Rapid Arctic Transitions due to Infrastructure and Climate Change (RATIC) initiative

RATIC goal

- ***Develop an international action plan to address adaptive approaches that utilize state-of-the-art science, modeling, engineering, education, involvement of local people, and management methods that lead to sustainable management of infrastructure development in the Arctic***.

RATIC is a cross-cutting IASC initiative.

IASC Terrestrial & Cryosphere Working Groups:

- Defining and quantifying primary changes to landscapes vegetation and permafrost.

IASC Social and Human Working Group:

- Examining perceptions of local people in communities, industry, agencies, and NGOs regarding the ongoing changes.
- Involving of local people in helping to define the important issues related to infrastructure
- Developing effective means to adapt to the changes.

IASC

RATIC activities at AC 2014

- **This Workshop: Tues**
- **Two Sessions of oral presentations (Room 208):**
  - **T40A: Thursday, 15:30-17:00**
  - **T40B: Friday, 10:30-12:00**
- **Posters: Tues and Wed 17:00-19:00, Nos. 325-341**
- **Wrap up to discuss ICARP III white paper: Friday afternoon after lunch (Room 208?)**

IASC

Today's RATIC Workshop

- A forum for developing and sharing new ideas regarding the best practices for assessing and responding to the cumulative effects of industrial infrastructure and climate change across the Arctic.
- Three case studies from Alaska, Russia, and Canada.
- Round table discussion to discuss four questions (next slide).
- Begin developing a RATIC white paper to be presented at ICARP III in Yohama, Japan, April 2014.

Co-applicants for IASC workshop support

- **Skip Walker:** Terrestrial Working Group
- **Gail Fondahl:** Social and Human Working Group
- **Hans Hubberton:** Cryosphere Working Group

Co-organizers of the workshop

- **Skip Walker:** University of Alaska Fairbanks, Alaska, USA
- **Michel Allard:** Université Laval, Québec, Canada
- **Timo Kumpula:** University of Eastern Finland, Joensuu, Finland

APECS co-organizers

- **Elena Kuznetsova:** SINTEF, Byggforsk, Oslo, Norway
- **Louis Philipp Roy:** Yukon Research Center, Whitehorse, Yukon, Canada

Financial Support for the Workshop

NSF Arctic Science, Engineering, and Education for Sustainability Program (ArcSEES)

NASA Land Cover Land Use Change Program (LCLUC)

IASC Terrestrial, Social and Human, and Cryosphere Working Groups

Expected outcomes of the workshop

(1) Summarize the status of international efforts to examine the cumulative effects of rapid transitions in Arctic social-ecological systems caused by infrastructure development and climate change.

(2) Develop a set of shared international objectives focused on effective means to address the key issues related to rapid transitions in Arctic social-ecological systems related to infrastructure and climate change.

(3) Develop a coordinated international science plan to address these issues.

(4) The long-term goal: Better planning and management of Arctic infrastructure in light of concerns of the local indigenous people and the constraints imposed by ongoing rapid climate change.

Structure of the Workshop

I. Three case studies (45 minutes each):

1. **Cumulative Effects in the Prudhoe Bay Oilfield, AK** (Chair: Skip Walker)
2. **Russian Arctic oil and gas development and climate change interactions** (Chair: Timo Kumpula)
3. **Canadian Arctic Development: The ADAPT and IRIS initiatives** (Chair: M. Allard)

II. Round-table discussion (4 questions, 15 minutes each)

- *Question 1:* How do we progress toward better planning and management of Arctic infrastructure in light of concerns of the local indigenous people and the constraints imposed by ongoing rapid climate change?
- *Question 2:* How do we develop closer exchange of cumulative-effects issues and solutions between the industry, governing agencies, and local communities?
- *Question 3:* Can we develop of a set of shared international objectives focused on developing effective means to address the key issues related to rapid transitions in Arctic social-ecological systems related to infrastructure and climate change?
- *Question 4:* What should we present regarding the RATIC initiative at the ICARP III conference, Yohama, Japan 2015?

Three Case Studies

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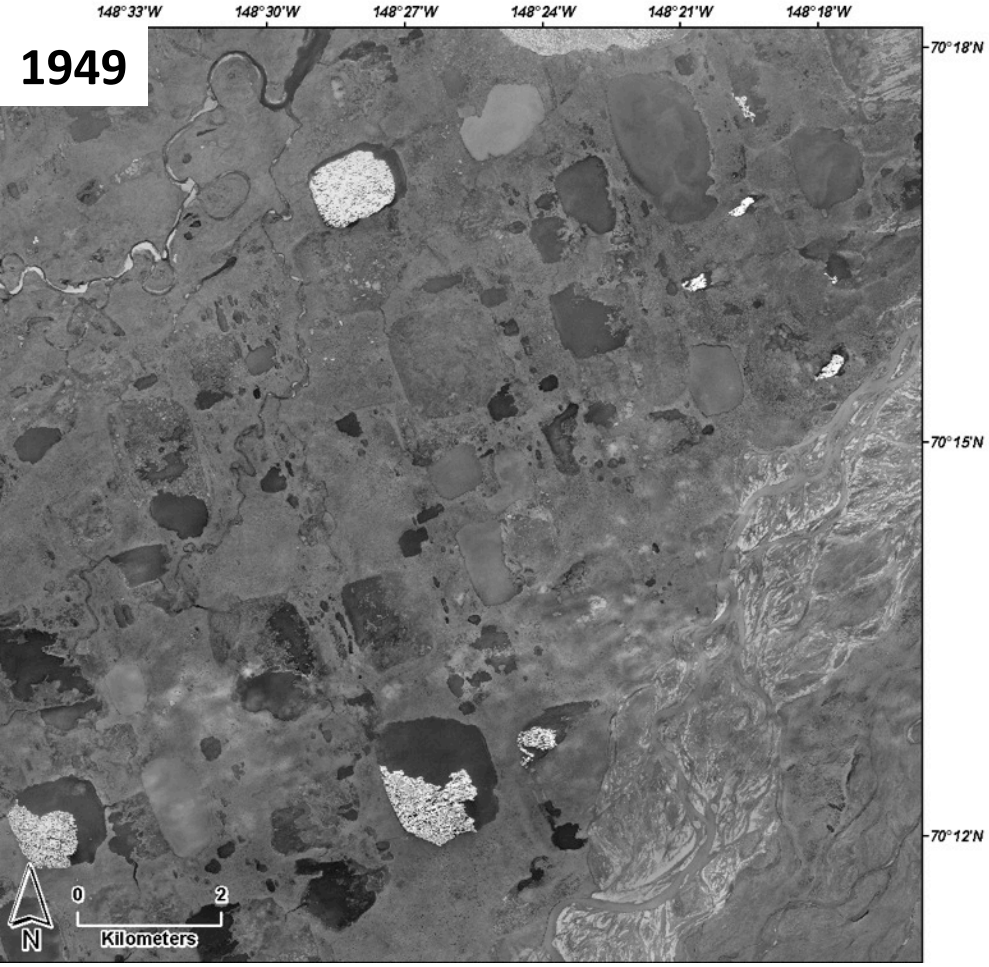
- *Question 4:* What should we present regarding the RATIC initiative at the ICARP III conference, Yohama, Japan 2015?

Two currently funded US-RATIC projects

- **Cumulative effects of infrastructure and climate change at Prudhoe Bay.** Funded by NSF ArcSEES (Arctic Science Engineering and Education for Sustainability). (Case Study 1)
- **SYN-YAMAL:** A synthesis of remote-sensing studies, ground observations and modeling to understand the social-ecological consequences of climate change and resource development on the Yamal Peninsula, Russia, and relevance the circumpolar Arctic. Funded by NASA LCLUC (Land Cover Land Use Change). (Case Study 2 in part)

CASE STUDY 1:
Cumulative effects infrastructure and climate change at Prudhoe Bay

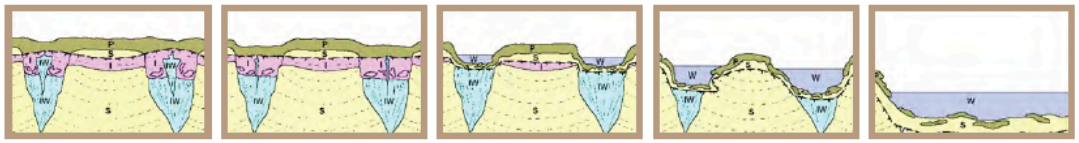


U.S. Navy BAR photography

NASA Landsat

Courtesy of Lisa Wirth, GINA

Just published!
Arc-SEES project: 62-year history of change in the Prudhoe Bay Oilfield



