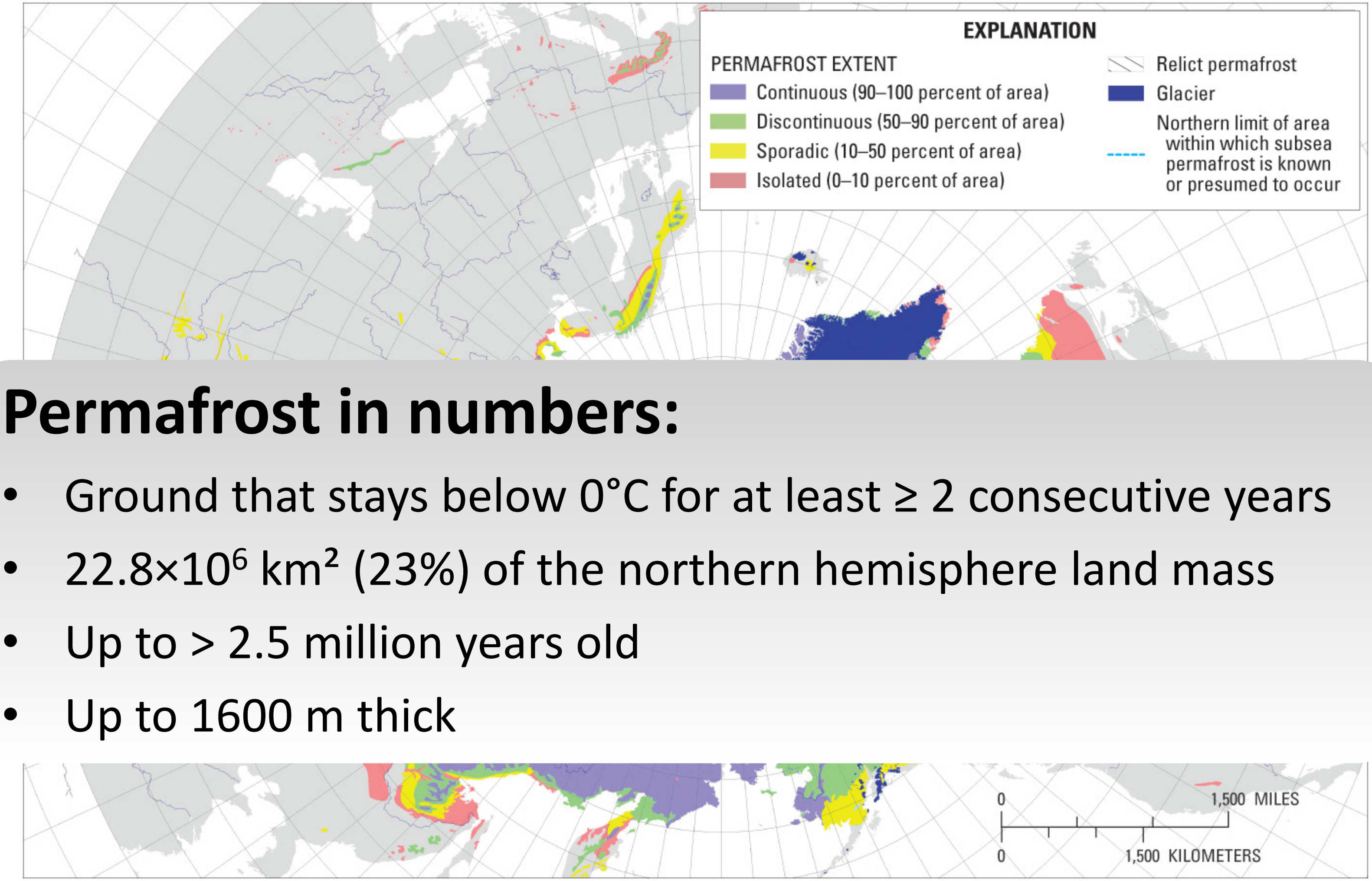
INTRO TO REMOTE SENSING OF PERMAFROST LANDSCAPES AND DYNAMICS

European Research Council
Established by the European Commission

Guido Grosse
Alfred Wegener Institute, Periglacial Research Unit

Northern Hemisphere Permafrost

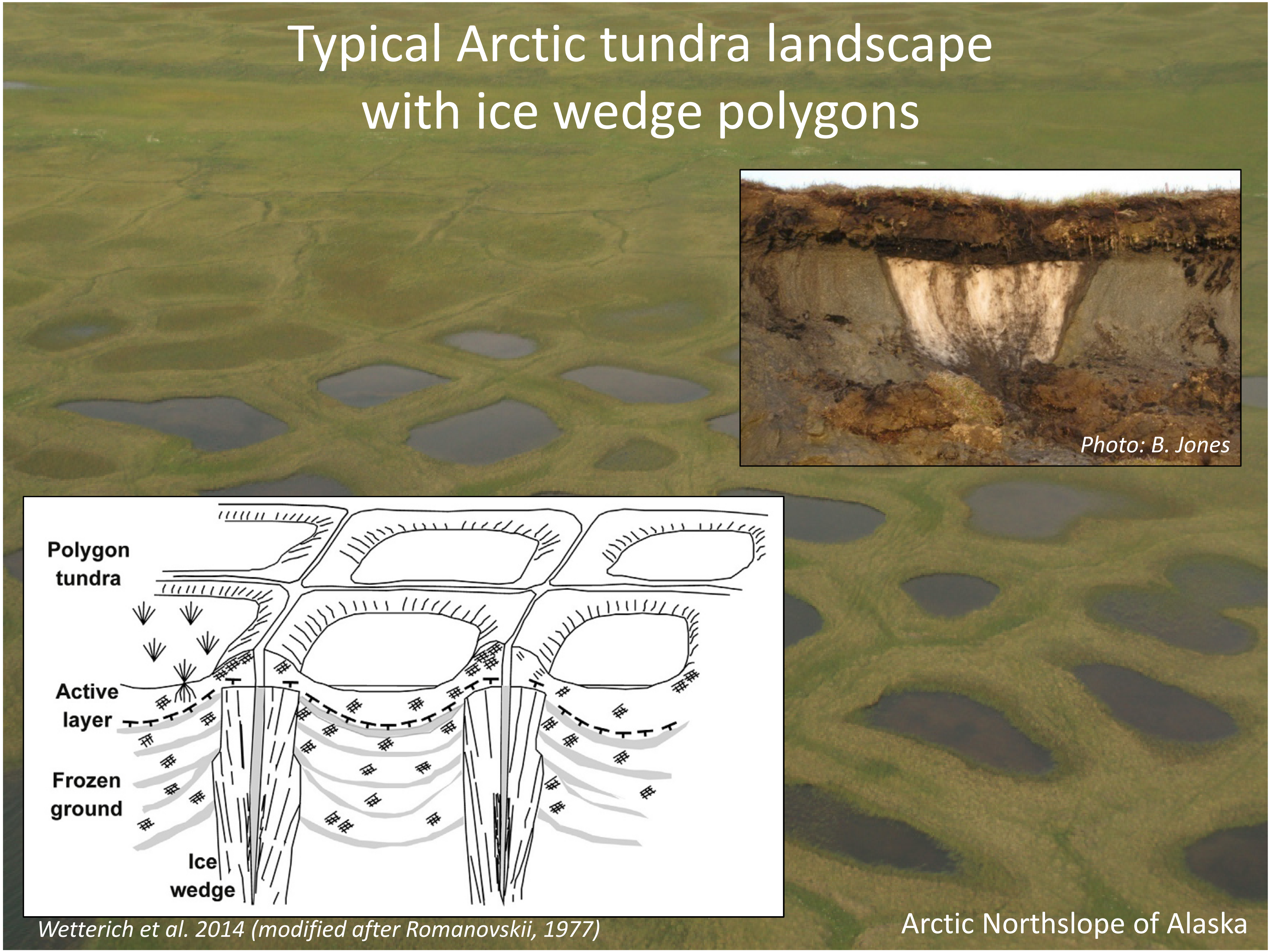


Permafrost in numbers:

