Remotely sensing post-fire land surface changes in the Arctic using repeat airborne LiDAR and Landsat trend analysis

Benjamin Jones[1], Ingmar Nitze[2], Guido Grosse[2], Daniel Mann[3], Benjamin Gaglioti[4], Daniel Hayes[5], Eric Miller[6]

[1] U.S. Geological Survey Alaska Science Center
[2] Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
[3] University of Alaska Fairbanks Department of Geosciences
[4] Columbia University Lamont-Doherty Earth Observatory
[5] University of Maine School of Forest Resources
[6] Bureau of Land Management Alaska Fire Service

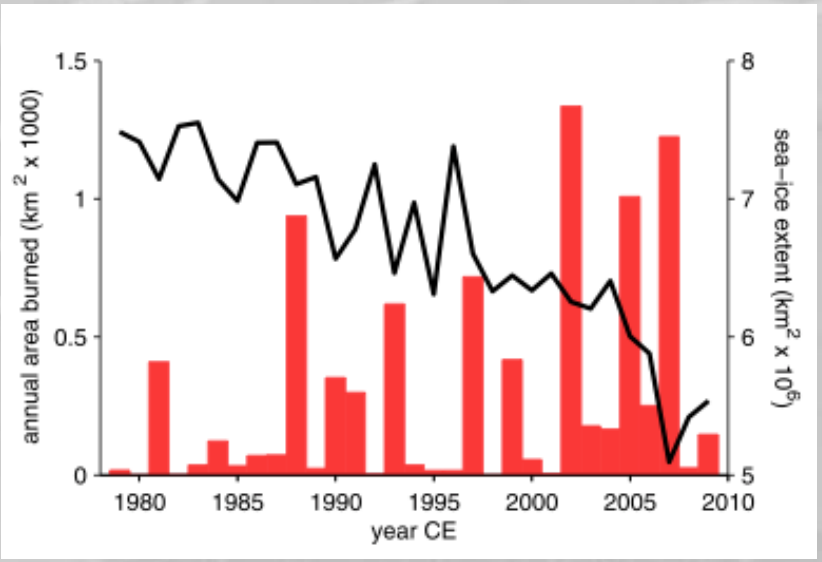
U.S. Department of the Interior
U.S. Geological Survey

Tundra fire disturbances in the Arctic

Large tundra fires (>50 km^2) between 1950 and 2014 (Alaska and Canada) and 2004 to 2014 (Siberia)

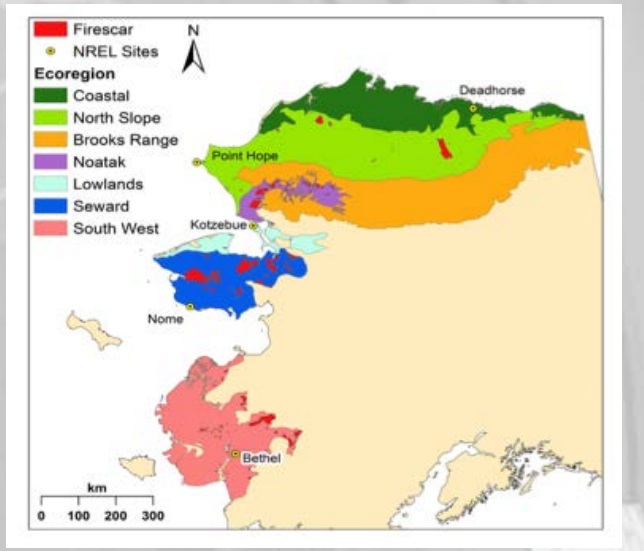
Tundra fire disturbances in Alaska

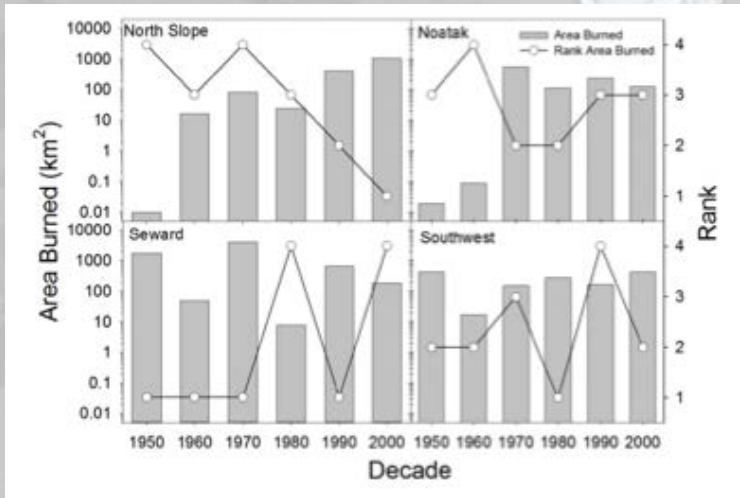
Increase in Tundra Fires Linked to Sea Ice Decline