Alaska Geobotany Center Publication Series
AGC 14-01

LANDSCAPE AND PERMAFROST CHANGES IN THE PRUDHOE BAY OILFIELD, ALASKA

DONALD A. WALKER, MARTHA K. RAYNOLDS, YURI L. SHUR, MIKHAIL KANEVSKIY, KENNETH J. AMBROSIUS, VLADIMIR E. ROMANOVSKY, GARY P. KOFINAS, JERRY BROWN, KAYE R. EVERETT, PATRICK J. WEBBER, MARCEL BUCHHORN, GRIGORY V. MATYSHAK, LISA M. WIRTH

EDITED BY
DONALD A. WALKER, MARTHA K. RAYNOLDS, MARCEL BUCHHORN AND JANA L. PEIRCE

NOVEMBER 2014

A PUBLICATION OF THE ALASKA GEOBOTANY CENTER 14-01
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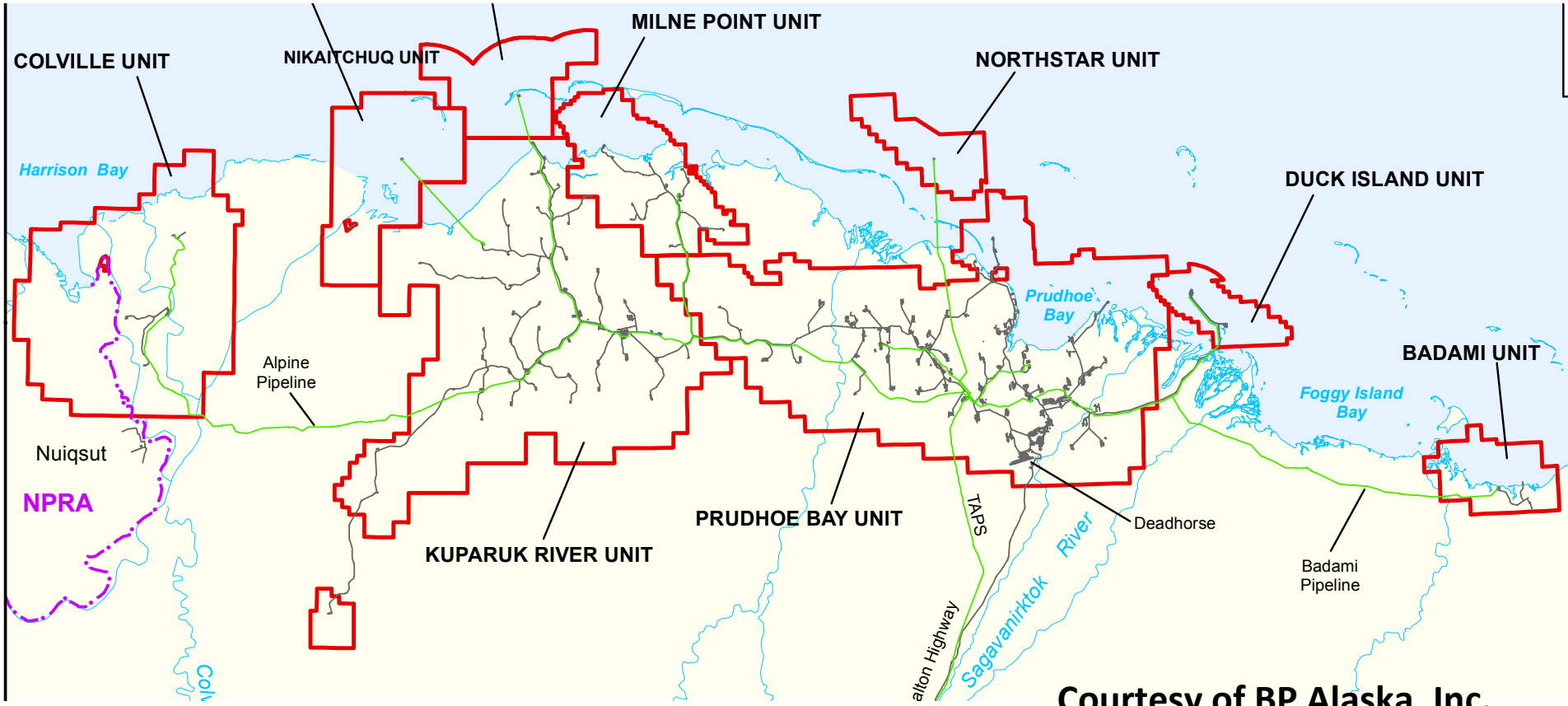
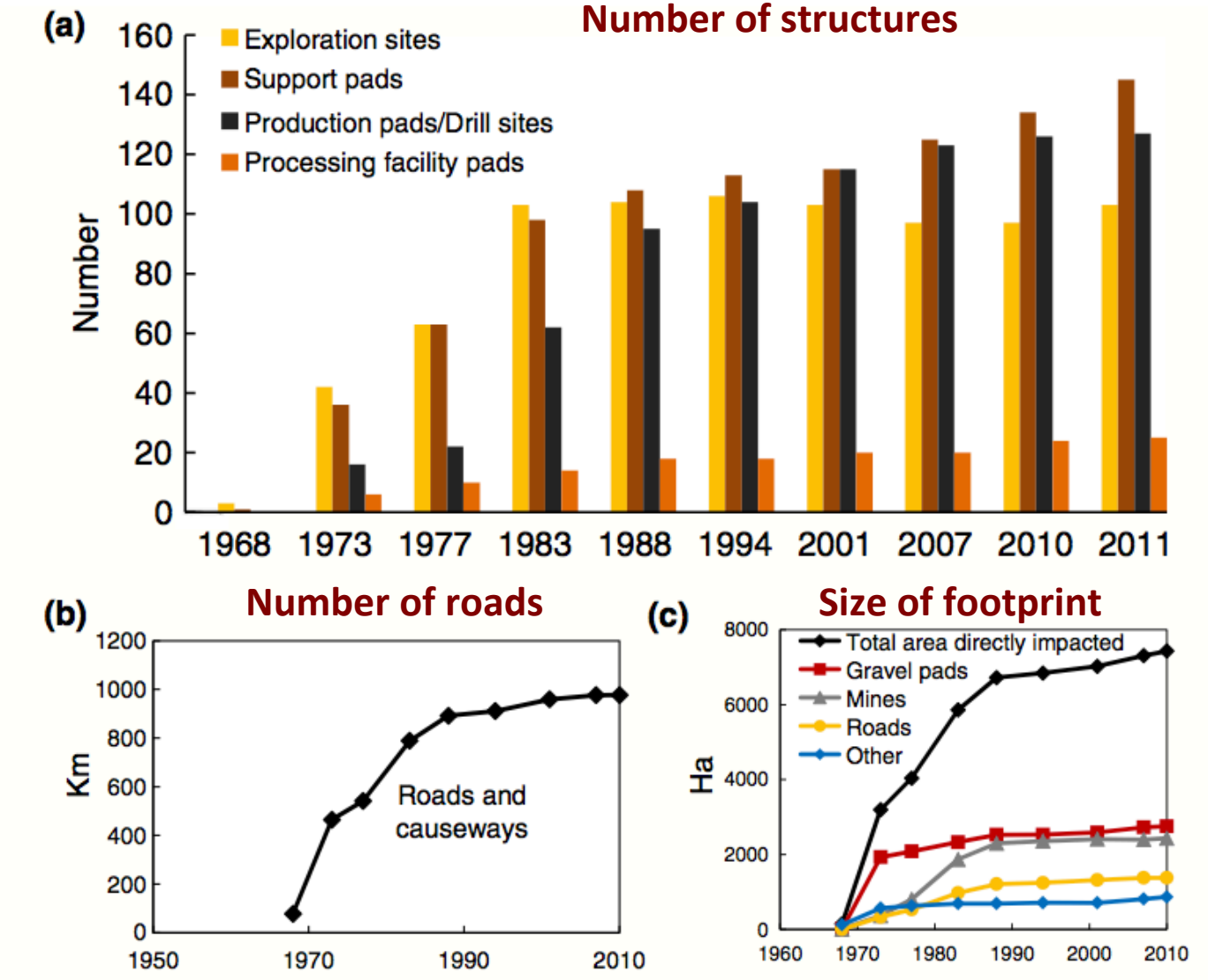
- **Regional-scale analysis of infrastructure extent.**
- **Landscape-scale analysis of changes to local landscapes and vegetation.**
- **Ground-base studies of vegetation, soil and permafrost changes associated with roads.**

Regional-scale studies: Time series catalog of infrastructure change for the entire North Slope region 1968-2010

