Effects of 45 years of heavy road traffic on permafrost and tundra along the Spine Road at Prudhoe Bay, Alaska

Buchhorn, M.[1,2] (mbuchhorn@alaska.edu); M. Kanevskiy[3]; G. Matyshak[4]; M.K. Raynolds[1]; Y. Shur[3]; L. Wirth[2]; D.A. Walker[1]

[1]University of Alaska Fairbanks, Institute of Arctic Biology, Fairbanks, AK 99775 USA; [2]University of Alaska Fairbanks, Geophysical Institute, Fairbanks, AK 99775 USA
[3]University of Alaska Fairbanks, Department of Civil & Environmental Engineering, Fairbanks, AK 99775 USA; [4]Moscow State University, Department of Soil Science, Moscow, Russia

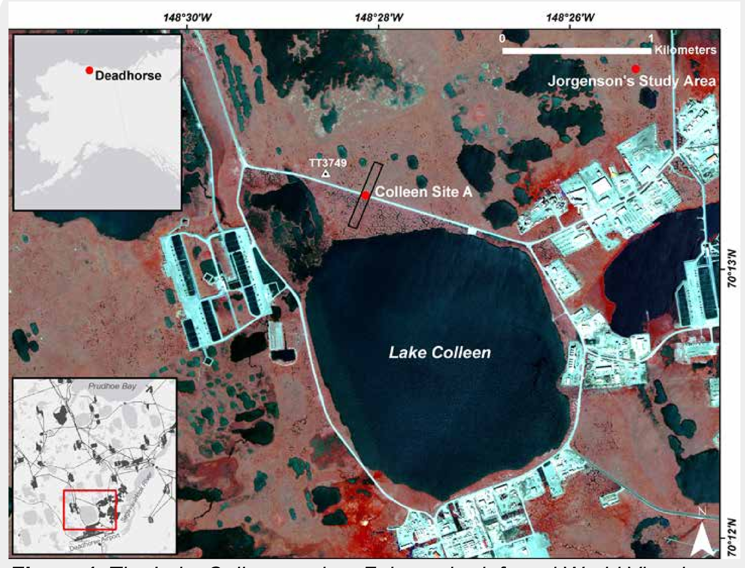


Figure 1. *The Lake Colleen region. False-color-infrared World View image (July 9, 2010). Note: red tones show areas of highly productive vegetation.*

Following the discovery of oil at Prudhoe Bay in 1968, a series of environmental changes occurred that were the result of natural long-term processes and changes caused directly and indirectly by infrastructure. Here we examine the changes associated with a road at Colleen Site A, near Deadhorse, Alaska (**Fig. 1**).

Most changes in landscapes along roads are caused by a combination of (a) **flooding** due to the elevated road beds that interrupt natural drainage flow patterns; (b) heavy **road dust**, which smothers the vegetation and changes the albedo of the tundra surface; and (c) **snow banks** that form along the edges of the elevated roads. All of these factors tend to raise soil temperatures, which in turn increase the active layer thickness near roads, leading to roadside thermokarst (**Fig. 2**).

