REMOTE SENSING OF PERMAFROST IN NORTHERN ENVIRONMENTS

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- What is permafrost?
- What can we monitor with satellite data?

- Permafrost is an Essential Climate Variable
- About 25 % of the land surface is underlain by permafrost

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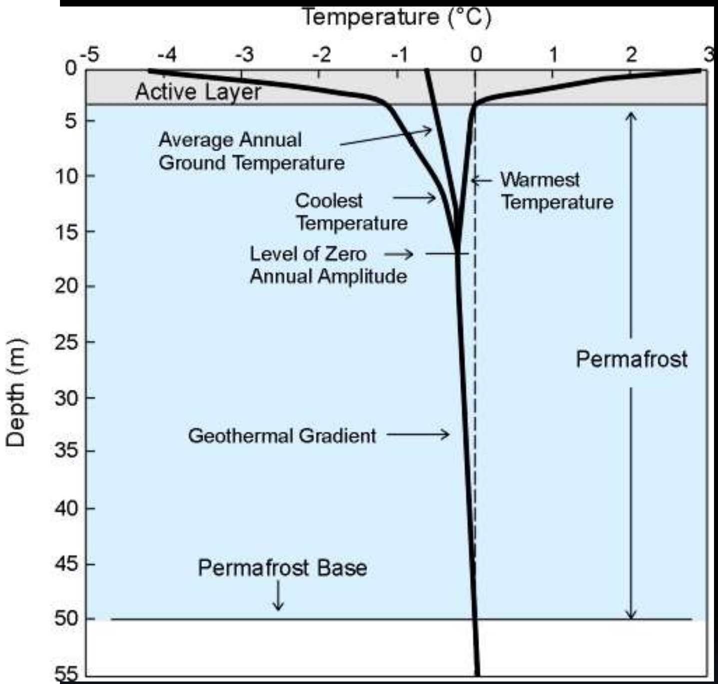
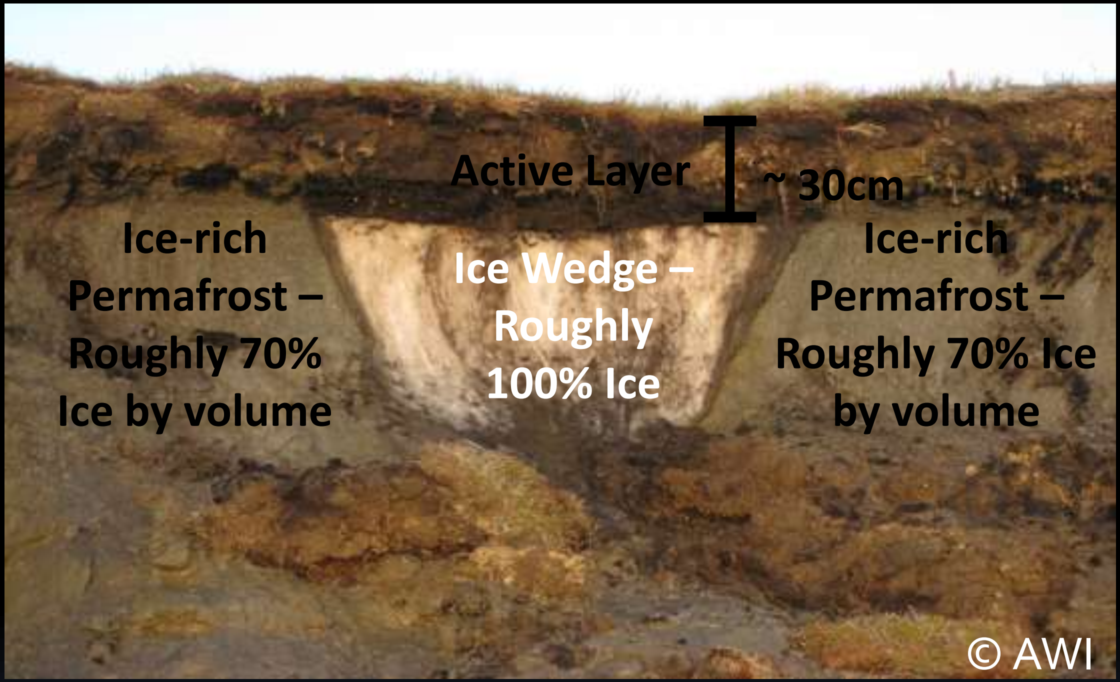
Permafrost?





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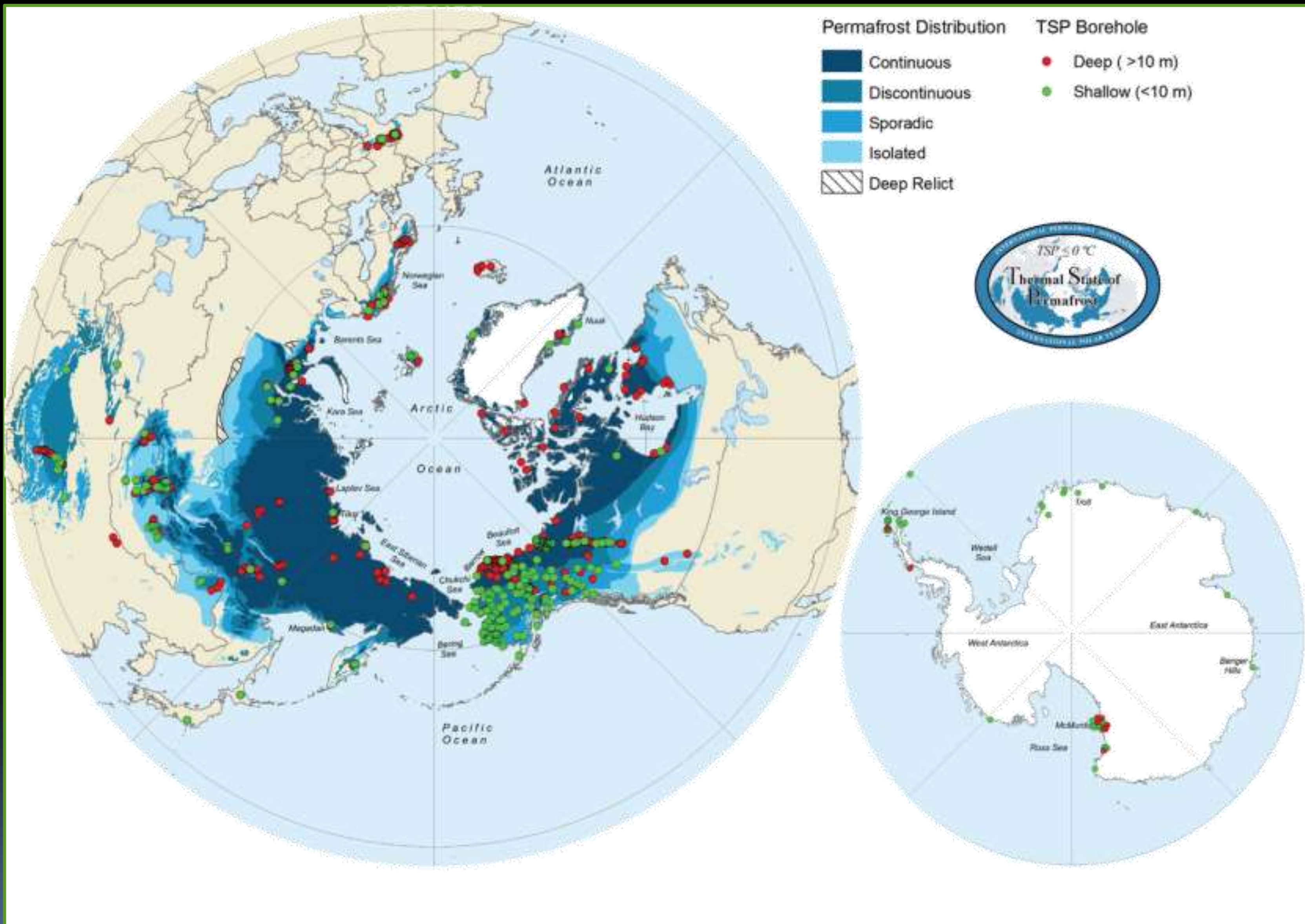
Boreholes



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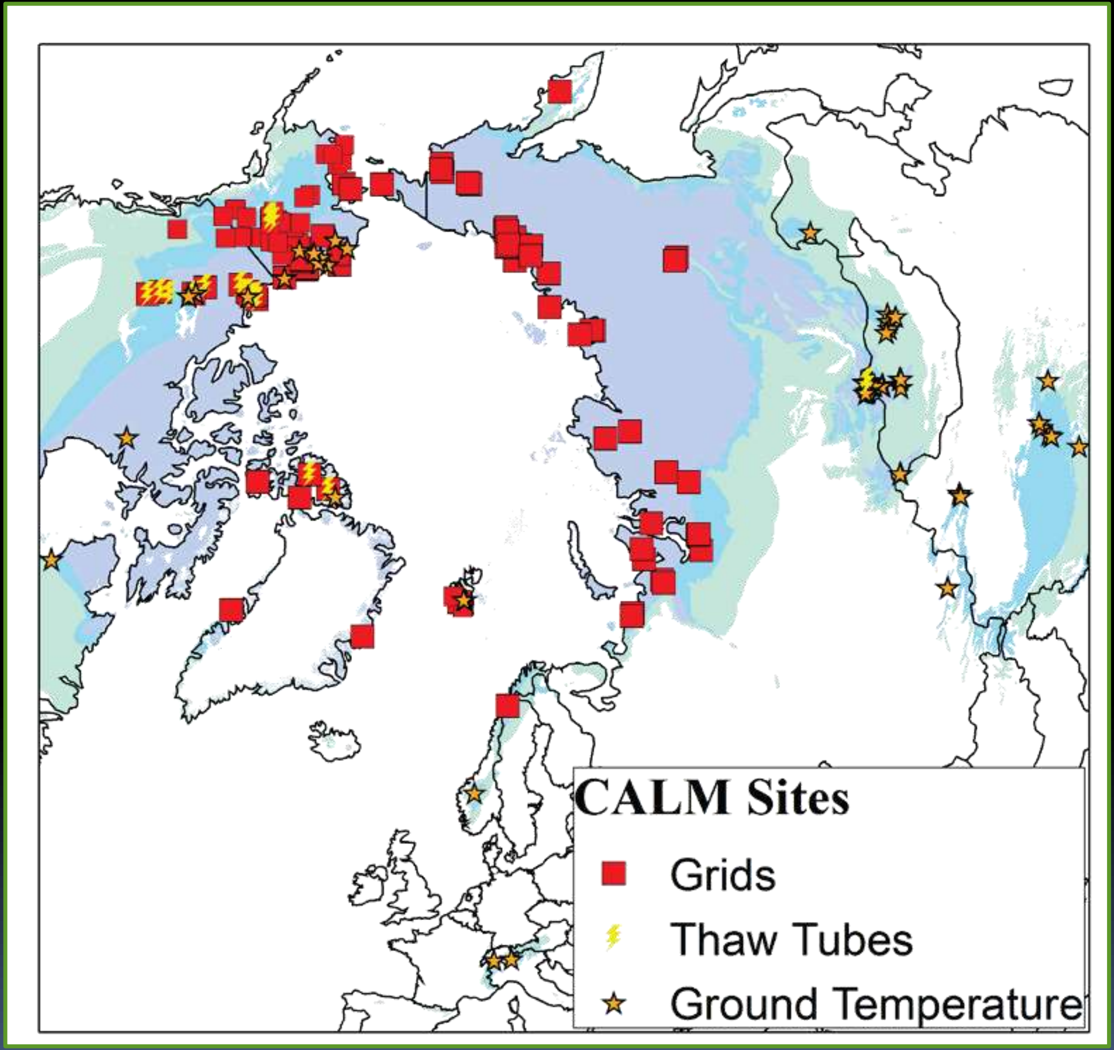
Active layer monitoring



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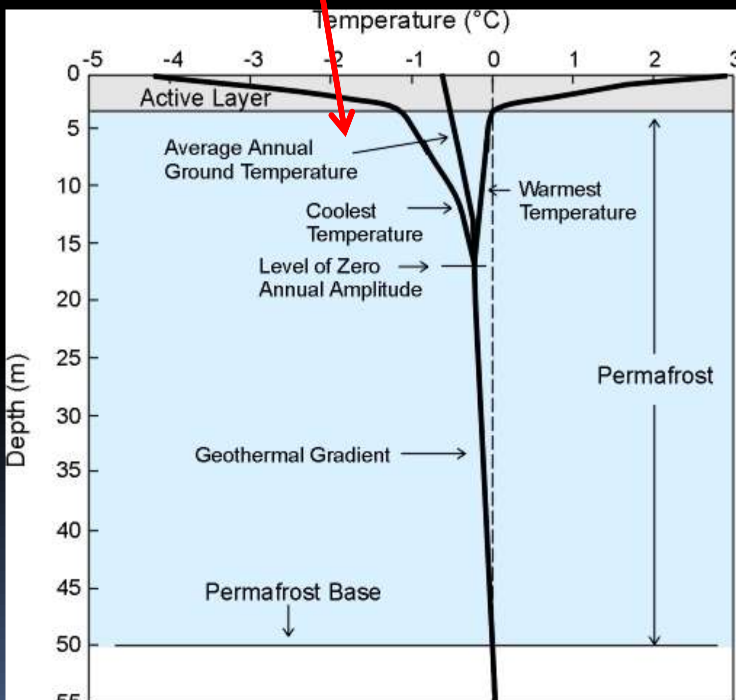
Complementing in-situ measurements ?

