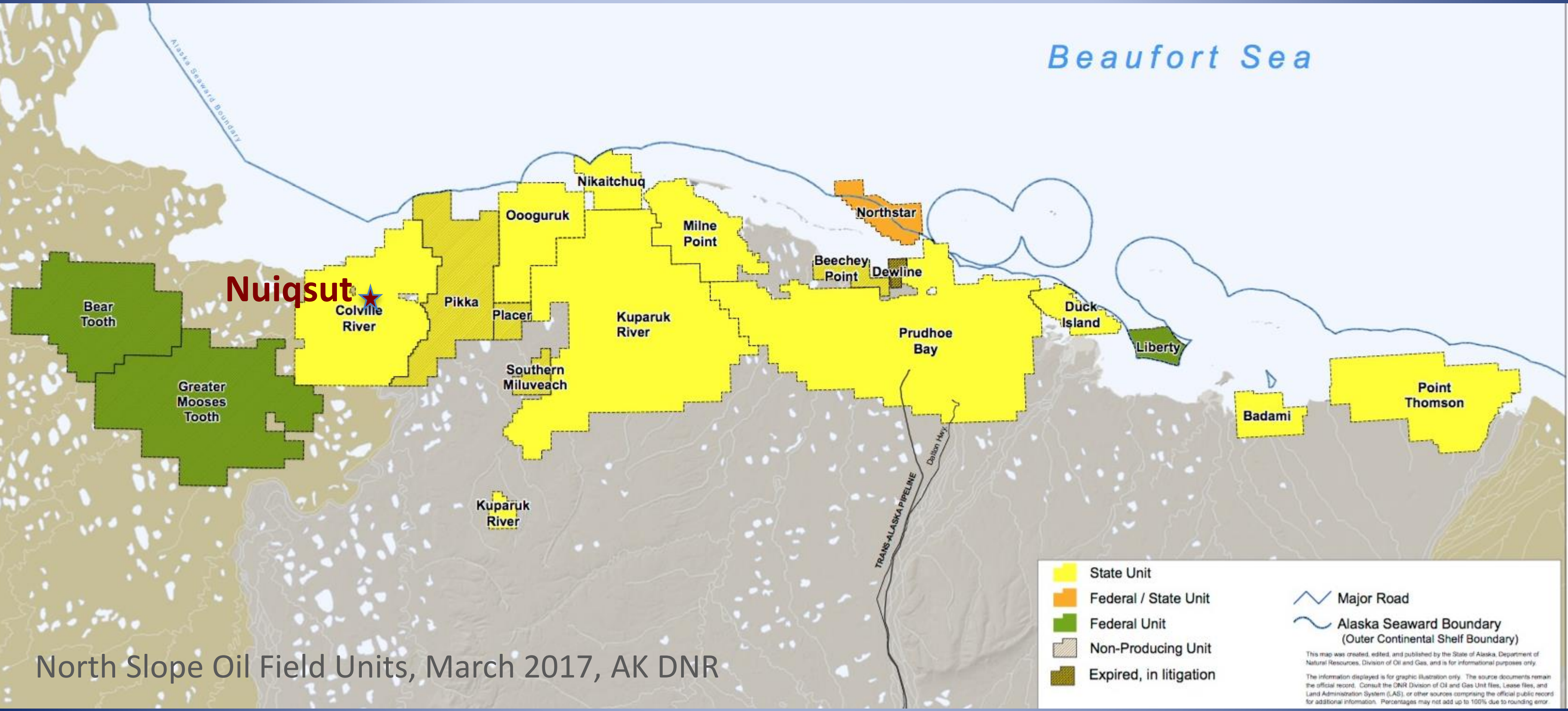
Cumulative Effects of Arctic Oil Development: Planning for a sustainable future

Skip Walker
Institute of Arctic Biology, UAF



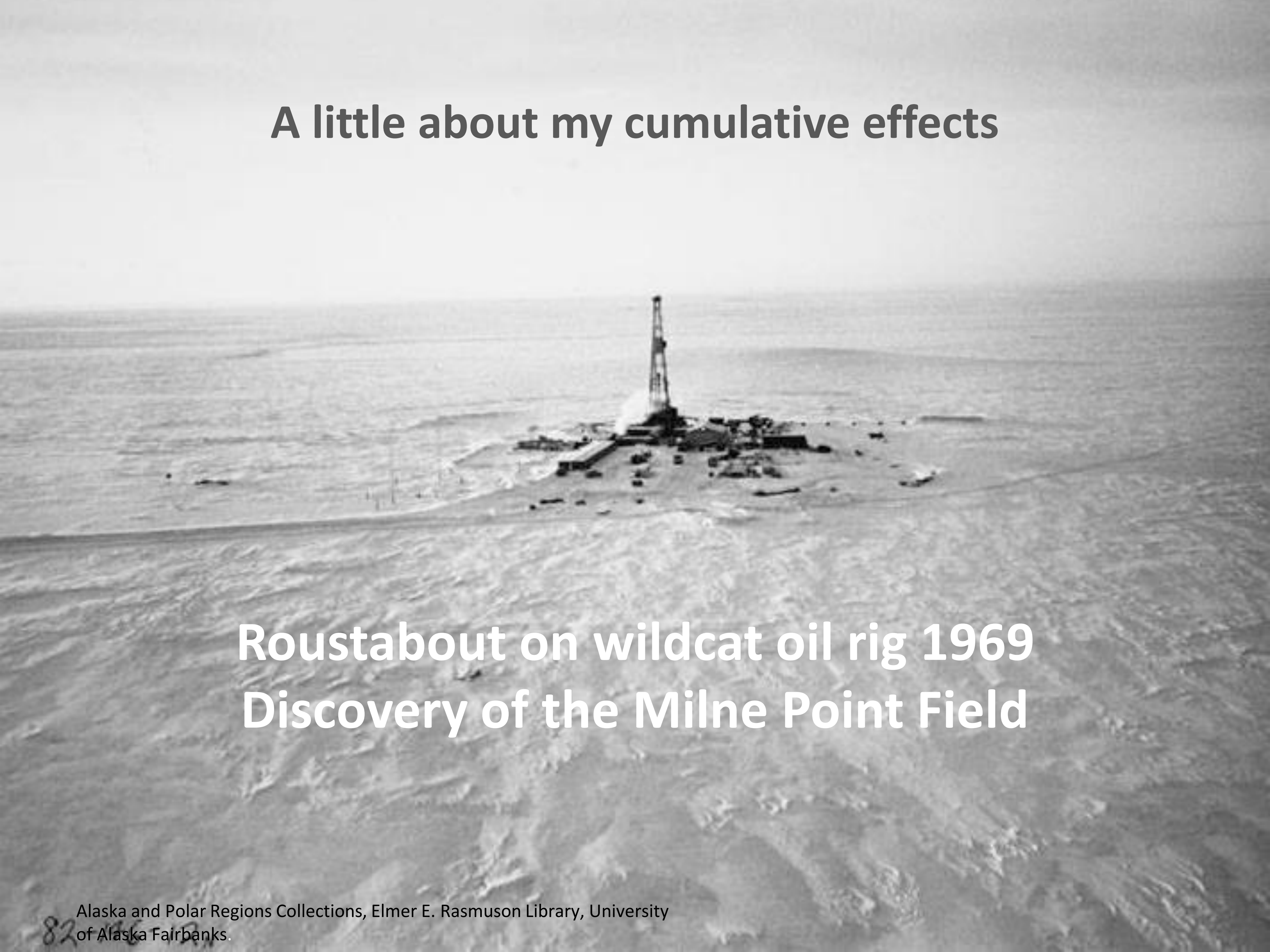
North Slope Oil Field Units, March 2017, AK DNR

Presentation to Kuukpik Corp., 6 Jun 2017

Introduction

- This study documents two events in the last six decades that have dramatically altered the rate of change of Arctic Alaska landscapes:
  - Rapid oil and gas exploration and development
  - Accelerated climate change.
- Historical imagery and GIS methods trace the complete history of the Prudhoe Bay oilfield.
- Field studies to document the ground-level changes.

A little about my cumulative effects



Roustabout on wildcat oil rig 1969
Discovery of the Milne Point Field

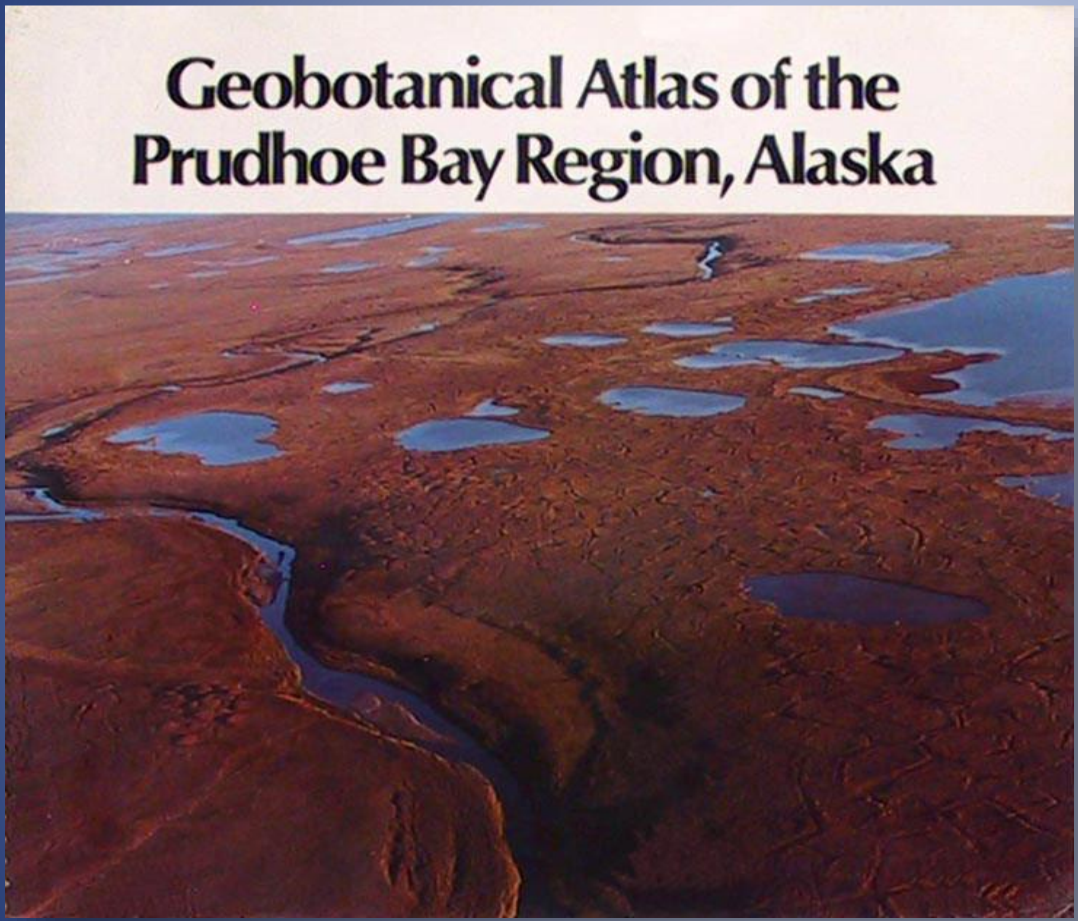
Alaska and Polar Regions Collections, Elmer E. Rasmuson Library, University of Alaska Fairbanks.

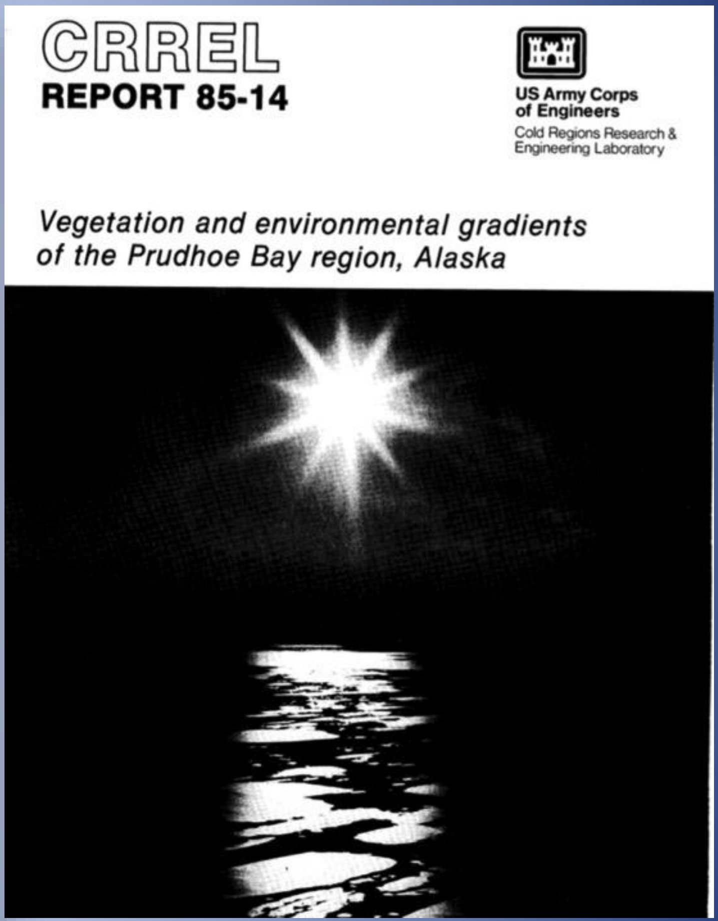
Point Storkerson 1969: Example of unregulated development

Prompted decision to go back to school.

Klein, D. R. 1969. The impact of oil development in Alaska (a photo essay). Pages 209–242 *in* W. A. Fuller and P. G. Kevan, editors. Proceedings of the Conference on Productivity and Conservation in Northern Circumpolar Lands.