- 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 1998

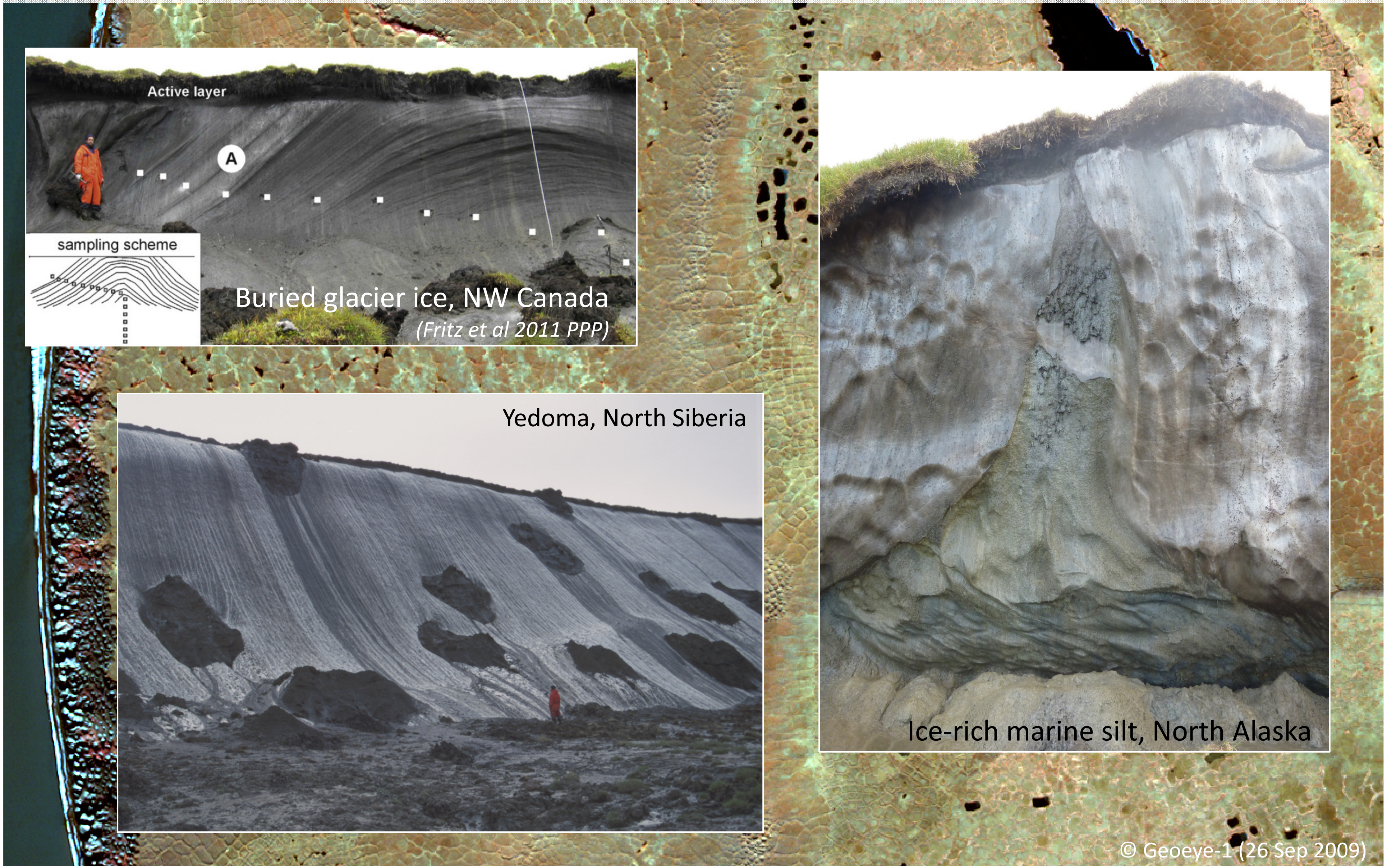
Typical Arctic tundra landscape with ice wedge polygons



Wetterich et al. 2014 (modified after Romanovskii, 1977)

Arctic Northslope of Alaska

Permafrost and ground ice



Permafrost and the Global Carbon Budget

Sergey A. Zimov, Ed

High stocks of soil organic carbon in the North American Arctic region

CHIEN-LU PING[1]*, GARY J. MICHAELSON[1], MARK T. JORGENSON[2], JOHN M. KIMBLE[3], HOWARD EPSTEIN[4], VLADIMIR E. ROMANOVSKY[5] AND DONALD A. WALKER[6]

The effect of permafrost thaw on old carbon release and net carbon exchange from tundra

Sickman[2] & T. E. Osterkamp[3]

Vulnerabil Carbon to Implicatio Carbon Cy

EDWARD A. G. SCHUUR, JAMES B FIELD, SERGEY V. GORYACHKIN, S MAZHITOVA, FREDERICK E. NELSC CHARLES TARNOCAI, SERGEY VEN

:Guire,[4] Philip Camill,[5] e Jorgenson,[9] ind,[10] Nancy French,[11] l[10]

A sleeping giant?

As the planet warms, vast stores of methane — a potent greenhouse gas — could be released from frozen deposits on land and under the ocean. **Amanda Leigh Mascarelli** reports on the race to understand a ticking time bomb.

nature reports climate change | VOL 3 | APRIL 2009 | www.nature.com/reports/climatechange

Amount and ti resp

By KEVIN SCHAEFER[1] BARRETT[1]. [1]*National Snow ar*

dbacks ite Change

e and Vladimir Romanovsky, Geo- ute, University of Alaska Fairbanks; e@gi.alaska.edu; Torre Jorgenson, ence, Fairbanks, Alaska; Katey Walter ute of Northern Engineering, Univer- Fairbanks; Jerry Brown, Woods Hole, r Paul Overduin, Alfred Wegener olar and Marine Research, Potsdam,

CARBON STORAGE

A permafrost carbon bomb?

The fate of permafrost soil carbon following thaw depends on hydrology.

Claire C. Treat and Steve Frolking

NATURE CLIMATE CHANGE | VOL 3 | OCTOBER 2013 | www.nature.com/natureclimatechange

Methane limited by

J. van Huissteden[1]*

Thermokars of Atmosph Last Deglac

K. M. Walter,[1,2]* M. E. Edwards,[3,4]

g to the its of the

ir Yusupov,[2]

Permafrost car accelerate glol

Charles D. Koven[a,b,1], Bruno Ring Gerhard Krinner[e], and Charles T

Soil temperatu the role of and permafrost soil

D. Wisser[1], S. Marchenko

bon under Future

PERMAFROST CARBON STORAGE

Pandora's freezer?

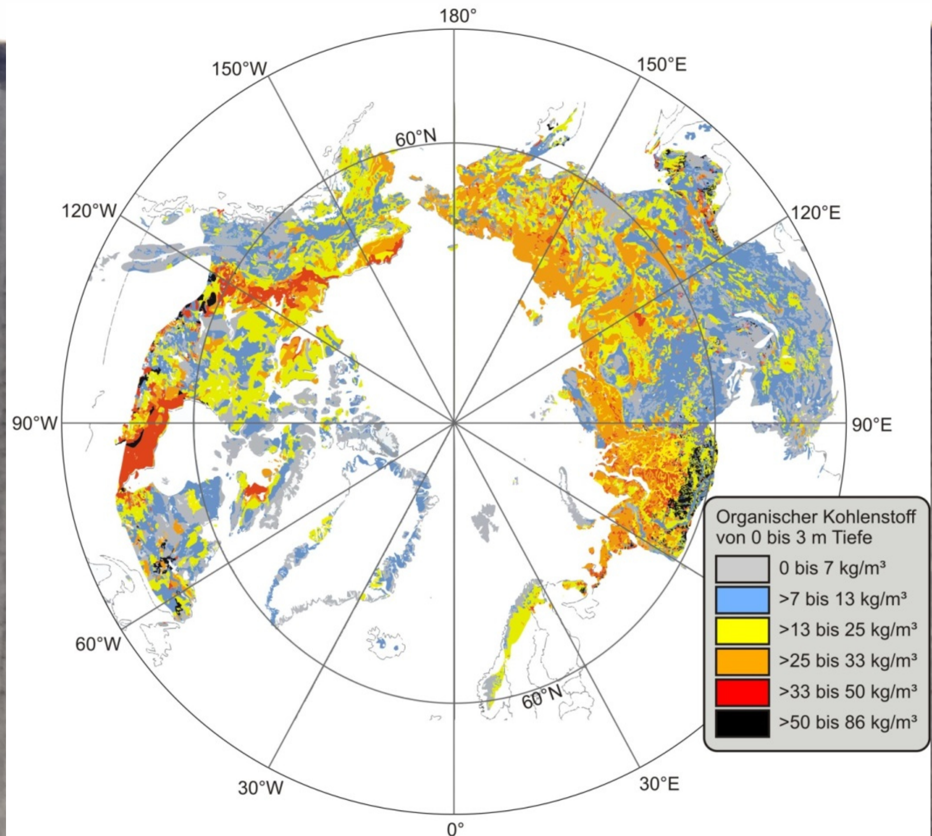
NATURE CLIMATE CHANGE | VOL 3 | MAY 2013 | www.nature.com/natureclimatechange

t thaw

er world, say

Edward A. G. Schuur, Benjamin Abbott and the Permafrost Carbon Network.

Permafrost Carbon Feedback



Permafrost	→ 1330-1580 GtC
Atmosphere	→ 800 GtC
Vegetation	→ 550 GtC
Fossil Fuel	→ 4,130 GtC
Global Soils	→ 2,300 GtC
Global Ocean	→ 38,000 GtC

Strauss et al. 2013 (GRL), Hugelius et al. 2014 (Biogeosciences), Walter Anthony et al. 2014 (Nature), Schuur et al. 2015 (Nature)

Sobo-Sise Yedoma Cliff, Lena Delta (Photo: Strauss)

Why remote sensing of permafrost landscapes?

Permafrost field research:

- Vast and remote regions
- Harsh climate
- Limited access
- Expensive logistics
- Sparse field sites
- Few long records
- Few continuous datasets

Remote Sensing:

- Covering large regions
- Remote data collection
- Increasingly long + continuous datasets
- Allows scaling of field data
- Can inform where permafrost is changing
- Provides spatially continuous data for models
- New platforms and sensors
- Increasing computational capacities
- New processing methods

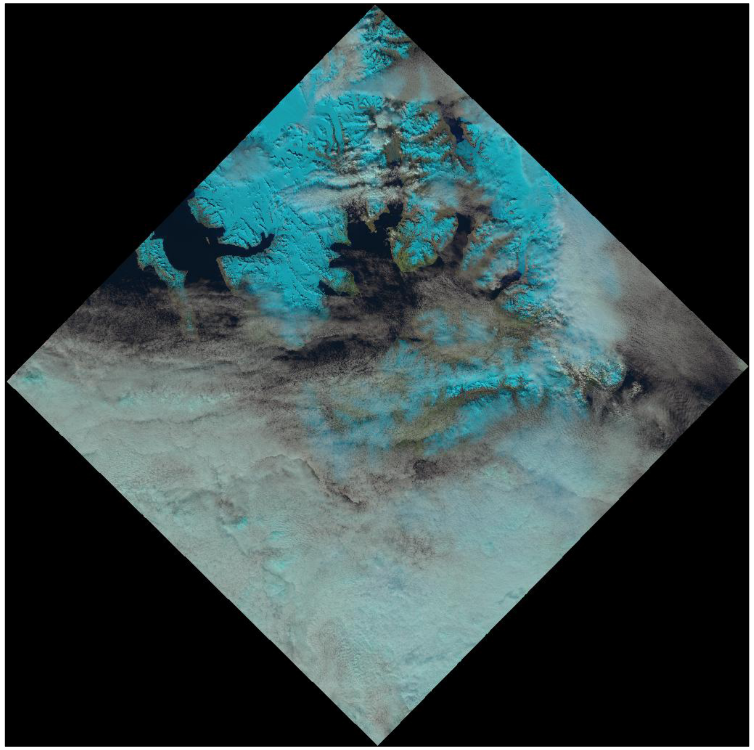
➡ Rapidly Growing Method in Permafrost Research

