Cumulative impacts of a gravel road and climate change in an ice-wedge polygon landscape, Prudhoe Bay Oilfield, AK

Landscape & vegetation impacts

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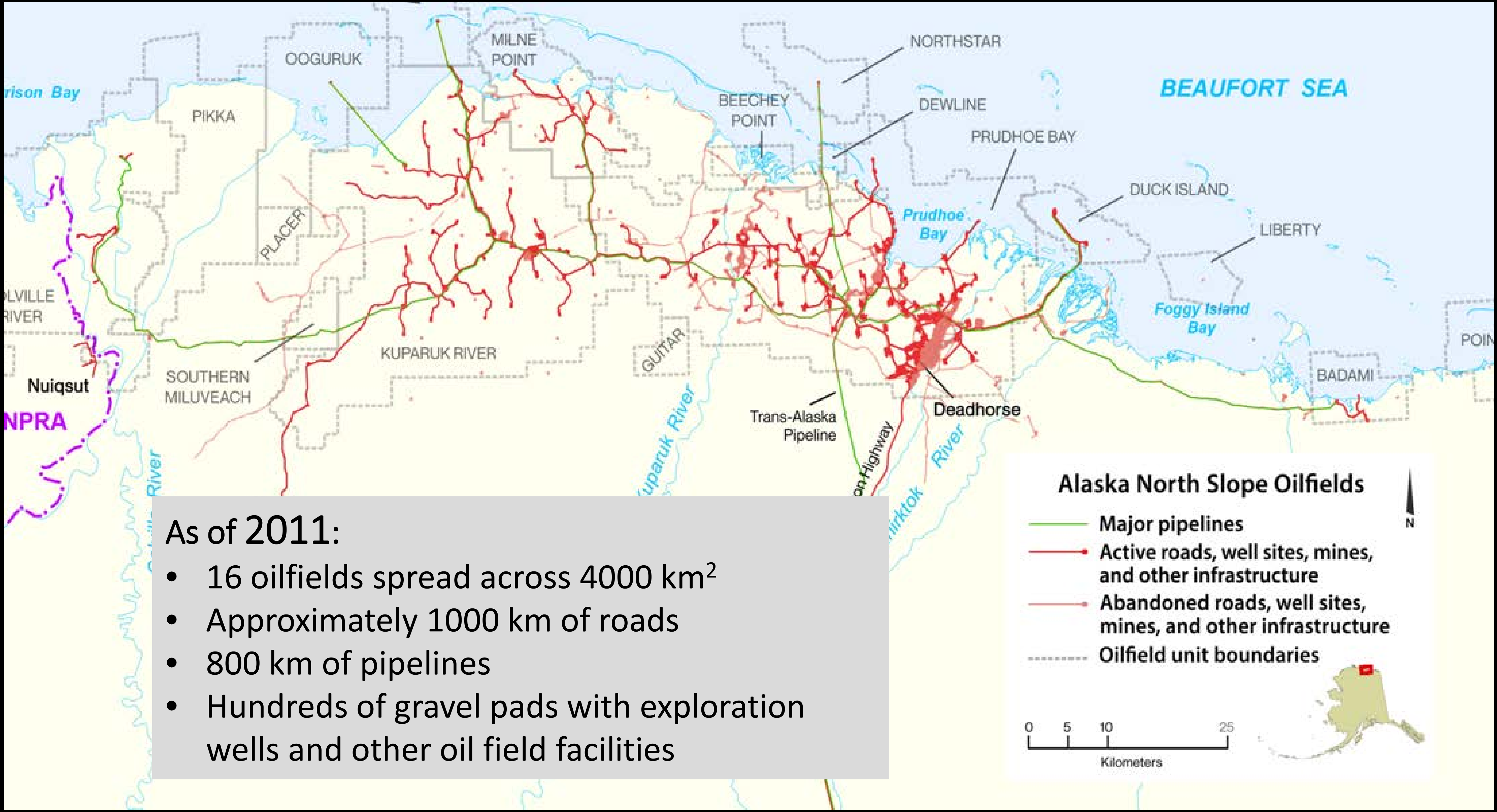
Oral talk at ASSW 2021, Lisbon, Portugal,
Northern Roads and Railways: Social and Environmental Effects of Transport Infrastructure (ID 19)

Environmental impact assessments for new Arctic roads do not adequately consider the long-term ***cumulative impacts*** *from infrastructure and climate change to permafrost landscapes.*

This is due in part to lack of long-term historical case-studies that followed the consequences of infrastructure once it was built.

Direct impacts (footprint) of infrastructure:



As of 2011:

- 16 oilfields spread across 4000 km^2
- Approximately 1000 km of roads
- 800 km of pipelines
- Hundreds of gravel pads with exploration wells and other oil field facilities

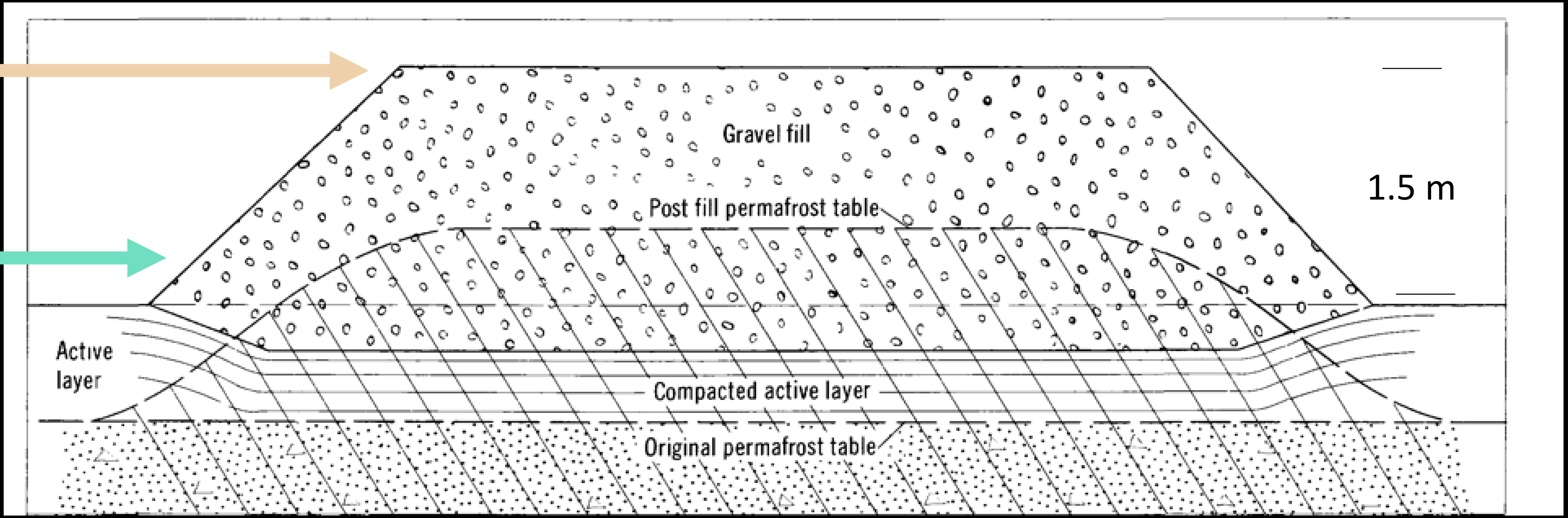
Raynolds et al. 2014. *Global Change Biology,* 20: 1211–1224.

Map courtesy of BP Exploration (Alaska)

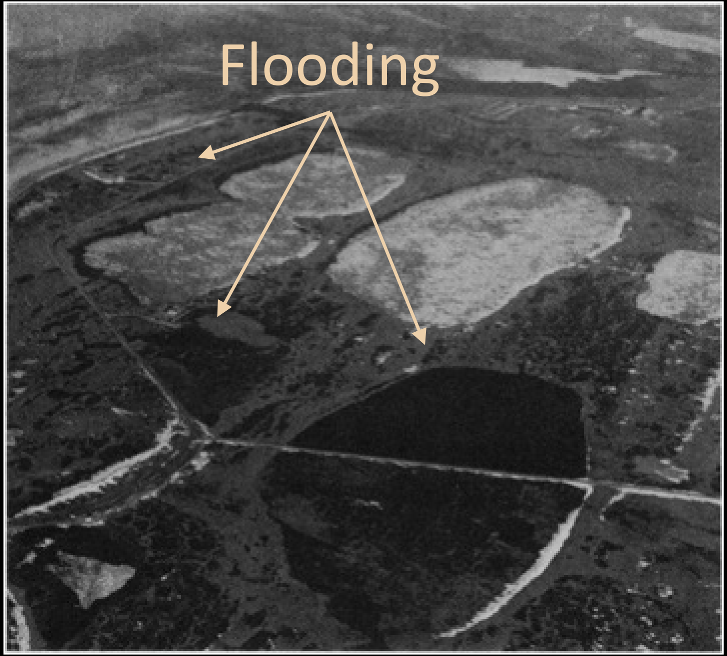
Elevated gravel roads

Source of fines for road dust

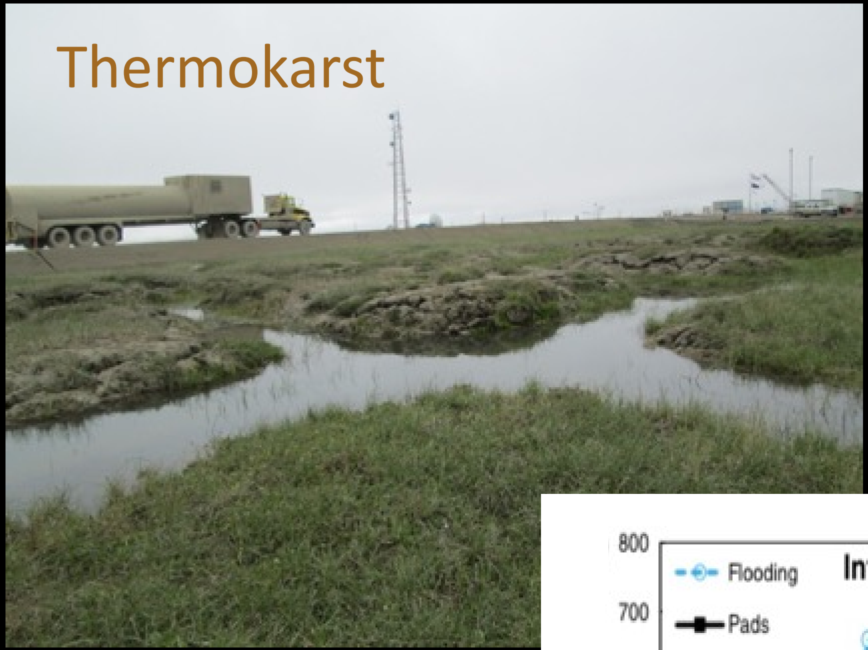
Barrier to snow and cross drainage of water



