Remote Sensing of Permafrost Landscape Dynamics

Prof. Dr. Guido Grosse
Periglacial Research Section

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Universität Potsdam
Erd- und Umweltwissenschaften

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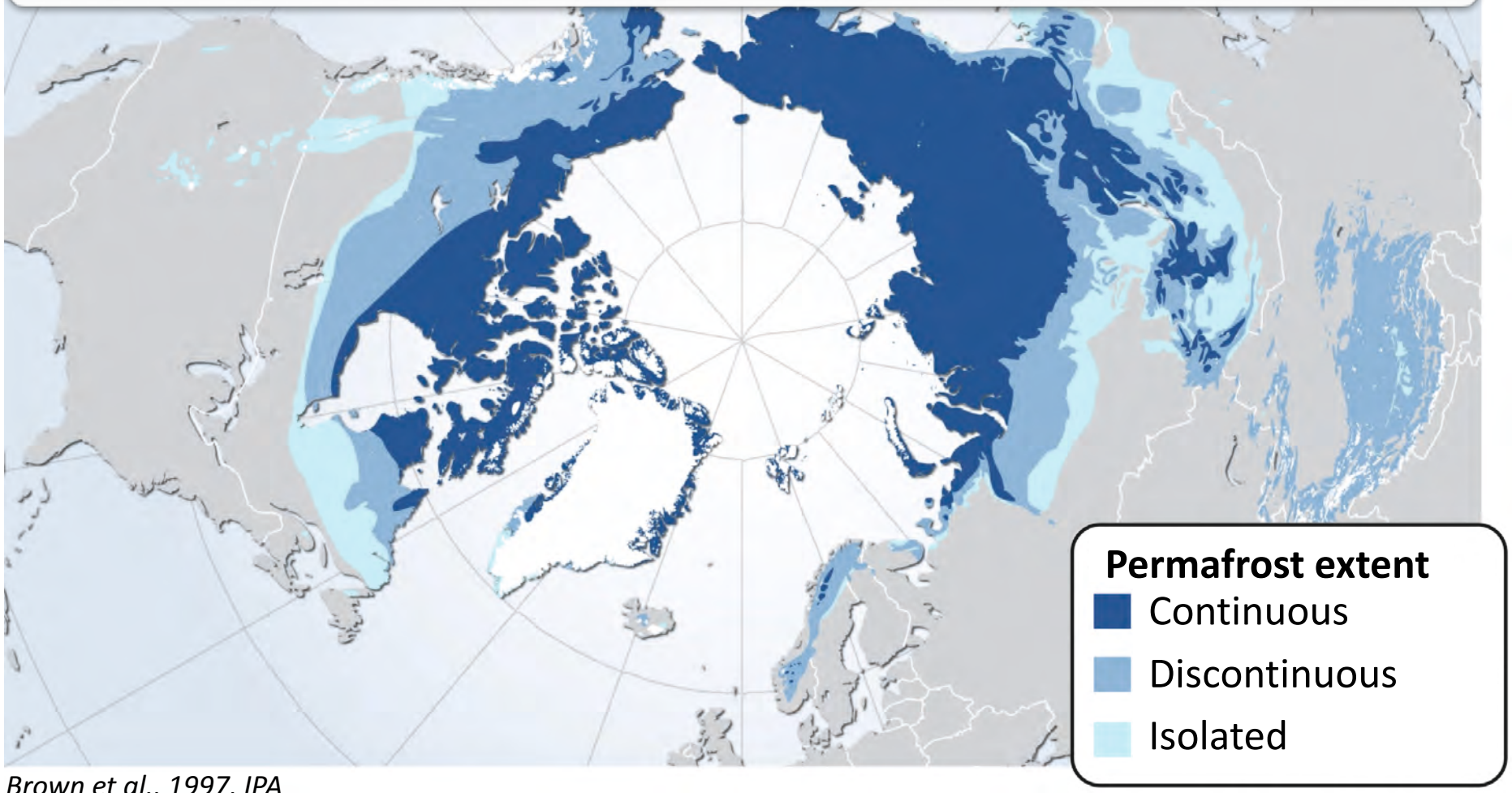
GLOBPERMAFROST

Lena Delta, 2014

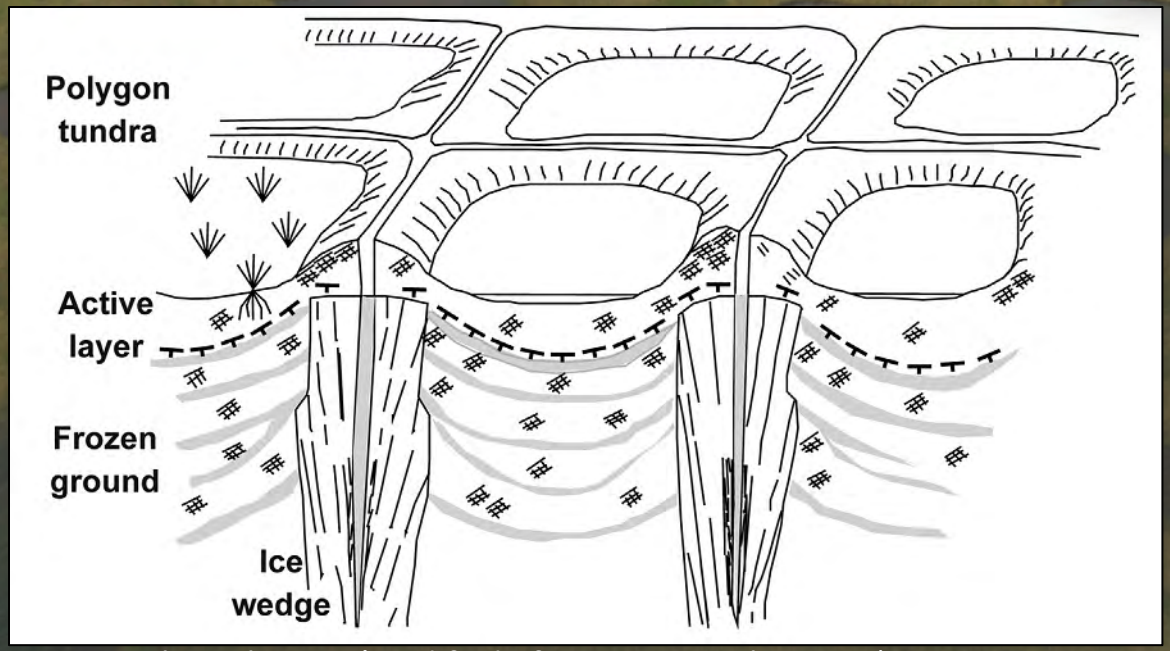
What is Permafrost?

- Ground that stays below 0°C for at least ≥ 2 consecutive years
- 22.8×10^6 km² (23%) of the northern hemisphere land mass