Remote sensing instrument categories

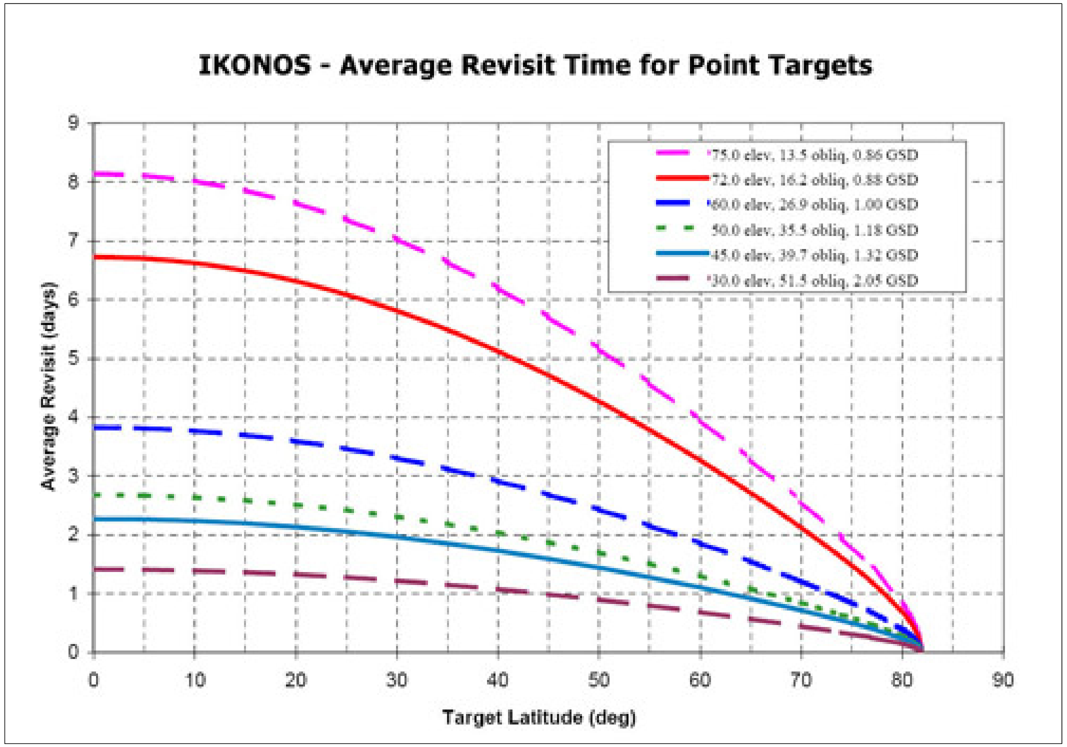
- Atmospheric chemistry instruments
- Atmospheric temperature and humidity sounders
- Cloud profile and rain radars
- Earth radiation budget radiometers
- High resolution optical imagers
- Imaging multi-/hyper-spectral radiometers (vis/IR)
- Imaging multi-spectral radiometers (passive microwave)
- Imaging microwave radars
- Lidars
- Multiple direction/polarisation instruments
- Ocean colour instruments
- Radar altimeters
- Scatterometers
- Gravity, magnetic field and geodynamic instruments
- Airborne geophysical instruments (tomography, resistivity)

Challenges and advantages of high latitude EO

- Challenges
  - Polar night, frequent clouds, ice/snow cover, low sun angles
- Advantages
  - Frequent revisit times
  - Strongly overlapping acquisition swaths



Landsat-8, Svalbard, 29-06-2014



Source: Satimagingcorp

Remote sensing of permafrost

Challenge:

- Permafrost is a subsurface temperature phenomenon
- Surface features related to permafrost may be non-existent, covered, abundant, or relict
- Permafrost changes may manifest at the surface or not
- Surface changes may have temporal lags to permafrost changes

Remote sensing of permafrost

Tasks for Remote Sensing:

- Constraining the presence or absence of permafrost (spatial extent, ground-ice content + distribution)
- Quantifying geo/biophysical characteristics of ground and land surfaces (temperatures, water content, resistivity, vegetation + soil layers)
- Measurement of permafrost change-related dynamics (thaw subsidence + frost heave, erosion, biogeochemical fluxes, energy, water, and matter fluxes)

Remote sensing approaches depend on:

- Permafrost type: mountain permafrost / lowland permafrost
- Target: surface features / geophysical parameters / processes

→ Choice of platform + sensors: ground-based / aerial / satellite

Permafrost variables vs. remote sensing

Permafrost State

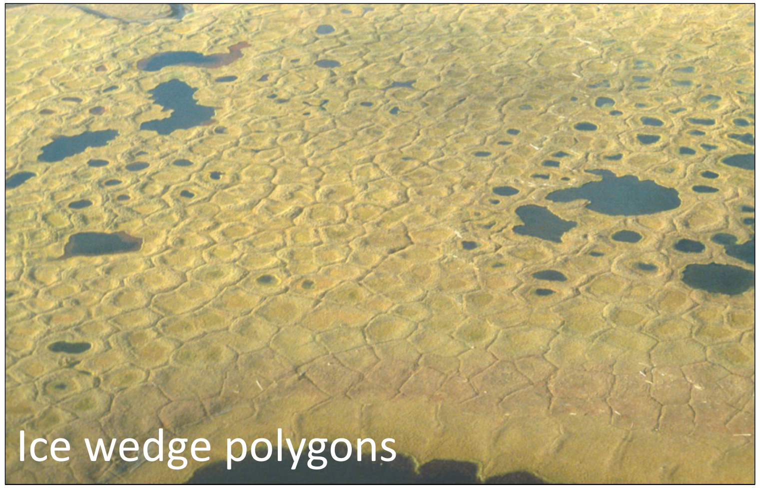
1. Ground temperature
2. Thickness of the active layer or depth to the permafrost surface
3. Thickness of permafrost
4. Spatial patchiness of permafrost
5. Ice content and distribution in permafrost

Remote sensing observables in permafrost regions

- Permafrost and active layer surface expressions
- Landscape change due to permafrost degradation/aggradation
- Seasonal active layer settlement/heave
- Vegetation related to permafrost properties
- Physical land surface properties related to permafrost and active layer (LST, Freeze-Thaw, snow)
- Subsurface properties related to permafrost (active layer thickness, ground ice)

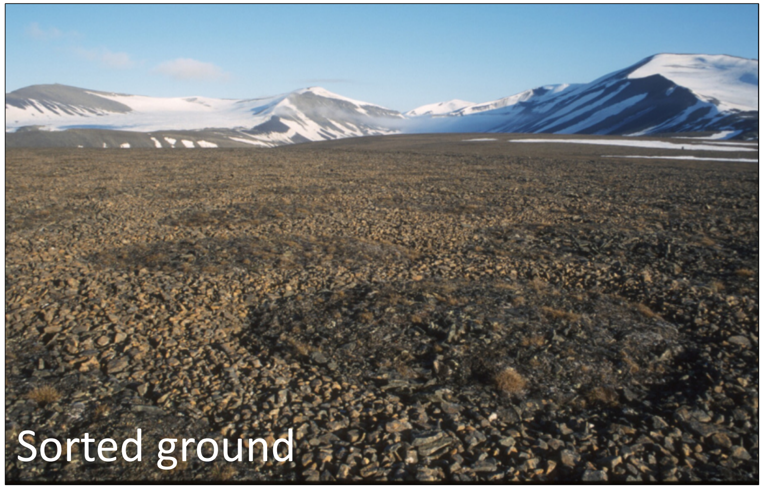
Permafrost and active layer features

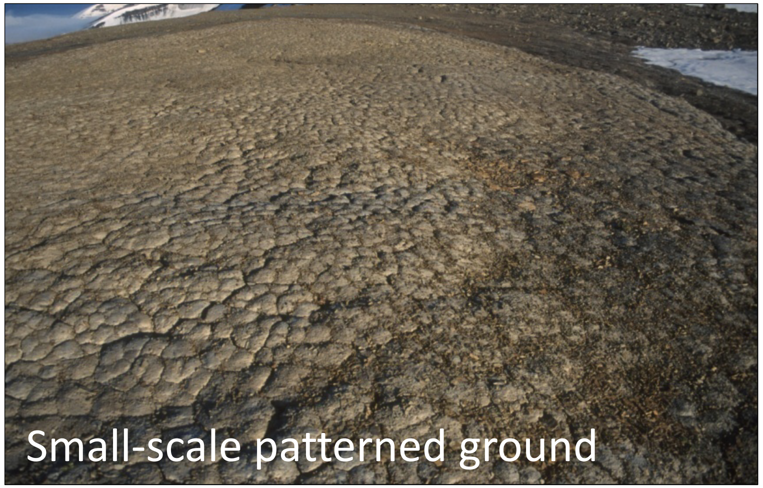
Permafrost features: Formed by permafrost aggradation


Ice wedge polygons


Perennial frost mounds (pingo)

