Arctic Vegetation Plot Archive


- Modeled after the Alaska Arctic Geoecological Atlas: http://alaskaaga.gina.alaska.edu
- Will include plot and map archives for the Yamal

# Toward adaptive management of infrastructure
# UAF Decision Theater North

New visualization facility at University of Alaska Fairbanks designed to facilitate dialogue and decision-making by agencies, industries, communities and academia

- 7 high definition monitors
- High-performance computing and storage
- Configurable to serve as either a conference room or theater

UAF Decision Theater North, funded by NSF Alaska Experimental Program to Stimulate Competitive Research (EPSCoR)

# Decision support tools for infrastructure planning in North Alaska

**Focus:** Dalton Highway; cumulative effects of road dust and other social-environmental factors

**Goal:** Interactive video with narration and visual media (maps, info-graphics, animations, etc.) to enhance multi- stakeholder communication and collaborative planning efforts

Photo: Gosha Matyshak






Yay, I made it!!!

**Thanks for your attention!**

# How to prepare for your LCLUC synthesis talk

# Summary of synthesis products of Component 1: Eurasia Arctic Transect

- **Four major disciplinary and interdisciplinary synthesis papers regarding the EAT**:
  - i) Vegetation (Ermokina, Walker et al, *Phytocoenologia,* in. prep.)
  - ii) Soils (Matyshak et al., in prep. )
  - iii)  Permafrost and active layer conditions (Leibman, Drozdov, Khomutov, Romanovsky, et al., in prep.)
  - iv) Spectral-reflectance characteristics of the EAT (Epstein et al.*, Environmental Research Letters,* in prep )
- **Synthesis comparing vegetation, soils, permafrost conditions along  the EAT and NAAT** (Walker et al., in prep. to *Environmental Research Letters*)
- **Yamal landslide synthesis** (4 chapters in Shan W, Guo Y, Wang F, Marui H and Strom A 2014 *Landslides in Cold Regions in the Context of Climate Change* (Cham: Springer International Publishing) (Leibman et al., Guberkov et al., Khomutov et al, and Ukraientseva et al.)
- **Nature Geoscience: Pan-Arctic ice-wedge degradation** (Liljedahl et al. 2016)

# Summary of synthesis products of Component 2:
## Social-ecological effects of rapid infrastructure and climate changes:

- **Review of Nenets social ecological systems** (Forbes 2013)
- **Rapid Arctic Transitions due to Infrastructure and Climate (RATIC)** (Walker & Peirce ed. 2015 White paper for ICARP III)
- **Comparison of social impacts Yamal and North Slope** (Kofinas, Forbes, et al. in prep.)
- **Synthesis of international best practices for adaptive management of Arctic local responses to cumulative effects of climate change and resource development** (Curry, Kumpula, Kofinas, Forbes et al in prep).
- **“Grand synthesis” Yamal-North Slope cumulative impacts of development: Biophysical, social, permafrost, remote sensing** (Walker, Kofinas, Forbes et al. *PNAS* in prep.)

# Summary of synthesis products
## Remote sensing, modeling, and visualization tools

- **Circumpolar sea-ice, land-temperature, and greening monitoring** (Bhatt, Epstein, Raynolds, Walker, Comiso, Pinzon, Tucker, et al.)
- **MODIS-based Circumpolar Arctic Vegetation Map** (Raynolds et al., in prep.)
- **Arctic Report Card: Annual greening synthesis** (Epstein et al.)
- **ArcVeg modeling synthesis** (Yu, Epstein)
- **Arctic Biomass Special Issue of ERL** (Tommervik et al. editors)
- **Yamal Arctic Geoecological Atlas (YA-AGA)** (Walker, Ermokhina, Breen, Epstein, Raynolds, Buchhorn, Sibik, Chasnikova, Khumotov, Bartsh, Heim, in prep.)
- **Decision Theater North** (Curry, Kofinas et al. in prep.)