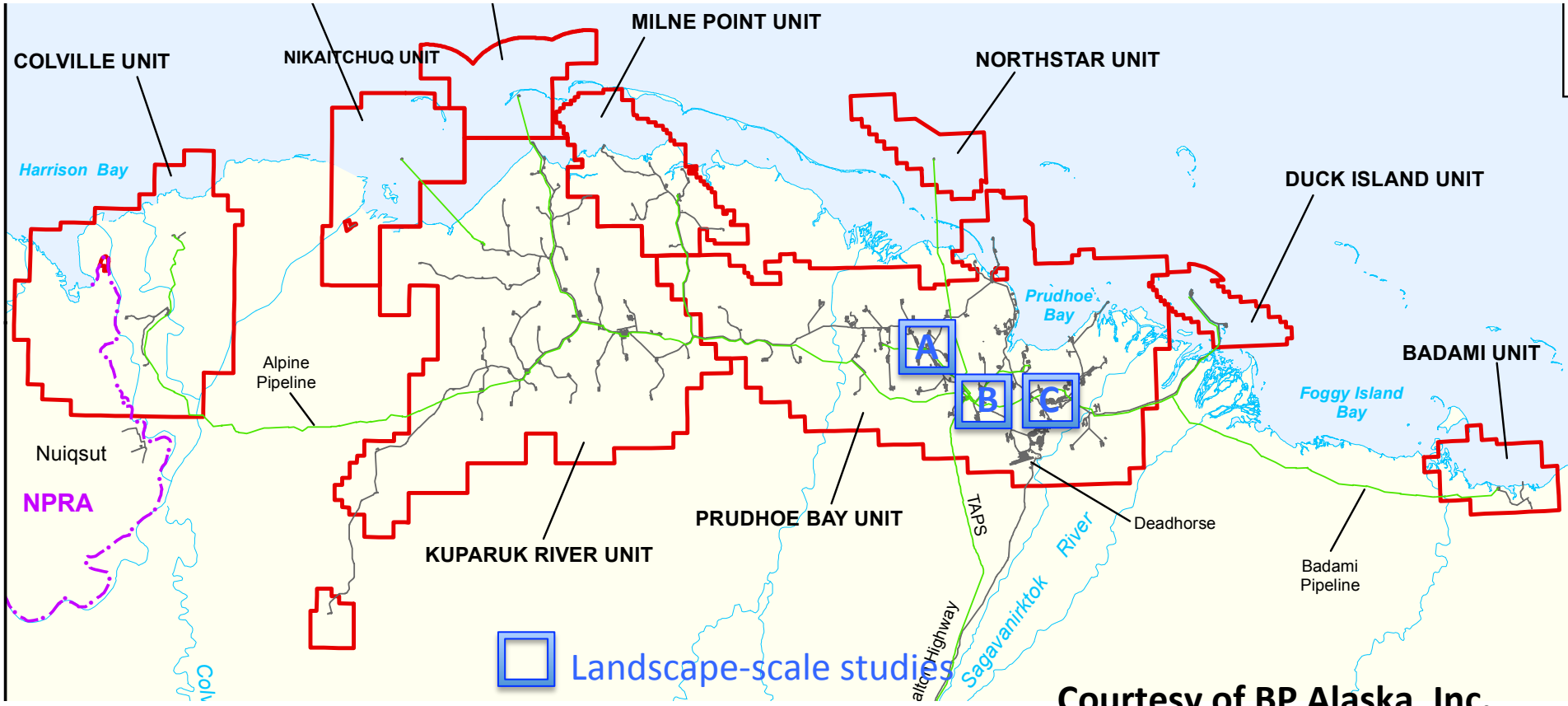


150 km

History of infrastructure change

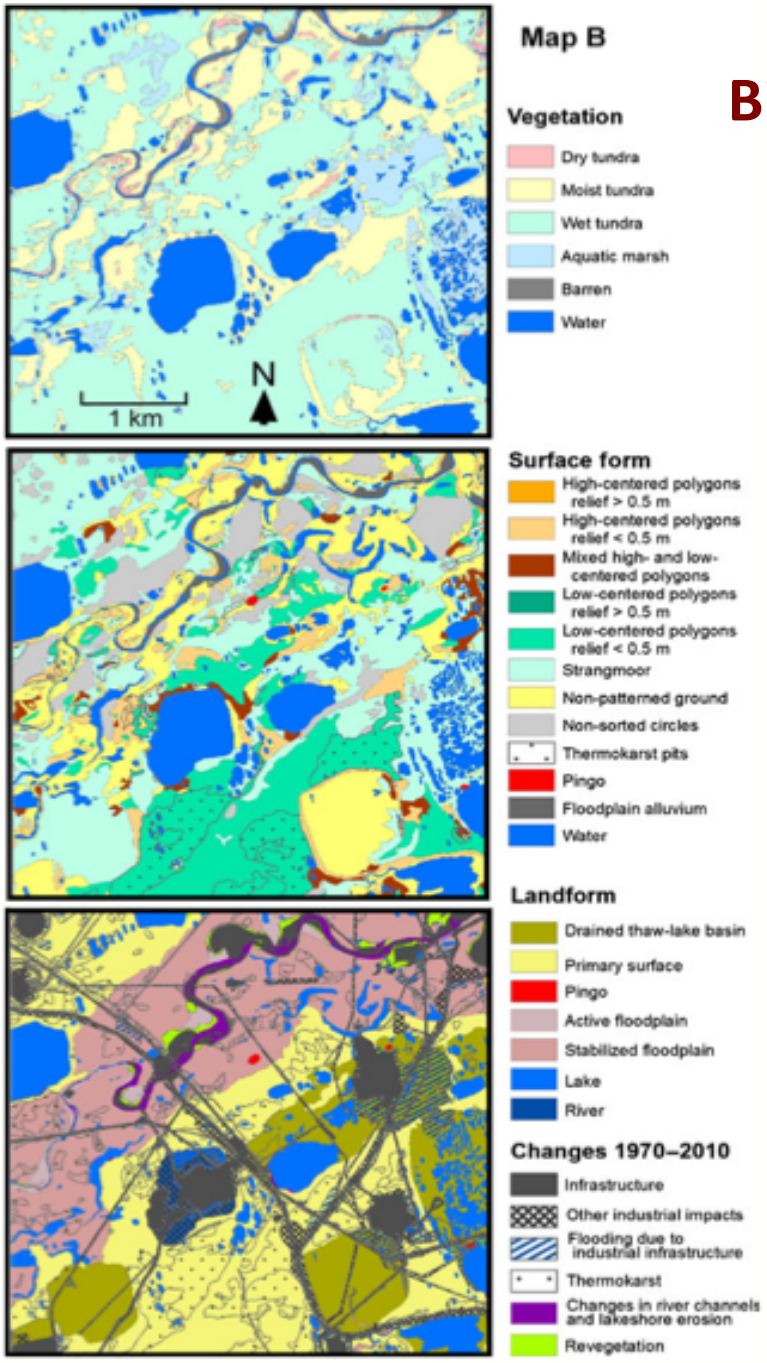


Landscape-scale studies: Time-series analysis of infrastructure-related effects to permafrost and landscapes in three 22-km^2 areas at Prudhoe Bay



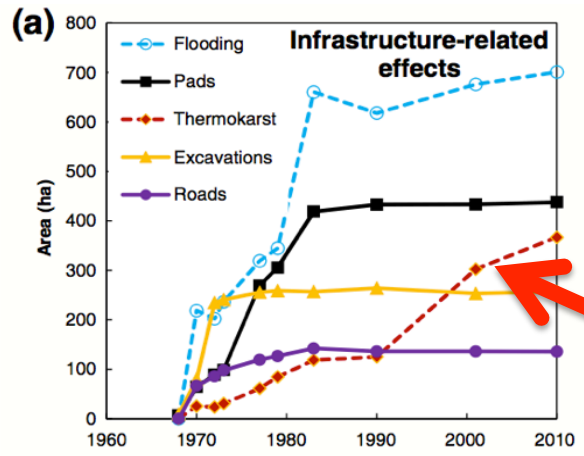
Courtesy of BP Alaska, Inc.