Filling gaps ?

?

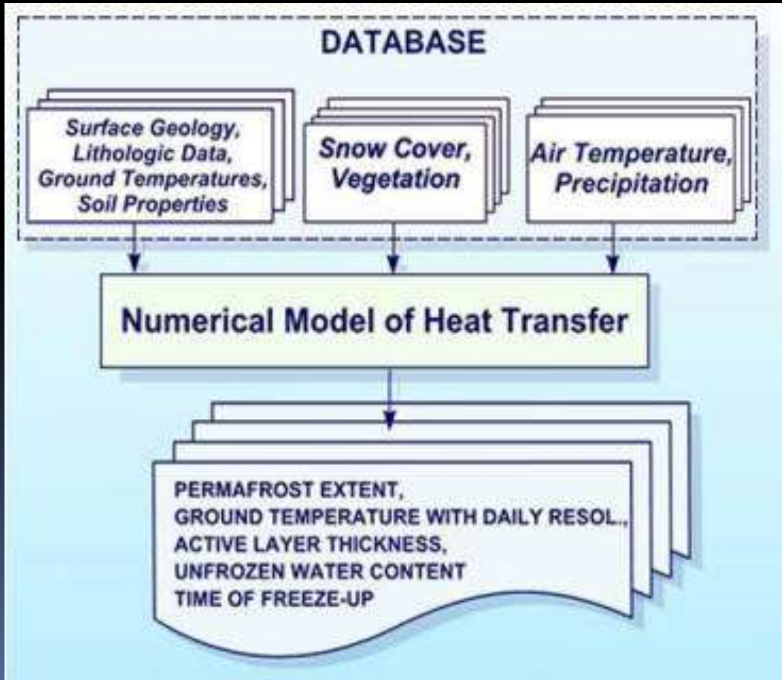


GTN-P
- Permafrost temperature
- Active layer depth

Changing permafrost

- Ground thermal regime changes due to
  - Changes in air temperature and/or precipitation
  - Surface disturbances
    - Clearing of vegetation
    - Removal of insulating organic layer
    - Forest fires
    - River channel migration
    - Shoreline erosion

- Response to climate change depends on variations in local seasonal factors
  - Snow cover
  - Vegetation
  - Surficial material
  - Moisture content
  - Drainage



Structure of the GIPL 2 model

Observable surface parameters

- Land Surface Temperature, status (frozen/unfrozen)
- Landcover & Disturbances
- Snow properties
- Soil moisture (near surface)
- Terrain

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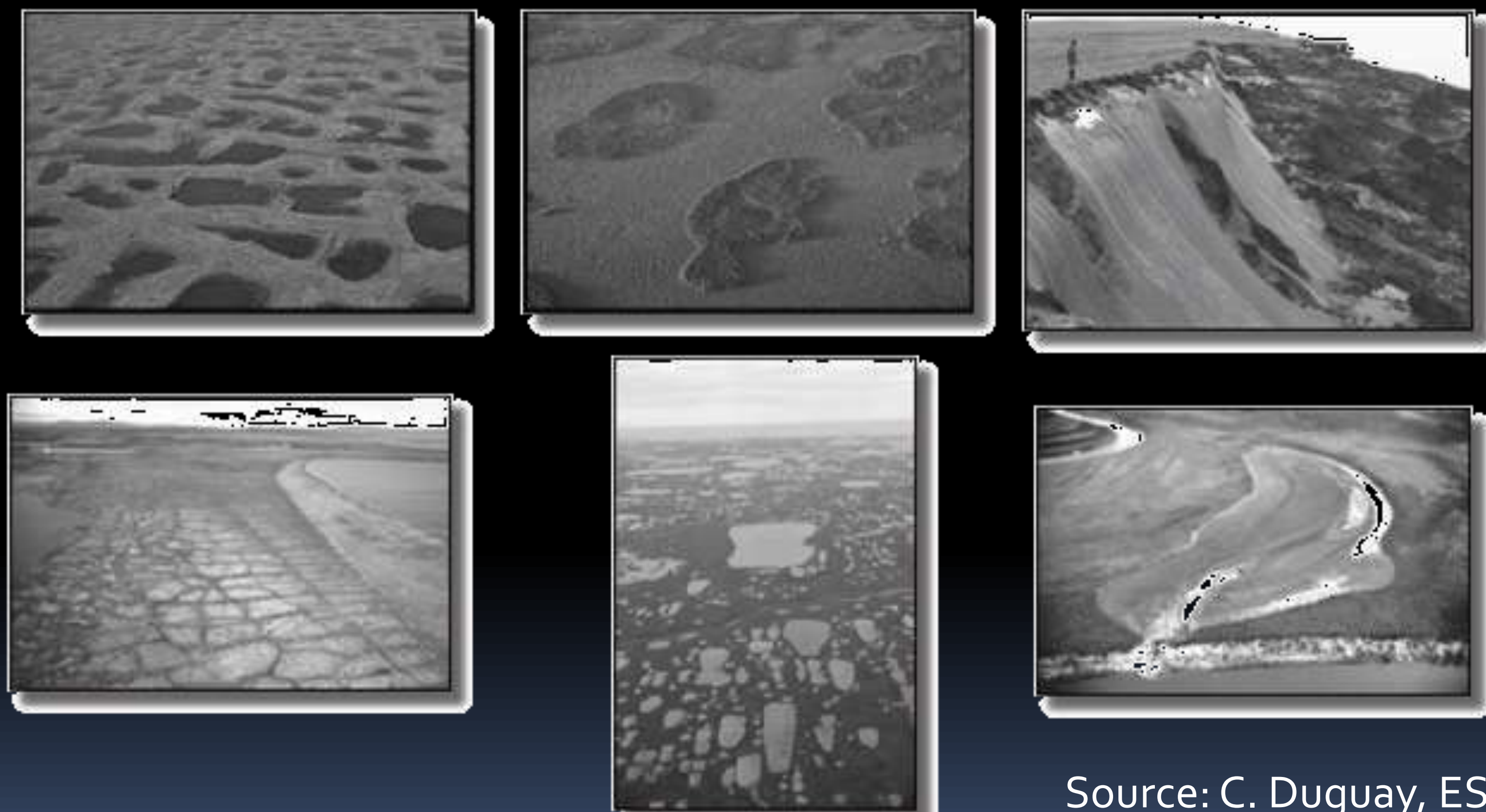
Surface expressions



Source: C. Duguay, ESA DUE Permafrost Tutorial 2010

Observable indicators

- Mass movements
  - Detachment slides
  - Backward erosion due to coastal processes and human impact

- Mapping the resulting land cover change

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Observable indicators

- Mass movements
  - ✓ Detachment slides
  - ✓ Backward erosion due to coastal processes and human impact
  - Solifluction
  - Rock glaciers
  - Frost heave and subsidence

- ➢ repeated surveys with stereophotogrammetry, Lidar, SAR Interferrometry

- (thaw) lakes

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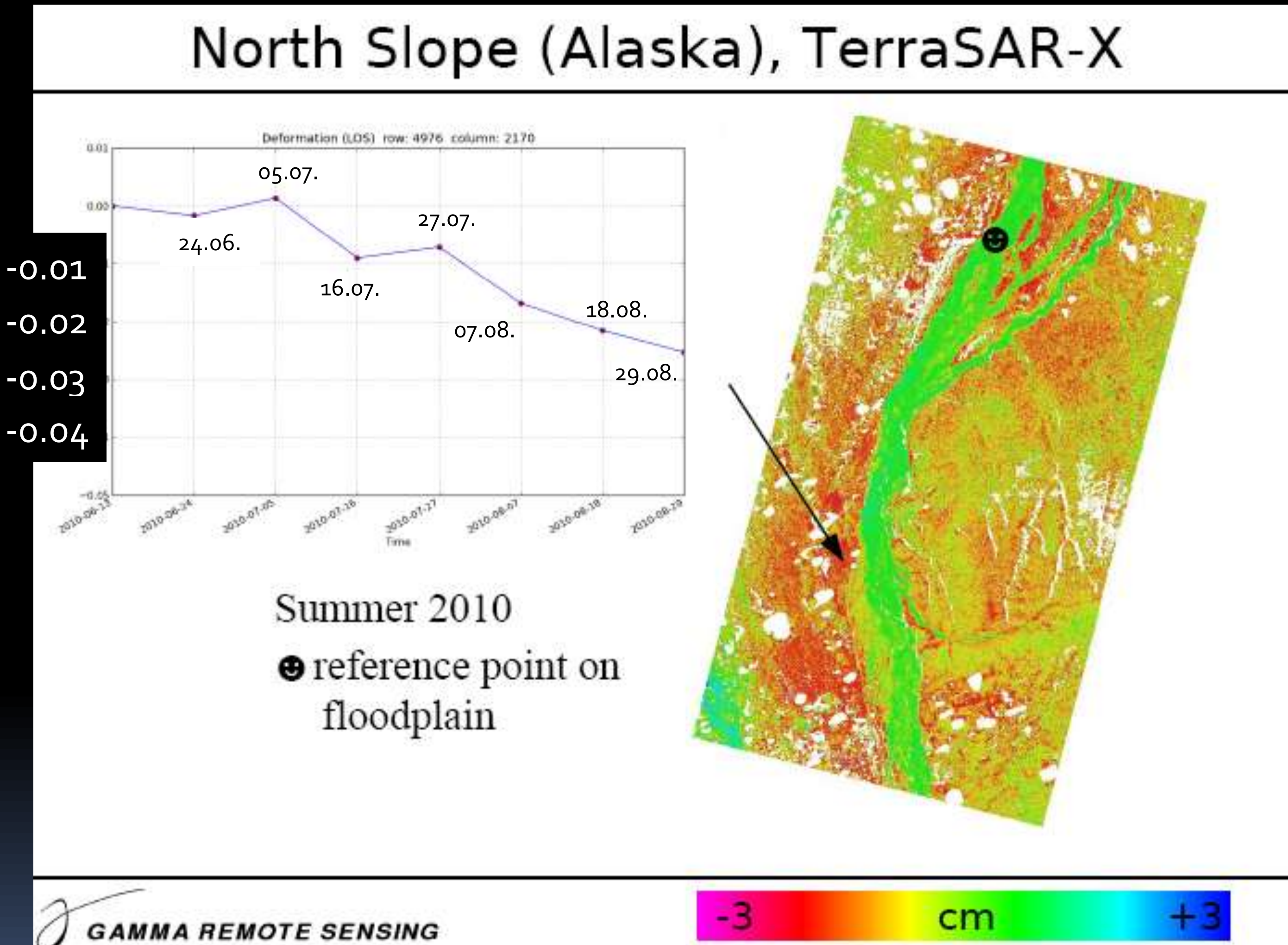
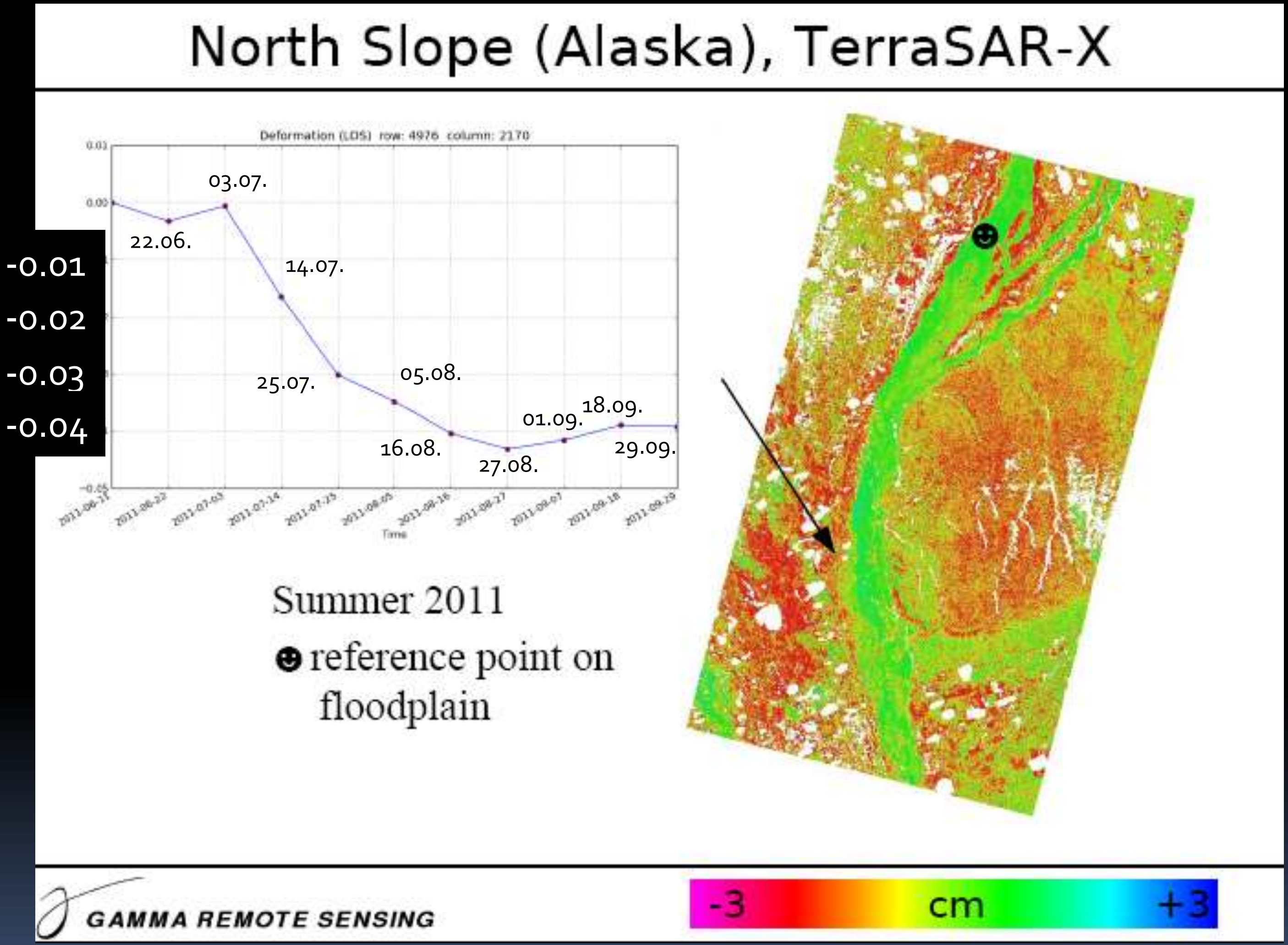
Observable indicators