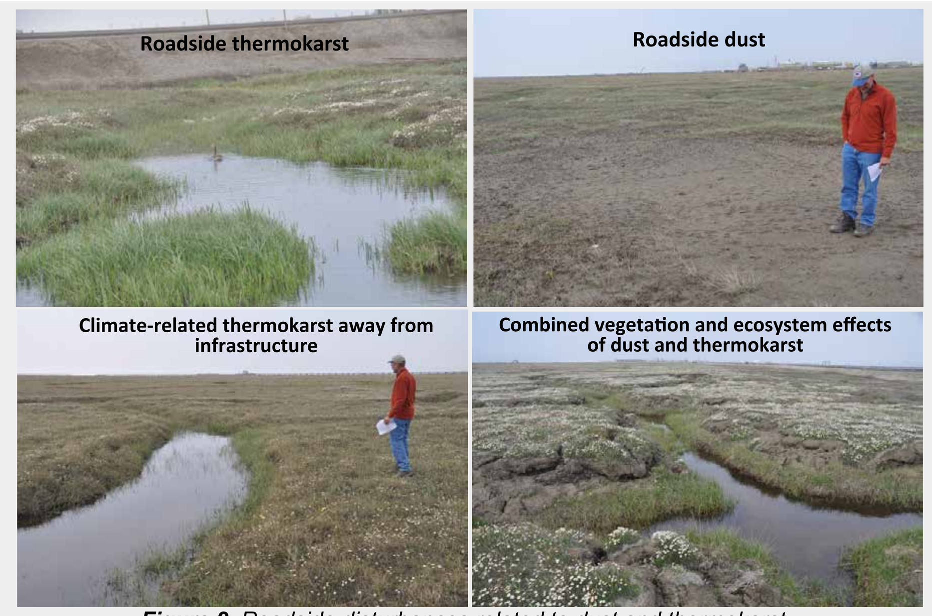


Figure 2. *Roadside disturbances related to dust and thermokarst.*

An abrupt increase in the abundance of thermokarst features has been noted in two studies (Jorgenson *et al.* 2006; Raynolds *et al.* 2014, **Fig. 3**).

The changes in non-infrastructure-related thermokarst are thought to be due to a combination of a long-term upward trend in summer warmth and exceptionally warm summers in 1989, 1998, and 2012 when the active layer (layer of soil that thaws in summer) increased in thickness and melted the tops of ice wedges (**Fig. 4**).

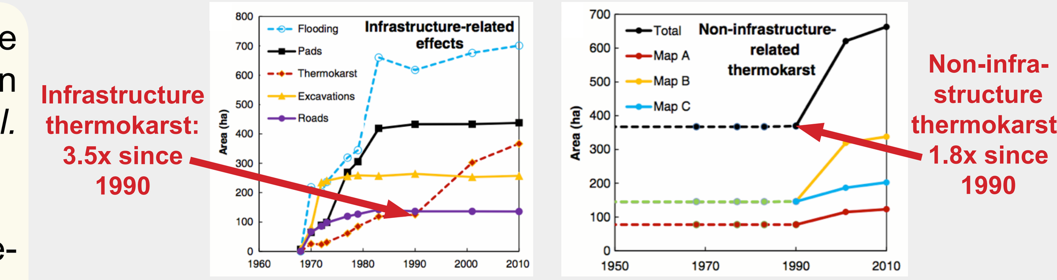


Figure 3. *Trends in thermokast for sample areas within the Prudhoe Bay oilfield 1970-2010.*