Returned to North Slope in 1971.
1971-1980: MS thesis at Barrow, PhD at Prudhoe Bay:
IBP studies from the 1970s provide baseline info for change analyses





- Walker, D.A., Everett, K.R., Webber, P.J., Brown, J. 1980. *Geobotanical Atlas of the Prudhoe Bay Region*, Alaska. CRREL Report 80-14.
- Walker, D. A. (1985). *Vegetation and Environmental Gradients of the Prudhoe Bay Region, Alaska*, CRREL Report 85-14.

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 construction. For example, in the wettest parts of the oil field (flat 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 Department of Interior has recommended leasing 1.5 million acres of the coastal plain portion of the Arctic National Wildlife Refuge (ANWR) for oil exploration (*1*–*3*). The recommendation was based on the nation's need for new energy resources and a perception that major ecological impacts could be avoided 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 permafrost regions and conflicts with wildlife, there are still difficult issues regarding cumulative effects of the existing and proposed oil fields.

The regulatory definition of cumulative impacts is (*4*)

> . . . 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.

Cumulative impacts are of particular concern in the ANWR because several oil fields may affect the wilderness and wildlife resources. A vast complex of roads, pipelines, and service centers stretching across the Arctic Coastal Plain could have unpredictable long-term impacts on the total function of the coastal plain ecosystem. The environmental impact statement process must, by law, examine cumulative impacts, but there currently are no standardized methods for doing this.

Cumulative Impacts in Arctic Wetlands

Flooding and thermokarst are important aspects of cumulative impacts in arctic wetlands. Permafrost is largely responsible for poor drainage and for thaw lakes that cover the Arctic Coastal Plain. Many of the most valuable wetlands form in drained thaw-lake basins that represent one phase in the thaw-lake cycle (*5*). These low areas are particularly susceptible to flooding caused by road and gravel-pad construction. Most buildings, oil wells, and roads in the region are constructed on thick gravel pads that rise 1.5 to 2 m above the flat tundra. This design helps prevent melting of the underlying permafrost and subsequent subsidence of the roads or buildings, but it also causes roads and gravel pads to act as dams, intercepting the natural flow of water. Where roads traverse drained thaw-lake basins, flooding is a predictable result (Fig. 2). Natural water levels, including their seasonal and year-to-year variability, are critical to maintaining the wetland diversity and function. A flooded wetland can have as large an impact on wildlife as a drained wetland because flooding alters the heterogeneous mosaic of water and

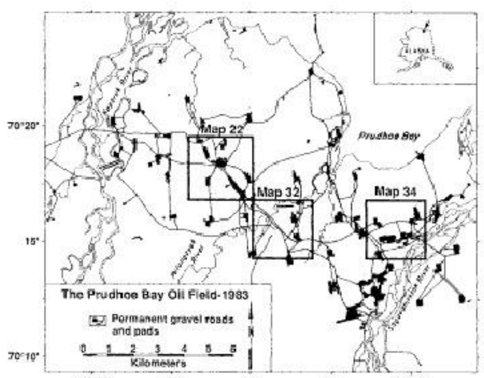


Fig. 1. Road network and facilities in the Prudhoe Bay Oil Field, 1983, with locations of the maps of the three intensive study areas used for the detailed analysis of oil-field impacts. Most of the area is part of a flat thaw-lake plain landscape unit. Maps 32 and 34 also have floodplains and terraces.

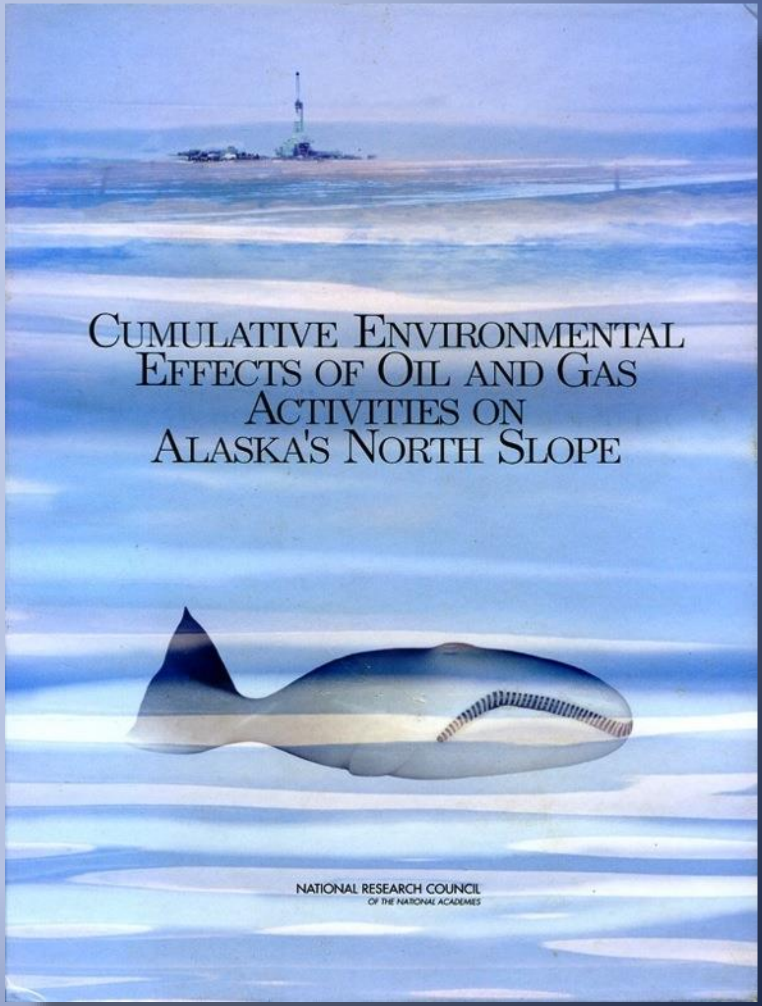
D. A. Walker, P. J. Webber, M. D. Walker, Plant Ecology Laboratory, Institute of Arctic and Alpine Research, and Department of Environmental, Population, and Organismic Biology, University of Colorado, Boulder, CO 80309. E. F. Binnian and E. A. Nordstrand, North Slope Borough GIS, Anchorage, AK 99501. K. R. Everett, Byrd Polar Research Center and Department of Agronomy, Ohio State University, Columbus, OH 43210. N. D. Lederer, Plant Ecology Laboratory, Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO 80309.

1987: First study of cumulative effects of oil development to Prudhoe Bay landscapes

Walker, D.A., Webber, P.J., Binnian, E.F., Everett, K.R., Lederer, N.D., Nordstrand, E.A., Walker, M.D. 1987. Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes. *Science*, 238:(4828):757-761.

2003: National Research Council (NRC) Report

- **Co-author of first major cumulative effects analysis in northern Alaska.**
- **Included effects to:**
  - ***Physical environment***
  - ***Marine environment***
  - ***Vegetation***
  - ***Animals***
  - ***Human environment***

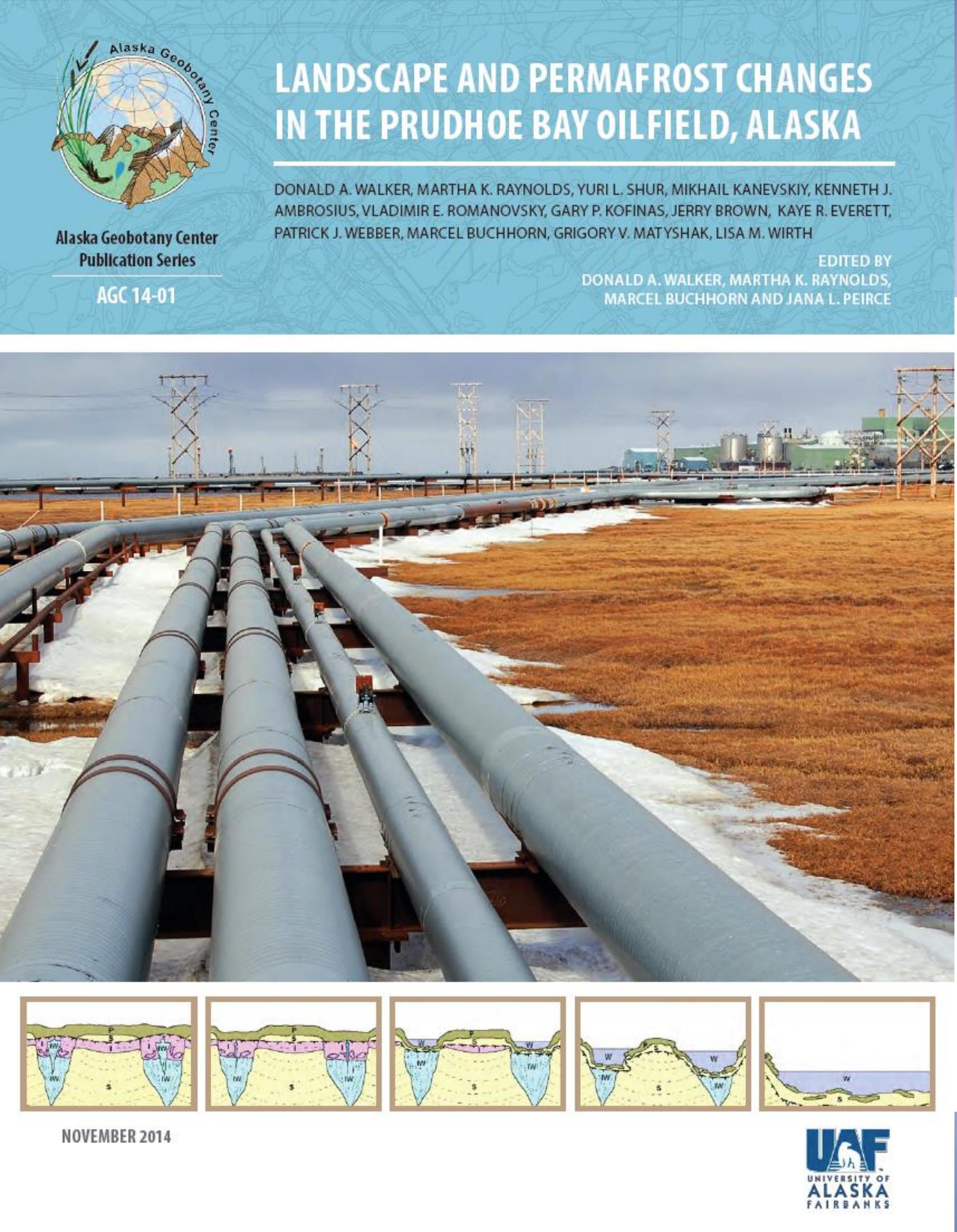


So what are cumulative effects?
Some key terms:

- **Cumulative effects:** 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 long period of time*.

- **Direct effects:** The physical foot print of the planned development (e.g. the area covered by gravel of a road or construction pad).

- **Indirect effects:** Unplanned effects that occur later or at some distance from the planned development (e.g. from seismic activities, road dust, thermokarst, flooding, impacts to wildlife or local communities.)



2014: NSF Arc-SEES project: 62-year history of change in the Prudhoe Bay Oilfield


A PUBLICATION OF THE ALASKA GEOBOTANY CENTER 14-01
UNIVERSITY OF ALASKA FAIRBANKS

LANDSCAPE AND PERMAFROST CHANGES IN THE PRUDHOE BAY OILFIELD, ALASKA

Edited by
DONALD A. WALKER, MARTHA K. RAYNOLDS, MARCEL BUCHHORN AND JANA L. PEIRCE

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Available at: http://www.geobotany.uaf.edu

Main Prudhoe Bay oilfield

Photo: Pam Miller. http://northern.org/media-library/photos/arctic/drilling-impacts/

- **Total area enclosed by development is about 2,600 km^2 (about the size of Rhode Island or Luxembourg.**
- **Most of this development is composed of widely dispersed drill pads and production facilities connected by roads and pipelines.**

Deadhorse Area

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

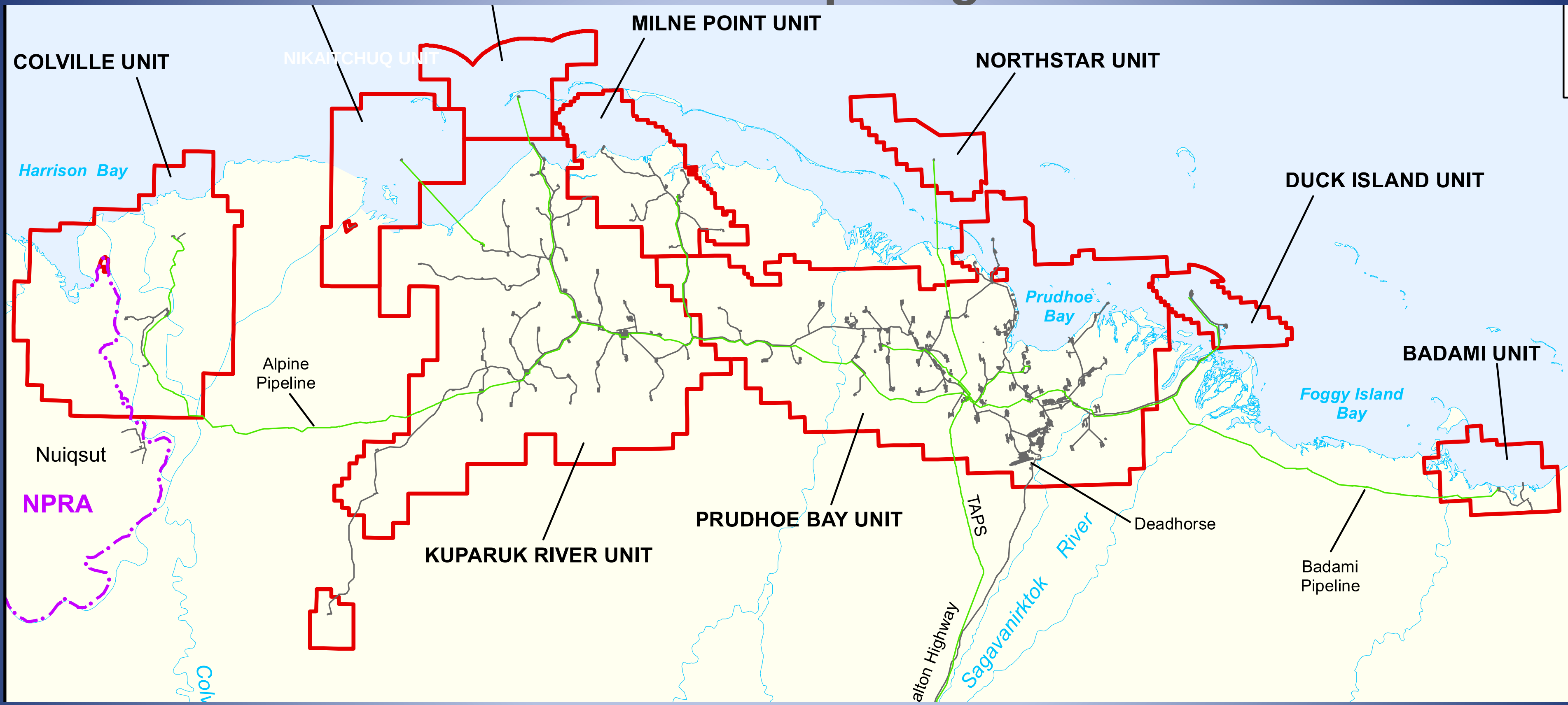
- Outside the main Prudhoe Bay Unit lease area.
- More densely developed.