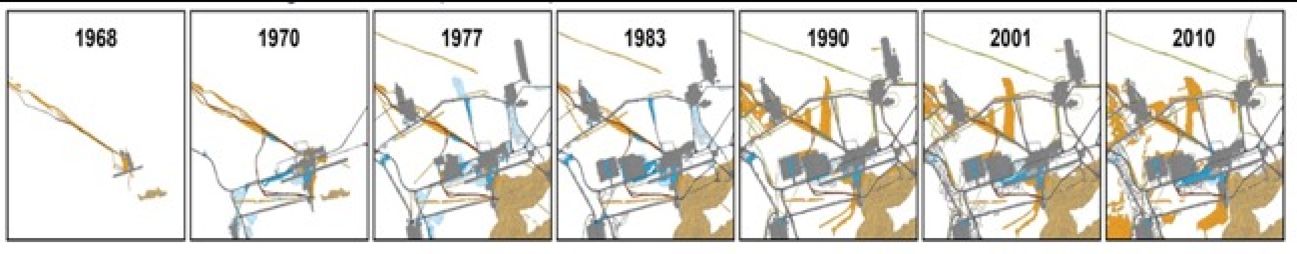
Indirect landscape effects of roads

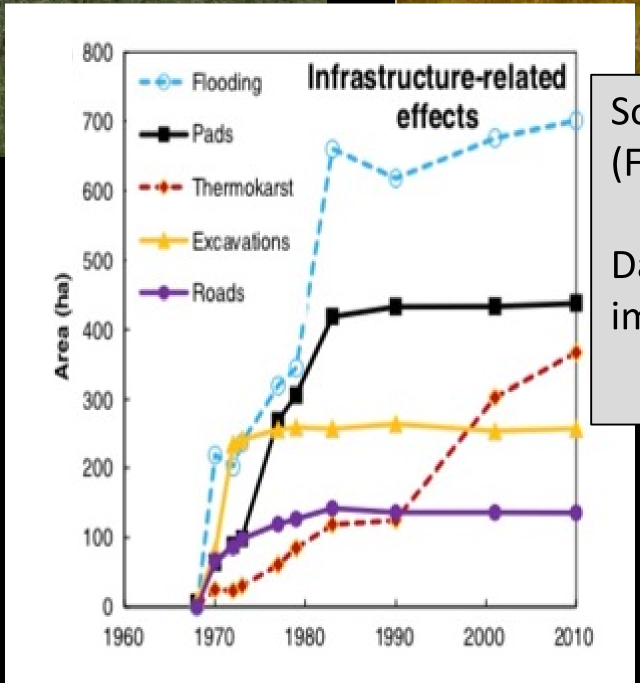


Walker, D.A. et al., 1987. *Science*, 238(4828), pp.757–761.



Infrastructure-related time series:





Solid lines: Direct impacts (Footprint)

Dashed lines: Indirect impacts

Raynolds et al. (2014) *Global Change Biology*, 20: 1211–1224

Difficult to evaluate complex cumulative indirect impacts adjacent to roads


Climate-related thermokarst away from infrastructure

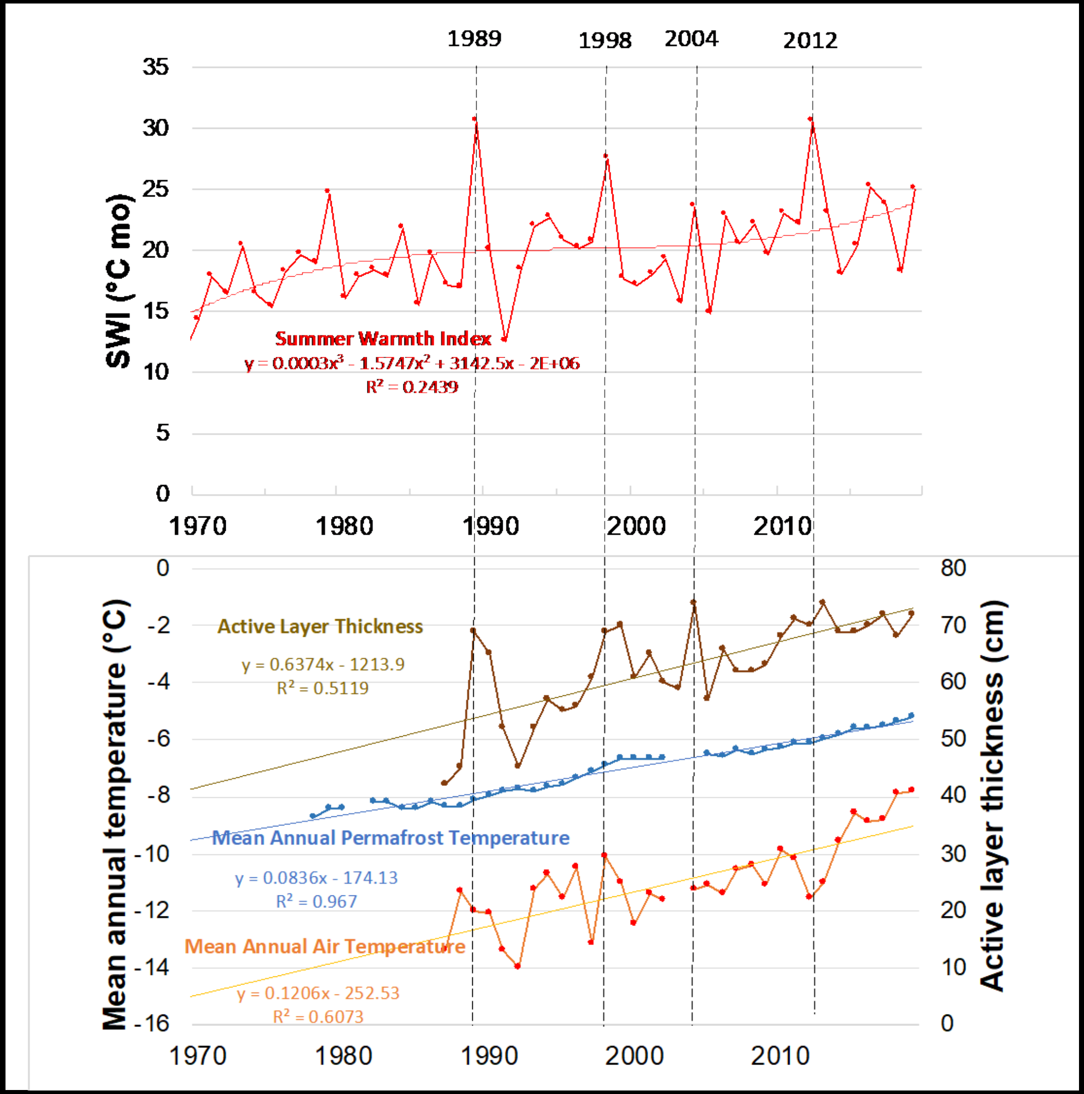

Roadside thermokarst and flooding


Roadside dust

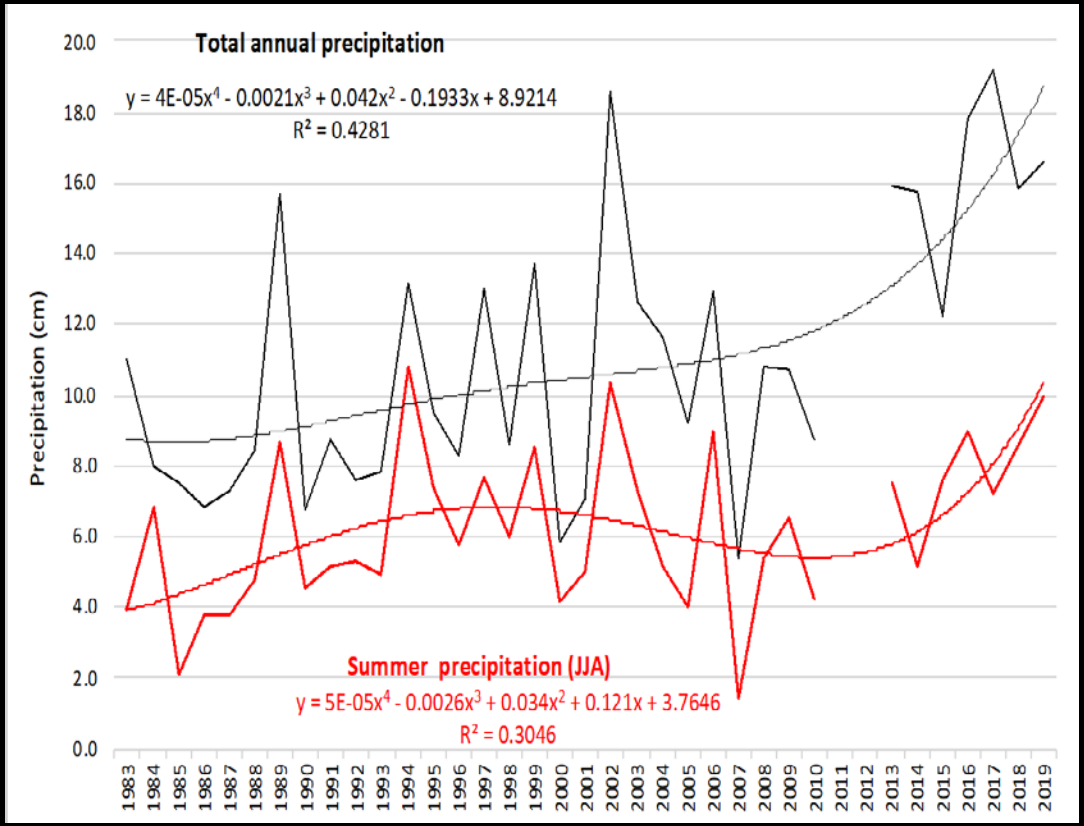

Combined effects of climate change, dust and flooding

Or to separate the climate-related impacts from the infrastructure-related impacts

