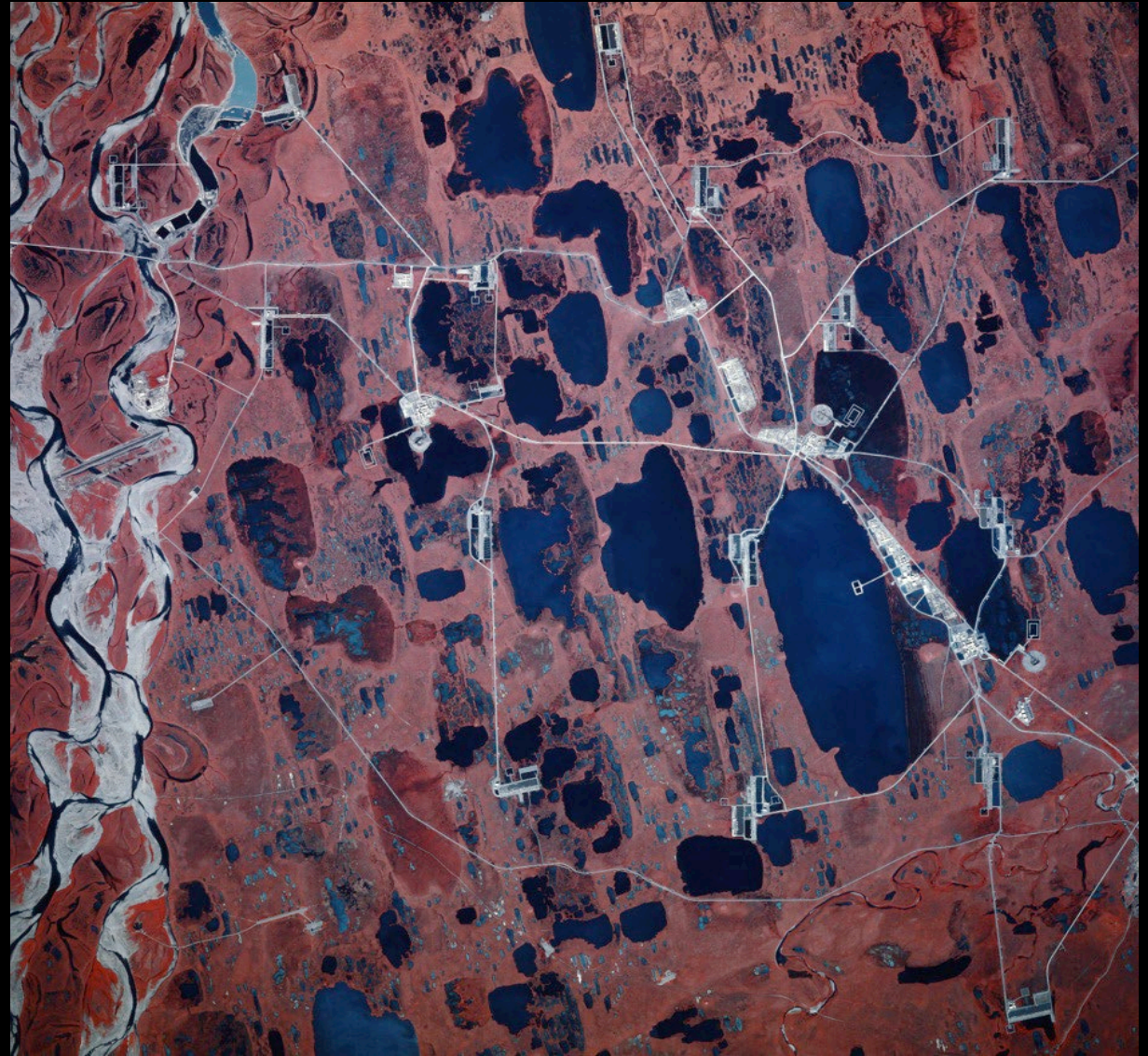


Navigating the New Arctic: Toward a new era of infrastructure and climate change cumulative impact assessment

Skip Walker
University of Alaska Fairbanks

CONTRIBUTORS: ANNETT BARTSCH, VLADIMIR ROMANOVSKY, DIMITRY NIKOLSKY, HELENA BERGSTEDT, AMY BREEN, BEN JONES, MICHAEL KANEVSKIY, JANA PEIRCE, YURI SHUR, MARTHA RAYNOLDS, RONALD DAANEN, TORRE JORGENSEN, ANNA LILJEDAHL, CHANDI WITHARANA, THOMAS SCHNEIDER VON DEIMLING, ELIAS MANOS

ARCTIC SCIENCE SUMMIT WEEK 2023, VIENNA;
SESSION ID 40, 22 FEB.



The western half for the Prudhoe Bay Oil Field.
NASA 1982 false-CIR aerial photo, 1:60,000 scale.



Introduction

“Are we entering a new era for predicting cumulative impacts of climate change and infrastructure in the Arctic?”



- This talk is about the IASC Rapid Arctic Transitions due to Infrastructure and Climate change (RATIC) initiative.
- One of RATIC’s goals is to examine the combined cumulative impacts of infrastructure and climate change using an interdisciplinary, whole-system, and panarctic approach that includes the social and human dimensions.
- Much of the talk is focused at the Prudhoe Bay Oilfield, AK.

Definitions

Cumulative impacts

“The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.” (CEQ 1987).

- First defined by U.S. Council on Environmental Quality, 1987
- Most countries have similar definition that generally, include:
 - Direct and indirect impacts
 - Impacts over large regional areas outside the area of direct impacts
 - Complex interactions from multiple sources over long periods of time
 - Non-linear responses and critical thresholds
 - Impacts to human social systems

Definitions

Direct landscape impacts

The "footprint"



Include areas covered by roads, pipelines, gravel pads, gravel mines, other semi-permanent structures

Photo: Grid Arendal, Peter Prokosh: http://www.grida.no/photolib/detail/prudhoe-bay-oil-field-alaska-1986_12be

Definitions

Indirect landscape impacts

- Impacts that accompany or follow the main impact
- Include the interactions with climate change.

Flooding and snowdrifts adjacent to infrastructure



Road-dust disturbance



Infrastructure-related ice-wedge thermokarst



Enhanced shrub growth due to disturbance and climate change



Photo credits: Ben Jones (upper left), Skip Walker (others)

Definitions

Ice-rich permafrost

- IRP is permafrost with *excess ice* (ice that exceeds the volume of the pore spaces in the soil).
- Includes areas with ice-wedges, tabular ice, lens ice, pingo ice.



Ice wedge, Misha Kanevskiy



Coastal erosion of Ice wedges, USGS



Low-centered and high-centered ice-wedge polygons, Misha Kanevskiy

Baseline Studies

There is a scarcity of long-term environmental studies after infrastructure was built — especially in areas with IRP.