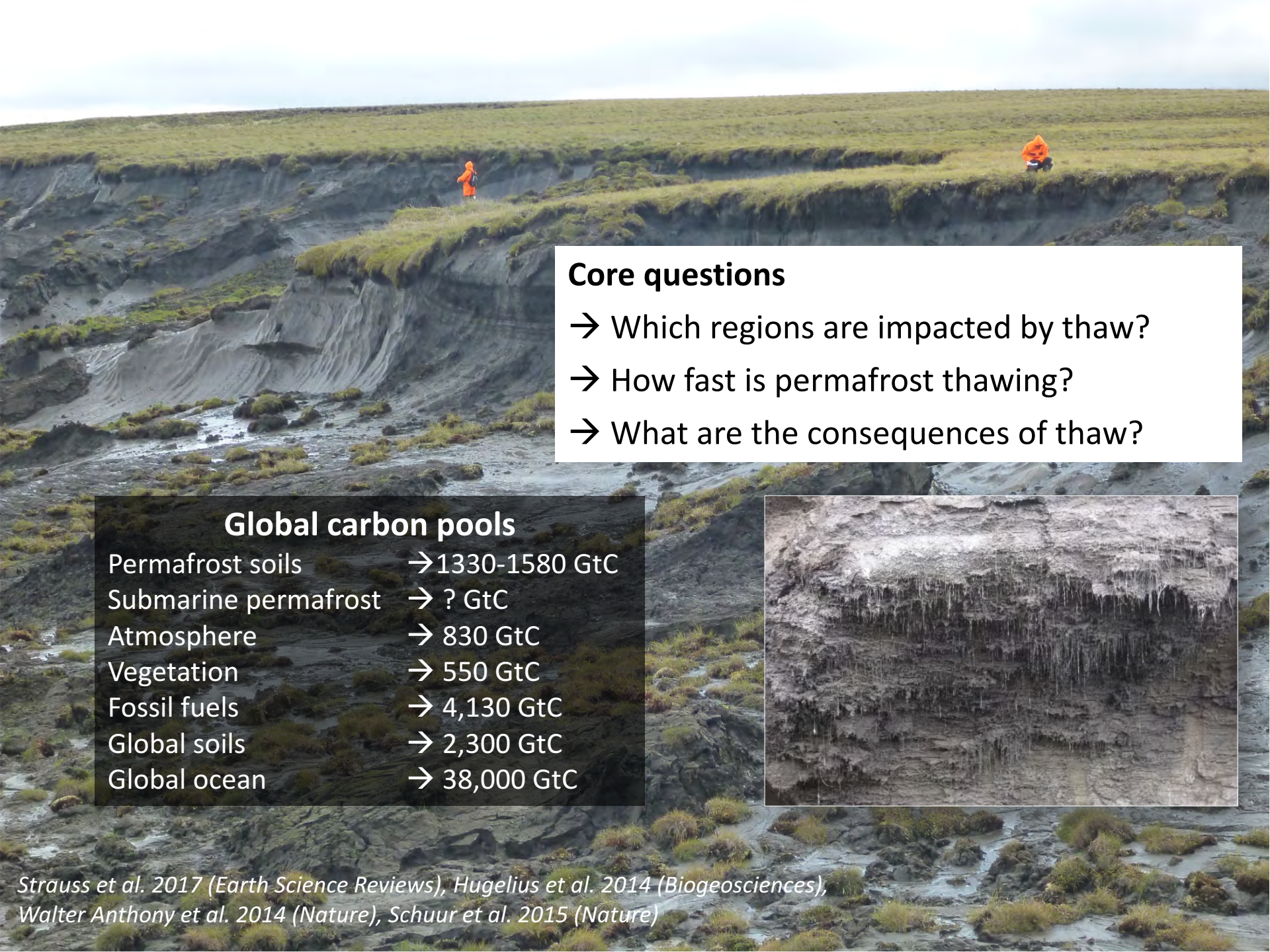
Brown et al., 1997, IPA

Typical Arctic tundra landscape with ice wedge polygons



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

Arctic Northslope of Alaska



Core questions

→ Which regions are impacted by thaw?

→ How fast is permafrost thawing?

→ What are the consequences of thaw?

Global carbon pools

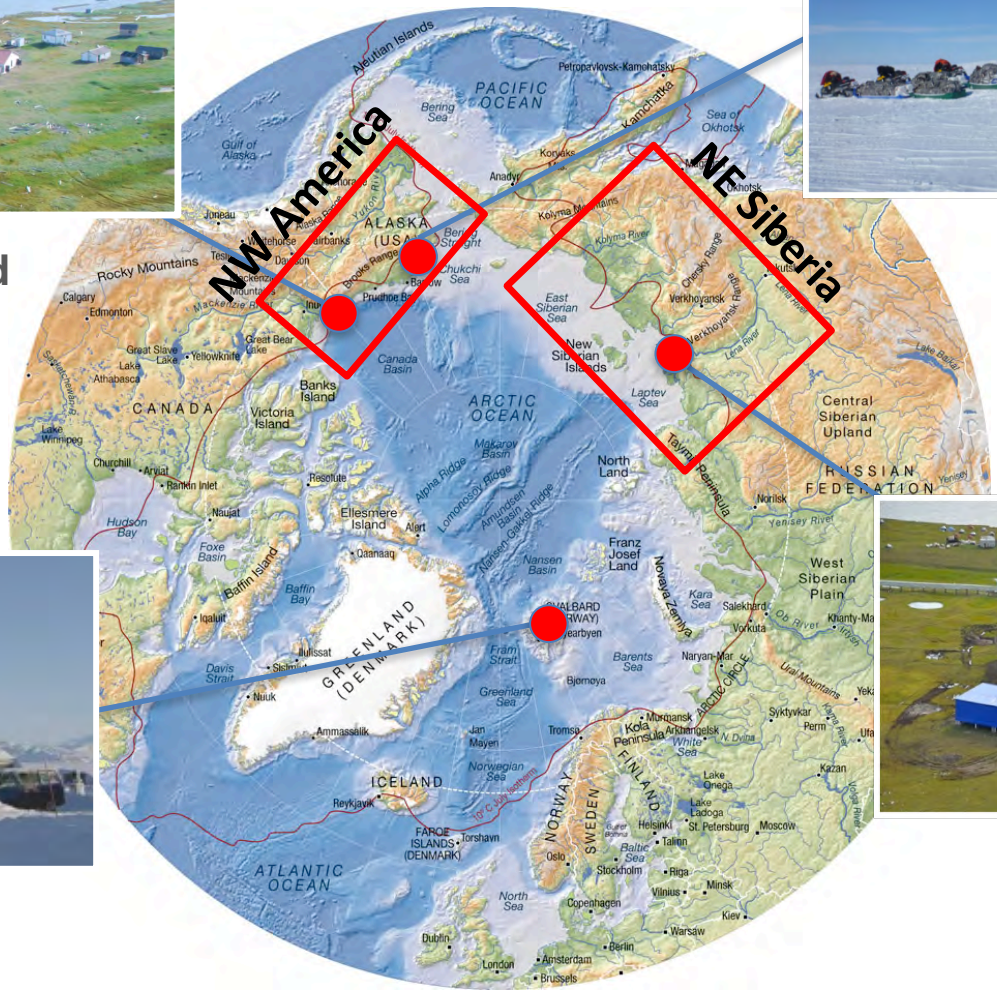
Permafrost soils	→1330-1580 GtC
Submarine permafrost	→ ? GtC
Atmosphere	→ 830 GtC
Vegetation	→ 550 GtC
Fossil fuels	→ 4,130 GtC
Global soils	→ 2,300 GtC
Global ocean	→ 38,000 GtC

Strauss et al. 2017 (Earth Science Reviews), Hugelius et al. 2014 (Biogeosciences), Walter Anthony et al. 2014 (Nature), Schuur et al. 2015 (Nature)

Key Research Areas in the Arctic

Herschel Island
Yukon Coast
Canada

Teshekpuk Lake Observatory
North Alaska



AWI-PEV Station
Ny Ålesund, Svalbard

Samoylov Station
Lena Delta, Siberia

Permafrost variables vs. remote sensing

Challenge: Permafrost is a subsurface temperature phenomenon

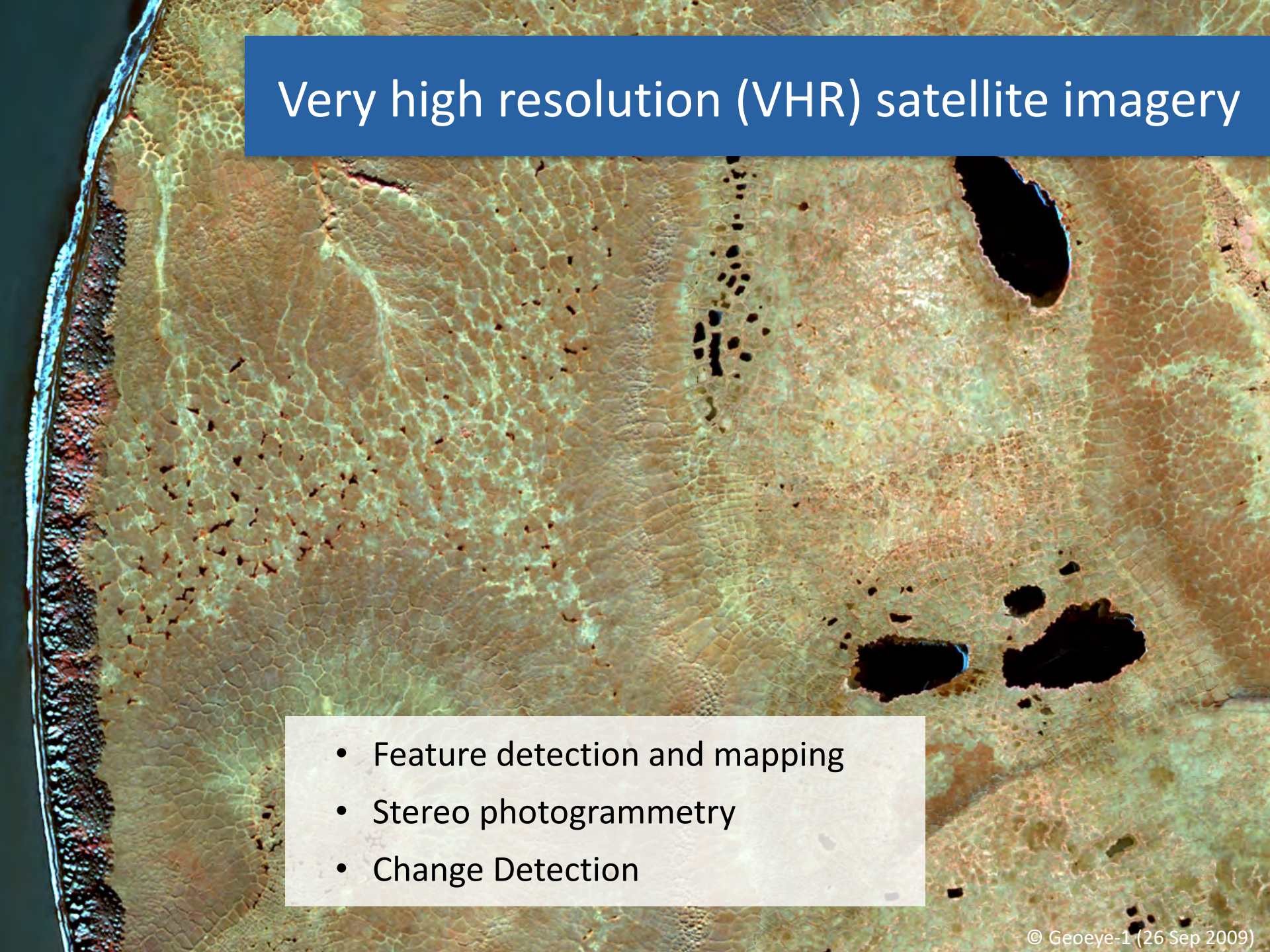
We want to know

1. Ground temperature
2. Thickness of the active layer (depth to the permafrost table)
3. Thickness of permafrost
4. Spatial patchiness of permafrost
5. Ice content and distribution in permafrost
6. Permafrost thaw and impacts

