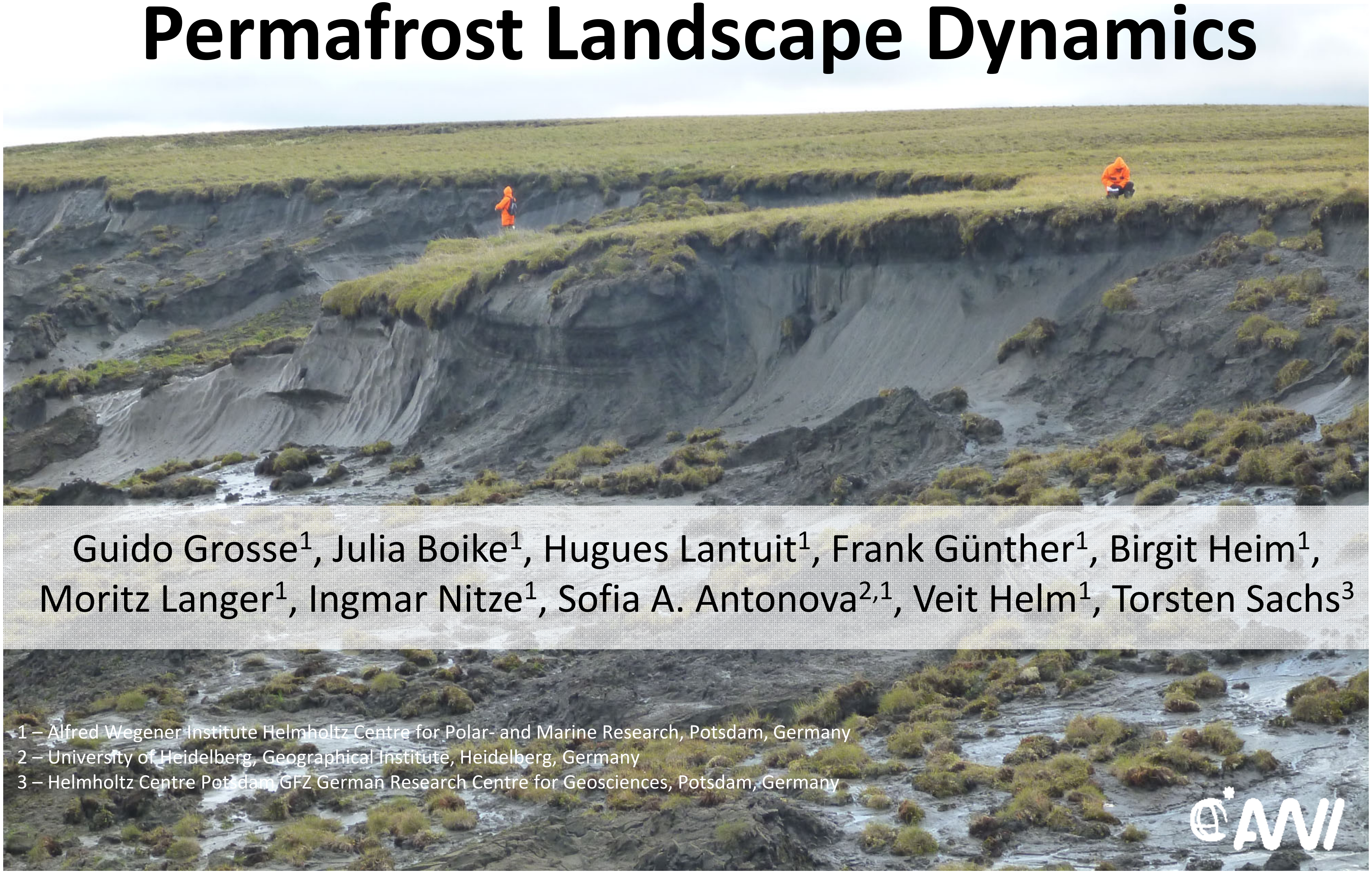
Airborne Remote Sensing of Permafrost Landscape Dynamics



Guido Grosse[1], Julia Boike[1], Hugues Lantuit[1], Frank Günther[1], Birgit Heim[1], Moritz Langer[1], Ingmar Nitze[1], Sofia A. Antonova[2,1], Veit Helm[1], Torsten Sachs[3]

1 – Alfred Wegener Institute Helmholtz Centre for Polar- and Marine Research, Potsdam, Germany
2 – University of Heidelberg, Geographical Institute, Heidelberg, Germany
3 – Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany

What is Permafrost?

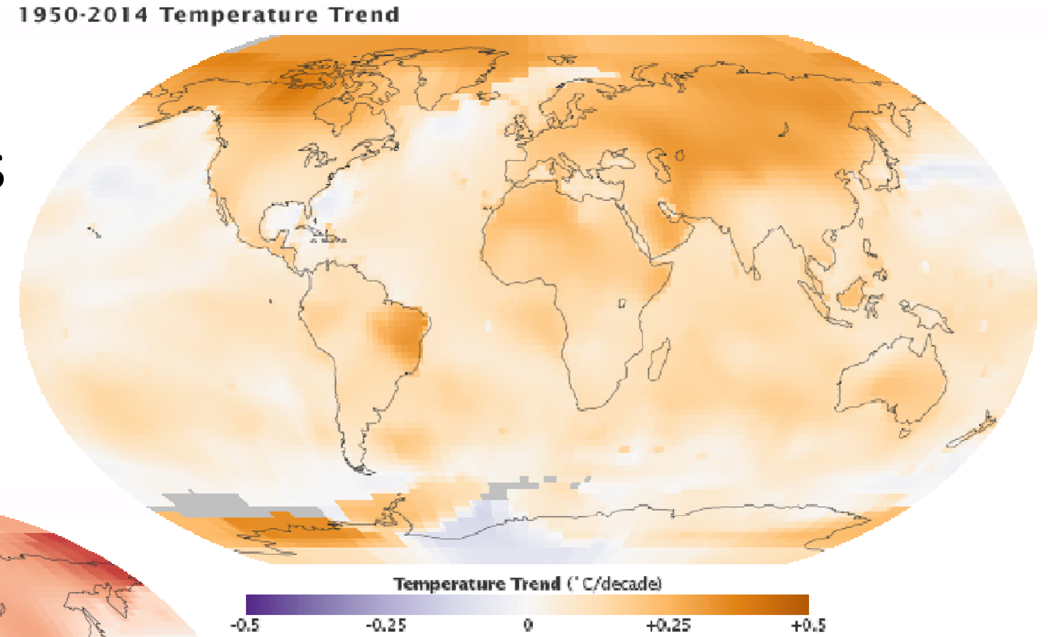
Permafrost in numbers:

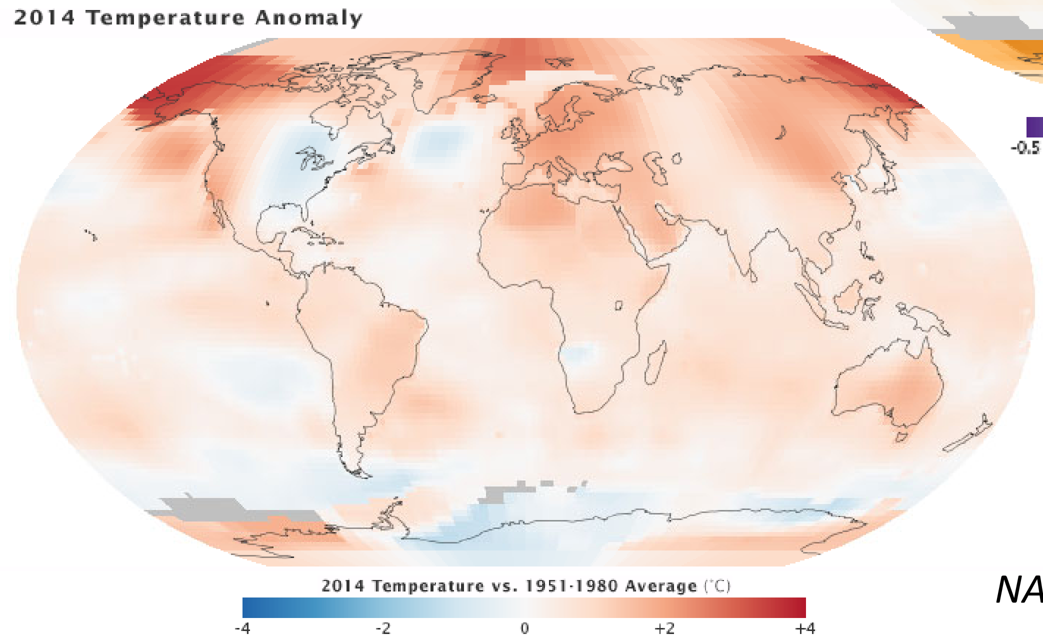
- Ground that stays below 0°C for at least ≥ 2 consecutive years
- 22.8×10^6 km² (23%) of the northern hemisphere land mass
- Up to > 2.5 million years old
- Up to 1600 m thick

Brown et al., 1997, IPA

Climate Change in the Arctic: Past + Present

- Polar Amplification of climate change increases ecosystems pressures





NASA/GSFC/Earth Observatory, NASA/GISS

Thawing Permafrost: Alaska

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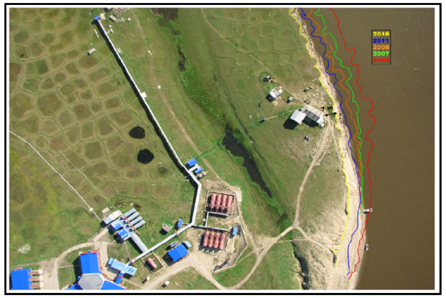
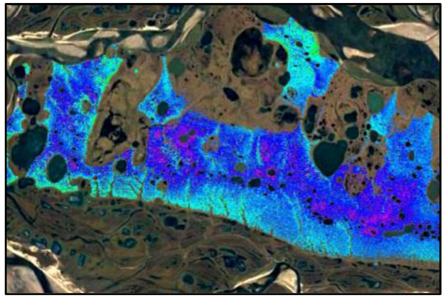
Permafrost Remote Sensing

Remote Sensing as tool for understanding
permafrost landscapes, dynamics, and ecosystem feedbacks