Prudhoe Bay Oilfield. Photos: Courtesy of Pam Miller

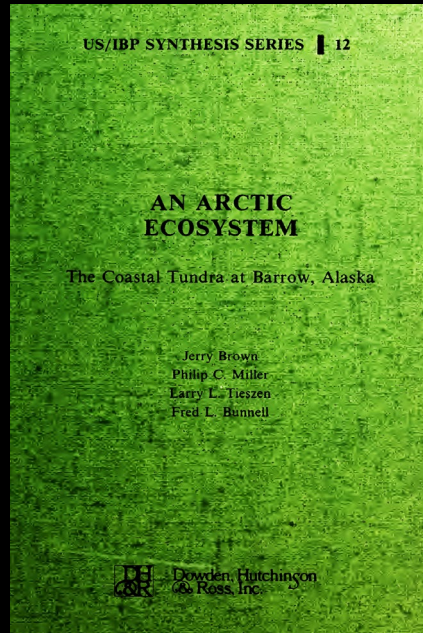


RATIC
background

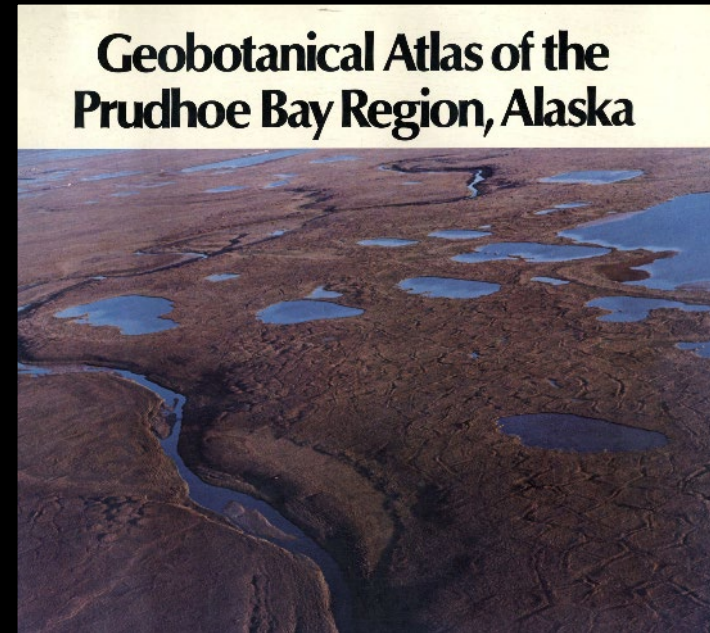
IBP Tundra Biome and U.S. Army CRREL investigations at Barrow, Prudhoe Bay, and the Dalton Highway

1970s-1980s

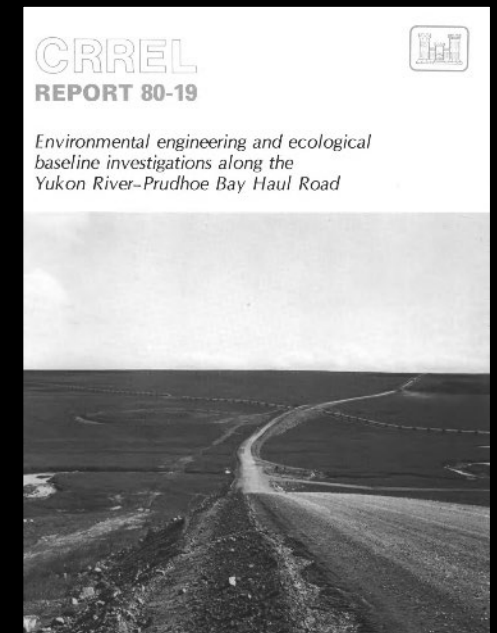
Baseline
environmental
studies



Brown et al. 1980 An Arctic Ecosystem: The Coastal Tundra at Barrow, Alaska.



Walker, D. A., K. R. Everett, P. J. Webber, and J. Brown. 1980. Geobotanical Atlas of the Prudhoe Bay Region, AK, CRREL Report 80-14.



Brown, J., and R. Berg. 1980. Environmental engineering and ecological baseline investigations along the Yukon River-Prudhoe Bay Haul Road. CRREL Report 8-19.

Key studies for examining change.



RATIC background

Cumulative impacts in the Prudhoe Bay region 1980s, 2000s, 2010s

1970s-2000s

Cumulative-impact studies



Articles

Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes

D. A. WALKER, P. J. WEBBER, E. F. BINNIAN, K. R. EVERETT, N. D. LEDERER, E. A. NORDSTRAND, M. D. WALKER

Proposed further developments on Alaska's Arctic Coastal Plain raise questions about cumulative effects on arctic tundra ecosystems of development of multiple large oil fields. Maps of historical changes to the Prudhoe Bay Oil Field show indirect impacts can lag behind planned developments by many years and the total area eventually disturbed can greatly exceed the planned area of occupation. For example, in the western part of the oil field that thaw-lake plains, flooding and thermokarst covered more than twice the area directly affected by roads and other construction activities. Protecting critical wildlife habitat is the central issue for cumulative impact analysis in northern Alaska. Comprehensive landscape planning with the use of geographic information system technology and detailed geobotanical maps can help identify and protect areas of high wildlife use.

THE DEVELOPMENT OF WETLANDS HAS DISRUPTED ABOUT 1.5 MILLION ACRES OF THE COASTAL PLAIN OF THE ARCTIC NATIONAL WILDLIFE REFUGE (ANWR) FOR OIL EXPLORATION (1) AND PRODUCTION (2). THE DISRUPTION WAS CAUSED BY THE CONSTRUCTION OF NEW OIL FACILITIES AND A GENERATION OF MAJOR ECOLOGICAL IMPACTS (3) IS EXPECTED BECAUSE OF KNOWLEDGE GAINED FROM EXPERIENCE IN THE PRUDHOE BAY OIL FIELD (Fig. 1). Although many lessons were learned at Prudhoe Bay about avoidance of problems related to construction in sensitive regions and wildlife, wildlife biologists are still difficult to see "integrating cumulative effects of the drilling and production fields."

The regulatory definition of sensitive wetlands is not ... the impact on the ecosystem which results from the cumulative effects of the action when added to other past, present, and reasonably foreseeable future actions (whether or not planned, ongoing, or imminent) undertaken with similar or cumulative effects. Cumulative effects are results that individually or in combination aggregate or compound, but are not a part of any ...

CUMULATIVE IMPACTS ARE OF PARTICULAR CONCERN IN THE ANWR BECAUSE OF THE MANY EFFECTS ON WILDLIFE AND WILDLIFE RESOURCES. A ONE-CENTURY OF ROAD, PIPELINE, AND OTHER CONSTRUCTION ACTING ALONG THE ARCTIC COASTAL PLAIN COULD HAVE UNDESIRABLE ...

E. A. Binnian, D. A. Walker, M. D. Walker, Peter Webber, "Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes," *Science*, 237(5337), 1997, pp. 1167-1170. © 1997 AAAS. Reprinted with permission from AAAS. www.aas.org. For a complete list of authors and their affiliations, see the full article at: www.sciencemag.org. Full article available at: www.sciencemag.org. Full article available at: www.sciencemag.org.

Walker et al. 1987. *Science*.

CUMULATIVE ENVIRONMENTAL EFFECTS OF OIL AND GAS ACTIVITIES ON ALASKA'S NORTH SLOPE

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES

National Research Council, 2003.

Global Change Biology

Global Change Biology (2014), doi:10.1111/gcb.12300

Cumulative geocological effects of 62 years of infrastructure and climate change in ice-rich permafrost landscapes, Prudhoe Bay Oilfield, Alaska

MARTHA K. RAYNOLDS¹, DONALD A. WALKER¹, KENNETH J. AMBROSIUS², JERRY BROWN³, KAYE R. EVERETT⁴, MIKHAIL KANEVSKIY⁵, GARY F. KOPINAS⁶, VLADIMIR E. ROMANOVSKY⁷, YURI SHUR⁸ and PATRICK J. WEBBER⁹

¹Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK 99775, USA, ²Arctic Slope Regional Corporation, Anchorage, AK 99501, USA, ³P.O. Box 7, Prudhoe Bay, AK 99724, USA, ⁴Sproul Point Research Center, Chukchi State University, Chukotka, CH 42314, USA, ⁵Department of Civil & Environmental Engineering, University of Alaska Fairbanks, Fairbanks, AK 99775, USA, ⁶School of Natural Resources and Agricultural Science, University of Alaska Fairbanks, Fairbanks, AK 99775, USA, ⁷Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99775, USA, ⁸Earth Crustal Institute SB RAS, Box 1230, Tyumen, 625001, Russia, ⁹P.O. Box 1230, Fairbanks, AK 99775, USA

