Remote Sensing of Changing Permafrost Landscapes in North Siberia

Projects and Some Results

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Permafrost is any ground that remains below or at 0°C for at least two consecutive years. 24% of the northern hemisphere land surface are affected by permafrost (Zhang et al. 1999).

Permafrost is an important factor for ecosystems, energy and matter cycles, infrastructure. Permafrost degradation processes, time scales, and impacts are poorly known.
Thermal State of Permafrost (TSP)

- International IPY endorsed project
- Funded by NSF (V. Romanovsky)
- Aiming at obtaining standardized ground temperature measurements in all permafrost regions
- Equipment of several 100 new boreholes in the circum-arctic with temperature data loggers
- Re-measurement of historic sites
- Contemporary snapshot of the thermal state of the permafrost realm
- Delivers data for modelling future trajectory of permafrost

Romanovsky et al.
Contemporary changes in central Yakutia

Romanovsky et al.
Definition of 'permafrost degradation'

- A naturally or artificially caused decrease in the thickness and/or areal extent of permafrost (National Research Council of Canada Technical Memorandum No. 142.1988).

Expressed as

- a thickening of the active layer
- a lowering of the permafrost table
- a reduction in the areal extent
- or the complete disappearance of permafrost.

In the Russian literature the term degradation usually is more specific in that permafrost starts to degrade when winter freezing no longer reaches the permafrost table and taliks begin to form. The formal indicator of this event is the mean annual temperature at the bottom of the active layer (seasonally frozen or seasonally thawed). Permafrost degradation begins when this temperature remains persistently above 0°C.

Fedorov & Konstantinov, 2003
Thermokarst: Processes and landforms resulting from the thawing of ice-rich ground, i.e. the surface subsidence related to the volume loss due to ground ice melting.

Two Main Messages:
- Permafrost degradation is not restricted to the southern permafrost boundary, where warm permafrost prevails
- Permafrost degradation is closely related to topographical + hydrological change
Thermokarst Impacts

- Coastal Erosion
- Shelf Topography
- Subsea Permafrost
- Coastal Morphology
- Matter Flux Land-to-Sea: Sediment
- Matter Flux Land-to-Sea: Carbon
- Matter Flux Land-to-Sea: Nutrients
- Matter Flux Land-to-Sea: Contaminants

Arctic Coasts+Shelves

- Matter Flux Land-to-Sea: Carbon

Surface+Subsurface Hydrology

- Ground Water Flow
- Relief Change
- Ground Water Storage
- Discharge Patterns
- Discharge Runoff
- Surface Runoff
- Ground Water Recharge
- Soil Moisture
- Energy and Matter Fluxes
- Ground Water Amounts

Infrastructure Building

- Water Supply
- Contaminant Distribution
- Subsistence Lifestyle
- Infrastructure Maintenance
- Sustainability

Energy and Matter Fluxes

- Surface Albedo
- Carbon Sequestration
- Biogeochemical Cycles
- Energy and Matter Fluxes
- Heat Exchange
- Evapotranspiration
- Greenhouse Gas Emissions

Society

- Climate Feedbacks
- Sustainability
- Farming
- Distribution Soil Carbon Pools
- Distribution Freshwater Ecosystems
- Paludification vs. Aridification

Ecosystem Functions + Feedback Mechanisms

- Greenhouse Gas Emissions
- Evapotranspiration
- Carbon Sequestration
- Biogeochemical Cycles
- Surface Albedo
- Heat Exchange
- Energy and Matter Fluxes

Ecosystem Structure

- Treeline Position
- Freshwater Ecosystems
- Distribution Freshwater Ecosystems
- Distribution Soil Carbon Pools
- Paludification vs. Aridification

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Distribution of Ice-Rich Permafrost (Yedoma) in Northeast Siberia

- Thickness of the deposit is between 5-100m
- Present day total coverage is > 1x10⁶ km
- Gravimetric ground ice contents in the sediments between 60-120%
- Including the ice wedges, total volumetric ice content of up to >75%
- Organic carbon content averages between 2-5%
- Accumulation during several 10 000 years

Zimov et al 2006 (Science), Schirrmeister et al., in review
Ice-rich Permafrost Enhances Coastal Erosion

In NE Siberia, steep cliffs consisting of ice-rich permafrost can be up to 40m high.
Ice-rich Permafrost Enhances Coastal Erosion

Coastal erosion rates in the NE Siberian Seas can reach up to 12m/year
Ice-rich Permafrost Enhances Coastal Erosion

At some sites, coastal erosion resulted in up to several 100m of coastal retreat during the remote sensing period (~60 years)
Ice-rich Permafrost Enhances Coastal Erosion

Large amounts of sediments are re-mobilized

Photo: V. Rachold
Permafrost Degradation and C-Cycle

Organic carbon that was stored for several ten thousands of years is released by coastal erosion, thermo-erosion, and thermokarst into the active carbon cycle.
Permafrost Degradation and C-Cycle