150 km

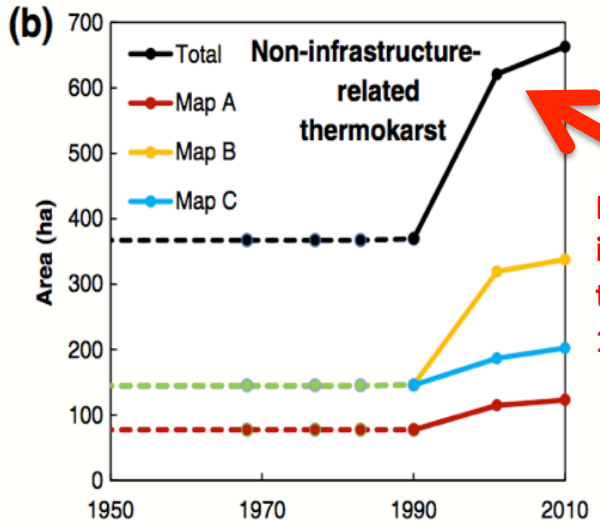


One of three 22-km^2 areas mapped

Big surprise was the sudden increase in thermokarst after 1990:

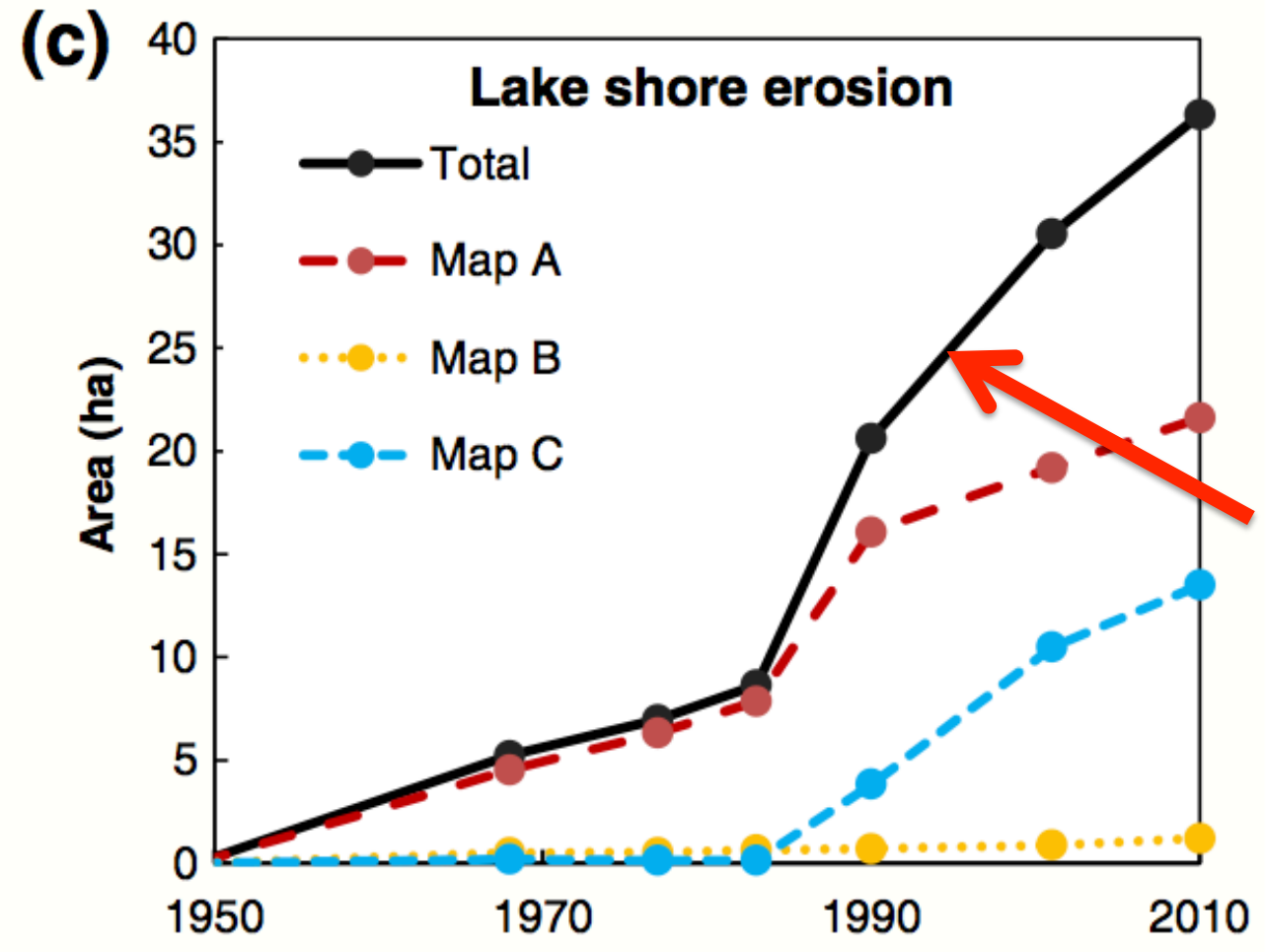


Infrastructure thermokarst: 3.5x since 1990

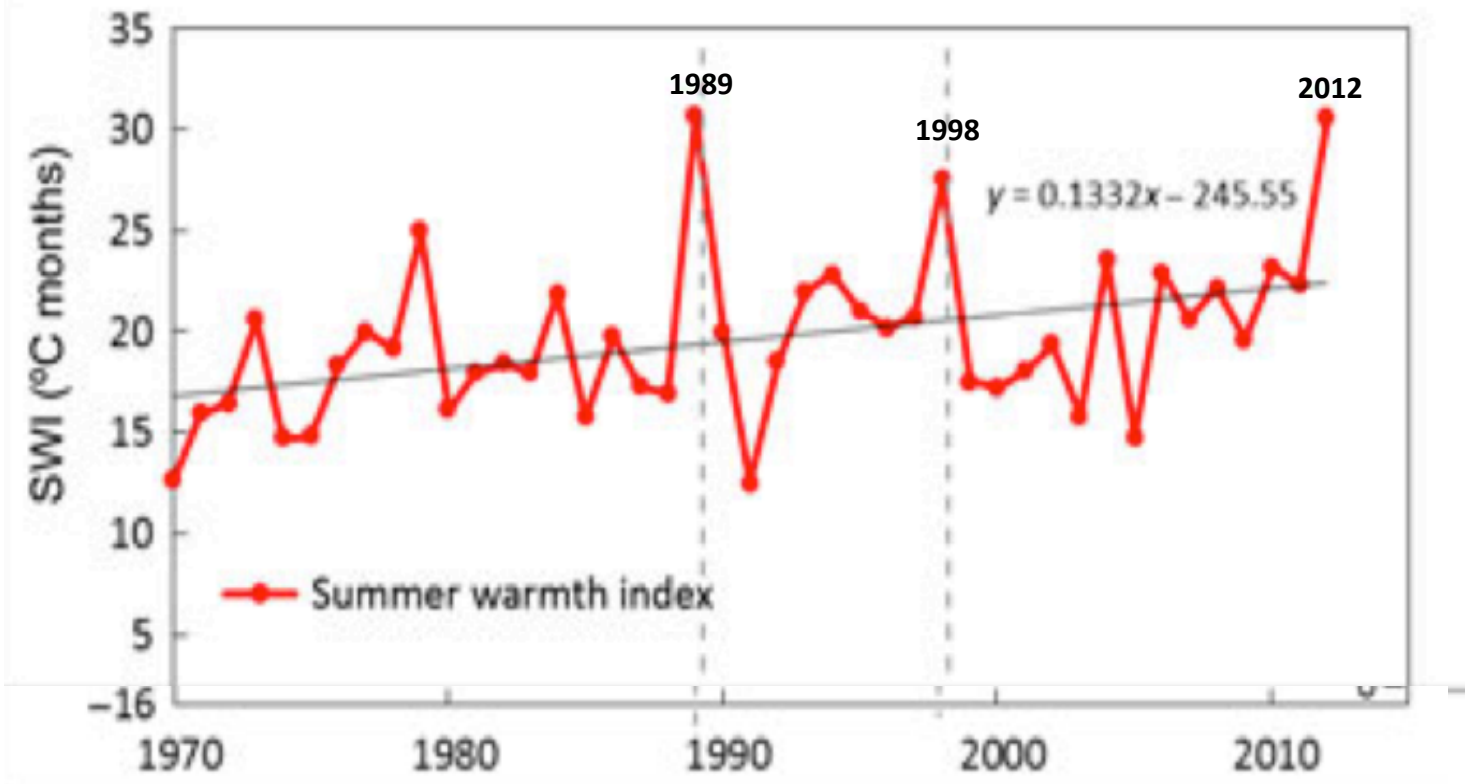


Non-infrastructure thermokarst: 1.8x since 1990

Also increase in lake shore erosion



Annual mean summer warmth index
SWI = annual sum of monthly mean temperatures above freezing (thawing degree months)