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)

Very high resolution (VHR) satellite imagery

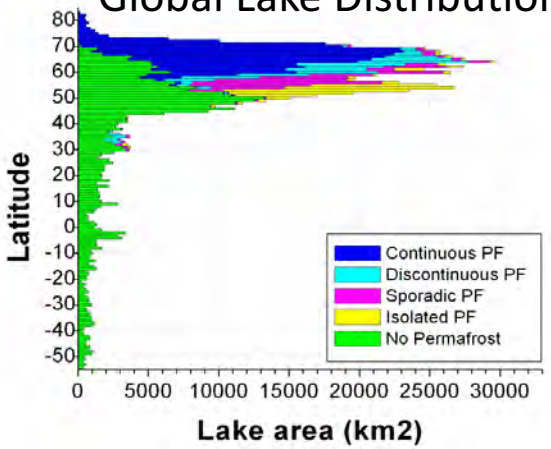


- Feature detection and mapping
- Stereo photogrammetry
- Change Detection

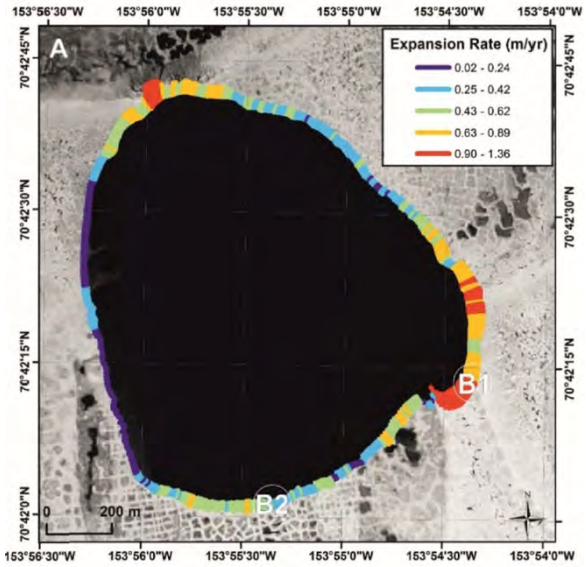
© Geoeye-1 (26 Sep 2009)

Thermokarst Lake Dynamics

Global Lake Distribution



Grosse et al., 2013



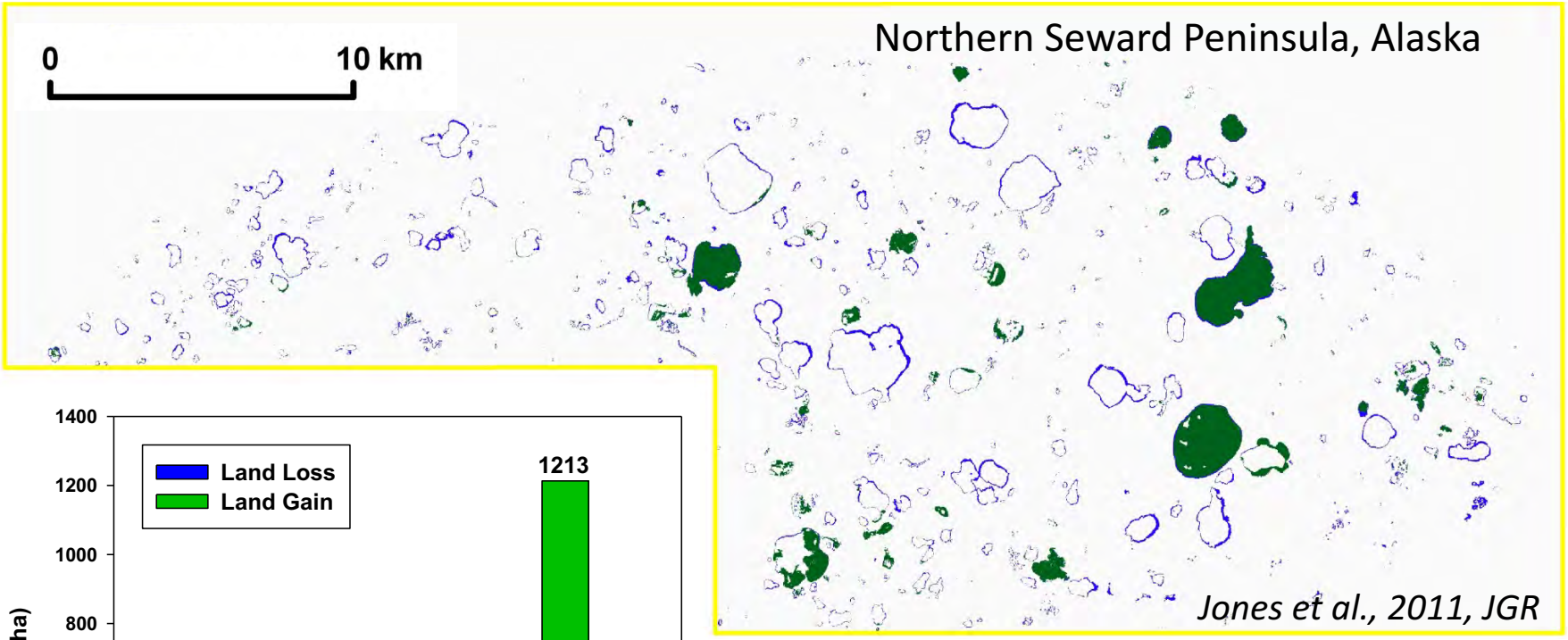
Lenz et al., 2016 (arktos)

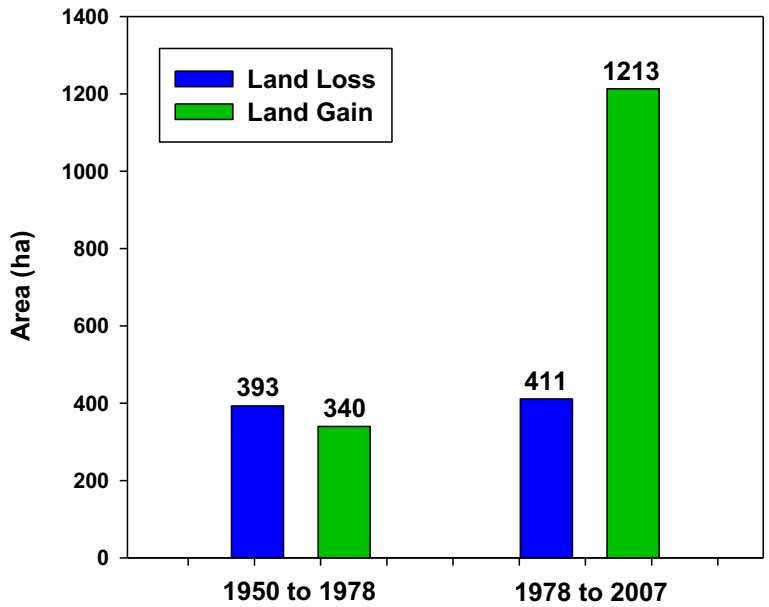
Thermo-erosion at lake shore of Teshekpuk Lake, North Alaska