Abstract

Many areas of the Arctic are simultaneously affected by rapid climate change and rapid industrial development. These areas are likely to increase in number and size as sea ice melts and abundant Arctic natural resources become more accessible. Documenting the changes that have already occurred is essential to inform management approaches to minimize the impacts of future activities. Here, we determine the cumulative geocological effects of 62 years (1948–2011) of infrastructure- and climate-related changes in the Prudhoe Bay Oilfield, the oldest and most extensive industrial complex in the Arctic, and an area with extensive ice-rich permafrost that is especially sensitive to climate change. The climatic effects that thermokarst has recently affected broad areas of the entire region, and that a steady increase in the area affected began shortly after 1950 corresponding to a rapid rise in regional summer air temperatures and related permafrost temperatures. We also present a conceptual model that describes how infrastructure-related factors, including road dust and roadside flooding are contributing to more extensive thermokarst in areas adjacent to roads and gravel pads. We mapped the historical infrastructure changes for the Alaska North Slope oilfield for 10 dates from the initial oil discovery in 1948–2011. By 2010, over 54% of the intensely mapped area was affected by oil development. In addition, between 1990 and 2010, a consistent shift toward atmospheric warming during the 1990s, 1998, of the remaining natural landscape (excluding areas covered by infrastructure, lakes and river floodplains) exhibited expansion of thermokarst features resulting in more abundant small ponds, greater microrelief, more active lakeshore erosion and increased landscape and habitat heterogeneity. This transition to a new geocological regime will have impacts to wildlife habitat, local residents and industry.

Keywords: Arctic, climate change, cumulative impacts, geocological mapping, ice-rich permafrost, ice-wedge polygons, infrastructure, photosynthesis, thermokarst, tundra

Received 18 September 2013 and accepted 6 November 2013

Introduction

Oil and gas exploration and extraction are occurring in ice-rich permafrost (IRP) areas of Alaska, Canada, and Russia, and it is inevitable that more extensive networks of infrastructure than presently exist will be required to extract the resources of these areas (AMAR, 2010). These will be constructed against a backdrop of rapid climate change, rapid technological changes, and

unprecedented social-ecological changes (Frank & Johnson, 2000; Oleson et al., 2008; ACA, 2009; AMAP, 2010; Kravitz et al., 2011; Kollias et al., 2013). Documenting the history of these developments as they occur will aid local communities, researchers, land managers, industry, and policy makers in developing adaptive approaches to plan for and respond to future changes (AMAR, 2010; Stravov et al., 2011).

The Prudhoe Bay Oilfield

The Prudhoe Bay Oilfield (PBO) in northern Alaska was the first developed oilfield in the Arctic, and is the

Raynolds, MK, et al. 2014. *Global Change Biology*.

Cumulative impacts as defined by the Council on Environmental Quality:

“The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.” (40 CFR ~ 1508.7, 1979).

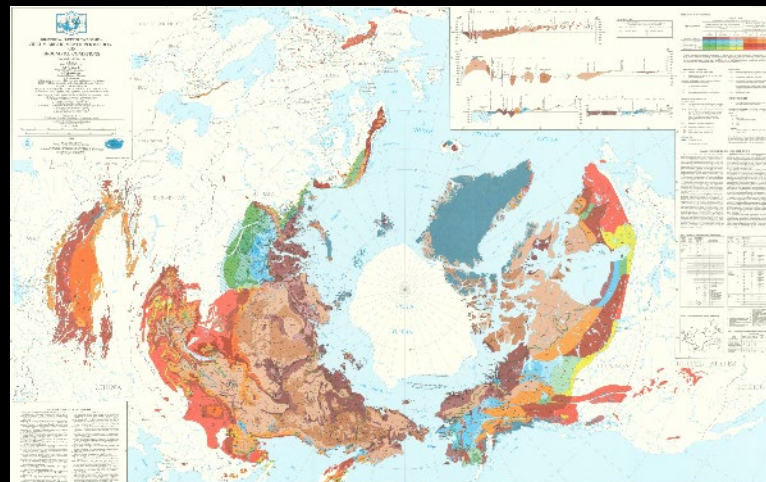
RATIC background

1990s-2010s

Pan-Arctic
landcover and
infrastructure
assessments

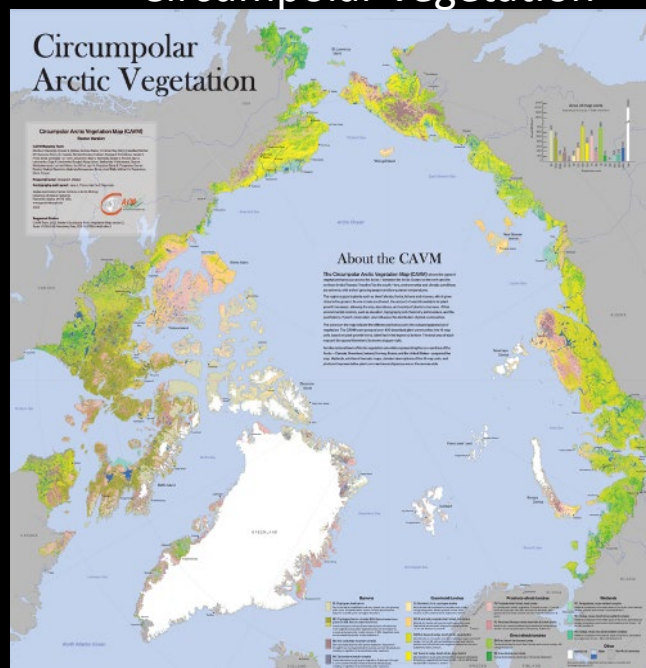


Pan-Arctic permafrost



Brown et al. 1997.

Circumpolar vegetation



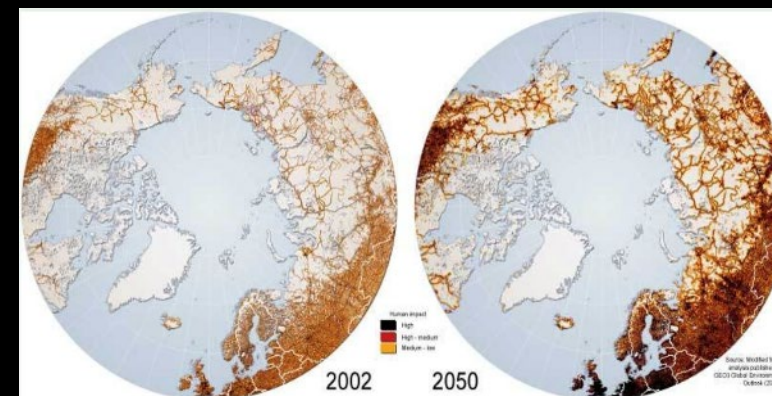
CAVM Team 2003 and 2023.

Pan-Arctic assessment of oil and gas



AMAP. 2010. Assessment 2007: Oil and Gas Activities in the Arctic — Effects and Potential Effects. Vol 1 and 2.

Pan-Arctic transportation corridors



Nellemann et al. GLOBIO 2001. global methodology for mapping human impacts on the biosphere: The Arctic 2050 scenario and global application. UNEP.

RATIC
background

Sustainability research Russia and U.S. Arctic oilfields

Finnish Academy/
Arctic Center project:
“Environmental and
Social Impacts of
Industrialization in
Northern Russia
(ENSINOR, 2004–2007)”

NASA Land-Cover Land-Use Change
program (LCLUC) and Northern
Eurasia Earth Science Partnership
Initiative (NEESPI) two projects:
Eurasia Arctic Transect (2007-2013)
and SYN-YAMAL (2014–17)

NSF program, Arctic Science
Engineering and Education for
Sustainability (ArcSEES), UAF
project: “Cumulative Effects of Arctic
Oil Development: planning and
designing for sustainability (2012-
2021)”



High resilience in the Yamal-Nenets social-ecological system, West Siberian Arctic, Russia

Ross, C., Nekrasov, A., and Stenroos, E. (2014). *Environmental Science and Technology*, 48(12), 4385-4392. doi:10.1021/es40282a011

Abstract: The Yamal-Nenets social-ecological system in the West Siberian Arctic, Russia, is a high-latitude region that has experienced rapid industrialization and resource extraction. This study examines the resilience of the system to these changes. The authors find that the system has a high degree of resilience, which is attributed to the Nenets people's traditional knowledge and practices. The study also identifies several key factors that contribute to the system's resilience, including the presence of traditional knowledge, the ability to adapt to change, and the presence of social networks. The authors conclude that the Yamal-Nenets social-ecological system is a model of resilience and that its study can provide valuable insights into the resilience of other high-latitude systems.