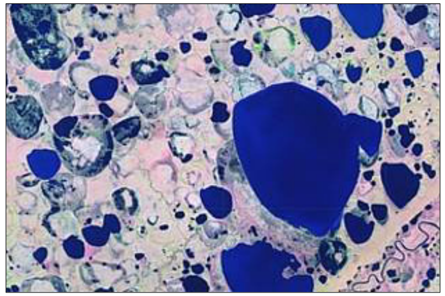


Permafrost coastal change



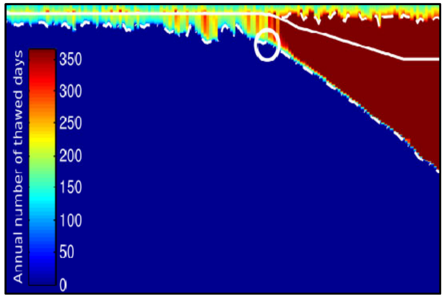
Abrupt thaw and subsidence

Energy and water fluxes



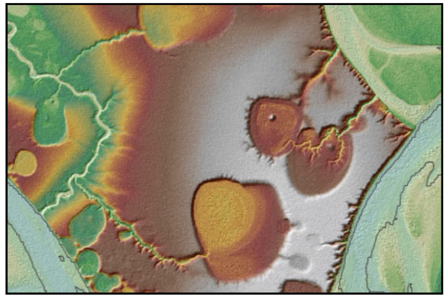
Hydrology and lakes

Carbon pools & fluxes



Permafrost modelling

Vegetation and land cover



Periglacial landform mapping

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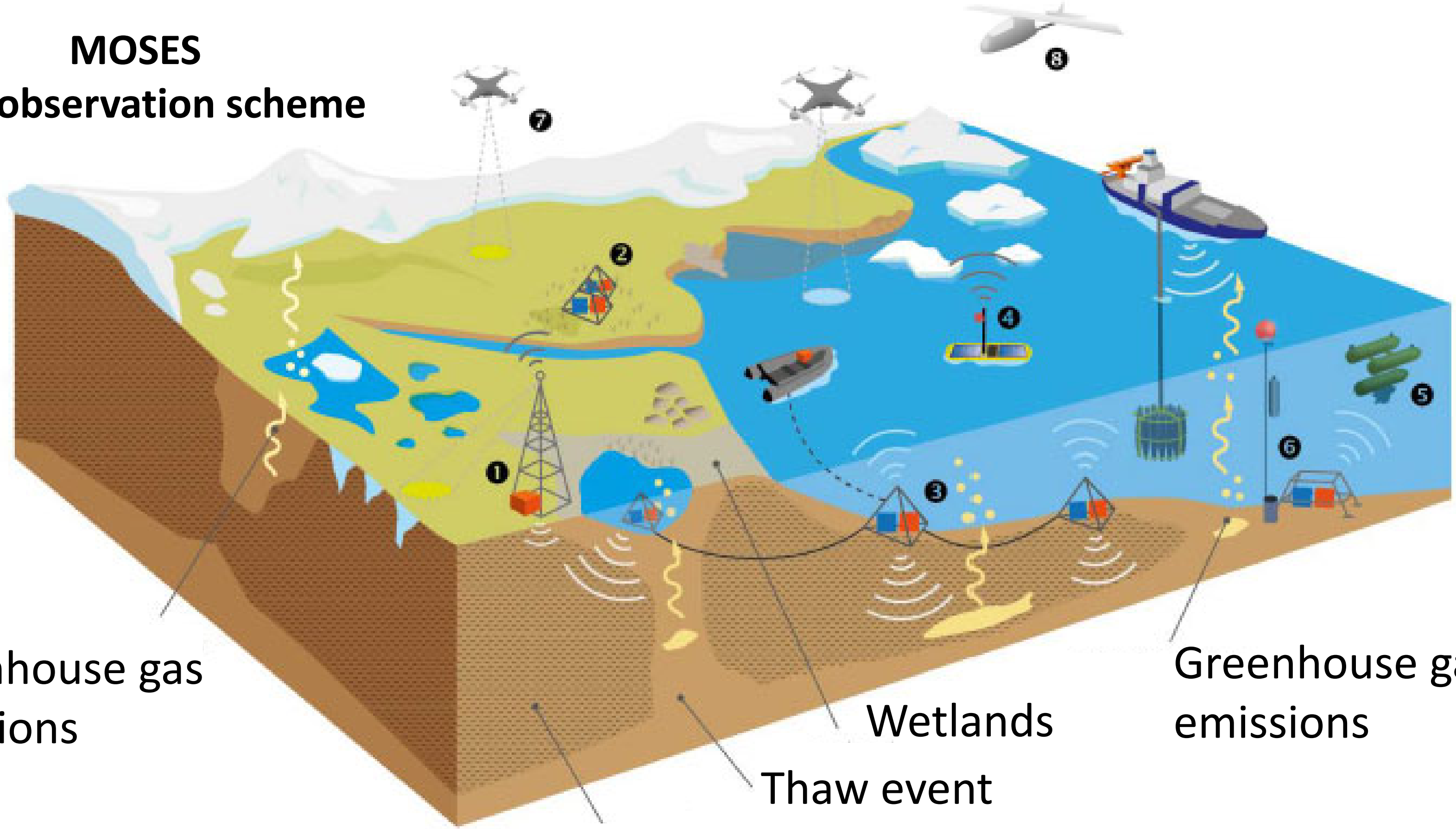
Bridging the Scales

Airborne platforms bridge scales between **field-based research** and observations by satellite platforms or model results from LSMs/GCMs

MOSES
field observation scheme

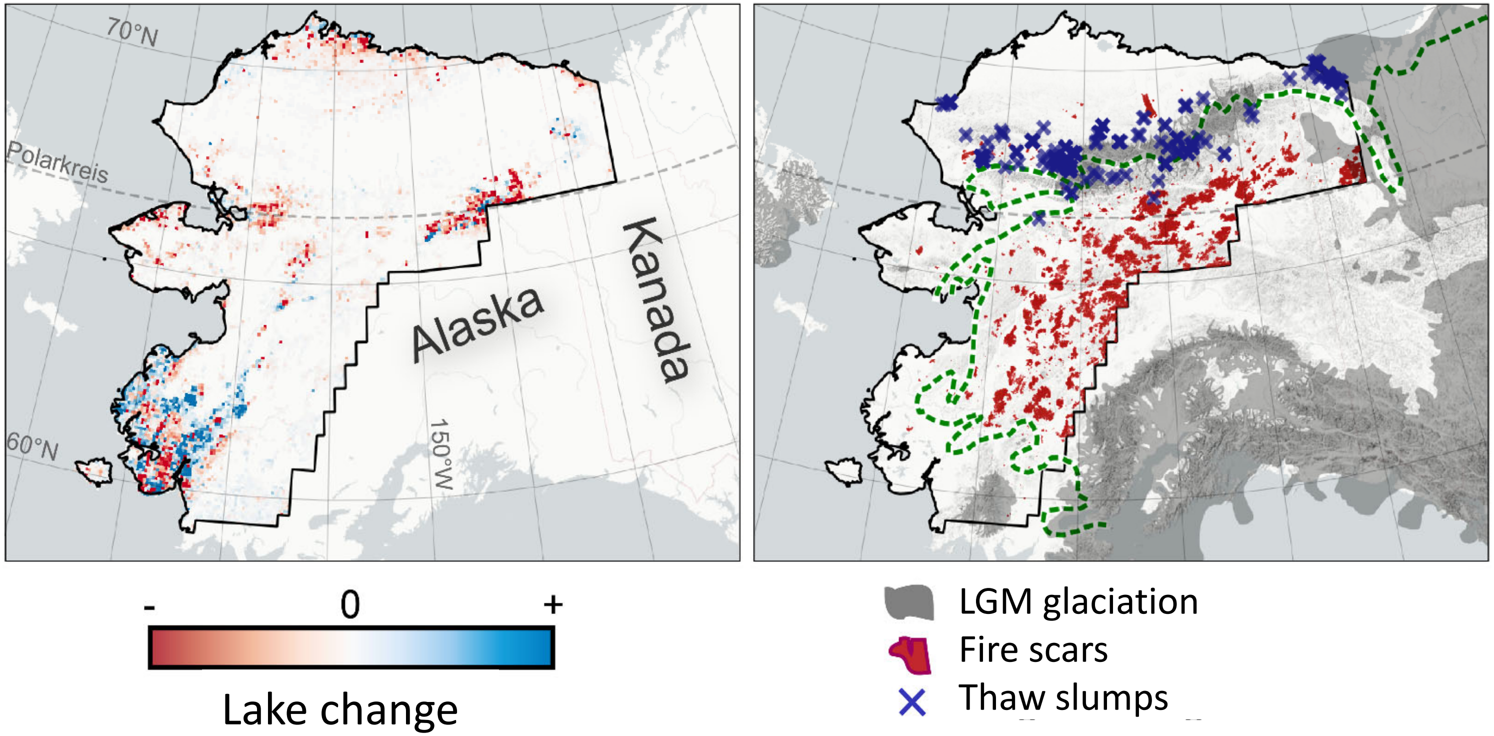


J. Boike et al.

Bridging the Scales

Airborne Platforms bridge scales between field-based research and
scales observed by satellite platforms or modelled with LSMs/GCMs

Regional coverage for detecting permafrost region disturbances with satellite remote sensing



Nitze et al. 2018: Remote sensing quantifies widespread abundance of permafrost region disturbances across the Arctic and Subarctic. *Nature Communications*

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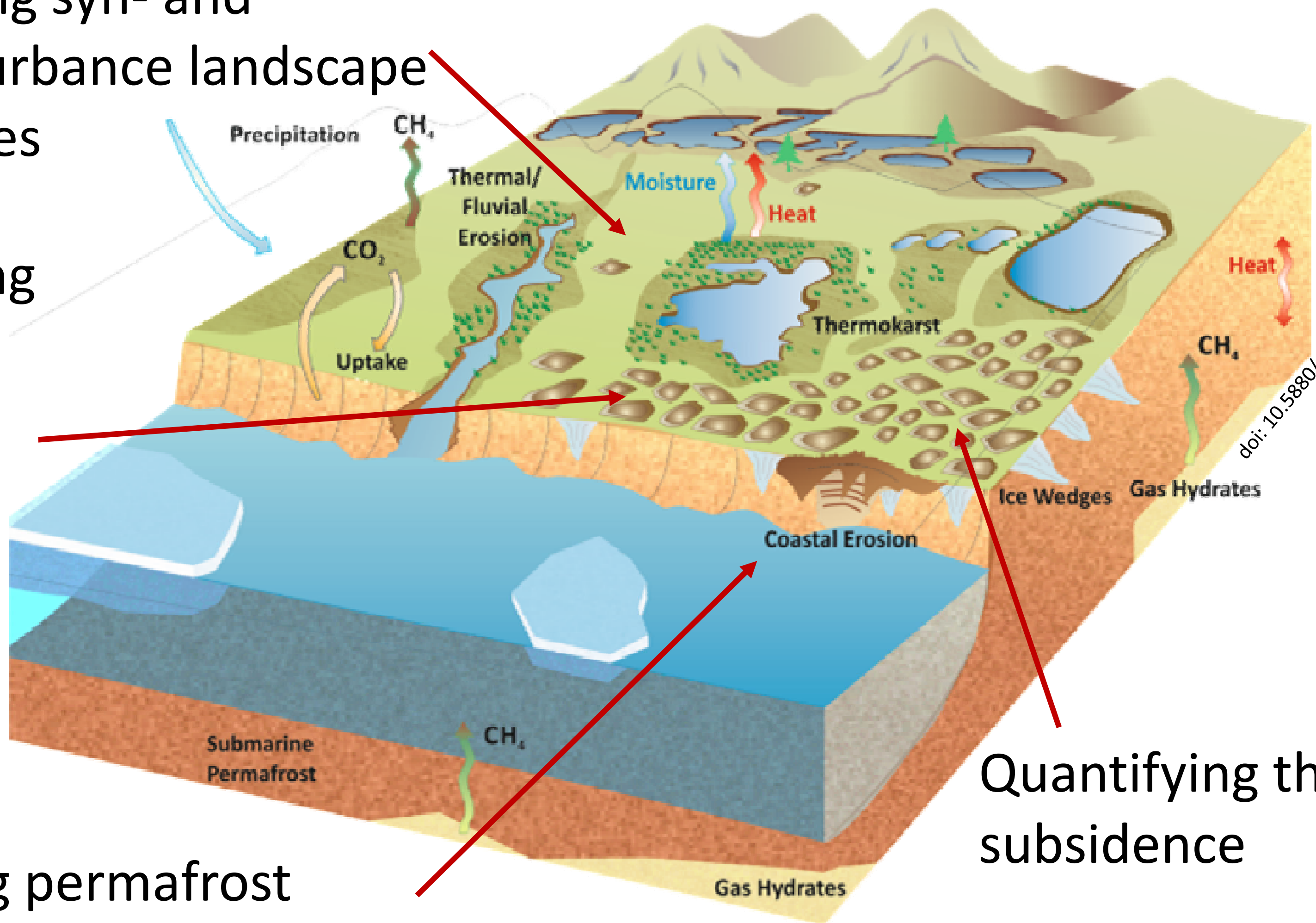
Airborne Observation Targets