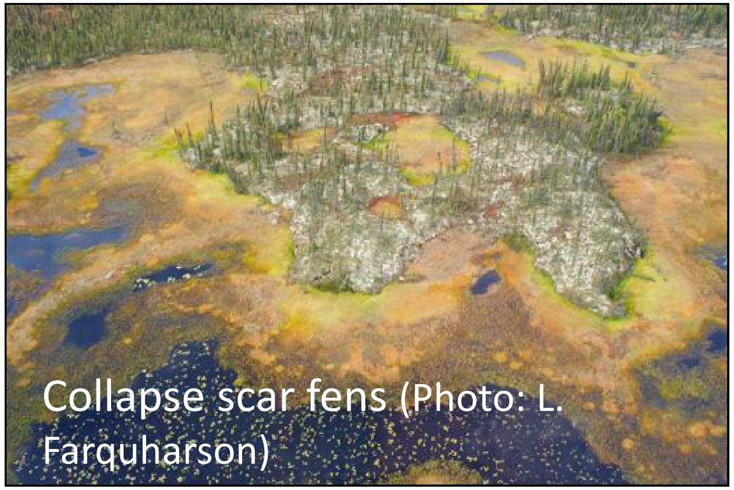
Active layer features: Formed by seasonal freeze-thaw cycles


Sorted ground


Small-scale patterned ground

Thermokarst features

- Formed by thaw settlement in ice-rich permafrost


Collapse scar fens (Photo: L. Farquharson)

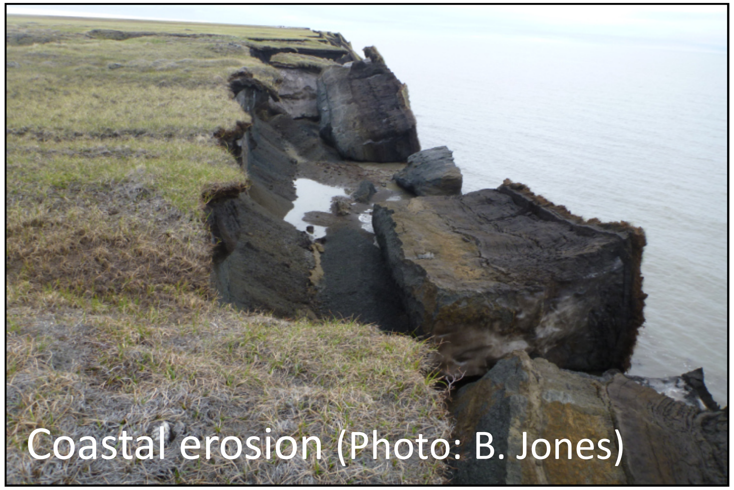

Collapsed pingo (Photo: B. Jones)


Thermokarst lakes (Photo: B. Jones)


Ice wedge collapse and TK ponds (Photo: B. Jones)

Thermo-erosion features

- Formed by thermal and mechanical erosion along topographic gradients


Coastal erosion (Photo: B. Jones)

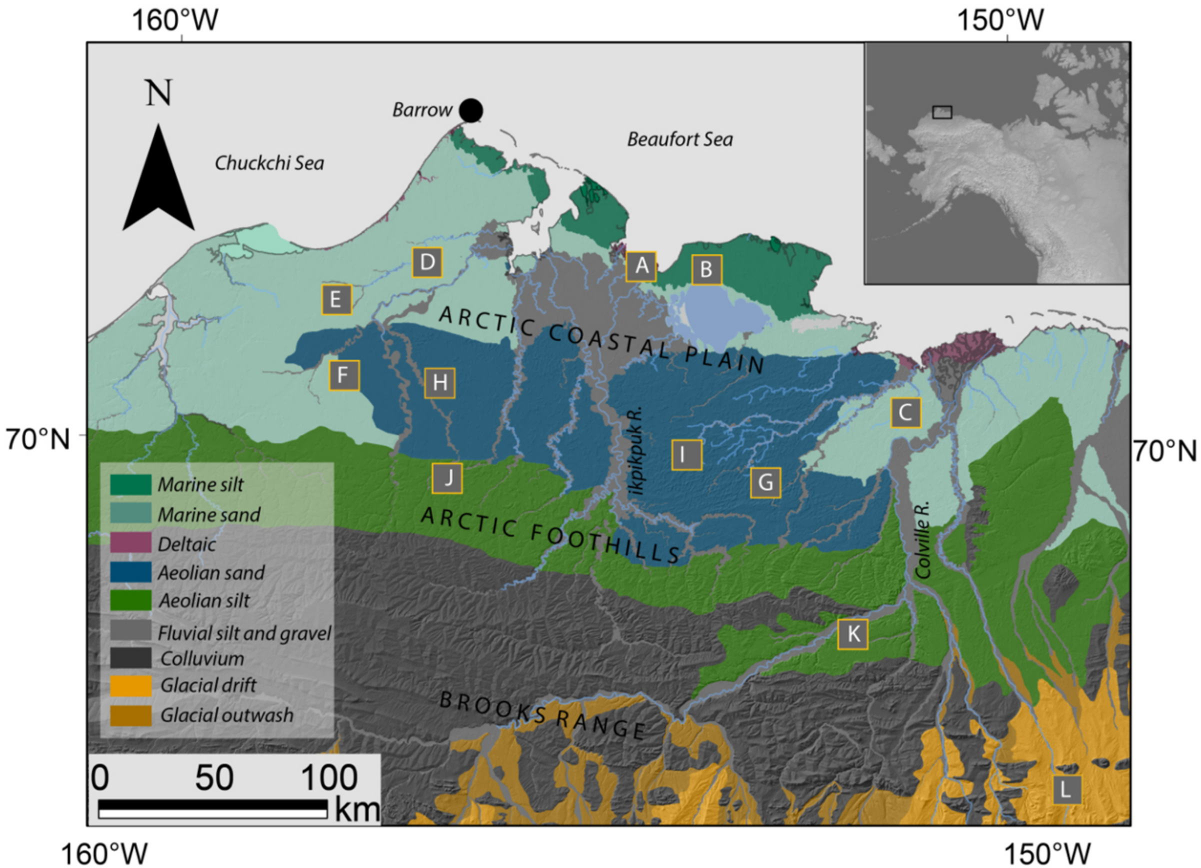

Thaw slump, glacial deposits (Photo: S. Kokelj)


Active layer detachment slide (Photo: G. Grosse)


Thermo-erosion gully (Photo: L. Farquharson)

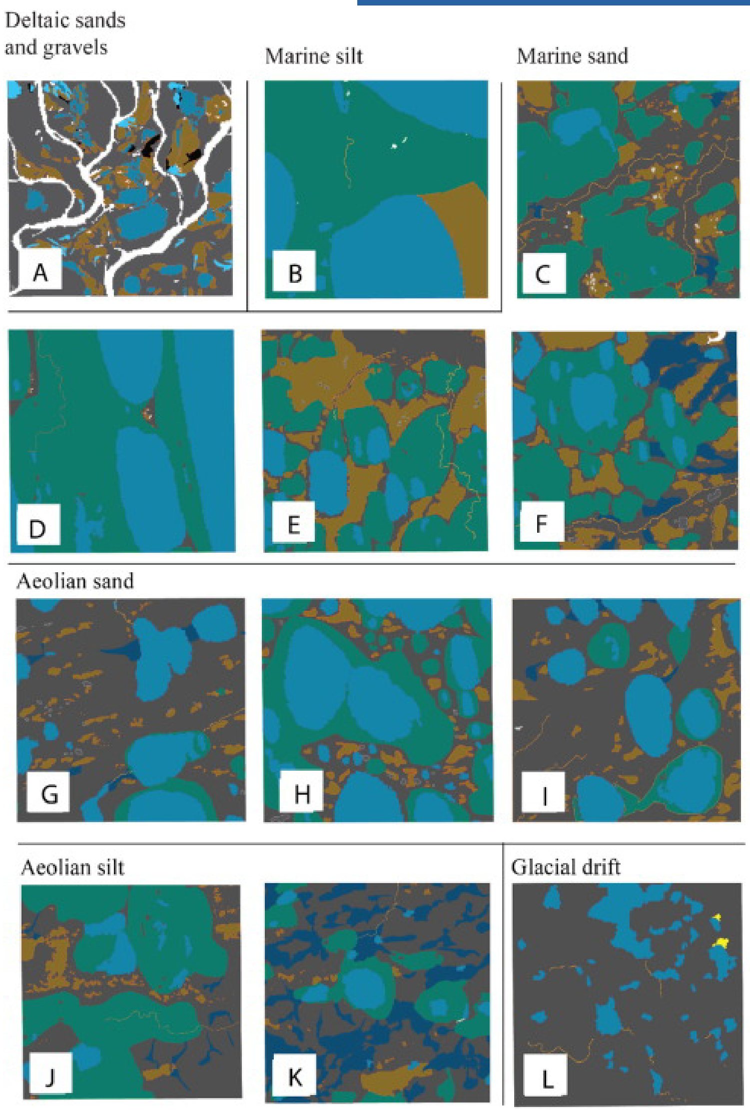
Mapping of lowland thermokarst features

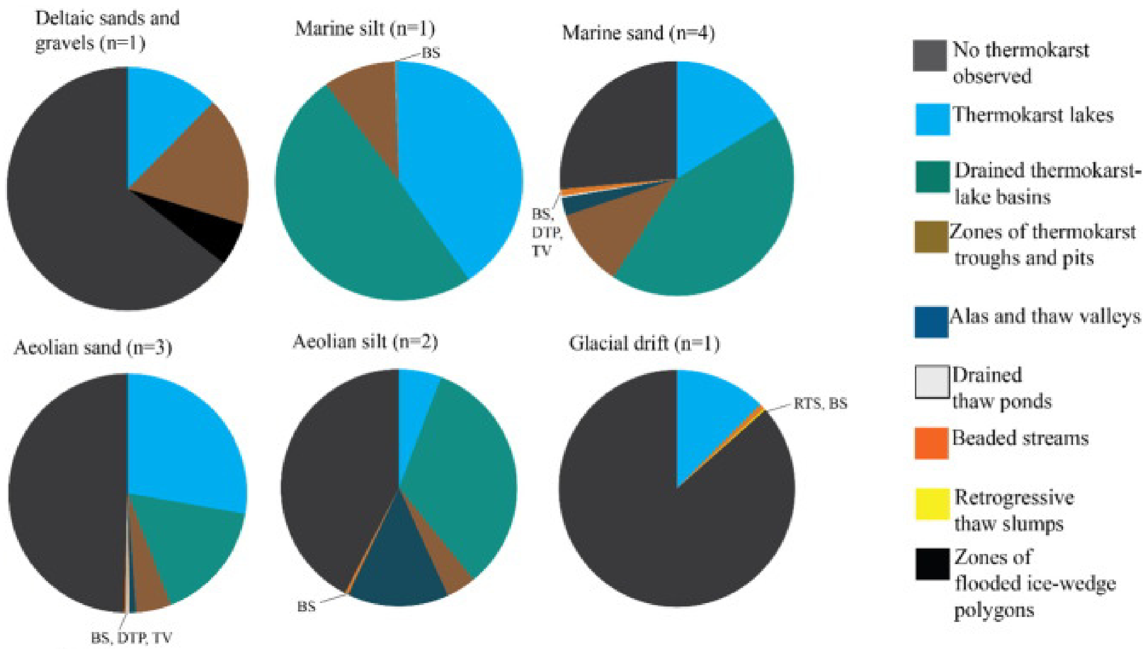
- Alaska North Slope
- Continuous Permafrost
- Based on ortho aerial photography, IfSAR DEM and NLCD data
- 9 types of thermokarst landforms mapped across 6 different surficial geology types
- 12 study areas @ 5x5 km