Keywords: resilience, social-ecological system, West Siberian Arctic, Russia, Nenets people, traditional knowledge, industrialization, resource extraction.

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 to the circumpolar Arctic

Skip Walker, Uma Bhatt*, Marcel Buchhorn†, Josefino Comiso†, Howard Epstein*, Keemia Ermokhina*, Bruce Forbes*, Gerald Frost*, Birgit Heister*, Gary Kattas*, Arseni Kuznetsov*, Timo Kumpan*, Marina LaBonne*, George Matyska*, Jorge Pinzon*, Martha Reynolds*, Vladimir Romanovsky*, Constan Tinoco*, Lisa Wirth*, Qin Yu**

*University of Alaska Fairbanks, Fairbanks, AK, USA; †University of Cologne, Cologne, Germany; ‡NASA Goddard Space Flight Center, Greenbelt, MD, USA; §University of Virginia, Charlottesville, VA, USA; ¶North Cryosphere Institute, SB, RAS, Tyumen, Russia; **Arctic Centre, Rovaniemi, Finland; ††Alaska Biological Research, Fairbanks, AK, USA; ‡‡University of Eastern Finland, Joensuu, Finland; ‡‡‡Moscow State University, Moscow, Russia

Abstract: The SYN-YAMAL project is 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. The project involves a multi-disciplinary team of scientists from various institutions, including the University of Alaska Fairbanks, the University of Cologne, NASA Goddard Space Flight Center, the University of Virginia, the North Cryosphere Institute, the Arctic Centre, and the Moscow State University. The project's findings are presented in this synthesis report, which includes a detailed overview of the project's objectives, methods, and results. The report also discusses the implications of the findings for the circumpolar Arctic and provides recommendations for future research and policy.

LANDSCAPE AND PERMAFROST CHANGES IN THE PRUDHOE BAY OILFIELD, ALASKA

Alaska Geobotany Center
Publication
AGC 14-01

EDITED BY
DONALD A. WALKER, MARCIA K. RAYNOLDS, YURI L. SHUI, MIKHAIL KANEVSKY, KENNETH J. AMBROSIO, VLADIMIR E. ROMANOVSKY, GARY P. KATTAS, JERRY BROWN, KATE R. EVERETT, PATRICK J. WEBBER, MARCEL BUCHHORN, GEORGE G. MATYSYAK, LISA M. WIRTH

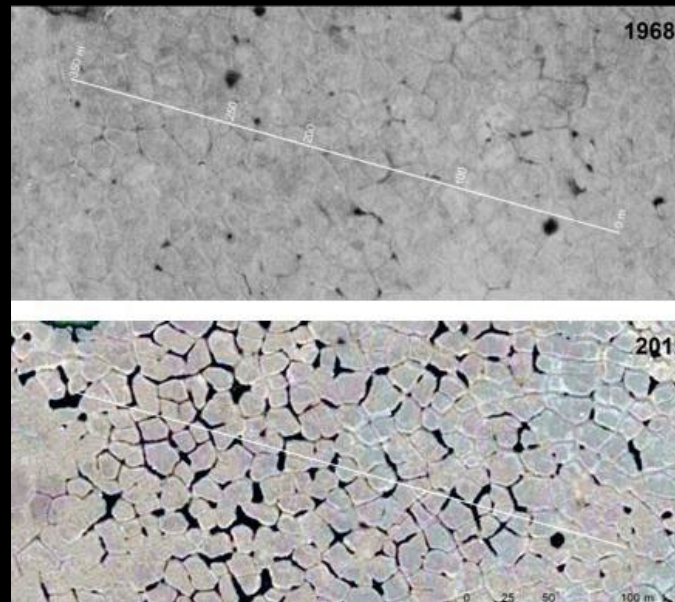


RATIC background

1980s-2020s

Hierarchy of studies of ice-wedge degradation

Abrupt ice-wedge degradation in natural systems due to climate change



Jorgenson et al. 2006. Abrupt increase in permafrost degradation in Arctic Alaska. *Geophysical Research Letters* 25:L02503.

Ice-wedge degradation due to infrastructure and climate change



Skip Walker photo

Kanevskiy et al. 2022. The shifting mosaic of ice-wedge degradation and stabilization in response to infrastructure and climate change, Prudhoe Bay Oilfield, Alaska, USA *Arctic Science*.

Pan-Arctic ice-wedge degradation



Pan-Arctic ice-wedge degradation in warming permafrost and its influence on tundra hydrology

Anna K. Liljedahl^{1*}, Julia Boike², Ronald P. Daanen³, Alexander N. Fedorov⁴, Gerald V. Frost⁵, Guido Grosse⁶, Larry D. Hinzman⁷, Yoshihiro Iijima⁸, Janet C. Jorgenson⁹, Nadya Matveyeva¹⁰, Marius Necsoiu¹¹, Martha K. Reynolds¹², Vladimir E. Romanovsky^{13,14}, Jörg Schulla¹⁵, Ken D. Tape¹, Donald A. Walker¹², Cathy J. Wilson¹⁶, Hironori Yabuki¹⁷ and Donatella Zona^{18,19}

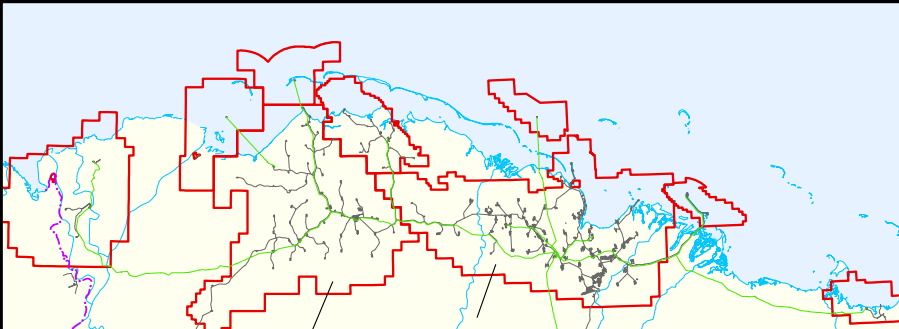
Ice wedges are common features of the subsurface in permafrost regions. They develop by repeated frost cracking and ice vein growth over hundreds to thousands of years. Ice-wedge formation causes the archetypal polygonal patterns seen in tundra across the Arctic landscape. Here we use field and remote sensing observations to document polygon succession due to ice-wedge degradation and trough development in ten Arctic localities over sub-decadal timescales. Initial thaw drains polygon centres and forms disconnected troughs that hold isolated ponds. Continued ice-wedge melting leads to increased trough connectivity and an overall draining of the landscape. We find that melting at the tops of ice wedges over recent decades and subsequent decimetre-scale ground subsidence is a widespread Arctic phenomenon. Although permafrost temperatures have been increasing gradually, we find that ice-wedge degradation is occurring on sub-decadal timescales. Our hydrological model simulations show that advanced ice-wedge degradation can significantly alter the water balance of lowland tundra by reducing inundation and increasing runoff, in particular due to changes in snow distribution as troughs form. We predict that ice-wedge degradation and the hydrological changes associated with the resulting differential ground subsidence will expand and amplify in rapidly warming permafrost regions.