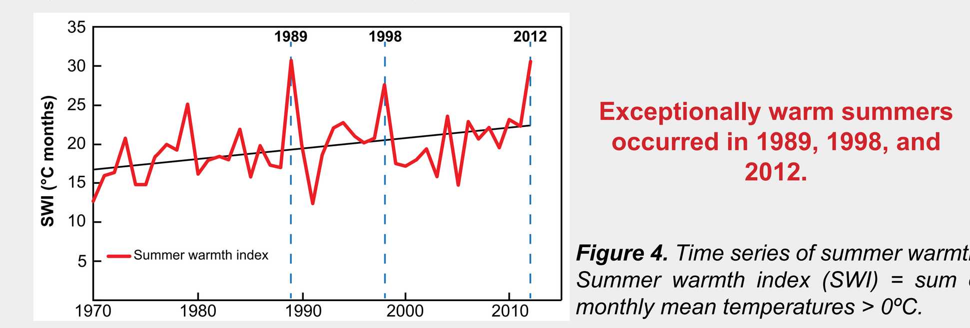
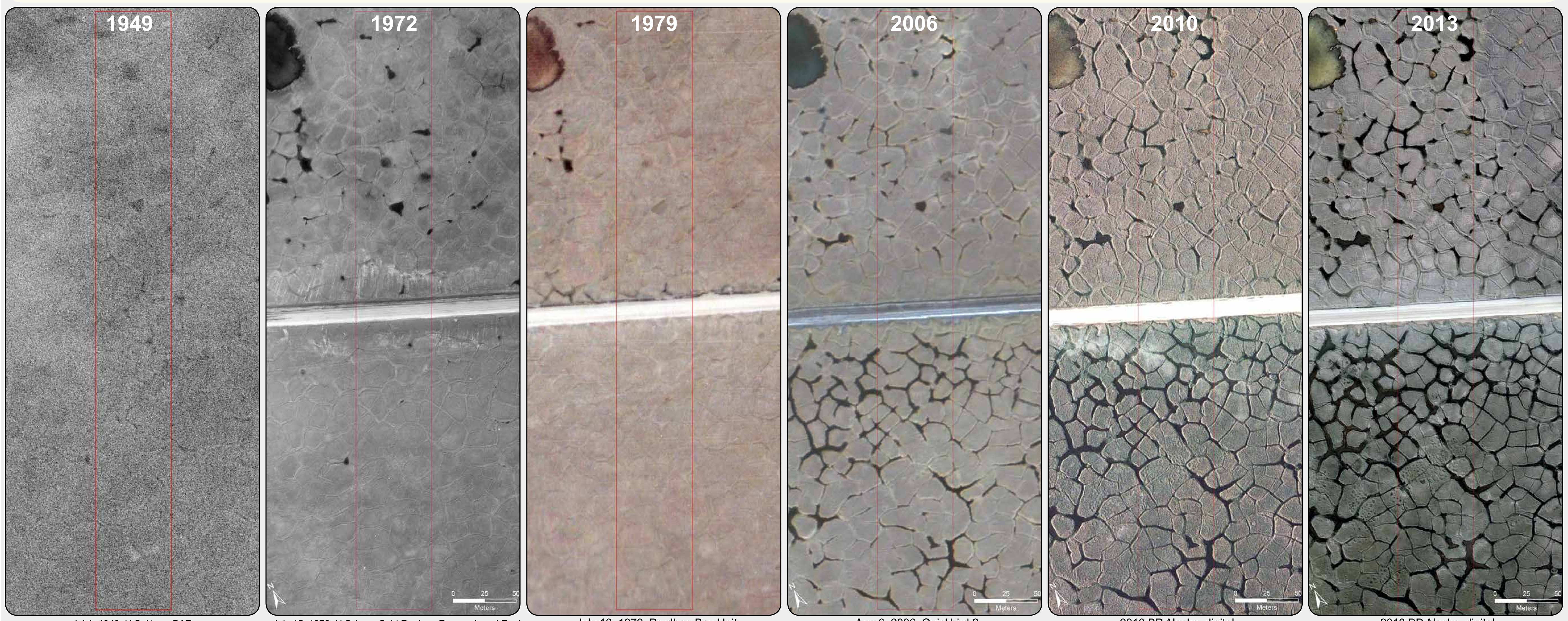


Figure 4. *Time series of summer warmth. Summer warmth index (SWI) = sum of monthly mean temperatures > 0ºC.*

Analysis Part A: Time series of the Lake Colleen Site A from 1949 to 2013

Six aerial photographs of Colleen Site A show the transition of the landscape between 1949 and 2013 (**Fig. 5**). Figure 2 shows ground views of common roadside thermokarst that now occurs along the Spine Road.



Jul 1, 1949, U.S. Navy, BAR, black & white, 1:20,000 | July 15, 1972, U.S Army Cold Regions Research and Engineering Laboratory (CRREL), black & white, 1:6000 | July 13, 1979, Prudhoe Bay Unit, color,1:18,000 | Aug 6, 2006, Quickbird 2, color, 2.4 m resolution (pan sharpend) | 2010 BP Alaska, digital, color, 1-foot resolution | 2013 BP Alaska, digital, color, 0.75-foot resolution

Figure 5. *Colleen Site A study area (as in Figure 1) time series 1949-2013, showing progression of change. Notes: The Spine Road was constructed in 1969 so does not appear on the 1949 image. Thin cloud cover obscures the small lake in the upper left in 1949, but most of the thermokarst pits that are present in 1972 are also visible on the 1949 image. Greatly expanded thermokarst is seen in 2006. The oil industry obtained aerial photographys of the road network nearly every year and we are now obtaining images to show the transition from the situation in 1979 to that in 2006.*

Summary of findings from the time series of aerial photos:

- Prior to construction of the Spine Road in 1969, the Colleen site A study area had numerous scattered thermokarst pits indicating that the area had some thawing ice wedges at the intersections of polygon troughs. The pattern of thermokarst changed very little between 1949 and 1972.
- The Spine Road was constructed in 1969, altering drainage patterns and introduced gravel and large quantities of dust to the tundra adjacent to the road, such that over the past 45 years the pattern of thermokarst has changed dramatically.
- Thermokarst is now deepest and most extensive on the southwest side of the road, which is periodically flooded. Historical climate data and photos indicate that between 1989 and 2012 a regional thawing of the ice-wedges occurred, increasing the extent of thermokarst on the both sides of the road.