Monitoring syn- and post-disturbance landscape trajectories

Characterizing patterned ground and ground ice distribution



doi: 10.5880/gfz.lis.2015.001

Quantifying thaw subsidence

Quantifying permafrost coastal and shore dynamics

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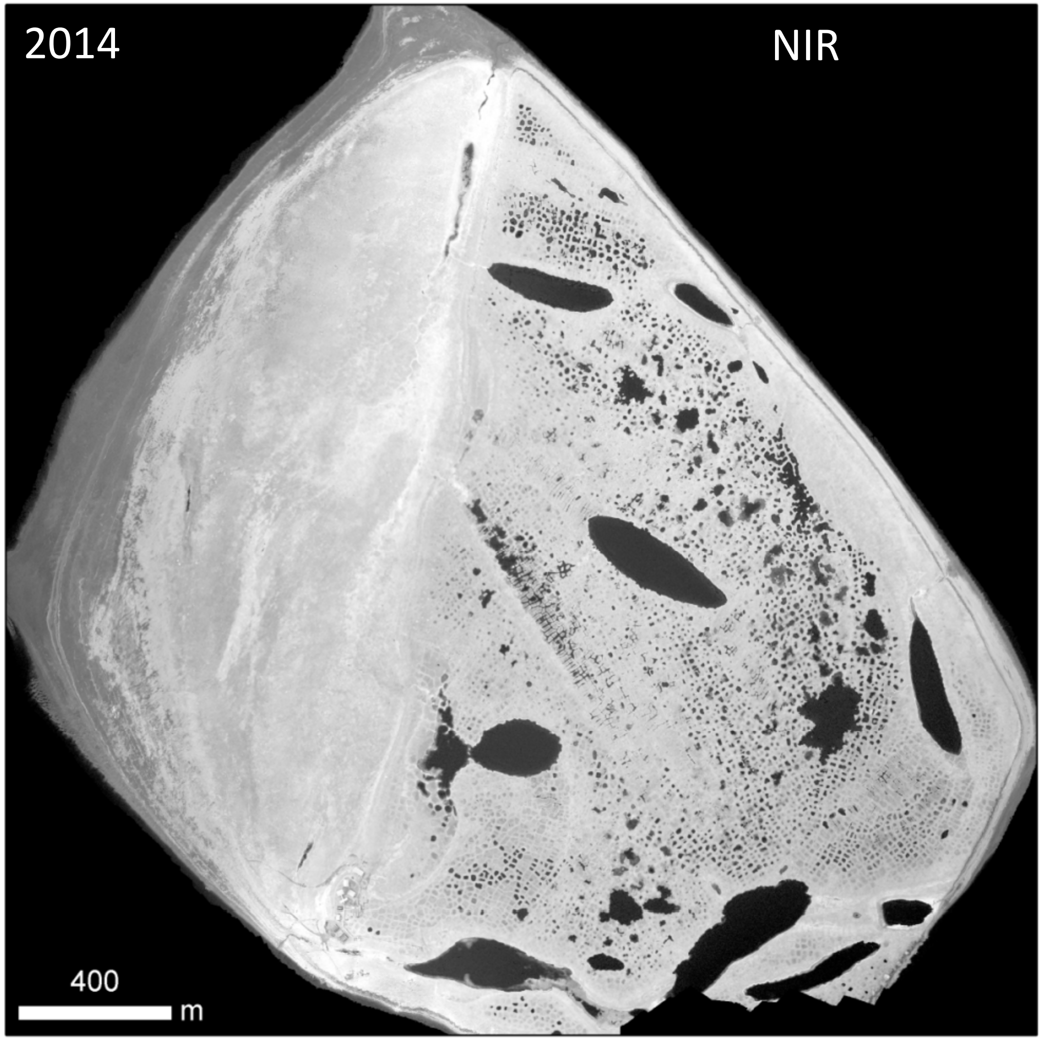
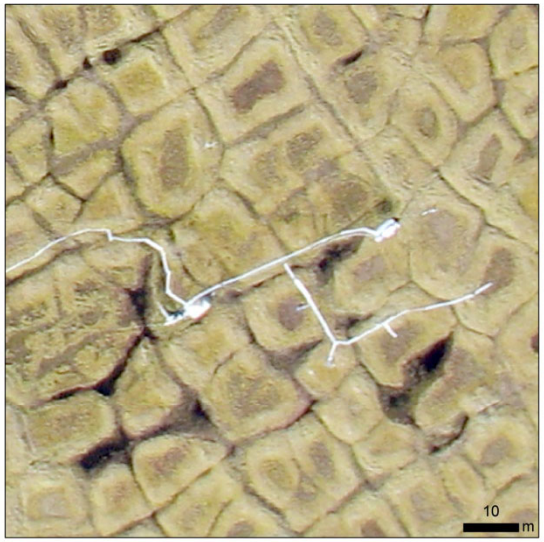
Ice Wedge Polygonal Ground

Samoylov Island: Kite and balloon remote sensing



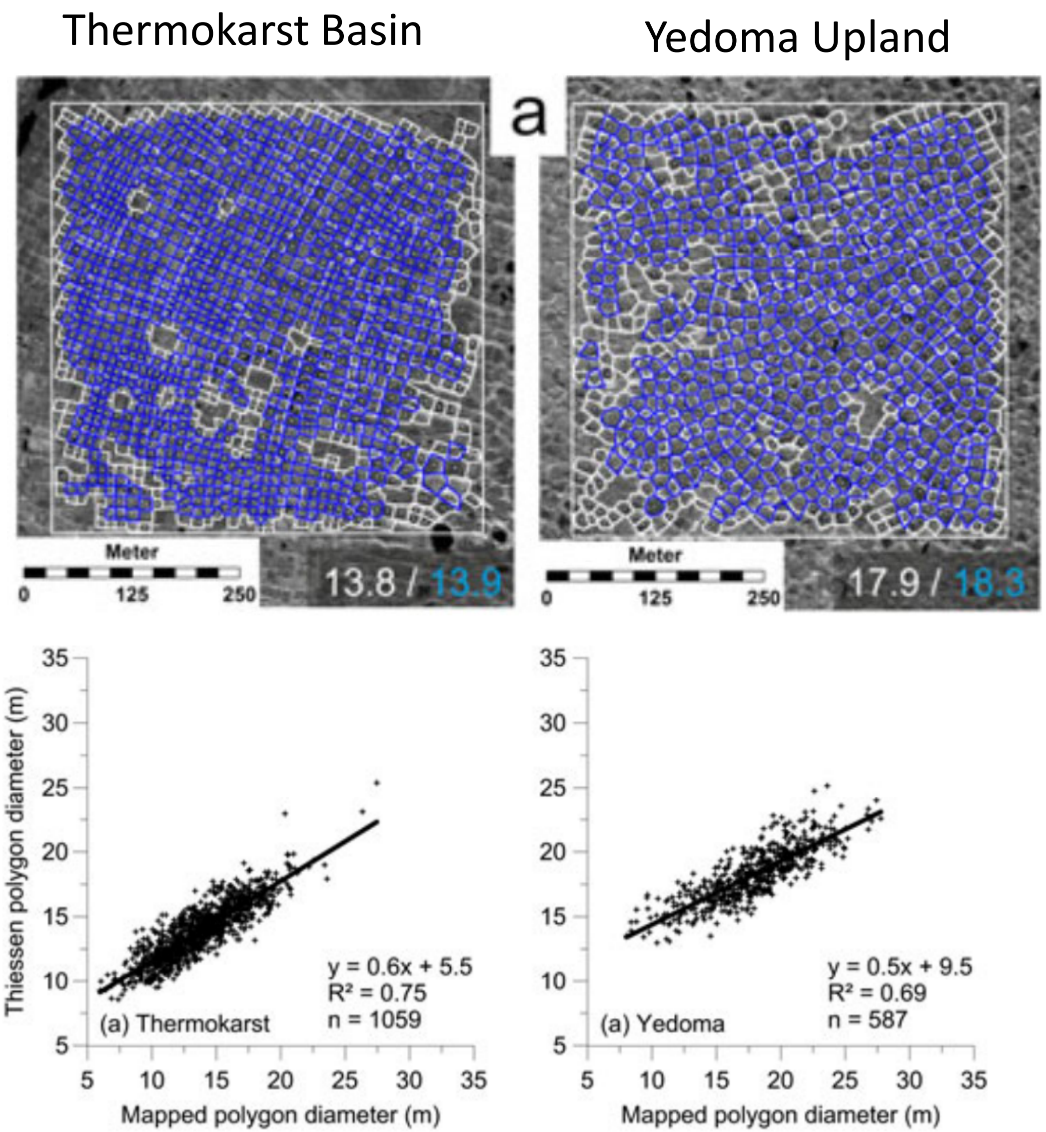
Boike et al.



VIS
2006

VIS

Ice Wedge Polygonal Ground



- Location: Ebe-Basyn-Sise Island, Lena Delta
- Comparison of polygon geomorphometry between manually mapped polygonal patterns (white lines) and automatically derived Thiessen polygons (blue lines)

Scatter plots showing relationship between manually mapped polygon sizes and automatically derived Thiessen polygon sizes

Ulrich et al 2014 (Permafrost & Periglacial Processes)

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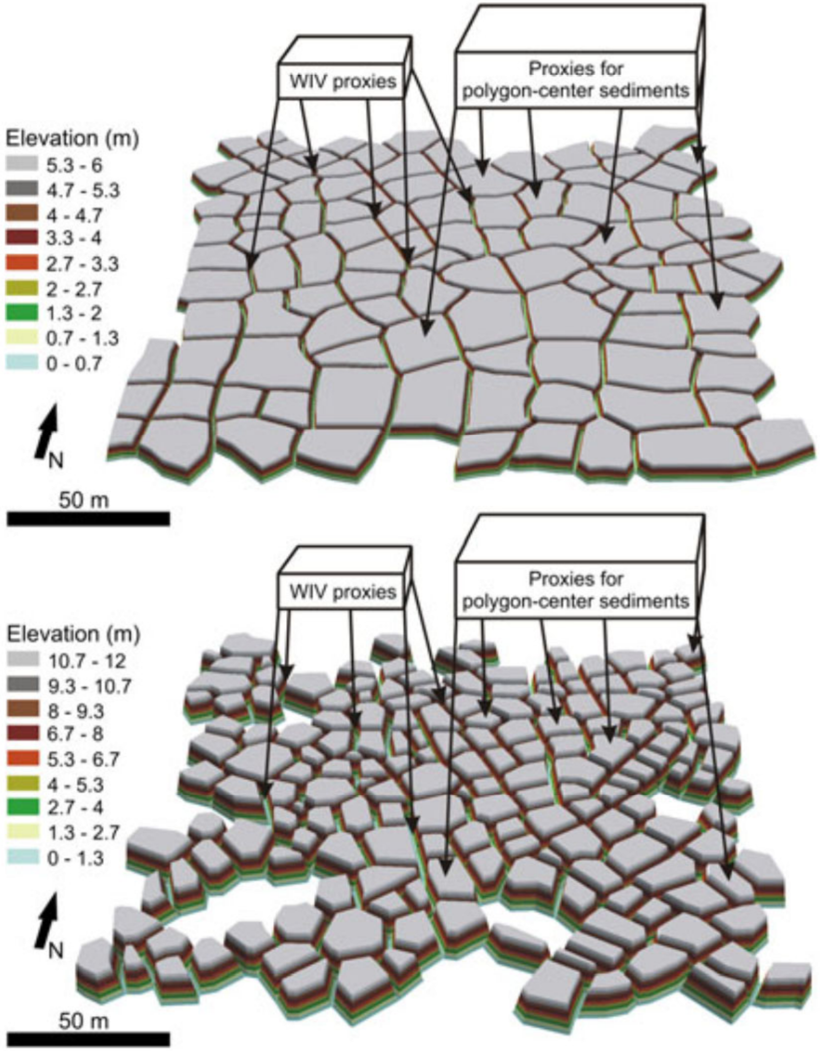
Ice Wedge Polygonal Ground



3D subsurface models (3D SSMs)

Epigenetic ice wedge polygonal network in drained thermokarst lake basin on the Buor Khaya Peninsula.

Equivalent Ground-Ice Content:
0.1 – 1.3 m (for 10m deposits)

Syngenetic ice wedge polygonal network on Yedoma deposits on Ebe-Basyn-Sise Island.