Farquharson et al., 2016, Geomorphology

Mapping of lowland thermokarst features



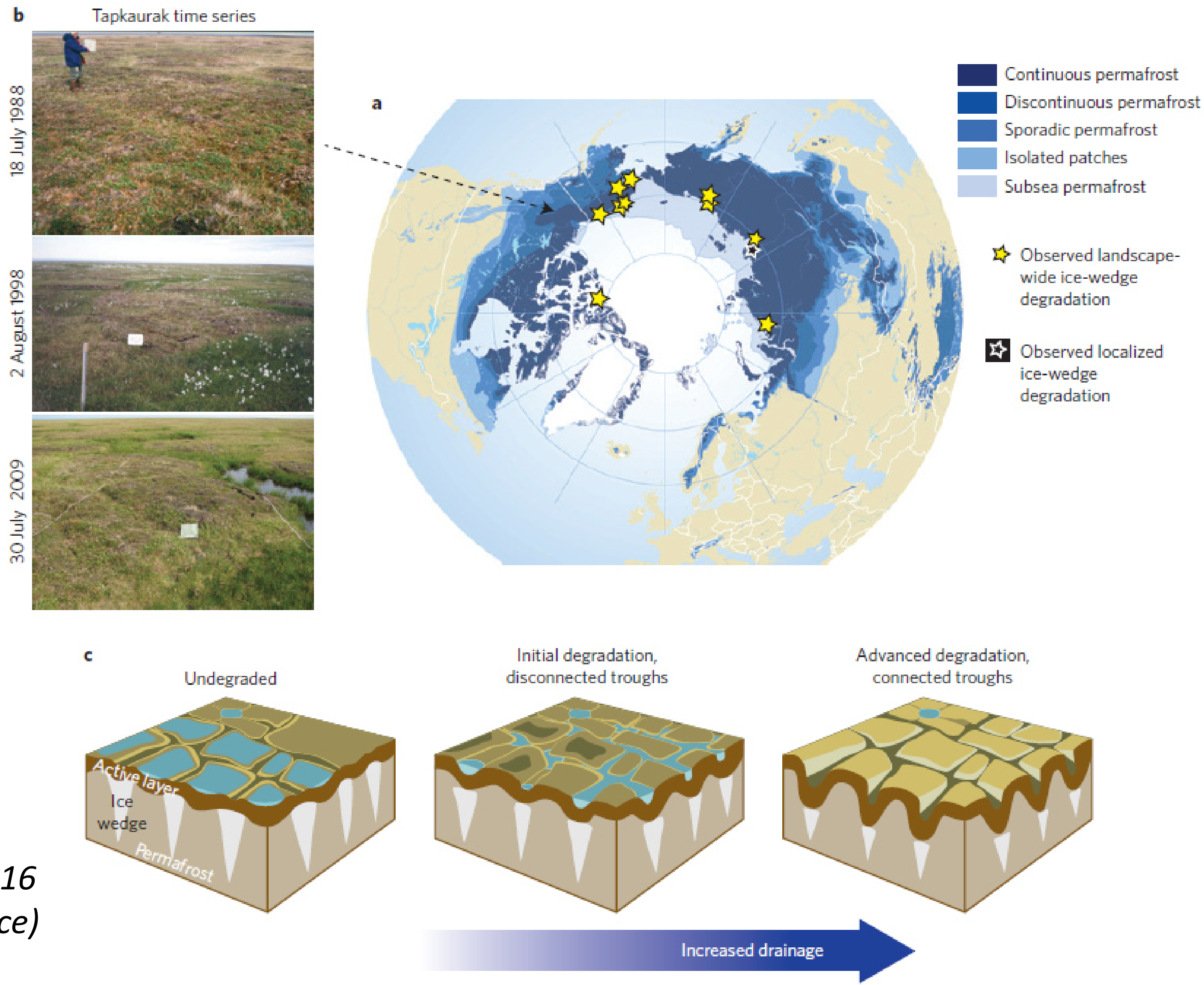


Farquharson et al., 2016, Geomorphology

Highlights

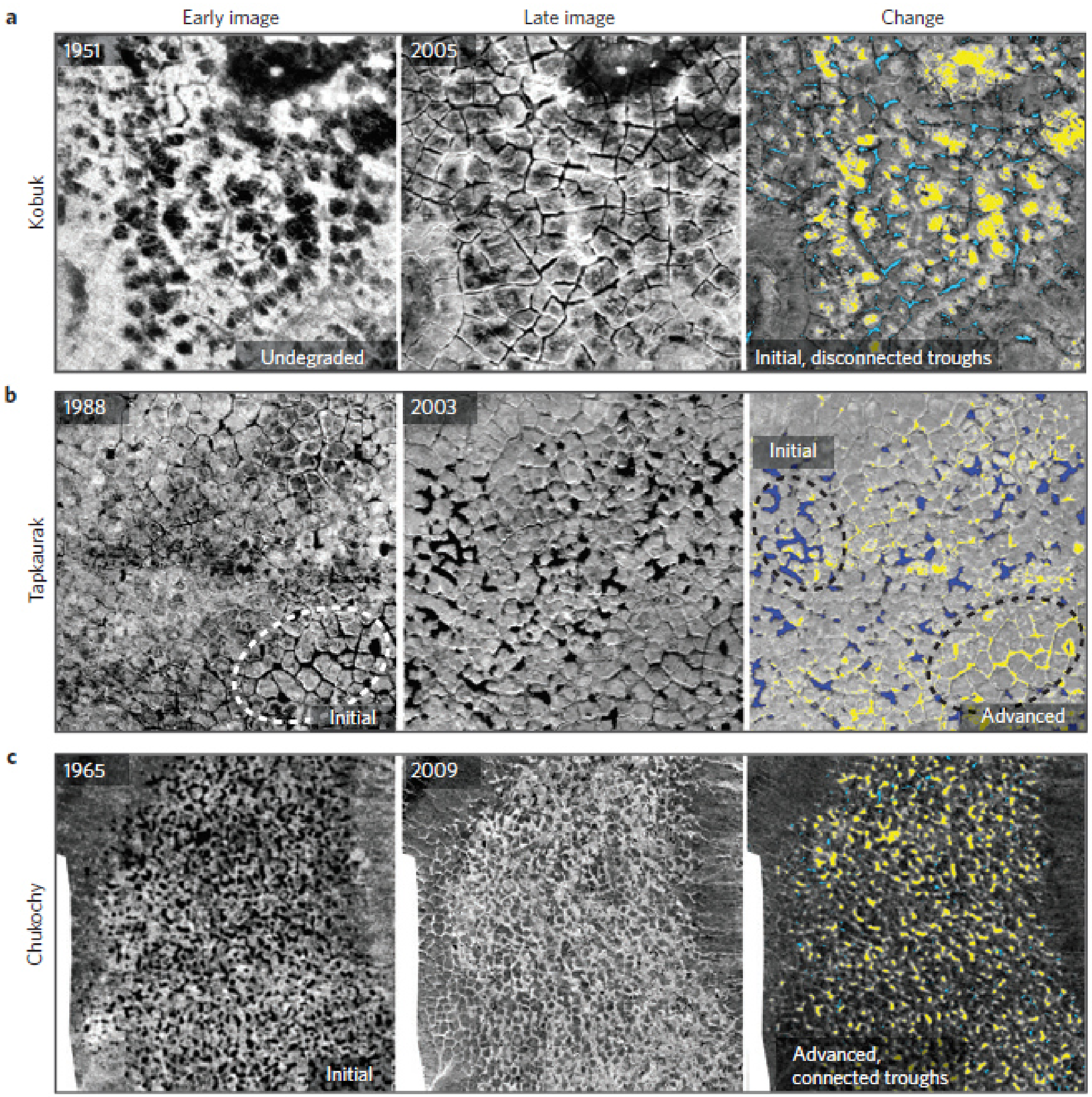
- 63% of the 300-km^2 study area covered by TK landforms
- TK landform distribution varies across surficial geology types, ice-rich marine silt areas most TK affected
- Drained TK lake basins are the most widespread thaw-related landform, covering 33% of study region
- In the future, ice-rich aeolian upland terrain (yedoma) and marine silt may be particularly susceptible to thaw

Ice wedge degradation with VHR imagery



Liljedahl et al., 2016 (Nature Geoscience)