Observable indicators



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Observable indicators

- Mass movements
  - ✓ Detachment slides
  - ✓ Backward erosion due to coastal processes and human impact
  - ✓ Rock glaciers
  - ✓ Frost heave and subsidence
  - ✓ Solifluction
- Thermokarst (thaw) lakes

Land cover classification

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- Thermokarst – melt of ground ice, development of depressions and filling with water
- Taliks – unfrozen ground under e.g. lakes due to heat capacity of water
- Therefore discussed as indicator for permafrost/climate change

Slowly shrinking ->

or sudden drainage when lake is tapped for some reason

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- Challenges for monitoring
  - Small features → good resolution needed
  - Growing and shrinking also related to flooding after snowmelt or wet/dry periods → very high temporal sampling needed
  - Frequent cloud cover in the arctic → radar data needed

Slowly shrinking → or sudden drainage when lake is tapped for some reason

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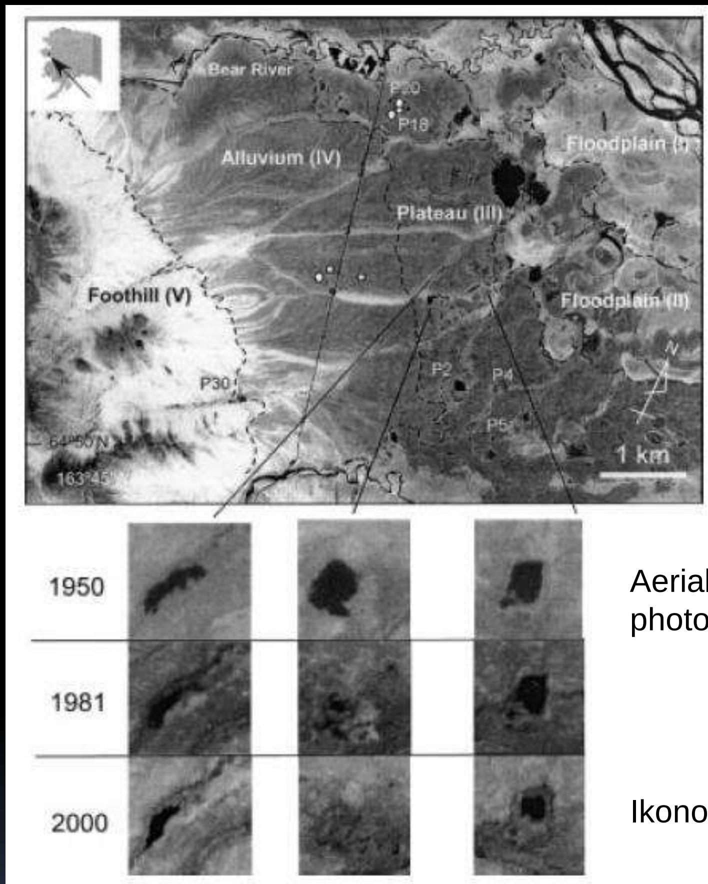
Observable indicators

Yoshikawa & Hinzman 2003



Aerial photographs

Ikonos

Monitoring over larger regions?

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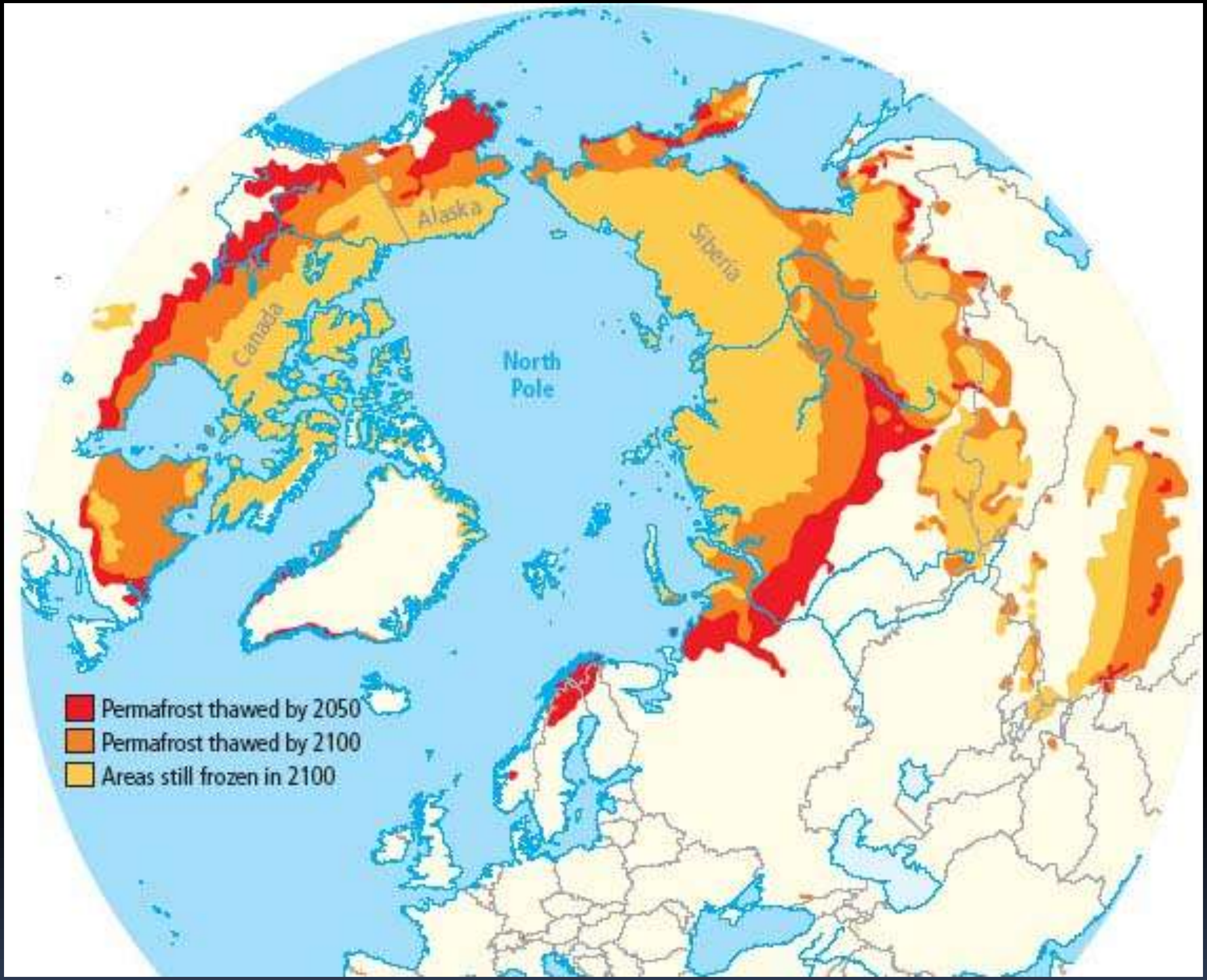

Romanovski 2009

COLD Yamal

COmbining remote sensing and field studies for assessment of Landform Dynamics and permafrost state on Yamal

COLD Yamal | SCIENCE | TEAM | EXPEDITIONS | RELATED PROJECTS | CONTACT

COLD News

- July 2014: Marina Leibman advises on crater discovery on Yamal: **news story**
- June 2014: COLD presented @ European Conference on Permafrost
- Apri 2014: COLD presented @ EGU
- Feb 7 - 9: COLD presented @ ESA-CliC-IPA-GTN-P Workshop at ESA in Frascati
- November 2013: Joint paper published in Environmental Research Letters
- Oct 23 - 24, 2013 Project Kick-off in Salzburg

EXPEDITIONS

Yamal crater expedition July 2014

Exposed soil at the hole

(c) Marina Leibman

cold.zgis.net

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Observable indicators

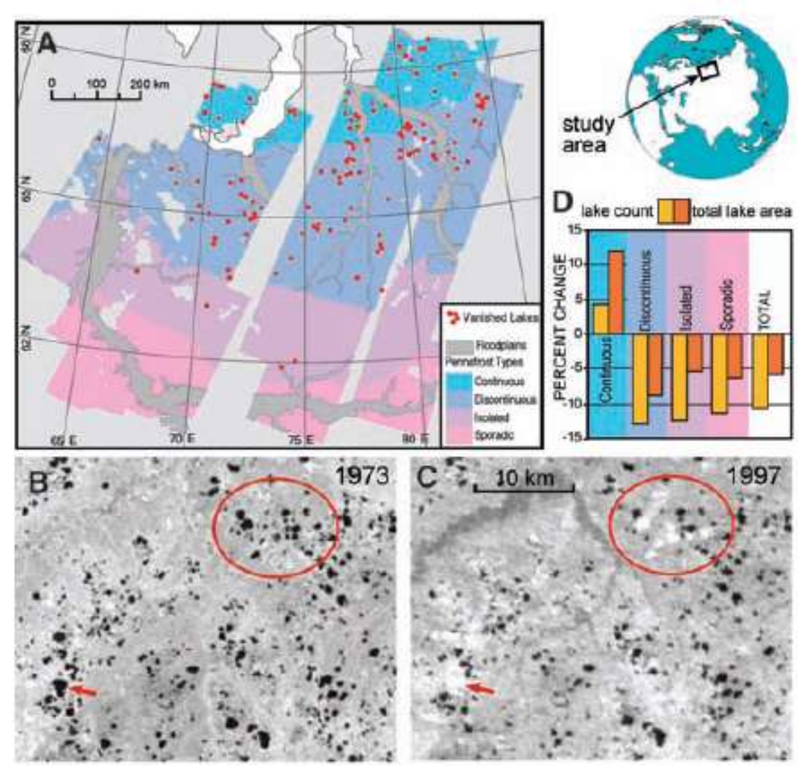
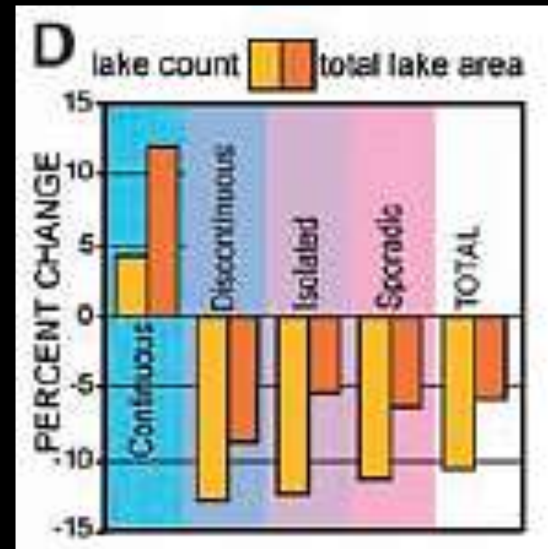


Fig. 1. (**A**) Locations of Siberian lake inventories, permafrost distribution, and vanished lakes. Total lake abundance and inundation area have declined since 1973 (**B**), including (**C**) permanent drainage and revegetation of former lakebeds (the arrow and oval show representative areas). (**D**) Net increases in lake abundance and area have occurred in continuous permafrost, suggesting an initial but transitory increase in surface ponding.