Liljedahl et al. 2016. *Nature Geoscience*



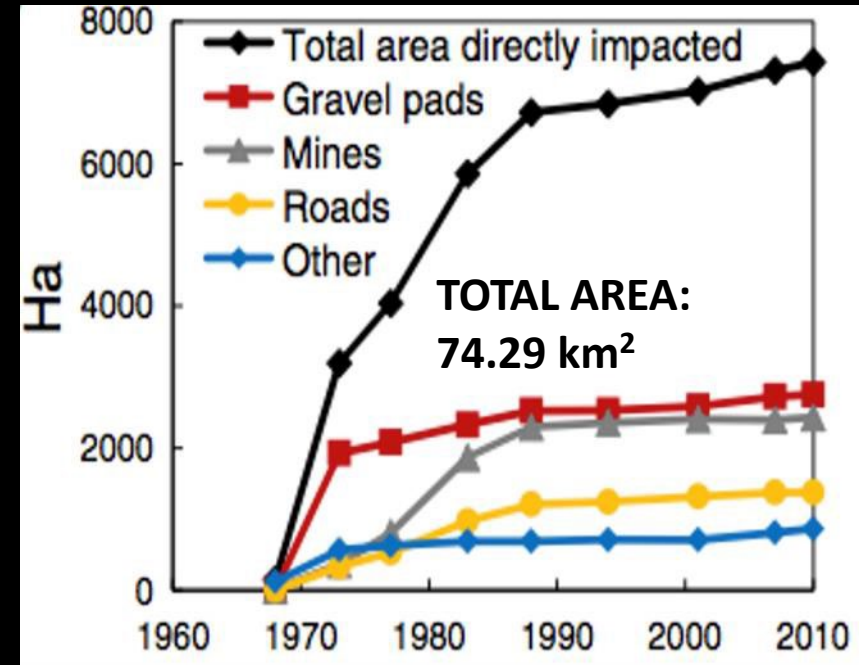
Cumulative impacts in the Prudhoe Bay Region

Oil-industry air photos, topographic maps, and GIS databases were used to map extent of infrastructure for regional cumulative-effects assessments in 1987, 2003, and 2014



Courtesy of BP Alaska, Inc. and NV5 Geospatial, Anchorage, AK

Regional footprint, 1968–2010



Number of features

- 103 exploration sites
- 127 production pads
- 145 support pads
- 25 proc. fac. pads
- 13 off-shore islands
- 9 airstrips
- 4 exploration airstrips
- 2037 culverts
- 78 Other (bridges, caribou crossings, landfill)

TOTAL: 2510 mapped items

Length of linear features

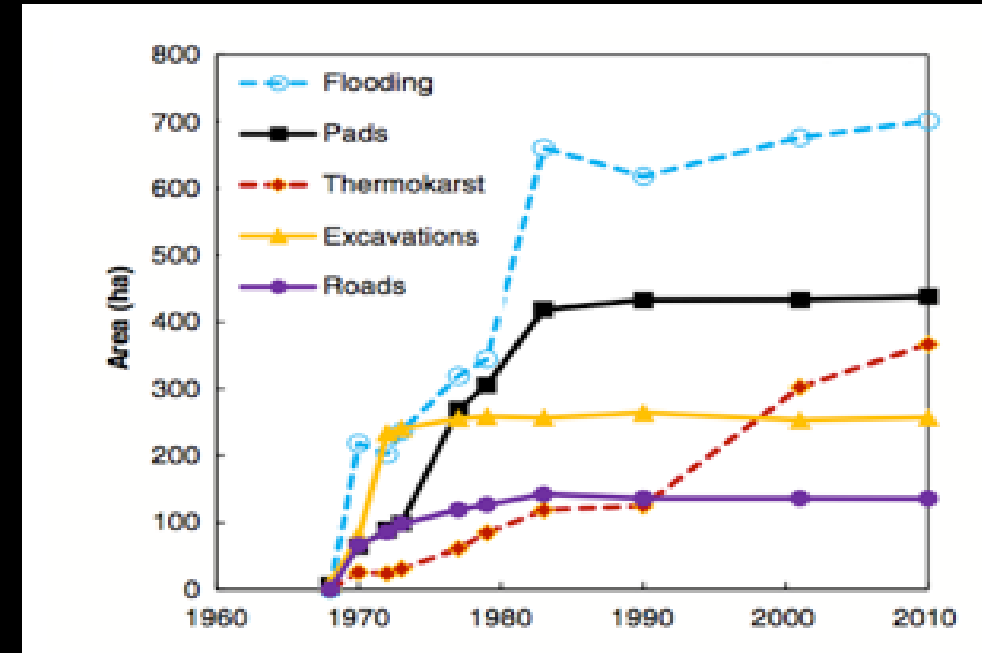
- 669 km gravel roads
- 154 km abandoned roads
- 12 km causeways
- 96 km old tractor trails
- 54 km exploration roads
- 790 km pipeline corridors
- 541 km powerlines

TOTAL: 2316 km of mapped linear items

Cumulative impacts in the Prudhoe Bay Region

These analyses showed that by 2010, within 3 mapped 25-km² areas, the indirect impacts were nearly double the area of the direct impacts.

Direct and indirect infrastructure-related impacts (1968–2010)