Photos: B. Jones, USGS

Thermo-erosion on lake shore of Peatball Lake, North Alaska

Thermokarst Lake Change



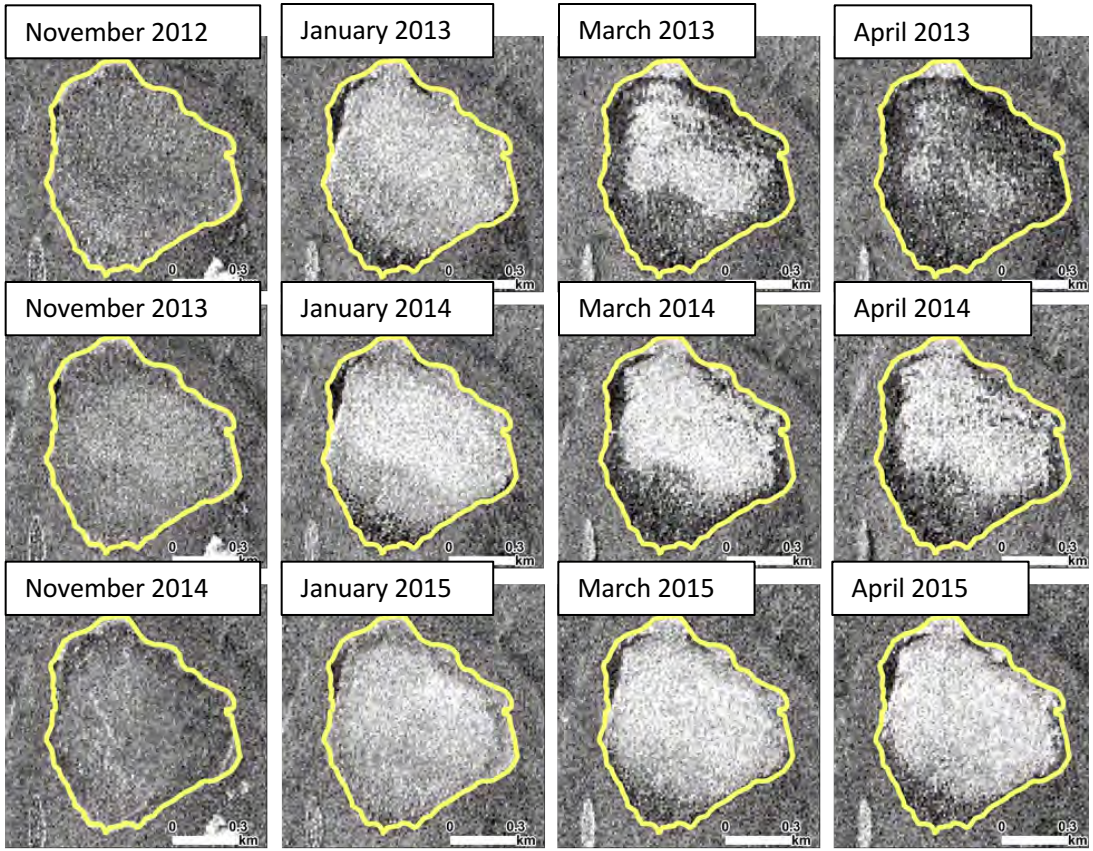


Aerial imagery 1950, 1978 + Ikonos 2007

- Land area lost was nearly equal to the area gained during the 1st period
- Land area gained was nearly three times higher due to lakes drainage in 2nd period
- Lake shore erosion = lake area gain
- Lake drainage = wetland area gain

Thermokarst Lakes and Ponds

TSX-backscatter: excellent for distinguishing floating and bedfast lake ice
Lena River Delta, Arctic Siberia



- bright – floating ice;
  dark – bedfast ice
- possible to observe spatial progression of ice grounding every 11 days
- different fraction of bedfast ice by the end of winter from year to year
- possible to extract the timing of ice grounding and to estimate the ice thickness from an ice growth model

***Antonova**, Duguay, Kääb, Heim, Langer, Westermann, Boike 2016.*
Monitoring Bedfast Ice and Ice Phenology in Lakes of the Lena River Delta Using TerraSAR-X Backscatter and Coherence Time Series. RS

Helmholtz Alliance:
Remote Sensing and Earth System Dynamics

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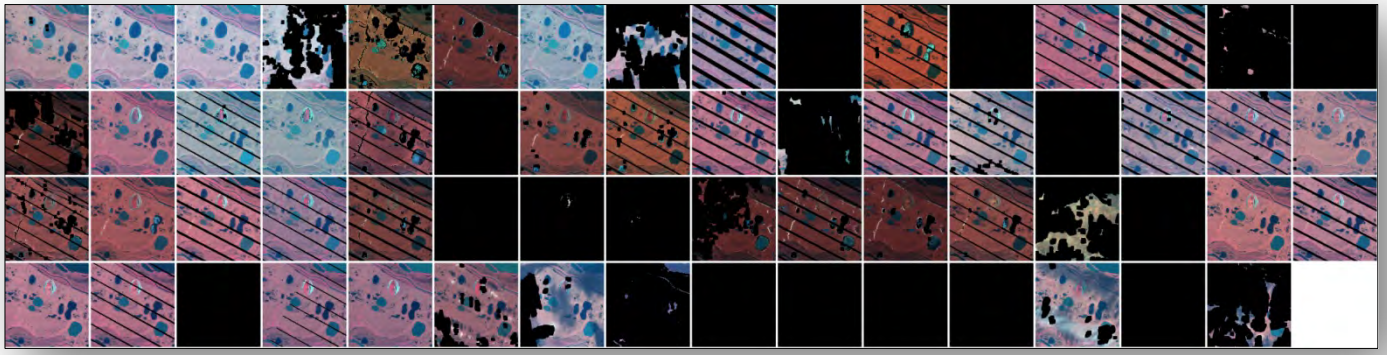
Analysis of temporally dense image time series

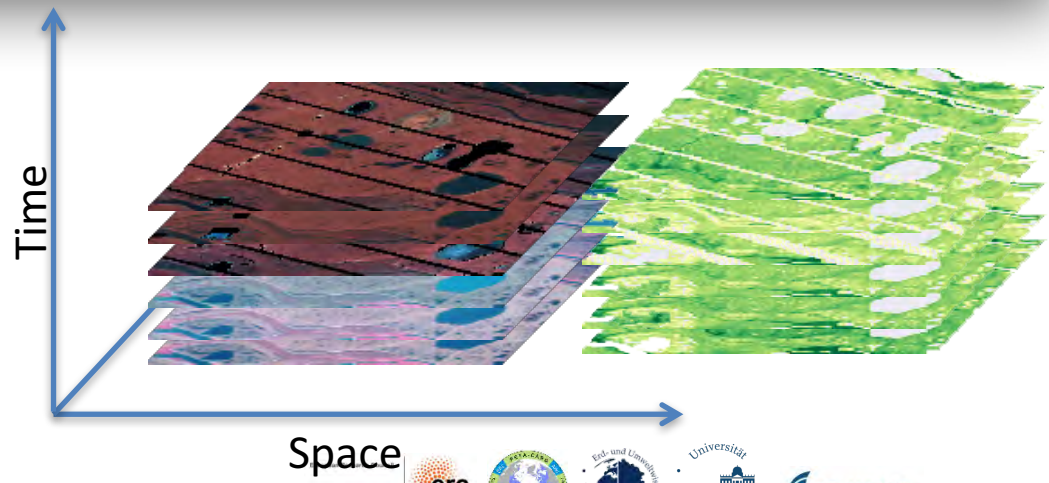
- Landsat-based time series analysis
  - Seasonal + multi-annual dynamics
  - Surface wetness, brigthness, greenness trends; Disturbances (lake change, erosion)
  - Fully scalable: Panarctic mapping possible