Analysis Part B: Transects

Differences in the flooding regimes on the northeast and southwest sides of the road cause major differences in the extent of thermokarst, microtopography, types of the vegetation (**Fig. 6**).

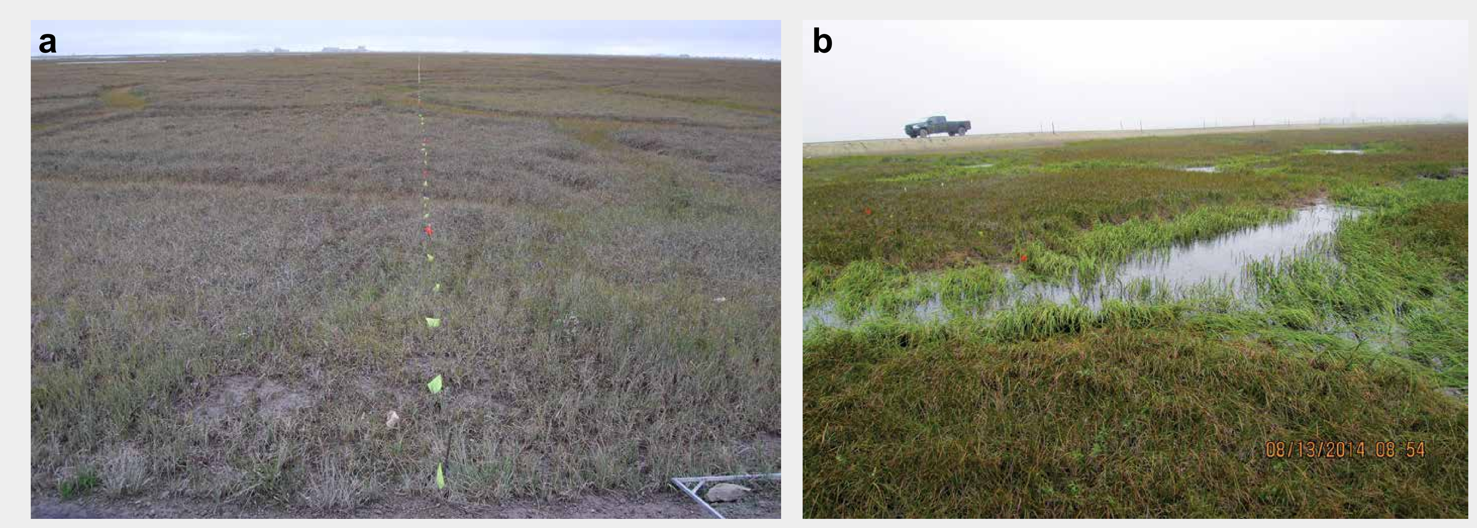


Figure 6. *(**a**) Transect T1 looking NE from the Spine Road. Note the low-centered polygons with the distinct rims and less than 0.5 m of trough-center relief. (**b**) Degraded ice-wedge polygon troughs along Transect T2 on the SW side of the road. Note the lack of rims on the ice-wedge polygon centers, greater than 0.5 m of trough-center relief, and lush sedge vegetation in the troughs and on the polygon centers.*

In 2014, two 200-m transects perpendicular to the Prudhoe Bay Spine Road were established. We measured the following along the transects at 1 m intervals within 100 m of the road and at 5 m intervals from 100 to 200 m from the road: surface elevation and water depth, vegetation type and surface geomorphology, depth of thaw (thaw probe), thickness of surface dust layer, height of vegetation, and leaf area index (**Fig. 7**).
We also did vegetation and soil surveys at permanent plots in centers and troughs on both sides of the road, and examined ice-content in boreholes (Raynolds *et al.*, 2014, and Kanevskiy *et al.*, 2014; poster this conference).