Hu et al (2010): *JGR Biogeosciences*

Increase in Tundra Burned in northern Alaska





Rocha et al (2012): *ERL*

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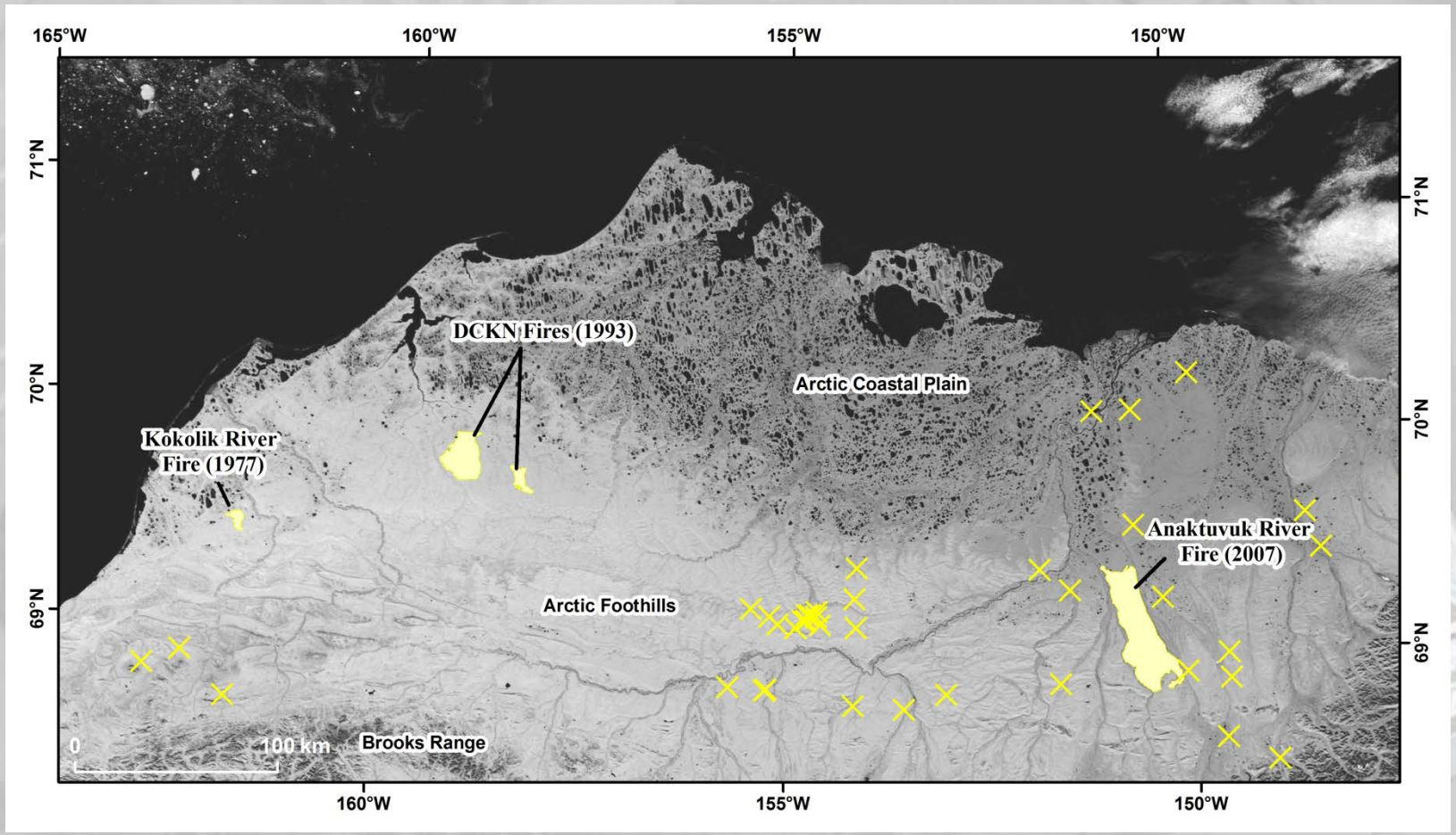
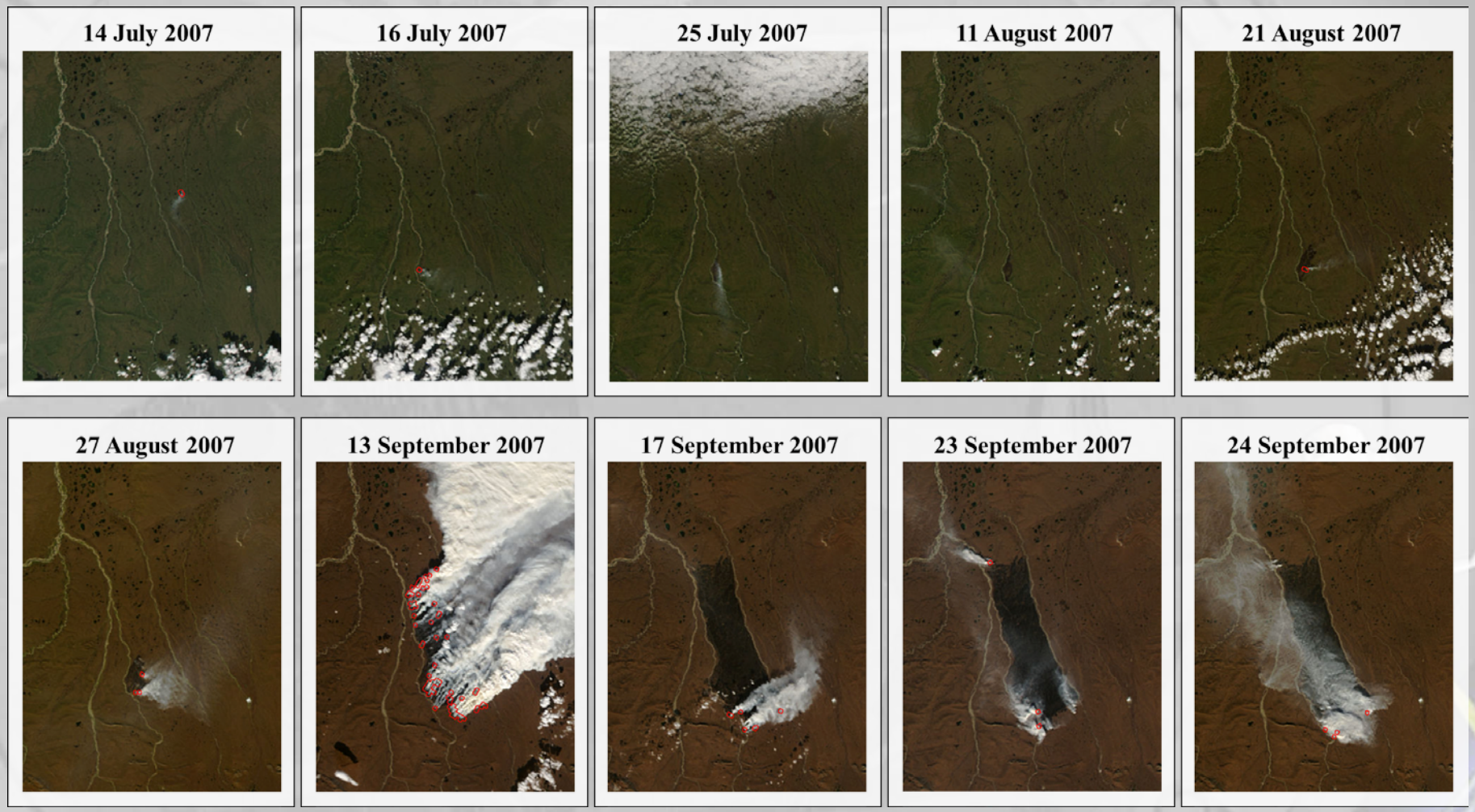
Fire History for the North Slope, 1950 to 2014



2007 Anaktuvuk River fire doubled the mapped burned tundra area between 1950 and 2014

2007 Anaktuvuk River Tundra Fire Progression



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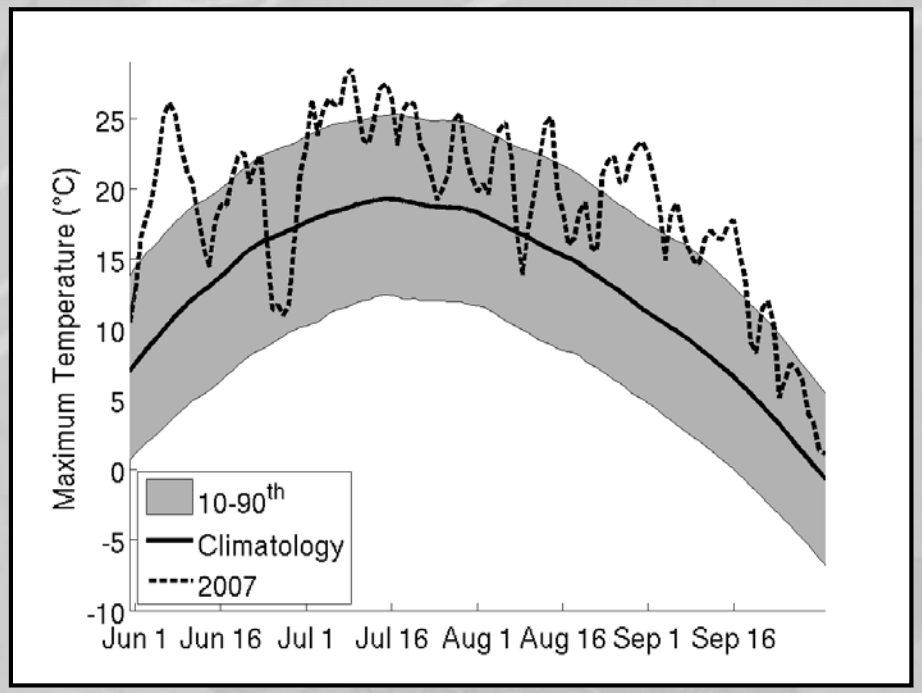
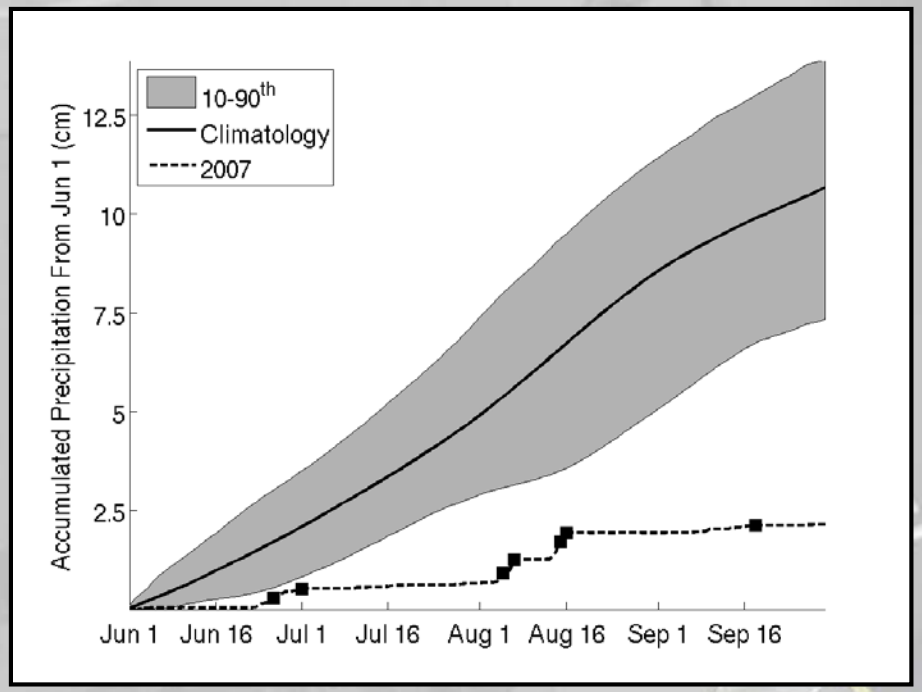
2007 Weather Conditions Relative to Climatology