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



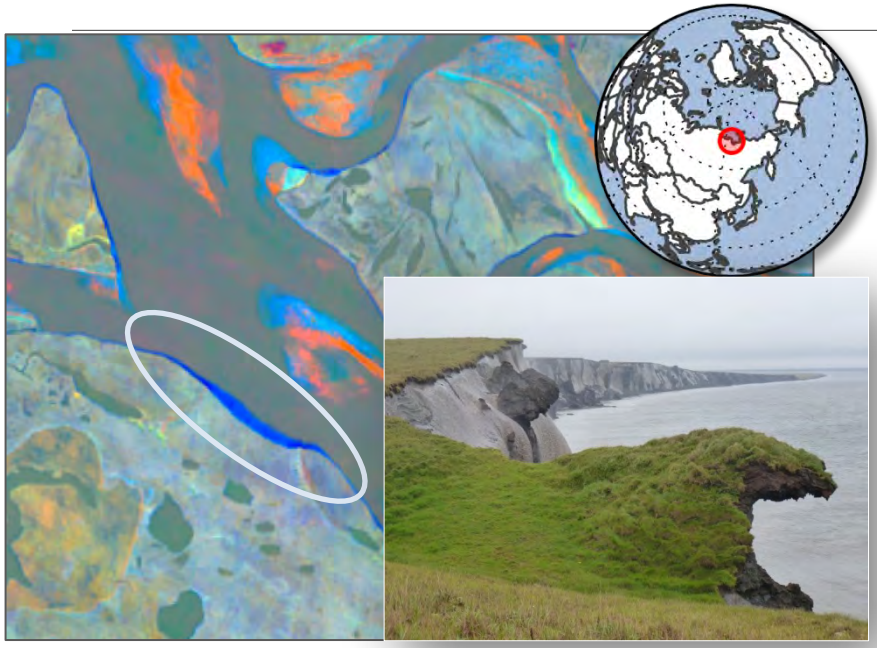
Automated Batch Processing

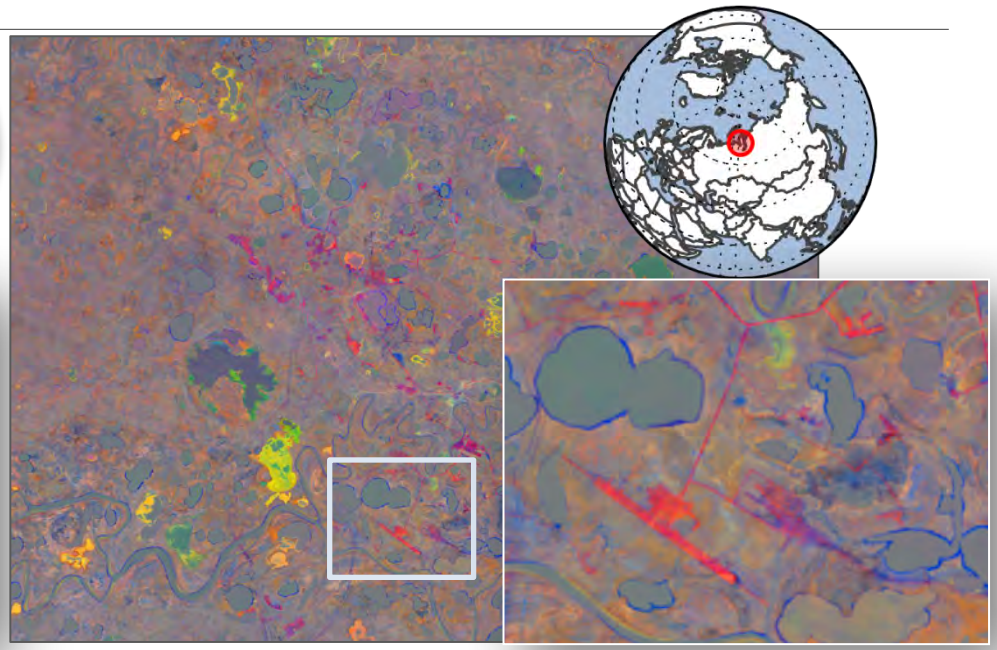
Data Download
File Operations
Image stacking/redistribution
Atmospheric correction
Index calculation (Tass Cap, NDVI, NDWI, …)
Subsetting
Trend analysis

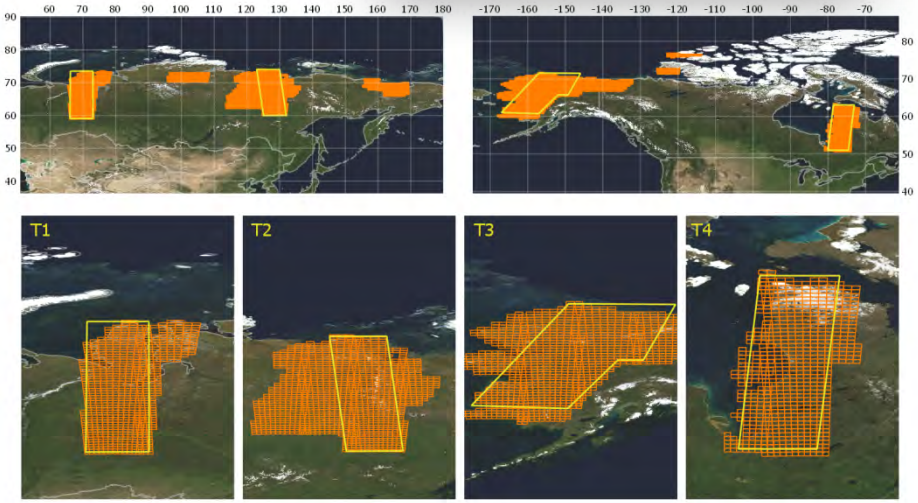


Nitze & Grosse 2016, Remote Sensing of Environment

Landsat-Based Land Cover Trend Analysis







~2,700,000 km^2 @ 30m resolution

Landsat TM, ETM+, OLI

~25,000 Scenes Jul+Aug 1999-2014

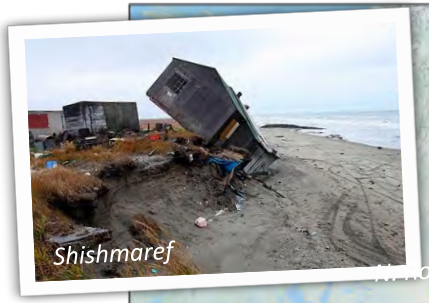
~10 TB raw data, 0.6 TB products

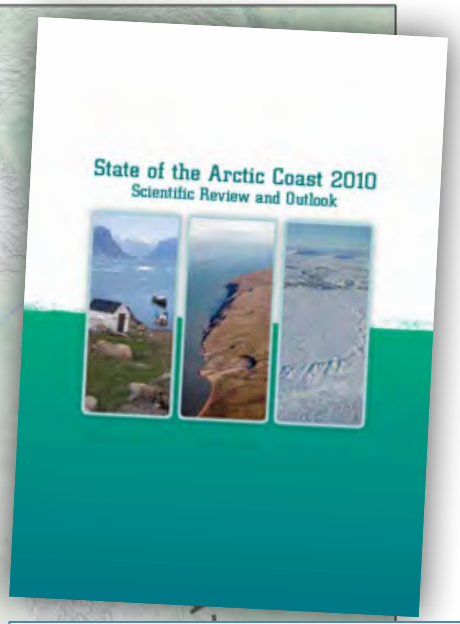
Products: Trends + Slope Intercepts

NDVI, NDMI, NDWI, TCB, TCG, TCW

Nitze et al in prep.

Permafrost Coasts: Arctic Coastal Erosion



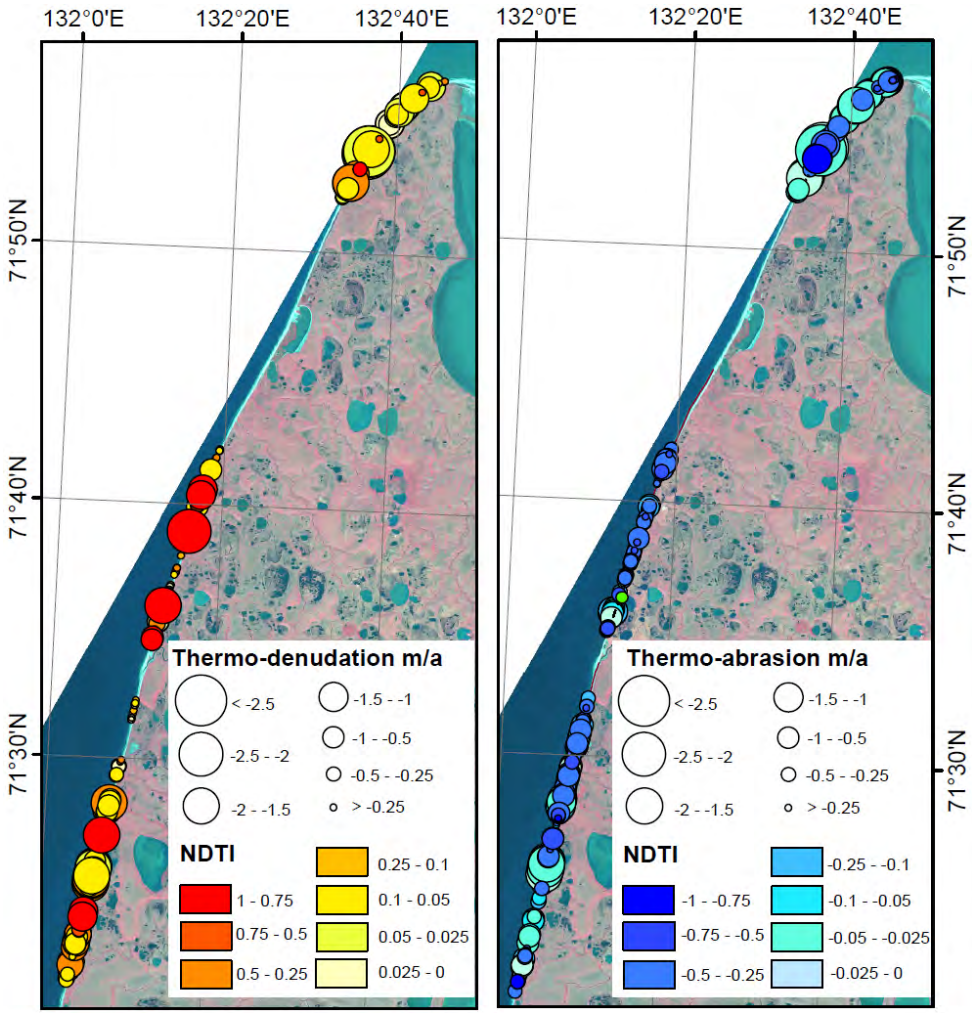


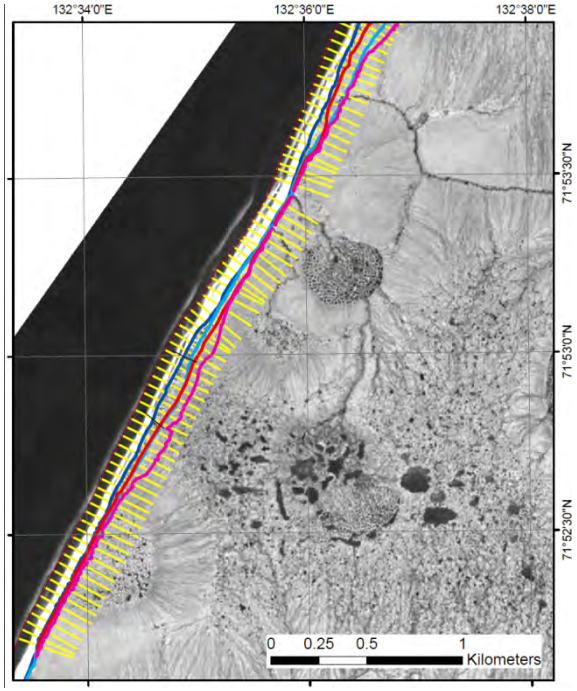
- Permafrost coasts erode with an annual average of 0,5 m/a
- Observed maximum rates of erosion are up to 50 m/a