Historical change studied at 3 scales:

- Regional-scale analysis of infrastructure extent.
- Landscape-scale analysis of changes to local landscapes and vegetation.
- Field studies of vegetation, soil and permafrost changes associated with roads.

Part I: Direct impacts

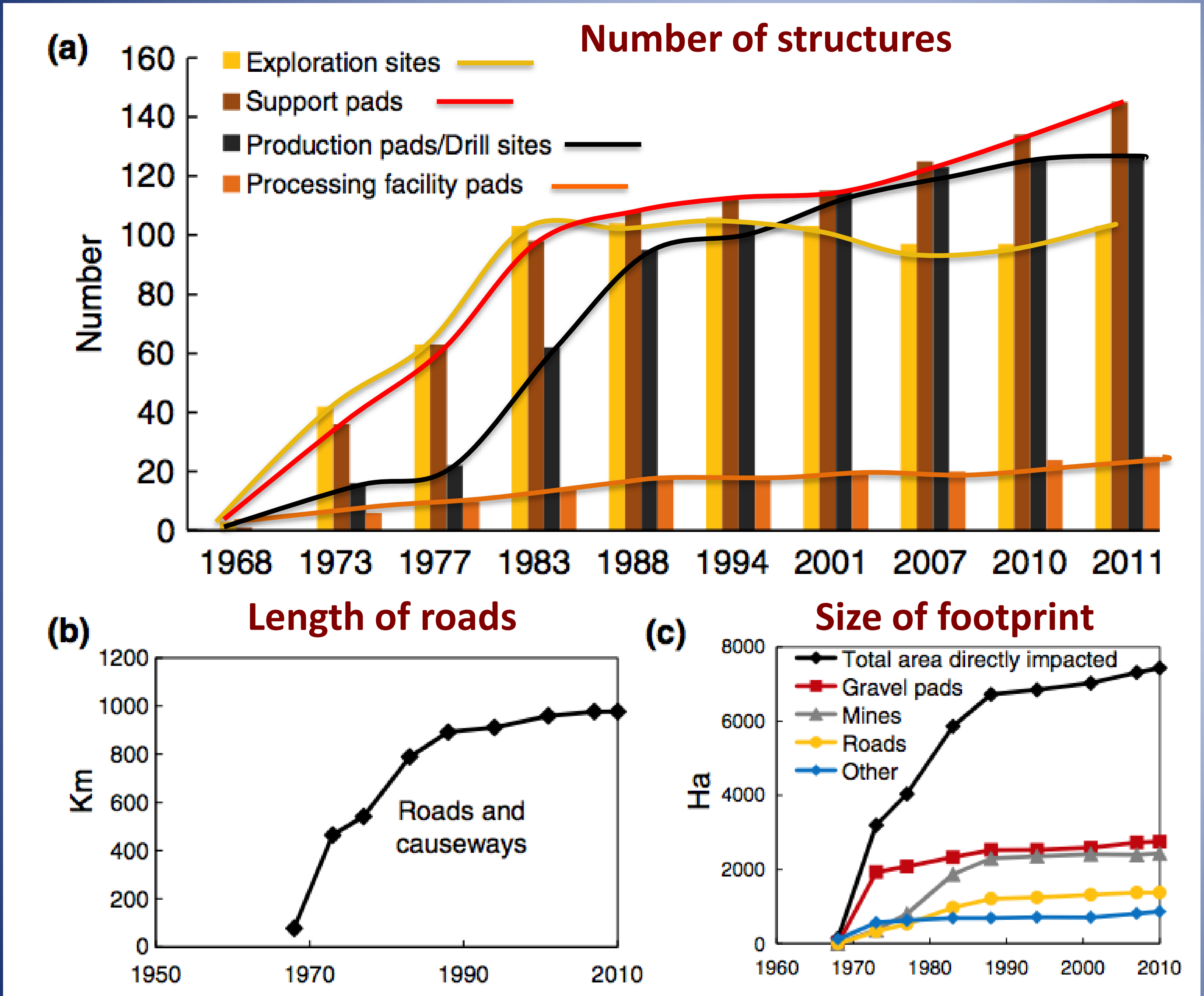
Regional-scale studies, time series of infrastructure change for the entire North Slope region 1968-2010



150 km

Courtesy of BP Alaska, Inc.

History of infrastructure change (1968-2011)



103 exploration sites
127 production pads
145 support pads
25 proc. fac. pads
13 off-shore islands
9 airstrips
4 exploration airsrips
2037 culverts
27 bridges
50 caribou crossings
1 landfill

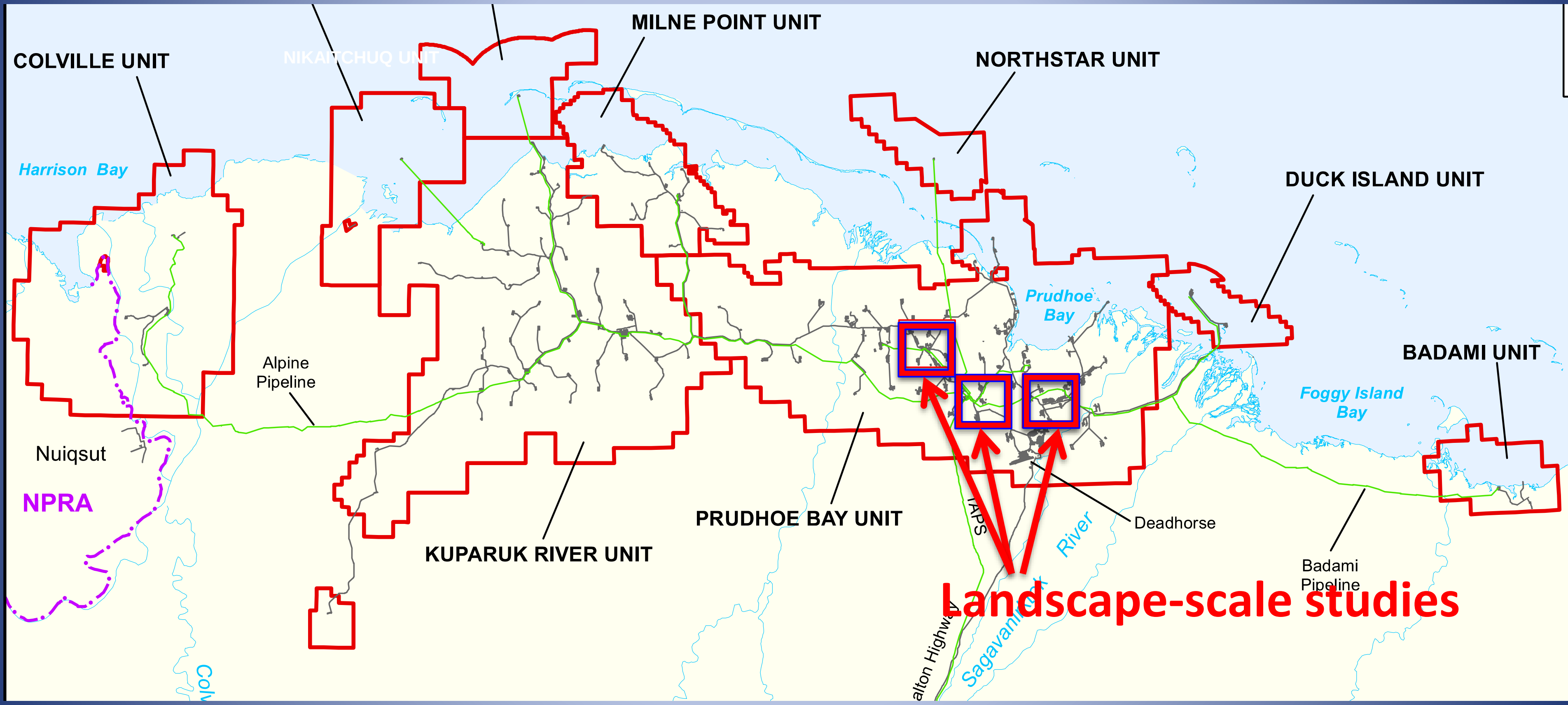
669 km gravel roads
154 km abandoned roads
12 km causeways
96 km old tractor trails
54 km exploration roads
790 km pipeline corridors
541 km powerlines

Total direct impacts (infrastructure footprint) = 7429 ha

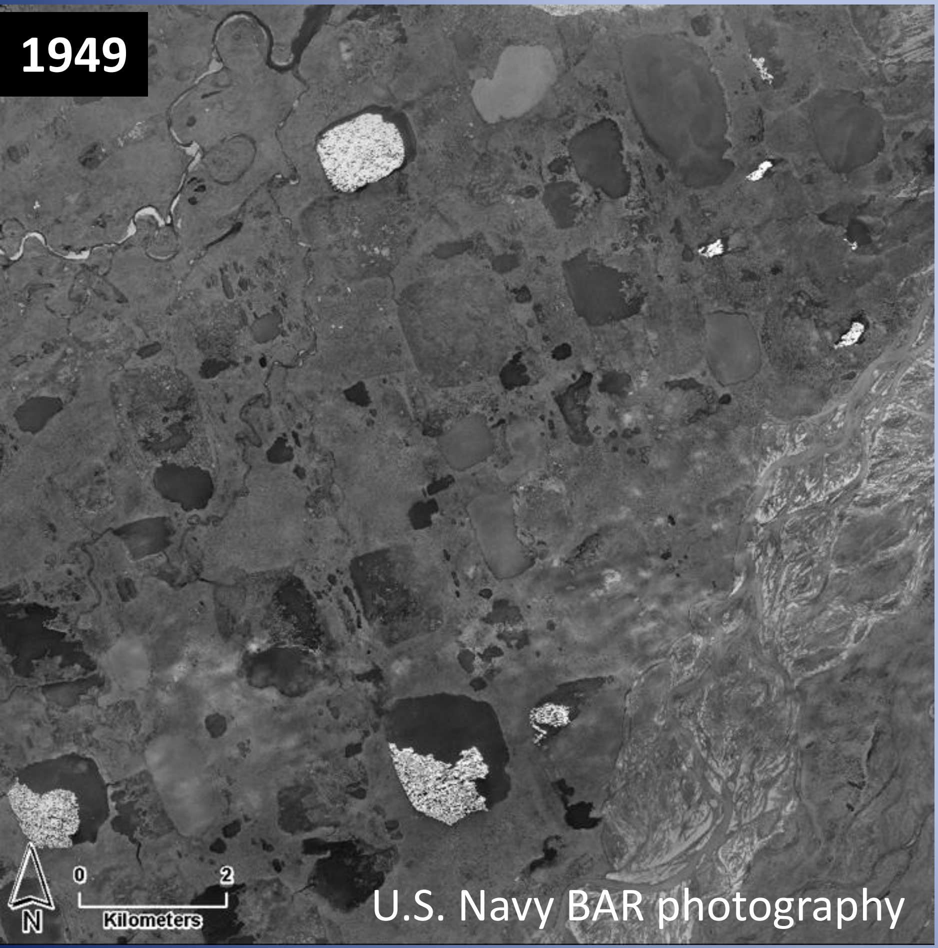
Raynolds et al. 2014. *Global Change Biology*