Temperatures and thaw depth



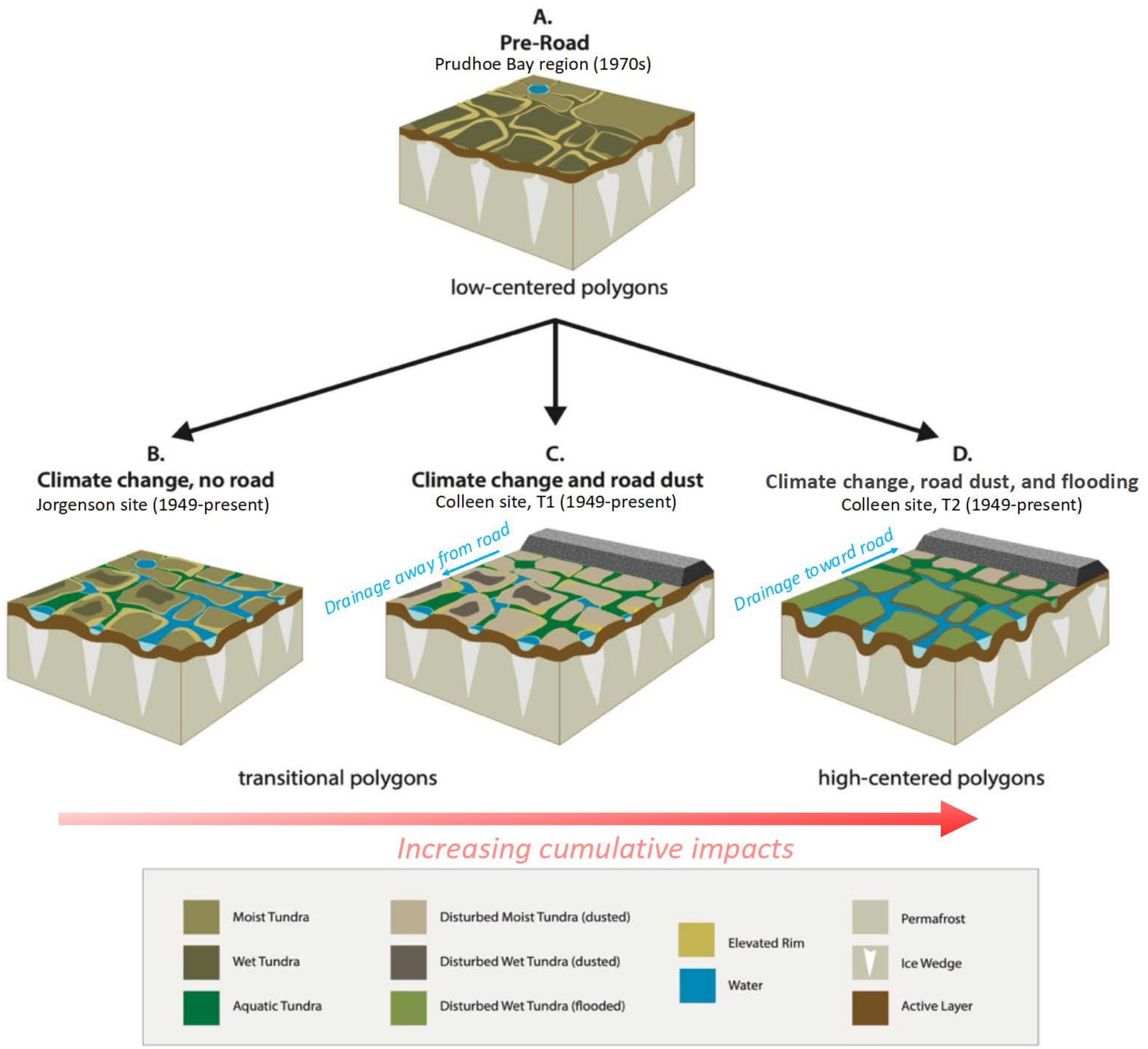
Precipitation



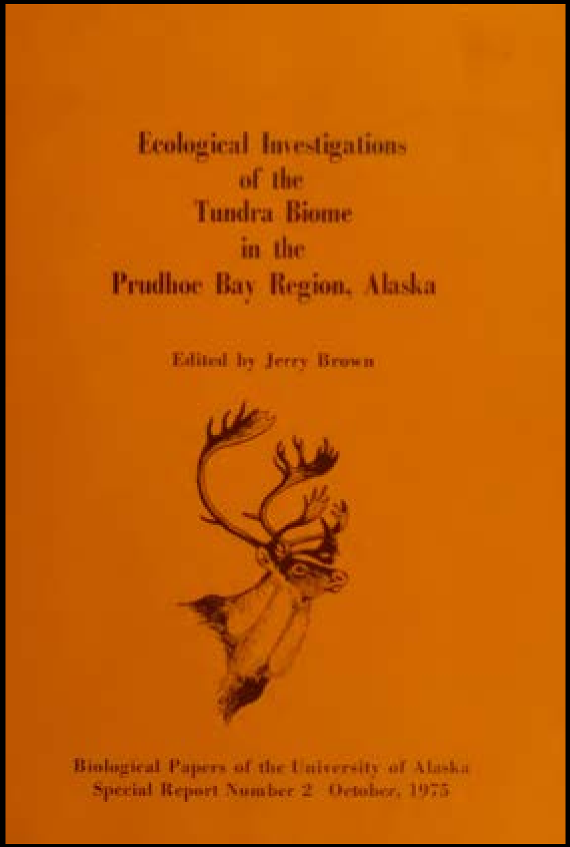
Four scenarios of landscape and vegetation change*

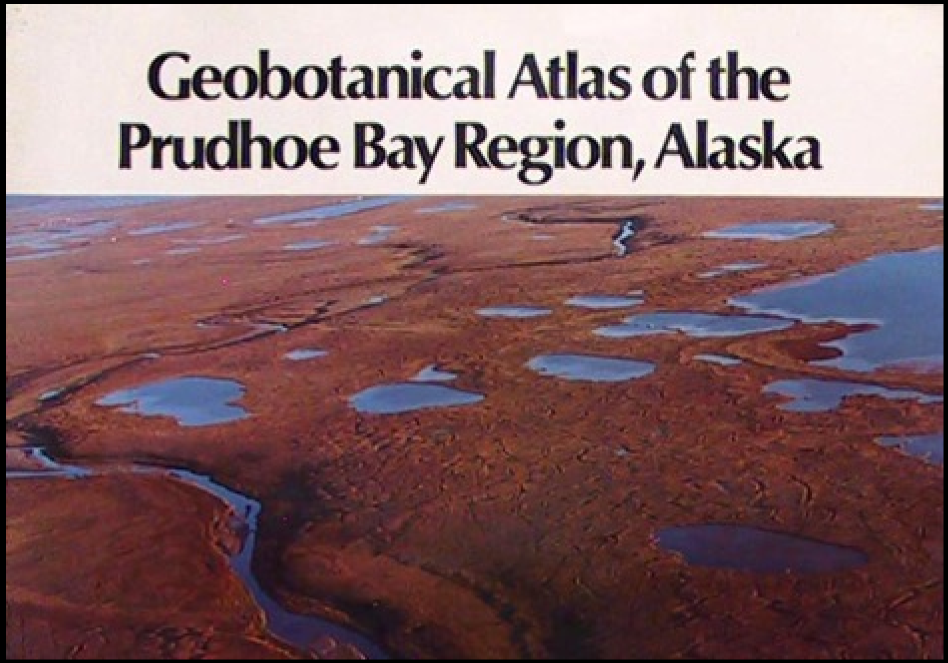
Ground-based studies to examine climate-related and indirect impacts of roads

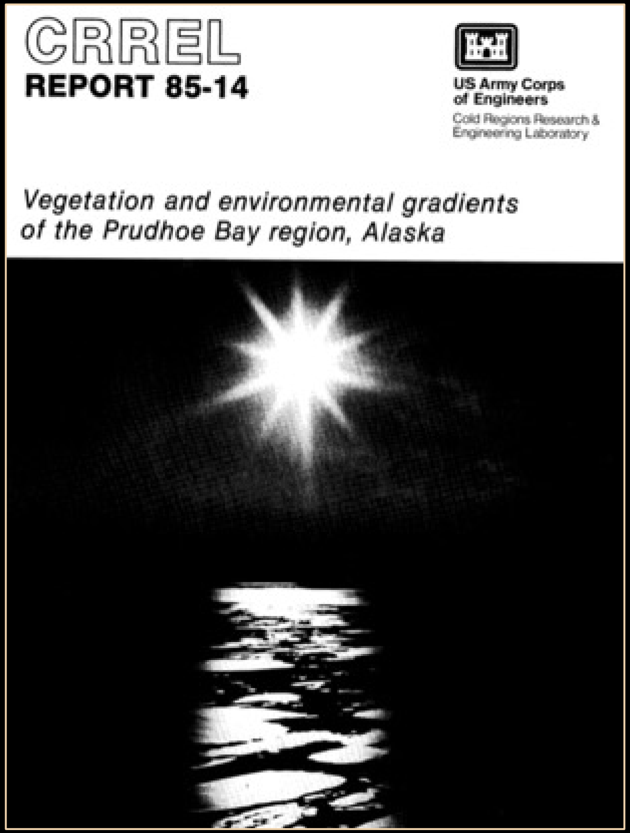
* Impacts to the ice wedges and protective intermediate layers are in separate papers (Jorgenson et al. 2015, Kanevskiy et al. 2017, 2021 in prep.)