Walter et al., 2006 (Nature), Walter et al., 2007 (Phil. Trans. Royal Soc. A)
Permafrost Degradation and C-Cycle

Methane emission from thermokarst lakes due to anaerobic degradation of released organic material

Olenek Channel, Lena Delta

Kolyma Lowland, NE Siberia

A tiny thermokarst lake in Fairbanks, Alaska
Tools and techniques for assessing permafrost degradation

Multi-temporal field monitoring on selected sites
- Surface and subsurface climate station data
- Mapping and change detection (active layer depth, subsurface temperatures, vegetation, soil moisture, surface subsidence, hydrology)
- Temporal patterns: Geochronology of permafrost degradation

Multi-temporal and multi-sensoral remote sensing
- Mapping and monitoring of permafrost degradation features (high spatial resolution)
- Provision of physical input parameters for modeling (various spatial and spectral resolutions)

GIS-based spatial analysis
- Spatial distribution of permafrost degradation features
- Relationship with other features (permafrost types, ice contents, sediment thickness, climate, hydrology, soils, vegetation, etc.)
- Quantification of processes and feedbacks (e.g. carbon, sediment, and energy fluxes; interactions with vegetation, hydrology, and coasts)

Retrospective and prognostic modeling
- Permafrost models
- Climate models
- Coupled models
Key parameters that can be measured with remote sensing sensors

Surface + Subsurface Hydrology
- Relief Change
- Discharge Patterns
- Surface Runoff
- Soil Moisture

Energy and Matter Fluxes
- Surface Runoff
- Energy and Matter Fluxes
- Soil Moisture

Arctic Coasts + Shelves
- Coastal Erosion
- Coastal Morphology
- Surface Disturbance
- Distribution Freshwater Ecosystems
- Ecosystem Functions + Feedback Mechanisms

Energy and Matter Fluxes
- Surface Albedo
- Greenhouse Gas Emissions
- Heat Exchange

Greenhouse Gas Emissions
- Heat Exchange

Ecosystem Functions + Feedback Mechanisms
- Treeline Position

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Projects focusing on the survey of a status baseline or changes in the system with a remote sensing component

G. Grosse: Climate-Induced Permafrost Degradation in the Arctic (CIPEDIA)

K. Walter: Impacts of Thermokarst Lakes on Carbon Cycling and Climate Change

V. Romanovsky: Permafrost Dynamics Within the Northern Eurasian Region and Related Impacts on Surface and Sub-Surface Hydrology

P. Overduin: Arctic Circum-Polar Coastal Observatory Network (ACCO-Net)

+ many projects focusing on local studies, e.g.:

Coastal Erosion at the Bykovsky Peninsula
Morphometry and Spatial Distribution of Lakes in the Lena River Delta
Methane Balance of the Wetlands in the Lena River Delta
Spectral Properties of Periglacial Landscapes in the Lena River Delta
## Overview of remote sensing data used or planned for use in these studies

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Bands</th>
<th>Wavelength</th>
<th>Ground Resolution</th>
<th>Period of Operation</th>
<th>Currently Used or Planned for Use in These Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial imagery</td>
<td>1</td>
<td>Pan</td>
<td>0.8 – 2m</td>
<td>ca. 1951-</td>
<td>Coastal erosion, lake change, thermokarst distribution</td>
</tr>
<tr>
<td>Corona KH-1 to 4B</td>
<td>1</td>
<td>Pan</td>
<td>up to 1.8m</td>
<td>1959-1972</td>
<td>Coastal erosion, lake change, thermokarst distribution</td>
</tr>
<tr>
<td>Gambit KH-7</td>
<td>1</td>
<td>Pan</td>
<td>up to 0.6m</td>
<td>1963-1967</td>
<td>Coastal erosion, lake change, thermokarst distribution</td>
</tr>
<tr>
<td>Ikonos-2</td>
<td>5</td>
<td>VIS-VNIR, pan</td>
<td>4.0 / 1.0m</td>
<td>1999-</td>
<td>Lake change</td>
</tr>
<tr>
<td>Landsat-7 ETM+</td>
<td>8</td>
<td>VIS-SWIR, TIR, pan</td>
<td>30 / 60 / 15m</td>
<td>1999-</td>
<td>Thermokarst distribution</td>
</tr>
<tr>
<td>Terra MODIS</td>
<td>36</td>
<td>VIS-SWIR, TIR</td>
<td>250-1000m</td>
<td>1999-</td>
<td>Land surface temperatures</td>
</tr>
<tr>
<td>CHRIS Proba</td>
<td>18</td>
<td>VIS-VNIR</td>
<td>17m</td>
<td>2001-</td>
<td>Thermokarst distribution, spectral characteristics</td>
</tr>
<tr>
<td>Spot-5</td>
<td>5</td>
<td>VIS-VNIR, pan</td>
<td>10 / 2.5m</td>
<td>2002-</td>
<td>Coastal erosion, lake change</td>
</tr>
<tr>
<td>ALOS PRISM</td>
<td>1</td>
<td>Pan</td>
<td>2.5m</td>
<td>2006-</td>
<td>Coastal erosion, lake change, Thermokarst distribution</td>
</tr>
<tr>
<td>ALOS AVNIR-2</td>
<td>4</td>
<td>VIS-VNIR</td>
<td>10m</td>
<td>2006-</td>
<td>Thermokarst distribution</td>
</tr>
<tr>
<td>Radarsat</td>
<td></td>
<td>SAR</td>
<td>10m</td>
<td>1995-</td>
<td>Upscaling of methane emissions from lakes</td>
</tr>
<tr>
<td>ALOS PALSAR</td>
<td></td>
<td>SAR</td>
<td>10m</td>
<td>2006-</td>
<td>SAR interferometry</td>
</tr>
</tbody>
</table>
Objectives