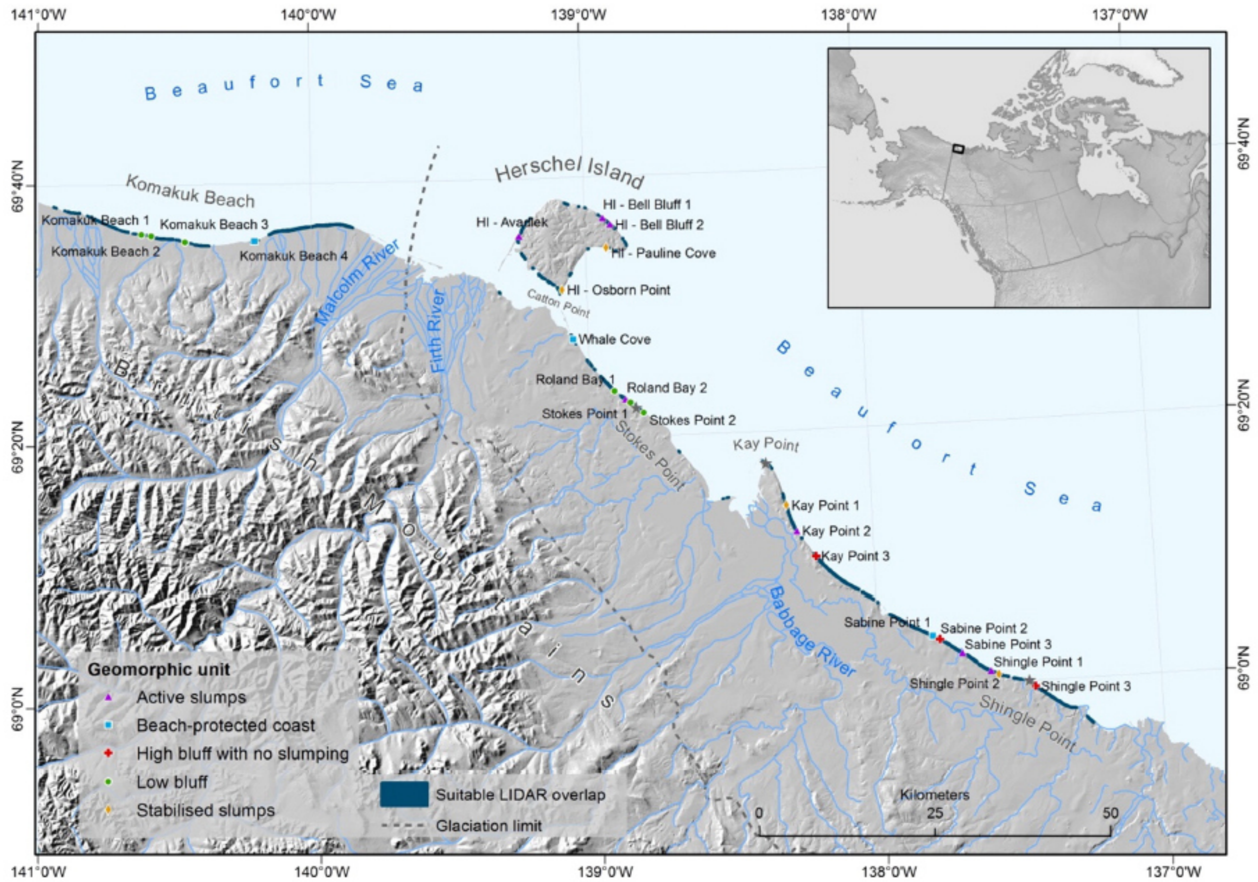
Ice wedge degradation with VHR imagery



Liljedahl et al., 2016
(Nature Geoscience)

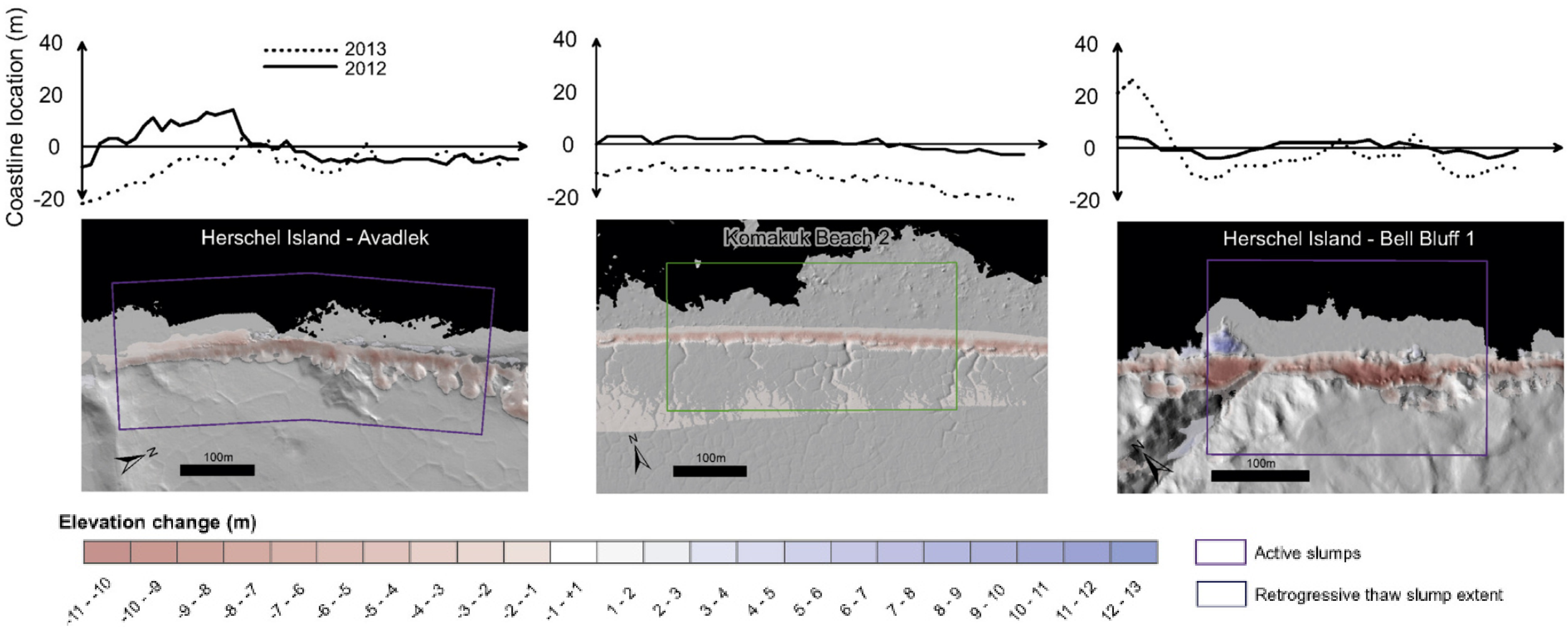
Arctic Coastal Dynamics with repeat LiDAR

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



Obu et al., 2016 (Geomorphology)

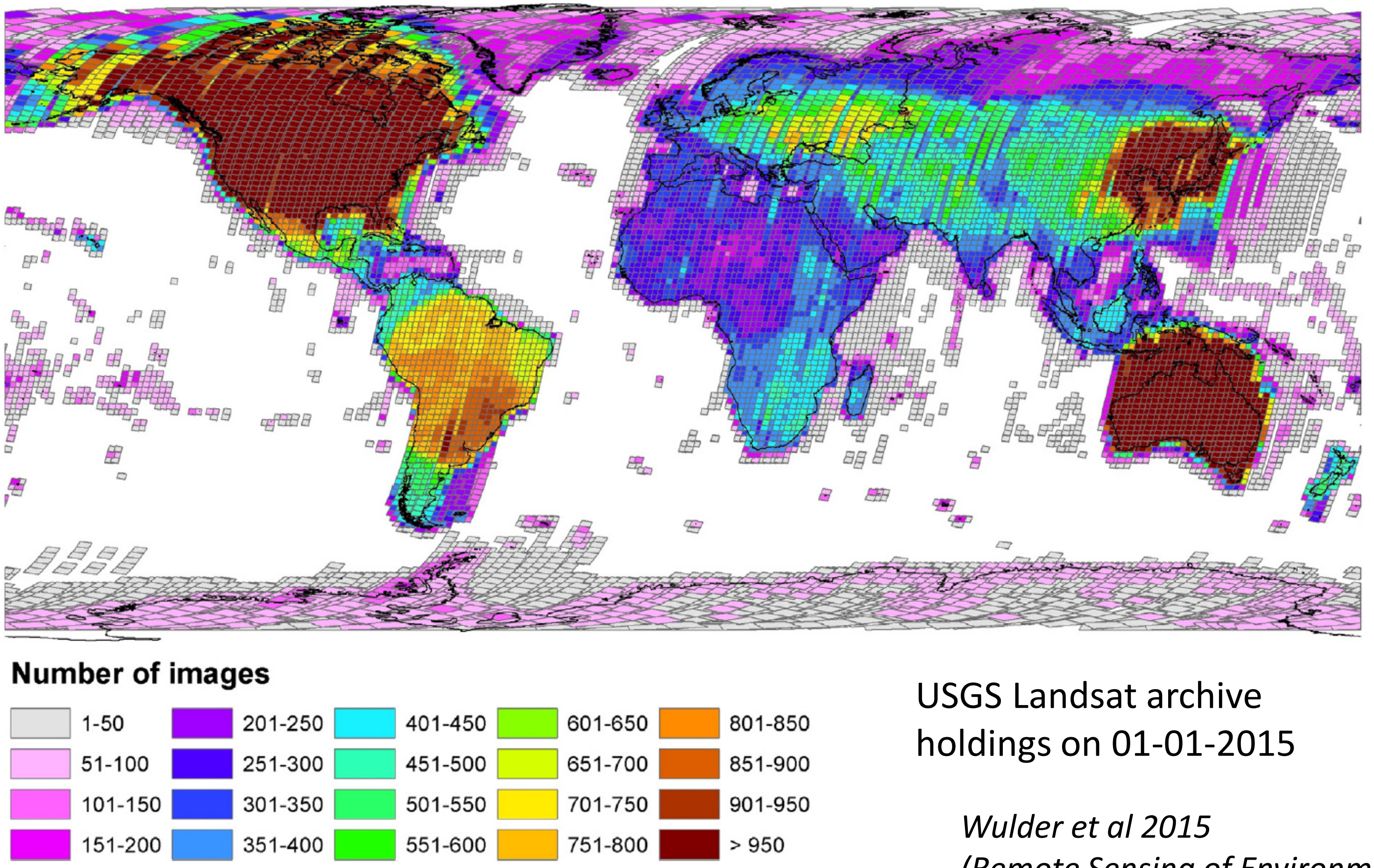
Arctic Coastal Dynamics with repeat LiDAR