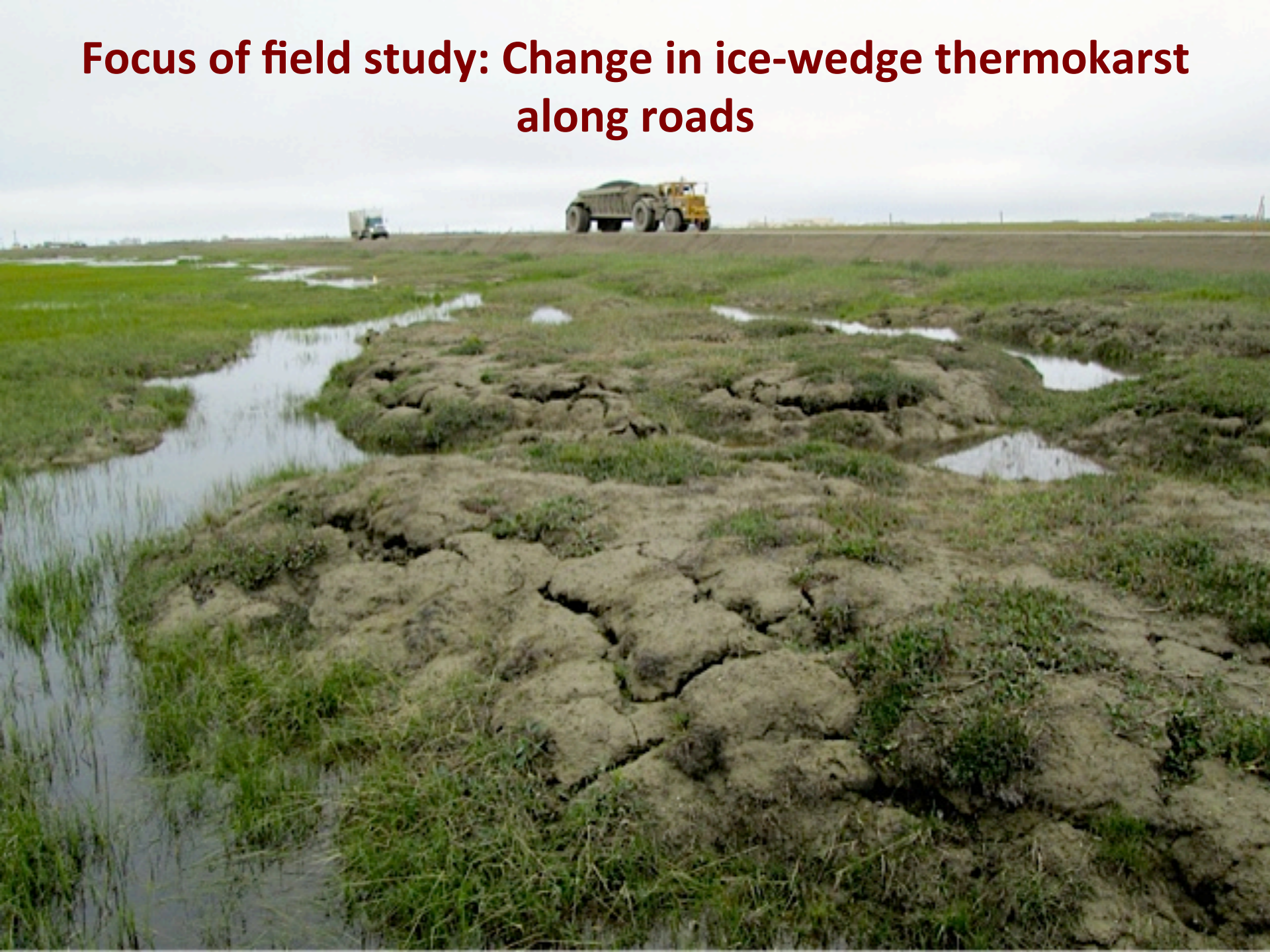


Raynolds et al. 2014.
Data from NWS: Prudhoe (1970-1986) + Deadhorse Airport (1987-2012).

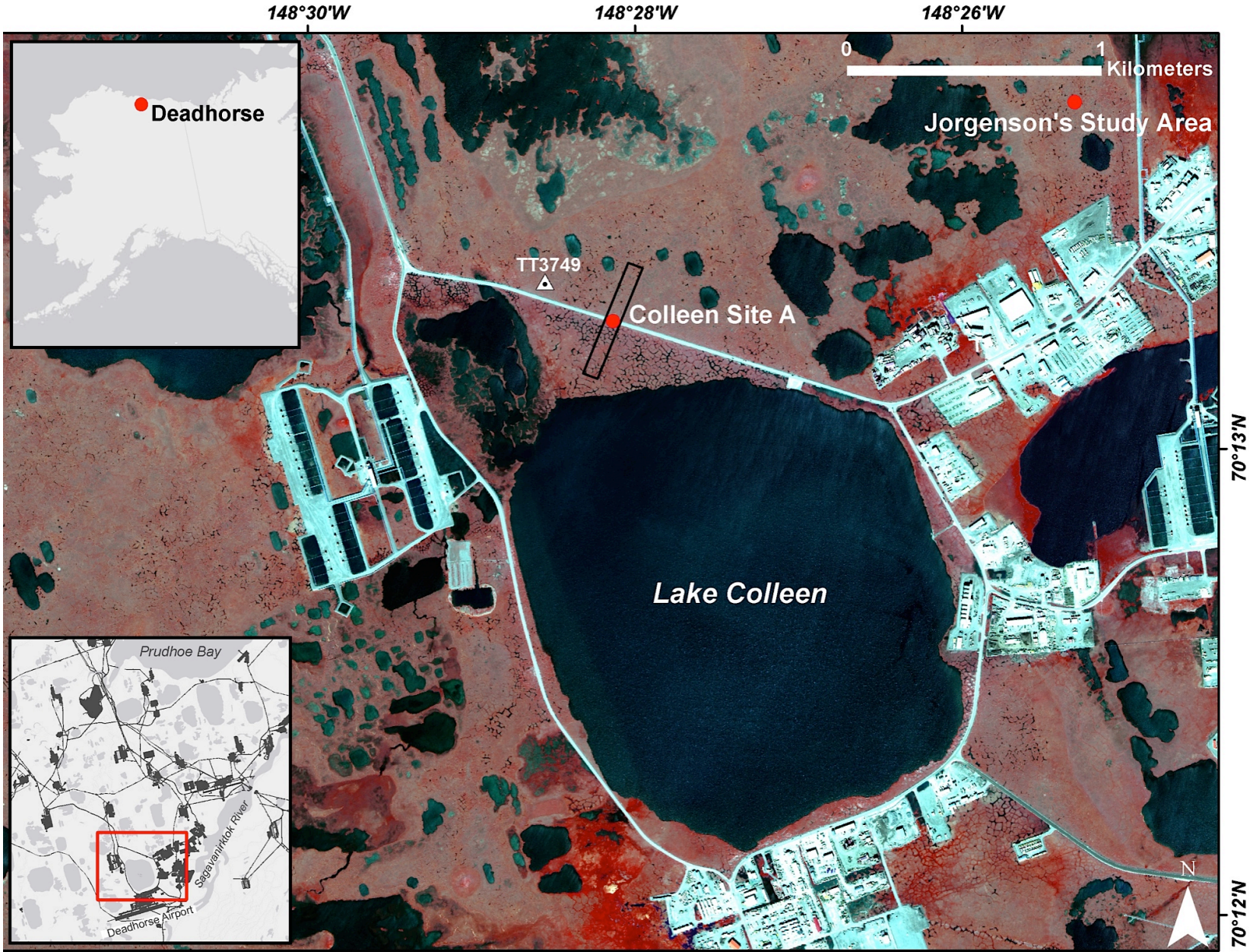
Series of exceptionally warm years between 1989 and 2012 likely caused melting of tops of ice wedges leading to the region-wide increase in ice-wedge thermokarst.