- Baseline classification of the different types of permafrost degradation terrain
- Qualitative and quantitative assessment of thermokarst distribution
- Based on multi-sensoral remote sensing, field data, and spatial data analysis
Important Steps for a Circum-Arctic Classification and Assessment

- Identify surface and subsurface properties, features and structures indicative for permafrost degradation
- Define a valid, unified and widely accepted classification scheme for permafrost degradation
- Develop and apply methods to detect (RS), quantify (GIS) and predict (Models) permafrost degradation
Within an upcoming (2008-2010) NSF IPY project (Walter & Grosse et al.:Understanding the impacts of thermokarst lakes on C cycling and climate change), the following tasks are proposed:

Create a medium resolution circum-arctic map of ice-rich yedoma deposits (largely Siberia + Alaska)
- Based on geological and geocryological field data and maps, RS imagery, and DEM

Map the distribution of thermokarst lakes and alases in regions with yedoma and yedoma-like deposits
- From key sites to the entire yedoma region: Upscaling
- Thermokarst lake detection and classification
- Alas detection and classification (based on geomorphology, spectral+textural properties, and DEM)
- Define scaling rules for extrapolating thermokarst classifications from local to regional datasets

Monitor the recent dynamics of thermokarst lakes and basins at the study sites
- Quantify the changes by thermokarst lake expansion using high-resolution RS data, ca. 1950-2010
- Ground truth with high-accuracy kinematic differential GPS (D-GPS) surveys along the lake shores
- Spectral surface characterization with a portable field spectrometer (ASD Fieldspec Pro FR) of areas with known thermokarst disturbance, for comparison with undisturbed sites, and for the identification of disturbed areas in multi-spectral RS images
Objectives

- Obtain a deeper understanding of the temporal (interannual to centennial time scales) and spatial (north to south and west to east) variability and trends in the active layer characteristics and permafrost temperatures in the 20th century and their impact on hydrology within the Northern Eurasia region.

- Develop more reliable predictive capabilities for the projection of these changes into the 21st century.

Data Acquisition

- Landscape characteristics
- Meteorology
- Active layer
- Permafrost temperatures
- GIS
- Hydrogeology

Remote Sensing

- Identify relevant products
- Acquire base data
- Use as physical model parameter

Modeling

- Calibrate models at key sites
- Reconstruct past temperature regimes
- Improve existing model
- Forecast future temperature regime
Permafrost Dynamics Within the Northern Eurasian Region and Related Impacts on Surface and Sub-Surface Hydrology

V. Romanovsky, S. Marchenko & C. Duguay

Remote Sensing

- e.g. Land Surface Temperatures (LST) derived from Terra + Aqua MODIS

![LST for the Laptev Sea region from 2006-07-09](image)

- e.g. snow cover derived from Terra + Aqua MODIS

![Snow cover for the Lena River Delta derived from MOD10A1](image)
Application of Historical Declassified Satellite Data for Periglacial Studies

G. Grosse, L. Schirrmeister, V. Kunitsky, H.-W. Hubberten

Satellite KH-4B

<table>
<thead>
<tr>
<th>Period of operation</th>
<th>15/09/1967 - 25/05/1972</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera type</td>
<td>J-3, panchromatic</td>
</tr>
<tr>
<td>Flight altitude</td>
<td>150 km</td>
</tr>
<tr>
<td>Focal length</td>
<td>61 cm</td>
</tr>
<tr>
<td>Frame format</td>
<td>5.5 cm x 75.7 cm</td>
</tr>
<tr>
<td>Film resolution</td>
<td>160 lines / mm</td>
</tr>
<tr>
<td>Photo scale of the film</td>
<td>1:247,500</td>
</tr>
<tr>
<td>Ground coverage</td>
<td>13.8 km x 188 km</td>
</tr>
<tr>
<td>Best ground resolution</td>
<td>1.8 m</td>
</tr>
</tbody>
</table>