Above Average Air Temperatures



Below Average Summer Precipitation



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Tundra Fires as a Source of C to the Atmosphere

LETTER

doi:10.1038/nature10283

Carbon loss from an unprecedented Arctic tundra wildfire

Michelle C. Mack[1], M. Syndonia Bret-Harte[2], Teresa N. Hollingsworth[3], Randi R. Jandt[4], Edward A. G. Schuur[1], Gaius R. Shaver[5] & David L. Verbyla[6]

The 2007 Anaktuvuk River Fire potentially released an amount of C equivalent to the annual net C sink in the entire tundra biome

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Impact of Tundra Fires on Land Surface Changes?

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

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The response of Arctic vegetation and soils following an unusually severe tundra fire

M. Syndonia Bret-Harte[1], Michelle C. Mack[2], Gaius R. Shaver[3], Diane C. Huebner[1], Miriam Johnston[3], Camilo A. Mojica[2], Camila Pizano[2] and Julia A. Reiskind[2]

"Although it is likely that, in the next century, climate warming will interact with fire to enhance permafrost degradation and vegetation change, the Anaktuvuk River fire does not seem to have pushed its landscape over a tipping point into a new regime [9]. Over much of the area of the Anaktuvuk River fire scar, it is likely that the vegetation will be similar to what was there before the fire."

PERMAFROST DATABASE DEVELOPMENT, CHARACTERIZATION, AND MAPPING FOR NORTHERN ALASKA

Final Report

Prepared for:

U.S. Fish and Wildlife Service
Arctic Landscape Conservation Cooperative
1011 E. Tudor Rd., MS-281
Anchorage, AK 99503

Prepared by:

M. Torre Jorgenson

"On hillsopes burned by the Anaktuvuk River fire, detachment slides were particularly abundant presumably because the subsequent abrupt increase in thaw depths penetrated extremely-ice rich intermediate layer at the top of the permafrost, but most of ice wedges in well-drained areas were only slightly affected by thermokarst."

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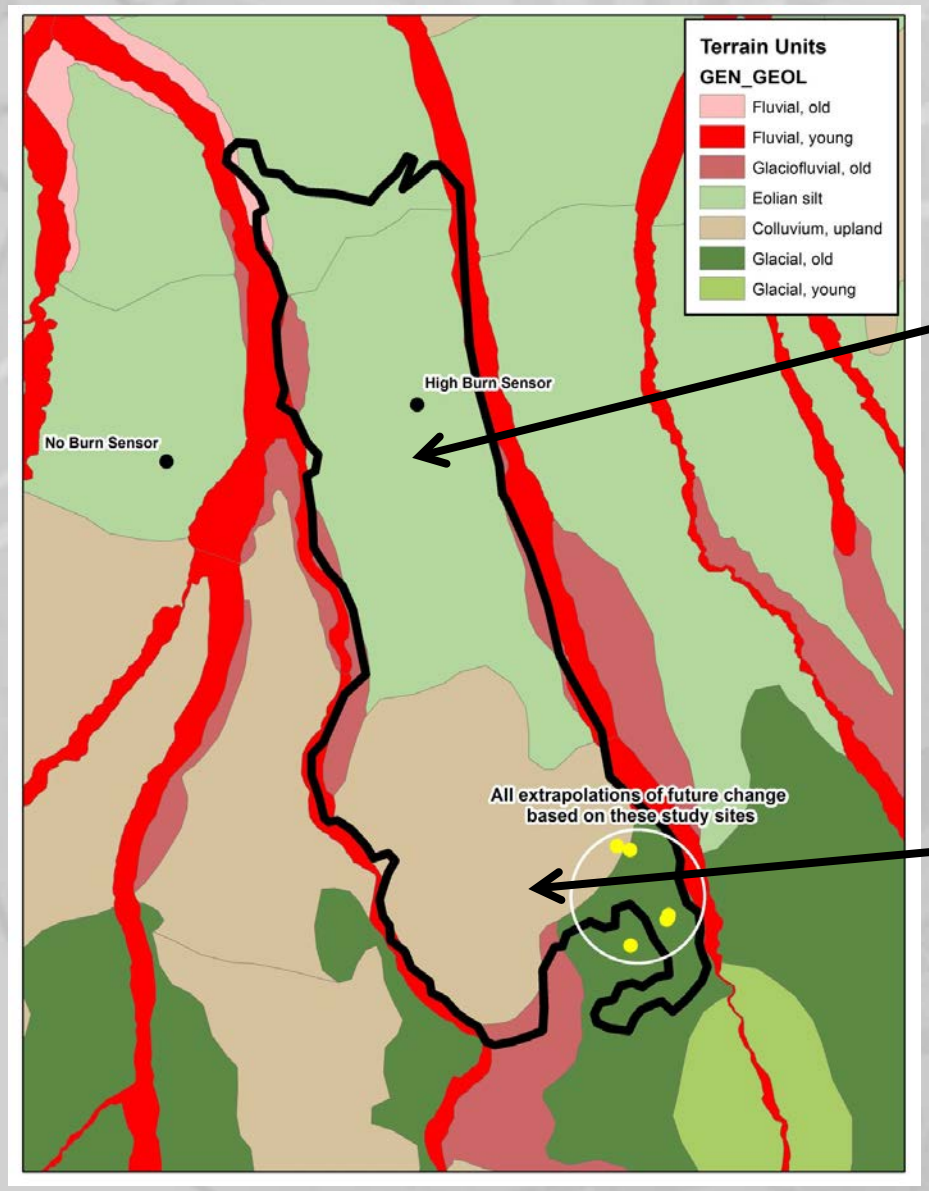
Variation in Permafrost Characteristics in the Burn Area



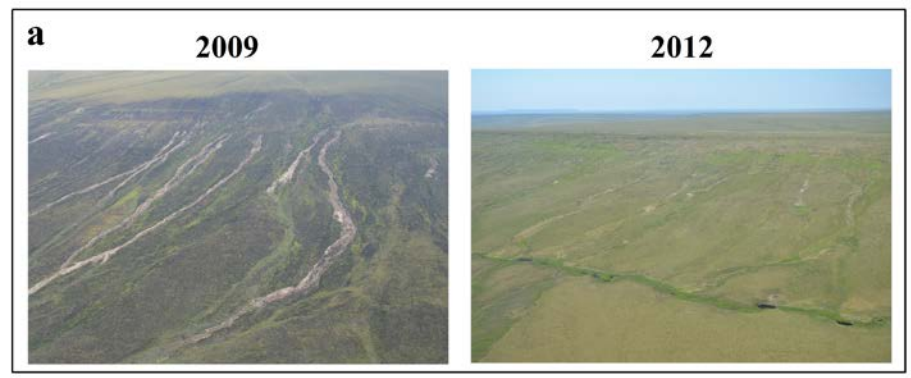
Representative photo of what underlies northern 2/3 of the burn area

Representative photo of what underlies southern 1/3 of burn area

Landscape level impacts of the Anaktuvuk River Fire will be greater in the northern 2/3 of the burn area where ice-rich permafrost is found.