Lantuit et al. (2012)

Thermo-erosion of permafrost coasts

Ortho-image based quantification of coastal erosion in GIS





- Digital Shoreline Analysis System
- Also used for thermokarst lake change detection (*Jones et al., 2012*)

Günther et al., 2013: Biogeosciences

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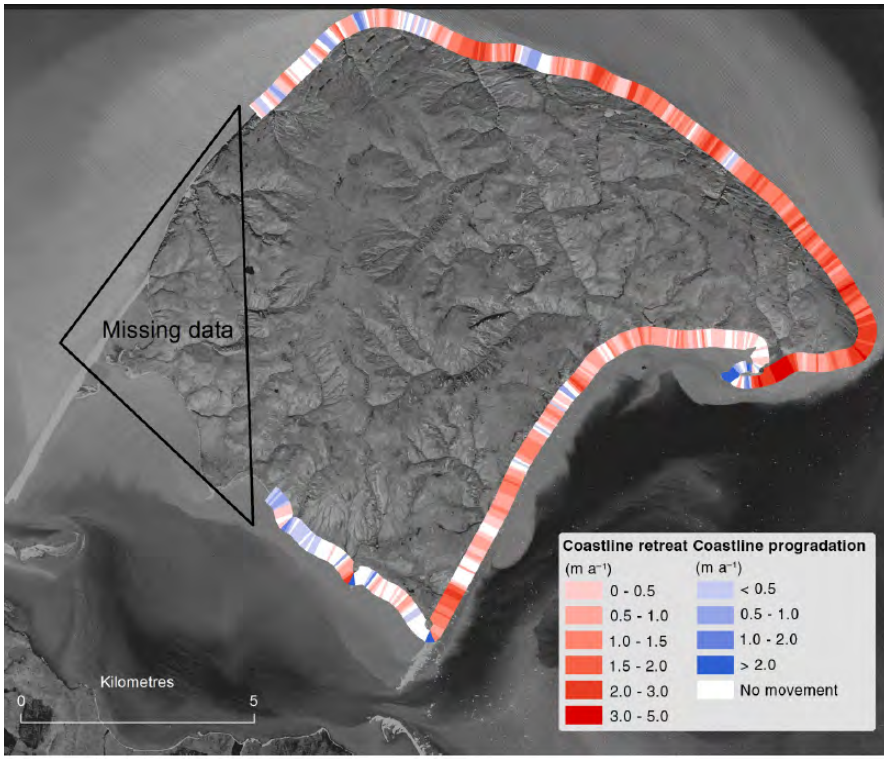
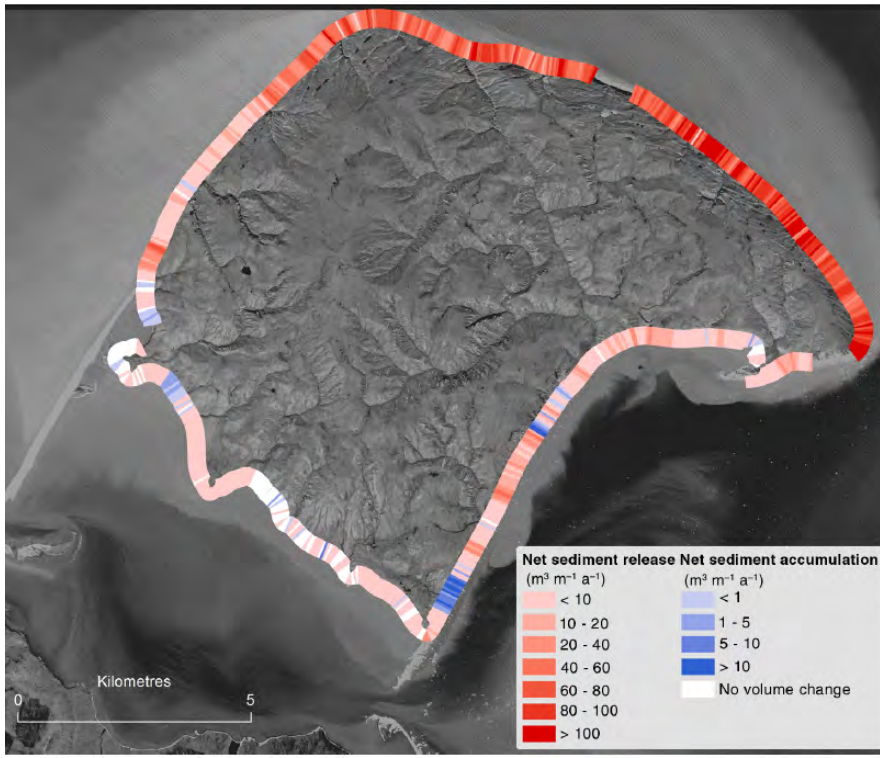
Coastal erosion and sediment, C+N loss

- Herschel Island, NW Canada
- Erosion rates increased by more than 50% compared to 1970-2000
- Annual release of sediment: 28.2 m^3 m^{-1}, TOC: 590 kg m^{-1} and N: 104 kg m^{-1}

Coastal erosion 2000-2011



Sediment loss 2000-2011



Obu et al. 2016 Polar Research

Impacts of Coastal Erosion

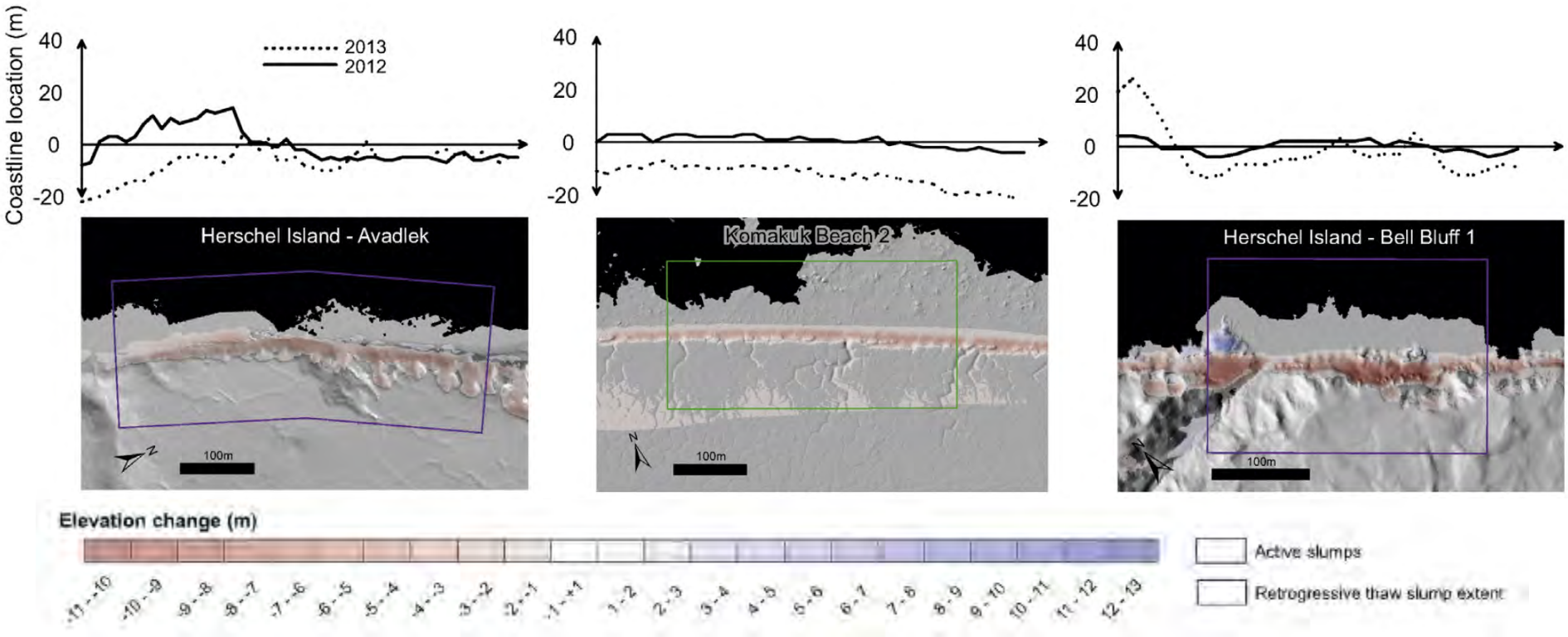
Permafrost coastal erosion surveys with annual repeat LiDAR at 24 sites on Yukon Coastal Plain, Canada