- 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 (Geomorphology)

Landsat Data Coverage



USGS Landsat archive holdings on 01-01-2015

Wulder et al 2015 (Remote Sensing of Environment)

→ Total of 5,532,454 images

→ 4134 TB of image data

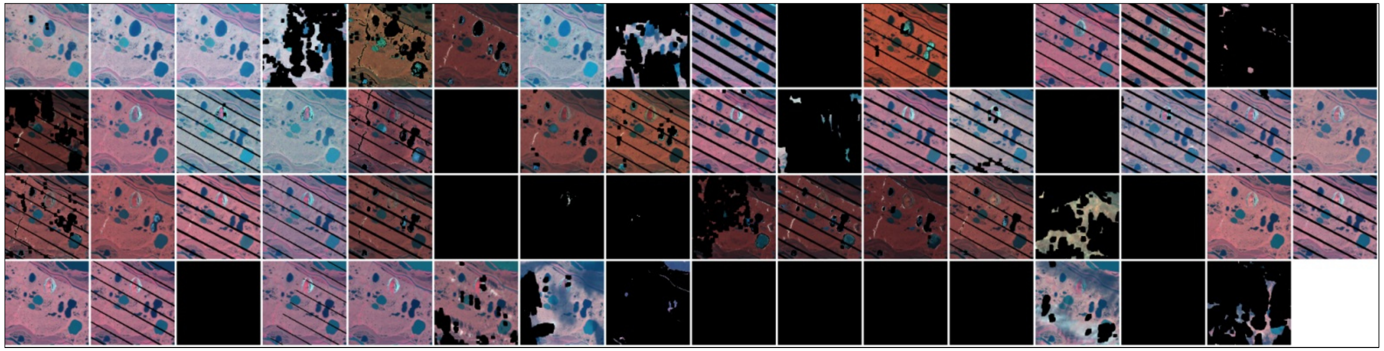
→ Annual acquisition rate L7: 119,135 images

→ Annual acquisition rate L8: 214,081 images

Analysis of temporally dense image stacks

- Increasing availability of data, long time series for Landsat
  - Seasonal + multi-annual dynamics in permafrost regions
  - Disturbances: thaw lake drainage, thermokarst pond initation, thaw slump and detachment slide evolution, coastal erosion
  - Land surface trends: Surface wetness, brightness, greenness

Example: 63 Landsat tiles for Lena Delta from 1999-2014

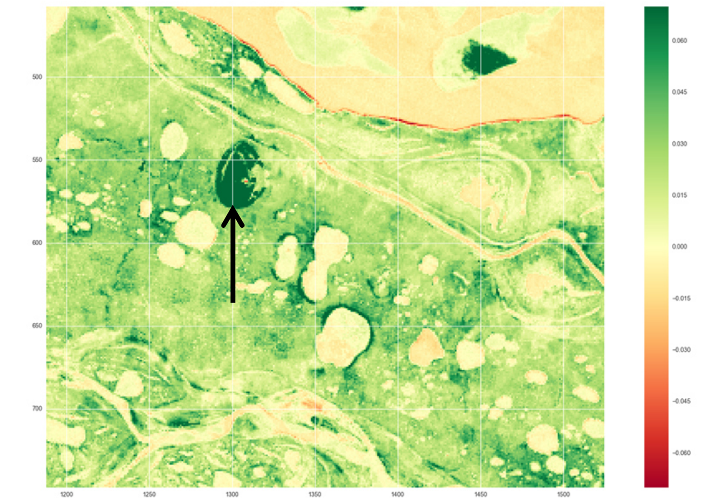


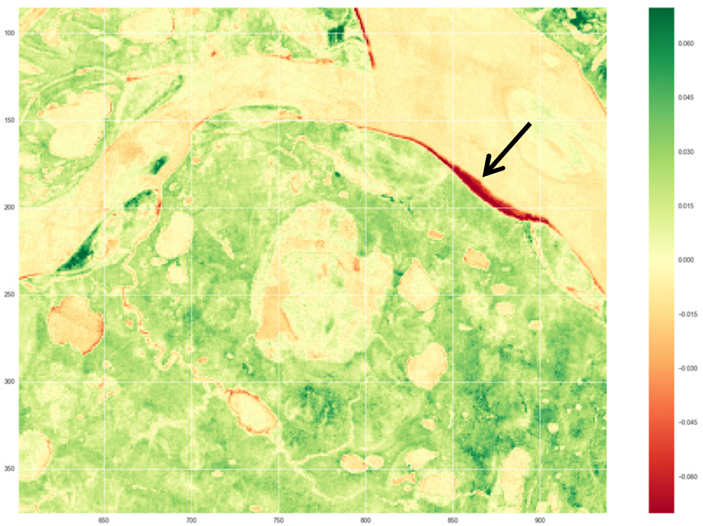
Paradigm shift:

- Interpreter-driven image processing, analysis → big data processing, analytics
- Panarctic monitoring of permafrost disturbances

Nitze & Grosse 2016 (Remote Sensing of Environment)

Analysis of temporally dense image stacks

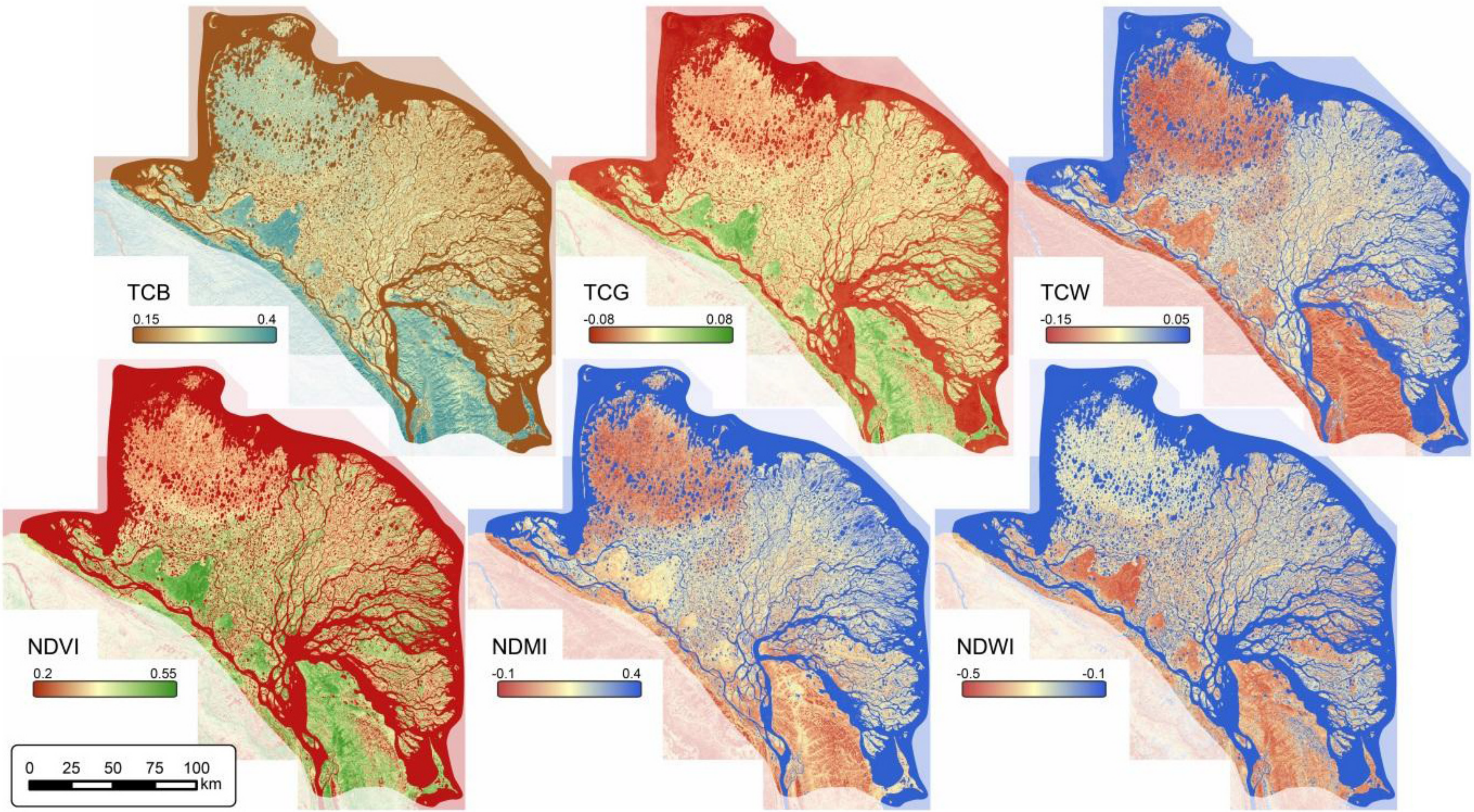




Landsat Tasseled Cap Greenness Trend (change per decade)
Years 2000 – 2014: 31 Landsat Scenes (TM, ETM+, OLI)

Nitze & Grosse 2016 (RSE)

Land surface properties based on Landsat trends



Nitze & Grosse 2016 (RSE)