CORONA images used

<table>
<thead>
<tr>
<th>D003003M1107-1AFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>D003002M1107-1AFT</td>
</tr>
</tbody>
</table>

Date of acquisition

24th July 1969

Film size per image subset

5.5 x 14 cm

Ground coverage per subset

13.8 x 35 km

Scan resolution

7 μm (3600 dpi)

Ground resolution

2.5 m

Grosse et al, 2005 (Permafrost & Periglacial Processes)
Application of Historical Declassified Satellite Data for Periglacial Studies

G. Grosse, L. Schirrmeister, V. Kunitsky, H.-W. Hubberten

Thermokarst depression
Thermo-erosional valleys
Retrogressive thaw slumps

Thermokarst lake
Thermokarst lagoon
Pingos + ice wedge polygons

Grosse et al, 2005 (Permafrost & Periglacial Processes)
Application of Historical Declassified Satellite Data for Periglacial Studies
G. Grosse, L. Schirrmeister, V. Kunitsky, H.-W. Hubberten

- Mapping surface features (geomorphology, hydrology)
- Extending the temporal range of high-resolution lake change and coastal erosion studies in regions without accessible aerial imagery

About 98% of the lakes and 14% of the water surface is not considered in current databases focusing on lakes >1 ha.

<table>
<thead>
<tr>
<th>Geomorphological feature</th>
<th>Number</th>
<th>Area (km²)</th>
<th>% of overall investigation area</th>
<th>% of Khorogor Valley</th>
<th>% of Bykovsky Peninsula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermo-erosional valleys</td>
<td>145</td>
<td>11.188</td>
<td>4.3</td>
<td>0.2</td>
<td>6.3</td>
</tr>
<tr>
<td>Thermokarst basins</td>
<td>16</td>
<td>80.713</td>
<td>31.2</td>
<td>-</td>
<td>46.1</td>
</tr>
<tr>
<td>Thermo-erosional cirques</td>
<td>7</td>
<td>1.170</td>
<td>0.5</td>
<td>-</td>
<td>0.7</td>
</tr>
<tr>
<td>Pingos</td>
<td>6</td>
<td>0.385</td>
<td>0.1</td>
<td>-</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Grosse et al, 2005 (Permafrost & Periglacial Processes)
Erosion of the ice-rich permafrost coasts of the Bykovsky Peninsula 1951-2006

H. Lantuit, D. Atkinson, V. Rachold, M. Grigoriev, G. Grosse, S. Nikiforov

High-resolution remote sensing record for the Bykovsky Peninsula

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Ground resolution</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial imagery</td>
<td>2 m</td>
<td>4-Aug-51</td>
</tr>
<tr>
<td>Aerial imagery</td>
<td>2 m</td>
<td>22-Jun-64</td>
</tr>
<tr>
<td>Corona KH-4B</td>
<td>2.5 m</td>
<td>24-Jun-69</td>
</tr>
<tr>
<td>Corona KH-4B</td>
<td>2.5 m</td>
<td>17-Jun-75</td>
</tr>
<tr>
<td>Hexagon KH-9</td>
<td>6 m</td>
<td>8-Aug-81</td>
</tr>
<tr>
<td>Spot-5 pan</td>
<td>2.5 m</td>
<td>9-Jul-06</td>
</tr>
</tbody>
</table>

Lantuit et al, in prep.
Objectives

- Characterize the spatial distribution of thermokarst lakes in ice-rich permafrost areas
- Assess temporal changes over the remote sensing period

<table>
<thead>
<tr>
<th>General environmental characteristics in the study regions</th>
<th>Cherskii (CHE)</th>
<th>Bykovsky (BYK)</th>
<th>Olenek (OLE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study site</td>
<td>Cherskii (CHE)</td>
<td>Bykovsky (BYK)</td>
<td>Olenek (OLE)</td>
</tr>
<tr>
<td>Location</td>
<td>68.8°N/161.3°E</td>
<td>71.8°N/129.3°E</td>
<td>72.9°N/122.9°E</td>
</tr>
<tr>
<td>Permafrost depth (m)</td>
<td>400 – 500</td>
<td>500 – 600</td>
<td>200-600</td>
</tr>
<tr>
<td>Active layer depth (m)</td>
<td>0.3 – 1.5</td>
<td>0.3 – 0.6</td>
<td>0.3 – 0.6</td>
</tr>
<tr>
<td>Annual ground temperature (20 m depth)(°C)</td>
<td>-3 – -11</td>
<td>-9 – -11</td>
<td>-9 – -11</td>
</tr>
<tr>
<td>Annual air temperature (°C)</td>
<td>-12.5</td>
<td>-14.0</td>
<td>X</td>
</tr>
<tr>
<td>Annual precipitation (mm)</td>
<td>222</td>
<td>232</td>
<td>X</td>
</tr>
<tr>
<td>Vegetation zone</td>
<td>Taiga / Tundra</td>
<td>Tundra</td>
<td>Tundra</td>
</tr>
<tr>
<td>Study area (km²)</td>
<td>288.97</td>
<td>170.09</td>
<td>79.82</td>
</tr>
</tbody>
</table>