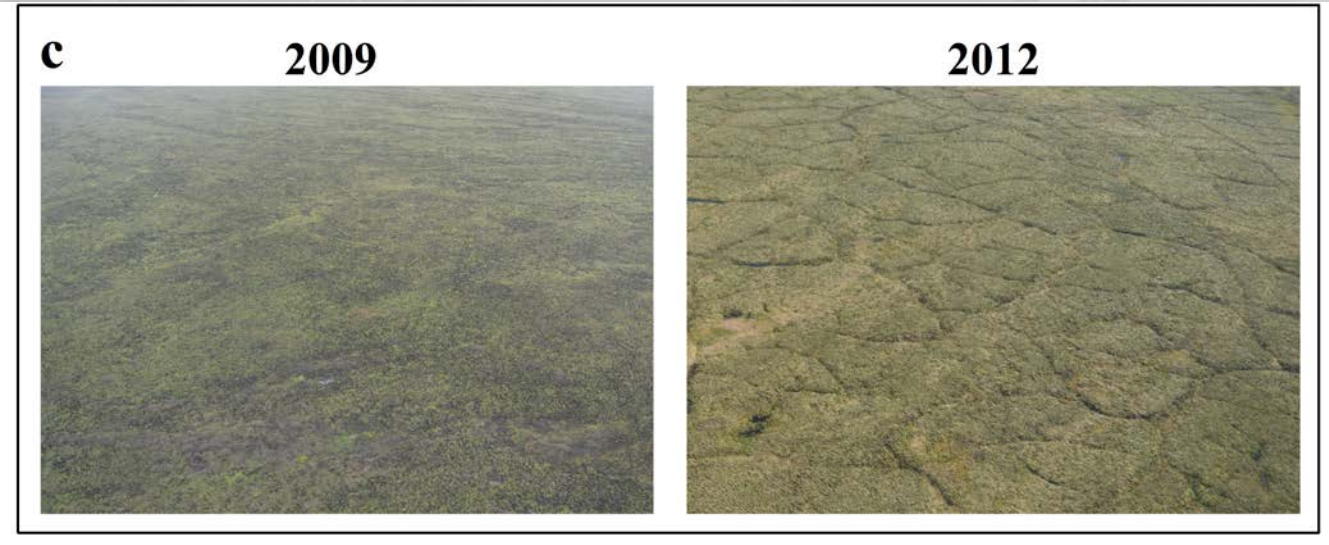
Initial Signs of Permafrost Degradation

Active Layer Detachment Slides

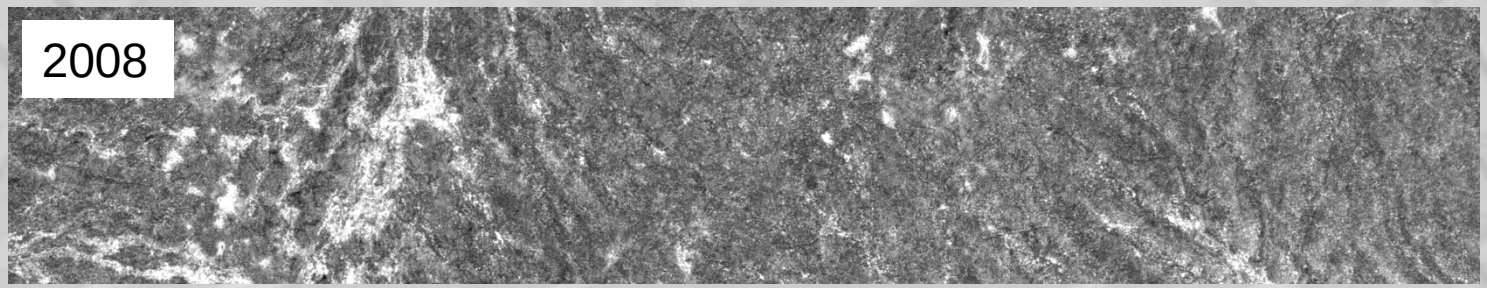


Retrogressive Thaw Slumps

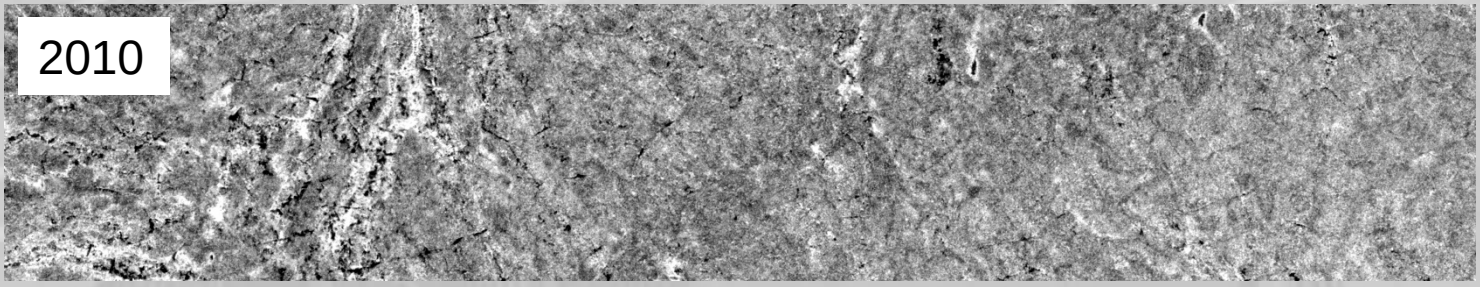
Ice Wedge Degradation



Evidence for Ice Wedge Degradation Post-Fire



No sign of ice wedge degradation

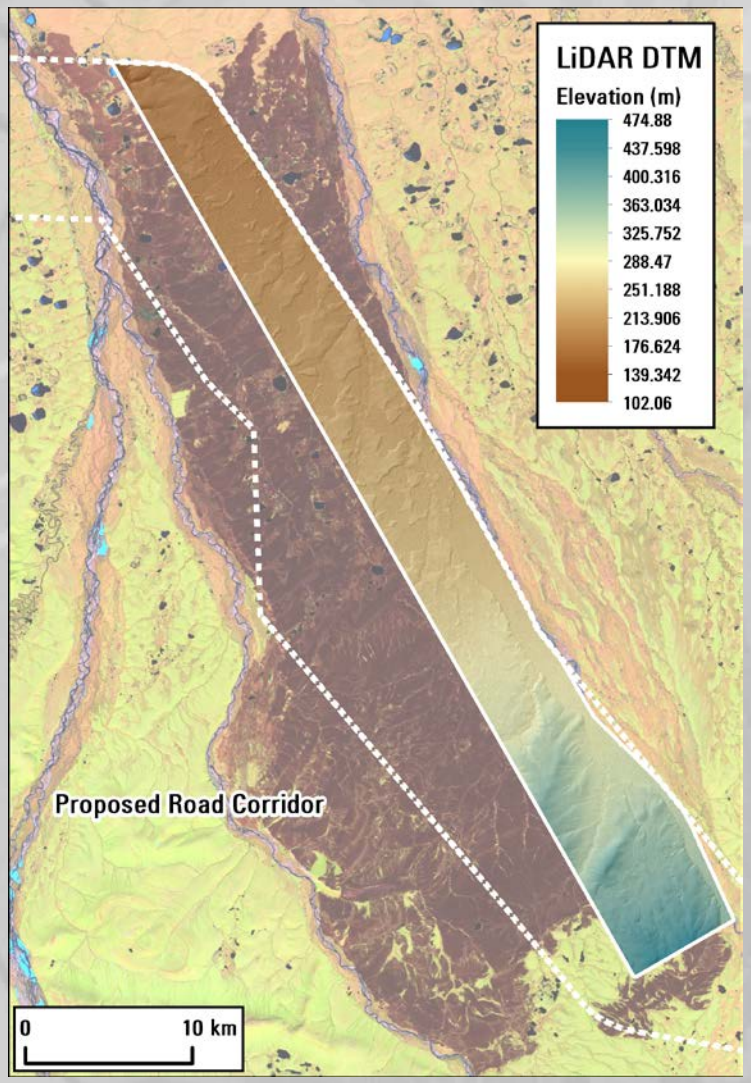


A hint of degrading ice wedges and pit formation

Ice wedge degradation becoming more evident

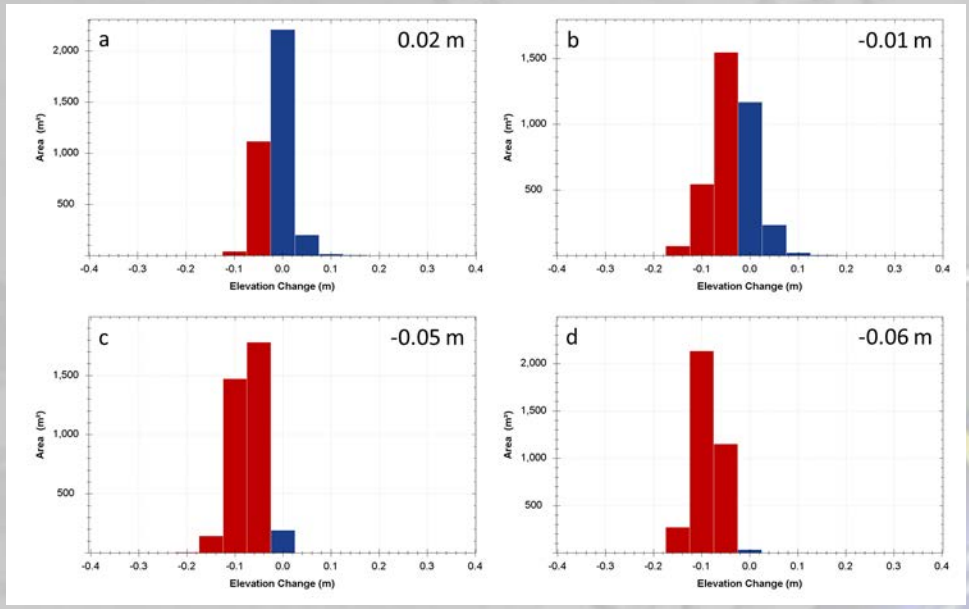
Ice wedge degradation ubiquitous by 2014; image gap between 2011 and 2014

Repeat Airborne LiDAR Dataset



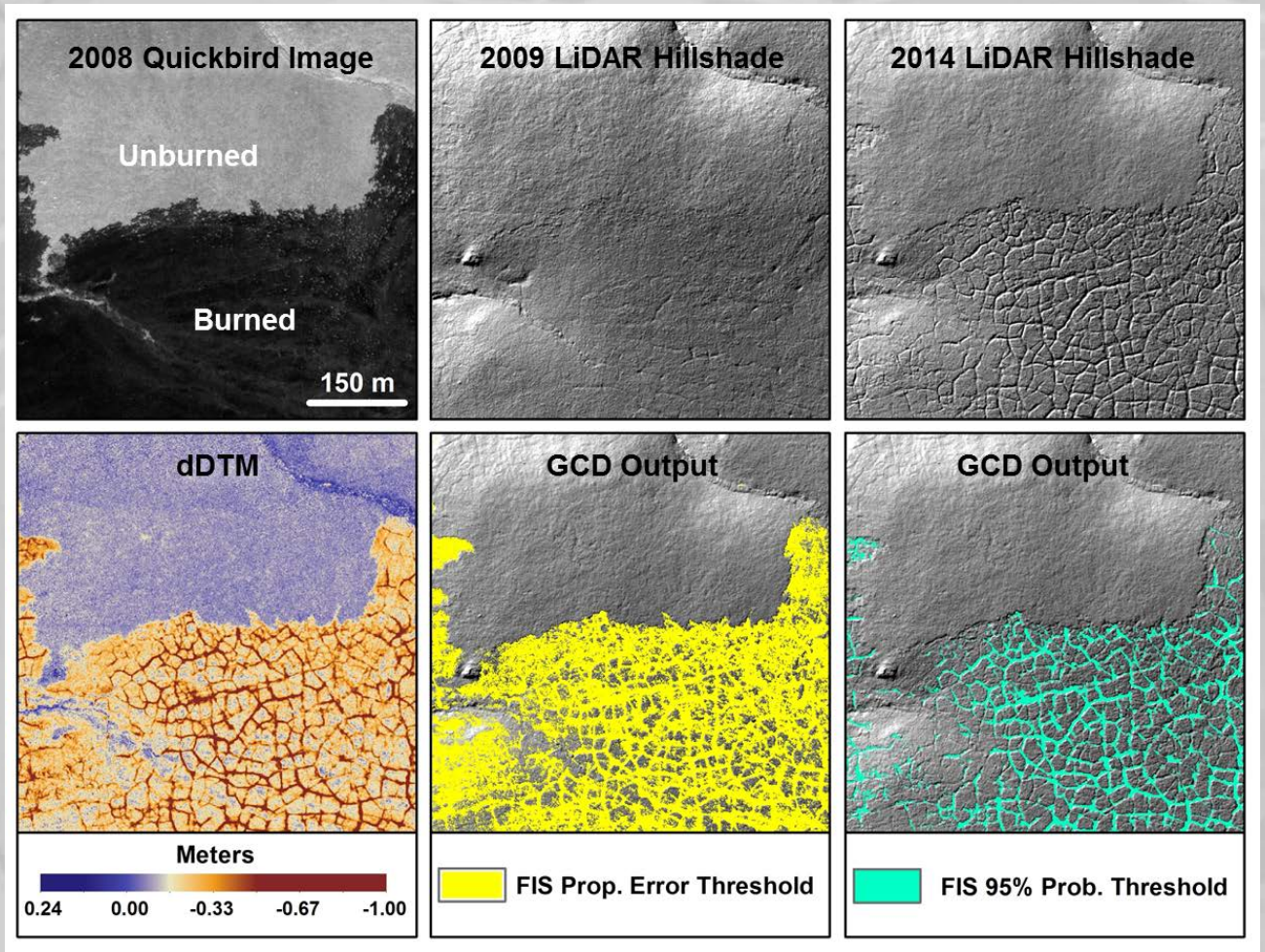
The Anaktuvuk River tundra fire burn area and the extent (350 km^2) of overlapping airborne LiDAR datasets that were acquired in 2009 (2 yrs post-fire) and 2014 (7 yrs post-fire).

Comparison of 2009 and 2014 datasets in unburned tundra



Quantifying Vertical Changes Post-Fire

Change was mapped with the Geomorphic Change Detection software in ArcGIS [Wheaton et al., 2010; GCD v. 6] using a propagation of errors threshold as well as a 95% probability threshold.



Inputs to GCD:

- Vertical RMSE of the two datasets
- Points Per Square Meter
- Slope

Outputs from GCD:

- Fuzzy Inference System assessment of per pixel uncertainty for thresholding vertical changes between the two LiDAR DTMs