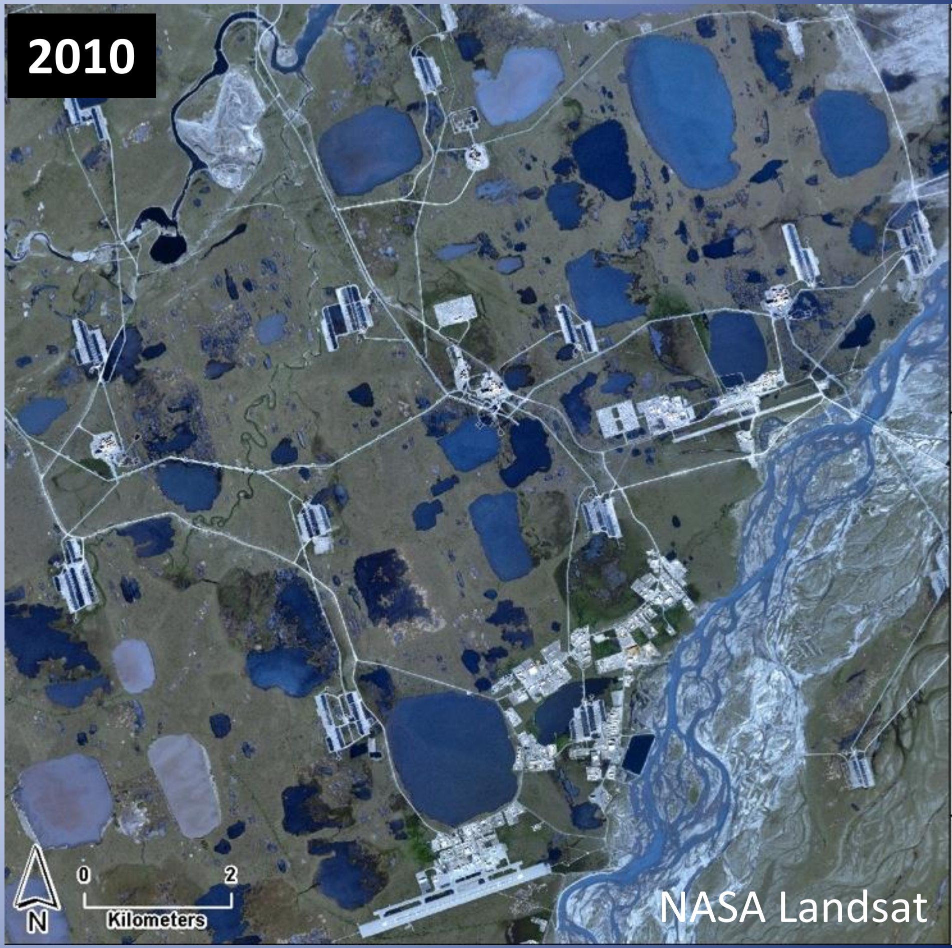
Part II: Indirect Impacts:

Landscape-scale studies: Time-series analysis of change in three 22-km² areas at Prudhoe Bay



Change analysis 1949-2010 using high-resolution aerial photographs and satellite imagery

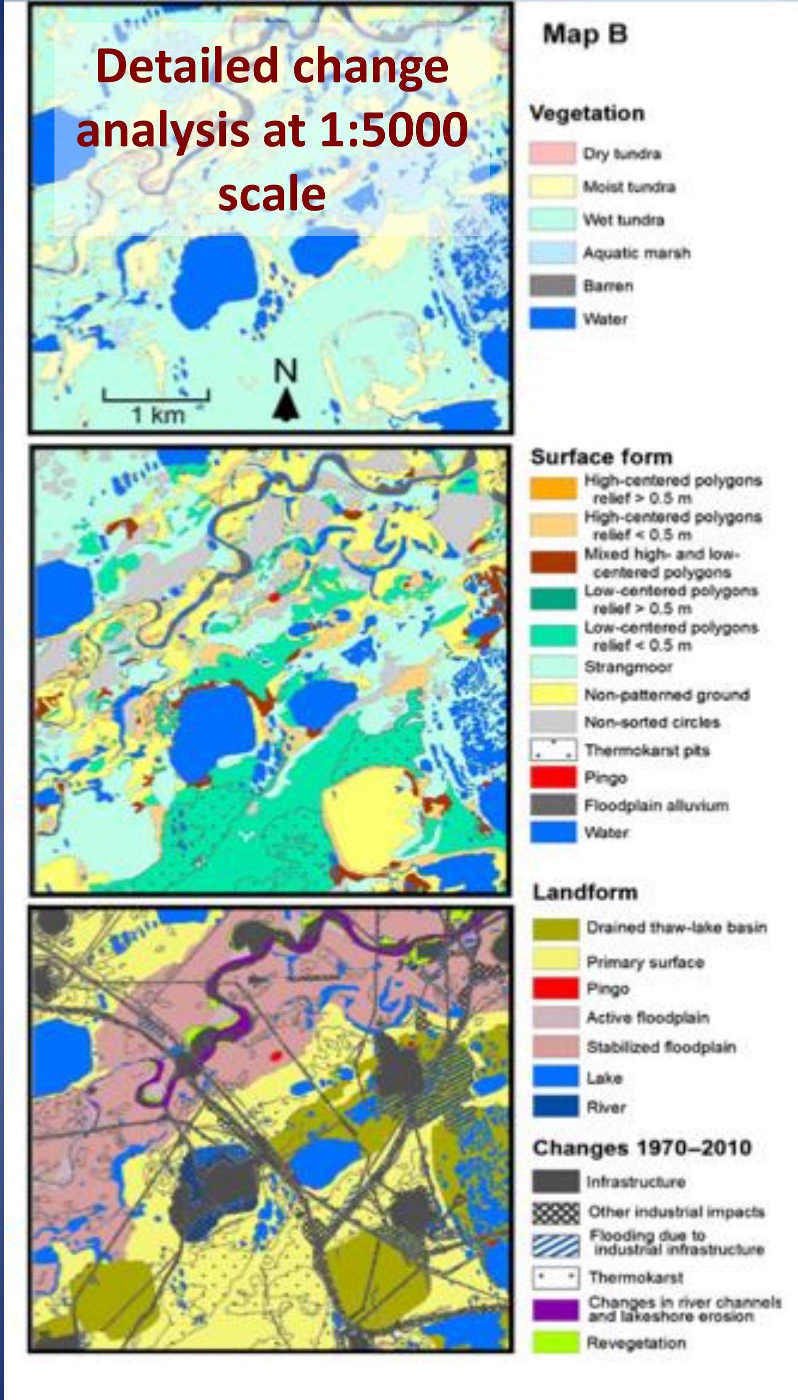


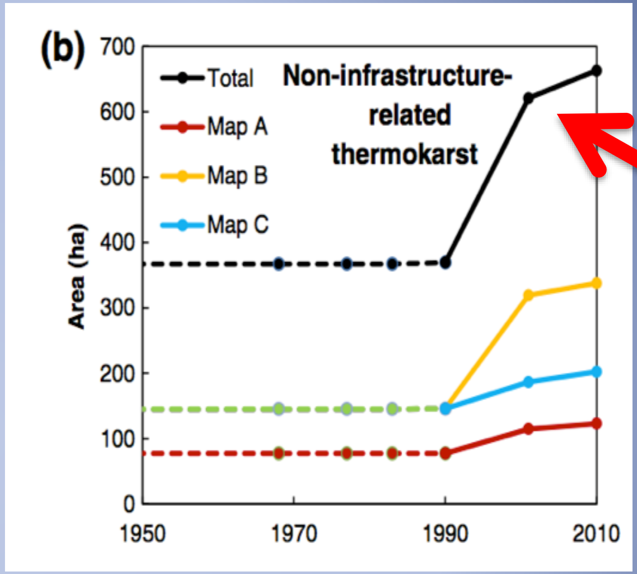


Courtesy of Lisa Wirth, GINA

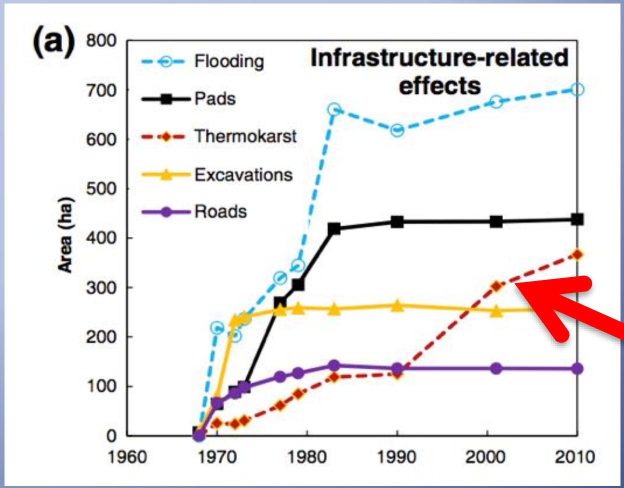
Big surprise was the sudden increase in thermokarst after 1990!

Detailed change analysis at 1:5000 scale





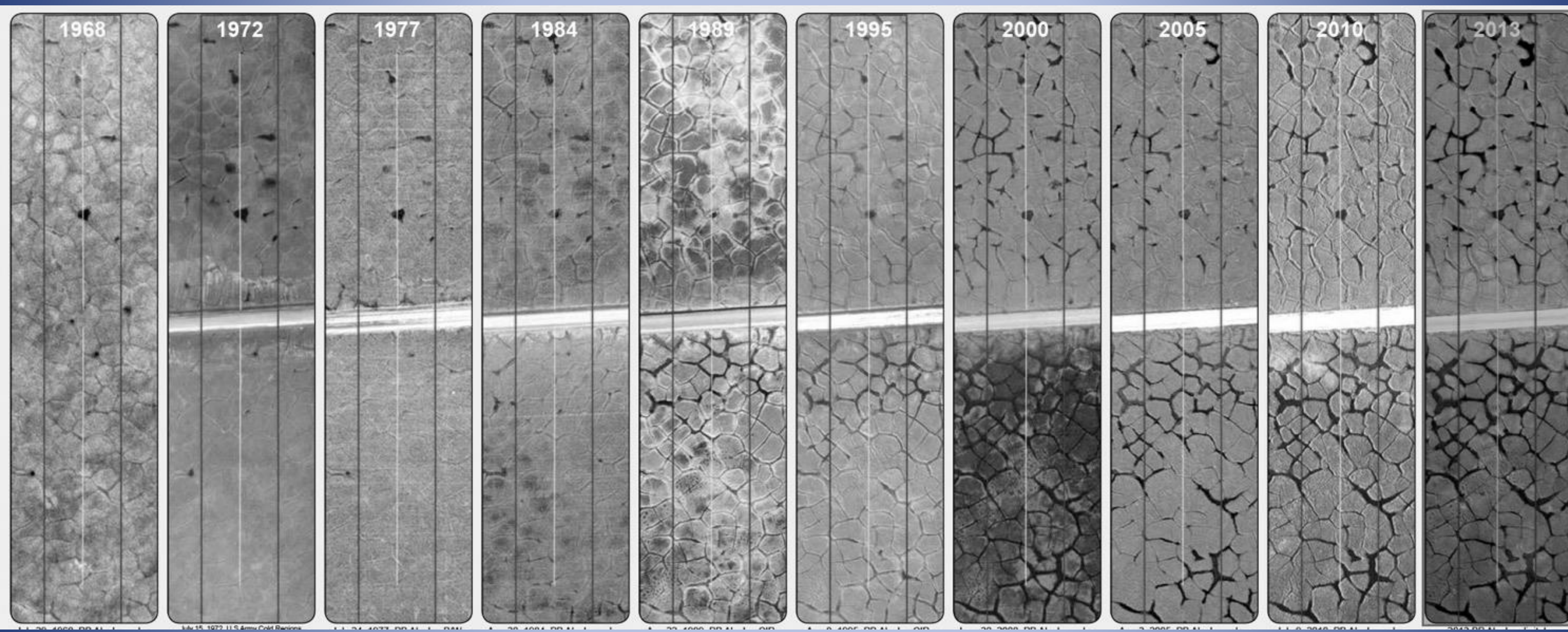
Total non-infrastructure-related thermokarst (Maps A, B, C): 80% increase since 1990



Infrastructure-related thermokarst: 250% increase since 1990

Thermokarst: Land-surface that results from the melting of ground ice.