Science: Disappearing Arctic Lakes, 2005, Smith et al.



Can we use global land cover maps?

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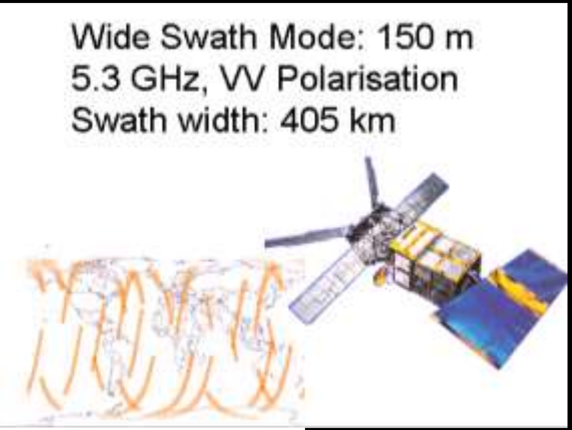
Observable indicators

Evaluation of global land cover products



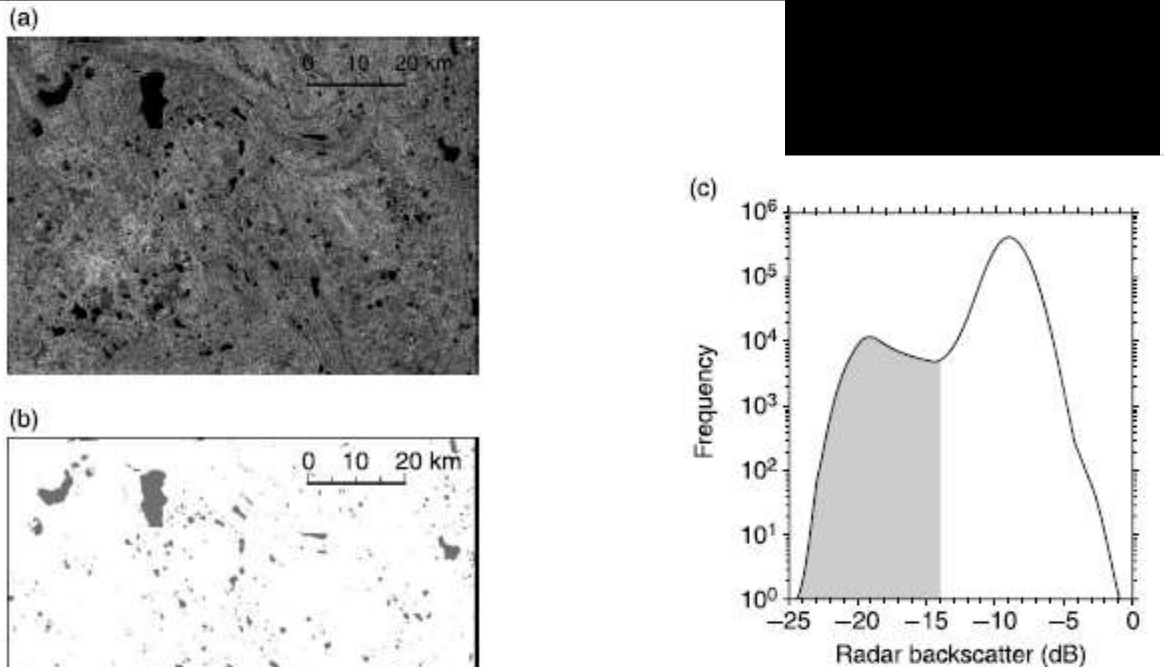


Figure 3 | Threshold classification example of a tundra site: (a) grayscale normalized image, (b) classified image with lakes in gray and (c) histogram of normalized backscatter in dB.

Bartsch et al. (2008) Hydrology Research
Bartsch et al. (2007) J. Aquatic Conservation

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Observable indicators

Evaluation of global landcover products

None water in MODIS

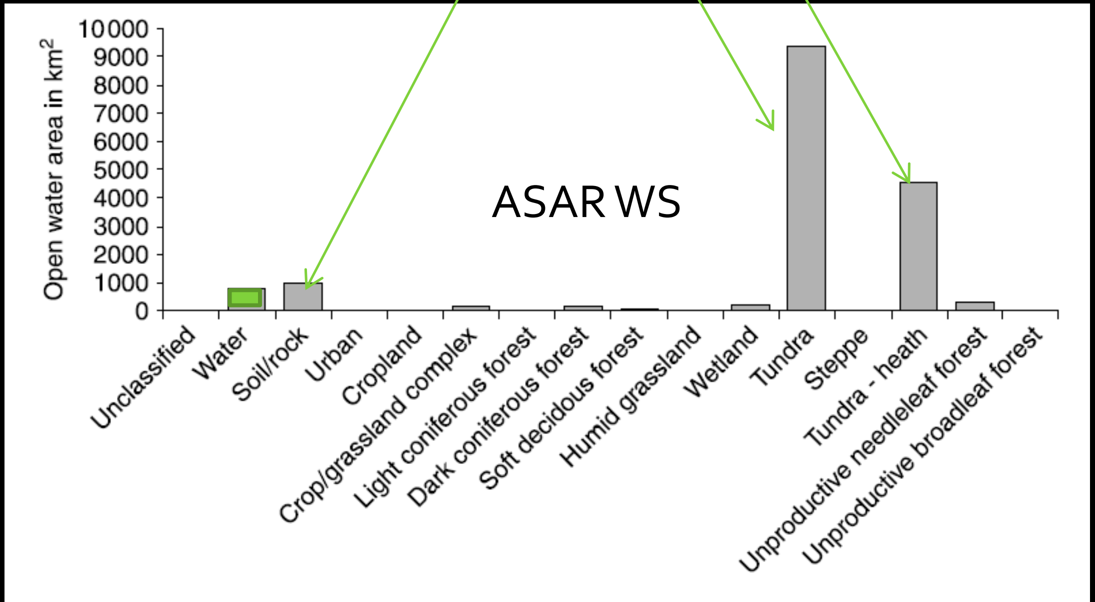
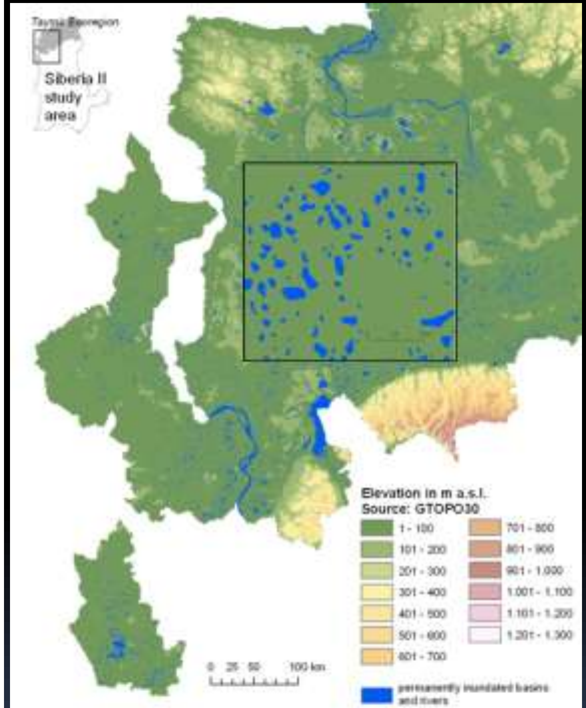


Figure 6 | Area (in km^2) of water bodies per MODIS level 2 land cover class for final water layer (natural lakes only).



Permanent water bodies in the tundra biome, Western Taymir Lowlands

Less than 10% of open water captured in MODIS landcover products in tundra environments

Bartsch et al. (2008) Hydrology Research
Bartsch et al. (2007) J. Aquatic Conservation

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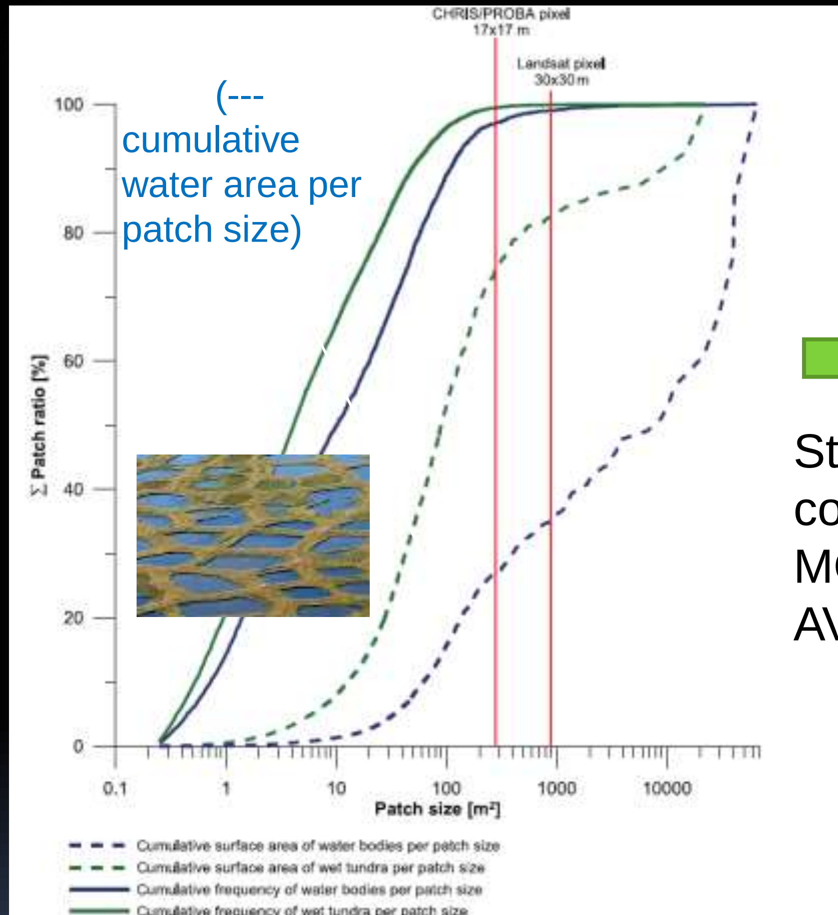
Water bodies and resolution

Cloud cover dependent



Standard Global land cover datasets MODIS, MERIS, AVHRR

Muster et al.