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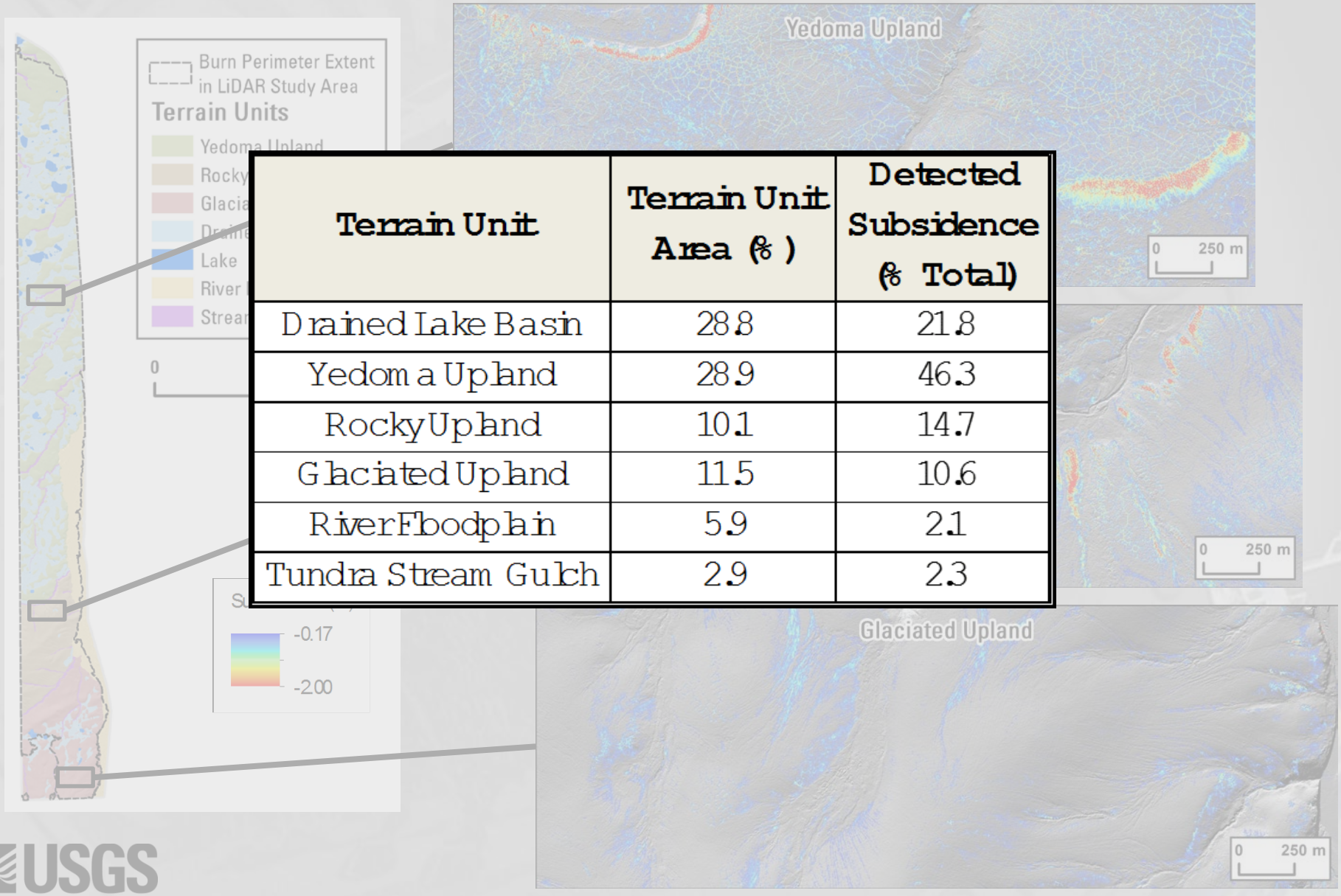
Spatial Variability in Thermokarst Post-Fire



Terrain Unit	Terrain Unit Area (%)	Detected Subsidence (% Total)
Drained Lake Basin	28.8	21.8
Yedoma Upland	28.9	46.3
Rocky Upland	10.1	14.7
Glaciated Upland	11.5	10.6
River Floodplain	5.9	2.1
Tundra Stream Gulch	2.9	2.3

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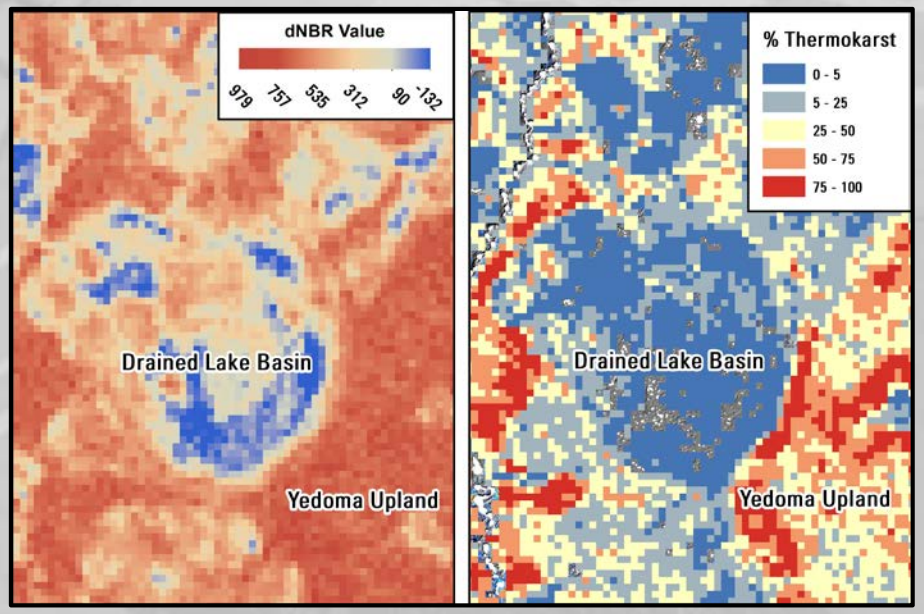
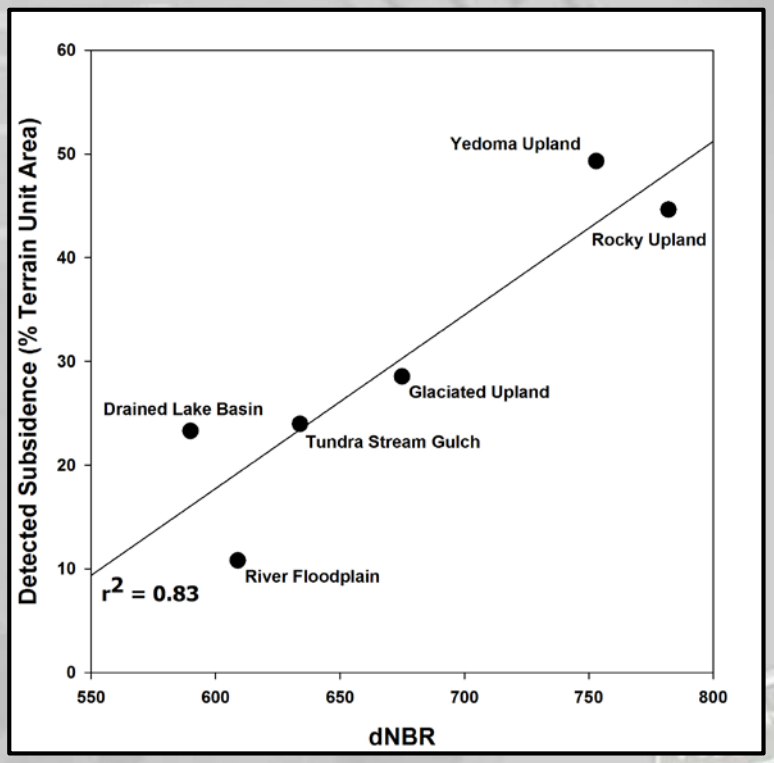
August 2016 “Fly By” over the AR Fire Burn

Burn Severity, Terrain Units, and Thermokarst

Burn Severity % Thermokarst



Comparison between Landsat-derived burn severity (left) [Kolden and Rogan, 2013] with the % thermokarst affected area mapped in the repeat airborne LiDAR and scaled up using a 30 m resolution vector grid (right).



The variability in thermokarst development appears to be influenced by the interaction of tundra fire burn severity and the near-surface, ground-ice content of the permafrost.