Grosse et al, in review
Distribution and Temporal Changes of Thermokarst Lakes in Siberian Yedoma

G. Grosse, V. Romanovsky, K. Walter, A. Morgenstern, H. Lantuit, S. Zimov

<table>
<thead>
<tr>
<th>Parameter</th>
<th>OLE</th>
<th>BYK</th>
<th>CHE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lakes N</td>
<td>15 012</td>
<td>13 001</td>
<td>1 348</td>
</tr>
<tr>
<td>Lake area A (ha)</td>
<td>1059.6</td>
<td>2622.1</td>
<td>242.3</td>
</tr>
<tr>
<td>Lake area A (%)</td>
<td>13.3</td>
<td>15.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Largest lake size (ha)</td>
<td>196.19</td>
<td>605.00</td>
<td>16.71</td>
</tr>
<tr>
<td>Mean lake size (ha)</td>
<td>0.0706</td>
<td>0.2017</td>
<td>0.1797</td>
</tr>
</tbody>
</table>
Distribution and Temporal Changes of Thermokarst Lakes in Siberian Yedoma

G. Grosse, V. Romanovsky, K. Walter, A. Morgenstern, H. Lantuit, S. Zimov

A – BYK (Spot-5)
B – OLE (Spot-5)
C – CHE (Ikonos-2)

Distribution of lakes in the study areas as the total number N of lakes larger than area A.

Grosse et al, in review
Table 2: Overview of remote sensing imagery used for lake area change detection

<table>
<thead>
<tr>
<th>Site</th>
<th>Platform</th>
<th>Date</th>
<th>Resolution</th>
<th>Spectral properties</th>
<th>RMS error</th>
<th>No. GCP</th>
<th>Transformation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYK</td>
<td>Corona KH-4B</td>
<td>1969-06-24</td>
<td>2.5 m</td>
<td>Panchromatic</td>
<td>4.58m / 3.42m</td>
<td>37 / 29</td>
<td>NN, 3rd polynomial</td>
</tr>
<tr>
<td>BYK</td>
<td>Spot-5</td>
<td>2006-07-09</td>
<td>2.5 m</td>
<td>Panchromatic</td>
<td>Base</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>OLE</td>
<td>Corona KH-4A</td>
<td>1964-06-22</td>
<td>2.5 m</td>
<td>Panchromatic</td>
<td>1.18m / 4.53m</td>
<td>14 / 38</td>
<td>NN, 3rd polynomial</td>
</tr>
<tr>
<td>OLE</td>
<td>Spot-5</td>
<td>2006-07-08</td>
<td>2.5 m</td>
<td>Panchromatic</td>
<td>Base</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CHE</td>
<td>Gambit KH-7</td>
<td>1965-10-01</td>
<td>1 m</td>
<td>Panchromatic</td>
<td>3.06m</td>
<td>28</td>
<td>NN, 3rd polynomial</td>
</tr>
<tr>
<td>CHE</td>
<td>Ikonos-2</td>
<td>2002-07-09</td>
<td>1 m</td>
<td>Panchromatic</td>
<td>Base</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4: Area-normalized number of lakes and lake areas

<table>
<thead>
<tr>
<th>Size class (ha)</th>
<th>N, normalized by area (N / 100 km²)</th>
<th>A, normalized by area (km² / 100 km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OLE</td>
<td>BYK</td>
</tr>
<tr>
<td>≤ 0.001-0.01</td>
<td>10 434</td>
<td>4 835</td>
</tr>
<tr>
<td>&gt; 0.01-0.04</td>
<td>6 332</td>
<td>2 102</td>
</tr>
<tr>
<td>&gt; 0.04-0.1</td>
<td>1 403</td>
<td>356</td>
</tr>
<tr>
<td>&gt; 0.1-0.25</td>
<td>397</td>
<td>152</td>
</tr>
<tr>
<td>&gt; 0.25-1</td>
<td>157</td>
<td>118</td>
</tr>
<tr>
<td>&gt; 1-5</td>
<td>63</td>
<td>54</td>
</tr>
<tr>
<td>&gt; 5-20</td>
<td>13.8</td>
<td>14.7</td>
</tr>
<tr>
<td>&gt; 20-100</td>
<td>7.5</td>
<td>9.4</td>
</tr>
<tr>
<td>&gt; 100-1 000</td>
<td>1.3</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Grosse et al, in review
Distribution and Temporal Changes of Thermokarst Lakes in Siberian Yedoma

G. Grosse, V. Romanovsky, K. Walter, A. Morgenstern, H. Lantuit, S. Zimov

Bykovsky Peninsula
(Corona KH-4B 1969 vs. Spot-5 2002)
(2.5m ground resolution)