Equivalent Ground-Ice Content:
1.7 – 6.3 m (for 10m deposits)

Ulrich et al 2014 (Permafrost & Periglacial Processes)

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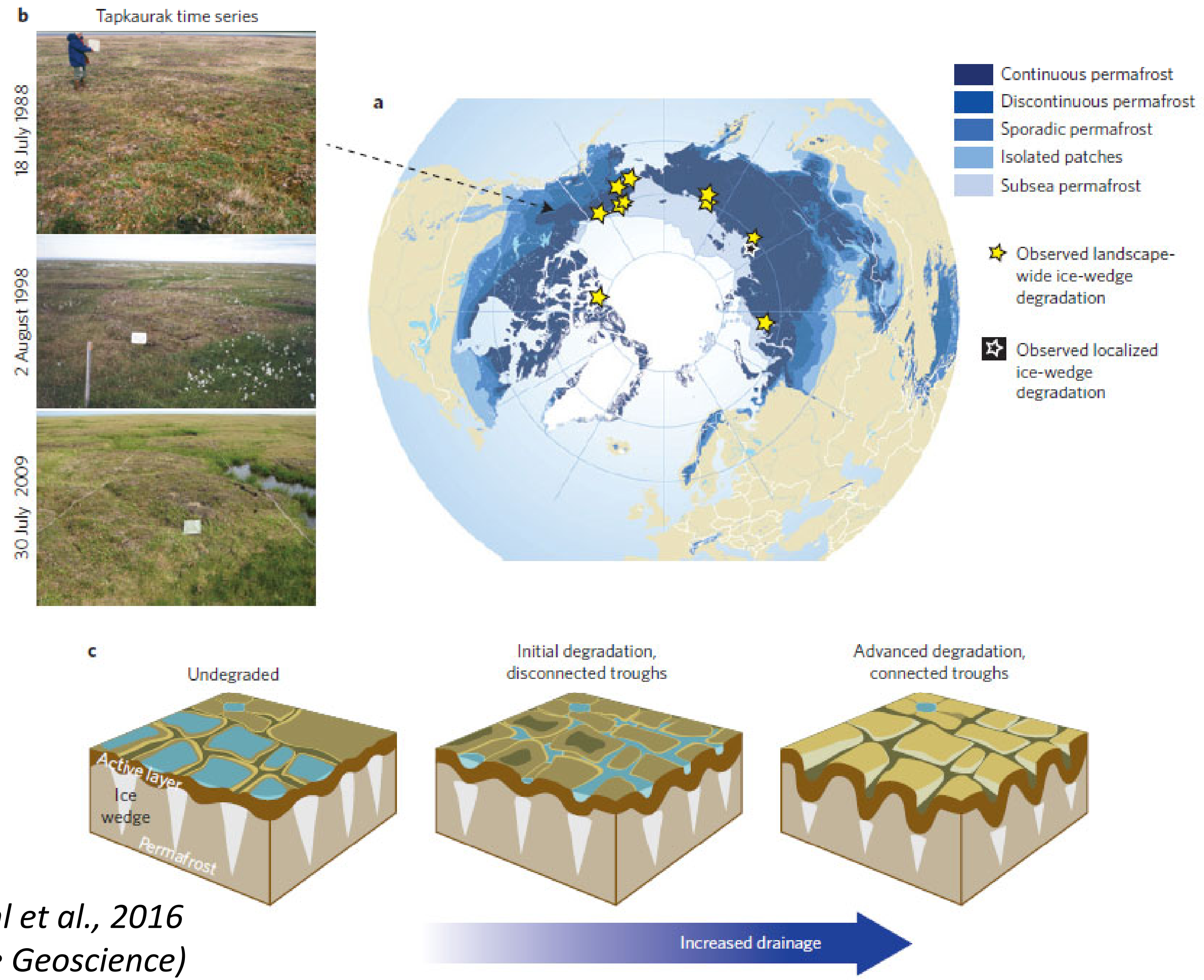
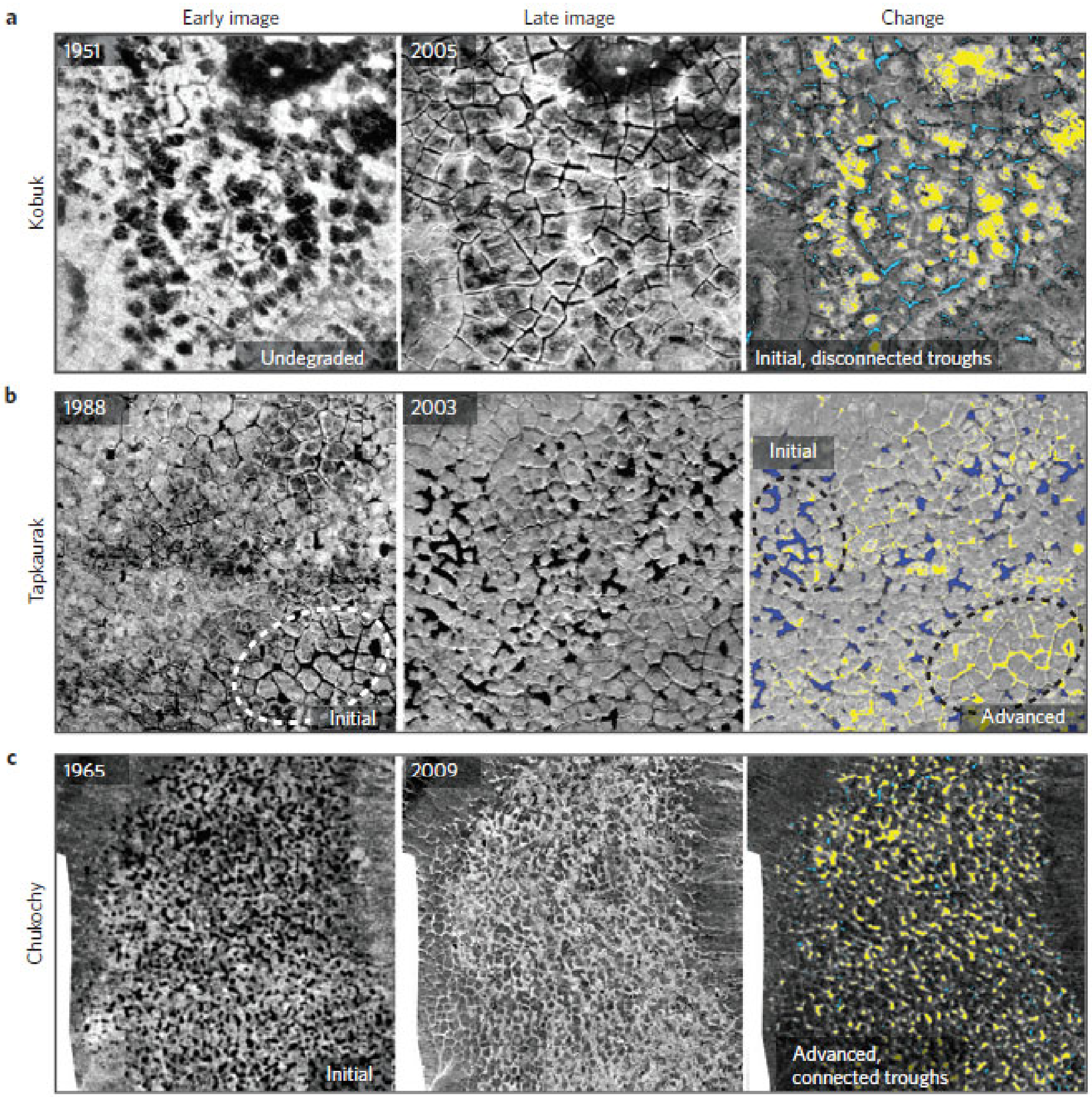
Ice Wedge Degradation



Liljedahl et al., 2016
(Nature Geoscience)

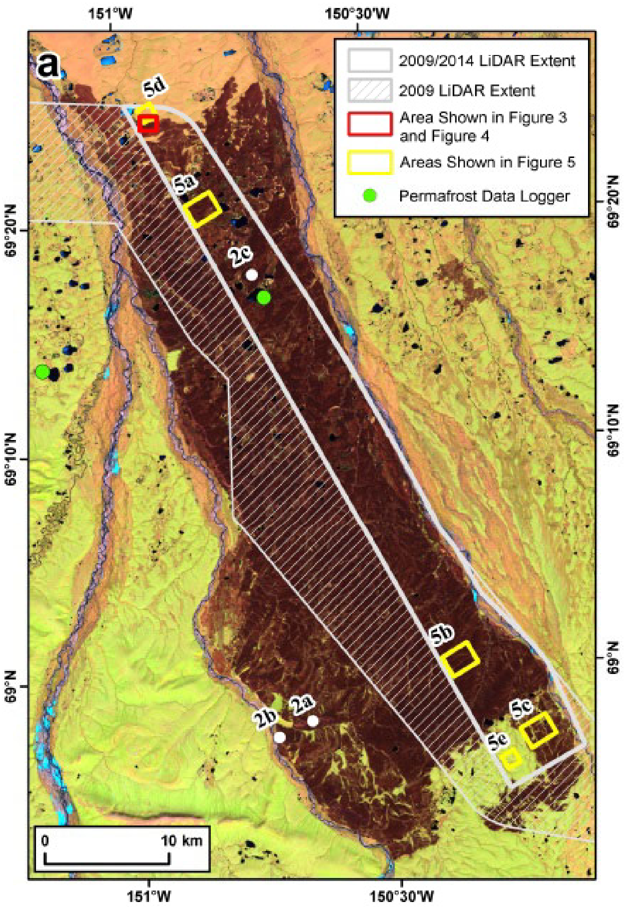
Ice Wedge Degradation



Liljedahl et al., 2016
(Nature Geoscience)

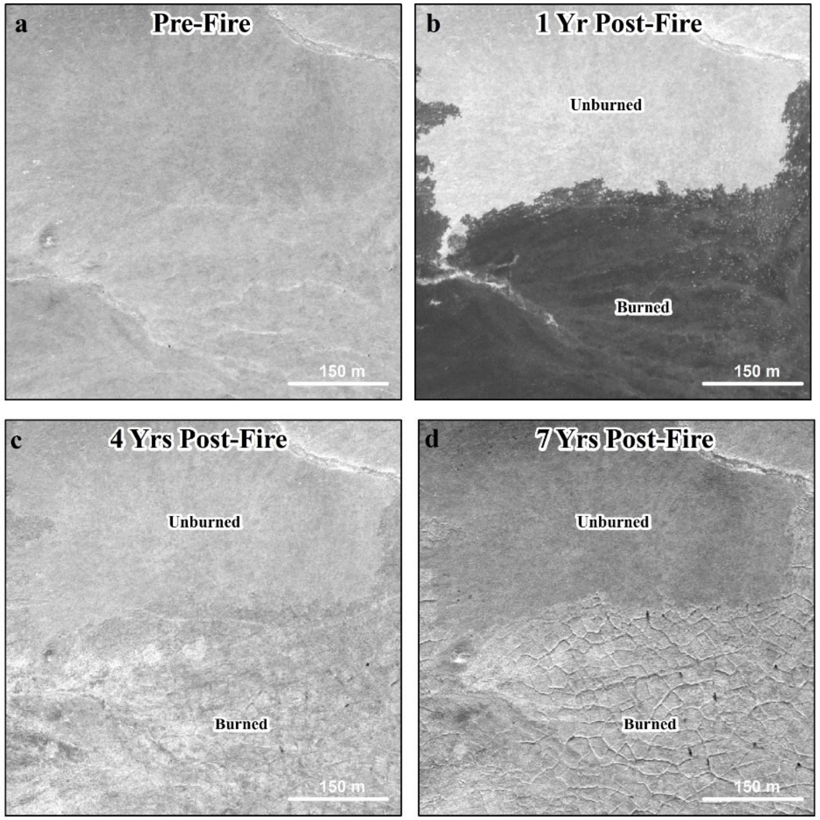
Post-Disturbance Repeat LiDAR

Anaktuvuk River Tundra Fire Scar, 1000 km^2



Jones et al. (2015): Recent Arctic tundra fire initiates widespread thermokarst development. _Scientific Reports._