Extensive roadside and climate-related changes since 1983

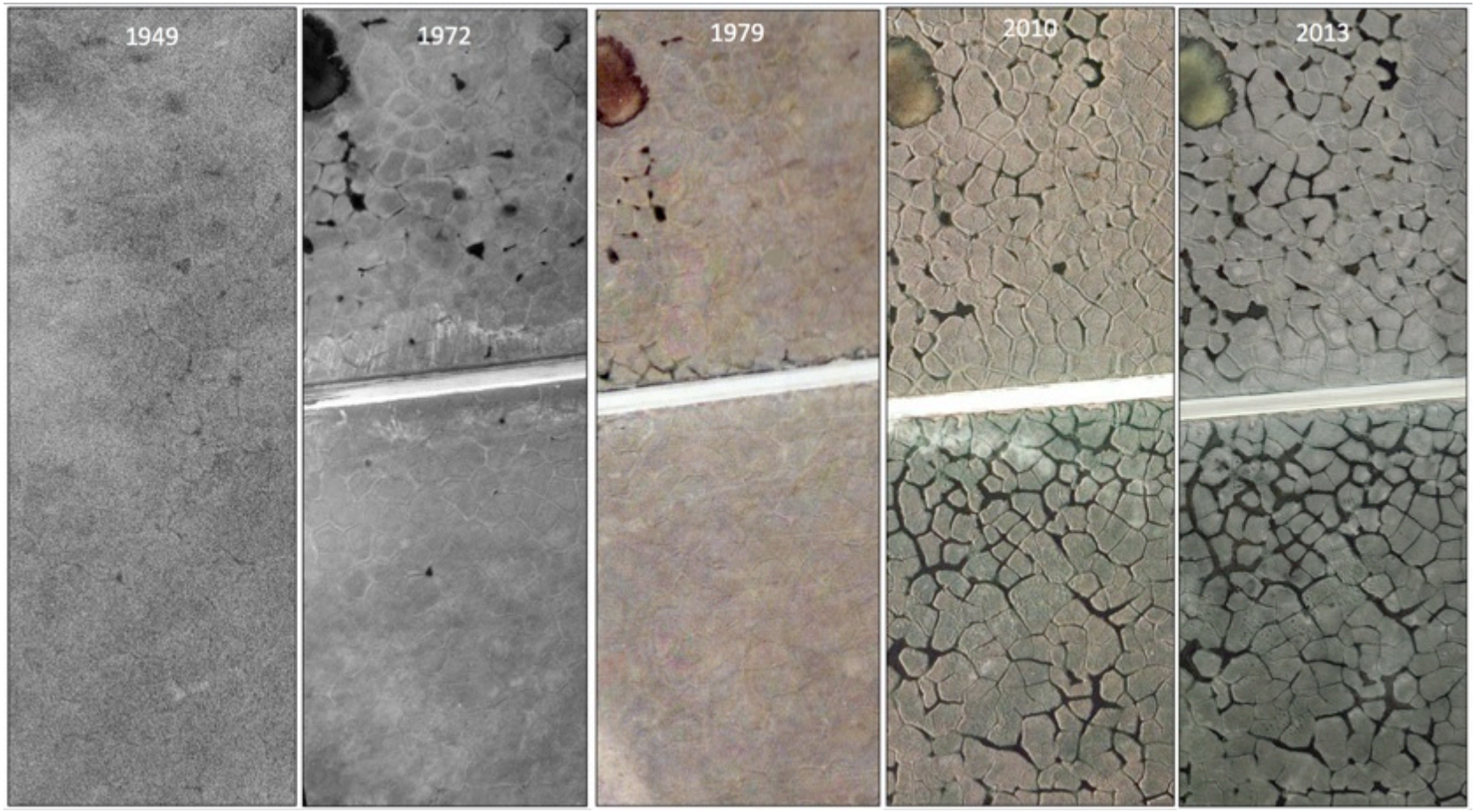
Focus of field study: Change in ice-wedge thermokarst along roads



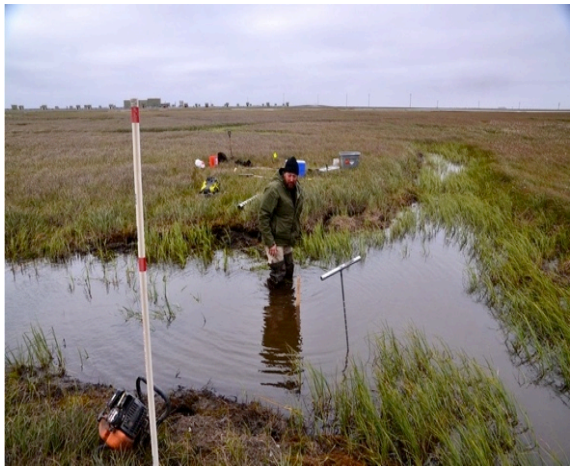
Colleen Site A near Deadhorse, AK



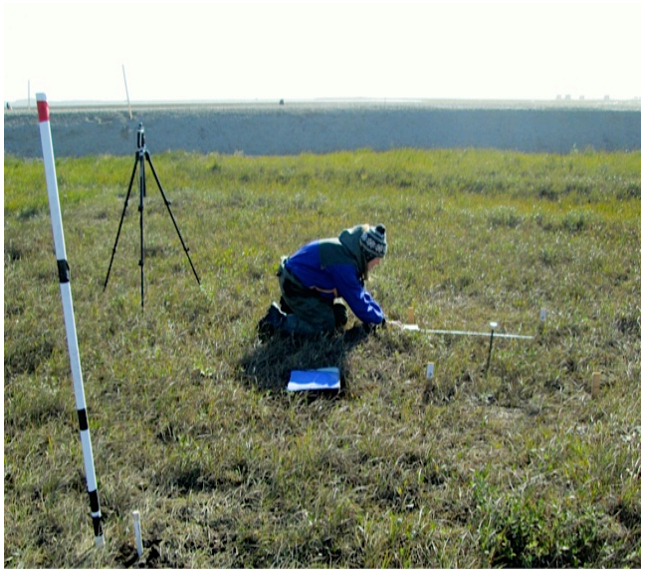
Changes at Colleen Site A (1949-2013)



Ground-based studies in 2014 of thermokarst changes along the Prudhoe Bay Spine Road (1949-2013)



Integrated geomorphology, soil, vegetation, and permafrost studies.



Walker et al. 2014, AGC Report 14-01.

Three posters tell the story of the field investigations

- **Buchhorn, Marcel et al., #339,** Effects of 45 years of heavy road traffic on permafrost and tundra along the Spine Road at Prudhoe Bay, Alaska
- **Kanevskiy, Mikhail et al., #337,** Degradation and recovery of ice wedges in relation to road infrastructure in the Prudhoe Bay Oilfield, AK
- **Raynolds, Martha et al., #333,** Vegetation changes related to 45 years of heavy road traffic along the Spine Road at Prudhoe Bay, Alaska

Comparison of Prudhoe Bay, AK and Bovanenkovo, RU:

Poster to be presented at AGU 2014

Rapid Arctic Transitions due to Infrastructure and Climate (RATIC):

Comparison of the geoecological conditions, permafrost hazards, and infrastructure spread in the Bovanenkovo Gas Field, Russia and the Prudhoe Bay Oilfield, Alaska

Donald A Walker[1], Martha K Raynolds[1], Timo Kumpula[2], Yuri Shur[1], Mikhail Z Kanevskiy[1], Marina O Leibman[3], Artem Khomutov[3], Ken Ambrosius[4], Marcel Buchhorn[1], Howard E Epstein[5], Bruce C. *Forbes*[6], Gary Kofinas[1], George V Matyshak[7], Vlad Romanovsky[1], Lisa Wirth[1]

[1]*University of Alaska Fairbanks, Fairbanks, AK, USA,* [2]*University of Eastern Finland, Joensuu, Finland,* [3]*Earth Cryosphere Institute, Siberian Branch, Russian Academy of Sciences, Tyumen, Russia,* [4]*Aerometrics Geospatial Solutions, Anchorage, AK, USA,* [5]*University of Virginia, Charlottesville, VA, USA,* [6]*University of Lapland, Rovaniemi, Finland,* [7]*Lomonosov Moscow State University, Moscow & Tyumen, Russia.*

Abstract

Many areas of the Arctic are undergoing rapid permafrost and ecosystem transitions resulting from a combination of industrial development and climate change as summer sea ice retreats and abundant Arctic natural resources become more accessible for extraction. The Bovanenkovo Gas Field (BGF) in Russia and the Prudhoe Bay Oilfield (PBO) in Alaska are among the oldest and most extensive industrial complexes in the Arctic, and both are situated in areas with extensive ice-rich permafrost. Case studies of the two hydrocarbon fields provide an overview of the baseline geoecological conditions, rates of hydrocarbon development, and perceptions of change by local cultures in these two remote Arctic areas.