Scenario A. Pre-road (1949-1968)







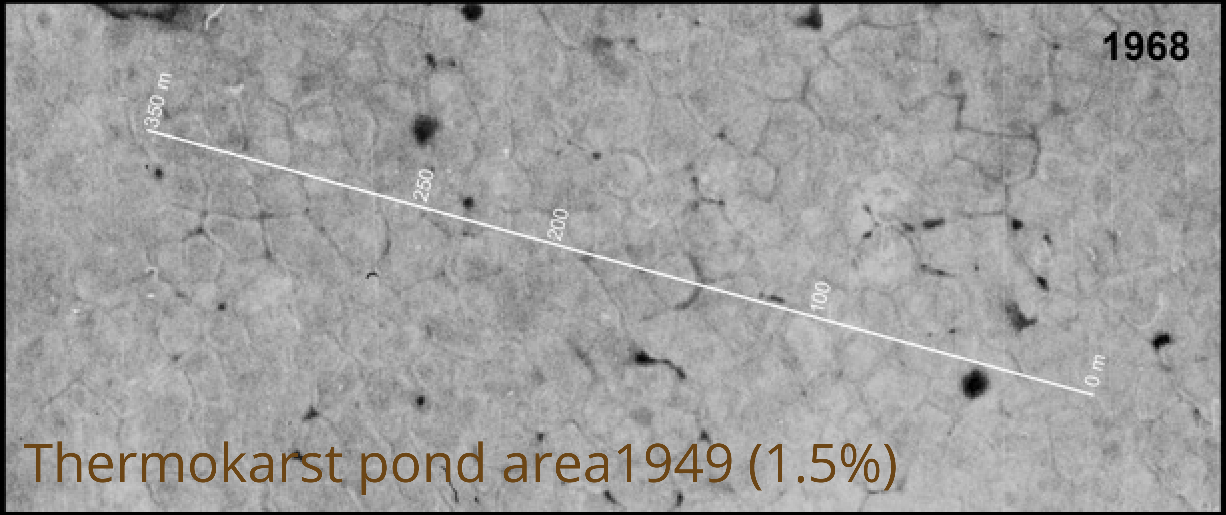
Aerial photos and 1970s baseline environmental studies,
U.S. IBP Tundra Biome and CRREL

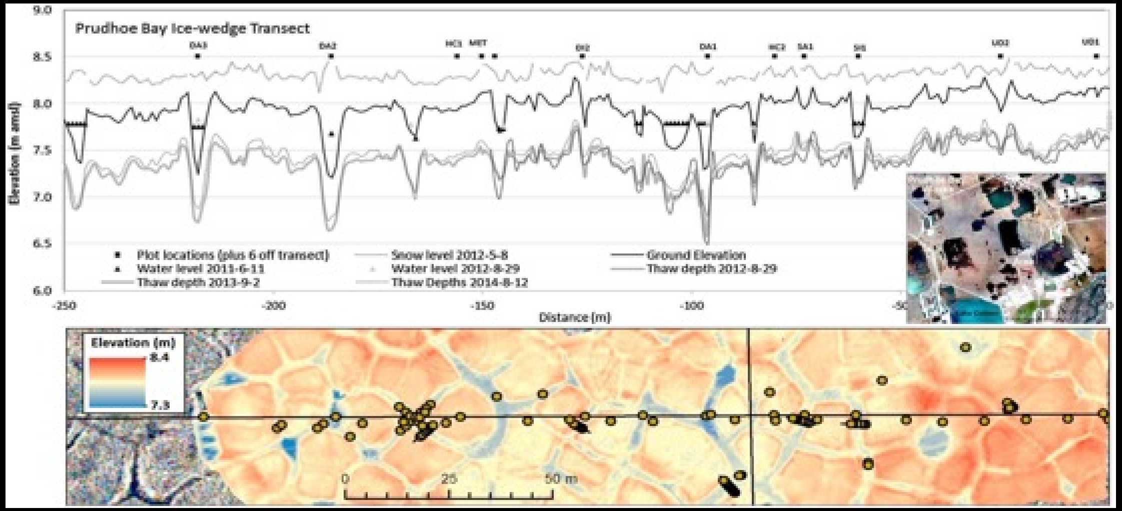
Scenarios B, C, D: Permafrost observatories

- Colleen Site (CS) and Jorgenson Site (JS)
- Climate and permafrost temperature data from Romanovsky Deadhorse station, Deadhorse Airport, Prudhoe (ARCO), and Kuparuk NWS data.

Scenario B. Jorgenson site, climate change, no road

Relatively isolated from infrastructure impacts, large changes in thermokarst ponds since 1968





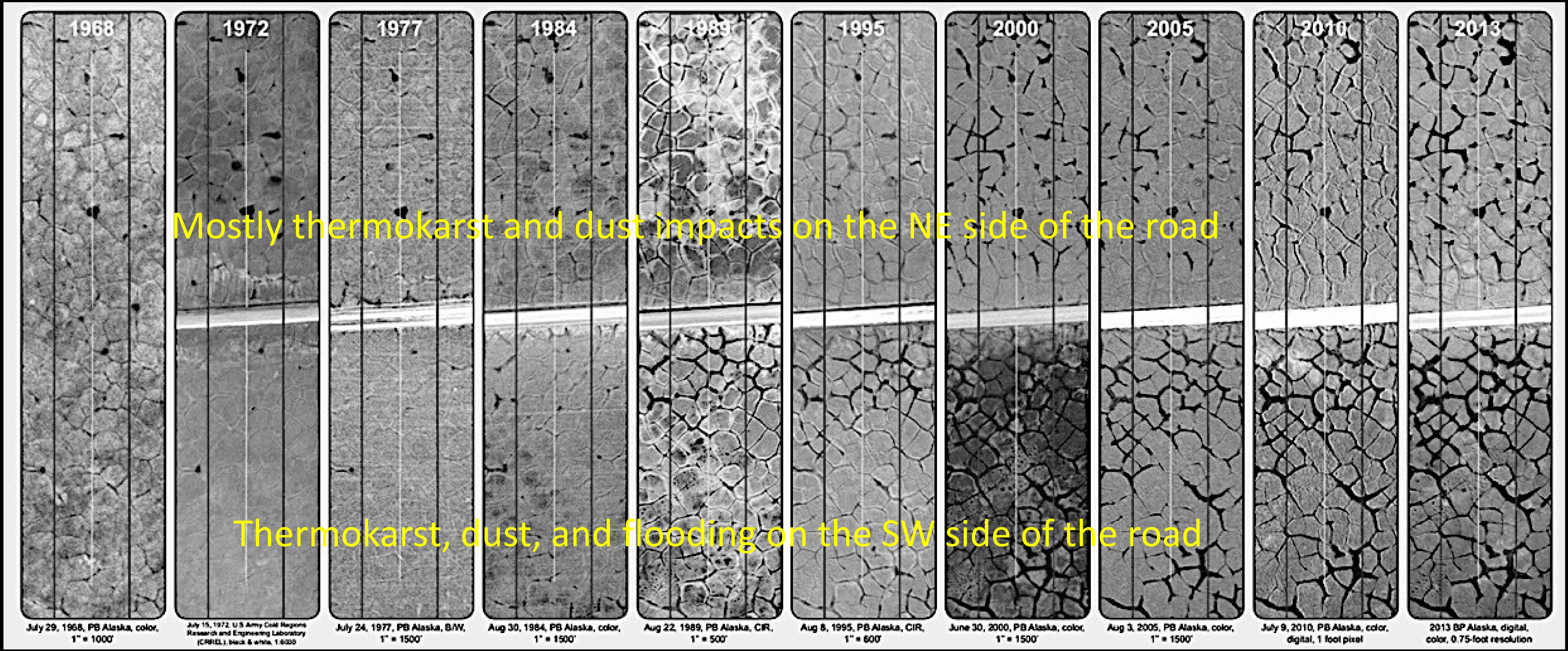
250 m transect, elevation, snow depth, thaw depth

Progression of thermokarst pond area: 1949 (0.9%), 1988 (1.5%), 2004 (6.3%), 2012 (7.5%)

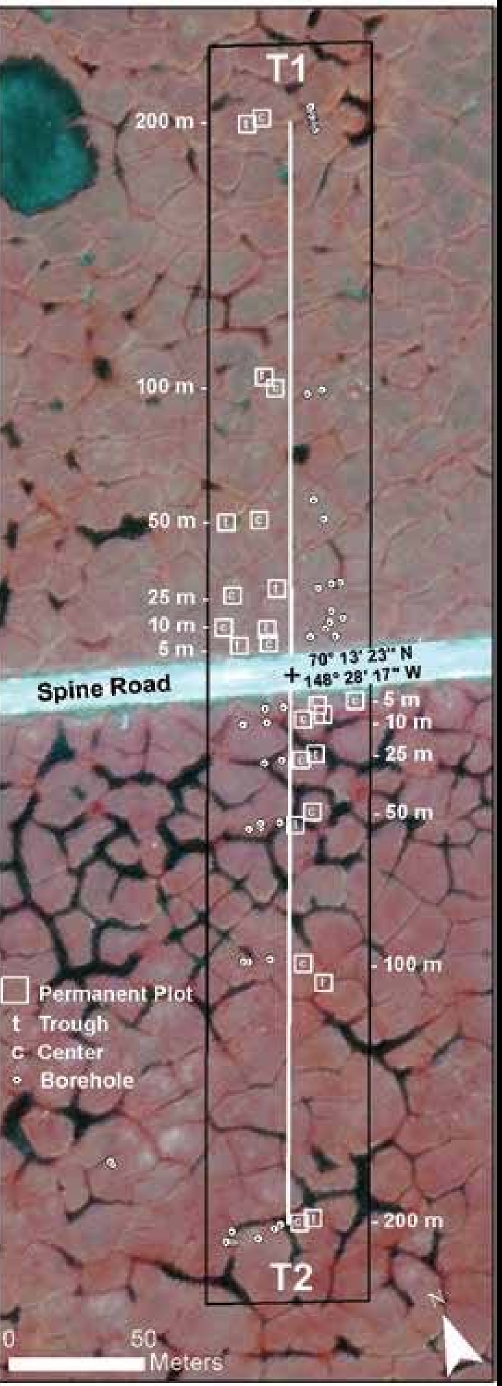
Jorgenson, M.T. et al., 2015. Role of ground ice dynamics and ecological feedbacks in recent ice wedge degradation and stabilization. *Journal of Geophysical Research: Earth Surface*, 120(11), pp.2280–2297.