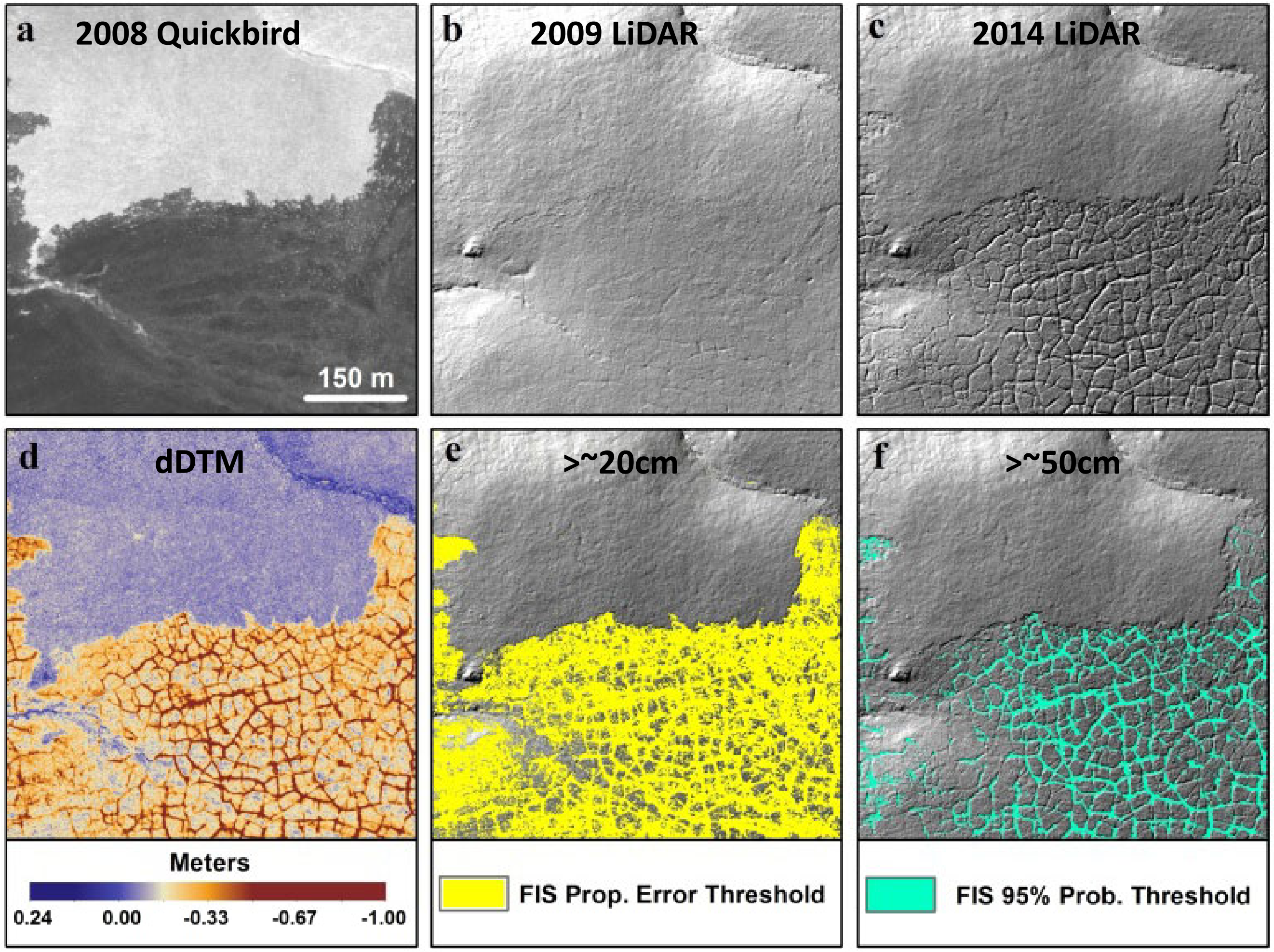
Time series of commercial satellite imagery



- Indicates ice wedge degradation between the 4th and 7th years post-fire
- Would be very difficult to quantify this type of change using high-resolution commercial imagery

Post-Disturbance Repeat LiDAR

Time series of commercial satellite imagery + repeat airborne LiDAR



Jones et al. (2015): Recent Arctic tundra fire initiates widespread thermokarst development. _Scientific Reports._

Permafrost Coastal Erosion

Lantuit et al, AWI Potsdam

- About 34% of all coasts on Earth are permafrost coasts
- Permafrost coasts erode with an average of 0,5 m/a, Observed maximum rates of erosion up to 50 m/a
- Erosion of permafrost coasts transports particular organic carbon into the Arctic Ocean
- Coastal infrastructure is endangered

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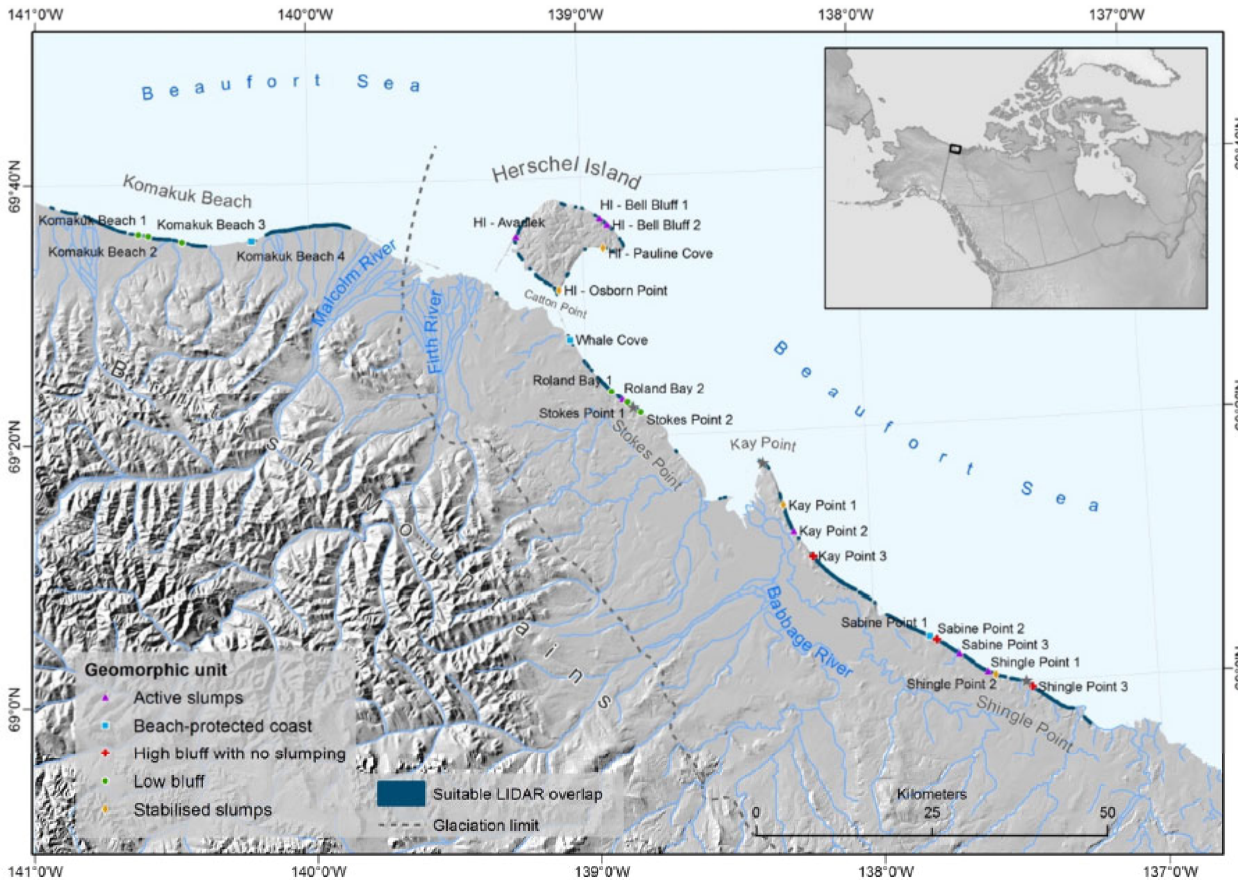
Permafrost Coastal Erosion

Permafrost coastal erosion surveys with annual repeat LiDAR at 24 sites on Yukon Coastal Plain, Canada.



Obu et al. (2016): Coastal erosion and mass wasting along the Canadian Beaufort Sea based on annual airborne LiDAR elevation data. *Geomorphology*.

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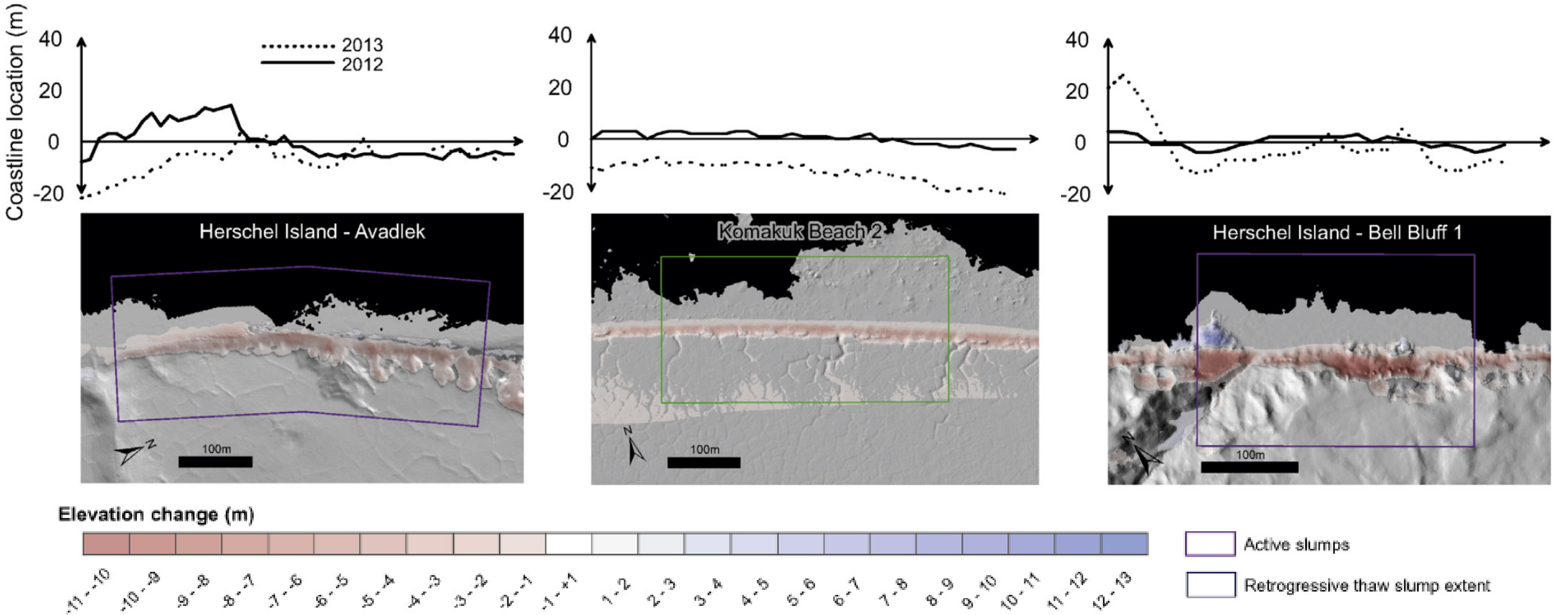
Permafrost Coastal Erosion

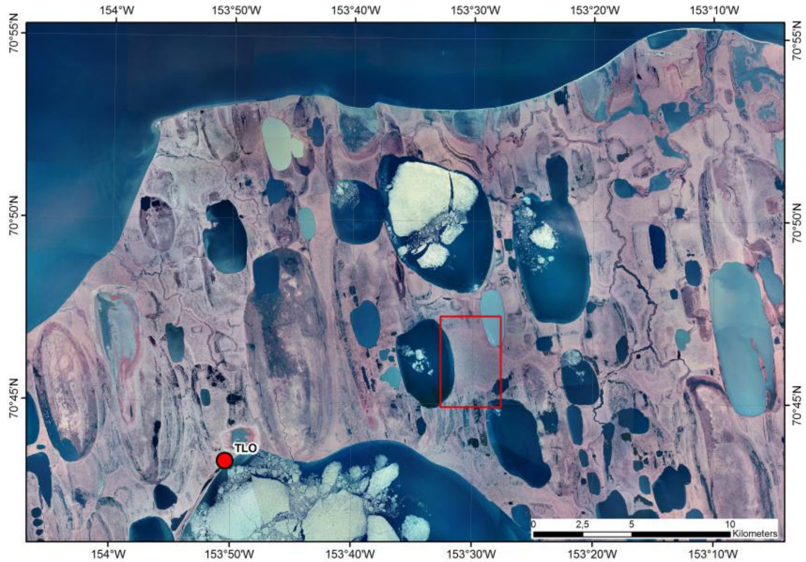


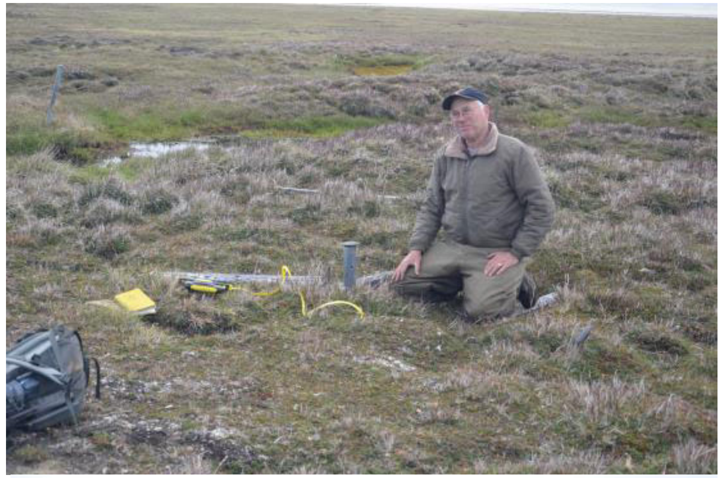
- Low-elevation ice-rich coasts erode uniformly by up to 20 m a^{-1}.
- Mass wasting causes high erosion variability of high-elevation permafrost coasts.
- Intensive slumping can result in coastline progradation by up to 40 m a^{-1}.
- Short-term coastline movements can impact erosion estimates from aerial imagery.