Conclusions

- Differences in the underlying surficial geology (BGF: hilly, with mainly marine clays overlaid by alluvial sands and peat; PBO: flat alluvial gravel overlaid by loess and peat) have resulted in very different permafrost conditions and hazards (BGF: mainly tabular ground ice in the uplands, with extensive cryogenic landslides and thermocirques on slopes; PBO: ice-rich loess with extensive thaw lakes, and ice-wedge polygons with extensive thermokarst)
- A recent series of warm summers has triggered a major increase in thermokarst in the PBO and thermocirques near the BGF.
- Both fields were discovered at about the same time (PBO: 1968; BGF: 1972). The PBO infrastructure network developed rapidly and by 1977 was connected to the rest of Alaska by the Dalton Highway and the Trans-Alaska Pipeline, which permitted additional development of adjacent oilfields, and export of the oil to the ice-free port at Valdez. The BGF development proceeded much slower. Transport of gas out of the region still awaits construction of pipeline linkages to other gas fields on the Yamal and points further south in Russia and Europe.
- The small populations of indigenous people in both areas have benefited economically from resource development, but with major social consequences. Most threatening to both groups is restricted free access by hunters and herders through their traditional lands.
- Future mega-expansion of infrastructure in both areas, combined with climate-induced changes to local landscapes and permafrost present unprecedented challenges to local communities. The shear scale of the proposed hydrocarbon developments in the next few decades could overwhelm the ability of the local communities to adapt to the changing conditions.
- Successful adaptive management will require full engagement of local people and governments with industry and national governing agencies.
- A new initiative called Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) is a forum for developing and sharing new ideas and methods to facilitate the best practices for assessing, responding to, and adaptively managing the cumulative effects of Arctic industrial infrastructure and climate change.

Funding:

USA: NASA Land Cover Land Use Change (LCLUC) Program, Grant No. NNX14AD90G. NASA ProABoVE (Arctic Boreal Vulnerability Experiment), grant no. 8949. NSF Arctic Science, Engineering and Education for Sustainability (ArcSEES) grant no. 1233854.
Finland: Academy of Finland, Russia in Flux program, ENSINOR project (decision 208147); Academy of Finland: Resilience in Social-Ecological Systems of Northwest Eurasia - RISES (decision 256991)
Russia: Russian Foundation for Basic Research (РФФИ 13-05-91001-АНФ_а).

References:

Kanevskiy M, Shur Y, Jorgenson MT et al. (2013) Ground ice in the upper permafrost of the Beaufort Sea coast of Alaska. *Cold Regions Science and Technology*, 85, 56-70.

Khomutov AV, & Leibman MO (2009) Landscape pattern and cryogenic landsliding hazard analysis on Yamal peninsula, Russia. In Martes JR, Christiansen HH & Doolittle JJ (eds). *Thermal state of frozen ground in a changing climate during the IPY.* Abstracts from the 3rd European Conference on Permafrost, 254. The University Centre, Svalbard.

Khomutov AV, Leibman MO & Andreeva MV (2012) Mapping of ground ice in Central Yamal, Tyumen State University Herald, *Earth Sciences*, 7, 68-76.

Kurkala, T., Forbes, B.C., Stammler, F. & N. Meschtyb (2012). Dynamics of a Coupled System: Multi-Resolution Remote Sensing in Assessing Social-Ecological Responses during 25 Years of Gas Field Development in Arctic Russia. Remote Sensing, 4, no. 4: 1046-1068.

Kurkala T, Paavola A, Kaarkkainen K, Forbes BC, Stammler F (2011) Land use and land cover change in Arctic Russia: Ecological and social implications of industrial development. *Global Environmental Change*, 1–13.

Leibman MO, Gadzhiev MA, & Khomutov AV (2014 in press) Research station "Vaskina Dacha". Review of long-term activities. Permafrost and Periglacial Processes.

Raynolds MK, Walker DA, Ambrosius KJ et al. (2014) Cumulative geoecological effects of 62 years of infrastructure and climate change in ice-rich permafrost landscapes, Prudhoe Bay Oilfield, Alaska. *Global Change Biology*, 1211–1224.

Romanovsky VE, Smith SL, Christiansen HH et al. (2012) Permafrost [in "State of the Climate in 2011]. *Bulletin of the American Meteorological Society*, 93, S137–S138.

Walker DA (1985) *Vegetation and Environmental Gradients of the Prudhoe Bay Region, Alaska, CRREL Report 85-14.* U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Walker DA, Everett KR, Webber PJ, Brown J (eds.) (1980) *Geobotanical Atlas of the Prudhoe Bay Region, Alaska, CRREL Report 80-14.* U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Bovanenkovo gas field, Yamal Peninsula Russia:

Highly erodible sands and the presence of massive tabular ground ice near the surface contributes to landslides and thermo-denudation of slopes. A large set of cryogenic landslides occurred in Bovanenkovo region in Central Yamal peninsula, Arctic Russia in late 1980's. Mega size Bovanenkovo gas field was found in 1970's and in 2012 production began after large infrastructure construction. In central Yamal peninsula both natural and anthropogenic changes has occurred during the past 40 years. These range from physical obstructions, such as roads, railways, and pipelines, to direct and indirect ecological impacts, such as changes in vegetation and hydrology. Analysis summarized from Kumpula et al. (2011), Kumpula et al. (2012), Khomutov & Leibman (2010), Khomutov et al. (2012) and Liebman et al. (2014).

Extent of Bovanenkovo gas field

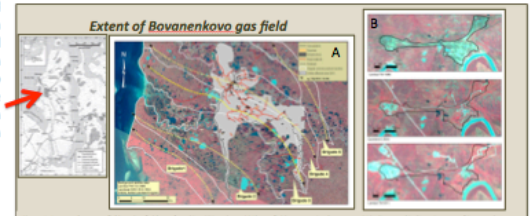


Figure 1. Bovanenkovo gas field. A. Gas field was found in 1972. In late 1980's gas field construction began. In 1988, direct and indirect impacts of Bovanenkovo gas field have affected summer pastures primarily on the territories used by brigades 4 and 8. Brigade 2 had been relatively unaffected until 2011. As Soviet Union collapsed in early 1990's development stopped in Bovanenkovo. In 2006 Gazprom made new plan to start production and heavy construction phase began. Since then pipeline construction has increased impacts significantly on lands used by herders south of the Mordy-yakha River. The main gas field no longer functions as an island as since it connects directly to southern transportation networks. B. Patterns of mechanical surface disturbance and revegetation in the vicinity of Kekh, the first gas worker settlement to be established at Bovanenkovo in the late 1980s. The top scene from 1988, when the development had just began, reveals a large zone of exposed mineral soils (marine clay) denuded of vegetation by heavy off-road vehicle traffic and construction activities. The black polygon circumscribes the extent of disturbance beginning in 1988 and remains consistent across all three images for spatial reference. In the middle scene, VHR Quickbird 2 shows the extent of revegetation after 14 years of natural regeneration. The bottom Landsat TM scene indicates that much of the bare ground has been totally revegetated by 2011. In addition, a significant amount of new permanent infrastructure has been built since 2004.

Examples of typical cryogenic landslides and thermocirques

Note the tabular ice below the layer of soil in right photo.

Historical changes

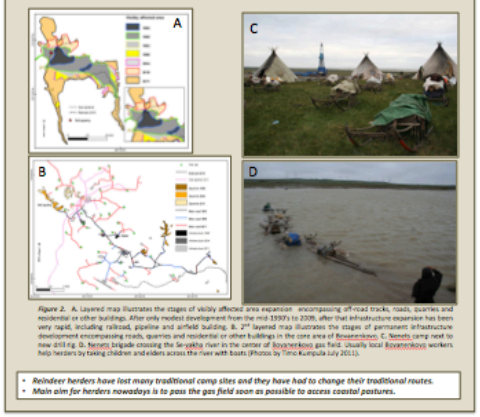


Figure 2. A. Layered map illustrates the stages of visibly affected area expansion encompassing off-road tracks, roads, quarries and residential or other buildings. After only modest development from the mid-1970's to 2009, after that infrastructure expansion has been very rapid, including railroad, pipeline and airfield building. B. 2nd layered map illustrates the stages of permanent infrastructure development encompassing roads, quarries and residential or other buildings in the core area of Bovanenkovo. C. Nenets camp next to new drill rig. D. Nenets brigade crossing the Se-yakha river in the center of Bovanenkovo gas field. Usually local Bovanenkovo workers help herders by taking children and elders across the river with boats (Photos by Timo Kumpula July 2011).

- *Reindeer herders have lost many traditional camp sites and they have had to change their traditional routes.*
- *Main aim for herders nowadays is to pass the gas field soon as possible to access coastal pastures.*

Geoecological and climate controls of cryogenic denudation

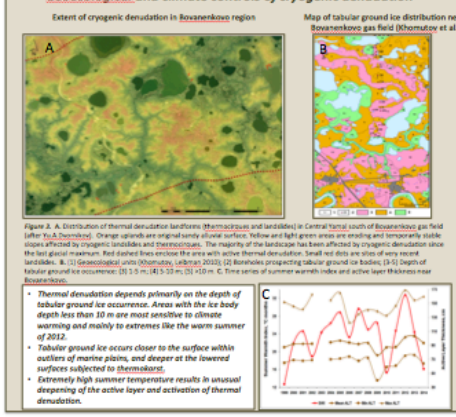


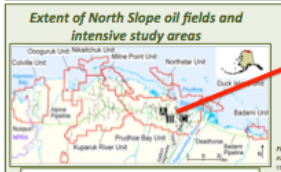
Figure 3. A. Distribution of thermal denudation landforms (thermokarsts and landslides) in Central Yamal south of Bovanenkovo gas field (after Yu.A.Tremyatkin). Orange uplands are original sandy eLoeial surface. Yellow and light green areas are eroding and temporarily stable slopes affected by cryogenic landslides and thermocirques. The majority of the landscape has been affected by cryogenic denudation since the last glacial maximum. Red dashed lines enclose the area with active thermal denudation. Small red dots are sites of very recent landslides. B. (1) Geoecological units (Khomutov, Leibman 2010); (2) Boreholes prospecting tabular ground ice bodies; (3-5) Depth of tabular ground ice occurrence: (3) 1.5 m; (4) 5-10 m; (5) >10 m. C. Time series of summer warmth index and active layer thickness near Bovanenkovo.