Increased ice-wedge degradation and thermokarst, Prudhoe Bay, 1949-2013

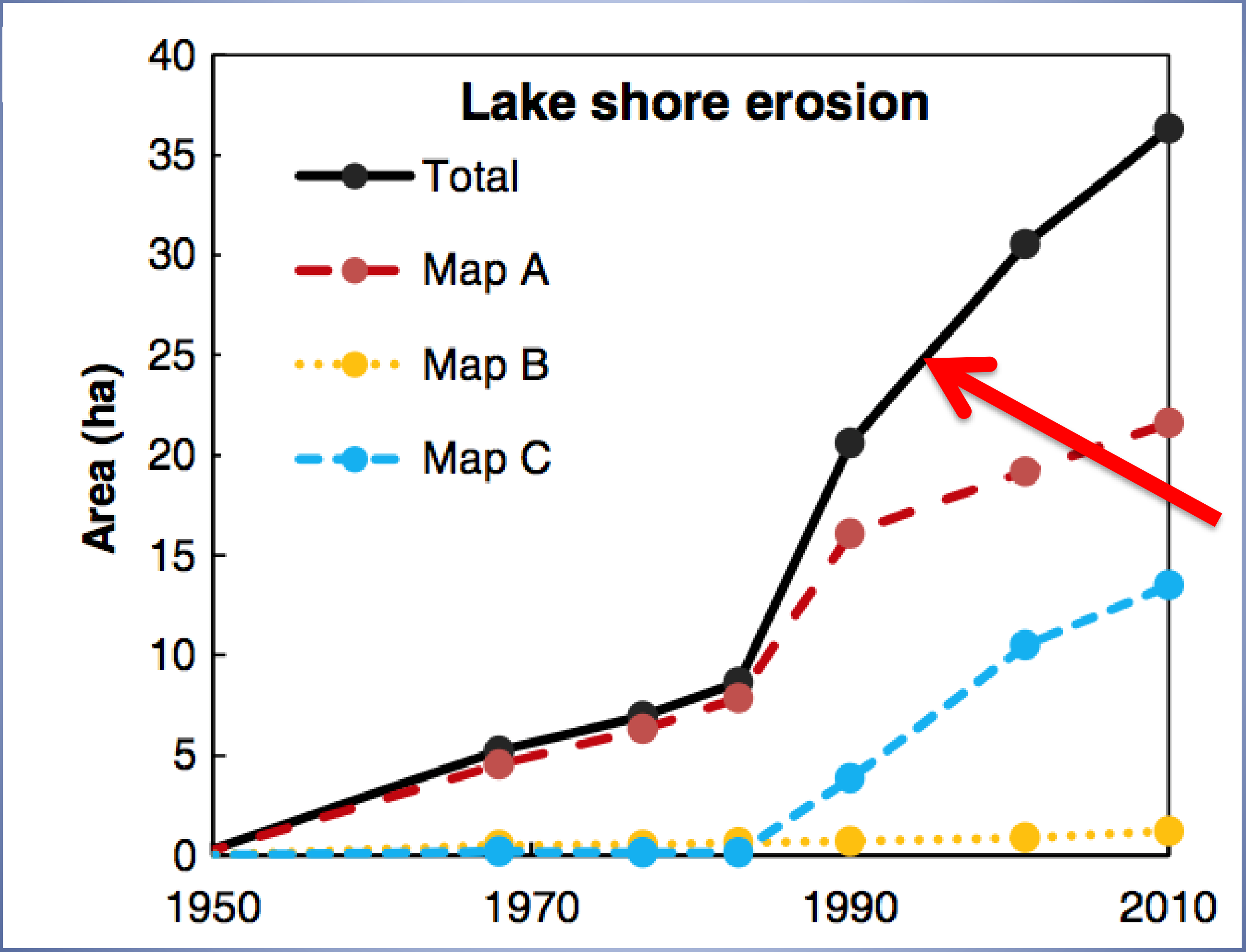


1949 (not shown) - 1985
Little change in non-roadside areas

1970-1999
Mainly roadside thermokarst changes

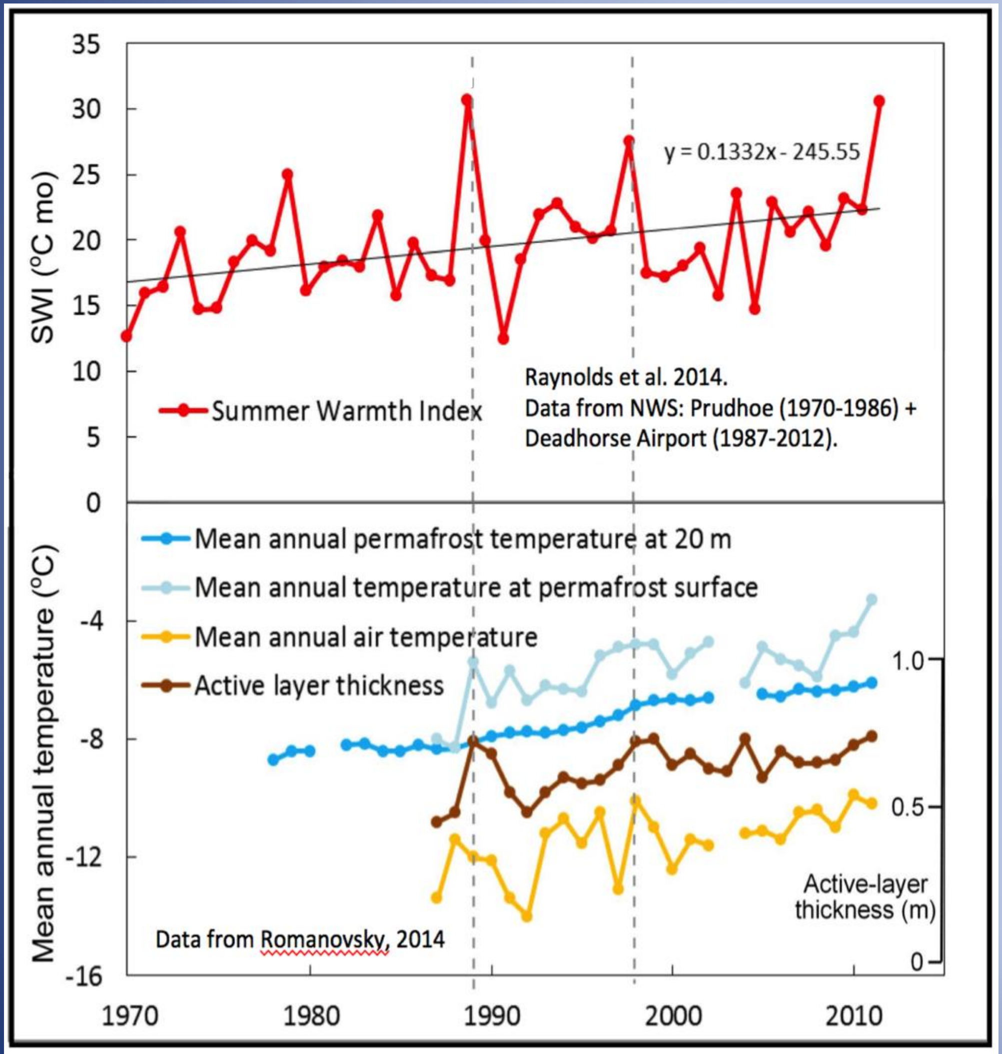
2000-2015
Widespread thermokarst in all areas near and distant from the road

Also 300% increase in lake-shore erosion since 1989



Total for all three map areas, but differed on each map according to type of terrain.

Series of exceptionally warm years between 1989 and 2012 likely caused region-wide increase in ice-wedge degradation.



Summer air temperature:

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

Permafrost and active layer:

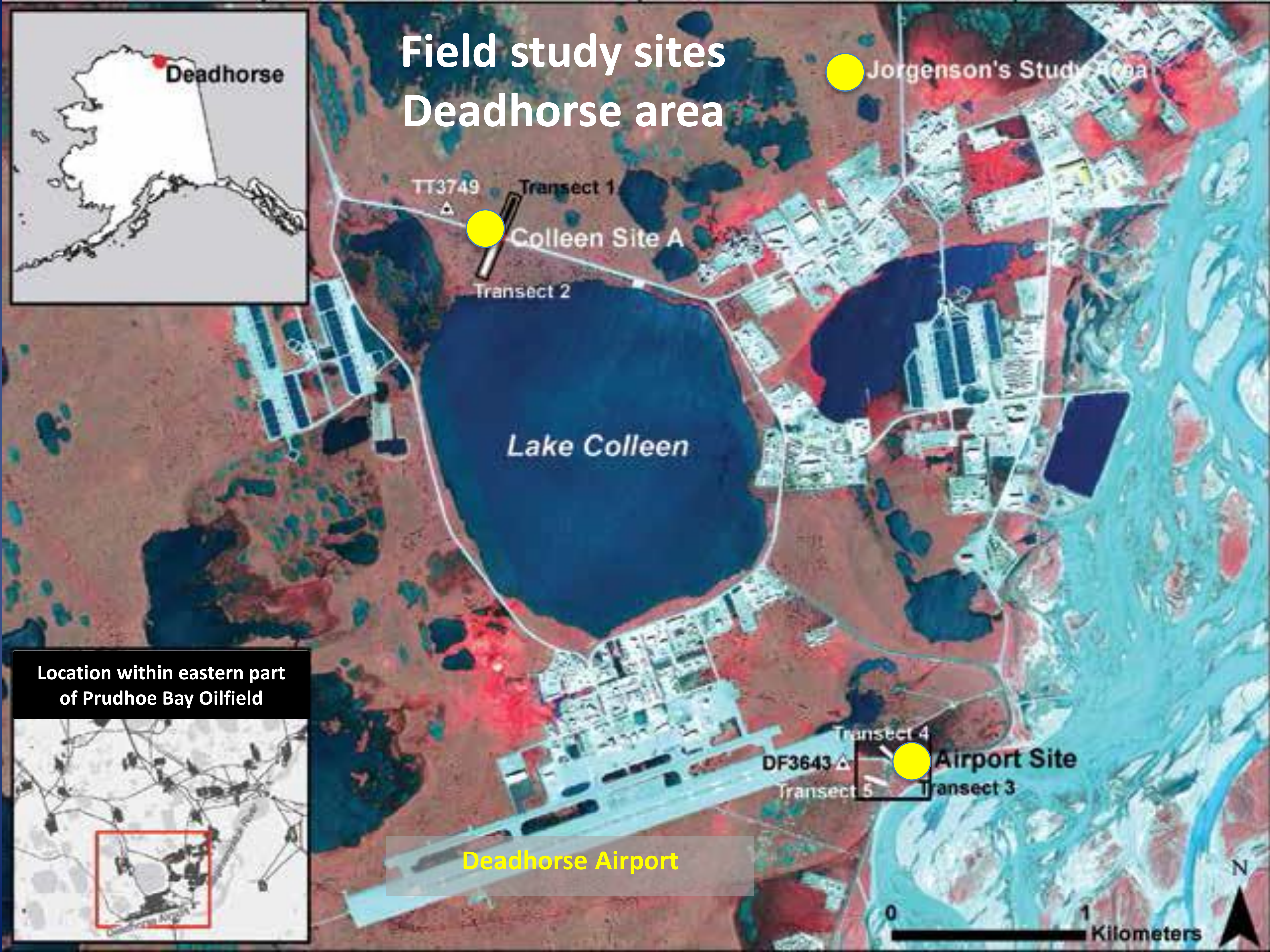
Light blue: Mean annual temperature at top of permafrost
Cyan: Mean annual permafrost temperature at 20 m.
Brown: Active layer thickness
Yellow: Mean annual air temperature

Data: Romanovsky, Deadhorse station.

Part III: Field studies: Change in ice-wedge thermokarst along roads

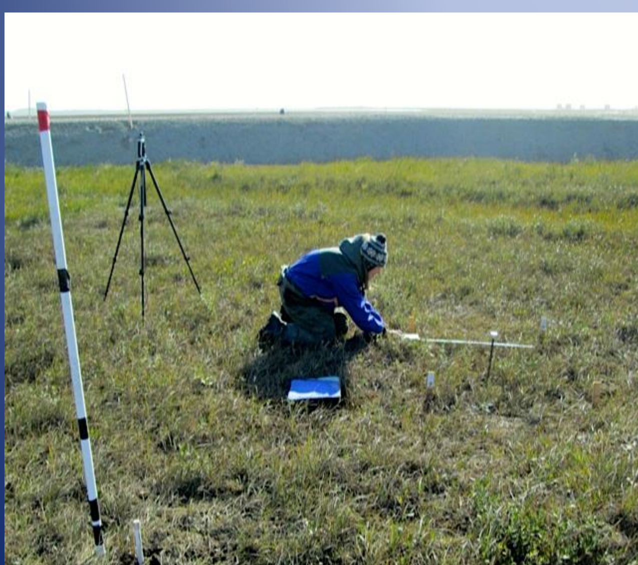
MAIN QUESTION FOR FIELD STUDIES: What are the consequences of thermokarst to surface landforms, soils, vegetation, and permafrost?

1. Roadside transects
2. Vegetation and soil studies
3. Ice-wedge boreholes
4. Effects of the 2015 Sagavanirktok R. flood


Field study sites
Deadhorse area
Deadhorse
Jorgenson's Study Area
TT3749
Transect 1
Colleen Site A
Transect 2
Lake Colleen
Location within eastern part of Prudhoe Bay Oilfield
Transect 4
DF3643
Airport Site
Transect 5
Transect 3
Deadhorse Airport
0
1
Kilometers
N

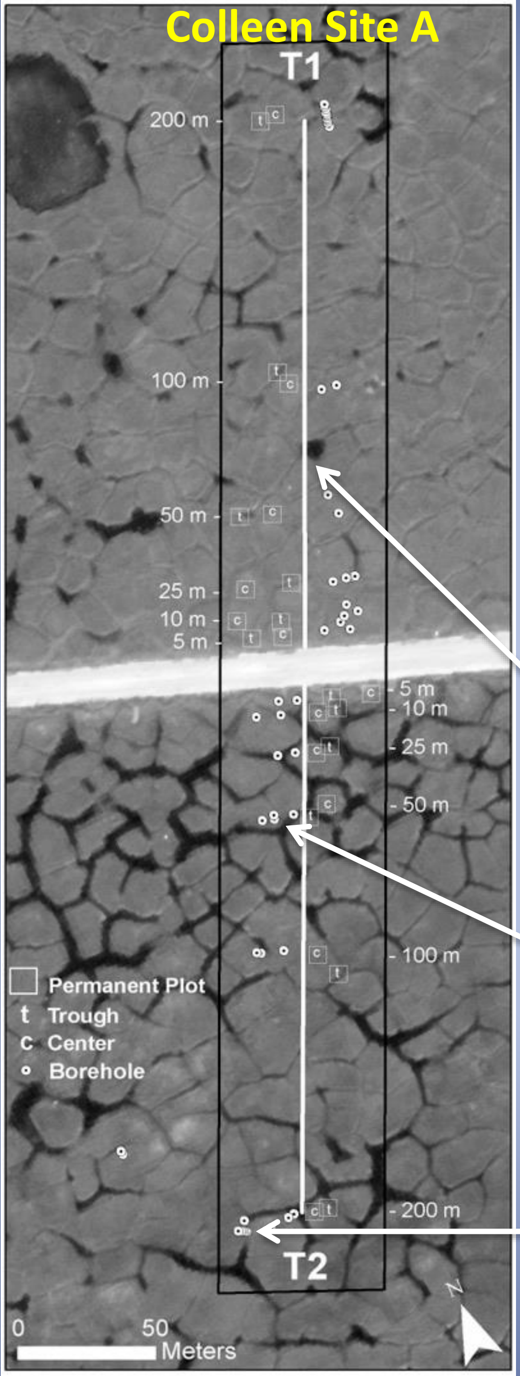
Ground-based studies of road-related changes:
Integrated geomorphology, vegetation, soils, and permafrost studies




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

Transects, plots, boreholes at each study site



Transects:

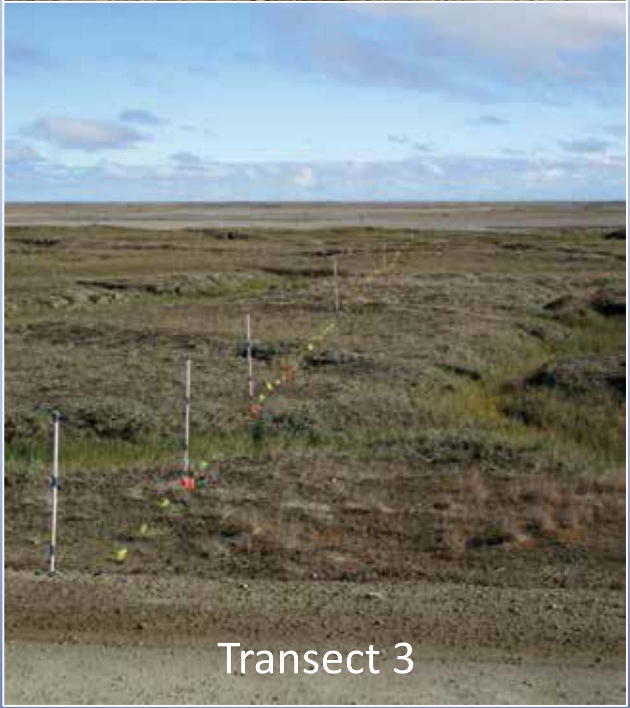
- Elevation, active layer, water depth, Veg height, Veg type, Microrelief type, NDVI, LAI

Plots:

- Vegetation, soils, active layer, NDVI, LAI, soil and snow temperature

Ice-wedge boreholes:

- Several holes across ice-wedge to gravel layer or ice wedge.