Obu et al. (2016): Coastal erosion and mass wasting along the Canadian Beaufort Sea based on annual airborne LiDAR elevation data. *Geomorphology*.

Thaw Subsidence Monitoring

Ground-ice rich terrain in the Arctic is being destabilized, yet few observations of widespread and irreversible thaw subsidence exist



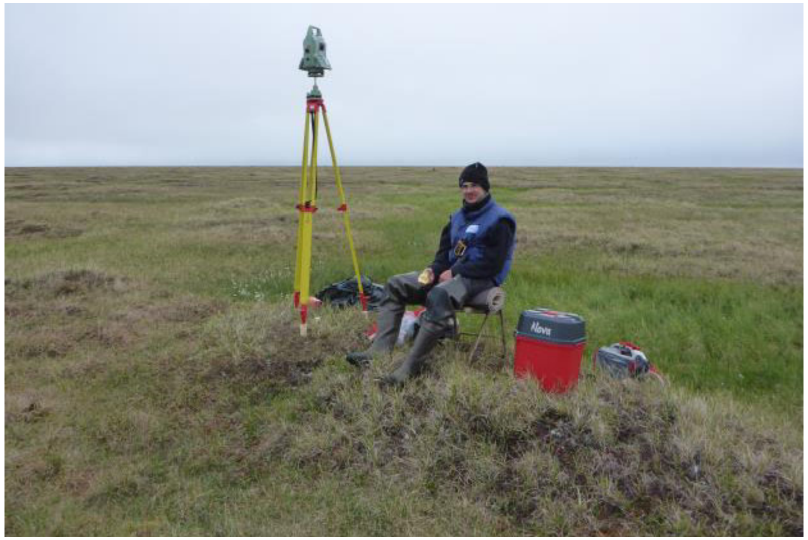


Available datasets

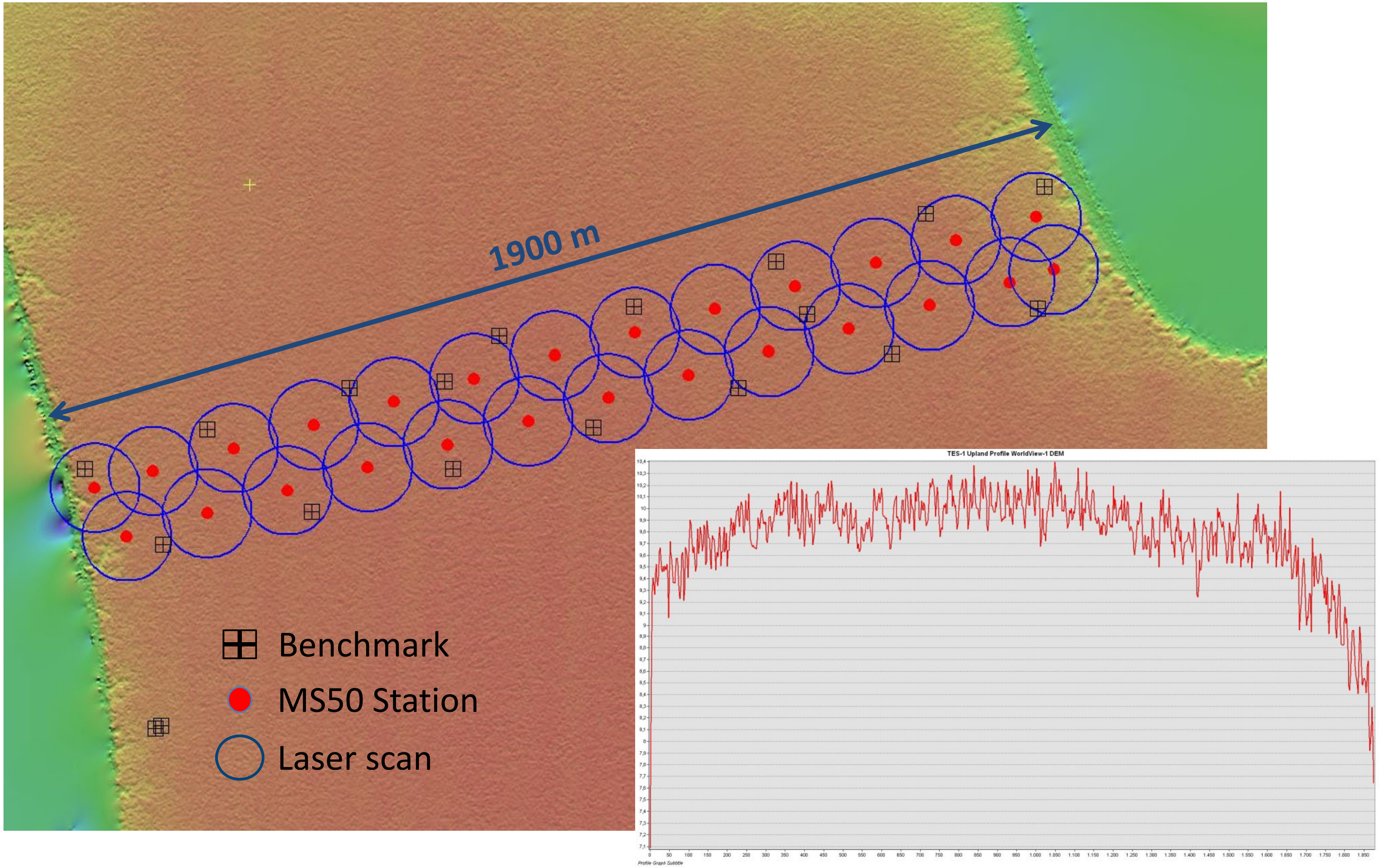
- DGPS surveys 2015
- Multistation Laserscan Surveys 2015 + 2017
- LiDAR Overflights 2018 canceled
- UAV overflight 2018
- LiDAR + DLR MACS Overflights 2019 planned
- Ground temperature + waether stations at site

Thaw Subsidence Monitoring

- Preparation and instrumentation of survey grid
- 16 height reference markers for repeat surveys (plastic pipes)
- 2 permafrost temperature data loggers (3 m depth)
- Profile across drainage gradient on upland between two thermokarst lakes