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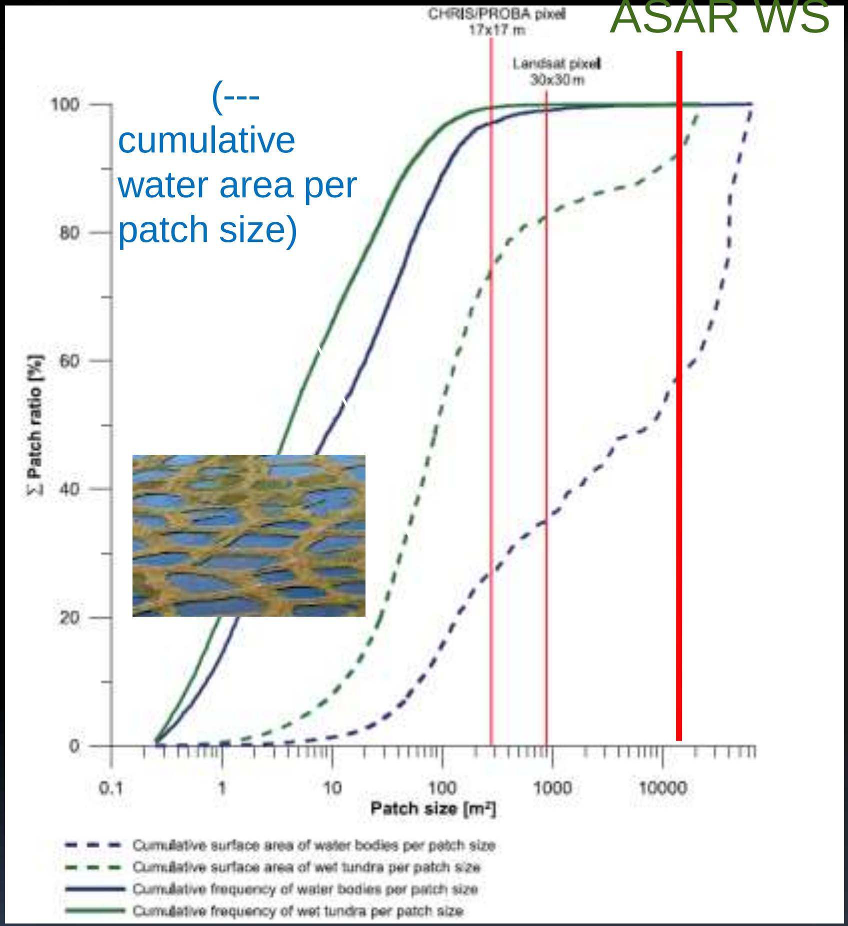
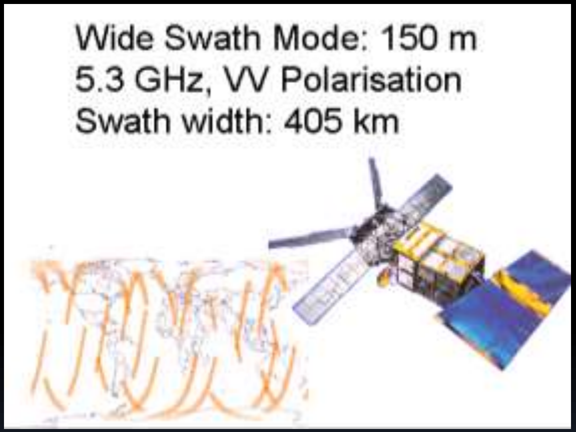
Water bodies and resolution



Muster et al.

SAR
Synthetic Apetrure Radar

Wide wath mode can cover large areas



Polar orbiting -> overlapping orbits

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Lakes as indicators

The assumption is that extent remains static during the snow free season

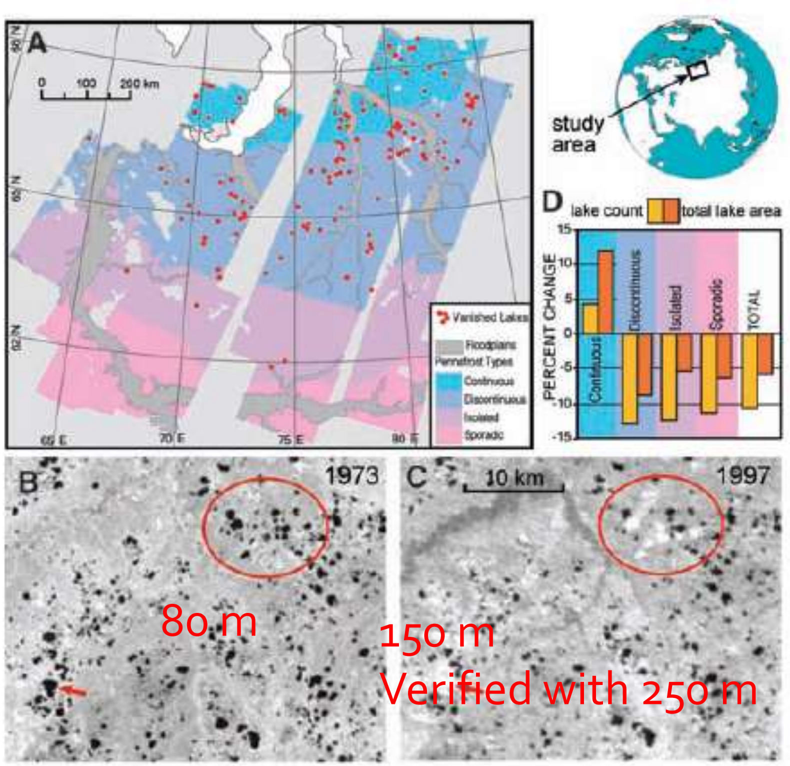
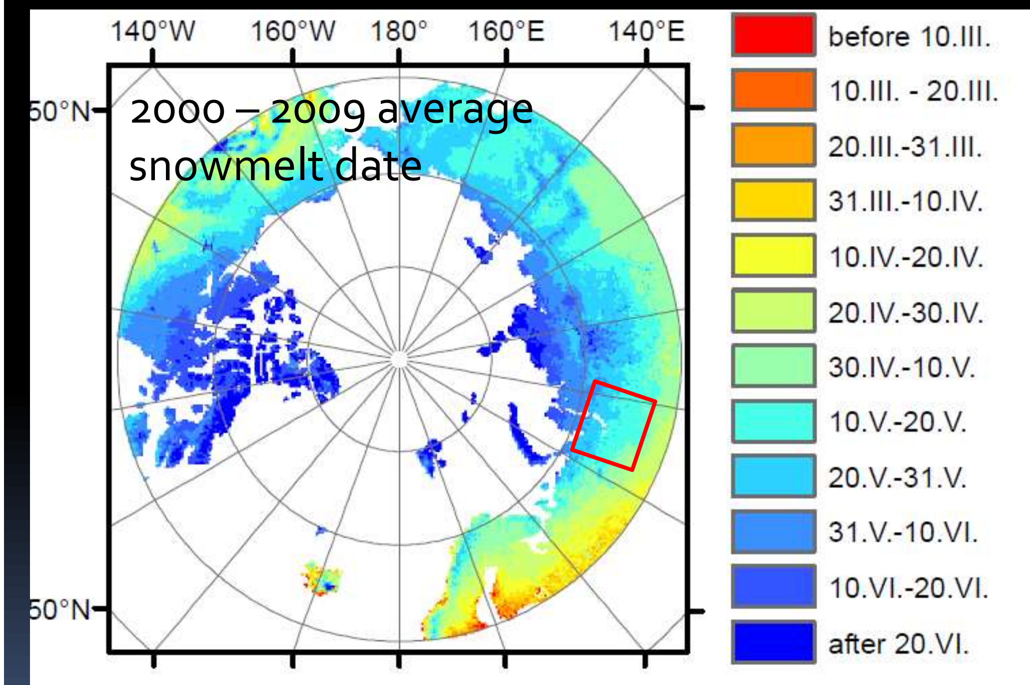


Fig. 1. (**A**) Locations of Siberian lake inventories, permafrost distribution, and vanished lakes. Total lake abundance and inundation area have declined since 1973 (**B**), including (**C**) permanent drainage and revegetation of former lakebeds (the arrow and oval show representative areas). (**D**) Net increases in lake abundance and area have occurred in continuous permafrost, suggesting an initial but transitory increase in surface ponding.

North south snowmelt timing gradient
Different timing of flooding,



Science: Disappearing Arctic Lakes, 2005, Smith et al.

Bartsch 2010, Remote Sensing
Bartsch et al. 2007, Remote Sensing of Environment

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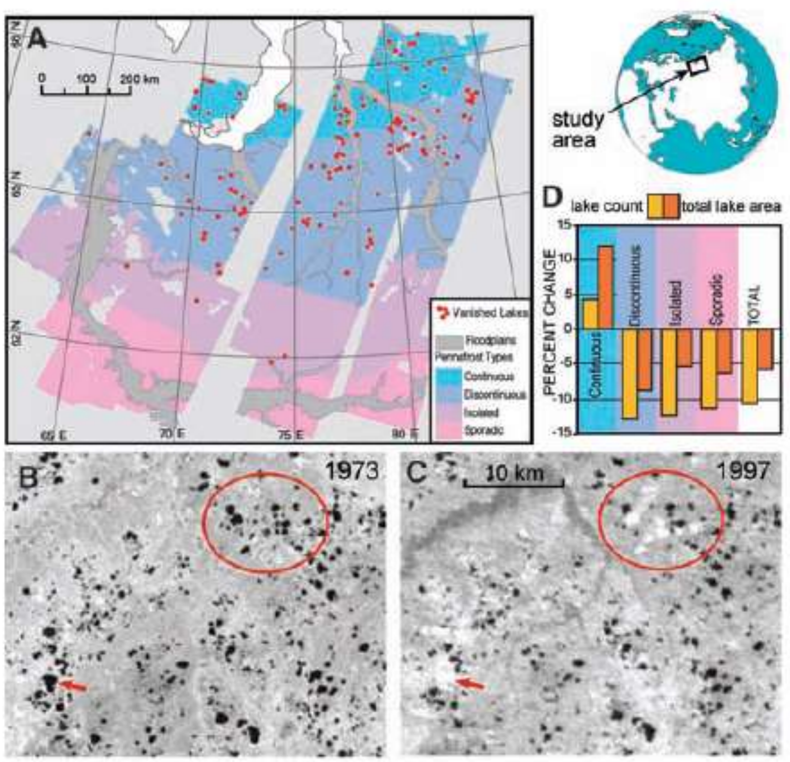

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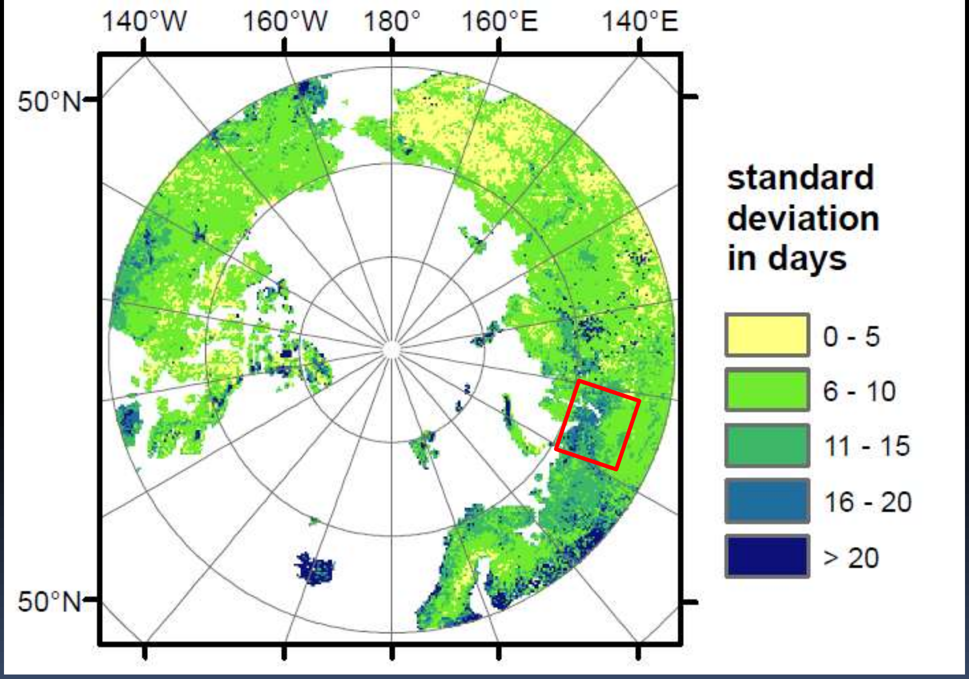

Bartsch 2010, Remote Sensing
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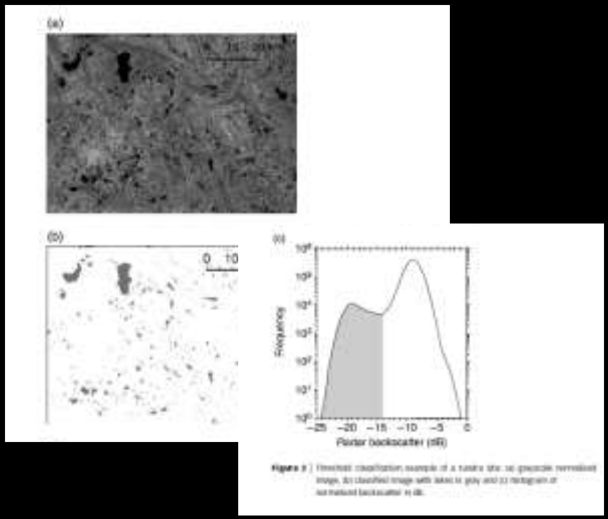
Observable indicators