- Lake shrinkage by 7.56 ha (-28.5 %)
- Lake shrinkage by 6.97 ha (-53.2 %)

- Of 308 arbitrary selected lakes, 244 indicate shrinkage, 44 growth, and 20 lakes drained completely
- Net shrinkage is 24.4 ha (-2.9%)

Grosse et al, in review
Thermo-erosion along shore bluffs of thermokarst lakes in the Cherskii region (Gambit 1965 vs. Ikonos-2 2002) (1.0 m ground resolution)

Grosse et al, in review
Thermo-erosion along shore bluffs of thermokarst lakes (Gambit 1965 vs. Ikonos-2 2002) (1.0 m ground resolution)
Human impact on permafrost

*Increase of surface wetness due to initial thermokarst at a former construction site, Cherskii (Russia)*

(Gambit 1965 vs. Ikonos-2 2002) (1.0 m ground resolution)
Human impact on permafrost

Massive thermokarst pond formation along former dirt roads, Cherskii (Russia)

(Gambit 1965 vs. Ikonos-2 2002) (1.0 m ground resolution)
Human impact on permafrost

Artificial drainage of a thermokarst lake, followed by the formation of retrogressive thaw slumps, Cherskii (Russia)

(Gambit 1965 vs. Ikonos-2 2002) (1.0 m ground resolution)
Classification of Thermokarst-Affected Terrain with Landsat-7 data and a DEM

G. Grosse, L. Schirrmeister, T. Malthus

Study site: Cape Mamontov Klyk
- Large scale study site: 3400 km²
- DEM with 30 m grid cell size
- 1 Landsat-7 ETM+ image + 4 Corona images
- Cryolithological data from outcrop profiles
- Surface data from 179 sites:
  - Macro-, Meso- and Micro- relief forms, relief position, slope inclination, surface / vegetation cover, water bodies and soil moisture, morphometric measurements, active layer depth

Grosse et al, 2006 (Polar Research)
Classification of Thermokarst-Affected Terrain with Landsat-7 data and a DEM
G. Grosse, L. Schirrmeister, T. Malthus

- Wet polygonal tundra in thermokarst basin
- Riverine floodplain with polygonal tundra
- Moist, Edoma-type upland tundra
- Wet lowland tundra in thermokarst valleys
- Riverine barren, Fluvial sand terrace
- Dry slopes with thermokarst hills

Grosse et al, 2006 (Polar Research)
Classification of Thermokarst-Affected Terrain with Landsat-7 data and a DEM
G. Grosse, L. Schirrmeister, T. Malthus

Classification approach

<table>
<thead>
<tr>
<th>Image stratification into regions</th>
<th>Major classes (+spectral subclasses)</th>
<th>Final classes after post-classification stratification</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM+GIS</td>
<td>Landsat-7 ETM+</td>
<td>DEM+GIS</td>
</tr>
<tr>
<td>Plain</td>
<td>Wet lowland tundra in thermokarst depressions (10)</td>
<td>Wet tundra in thermokarst depressions</td>
</tr>
<tr>
<td></td>
<td>Wet lowland tundra in thermo-erosional valleys (1)</td>
<td>Wet tundra in thermo-erosional valleys</td>
</tr>
<tr>
<td></td>
<td>Wet lowland tundra on floodplains (2)</td>
<td>Wet coastal floodplain</td>
</tr>
<tr>
<td></td>
<td>Dry to moist Edoma slopes (1)</td>
<td>Wet riverine floodplain</td>
</tr>
<tr>
<td></td>
<td>Moist, Edoma-type upland tundra (2)</td>
<td>Moist, Edoma-type upland tundra</td>
</tr>
<tr>
<td></td>
<td>Barrens (4)</td>
<td>Barrens, riverine</td>
</tr>
<tr>
<td></td>
<td>Dry, sparse tundra above sandy deposits (2)</td>
<td>Barrens, lacustrine</td>
</tr>
<tr>
<td></td>
<td>Water bodies, various types (15)</td>
<td>Barrens, coastal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Barrens, other types</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td>Sparse tundra on sandy deposits</td>
</tr>
<tr>
<td>Inland</td>
<td></td>
<td>Large, deep lakes</td>
</tr>
<tr>
<td>Marine</td>
<td></td>
<td>Large, shallow lakes</td>
</tr>
<tr>
<td>Hill range</td>
<td></td>
<td>Small shallow lakes &amp; rivers</td>
</tr>
<tr>
<td>Clouds</td>
<td></td>
<td>Grosse et al, 2006 (Polar Research)</td>
</tr>
</tbody>
</table>
Classification of Thermokarst-Affected Terrain with Landsat-7 data and a DEM

G. Grosse, L. Schirrmeister, T. Malthus

Mean values for each class

Spectral bands + NDVI

Surface elevation

Grosse et al, 2006 (Polar Research)
Classification of Thermokarst-Affected Terrain with Landsat-7 data and a DEM
G. Grosse, L. Schirrmeister, T. Malthus
Classification of Thermokarst-Affected Terrain with Landsat-7 data and a DEM

G. Grosse, L. Schirrmeister, T. Malthus
Assumption based on field data: All of the coastal plain was covered by ice-rich deposits.