Retrogressive thaw slumps

Photo: N. Couture

Obu et al., 2016 (Geomorphology)

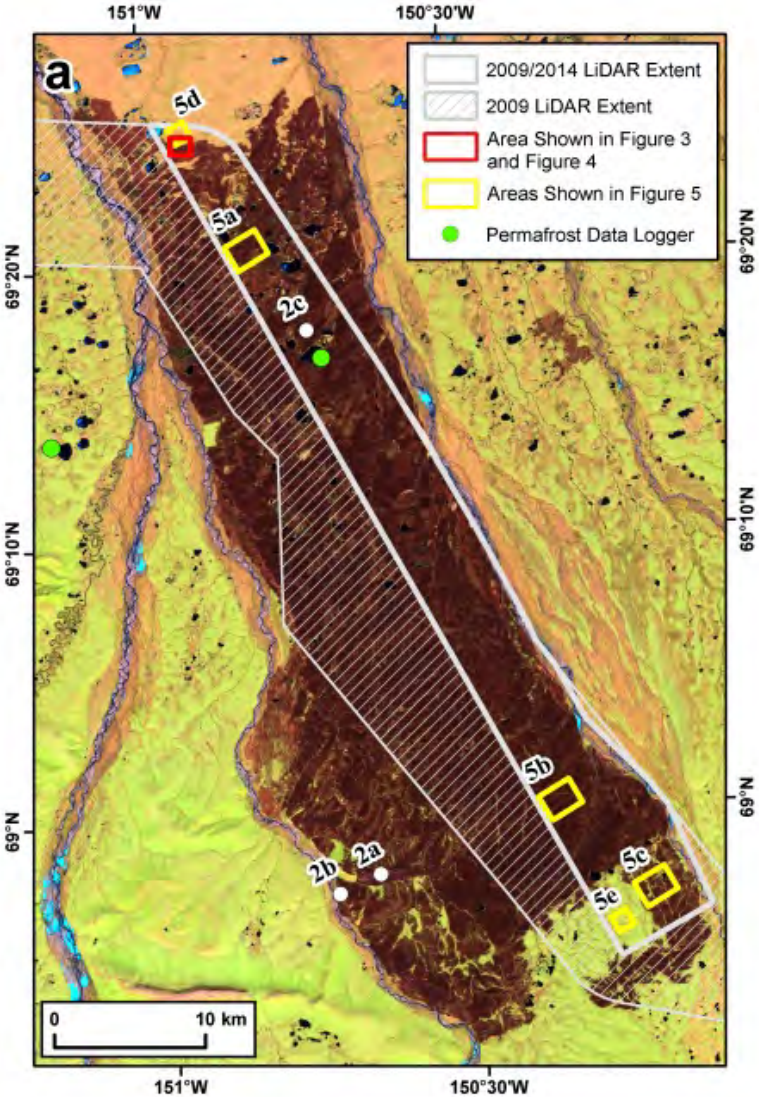
Impacts of Coastal Erosion



- 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.

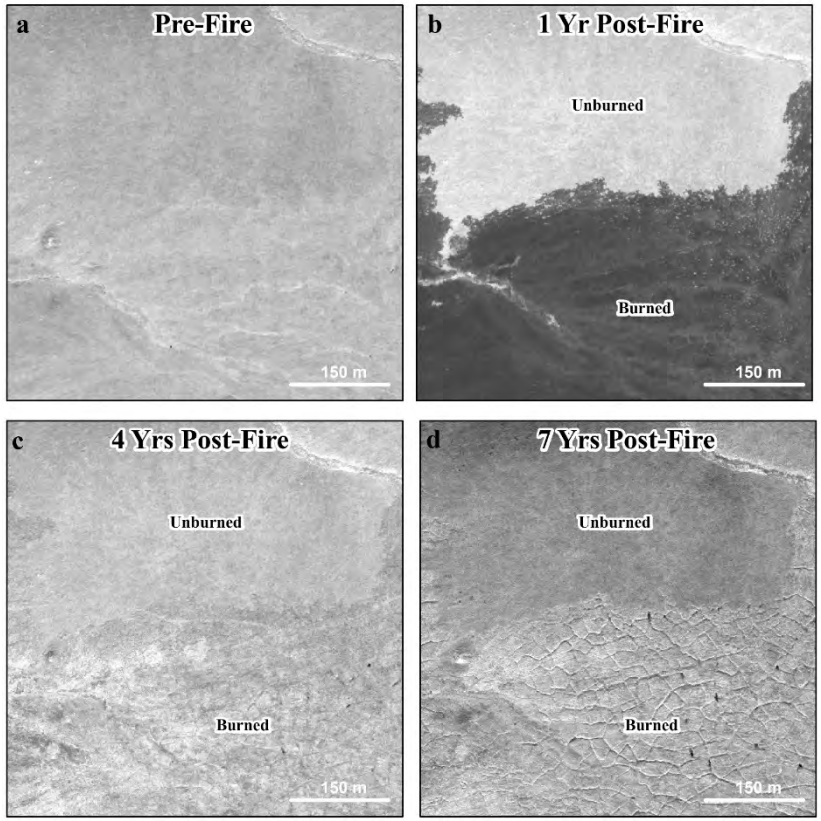
Obu et al., 2016 (Geomorphology)

Repeat LiDAR to detect post-fire thaw subsidence



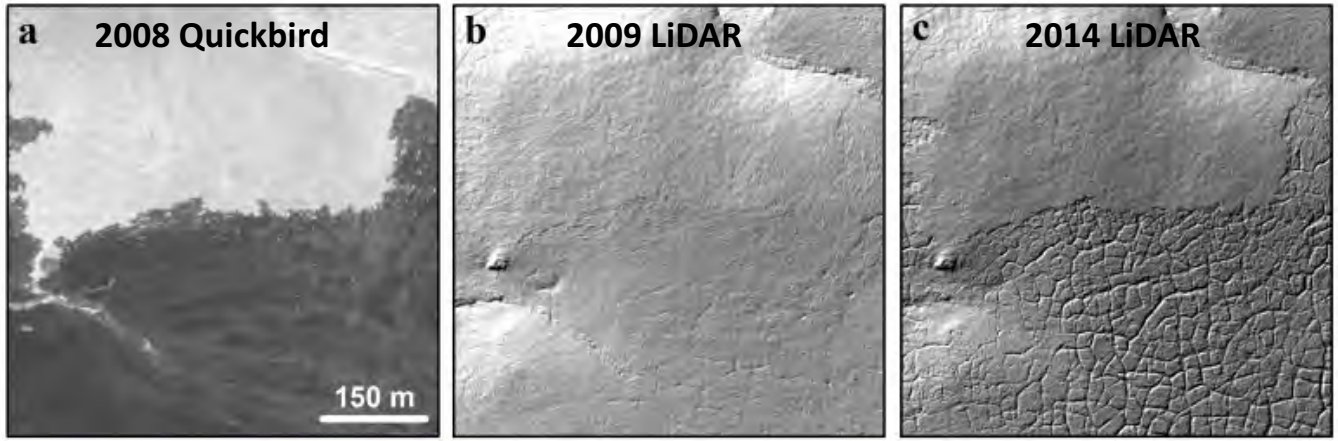
Jones et al 2015 (Scientific Reports)

Time series of commercial satellite imagery



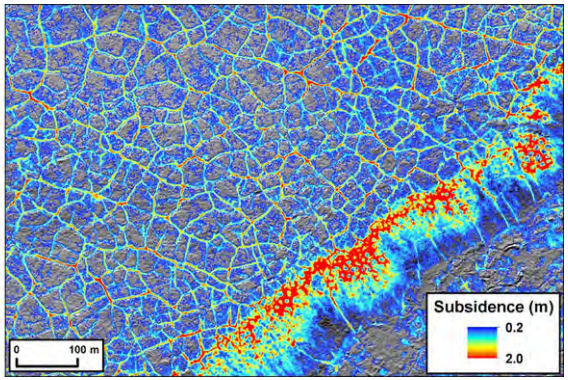
- Indicates ice wedge degradation between the 4th and 7th years post-fire
- Would be very difficult to quantify this type of change using high-resolution commercial imagery