Scenarios C and D. Colleen site, climate change and road

Straddles the Spine Road with different effects on each side



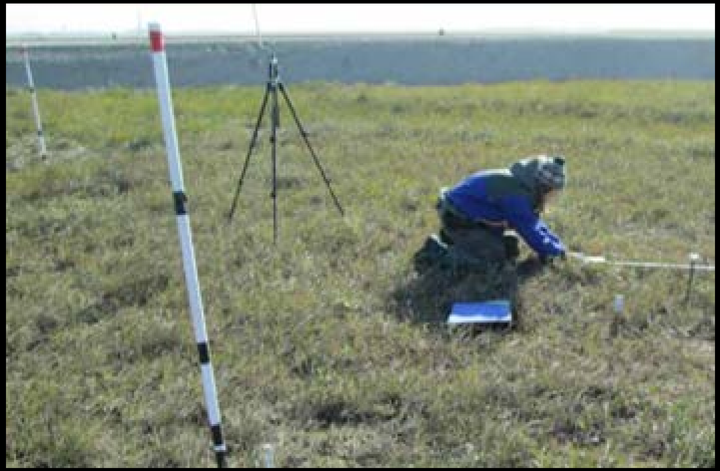
Time series of aerial photograph: 1949, and nearly annual 1968-2014



Transects and plots
Colleen site

- Aerial photo time series mapping
- Transect & plot surveys
  - Micro-topography
  - Permafrost cores
  - Active layer

- Environmental factors
- Vegetation
- Soil
- Snow
- Dust
- Flooding



Colleen transects for scenarios C and D

Scenario C: Transect T1 (Thermokarst, and heavy road dust)

Scenario D: Transect T2 (thermokarst, dust, and flooding

Most evident impacts:

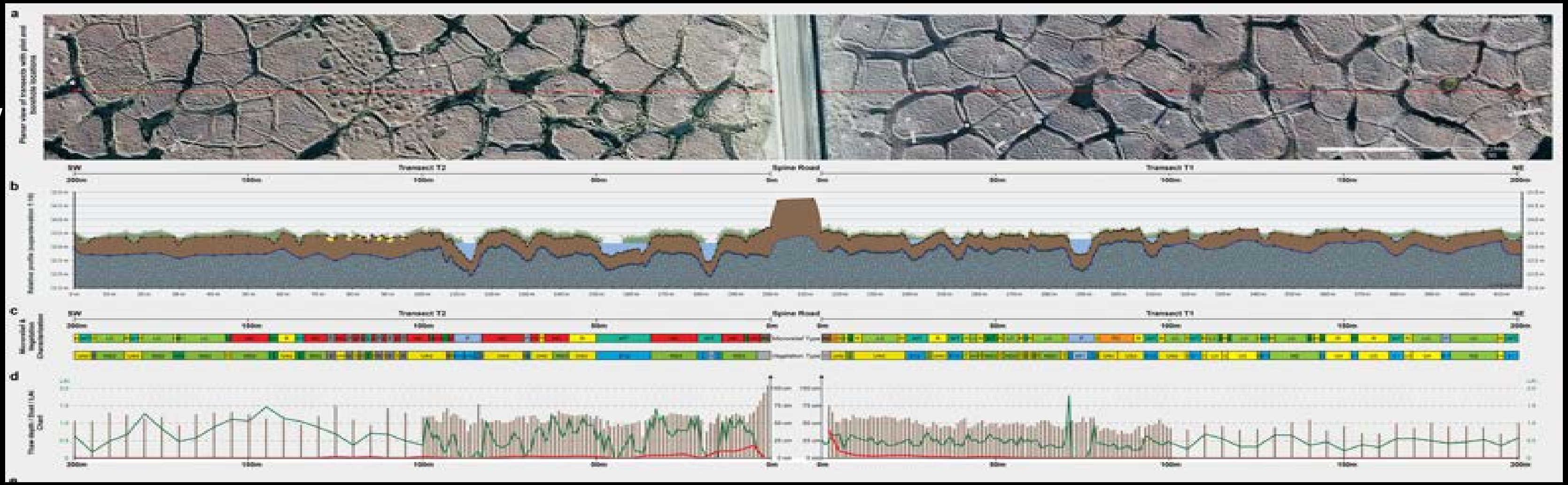
T1 — dust & thermokarst

T2 — flooding & thermokarst

Data: Transects T1 and T2 and 29 plots

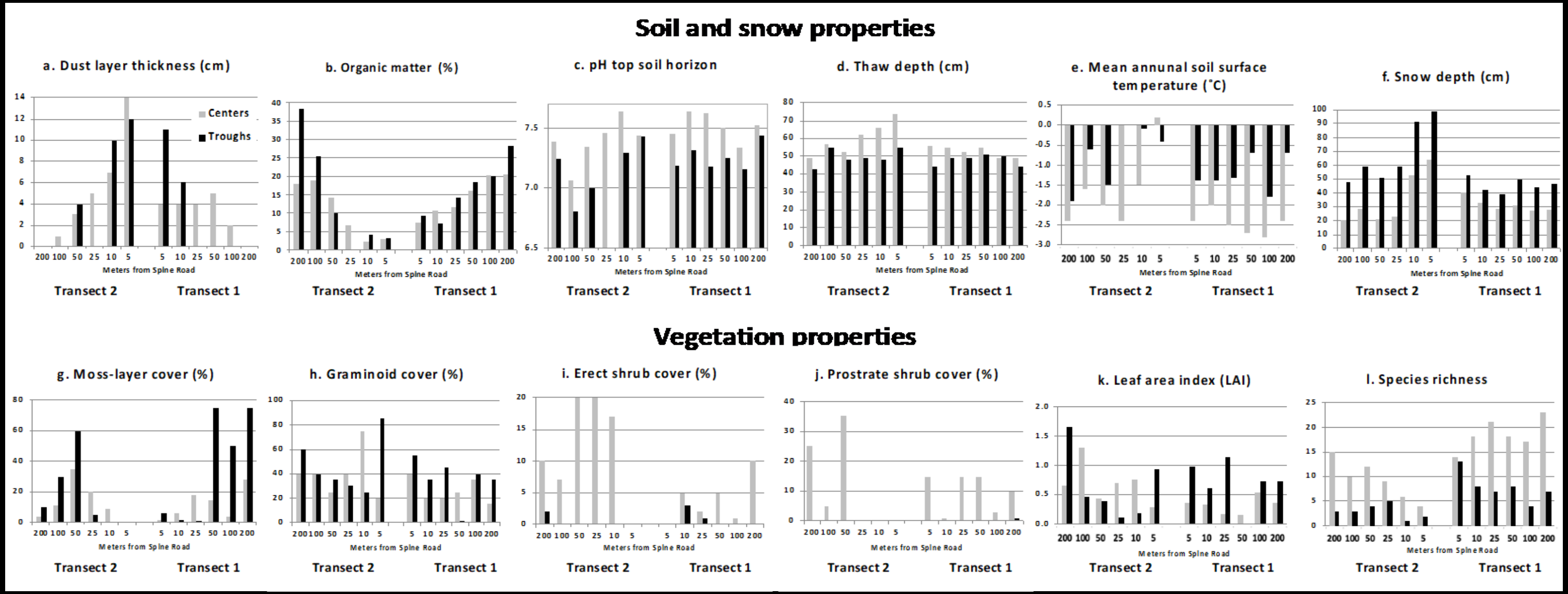
Transects T1 and T2:

Ground-surface elevation, thaw depth, water depth, vegetation height, patterned-ground element, vegetation type, LAI, dust-layer thickness



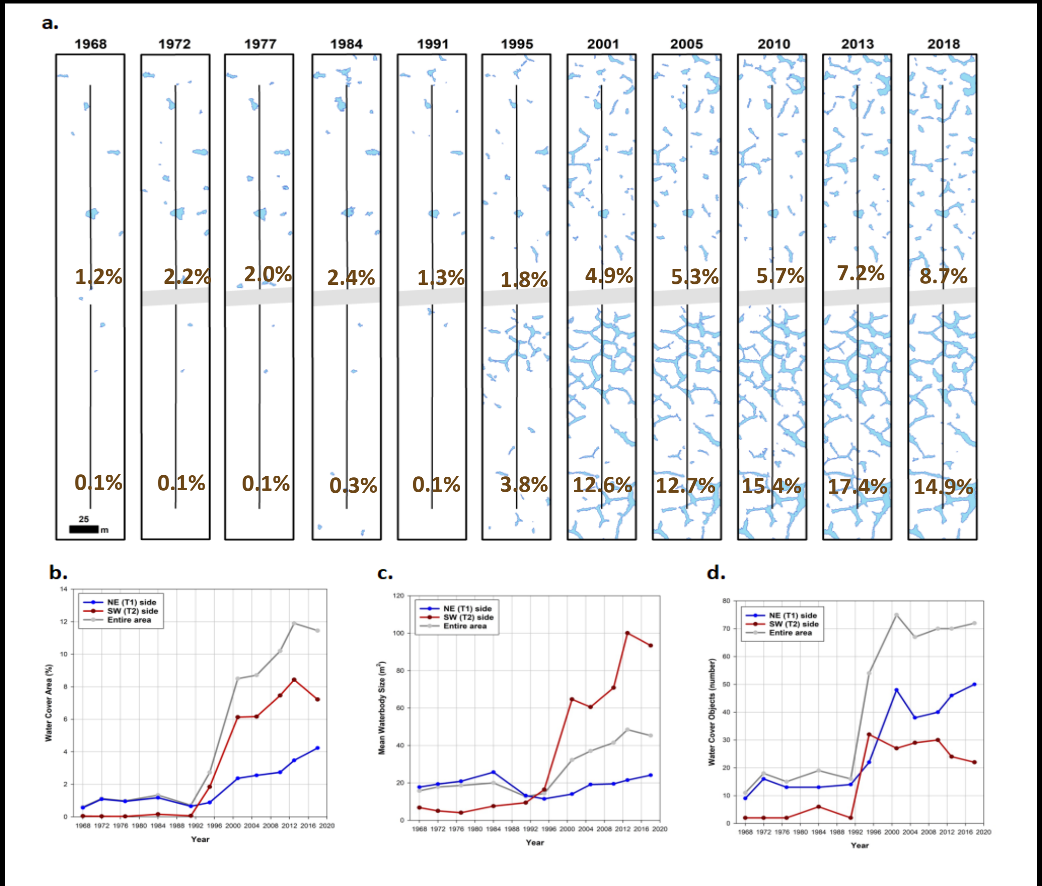
Vegetation plots:

Soil, snow, vegetation properties in polygon centers and troughs, vs. distance from road along Transects T1 & T2



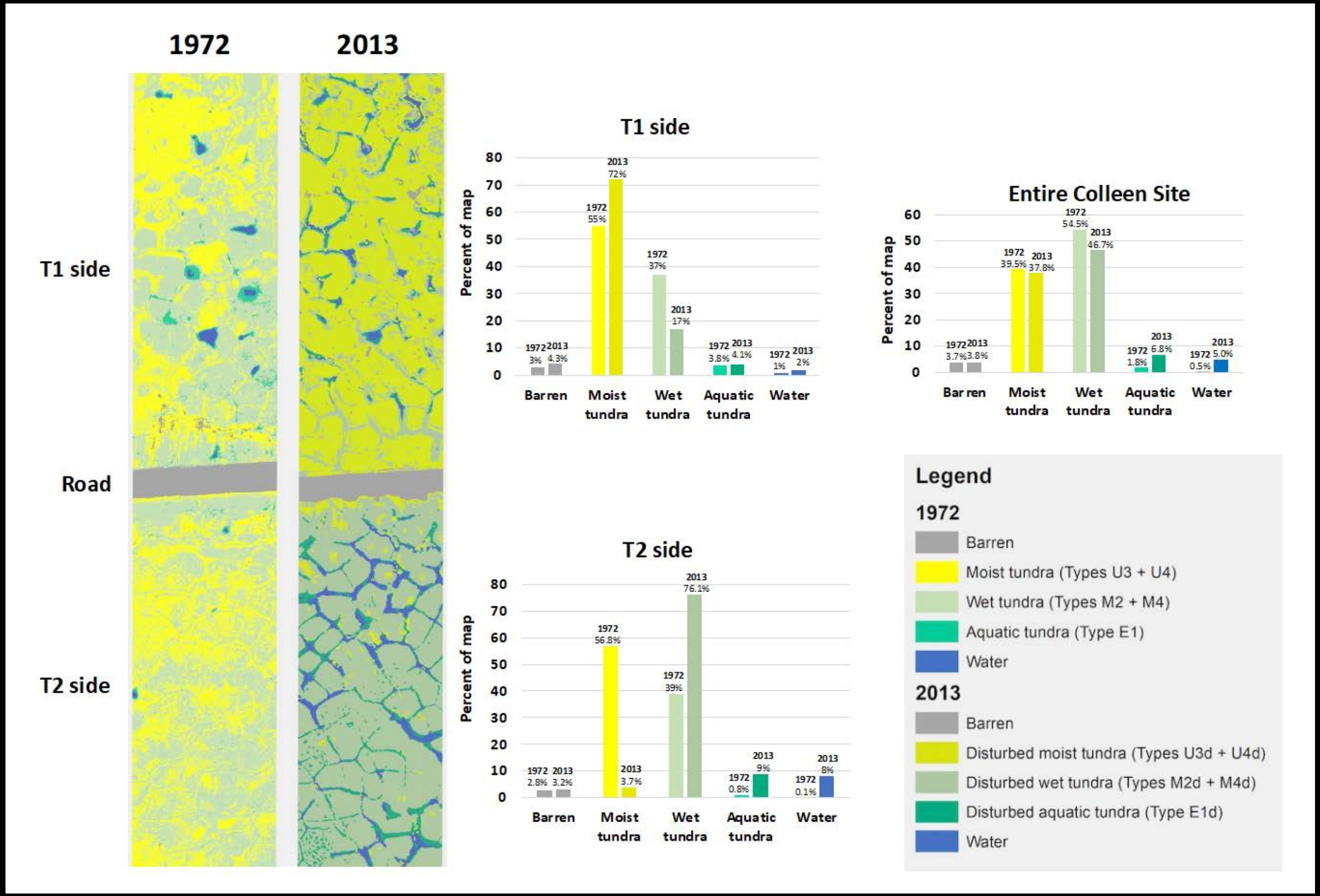
Mapping Colleen site changes

Water bodies (1968–2018)



Jones, B. 2020.

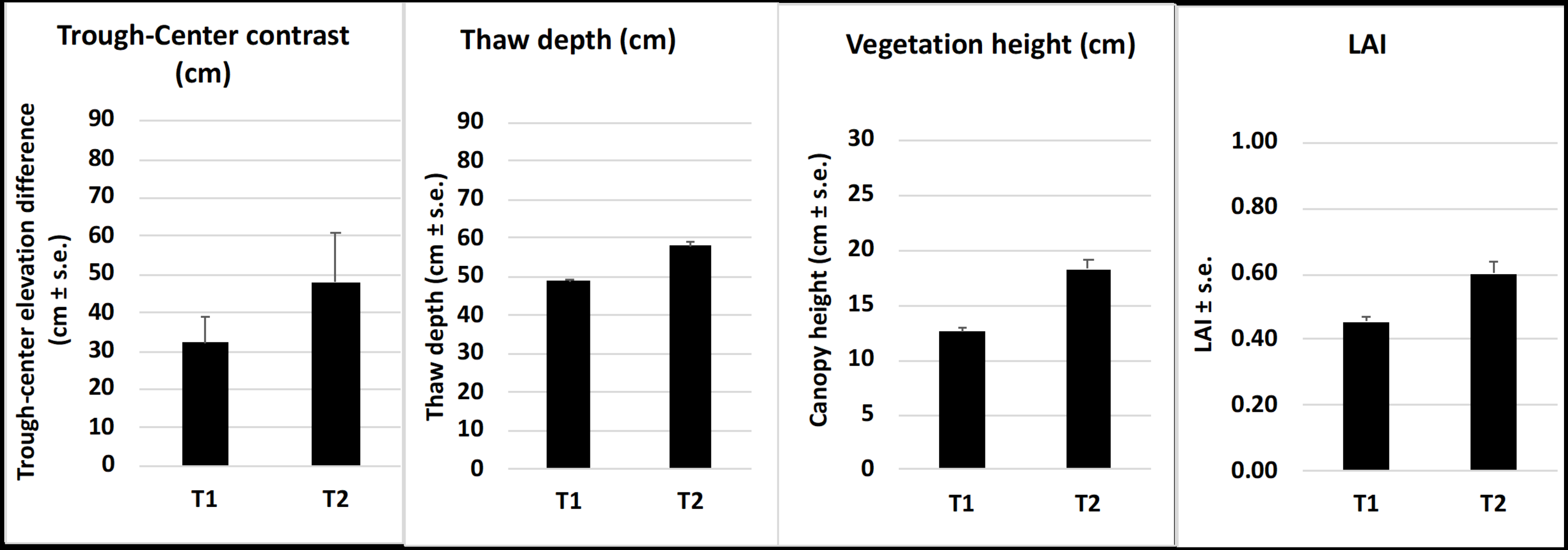
Vegetation (1972 & 2013)



Raynolds et al. 2014. Poster *Arcitic Change 2014*

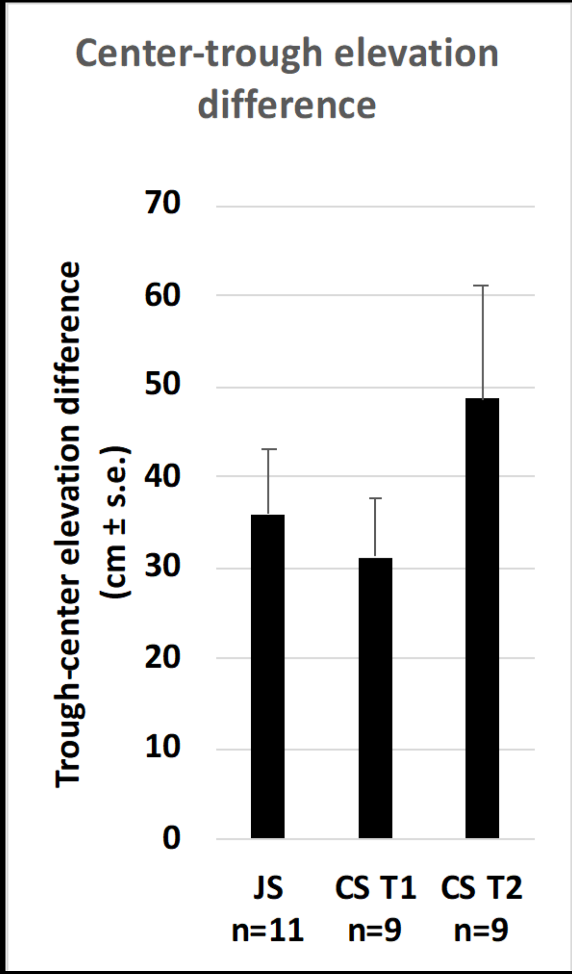
Differences between T1 (dusted) and T2 (flooded)