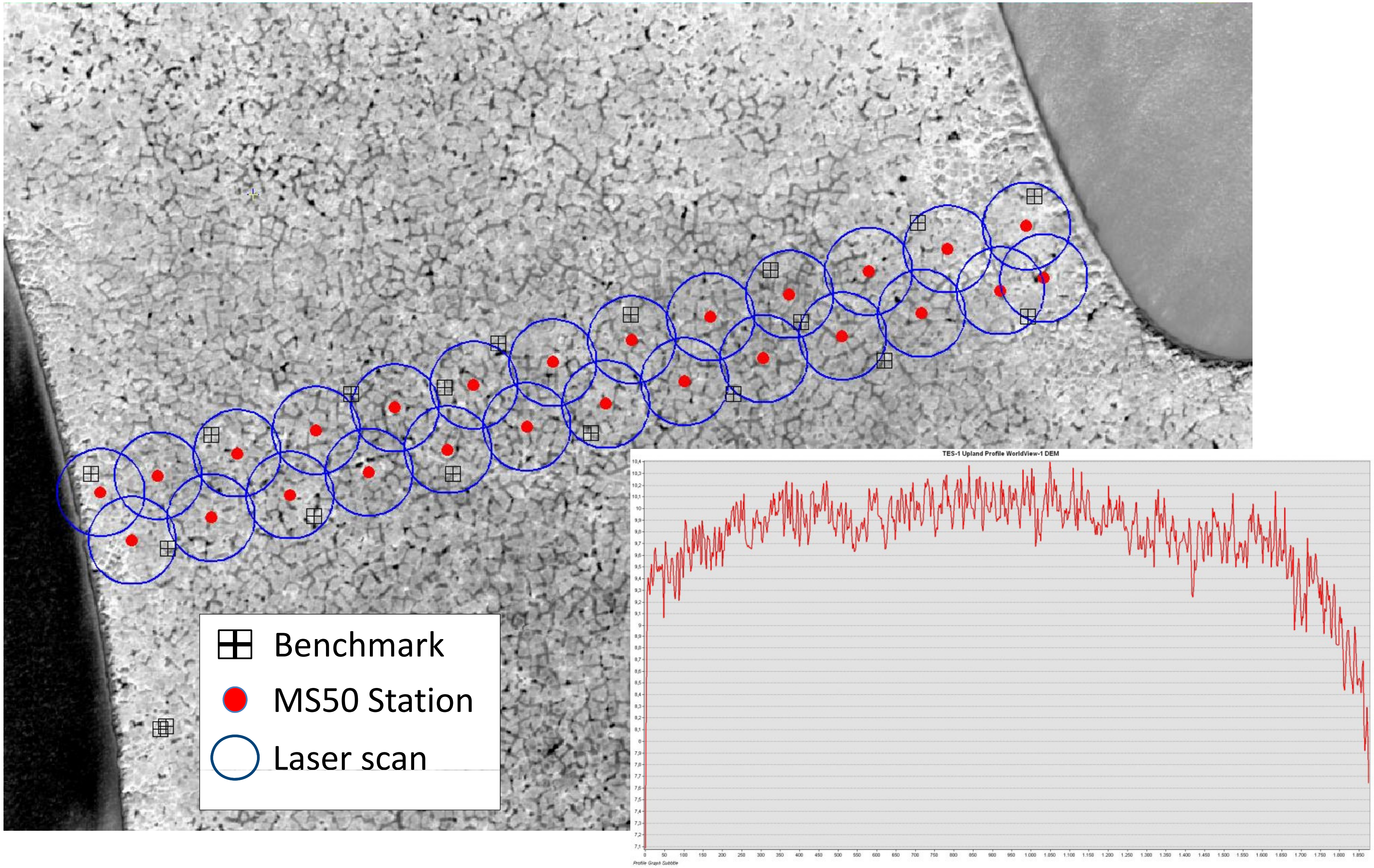


Thaw Subsidence Monitoring



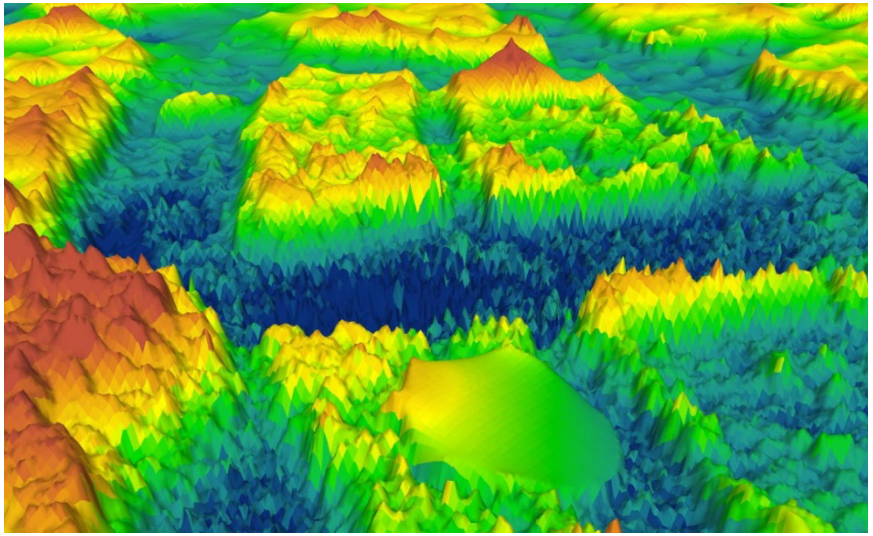
Günther et al., unpublished

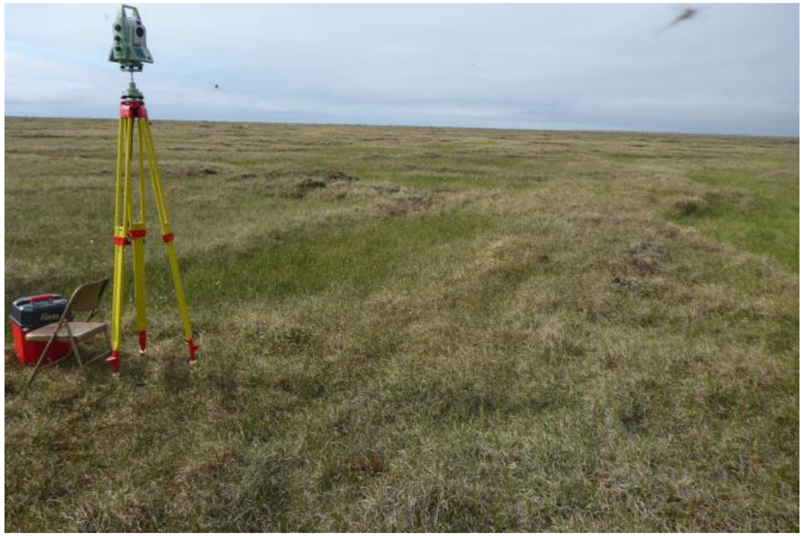
Thaw Subsidence Monitoring

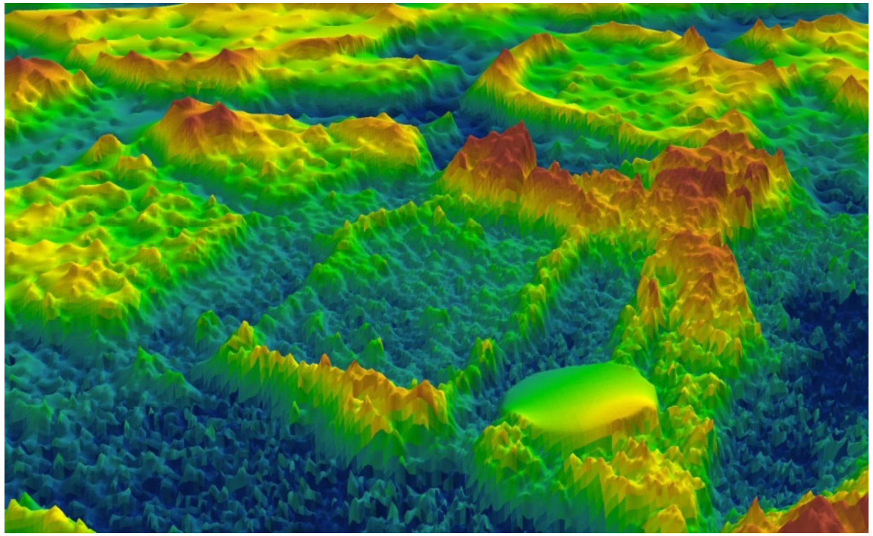


Günther et al., unpublished

Thaw Subsidence Monitoring

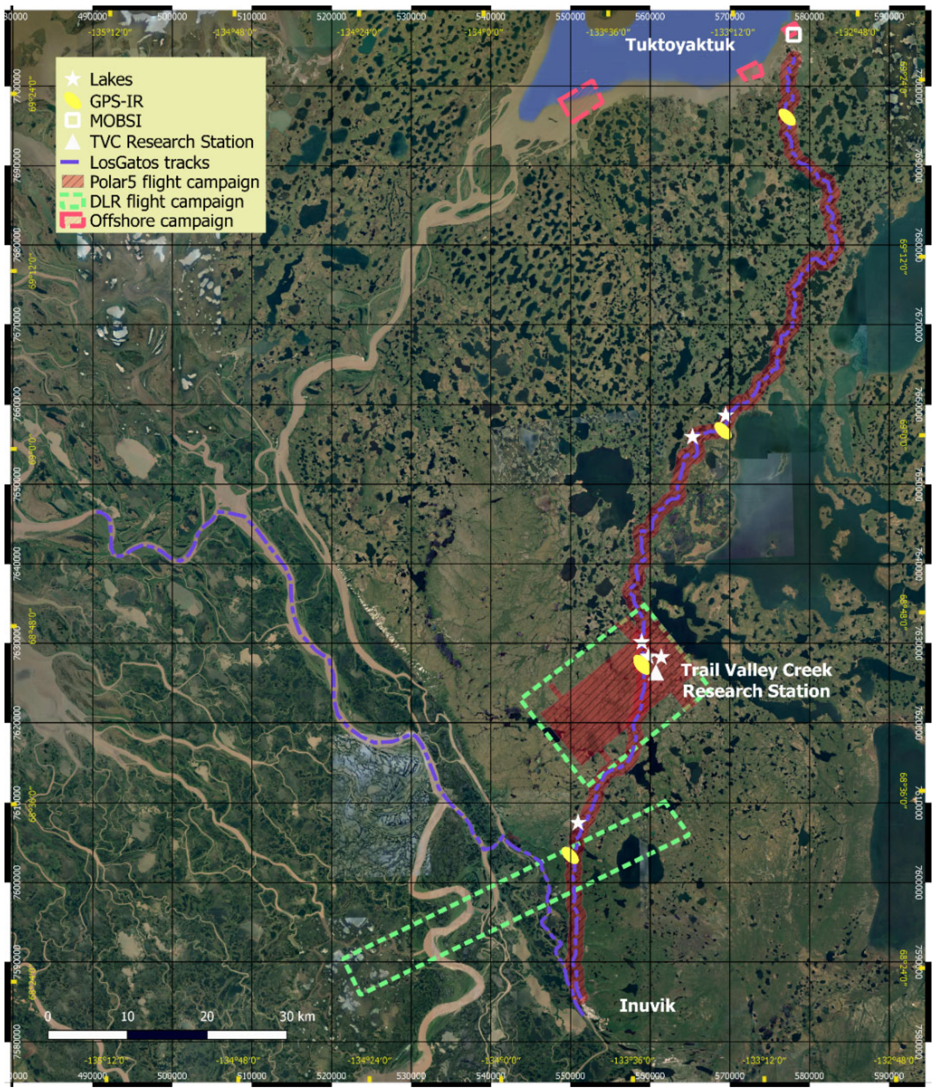






Günther et al., unpublished

PermaSAR / MOSES 2018

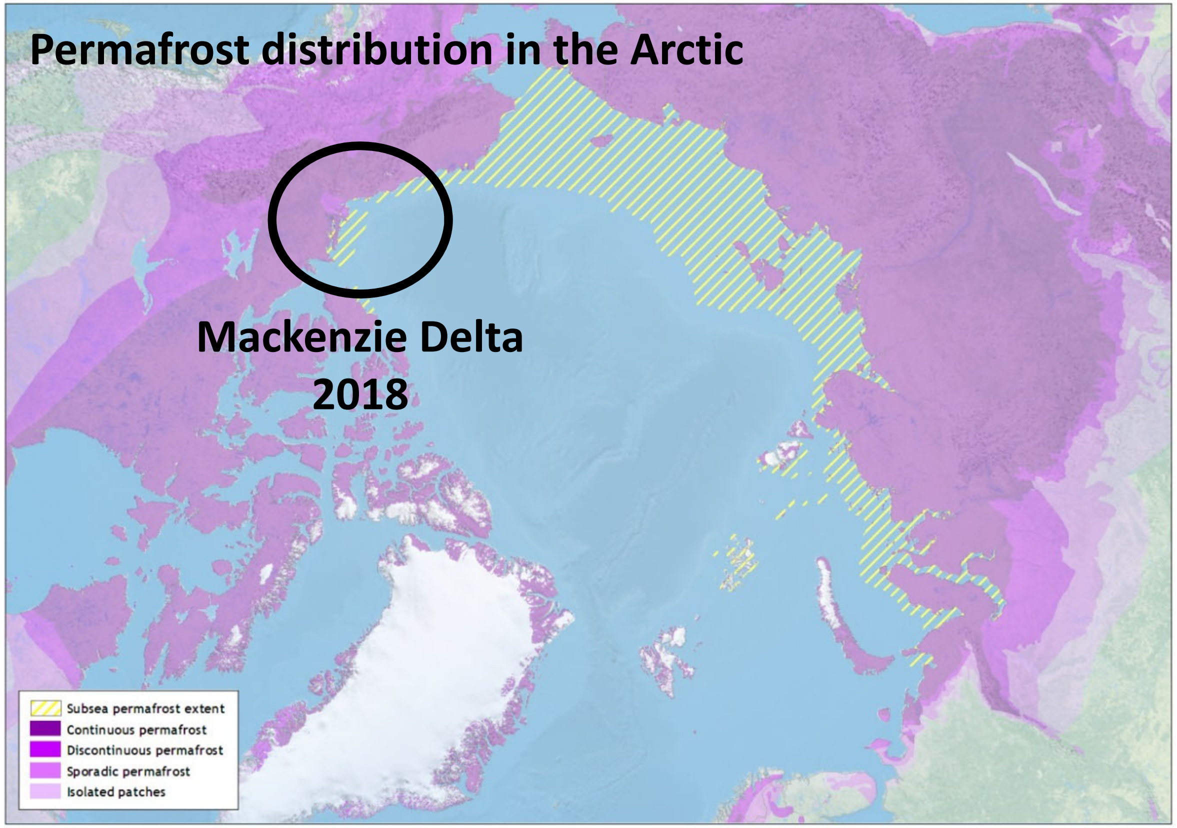


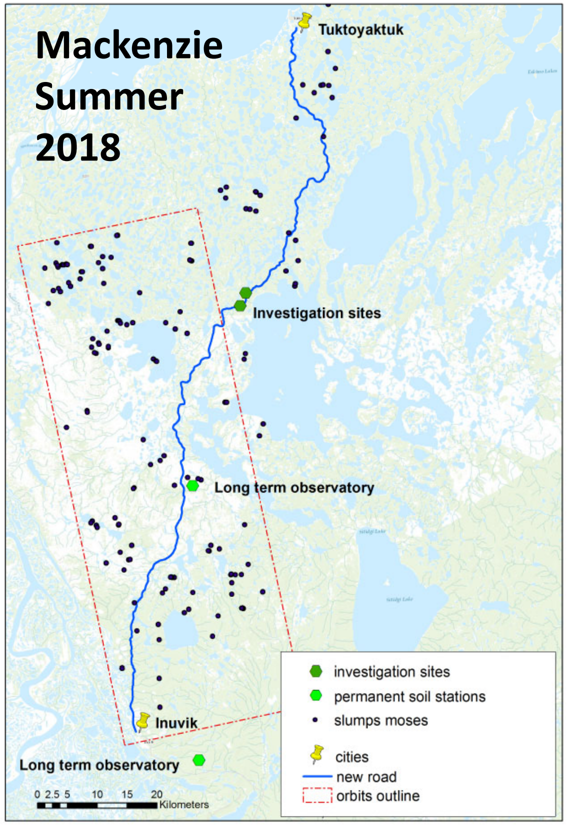
MOSES- Polar 5- PermaSAR

Lead: Julia Boike

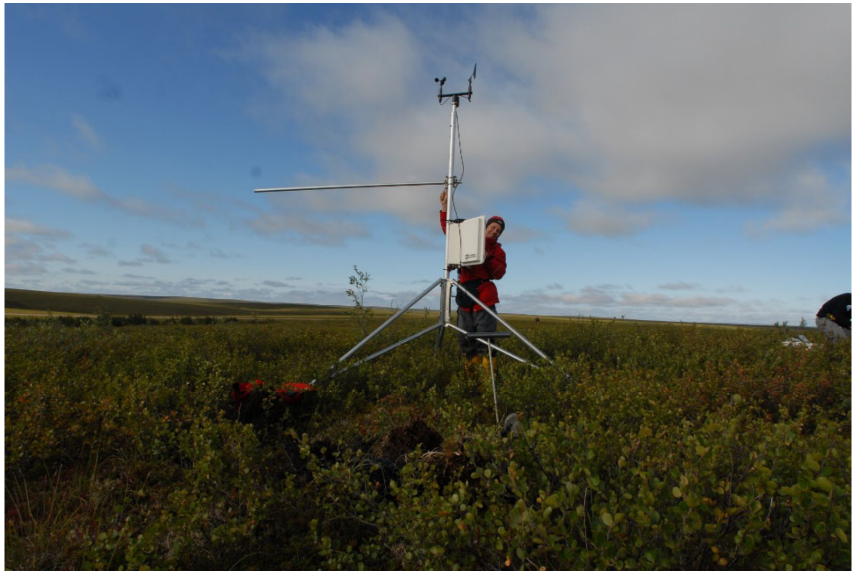
- 4 weeks (12.8.-7.9.)
- DLR/Polar 5 & AWI ground team working at same sites
- Successful Polar5 repeat survey of Trail Valley Creek and road
- Outreach: public presentation at ARI, blog, Wochenberichte