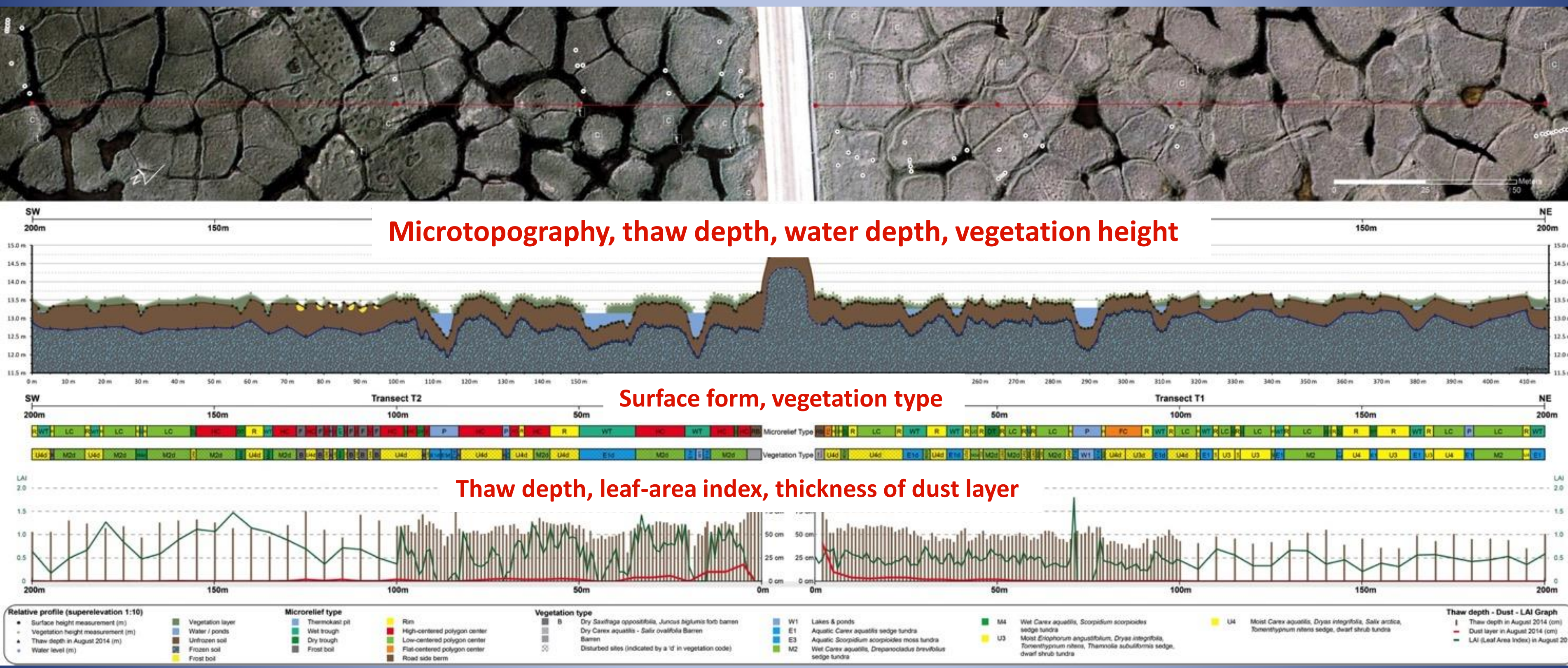


Both sites have large contrasts between the flooded and drained sides of the road.

- Much more productive, greener vegetation on the flooded side.
- Dust effects most evident on the drained side.

Transect surveys

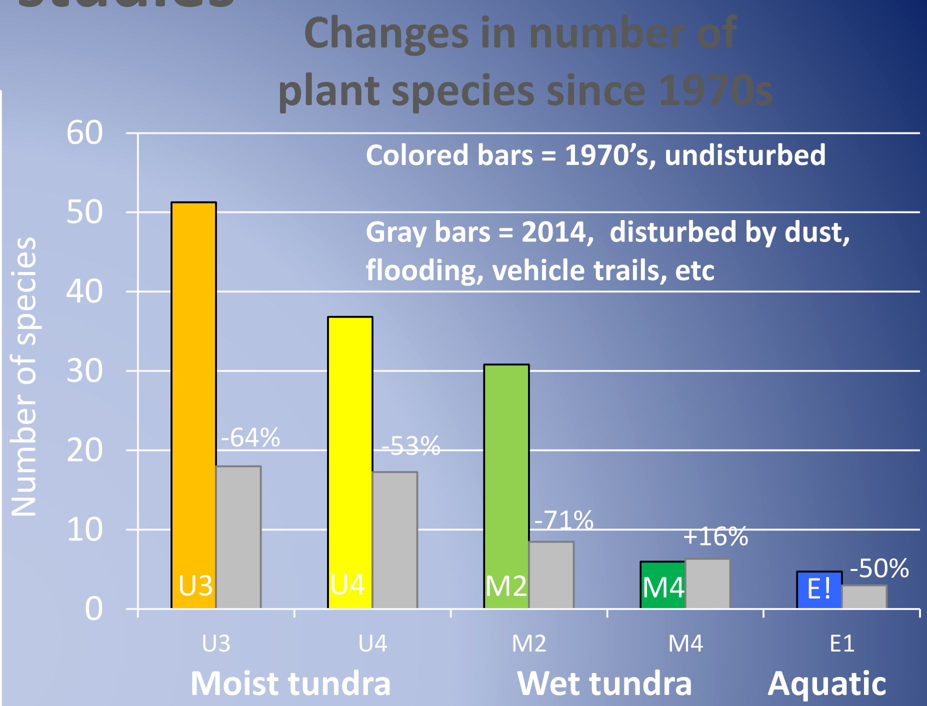
T2: Southwest side High-resolution Image T1: Northeast side



Take home message from Marcel Buchhorn

- "The striking contrasts on either side of the road are caused primarily by altered hydrology.
- Flooding on the SW side of the road caused considerable subsidence of the ice wedges, greater micro-relief contrast, conversion of low-centered polygons to high-centered polygons, water accumulation in the troughs, deeper thaw, and higher productivity.
- Dust had greater impact on the non-flooded side.
- Thermokarst has resulted in much more heterogeneous landscapes than existed in the 1970s."

Vegetation studies



- **Large declines in species diversity in 1-m plots in moist and wet tundra since 1970**

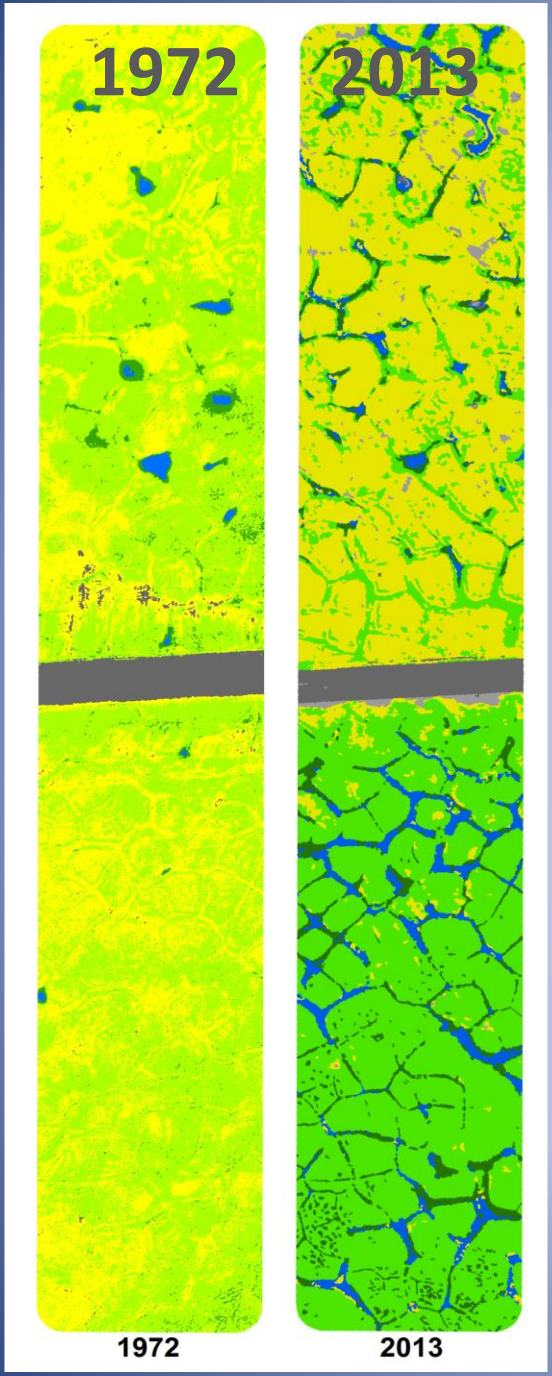
- **Many species recorded in 1970s plots were not recorded in 2014**

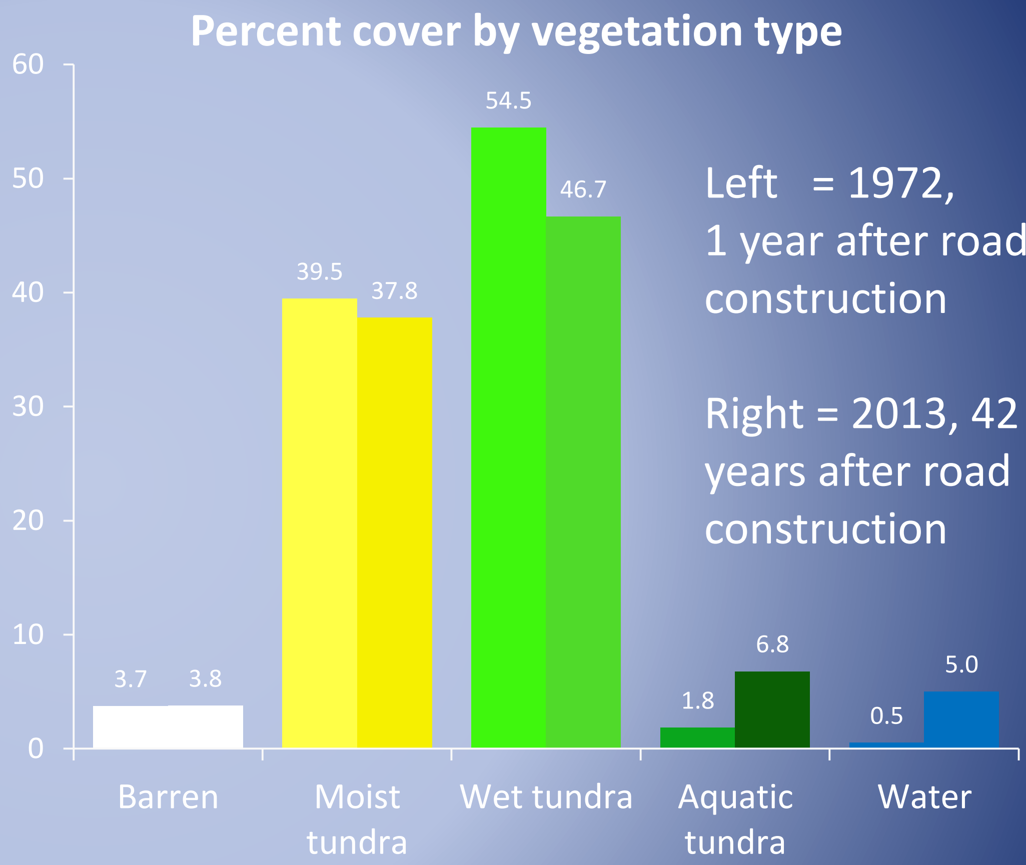
  7 forbs, 2 graminoids, 7 mosses, 6 lichens

- **A few species showed noticeable increases**

  mostly shrubs, wet sedges, and a few disturbance-related forbs

Changes in mapped vegetation patterns





Left = 1972, 1 year after road construction

Right = 2013, 42 years after road construction

- **Reduced areas of moist tundra (-2%) and wet tundra (-8%)**
- **Increased areas of aquatic tundra (+4%) and water (+10%)**

Dust effects

Soil plug from polygon center 50 m from road with new 20-cm thick mineral horizon.