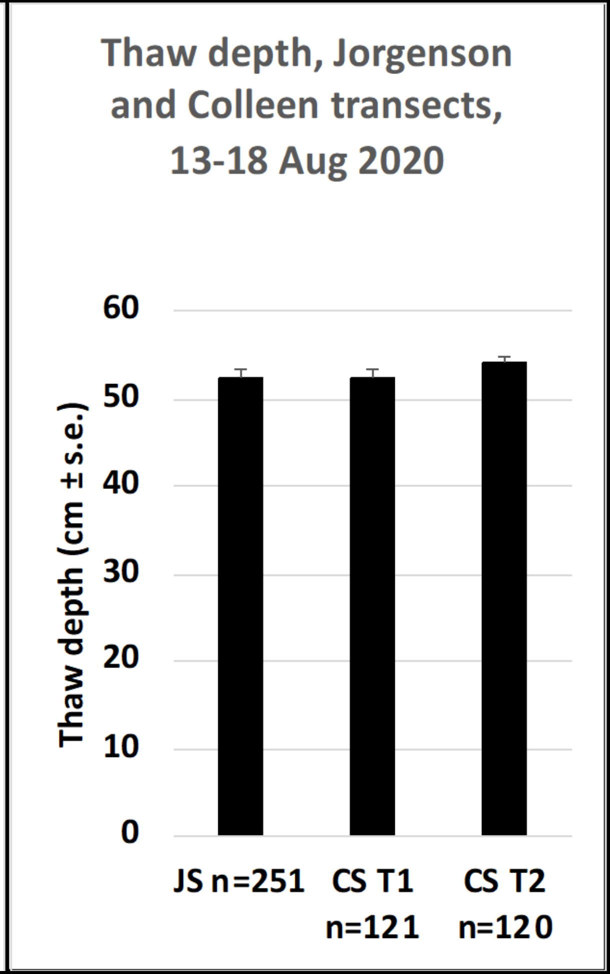
Key environmental and vegetation variables, 2014

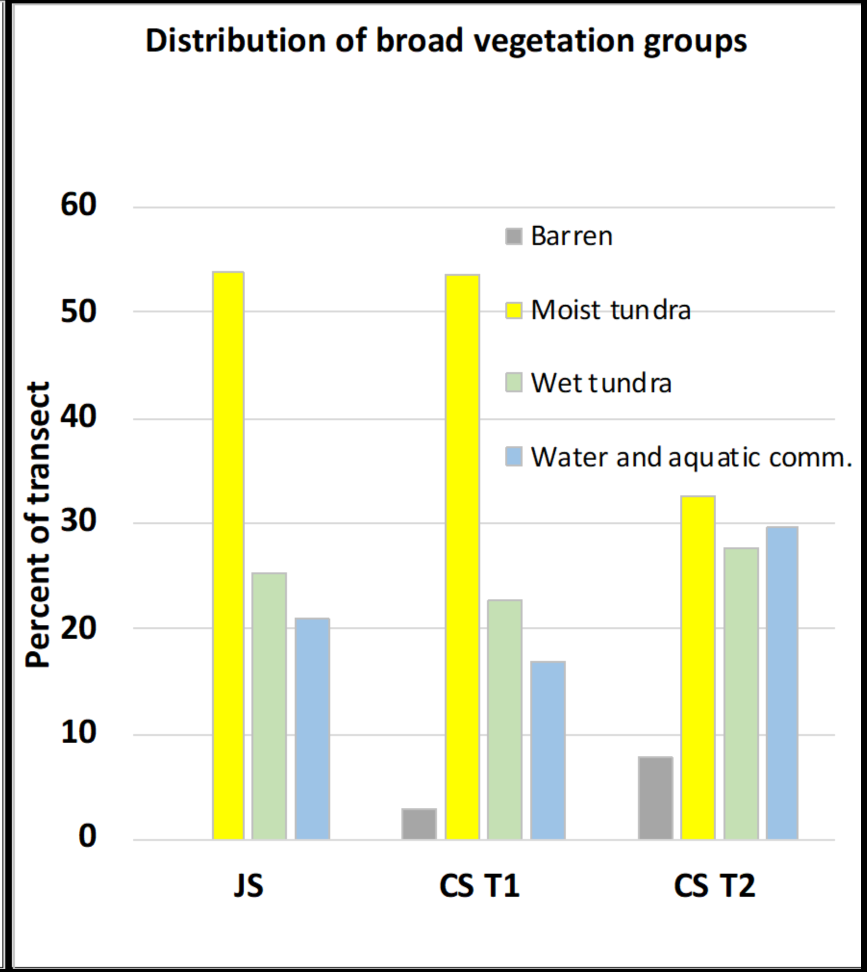


Conclusion: Polygon trough-center relief, thaw depths, and productivity are greater on the flooded side of the road.

Comparison of key site factors Jorgenson (Scenario B) and Colleen transects, 2020 (Scenarios C and D)



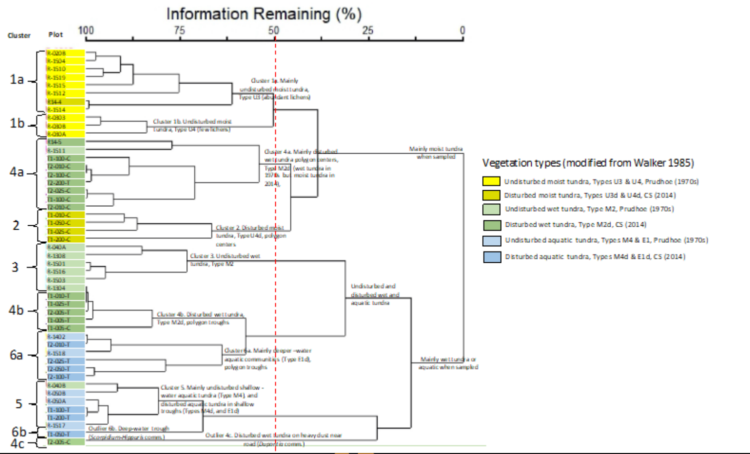




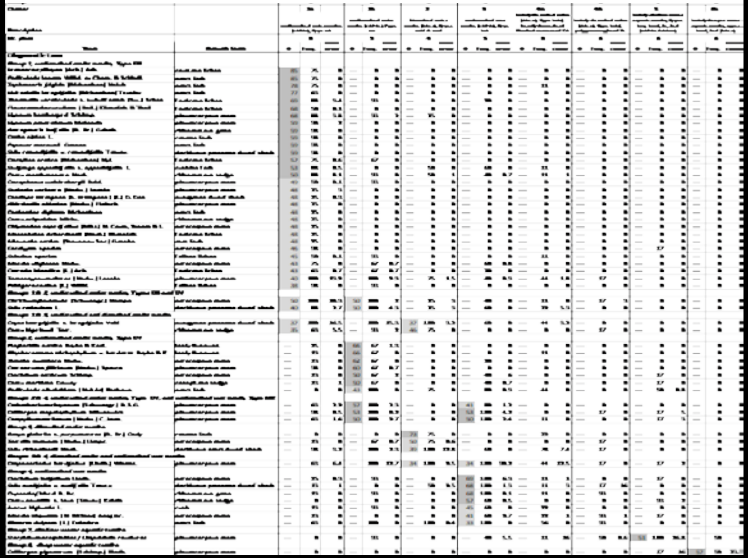
Conclusion: Pond area, polygon morphology , thaw depths, and distribution of broad vegetation types are similar at JS and CS T1, and different at CS T2.

Comparison of disturbed Colleen plots (Walker et al. 2014) with similar undisturbed plots from 1970s (Walker 1985)

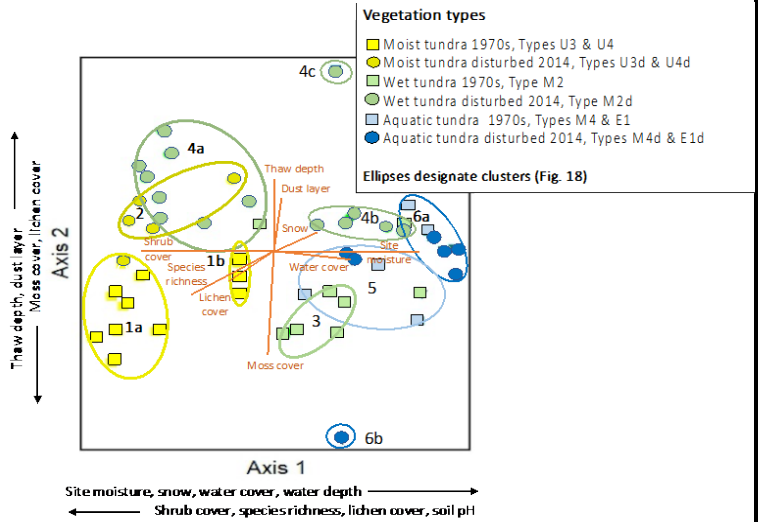
Cluster analysis: Vegetation-unit classification



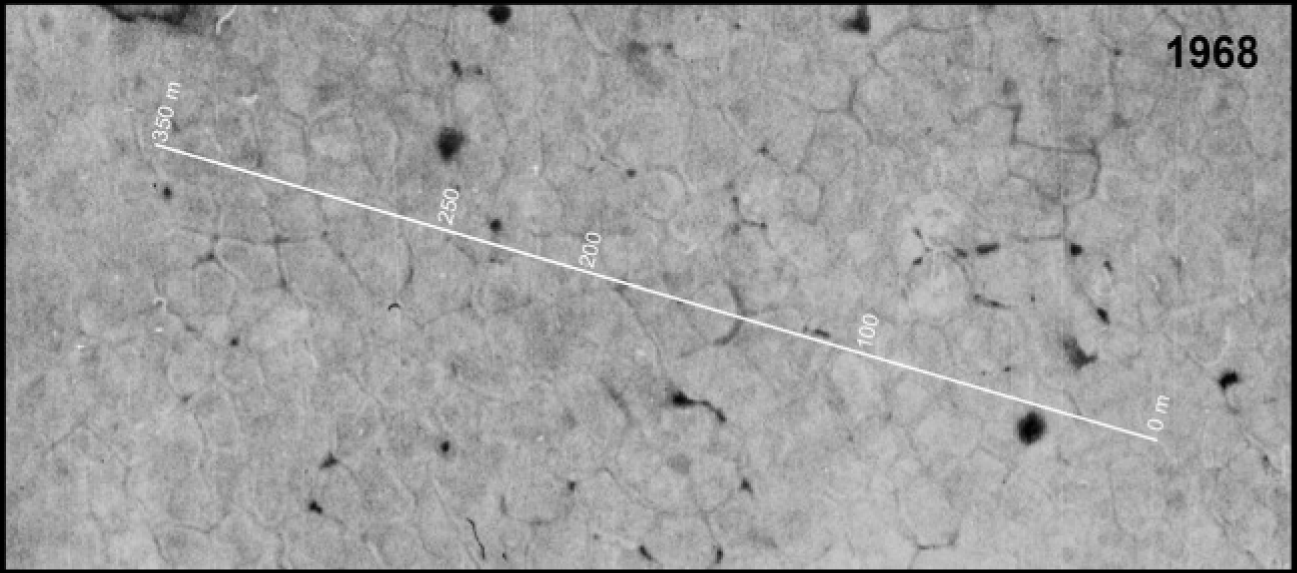
Synoptic table analysis of species distributions in veg units