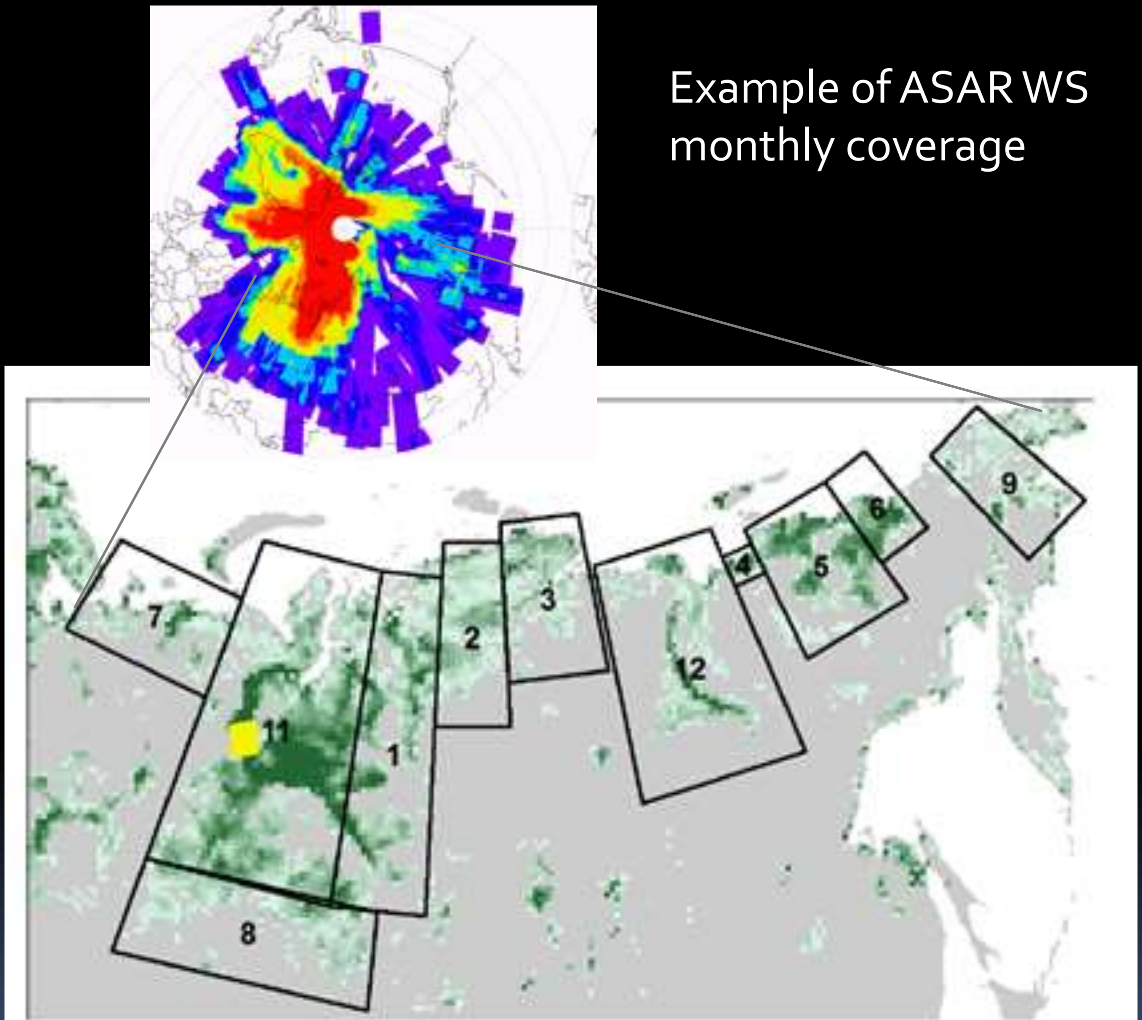


Fig. 1: Extent of subzones of the local wetland product. Green areas indicate wetland extent from the regional wetland product. The yellow area shows the extent of the sample dataset.

Example of ASAR WS monthly coverage

alanis methane
support to science element

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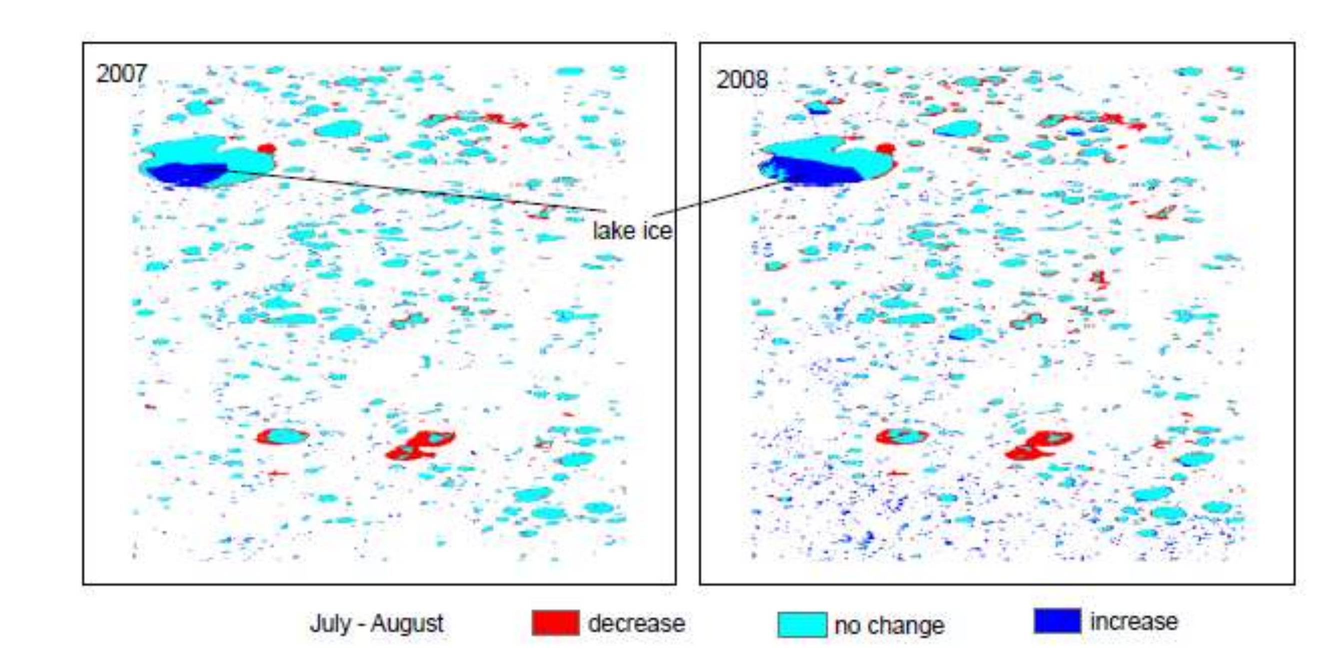
Seasonal variations



7 July to 28th of August 2007 6 July to 21th of August 2008

Bartsch et al. 2012

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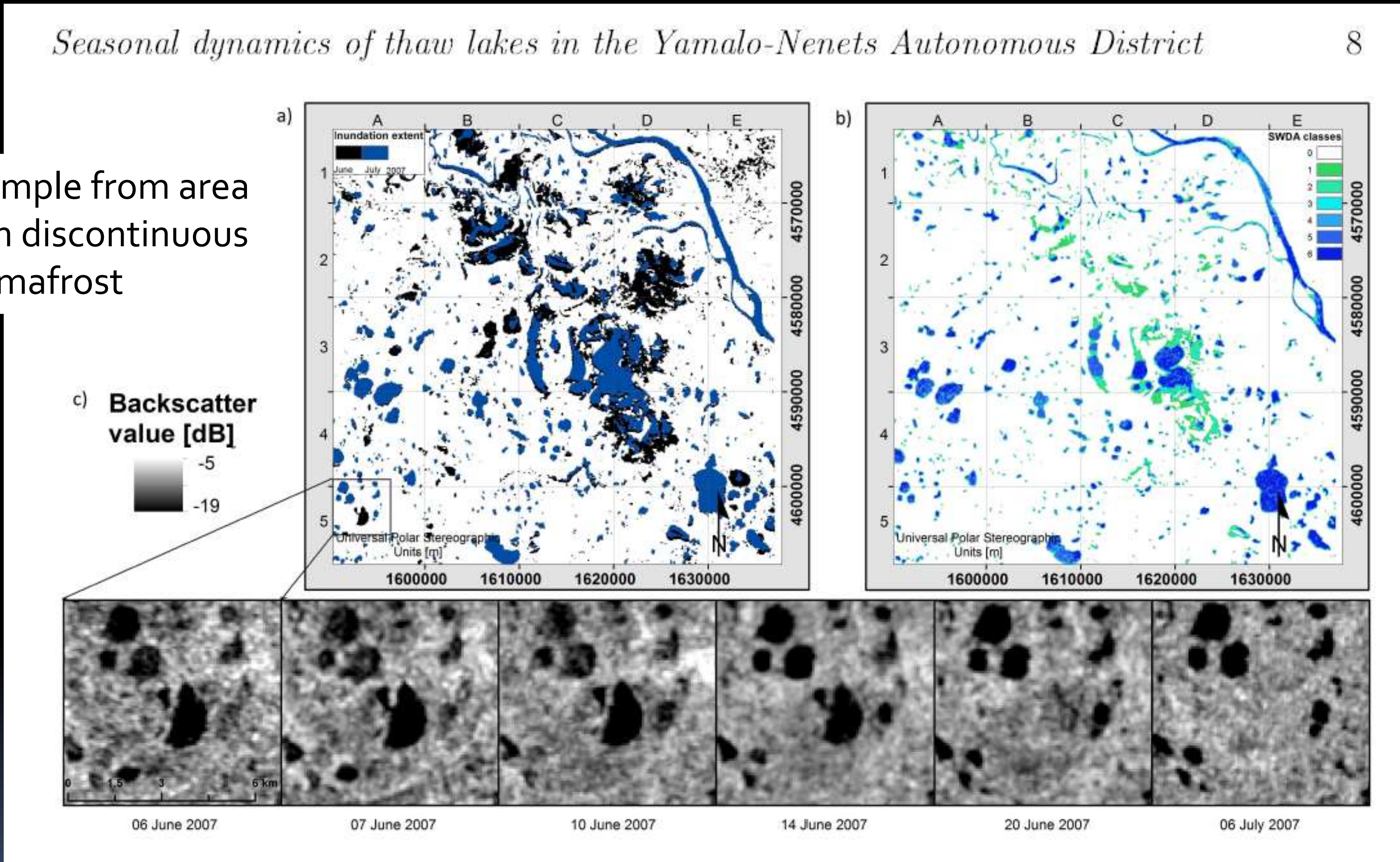
June - July

July-August

Example from area with discontinuous permafrost

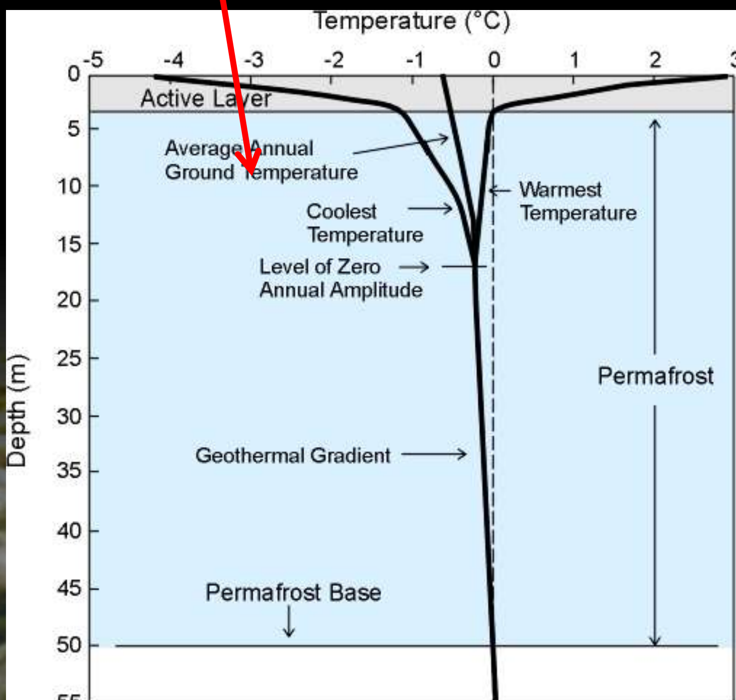


Trofaier et al. 2013

?

Complementing in-situ measurements ?

Filling gaps ?