Summary

- Remote sensing is a useful tool for a wide range of research on permafrost and periglacial landscape dynamics

- Remote sensing is key to scale field research and observe rapid and gradual changes across large permafrost regions

- The future for remote sensing of permafrost is bright:
  - New airborne and satellite sensors
  - Better data availability and accessibility
  - Longer data time series
  - Enhanced methods for processing and analysis

The future of permafrost remote sensing

- LiDAR!: Excellent tool for mapping thermokarst and thaw-related landscape modifications
- Analysis of temporally dense image stacks to determine landscape changes + trends
- Refining permafrost extent maps using MS remote sensing combined with various geophysical measurement techniques: Some great examples from Interior Alaska
- Potential applications of UAVs for deriving SfM type terrain models, sensor miniaturization: High deployment flexibility, lots of prohibitive rules currently
- SAR time series analysis and InSAR deformation mapping: Issues with trying to remotely sense thermokarst development as it leads to loss of coherence
- Optical and radar remote sensing data fusion
- New and planned satellite and airborne missions

ESA GlobPermafrost

A service for permafrost monitoring

OBJECTIVES

- Define Earth Observation (EO) applications for permafrost monitoring based on user requirements
- Integrate the latest EO technology with state-of-the-art ground based measurements and models
- Demonstrate and validate the products with the user organizations
- Develop mid to long term scenarios for polar and mountain permafrost monitoring
- Contribute to new scientific results in the domain of climate change, climate modelling and hydrological modelling

CONSORTIUM

- Zentralanstalt für Meteorologie und Geodynamik (Austria)
- AWI for Polar and Marine Research (Germany)
- University of Oslo (Norway)
- Gamma Remote Sensing (Switzerland)
- H2O Geomatics (Canada)
- Deutsches Zentrum für Luft- und Raumfahrt (Germany)
- IGOT, University of Lisbon (Portugal)

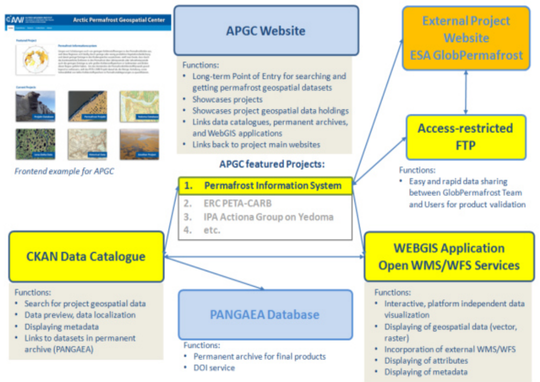
www.globpermafrost.info

ESA GlobPermafrost

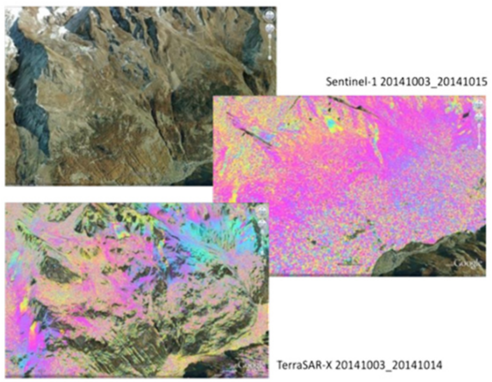
5 THEMATIC PRODUCTS

Permafrost Information System (PerSys)

Open Access Data Catalog

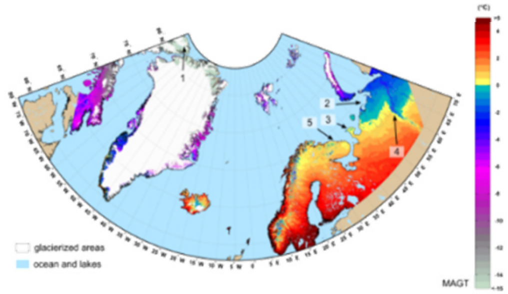


Mountain permafrost areas

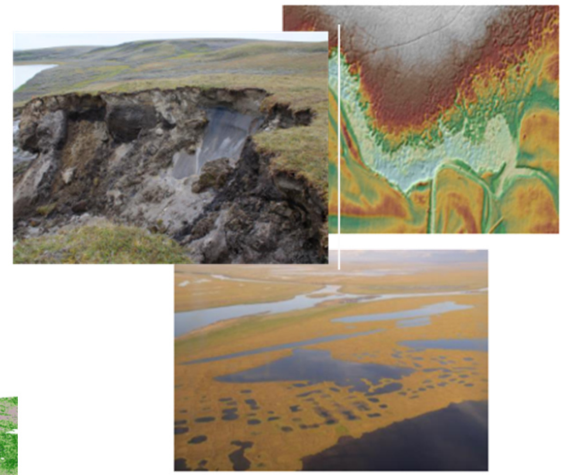


InSAR signals related to rockglaciers dynamic in TerraSAR-X 11 days and Sentinel-1 12 days interferograms over part of the Oberwallis region in Switzerland.

Permafrost extent



Local "cold spots"

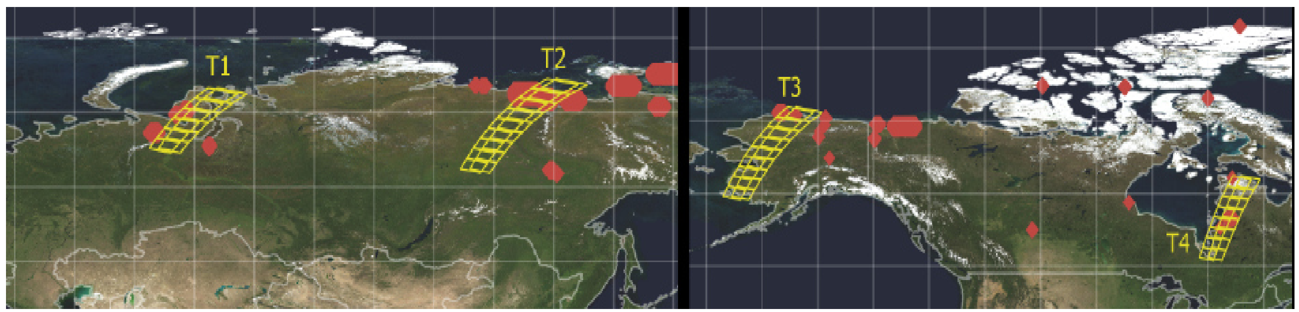


Lakes and periglacial processes

Permafrost dedicated land cover class prototypes

Wetland classes based on C-Band SAR

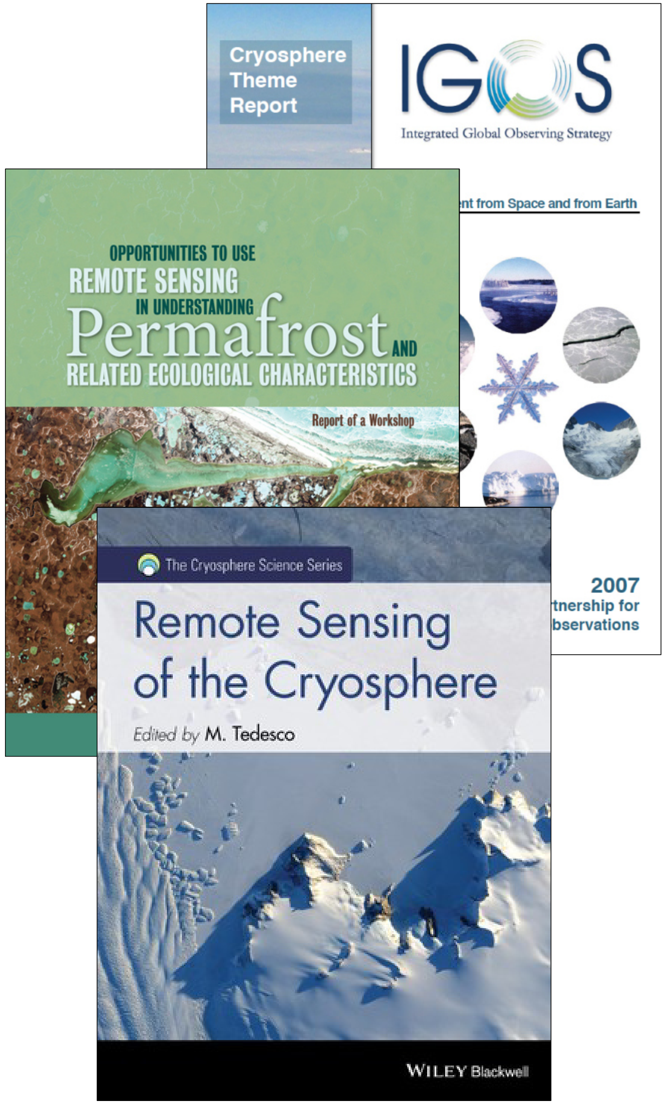
Transects for identification of hotspot regions of permafrost change



Where to find more information?

Reviews

- Duguay et al. (2005): Remote sensing of permafrost and seasonally frozen ground. In *Remote Sensing in Northern Hydrology: Measuring Environmental Change,* Geophysical Monograph 163, AGU.
- Kääb et al. (2005): Remote sensing of glacier- and permafrost-related hazards in high mountains: an overview, *Natural Hazards and Earth System Sciences*.
- Westermann et al. (2015): Remote sensing of permafrost and frozen ground. In: *Remote Sensing of the Cryosphere*. Wiley.
- Jorgenson & Grosse (2016, accepted): Remote Sensing of Landscape Change in Permafrost Regions, *Permafrost & Periglacial Processes*.



Community Reports

- IGOS Cryosphere Theme Report (2007), Chapter Remote Sensing of Permafrost.
- Gogineni & Romanovsky, et al. (2014), Opportunities to use remote sensing in understanding permafrost and ecosystems. National Research Council of the National Academies. The National Academies Press, Washington, D.C.

Thank you

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Universität Potsdam

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