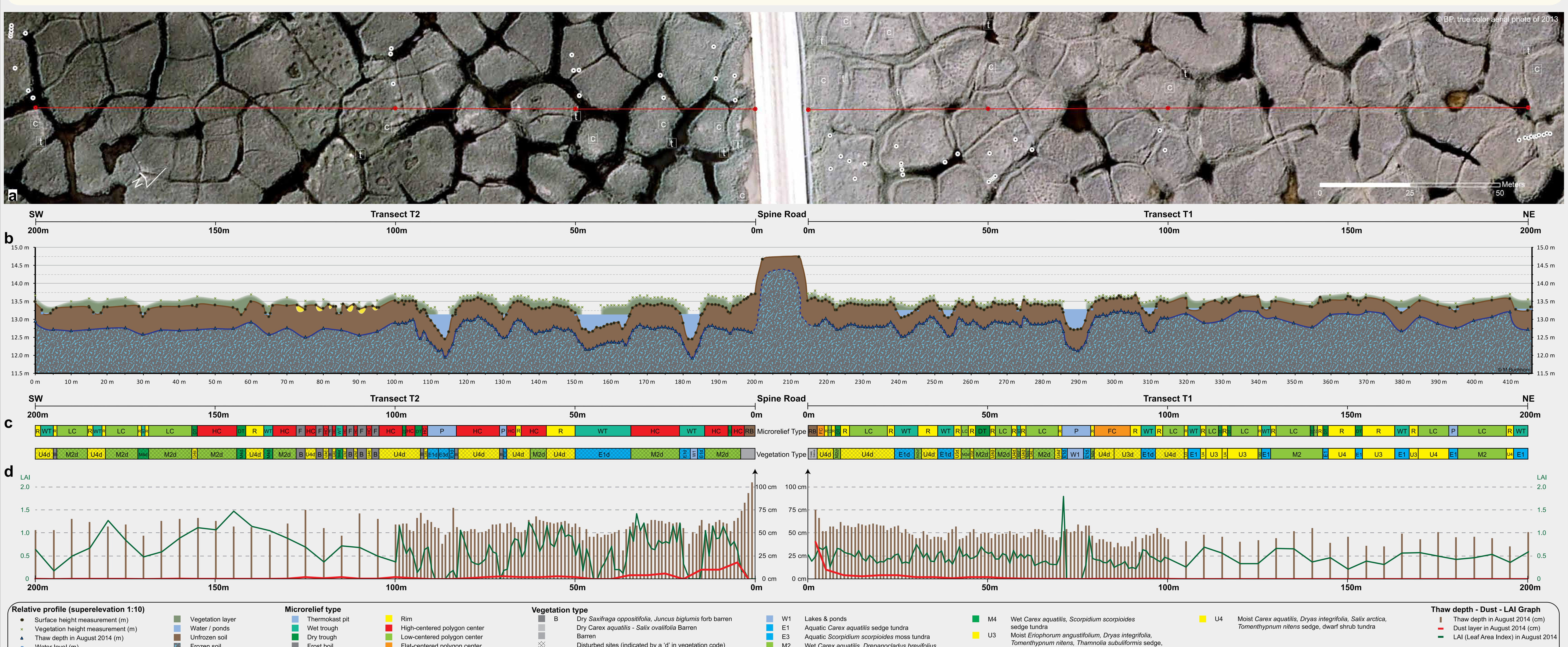


Figure 7. *(**a**) Overview of the transects T1 and T2. Note: red line mark the location of the transects NE and SW from the Spine Road. Position of center and trough permanent vegetation plots are marked as squares, and boreholes as white dots. (**b**) relative profiles of the transects T1 and T2. Note the vertical exaggeration 1:10. (**c**) Microrelief and vegetation along the transects. (**d**) Graph showing the thaw depths, dust depths, and LAI measurements along the transects.*

Summary of findings from the transects:

- Transect T2 shows a nearly double trough to center of polygon contrast (**Fig. 8a**)
- Increased thaw depths at the south side of the road (T2) for all vegetation communities (**Fig. 8b**)
- Heigher average vegetation heights in overall and for all plant communities at the south side of the road (transect T2) (**Fig. 8c**)
- Transect T2 shows higher productivity compared to transect T1 expresed by higher LAI (**Fig. 8d**)

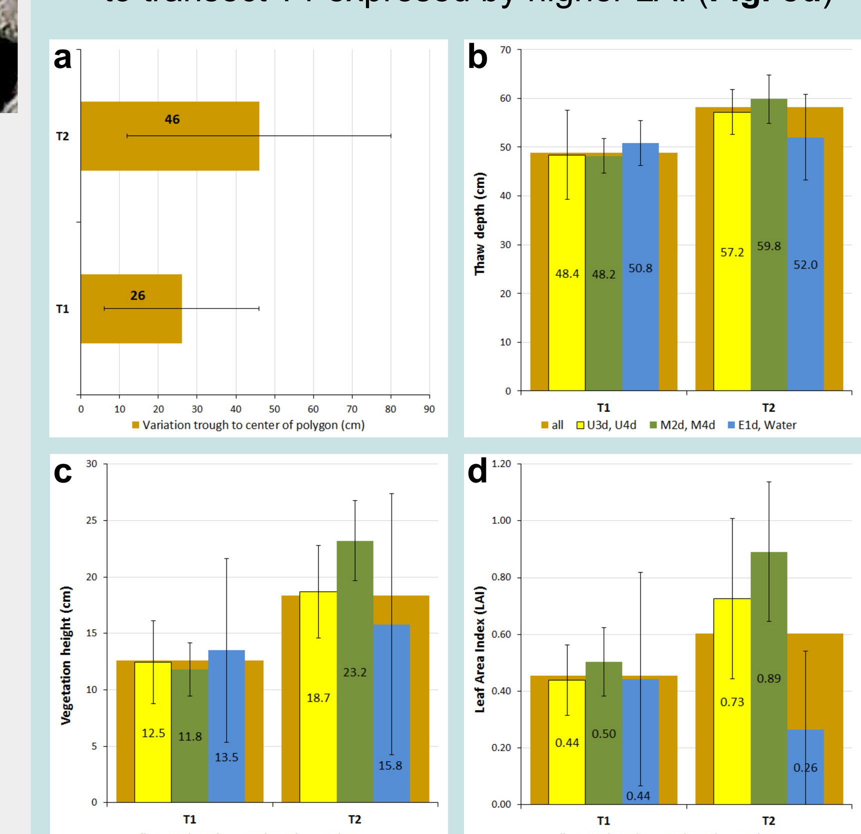


Figure 8. *Differences in (**a**) trough-polygon center contrast, (**b**) thaw depth, (**c**) vegetation height, and (**d**) Leaf Area Index (LAI) between the transects T1 and T2.*

CONCLUSIONS

I
Information from the Colleen Site A studies, combined with the rich record of historical aerial photographs provide an excellent basis for examining the changes to this region.

II
Prior to construction of the Spine Road in 1969, the Colleen site A study area had numerous scattered thermokarst pits indicating that the area had some thawing ice wedges at the intersections of polygon troughs. The pattern of thermokarst changed very little between 1949 and 1972.

III
The Spine Road was constructed in 1969, altering drainage patterns and introduced gravel and large quantities of dust to the tundra adjacent to the road. Thermokarst is now deepest and most extensive on the southwest side of the road, which is periodically flooded.

IV
Historical climate data and photos indicate that between 1989 and 2012 a regional thawing of the ice-wedges occurred, increasing the extent of thermokarst on both sides of the road. Aerial photos between 1979 and 2010 are needed to better examine the variation in thermokarst with the respect to the climate record.

V
The regional warming, flooding, road dust, and snow drifts have all contributed to creating warmer soil temperatures, and deeper active layers near the road. These factors have all contributed in different ways to alteration of the plant canopy. The altered plant canopies in turn further alter the surface albedo and the ground temperatures.

VI
The implications of these changes to total ecosystem function need to be thoroughly investigated.

References

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