Ordination: Relationship of vegetation units to environmental gradients



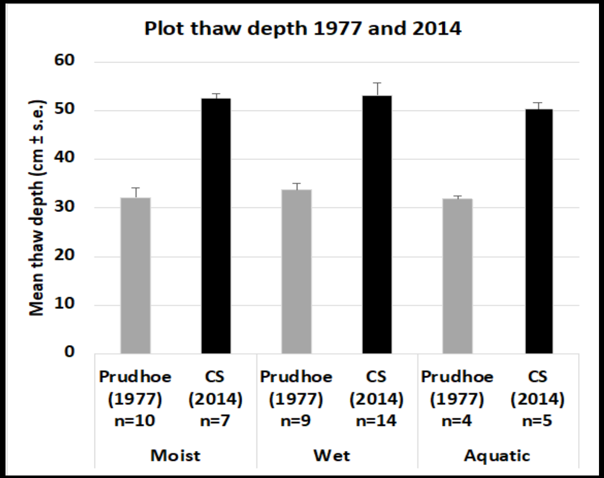
Scenario A: Pre-roads



- Dominantly low-centered polygons, <30 cm trough-center microrelief, dominated by wet nonacidic tundra in polygon basins and troughs.
- 1949-1968: Little change to ice-wedge thermokarst, water-bodies, or landforms… and by inference, to the vegetation.

Scenario B: Climate-change, no road

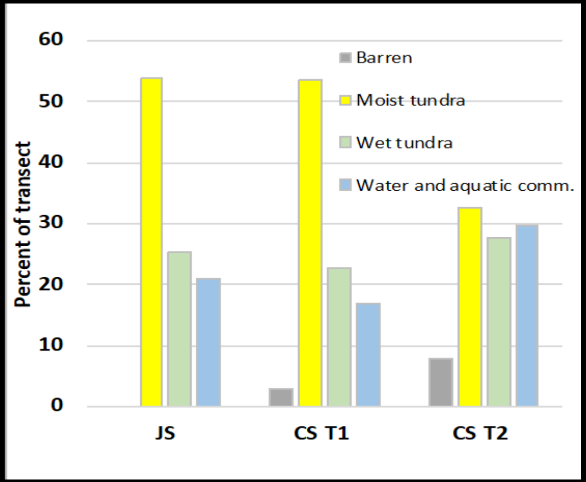
Deeper thaw depths, degrading ice wedges, trough subsidence



More, larger thermokarst ponds, conversion to transitional and high-centered polygons, with > 50 cm microrelief, changes to drainage patterns

More willows

Changes to vegetation patterns

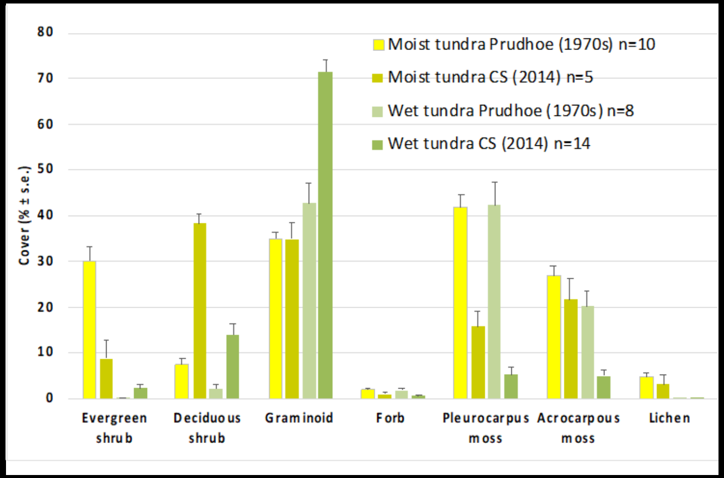


Scenario C: Climate change + dust

Dust layer
added to soils

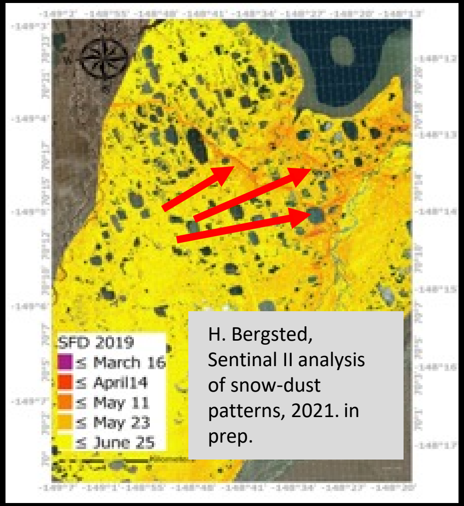
Smothered low-growing vegetation near
roads, reduced polygon microrelief

Large reductions in cover and species
diversity of small forbs, mosses, lichens



Introduction of halophytic species
from dust control chemicals

Dust layers in snowpack near roads, altered snow albedo, early snow
melt, earlier green-up, impacts to waterfowl and wildlife



Scenario D: Climate change + dust + flooding consequences

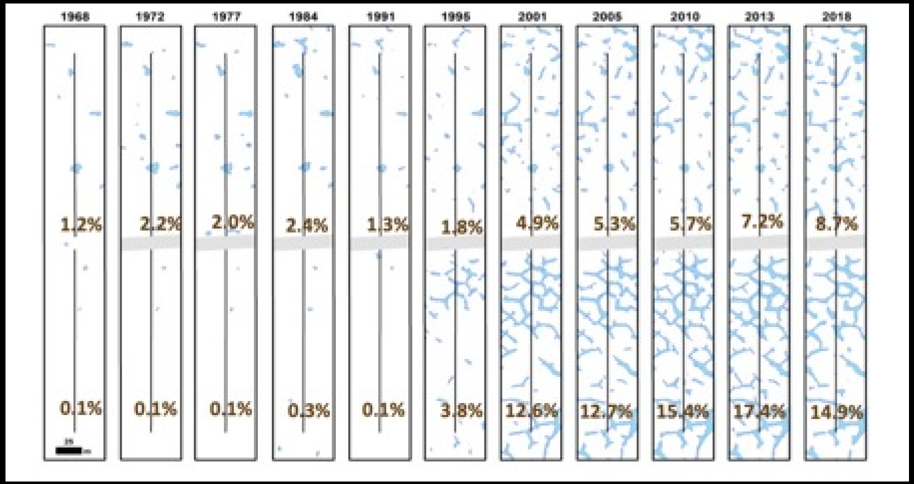
Very large dust impacts near road

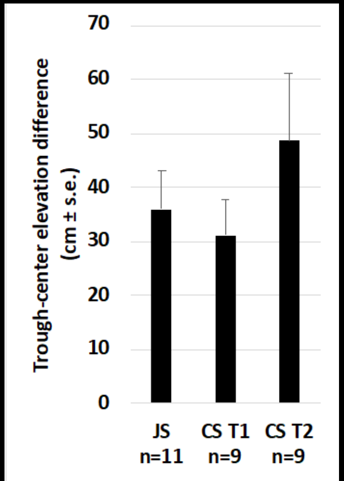
Extensive flooding, deep troughs, conversion of L.C. to H.C. polygons

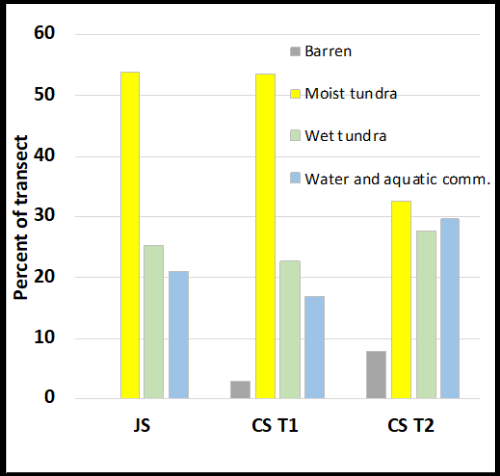
Water bodies interconnected to each other and to Lake Colleen

Lush growth of wet sedge vegetation on polygon centers and aquatic sedges in troughs

Largest cumulative changes to water bodies, polygon morphology, and vegetation patterns







Conclusions

- Scenario approach was useful to examine gradients of cumulative impacts.
- More work is needed to model the complex interactions of climate change and indirect infrastructure-related impacts.
- The results should be helpful for recommendations regarding future cumulative impact assessments of indirect impacts and climate change.

Acknowledgments

- Jerry Brown, Kaye Everett, Pat Webber for foresight to establish 1970s IBP Tundra Biome baseline studies
- Bill Streever, BP Alaska
- IASC Terrestrial WG, RATIC, T-MOSAiC
- NSF NNA
- Previous funding from NSF ArcSEES, NASA PreABoVE and LCLUC, CRREL, BP, Sohio, USFWS, USGS, BOEM
- Everyone in the IRPS project!
- The audience!

2014 Colleen field team