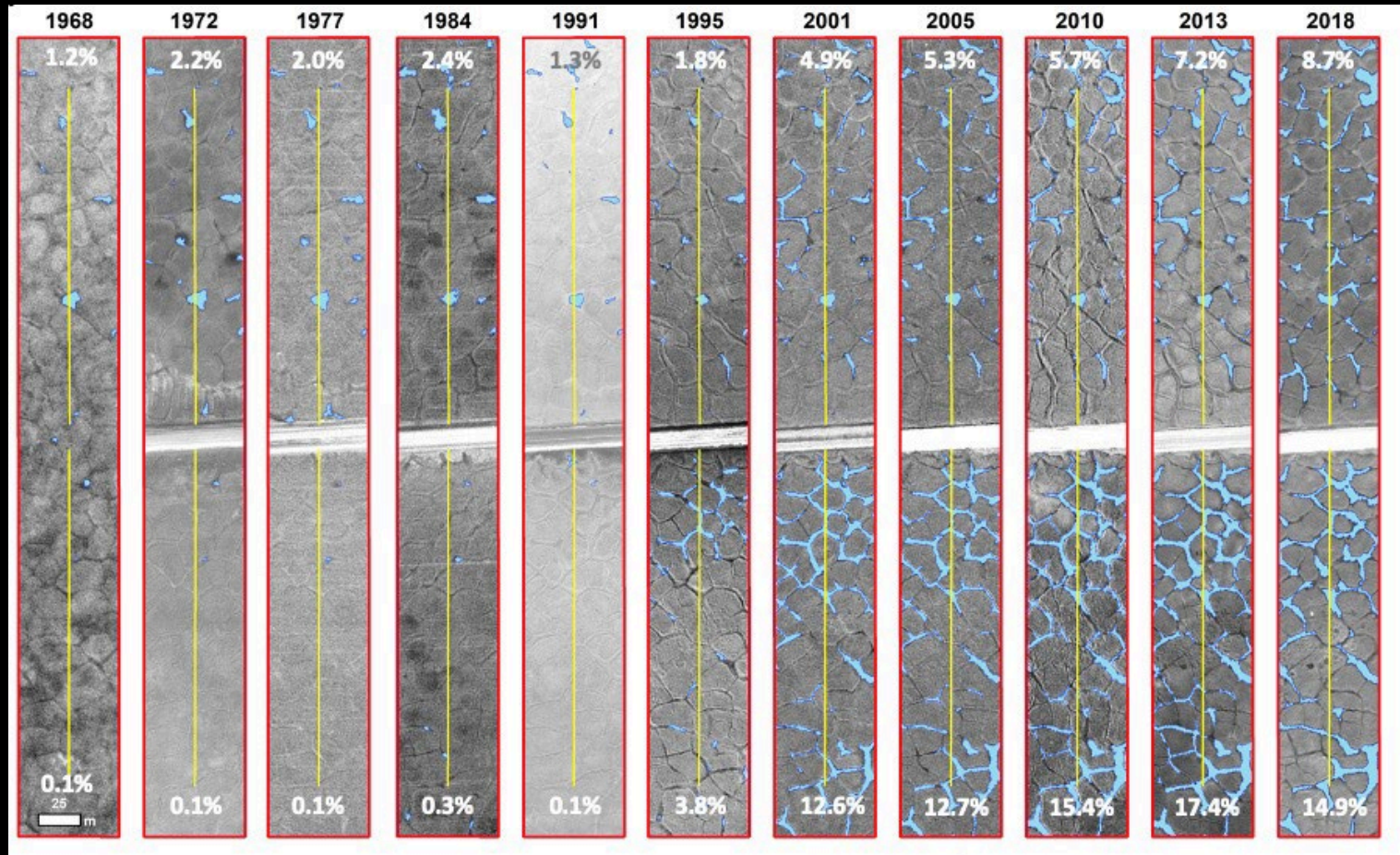
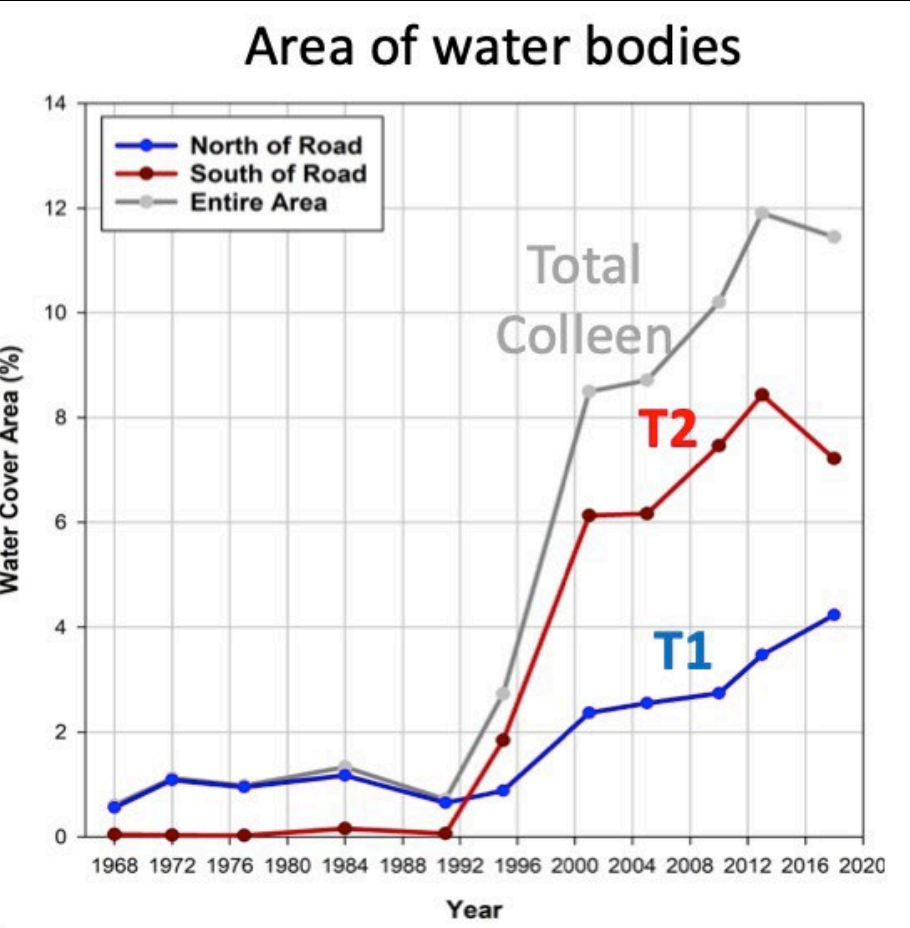
Direct impacts (solid lines): 919 ha (15% of mapped area) Levelled off after 1980.

Indirect impacts (dashed lines): 1794 ha (28.6% of mapped area) Continued to increase after the 1980s.

Thermokarst (red dashed line): increased 250% after 1990. Includes only infrastructure-related thermokarst.

Cumulative impacts in the Prudhoe Bay Region

Growth of ice-wedge thermokarst ponds 1968-2018



Ben Jones graphics, Walker et al. *Arctic Science*. 2022.

Nearly all these historical regional,- landscape-, and plot-level analyses of cumulative impacts of infrastructure and impacts to adjacent tundra up to about 2010 relied on detailed infrastructure maps, historical high-resolution aerial photographs of the oil-industry.

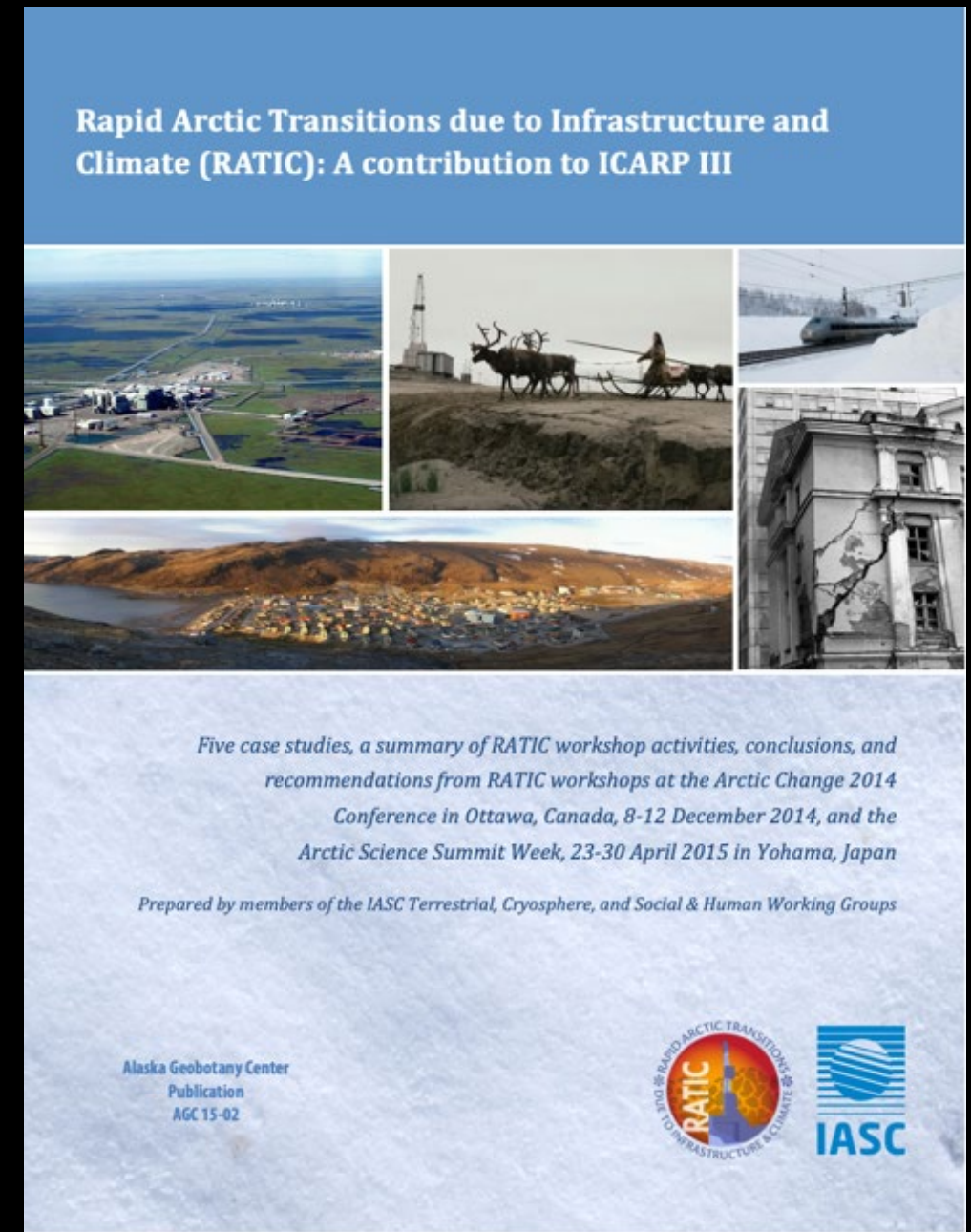
Historic challenges for assessing cumulative impacts using remote sensing in northern Alaska

- Scarce baseline environmental information.
- Insufficient spatial resolution to detect many impacts.
- Insufficient temporal resolution.
- Analyses of Pan-Arctic changes to infrastructure were not possible.
- Lack of modeling tools to span the scale differences between most remote sensing imagery and the scale of information needed for engineers and land-use planners.