GTN-P
- Permafrost temperature
- Active layer depth

- Review of objectives
  - **Identification** and **assessment** of permafrost relevant Earth Observation products and **provision** to permafrost scientists
  - Establishing a monitoring system on mostly <u>existing</u> remote sensing products
  - Supporting
    - The GCOS implementation plan
      - Global Terrestrial Network for Permafrost (**GTN-P**)
    - National and intergovernmental bodies
    - Scientific groups involved in climate change research

February 2008 - ESA User consultation workshop at AWI

June 2009	June 2010	March 2012	March 2014

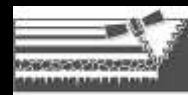
Phase 1
User requirement engineering
Monitoring strategy
Design engineering
System development

Phase 2
Demonstration and validation
Data dissemination
Phase-out

Preliminary service duration: 2 years

Workshops

May 2010	March 2011	February 2012	February 2014
TU WIEN, IPF	IARC	AWI	esa

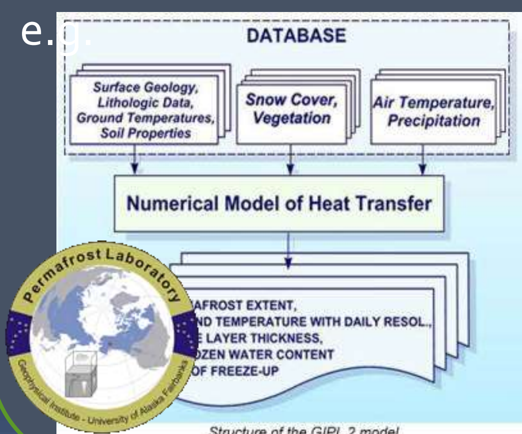


ESA Data User Element Permafrost (2009-2012)

Service components

Support Permafrost/ Climate Models

e.g.



Structure of the GIPL 2 model

Supply complementary information (time series) to ground measurements

- Land surface temperature
- Surface moisture and status

‚Show case'

Potential of satellite data for derivation of surface indicators

Subsidence
Land surface hydrology
....

Data access

www.geo.tuwien.ac.at/permafrost

DUE Permafrost data portal

Vizualization of time series , overlays with other data possible

data by time period including documentation

Arctic Portal

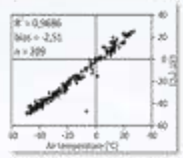
Time series for selected GTN-P monitoring sites - LST, Soil moisture and surface status

PANGAEA

Full data set including documentation and updates

Datasets have a DOI -> are citable

Remote sensing product validation within service setup time frame



Hachem et al. 2012, Elger et al. 2012

PAGE21

SEVENTH FRAMEWORK PROGRAMME

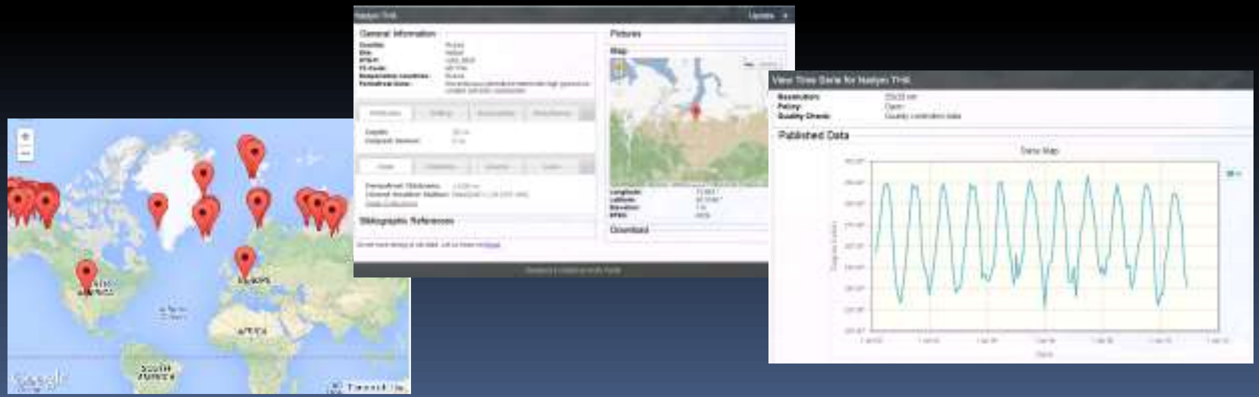
GTN-P Global Terrestrial Network for Permafrost

Utilization of service

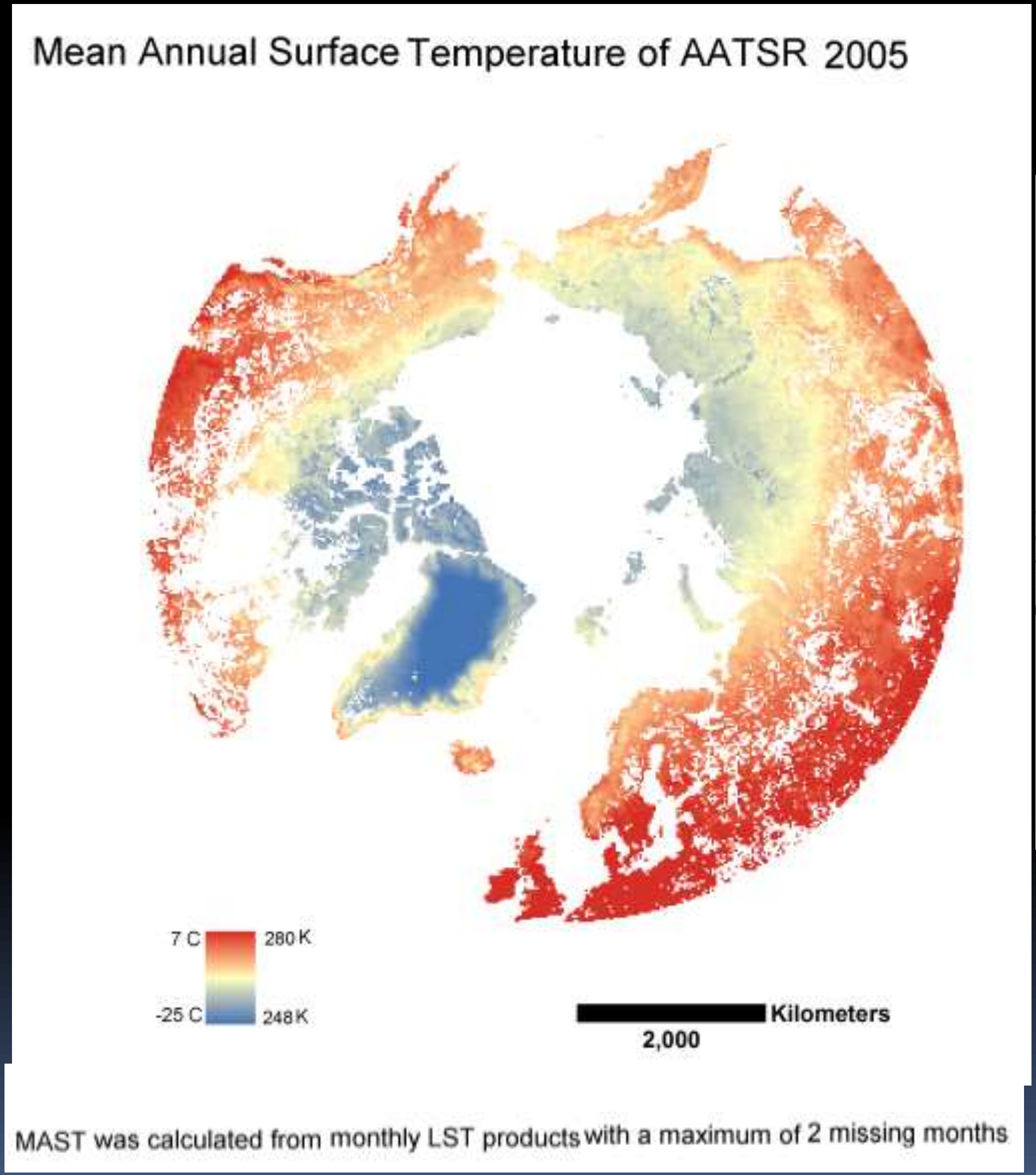
Arctic Portal

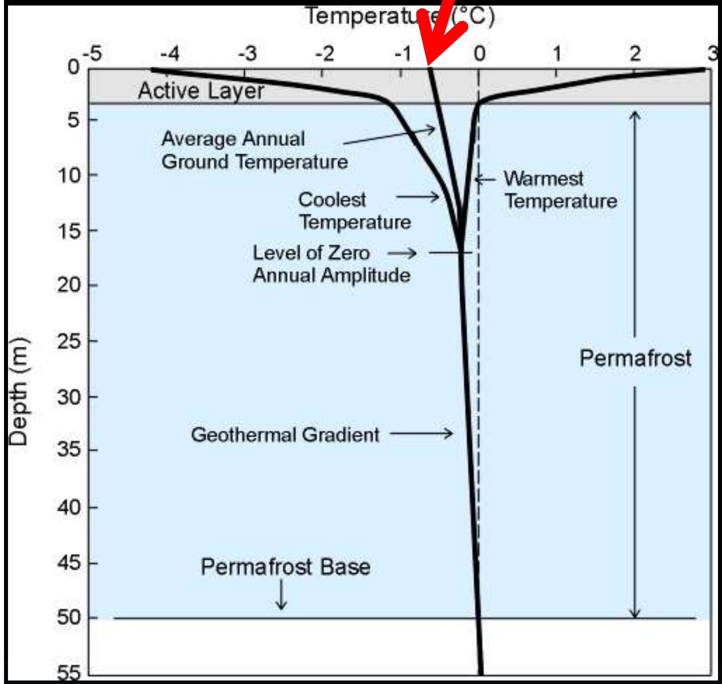
Time series for selected GTN-P monitoring sites - LST, Soil moisture and surface status

Arctic Portal/GTN-P/PAGE21 sites borehole management system (www.arcticportal.org)

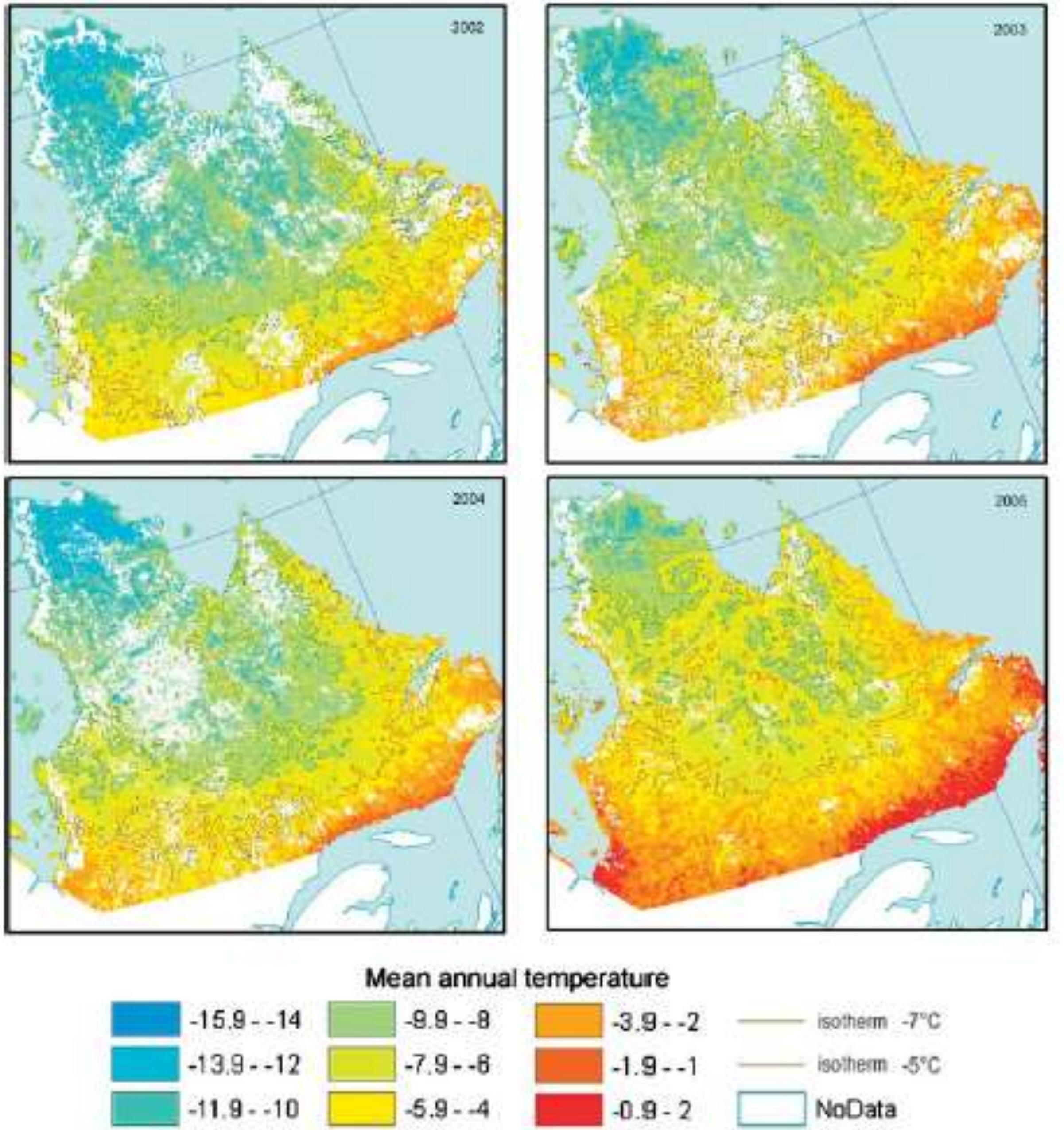


Land surface temperature





Soliman et al. 2012



- 7°C isotherm, boundary between widespread discontinuous and continuous permafrost