- *Thermal denudation depends primarily on the depth of tabular ground ice occurrence. Areas with the ice body depth less than 10 m are most sensitive to climate warming and mainly to extremes like the warm summer of 2012.*
- *Tabular ground ice occurs closer to the surface within outliers of marine plains, and deeper at the lowered surfaces subjected to thermokarst.*
- *Extremely high summer temperature results in unusual deepening of the active layer and activation of thermal denudation.*

Prudhoe Bay oilfield, Alaska:

Thermokarst in the form ice-wedge degradation, is expanding along ice-wedges adjacent to roads and in areas away from roads. Between 1990 and 2001, coincident with strong atmospheric warming during the 1990s, natural thermokarst resulted in conversion of low-centered ice-wedge polygons to high-centered polygons, more active lakeshore erosion and increased landscape and habitat heterogeneity. These geoecological changes have local and regional consequences to wildlife habitat, land-use, and infrastructure. Analysis summarized from Raynolds et al. (2014), Walker et al. (1980, 2014), Romanovsky et al. (2012), Kanevskiy et al. (2013).

Extent of North Slope oil fields and intensive study areas



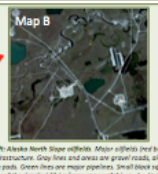


Figure 1. Left: Alaska North Slope oilfields. Major oilfields (red boundaries) and extent of infrastructure. Gray lines and areas are gravel roads, airstrips and construction pads. Green lines are major pipelines. Small black squares A, B and C are locations of the detailed 22-km² map areas of this study. Note the Nuiqsut village of Nuiqsut at left in the National Petroleum Reserve Alaska (NPRA), the Trans Alaska Pipeline System (TAPS), and Dalton Highway that link the oilfields to southern Alaska. Inset: Location within Alaska. Map courtesy of Aerometric, Inc. and BP Alaska, Inc. Above: Detail of Area B showing typical terrain consisting of the meandering Putuligayuk River and its floodplain, thaw lakes, drained lake basins, and primary surfaces between lakes. The infrastructure network consists of network of roads, drill sites, and processing facilities. The width of the area shown is 4.7 km. NASA GeoEye image, 14 Aug 2006.

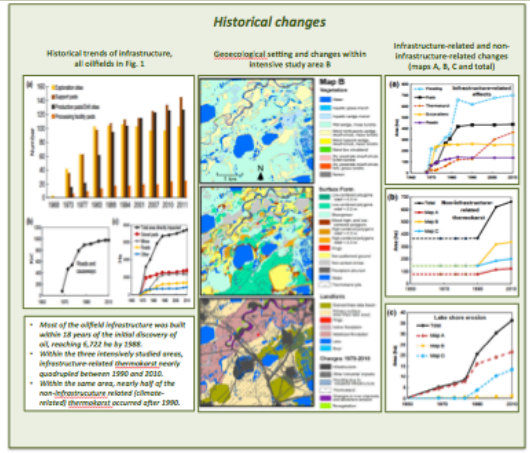
Infrastructure of the North Slope oilfields as of 2011

Count of facilities: 127 production pads, 25 facility pads, 345 support pads (power stations, camps staging areas, etc.), 103 exploration sites, 19 offshore exploration islands, 7 offshore production islands, 9 airstrips, 4 exploration airstrips, 2097 culverts, 27 bridges, 50 caribou crossings, and one active landfill.
Length of facilities: roads, 669 km; gravel fills, 760 km; powerlines, 541 km.
Area of facilities: gravel mines, 2,737 ha; gravel pads, 2,345 ha; gravel roads 669 ha; other, 652 ha; areas where pads have been removed and are in the process of recovery, 130 ha.

Examples of typical ice-wedge polygon thermokarst

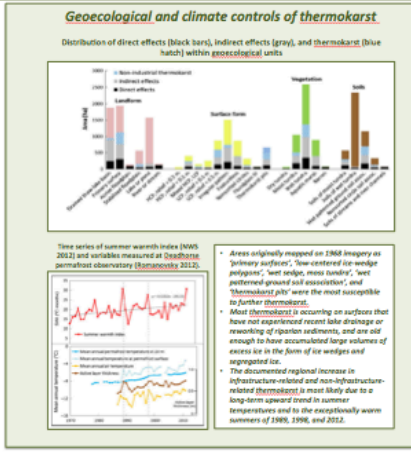
Figure 2. Flooding and thermokarst along roads at Prudhoe Bay, AK. a. Flooding of ice-wedge polygon troughs due to blocked drainage. Previous low-centered ice-wedge polygons are converted to high-centered polygons. b. Typical roadside environment showing flooded troughs and resulting thermokarst terrain. Heavy road dust has killed vegetation on the centers of ice-wedge polygons near the road. c. Thermokarst with active erosion of resulting high-centered polygons and widening of polygon troughs. Photos: D.A. Walker, 1 Jul 2013.

Historical changes



- *Most of the oilfield infrastructure was built within 18 years of the initial discovery of oil, reaching 6,722 ha by 1988.*
- *Within the three intensively studied areas, infrastructure-related thermokarst nearly quadrupled between 1990 and 2010.*
- *Within the same area, nearly half of the non-infrastructure related (climate-related) thermokarst occurred after 1990.*

Geoecological and climate controls of thermokarst



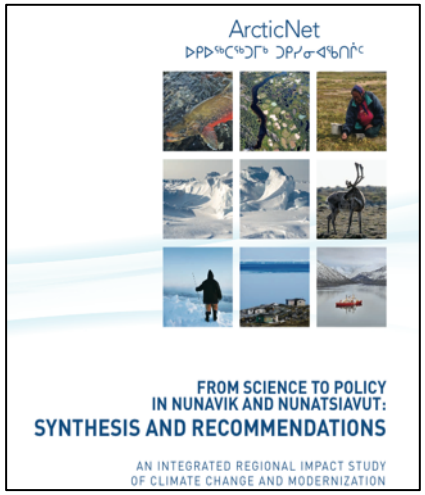
- *Areas originally mapped on 1968 imagery as 'primary surfaces', 'low-centered ice-wedge polygons', 'wet sedge, moss tundra', 'wet patterned-ground soil association', and 'thermokarst pits' were the most susceptible to further thermokarst.*
- *Most thermokarst is occurring on surfaces that have not experienced recent lake drainage or reworking of riparian sediments, and are old enough to have accumulated large volumes of excess ice in the form of ice wedges and segregated ice.*
- *The documented regional increase in infrastructure-related and non-infrastructure-related thermokarst is most likely due to a long-term upward trend in summer temperatures and to the exceptionally warm summers of 1989, 1998, and 2012.*

Poster presented at the AGU Fall Meeting, San Francisco, CA, 15-19 Dec 2014. Session GC04, Session GC04, Environmental, Socio-economic and Climatic Changes in Northern Eurasia and their Feedbacks to the Global Earth System. Abstract ID #8266.

RATIC International initiatives:

Yamal, Russia:

Forbes, B.C., et al., 2009, High resilience in the Yamal-Nenets social-ecological system, west Siberian Arctic, Russia: *Proceedings of the National Academy of Sciences*.



Arctic Canada:

Allard, M. and M. Lemay (Editors). 2012. Nunavik and Nunatsiavut: From Science to Policy. An Integrated Regional Impact Study (IRIS) of climate change and modernization. ArcticNet Inc. Quebec City, Canada, 3.

Case Study 2: **A synthesis of remote-sensing studies, ground observations and modeling to understand the social-ecological consequences of climate change and resource development on the Yamal Peninsula, Russia, and relevance to the circumpolar Arctic**

Case Study 3: Canadian Arctic Development: The ADAPT and IRIS initiatives: Community management in a changing permafrost landscape

Thank you!

Arc-SEES research team at Prudhoe Bay, AK.