2015

ICARP III, Yohama

- RATIC defined as 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 infrastructure and climate change.”
- **A call for funding and new tools to delineate, monitor, and model the cumulative impacts of Infrastructure and climate change.**



Examining Arctic change through big data, neural networks, artificial intelligence, and cyberinfrastructure

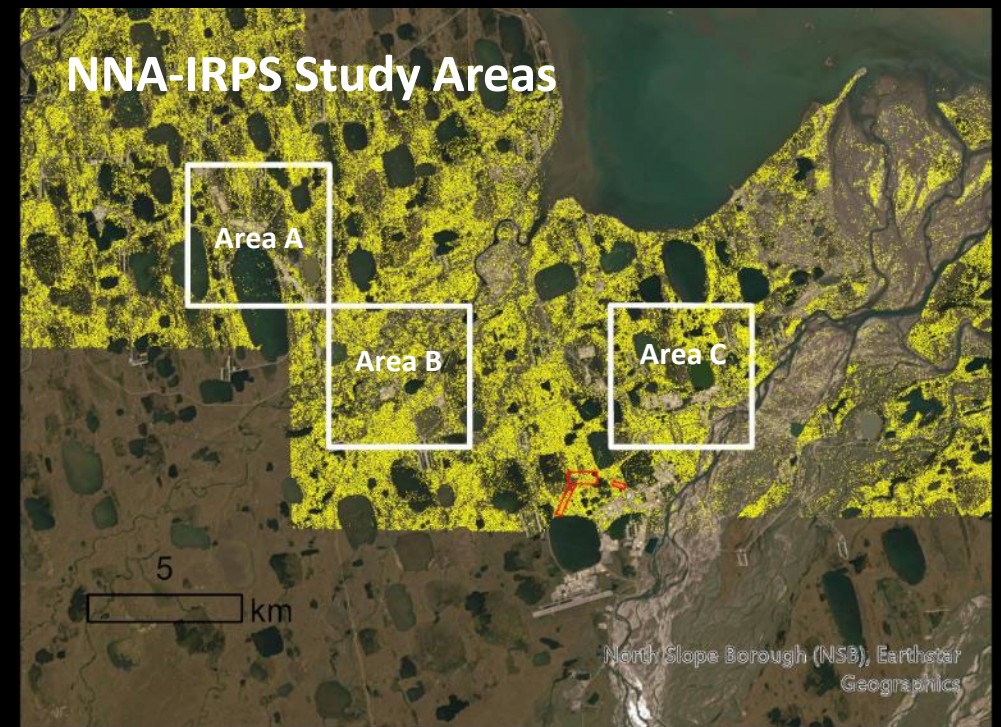
Mapping ice-wedge polygons in the Prudhoe Bay Oilfield at landscape to regional scale

RATIC Highlights

Circumpolar-scale infrastructure mapping and monitoring



Permafrost
Discovery Gateway



Witharana, et al.. 2021. An Object-Based Approach for Mapping Tundra Ice-Wedge Polygon Troughs from Very High Spatial Resolution Optical Satellite Imagery. Remote Sensing 13:558. [doi: 10.3390/rs13040558](https://doi.org/10.3390/rs13040558)

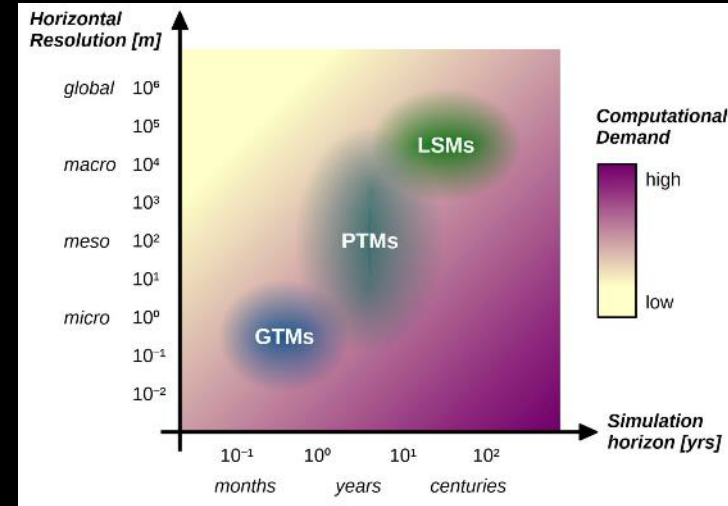
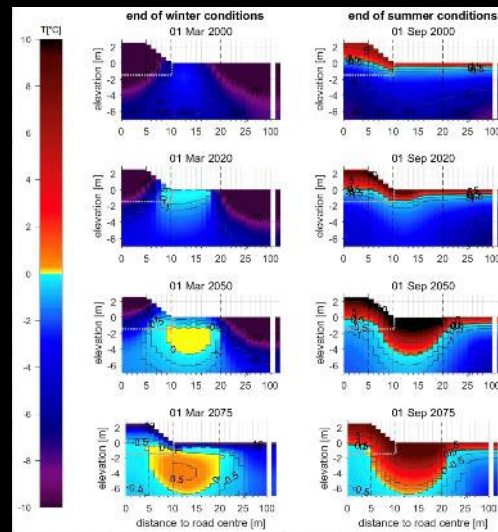
Use of hierarchy of spatial data sets to bridge the model gap between regional and engineering scales

RATIC Highlights

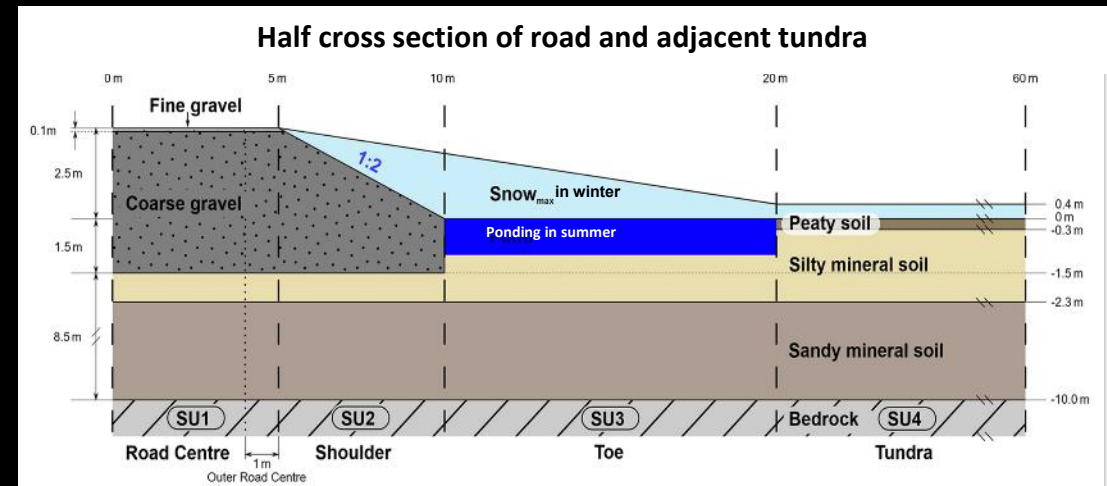
Hierarchical modeling for predicting impacts of infrastructure



Process-based tiling model (PTM) of road and adjacent permafrost



Spatial and temporal scales for models



Schneider von Deimling, et al. 2021. Consequences of permafrost degradation for Arctic infrastructure – bridging the model gap between regional and engineering scales. *The Cryosphere* 15:2451–2471.



