REMOTE SENSING OF PERMAFROST IN NORTHERN ENVIRONMENTS
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
Permafrost?

Ice-rich Permafrost – Roughly 70% Ice by volume

Ice Wedge – Roughly 100% Ice

© AWI
Boreholes

EO Summer School 2014

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Active layer monitoring

**CALM Sites**
- Grids
- Thaw Tubes
- Ground Temperature
Complementing in-situ measurements?
Filling gaps?

GTN-P
- Permafrost temperature
- Active layer depth

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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
Observable surface parameters

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

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

- Solifluction
- Rock glaciers
- Frost heave and subsidence

- (thaw) lakes

- repeated surveys with stereophotogrammetry, Lidar, SAR Interferrometry

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Observable indicators

North Slope (Alaska), TerraSAR-X

Summer 2010

Reference point on floodplain

Gamma Remote Sensing
Observable indicators

North Slope (Alaska), TerraSAR-X

Summer 2011
reference point on floodplain

GAMMA REMOTE SENSING
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
- 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

Yamal peninsula Siberia

Seward Peninsula Alaska

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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
Observable indicators

Yoshikawa & Hinzman 2003

Monitoring over larger regions?

Aerial photographs

Ikonos

A. Bartsch 2008

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Romanovski 2009
COLD Yamal
CCombining remote sensing and field studies for assessment of Landform Dynamics and permafrost state on Yamal

EXPEDITIONS

Yamal crater expedition July 2014

Exposed soil at the hole

(c) Marina Leibman
Observable indicators

Can we use global land cover maps?

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

Evaluation of global land cover products
Observable indicators

Evaluation of global landcover products

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

(--- cumulative water area per patch size)

Standard Global land cover datasets MODIS, MERIS, AVHRR

Muster et al.
Water bodies and resolution

SAR
Synthetic Aperture Radar

Wide swath mode can cover large areas

ASAR WS

Muster et al.

---
cumulative water area per patch size

Polar orbiting -> overlapping orbits

Wide Swath Mode: 150 m
5.3 GHz, VV Polarisation
Swath width: 405 km
Lakes as indicators

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

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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Different timing of flooding,

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.

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Observable indicators

Example of ASAR WS monthly coverage

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.
Seasonal variations

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

Bartsch et al. 2012
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Seasonal dynamics of thaw lakes in the Yamalo-Nenets Autonomous District

Example from area with discontinuous permafrost
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 existing 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
Support Permafrost/Climate Models

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

DUE Permafrost data portal

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

Mean Annual Surface Temperature of AATSR 2005

MAST was calculated from monthly LST products with a maximum of 2 missing months

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
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.

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Surface status from scatterometer

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

<table>
<thead>
<tr>
<th>Station</th>
<th>Temperature</th>
<th>Agreement with SSF [%]</th>
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</thead>
<tbody>
<tr>
<td>Nadym R1</td>
<td>surface</td>
<td>91.79</td>
</tr>
<tr>
<td>Nadym R1</td>
<td>air</td>
<td>90.36</td>
</tr>
<tr>
<td>R3 Marre Sale</td>
<td>0.02m below ground</td>
<td>82.75</td>
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<tr>
<td>R3 Marre Sale</td>
<td>0.5m below ground</td>
<td>80.13</td>
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<tr>
<td>R33 Borehole 3</td>
<td>0m surface</td>
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<tr>
<td>R33 Borehole 3</td>
<td>0.5m below ground</td>
<td>71.90</td>
</tr>
</tbody>
</table>

ASCAT (METOP-A) SSF
- Unfrozen
- Frozen
- Unknown
- Temporary Water on Surface/Snow melt

Precipitation 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)

Paulik et al. 2012
Summary

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