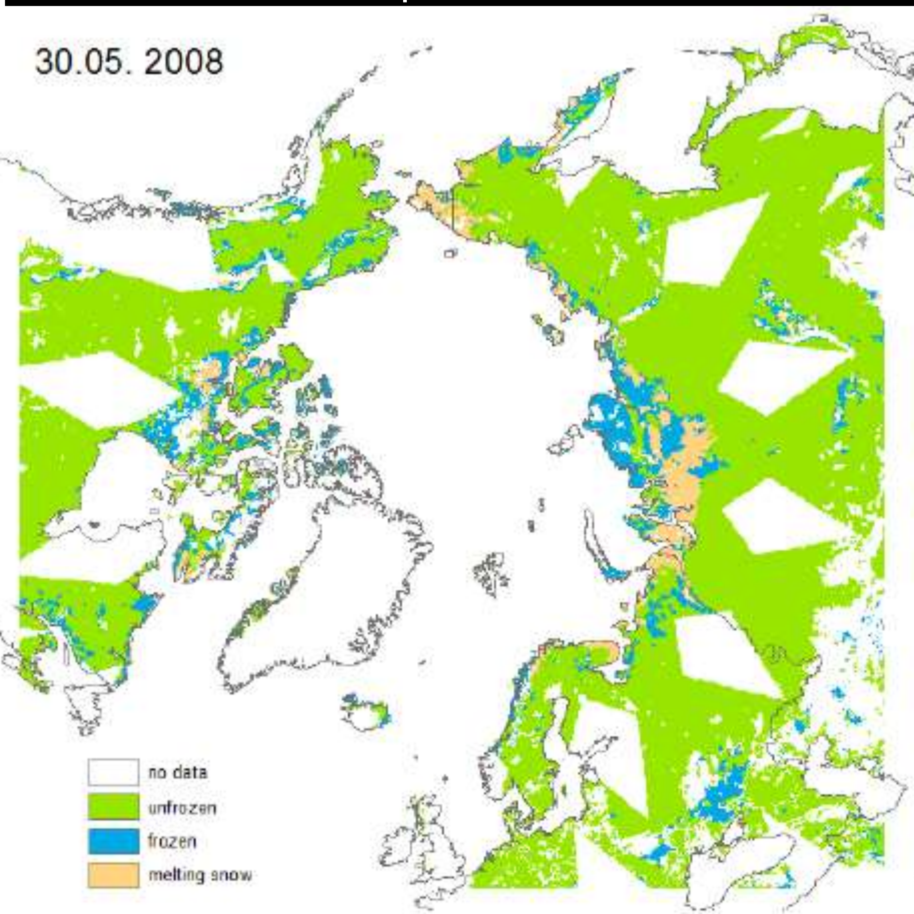
- 5 °C isotherm boundary between sporadic and widespread discontinuous permafrost

Hachem et al. 2009, MODIS LST

EO Sui

Surface status from scatterometer

Metop ASCAT



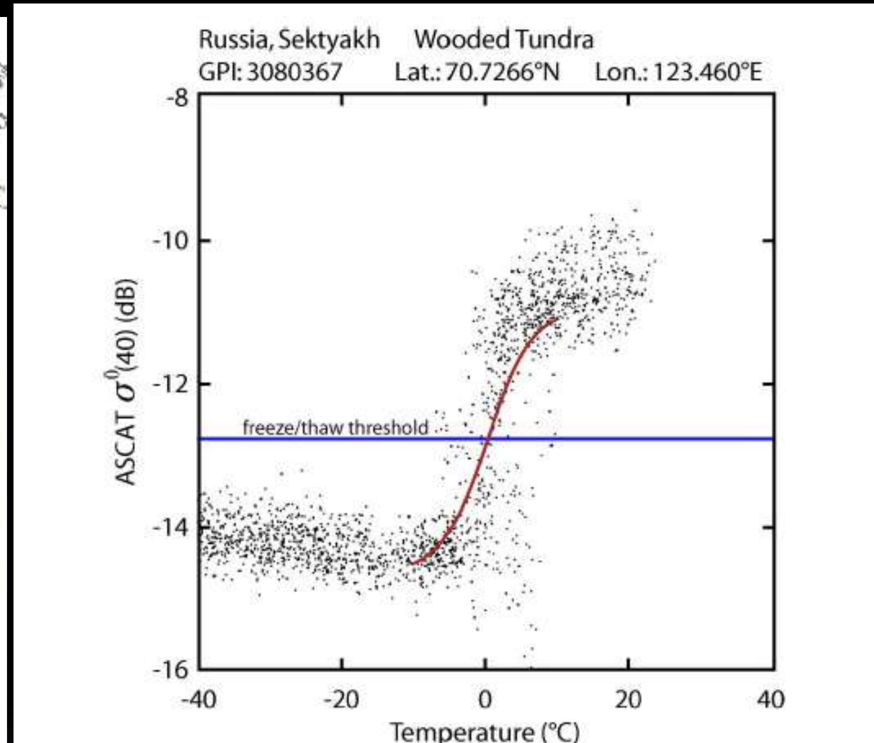


Fig. 4. ASCAT normalized backscatter versus temperature in a grid point near to Sektyakh meteorological station in Russia. Red curve indicates the best logistic function fitted to the measurements. Blue line shows the inflection point of the logistic curve which is assumed as backscatter level at freeze/thaw point.

V. Naeimi, C. Paulik, A. Bartsch, W. Wagner, R. Kidd, J. Boike, and K. Elger (2012),IEEE Transactions on Geoscience and Remote Sensing

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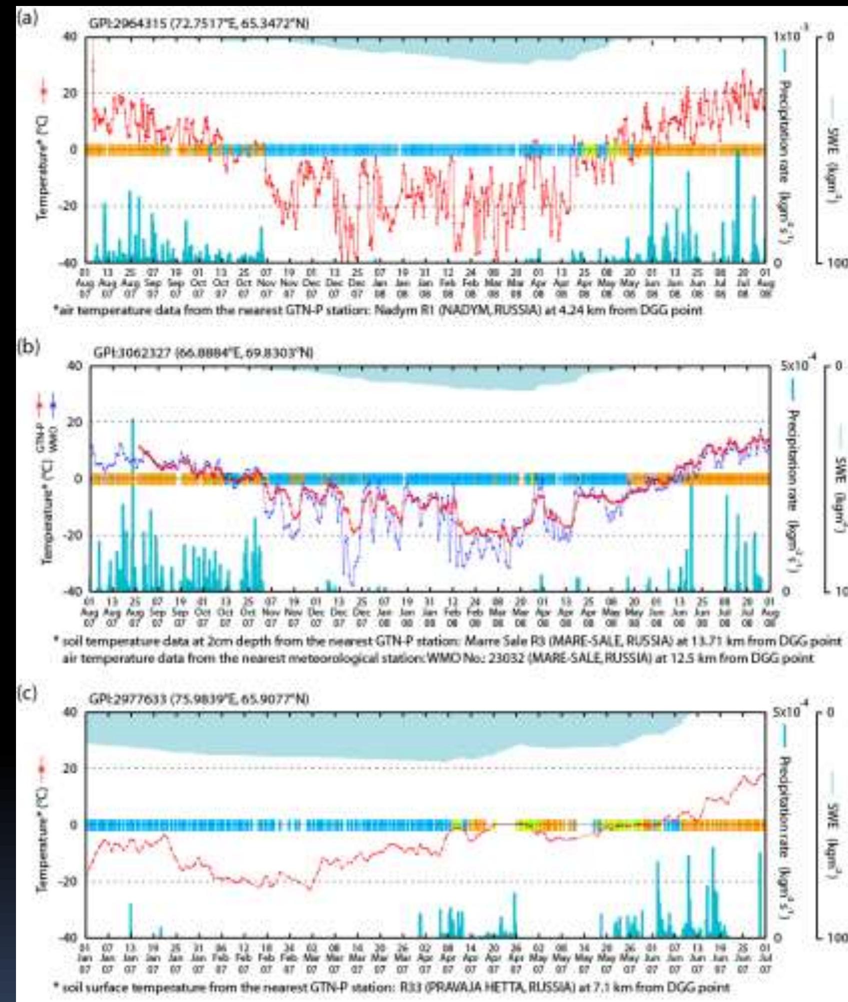
Surface status from scatterometer

GTN-P borehole data (point versus 25km gridded ASCAT)

Station	Temperature	Agreement with SSF [%]
Nadym R1	surface	91.79
Nadym R1	air	90.36
R3 Marre Sale	0.02m below ground	82.75
R3 Marre Sale	0.5m below ground	80.13
R33 Borehole 3	0m surface	80.36
R33 Borehole 3	0.5m below ground	71.90



ASCAT (METOP-A) SSF
Unfrozen Frozen Unknown Temporary Water on Surface/Snow melt
Precipitaion and SWE (Snow Water Equivalent) data are extracted from GLDAS-NOAH dataset

Naeimi et al. 2012

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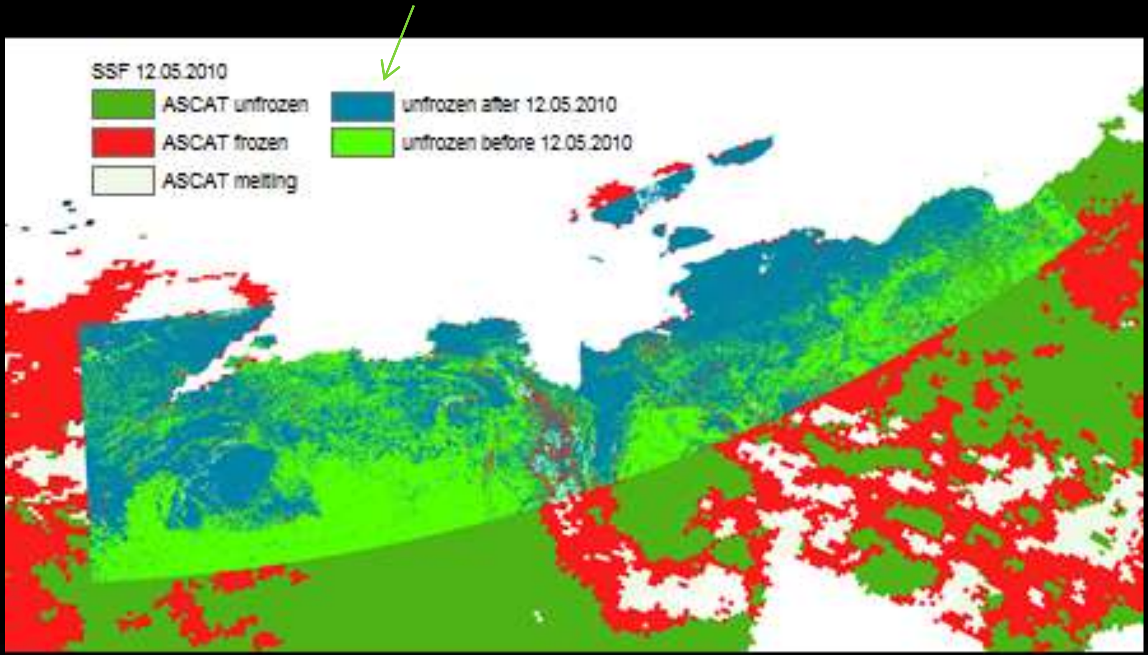
Surface status from synthetic aperture radar?

From SAR thaw data (ENVISAT ASAR GM, 1km)



Algorithm based on S.-E. Park, Bartsch, A., D. Sabel, W. Wagner, V. Naeimi, Y., Yamaguchi (2011): Remote Sensing of Environment
Paulik et al. 2012

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Summary

- Modelling required
- EO can be used for input or model evaluation
- Indicators
  - Changes in land surface hydrology (longterm – seasonal, suffiecient spatial and temporal resolution)
  - Changes in terrain