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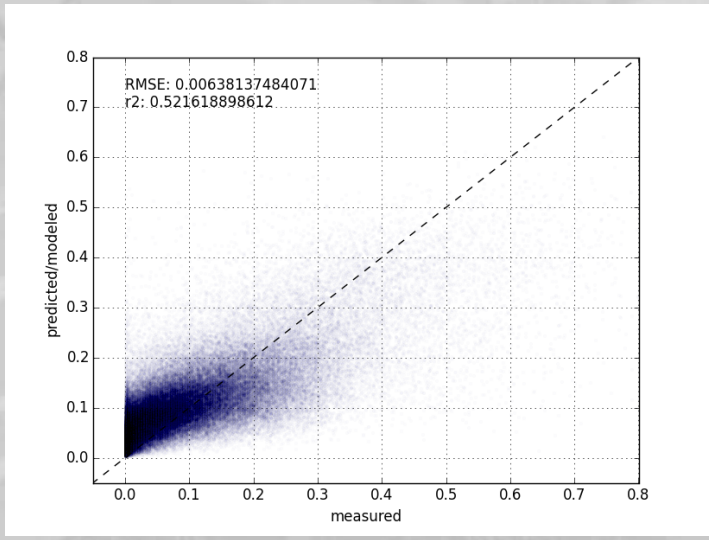
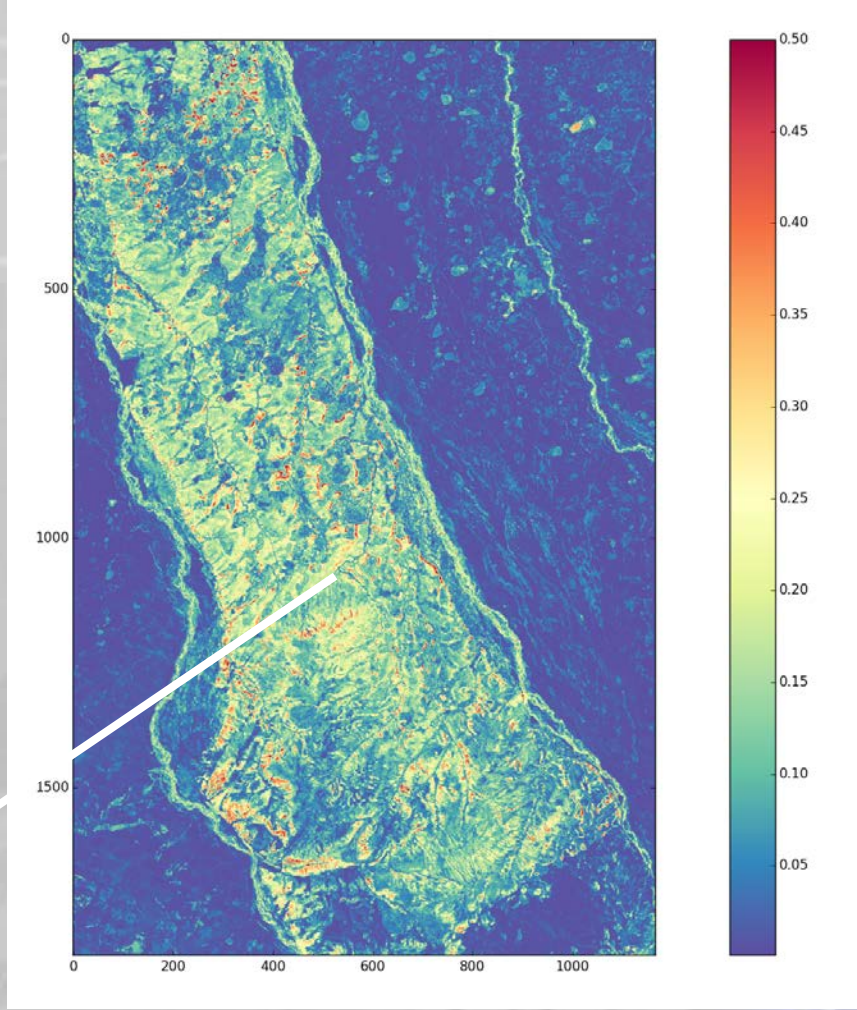
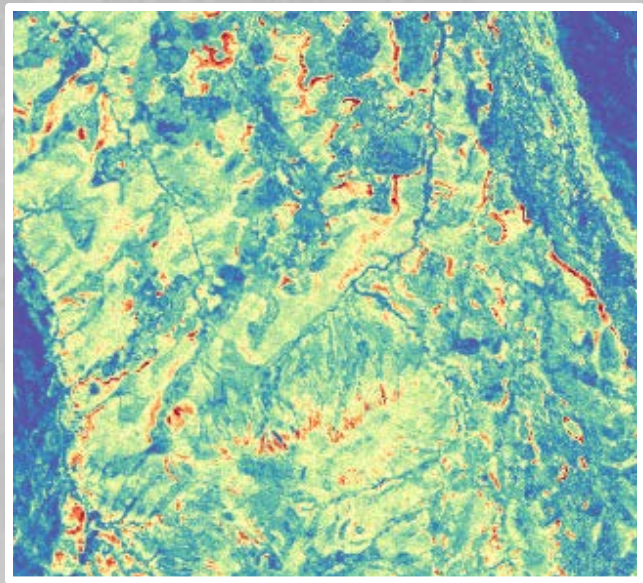
Scaling Post-Fire Thermokarst using Landsat

Random Forest Regression with 6 indices

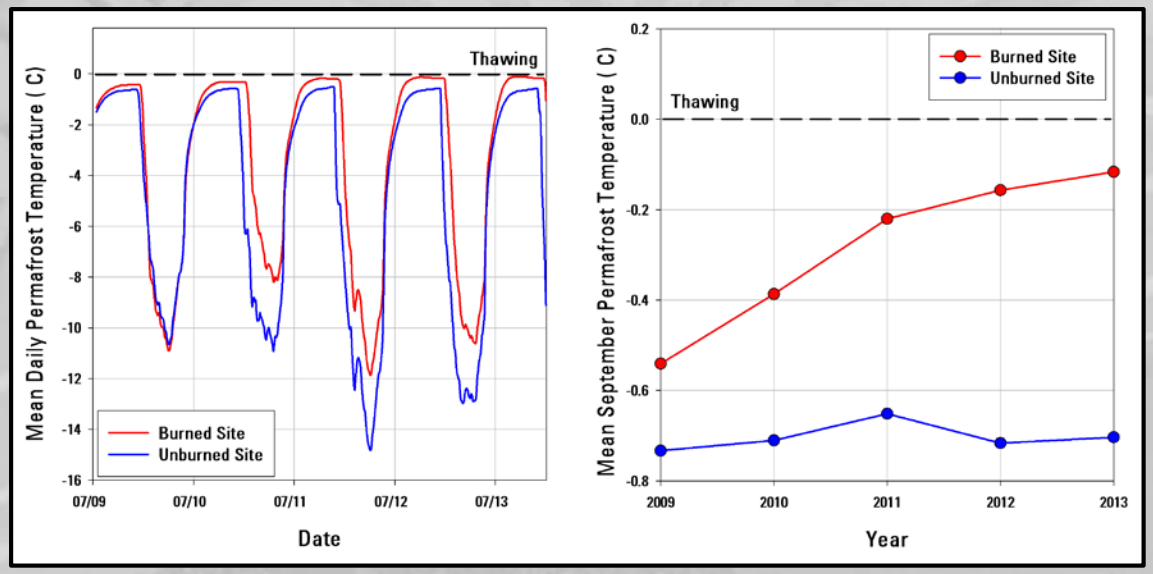


Modeling Subsidence using Landsat Trend Analysis

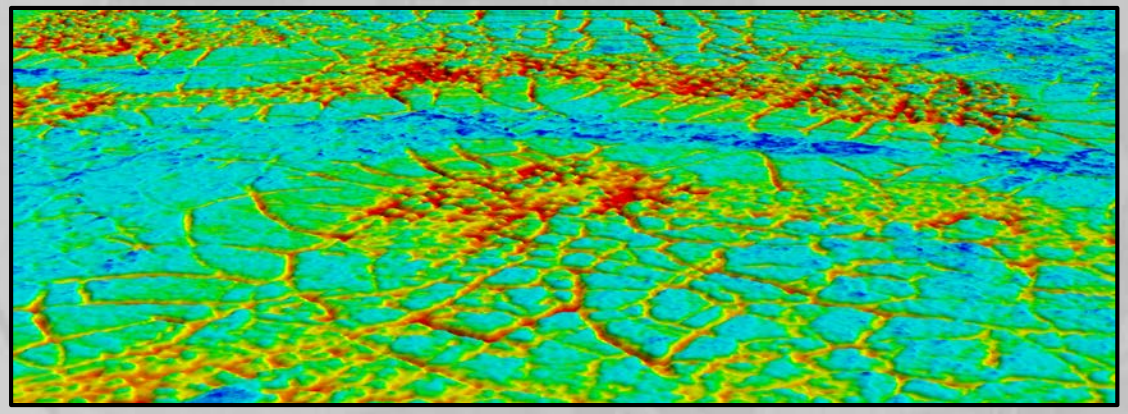




Will Permafrost Degradation Continue?