PermaSAR / MOSES 2018





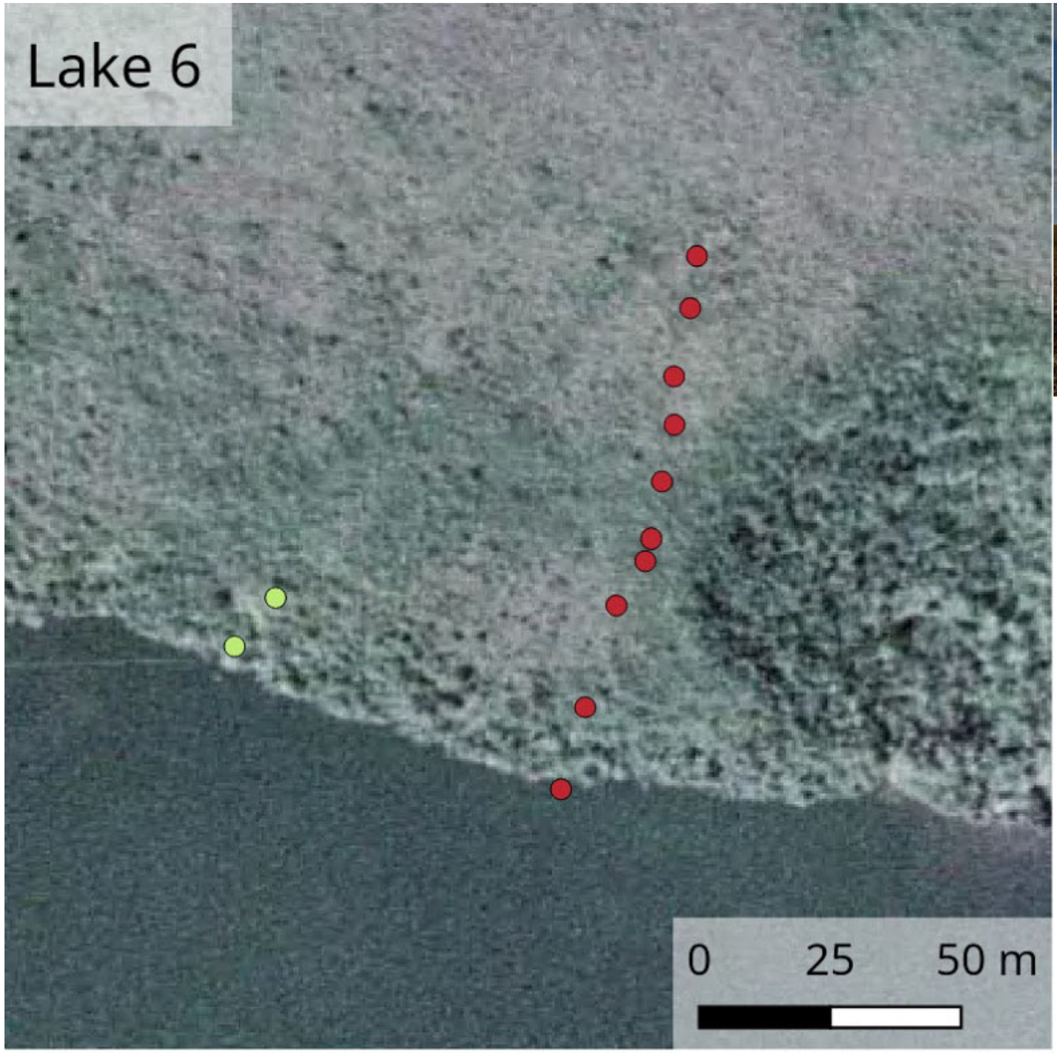
PermaSAR / MOSES 2018

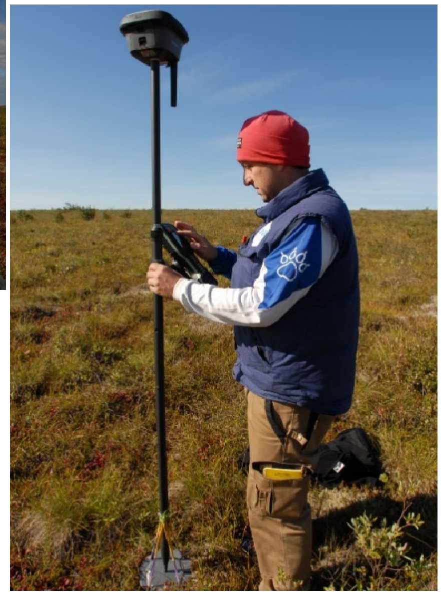



Trail valley creek, NWT, Canada
https://blogs.helmholtz.de/moses/

PermaSAR / MOSES 2018

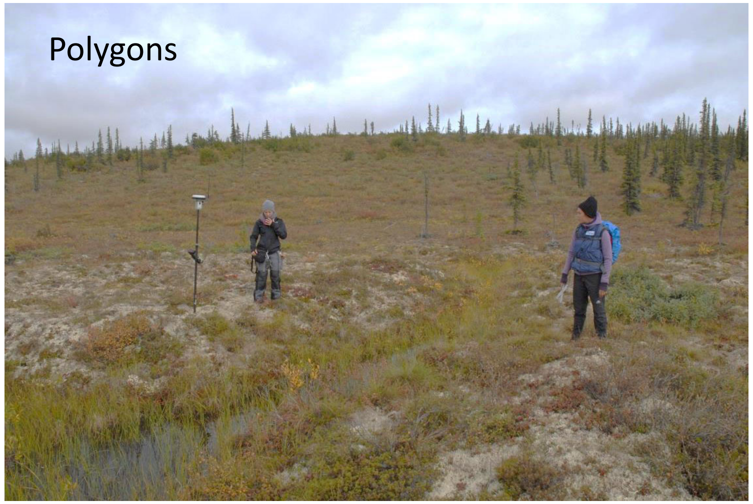
Detailed measurements of land surface characteristics





PermaSAR / MOSES 2018

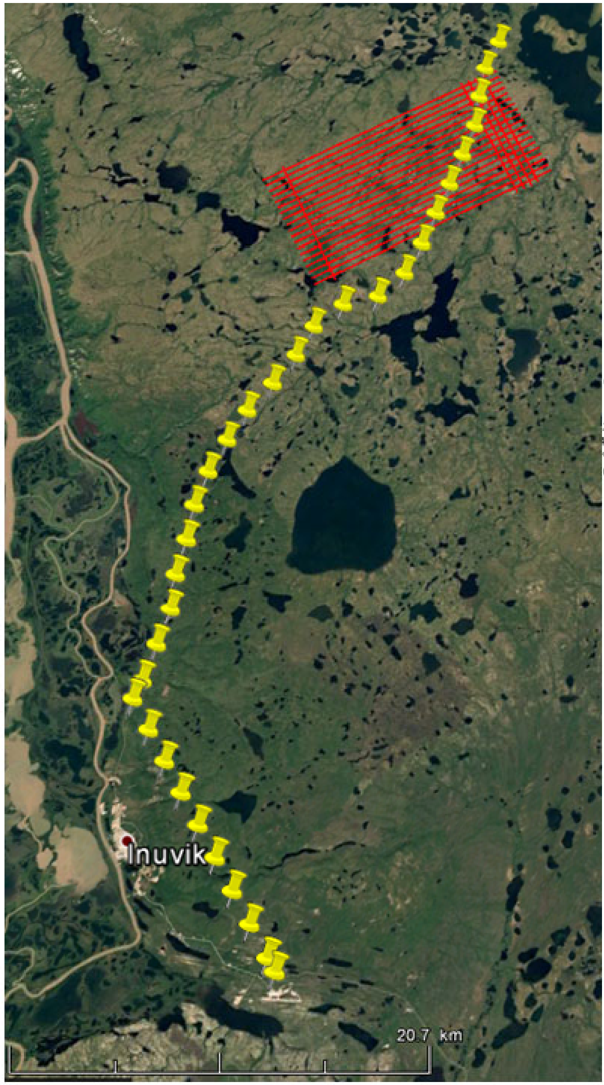
GNSS surveys, 2016+2018

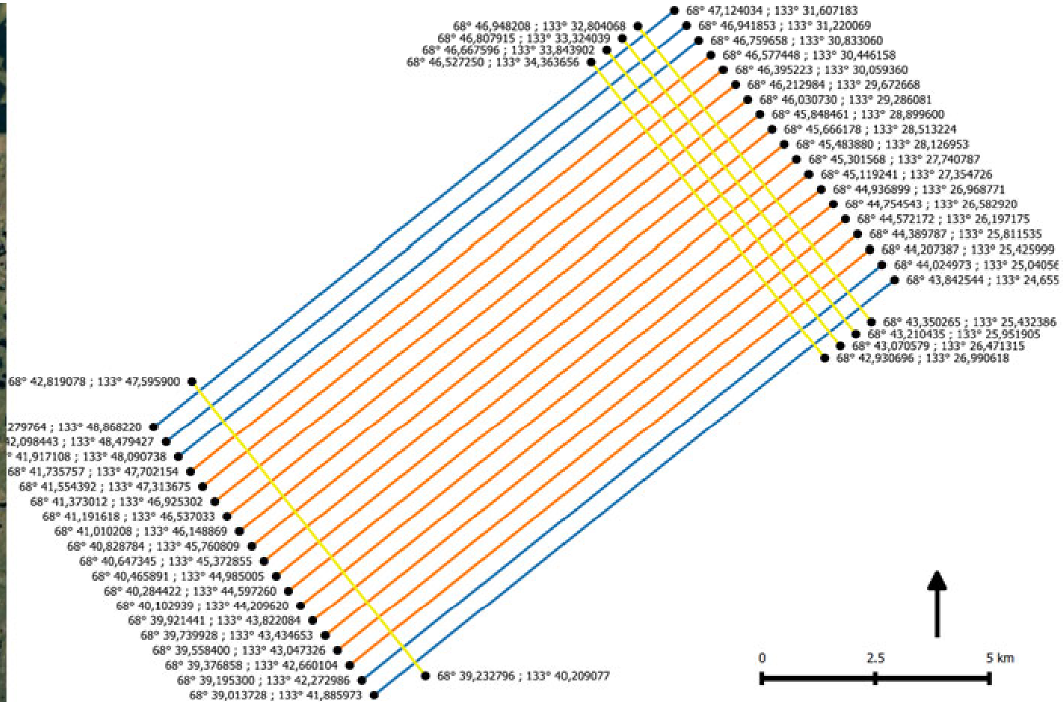


→Detecting of small-Scale Subsidence (point scale)

→ Validation of DEMs

PermaSAR / MOSES 2018





yellow = cross lines
blue = additional lines

Google Earth screenshot: Inuvik airport to Trail Valley via the Inuvik Tuk Highway

DLR MACS onboard Polar-5

- First Campaign in end of August 2018
- Alaska and NW Canada were targeted
- Due to technical issues with plane only Canada was realized (few observation days)
- Second campaign planned in Alaska in summer 2019 (several weeks field time)
- Targets will include permafrost coastal erosion, thaw subsidence, tundra fire scars, ice wedge polygonal ground, drained thaw lake basins
- Onboard sensors will include Riegl LiDAR for comparison

Conclusions

- Airborne Cameras and LiDARs provide high-resolution, high-accuracy data types currently not available from other platforms
- Airborne Cameras and LiDARs are key to detect and quantify rapid and gradual changes across large permafrost regions
- Airborne remote sensing provides a critical tool for scaling field research and bridging to satellite / model scales
- AWI Polar planes offer unique access to conduct repeated surveys
- Expanding the AWI airborne sensor suite would provide continued capacities for observations of polar landscapes


Questions?