>40 cm of dust adjacent to road has increased drainage and eliminated thermokarst within 5 m of the road

Take home message from Martha Raynolds

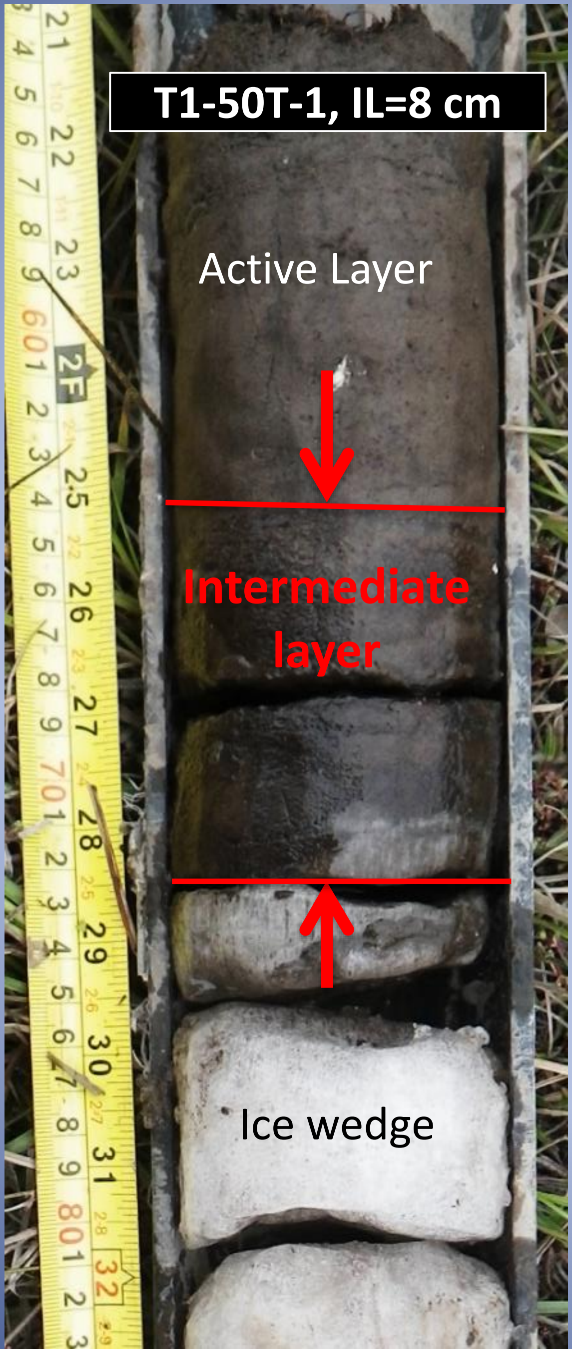
- "I was impressed with how many species had been lost from the plant communities since the 1970s.
- Dust, flooding, vehicle trails, and other disturbances have had cumulative effects on plant communities, even if the vegetation looks relatively undisturbed."

Permafrost boreholes

Misha Kanevskiy & Yuri Shur

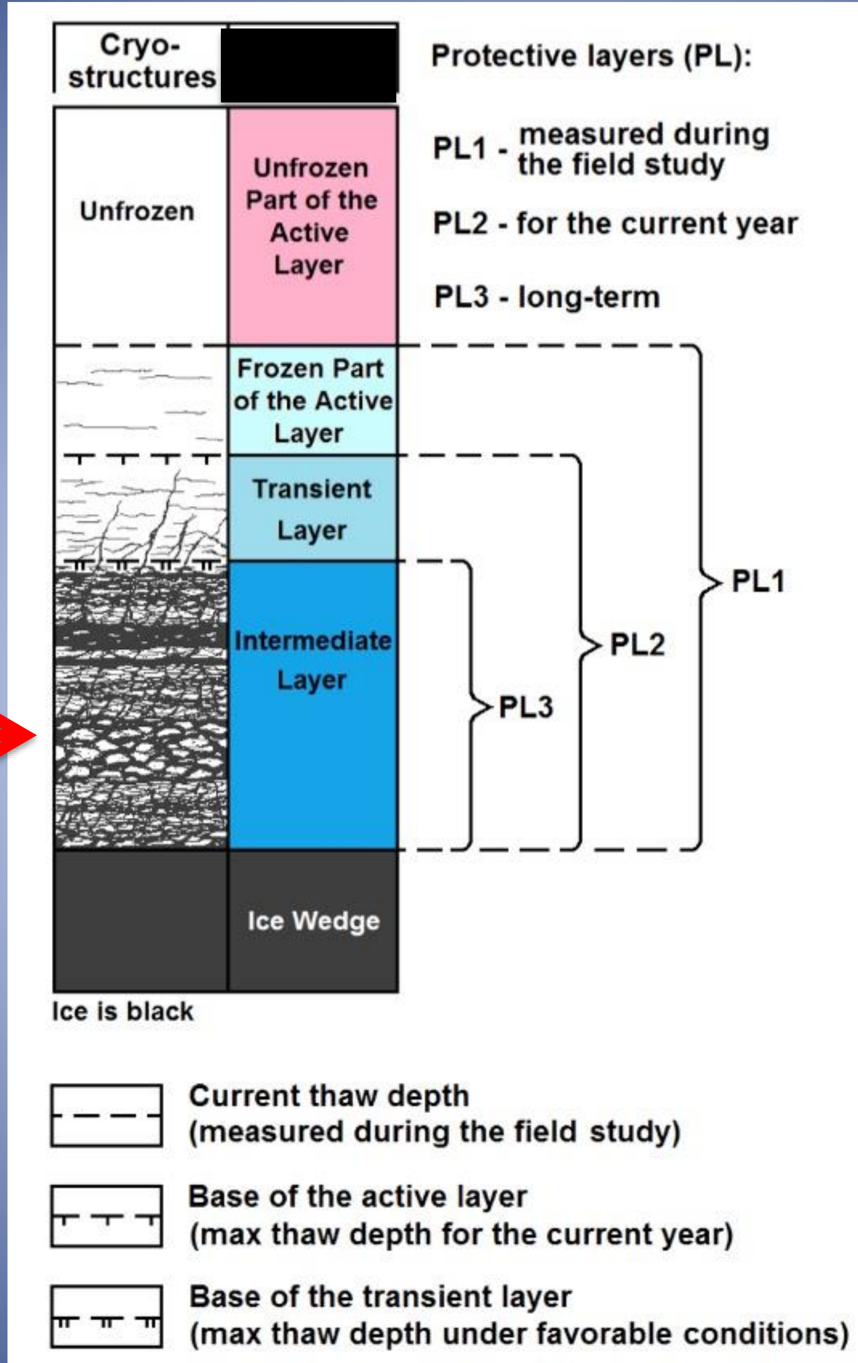
Ice cores from boreholes drilled in ice-wedge troughs

Misha was most interested in the health of the intermediate layer.



The intermediate layer

Intermediate layer



- Ice-rich and organic-rich layer resistant to thaw.
- Protects the underlying ice-wedge from thaw.
- Forms when there is an aggrading permafrost table.
- If missing and summer thaw penetrates to the ice wedge, the wedge is in a degrading state.

Modified from Kanevskiy et al. 2016, EICOP.

Surprise: The flooded side of the road had thicker intermediate layers and no degrading ice wedges!

Transect	Mean intermediate layer thickness (cm)	Actively degrading ice wedges***, %
T1, (NE, nonflooded)	1.2 (n=22)	9.1% (n=22)
T2 (SW, flooded	5.0 (n=13)	0% (n=13)

*** Percent of boreholes drilled between late July and mid-September, which encountered ice wedges actively degrading on the day of drilling (PL1=0).

Overall risk of ice-wedge degradation (Kanevskiy, 2016 EICOP)
Very High (PL3=0)
High (PL3=1-5)
Moderate (PL3=5-15)
Low (PL3=15-25)
Very Low (PL3>25)

Factors contributing to thicker intermediate layers on the flooded side:

- Taller more productive vegetation.
- Thicker organic soil layers produced by high vegetation production reduced heat flux to the ice wedges.
- Thicker dust layers, and mineral material redistributed from the eroding polygon centers also protected the ice wedges.

Take home message from Misha Kanevskiy

- “I was surprised that ice wedges under the deep water-filled troughs were more stable at the present time than wedges not affected by flooding.
- The insulative protection provided by more plant production, thick organic layers, and accumulation of mineral material in the troughs promotes intermediate-layer formation and permafrost aggradation.”

The 2015 Sagavanirktok River Flood

Photo: Loren Holmes / Alaska Dispatch News, May 21, 2015

Routing of flood waters to the west side of the road was caused by massive aufeis formation in the delta of the river.

- Major area of aufeis to the north blocked much of the flow of the river.
- This caused a major flow of water northward on the west side of the road.

Photos by KTUU News [h](h)

Flooding at Deadhorse Airport and our Airport study site

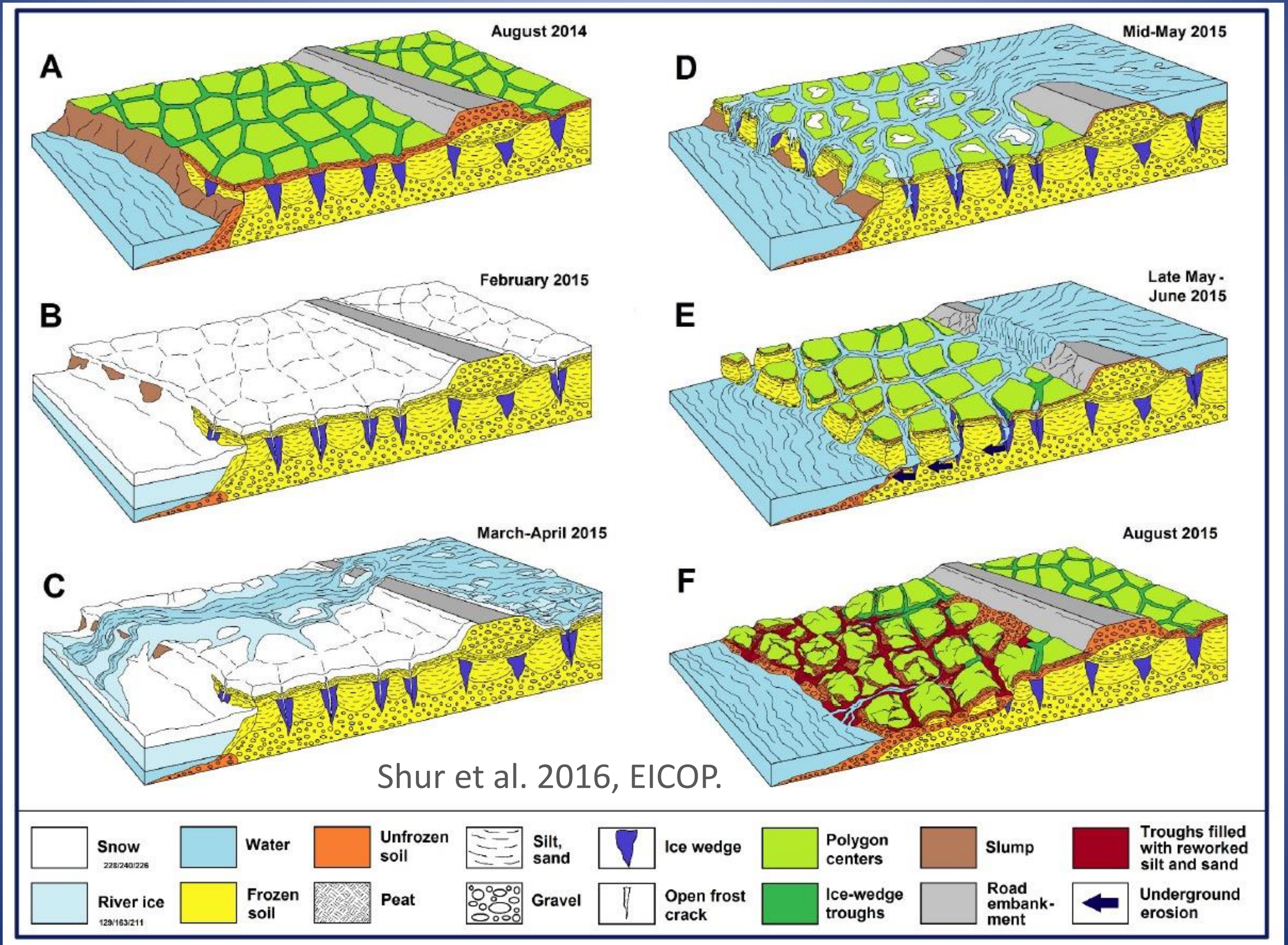
Photos: Alaska Department of Transportation and Public Facilities

Massive thermokarst occurred where high-velocity flood waters were concentrated.

- Near the airport the road had to be breached to allow the flood waters to drain back into the main Sagavanirktok River channel.
- Massive underground ice-wedge thermokarst destroyed the Dalton Highway near the Airport.

Photos courtesy of Alaska DOT & PF

Conceptual model of underground thermokarst erosion process: Newly described form of thermokarst.



Shur et al. 2016, EICOP.