The ground thermal regime is still re-equilibrating to the fire disturbance, indicating that thermokarst development will likely continue.



Additional airborne LiDAR data, or other high-resolution topographic data, will be necessary to measure the potential continued permafrost thaw subsidence that has resulted from the severe Anaktuvuk River tundra fire.

Implications of Fire-Induced Permafrost Thaw

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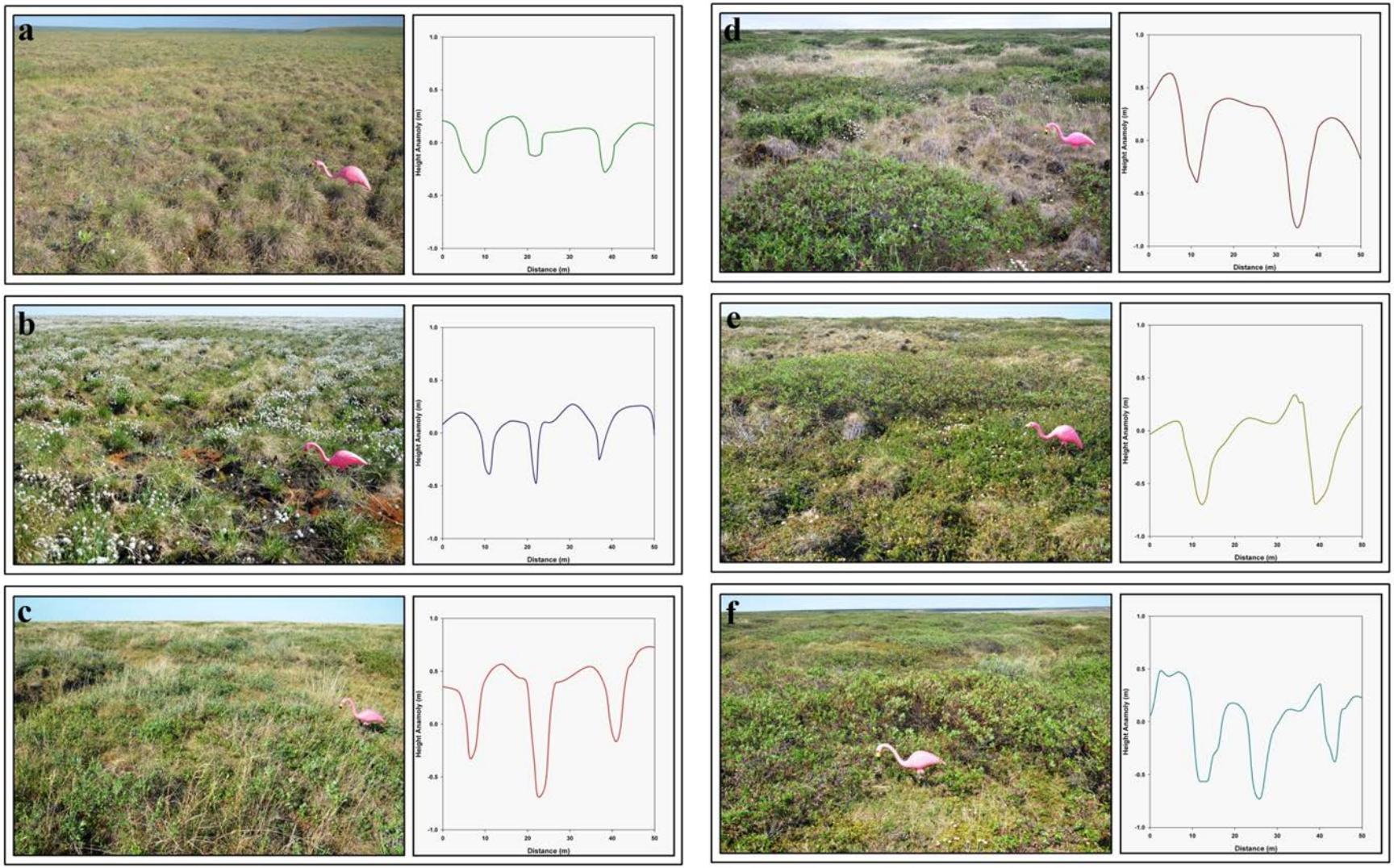
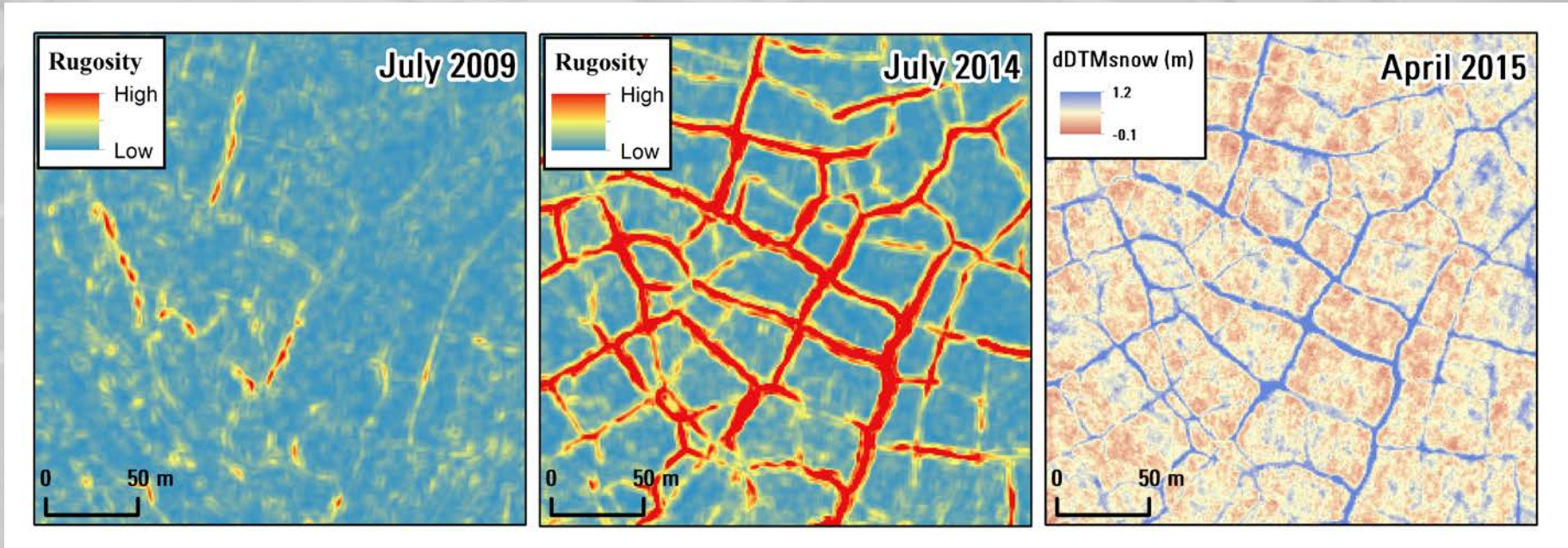


Implications of Fire-Induced Permafrost Thaw

Increased Microtopography Leads to Enhanced Snow Accumulation



Calculation of surface roughness showed a doubling in microtopography on average across the burned portion of the study area, with a 340% increase in yedoma upland terrain. This increase has led to an increase in the amount of snow stored on the landscape in degrading ice wedge troughs as imaged in an April 2015 airborne LiDAR data collection.

Role of Tundra Fires in Changing Arctic Landscapes

- Severe tundra fires can cause widespread permafrost degradation
- Our analysis of airborne LiDAR data, acquired two and seven years after the Anaktuvuk River tundra fire, documented widespread thermokarst development
- The landscape scale impact of a particular fire depends on burn severity, terrain characteristics, and permafrost characteristics
- Post-fire thermokarst development has increased the microtopography of the landscape and is likely impacting ongoing vegetation succession, mobilizing permafrost carbon, and increasing winter snow accumulation and summer surface runoff