Degree of thermokarst degradation for the coastal plain (=2317.5 sqkm)

- 22.2% No degradation of ice-rich deposits
- 31.1% Partial degradation of ice-rich deposits
- 14.7% Strong degradation of ice-rich deposits
- 11.4% Complete degradation of ice-rich deposits
- 20.6% Complete degradation of ice-rich deposits + deeper deposits

Grosse et al, 2006 (Polar Research)
Morphometry and spatial distribution of lakes in the Lena Delta

A. Morgenstern, G. Grosse, L. Schirrmeister

Goals:
- Development of a detailed GIS-based lake inventory for the largest Arctic River Delta
- Analysis of morphometric lake parameters for lake classification (lake genesis, phenomenon of lake orientation)
- Investigation of relationship between lake morphometry and environmental properties (cryolithology, geomorphology, weather patterns)
Morphometry and spatial distribution of lakes in the Lena Delta
A. Morgenstern, G. Grosse, L. Schirrmeister

- Remote sensing data used: Landsat-7 ETM+
- Land-water classification based on band 5 (SWIR)
- Lakes >20ha are considered in the database

1st: Modern active delta

2nd: Late Pleistocene – Early Holocene, fluvial sands

3rd: Late Pleistocene yedoma

Landsat-7 ETM+ mosaic (Schneider, 2005)

Morgenstern et al, in review
Morphometry and spatial distribution of lakes in the Lena Delta

A. Morgenstern, G. Grosse, L. Schirrmeister

1st: Modern active delta

2nd: Late Pleistocene – Early Holocene, fluvial sands

3rd: Late Pleistocene yedoma

Mean lake types

- small
- irregular shape
- strong deviations from mean orientation
- often oxbows

Landsat-7 ETM+ mosaic (Schneider, 2005)

photo: AWI Potsdam

Morgenstern et al, in review
Morphometry and spatial distribution of lakes in the Lena Delta

A. Morgenstern, G. Grosse, L. Schirrmeister

Mean lake types

- large
- elongated
- NNE orientation
- probably secondary thermokarst lakes

Landsat-7 ETM+ mosaic (Schneider, 2005)

Morgenstern et al, in review
Morphometry and spatial distribution of lakes in the Lena Delta
A. Morgenstern, G. Grosse, L. Schirrmeister

1st: Modern active delta
2nd: Late Pleistocene – Early Holocene, fluvial sands
3rd: Late Pleistocene yedoma

Mean lake types
- near circular
- regular shorelines
- primary thermokarst lakes

Landsat-7 ETM+ mosaic (Schneider, 2005)
photo: M. Krbetschek

Morgenstern et al, in review
Morphometry and spatial distribution of lakes in the Lena Delta

A. Morgenstern, G. Grosse, L. Schirrmeister

Number of lakes

Orientation in °

1st terrace

Number of lakes

Orientation in °

2nd terrace

Number of lakes

Orientation in °

3rd terrace
Results

• main terraces vary strongly in the morphometric characteristics of their lakes

• lithology / cryolithology strongly control orientation processes

• active fluvial processes inhibit orientation processes on the 1st terrace

• since the same exogenous factors influence the 2nd and 3rd terraces, different lithology and cryolithology are the main driver for a different response to orienting forces

• oriented lakes on the 2nd terrace:
  - mean orientation = 79° (NNE-SSW)
  - 63% with deviation from mean orientation ≤ 10°
Methane Fluxes from Periglacial Landscapes in the Lena River Delta

J. Schneider, G. Grosse, D. Wagner


Landsat 7 ETM+ satellite images

Rectification, resampling, radiometric correction, image-based atmospheric correction

Image mosaic of the Lena Delta

Selected training areas (34 for 9 land cover classes)

Local thematic maps, field reports, aerial and field photography

Supervised land cover classification of bands 1-5 and 7, based on minimum distance algorithm

Helicopter-based aerial RGB image from main study site Samoylov Island

High-resolution habitat characterization (maximum likelihood supervised classification)

Methane closed chamber measurements in various habitats (1999-2006). Methane concentration measured with gas chromatograph in the field laboratory (Wagner et al., 2003)

Methane balance of the Lena Delta

Published methane emission results for some habitat types

Schneider et al, in review
Methane Fluxes from Periglacial Landscapes in the Lena River Delta

J. Schneider, G. Grosse, D. Wagner

a. mainly non-vegetated areas;
b. dry to moist, dwarf shrub dominated tundra
c. dry grass and dwarf shrub dominated tundra
d. dry sandy, moss, sedge, and dwarf shrub dominated tundra
e. wet sedge and moss dominated tundra
f. moist sedge and moss dominated tundra

Schneider et al, in review
Methane Fluxes from Periglacial Landscapes in the Lena River Delta

J. Schneider, G. Grosse, D. Wagner

Wet, sedge and moss dominated tundra
Moist, grass and moss dominated tundra
Moist to dry dwarf shrub dominated tundra
Thermokarst lakes
All other lakes
Vegetated lake margins
DMSD, DG, DT

Percentage of methane emissions of individual land cover classes based on the total methane emission of the Lena Delta.