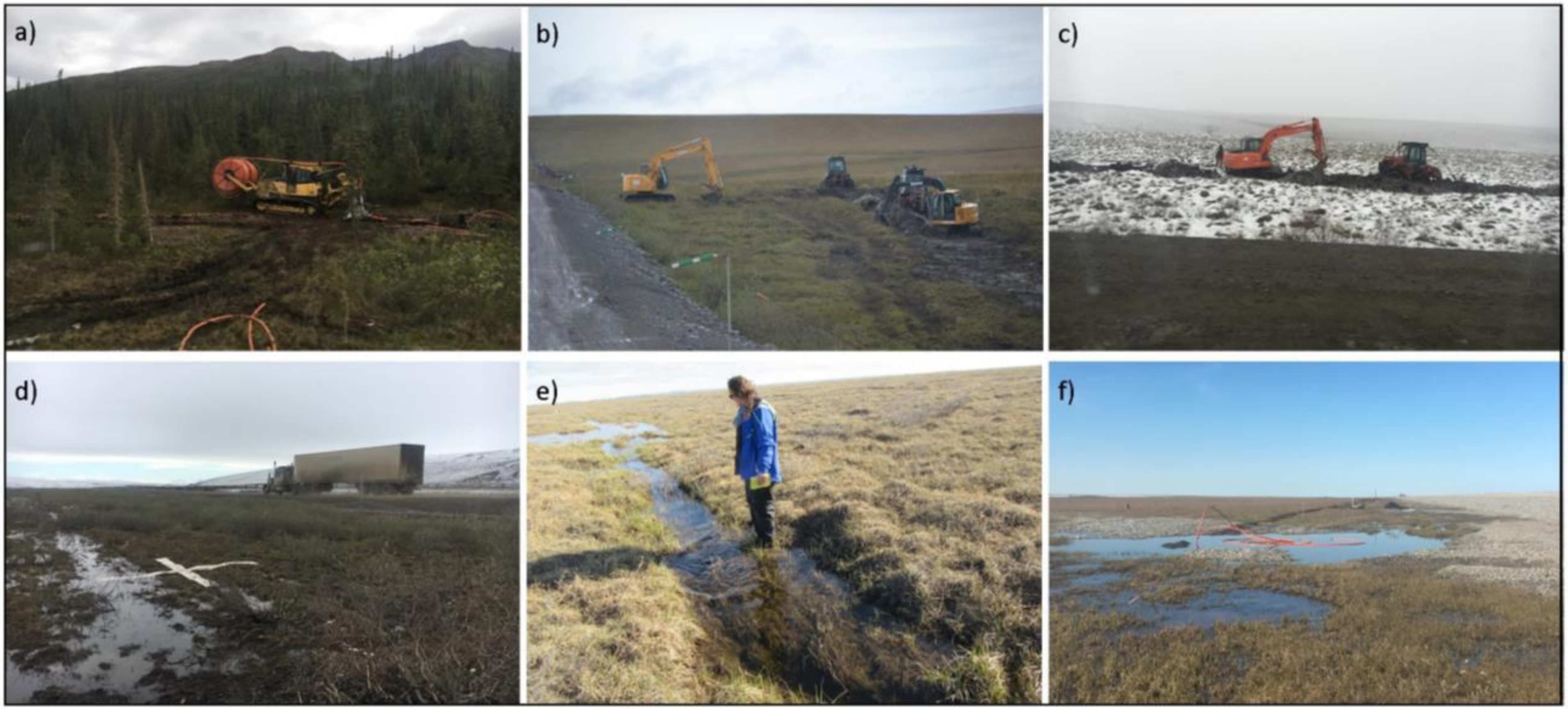
Take home message from Yuri Shur

- “The scale of the underground erosion and the forms which it left surprised me most of all.
- Also the huge icing in the Sagavanirktok River delta, which worked as a dam during spring runoff.“

Based on Shur, Y., Kanevskiy, M., Walker, D. A., Jorgenson, M. T., Buchhorn, M., & Raynolds, M. K. (2016). Permafrost-related causes and consequences of Sagavanirktok River flooding in Spring 2015, Abstract 1065. Presented at the 11th International Conference on Permafrost, Potsdam, Germany.

Are cumulative effects still occurring?

2016: The Quintillion Fiber-Optic Cable Deadhorse-Fairbanks, 500 miles, 10-m wide swath



Rosemary Dwight, Student Project 2016, Arctic Environmental Change, Field Excursion to the North Slope

2016: Large impacts of the Quintillion Fiber-Optic Cable

No Environmental Impact Assessment required!

Photos D.A. Walker

Gap between physical and biological science investigations and needs of the local people

- We now have a pretty good handle on the key components of the ecosystem and their response to climate and infrastructure changes.

- But we definitely need more whole-system approaches that include relevance to the local people.

- Are we any closer to satisfy the key concerns of the local people?

From a 1979 North Slope Borough Report “Nuiqsut Heritage”

….”After all this picking apart, the big question for Nuiqsut remains:

Can national, state, regional, and Nuiqsut interests be made compatible? Can the people of this village continue their way of life, blending traditional and modern? Can they remain Inupiat, attuned to their homeland, but also at home in the other world that each year takes over more of the Arctic’s spaces?

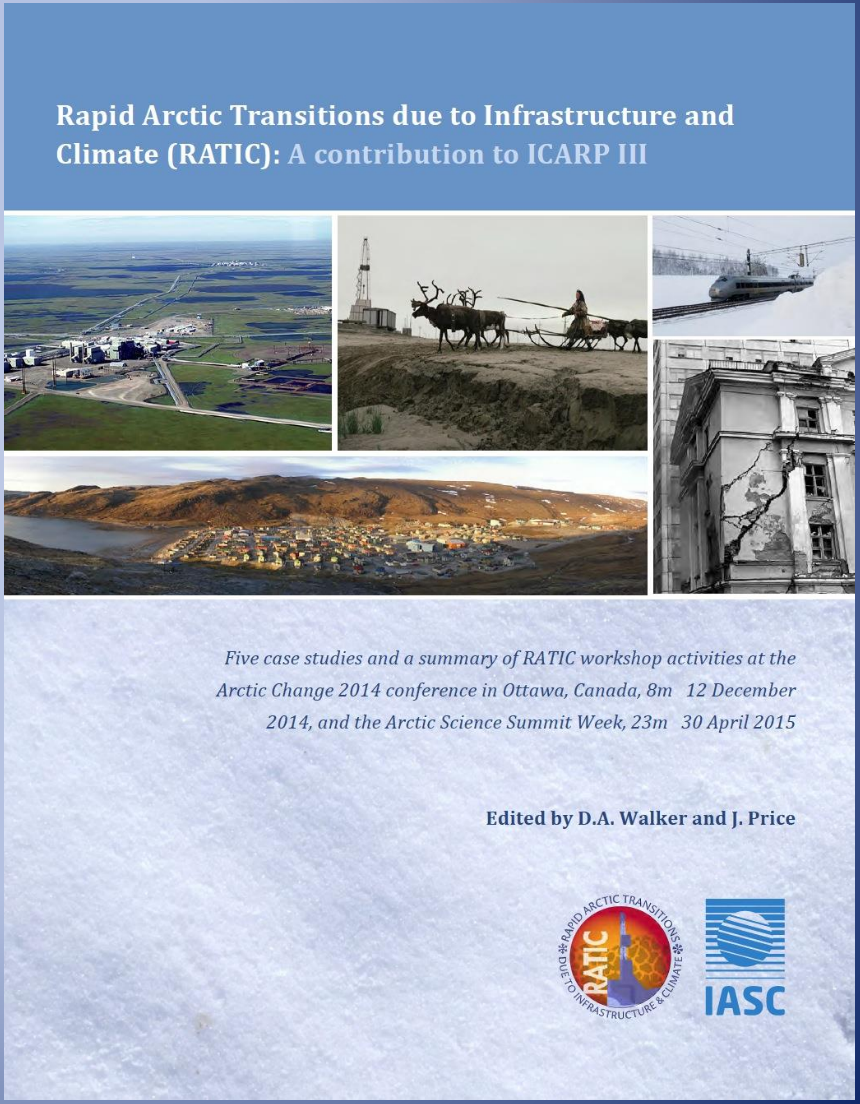
Rapid Arctic Transitions due to Infrastructure and Climate (RATIC)

- 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.

- An International Arctic Science Committee (IASC) initiative to examine RATIC from a more interdisciplinary, global, whole-system perspective that includes the social and human aspects.

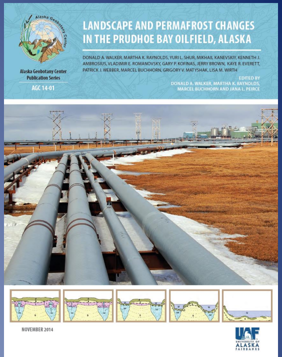
2015 white paper for IASC 10-yr science plan

- *Summary of RATIC workshop activities:*
- *Conclusions*
- *Recommendations*



RATIC white paper: Five case studies

Case Study 1: Cumulative effects of infrastructure and climate in the permafrost landscapes of the Prudhoe Bay, Region



Case Study 2: Russian Arctic oil and gas development and climate change interactions in the Bovanenkovo Gas Field, Yamal Peninsula

Case Study 3: ADAPT and IRIS remote communities in Canada

Case Study 4: Road infrastructure and climate effects in Norway

Case Study 5: Urban landscapes on permafrost: the Oganer district of Norilsk, Russia

Sustainable Arctic Infrastructure Forum (SAIF)

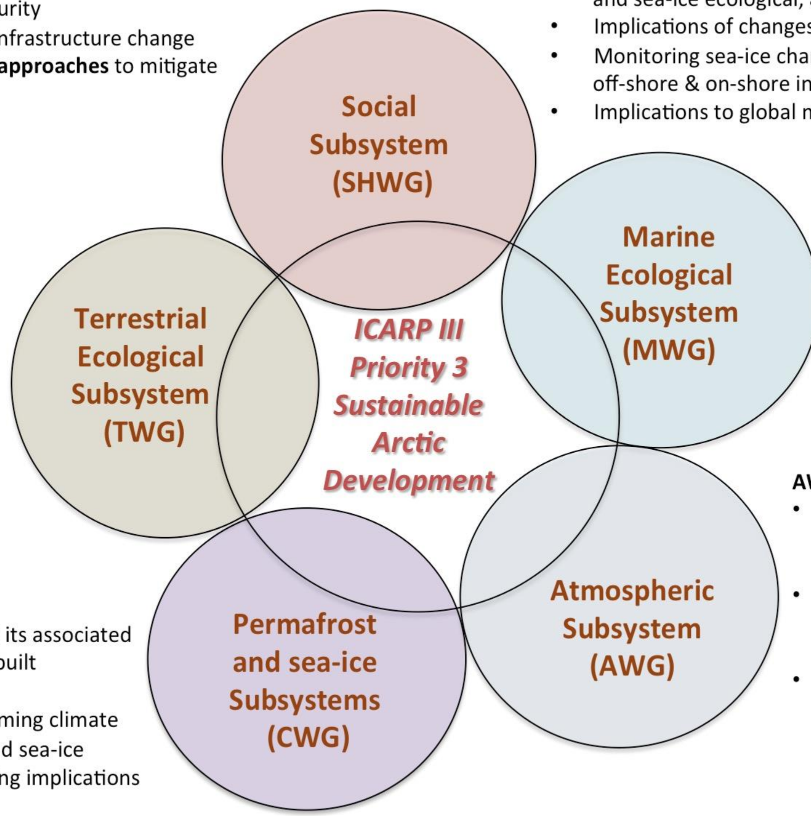
A cross-cutting workshop across all five IASC working groups to address the ICARP III priority issue of "Sustainable Arctic Development"

Possible SAIF-related themes and activities in each IASC Working Group

SHWG
- Subsistence and culture
- Business and institutions
- Terrestrial and marine infrastructure
- Legal framework, state and federal regulations
- Social, economic, political & technological **Drivers of change**
- **Implications of change** to human residents, communities, global economy and global security
- Historical responses to infrastructure change
- **Adaptive management approaches** to mitigate adverse change

MWG
- Marine pollution and contaminants
- Implications of industrial infrastructure to marine and sea-ice ecological, and social subsystems
- Implications of changes in marine transport
- Monitoring sea-ice changes to marine transport, off-shore & on-shore infrastructure, developments
- Implications to global marine systems.

TWG
- Terrestrial ecosystem responses to changes in land/ air temperatures, hydrology, permafrost snow &, contaminants
- Monitoring terrestrial system response at multiple scales
- Predictive models of change
- Input to engineering, land-use planning and adaptive management responses



CWG
- Permafrost thawing and its associated impacts on natural and built environment
- Sea-ice response to warming climate
- Modeling permafrost and sea-ice response, and engineering implications

AWG
- Climate drivers of change to terrestrial and marine subsystems.
- Atmospheric contaminants, black carbon, dust.
- Implications to global climate system.

Five conclusions

1. ***There is a great need to examine the cumulative effects of infrastructure in the context of Arctic social-ecological systems.***
2. ***Permafrost response is a pressing ecological issue with large social costs.***
3. ***The indirect effects of infrastructure exceed the direct effects of the planned footprints.***
4. ***New tools are needed to monitor infrastructure and landscape changes and to develop sustainable approaches for future development.***
5. ***Currently, the cumulative effects of Arctic infrastructure and climate change are not addressed by any of the IASC working groups nor in national-level Arctic science plans.***

A sixth conclusion

- The current SAIF Forum consists mainly of scientists.

  A more interdisciplinary, global, whole-system perspective with satisfying solutions for the local people will require more indigenous people’s voices in the discussion (and more open ears on the side of industry, government, and science communities).


Thank you!
Martha Raynolds
Skip Walker
Marcel Buchhorn
Lisa Wirth
Gosha Matyshak
Yuri Shur
Misha Kaneveskiy
2014 Prudhoe Bay crew