Alfred Wegener Institute

CONCLUSIONS

Are we entering a new era for predicting cumulative impacts of climate change and infrastructure in the Arctic?

- Recent advances using remote sensing products and models have greatly expanded the capability to monitor and predict change in IRP landscapes from fine-scale changes within patterned-ground features to circumpolar changes.
- However, the full consequences of major ongoing changes in thermokarst and hydrology to other components of the system (e.g. aquatic plant communities, invertebrates, birds, other fauna, and local people) still need to be documented.
- Studies in other climate regimes, geologic and topographic setting, and different types of construction methods are needed to broaden the knowledge base and improve models that are useful to engineers and land-use managers.
- Predictions of the full likely cumulative impacts of future development and climate change in areas with IRP remains a grand interdisciplinary research challenge. A follow-up to RATIC is needed at the next ICARP (ICARP IV, 2025, Boulder, CO).

End of talk

RATIC
history

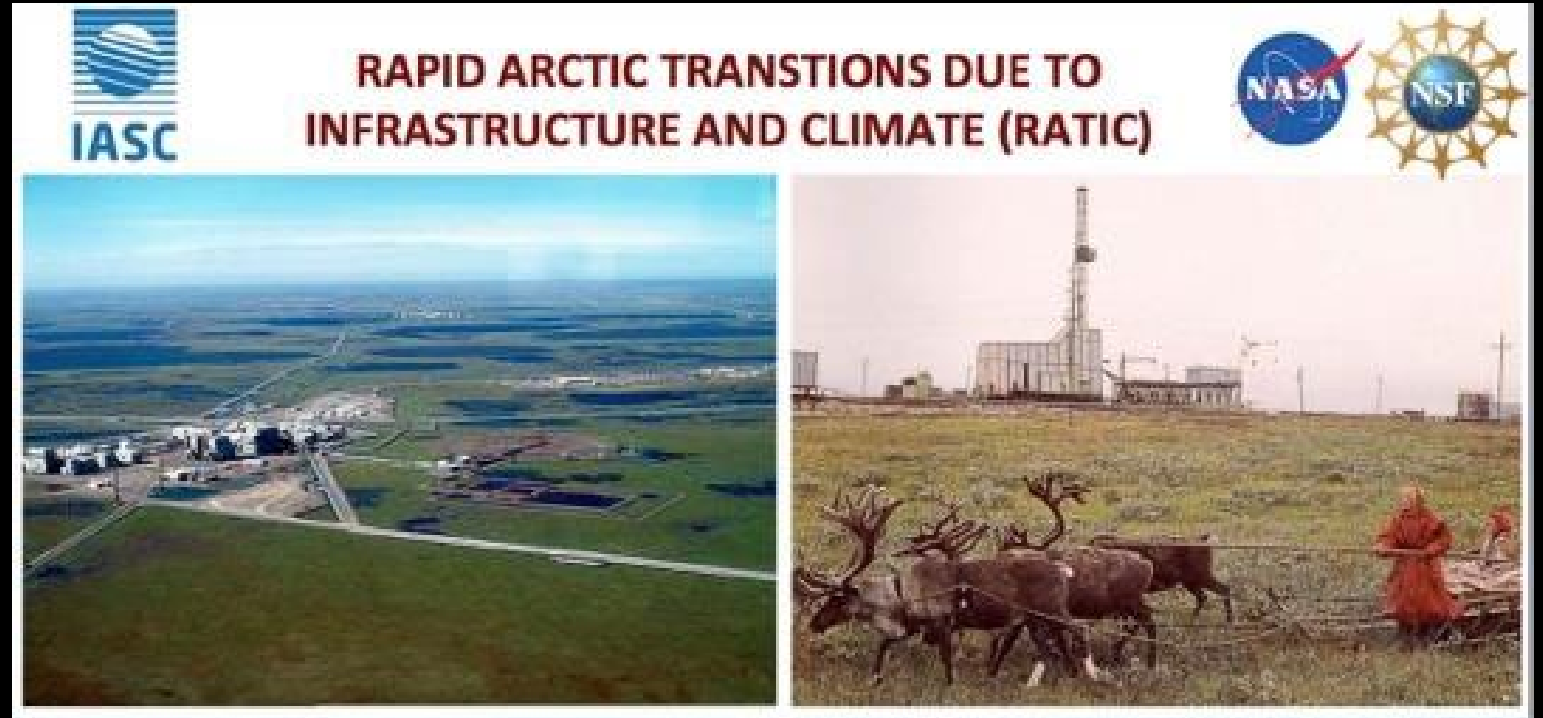
ARCTIC CHANGE 2014

8-12 DECEMBER - OTTAWA CONVENTION CENTRE - OTTAWA, CANADA

2014

Birth of RATIC

First RATIC session and workshop

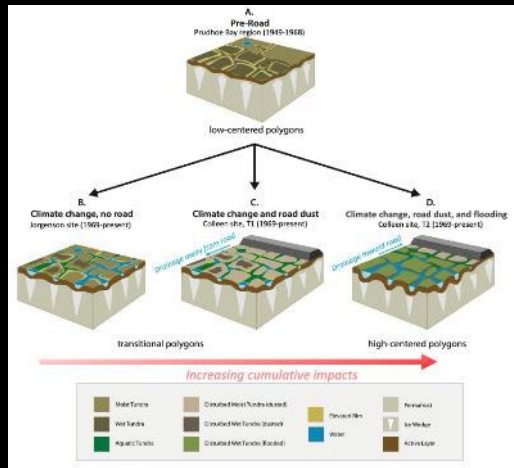


Result of IASC TWG Scoping Workshop at ASSW 2013 (Krakow) to examine the Social-Ecological Effects of Rapid Transitions in Arctic Permafrost Landscapes. Cross-cutting proposal: TWG, SWG, and CWG (Skip Walker and Gail Fondahl leads)



Cumulative impacts in the Prudhoe Bay Region

Integrated ground-based geo-ecological studies during NSF Navigating the New Arctic research at Prudhoe Bay, AK



4 scenarios of change

Plot-scale cumulative-impact field studies (2014–present)

Transects perpendicular to the road



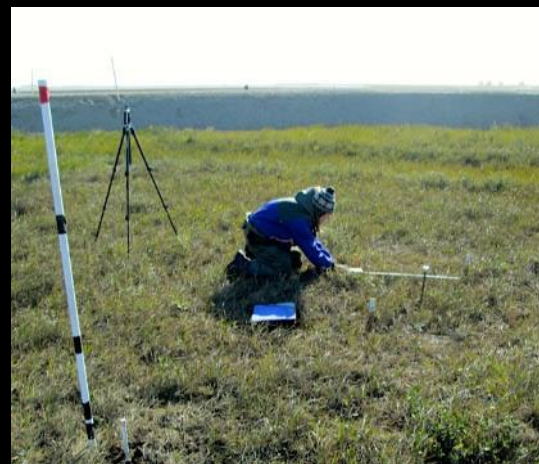
Micro-topography surveys



Thaw, water depth, vegetation height, leaf area index, NDVI



Vegetation plots: species composition, LAI, soils, environmental factors



Soil dust layers



Permafrost cores