Total delta area: 29 036 km²
Mean daily methane emission (July): 10.35 mg CH₄ m⁻² d⁻¹.
Annual methane emission: 972 mg m⁻² a⁻¹ or ~0.03 Tg

Schneider et al, in review
Spectral Properties of Periglacial Landscapes in the Lena Delta

M. Ulrich, G. Grosse, L. Schirrmeister

Objectives
- Characterization and classification of typical periglacial surfaces
- Development of a spectral database for periglacial / tundra surfaces

Study area
- Covers all 3 main terraces of the Lena Delta
- Contains a wide range of periglacial surface features
### Spectral Properties of Periglacial Landscapes in the Lena Delta

*M. Ulrich, G. Grosse, L. Schirrmeister*

<table>
<thead>
<tr>
<th></th>
<th>LANDSAT 7 ETM+</th>
<th>CHRIS/PROBA Mode 3 Land Channels</th>
<th>ASD FieldSpec-FR™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor height</td>
<td>705 km</td>
<td>556 km</td>
<td>~1 m</td>
</tr>
<tr>
<td>Coverage</td>
<td>185 km swath width</td>
<td>13 x 13 km</td>
<td>Points</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>30 x 30 m (VIS-SWIR) 15 x 15 m (pan) 120 x 120 m (TIR)</td>
<td>17 x 17 m (VIS-VNIR)</td>
<td>ca. 0,4 x 0,4 m (VIS-SWIR) (when instrument height above target is 1 m and 24° fore opticis used)</td>
</tr>
<tr>
<td>Spectral bands</td>
<td>8 for 450-12500 nm</td>
<td>18 for 438 – 1035 nm</td>
<td>512 for 350 – 1000 nm 1060 for 1000 – 2500 nm 2151 interpolated for every nanometer</td>
</tr>
</tbody>
</table>
Spectral Properties of Periglacial Landscapes in the Lena Delta
M. Ulrich, G. Grosse, L. Schirrmeister

Results
- 12 spectral classes derived from field spectral measurements
- periglacial surfaces can be well distinguished by their spectral properties

Spectral signatures of green and dry grass, bare soil and water in tundra landscapes (August 2005) using an ASD FieldSpec Pro FR®. Atmospheric water absorption bands around 1400 nm and 1900 nm are masked.

Ulrich et al, in prep.
Upcoming projects
Pan-Arctic Lake-Ice Methane Monitoring Network

PALIMMN

K. Walter, G. Grosse et al.
University of Alaska, Fairbanks

‘An open network to quantify methane emissions from northern lakes’
Remote Sensing Baseline for Long-Term Monitoring of the Arctic Circumpolar Coastal Observatory Network (ACCO-Net)

P. Overduin, H. Lantuit, M. Allard, G. Grosse, & the ACD Steering Committee

- 2007-2009
- Aims at the acquisition and analysis of multi-sensoral + multi-temporal remote sensing data for the ACCO-Net project (IPY Activity ID: 90) and its sites (currently 41)
- Imagery sponsored by ESA IPY programme:
  --> new ALOS PRISM + AVNIR-2 images
  --> archived + new SPOT images

Goal of this project is to deliver important base data for the ACCO-Net objectives

- establish the rates and magnitudes of erosion and accumulation of Arctic coasts;
- estimate the amount of sediments and organic carbon derived from coastal erosion;
- refine and apply an Arctic coastal classification (incl. ground ice, permafrost, geology, etc.);
- produce a series of thematic and derived maps (e.g. coastal classification, ground-ice, sensitivity etc.);

www.awi-potsdam.de/acd/acconet

Overduin et al. ESA IPY proposal
Thank you!

Collaborators:

Vladimir Romanovsky, GI UAF
Katey Walter, INE / IARC UAF
Hugues Lantuit, AWI for Polar and Marine Research Potsdam, Germany
Anne Morgenstern, AWI for Polar and Marine Research Potsdam, Germany
Lutz Schirrmeister, AWI for Polar and Marine Research Potsdam, Germany
Paul Overduin, AWI for Polar and Marine Research Potsdam, Germany
Julia Schneider, University of Greifswald, Institute of Botany and Landscape Ecology
Mathias Ulrich, University of Leipzig, Department of Geography, Germany
+ several other colleagues from Alaska, Russia, and Germany