Repeat LiDAR to detect post-fire thaw subsidence



dDTM | >~20cm | >~50cm

Field Foto of degrading ice wege polygons

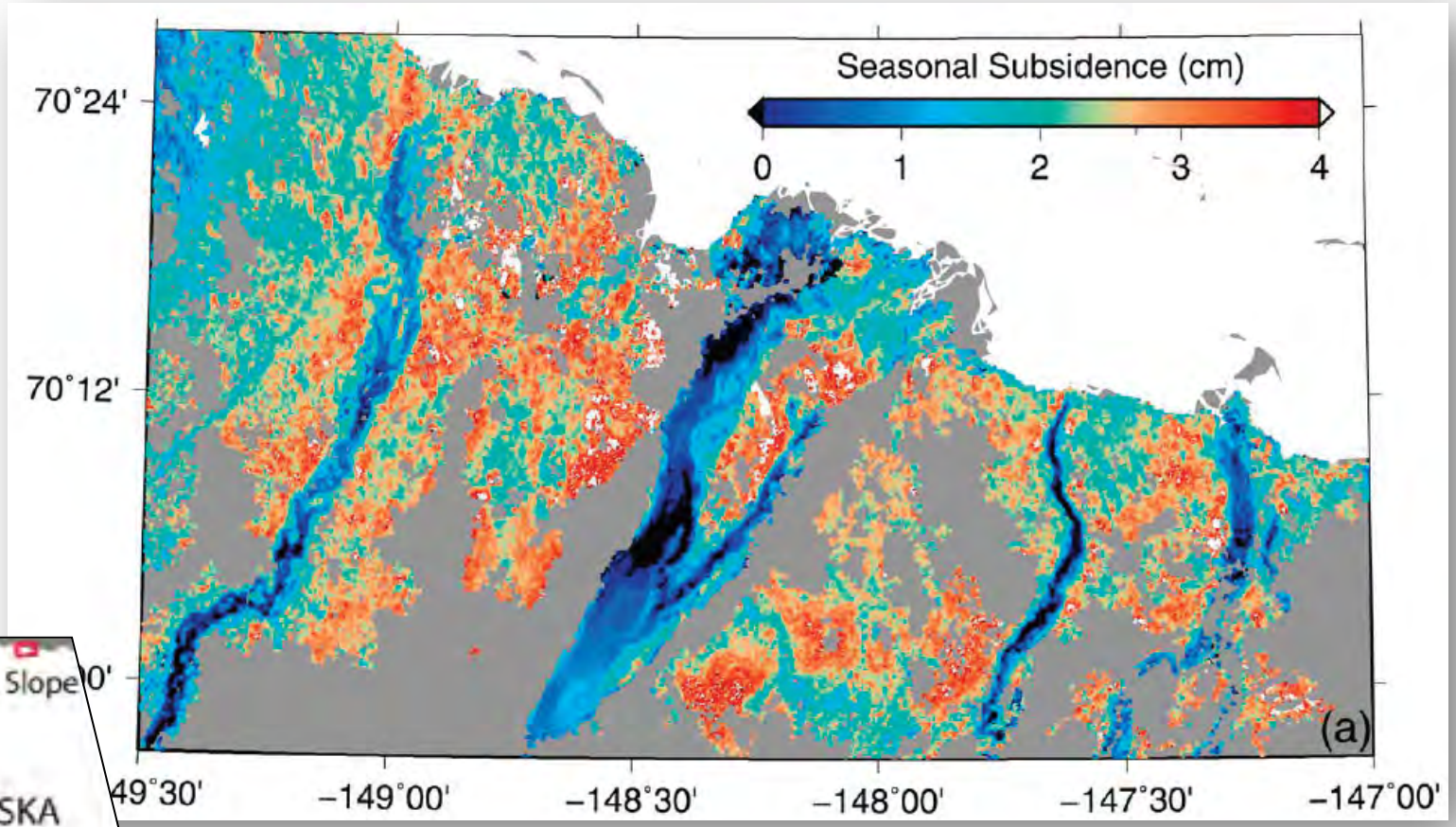


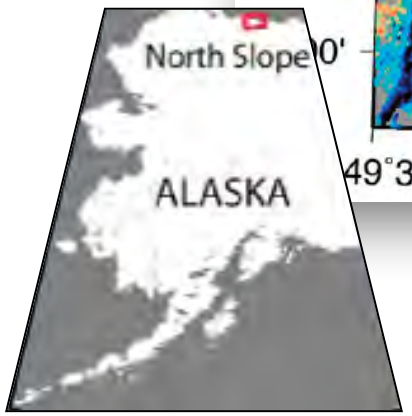
Subsidence map of degrading ice wege polygons

Analysis conducted with the Geomorphic Change Detection Tool: http://gcd.joewheaton.org/

Jones et al 2015 (Scientific Reports)

Seasonal thaw subsidence from InSAR





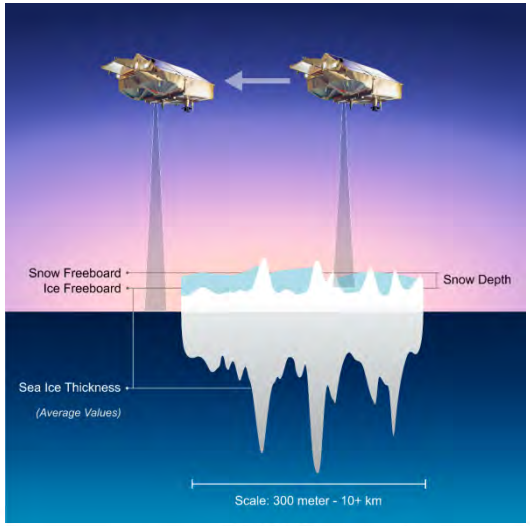
Liu et al. 2010 (Journal of Geophysical Research)

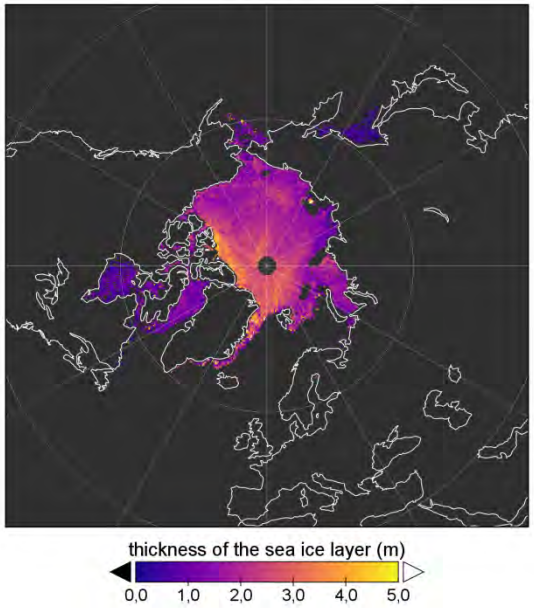
- ERS-1/2 C-band SAR
- Seasonal subsidence in the Alaska Arctic coastal plain
- Continuous permafrost

Needs and Requirements

- **Free data access** (science), long + dense time series, high spatial resolution
- Polar orbiting, frequent revisits
- **VHR imagery** (<1m), stereo, pan, ms
  - Feature and disturbance detection, mapping, change detection, rapid thaw, coastal erosion
- **Moderate resolution** (<30m), ms
  - Frequent revisits (<1 week), VIS, NIR, SWIR; atmospherically corrected
  - Land Cover Change, Arctic-specific vegetation, water, snow, disturbances,
  - Temporal Trends
- **SAR**, different bands, polarisations
  - X-, C-, L-bands
  - Single, dual, quadpol
  - Vegetation, soil moisture, ice conditions (grounded, floating, gas bubble content)
- **Thermal**, high spatial (<1km) and temporal resolution (subdaily)
  - LST as permafrost model input, high accuracy T (<1K)
- **LiDAR, Arctic DEM, WorldDEM**, high resolution (<12m), panarctic coverage
  - Hydrological modelling (high vertical accuracy, cm - dm), feature detection and mapping
  - DSM differencing, quantification of thaw subsidence and erosion
- **InSAR**
  - seasonal actve layer elevation changes (1-10cm)
  - multi-annual subsidence or heave (cm to m)

Sea Ice Radar Altimetry





Scientific Objective

- Arctic & Antarctic sea ice mass balance
- Retrieval sea-ice freeboard and thickness with satellite radar altimetry (ERS-1/2, Envisat, CryoSat-2, Sentinel-3A)

AWI Sea Ice Physics

Dr. Stefan Hendricks

Dr. Rober Ricker

Prof. Dr. Christian Haas

Activities and Contributions

- Full in-house processing chain for satellite radar altimeter data
- Core activity of Sea Ice Physics Section and AWI research frame work
- Production of free and open sea-ice thickness climate data records
  - ESA Climate Change Initiative on Sea Ice, Phase 2 (SICCI-2)
  - Copernicus Climate Change Services (C3S) (feeds in CMEMS: Copernicus Marine Environment Monitoring Service)

User Need

- CryoSat-2 follow-on (Sentinel-3x: insufficient orbit inclination for Arctic sea ice)