

Thermal State of Frozen Ground in a Changing Climate During the IPY



**Abstracts from the
Third European Conference on
Permafrost
13-17 June 2010**

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Editors: Jordan R. Mertes, Hanne H. Christiansen and Bernd Etzelmüller

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Jordan R. Mertes



Permafrost and Periglacial Processes



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This book of abstracts contains all the abstracts approved by members of the International and National Organising Committees for presentation during the Third European Conference on Permafrost. There has been no editing of approved abstracts.

The Scientific Programme

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- Jordan Mertes, The University Centre in Svalbard, Norway (Secretary)

Welcome from the Organizers

As Chairs of the Organizing Committees for the Third European Conference on Permafrost we would like to extend a warm welcome to all delegates here in the Arctic! It is a great pleasure for us to especially welcome all of you to Svalbard at 78°N and to the University Centre in Svalbard, UNIS, which hosts this conference. The previous Second European Conference on Permafrost was held at the Alfred Wegener Institute for Polar and Marine Research, Potsdam in June 2005, and since then the Fourth International Polar Year (IPY) 2007-2008 has increased the research activities within permafrost science and engineering. Thus this conference focus on the various output within the different permafrost research fields obtained during the IPY including the first international overview of the thermal state of frozen ground.

This Third European Conference on Permafrost has been primarily sponsored by the Norwegian Research Council, The University Centre in Svalbard and the University in Oslo in addition to several other sponsors (as presented in this volume), to all of whom we extend our thanks. We want to also thank all the members of the International and National Organizing Committees for the Third European Conference on Permafrost for their important contributions to assisting us in developing the conference programme. Particularly we want to thank the Conference Secretary Jordan Mertes for patiently putting together this Book of Abstracts.

We hope you will all enjoy the conference and have good experiences with the permafrost in Svalbard !

Bernd Etzelmüller and Hanne H. Christiansen

Session Themes

- Periglacial Processes and Landforms
- The Thermal State of Permafrost
- Permafrost Foundation Behavior in a Warmer Climate
- Soils in Periglacial Regions
- Remote Sensing Techniques and Geohazards
- Circumpolar Arctic and Antarctic Active Layer Monitoring
- Palaeo-Permafrost and Coastal Dynamics
- Mathematical and Physical Modelling of Permafrost
- Soil Carbon Microbiology and Trace Gas Release in Permafrost Environments
- Analysis of Sensitivity of Permafrost Modelling
- Geophysical Monitoring in Permafrost Regions

Time	Sunday 13 June	Monday 14 June	Tuesday 15 June	Wednesday 16 June	Thursday 17 June	Friday 18 June
8:30-9:00			Keynote 3 8:30-9:00	Keynote 5 8:30-9:00		
9:00-9:30			Keynote 4 9:00-9:30	Keynote 6 8:30-9:00		
9:30-10:00		Opening Session 9:00-10:30	COFFEE 9:30-10:00	COFFEE 9:30-10:00		
10:00-10:30	Various IPA Business Meetings 10:00-13:30 Lunch Buffet in UNIS Canteen (not sponsored) 12:30-14:00					
10:30-11:00		COFFEE 10:30-11:00	Three ORAL Parallel Sessions 10:00-12:00	Three ORAL Parallel Sessions 10:00-12:00		
11:00-11:30		Keynote 1 11:00-11:30				
11:30-12:00		Keynote 2 11:30-12:00				
12:00-12:30		Lunch 12:00-13:00	Lunch 12:00-13:00	Lunch 12:00-13:00		
12:30-13:00						
13:00-13:30						
13:30-14:00		Three ORAL Parallel Sessions 13:00-15:00		Three ORAL Parallel Sessions 13:00-15:00	Full Day Excursions 9:00-16:00 SITES: Hjortfjellet Gruvefjellet Todalen Longyearbreen & Larsbreen Pyramiden	Full Day Excursions 9:00-16:00 SITES: Hjortfjellet Gruvefjellet Todalen Longyearbreen & Larsbreen Remote Sensing Svalbard Coal Mining
14:00-14:30	Travel To Longyearbyen Registration Desk Open 10:00-18:00					
14:30-15:00		COFFEE 15:00-15:15	Field excursion to infrastructure and permafrost research sites near Longyearbyen 13:00-18:00	COFFEE 15:00-15:15		
15:00-15:30						
15:30-16:00	IPA Council Meeting 15:00-17:30	Poster Session 15:15-17:00		Poster Session 15:15-17:00		
16:00-16:30						
16:30-17:00						
17:00-17:30						
17:30-18:00		BREAK		Closing Ceremony 17:00-18:00		
18:00-18:30						
18:30-19:00	Icebreaker 18:00-19:00 Starting in the Svalbard Museum	Open Public Lecture 18:00-19:00	Barbeque Dinner Between SAS Hotel and UNIS 18:00-22:00	BREAK		
19:00-19:30	19:00-21:00 in the UNIS Canteen	IPA Council Meeting 19:00-21:00		Conference Dinner 19:00-		
19:30-20:00		PYRN Social Event 19:00-21:00				

- The conference registration desk, which is located in the UNIS Entrance Hall, will be open the following times during the conference:
 - Sunday 13 June: 10:00-18:00
 - Monday 14 June: 8:00-18:00
 - Tuesday 15 June: 8:00-13:00
 - Wednesday 16 June: 8:00-17:00
 - Thursday 17 June: 8:00-10:00
 - Friday 18 June: 8:00-10:00
- The Svalbard Museum will be open everyday of the conference from 10:00-17:00.

Monday

Time	Monday, June 14
8:00 – 18:00	Registration Desk Open <i>in UNIS Entrance Hall</i>
9:00 – 10:30	OPENING Session <i>in Møysalen and video streamed to Lassegrotta</i>
10:30 – 11:00	COFFEE/TEA
11:00 – 11:30	KEYNOTE <i>in Møysalen and video streamed to Lassegrotta</i> Thermal State of Permafrost – an Overview and Status of the Activities in the Polar Northern Hemisphere Vladimir Romanovsky
11:30 – 12:00	KEYNOTE <i>in Møysalen and video streamed to Lassegrotta</i> Permafrost Research in Norway and Svalbard Ole Humlum
12:00 – 13:00	LUNCH in UNIS Canteen
ORAL Parallel session: Permafrost Foundation Behavior in a Warmer Climate <i>co-chairs: Sarah Springman & Gisle Håland in Kapp Mitra</i>	
13:00 – 13:15	Thermal Modeling of Variations in the Depth of the Frost Table Caused by Increasing Temperatures in Kangerlussuaq Airport, Western Greenland A.S. Jørgensen
13:15 – 13:30	Foundation Behavior in Longyearbyen, Svalbard M. Nokken, L. Grande
13.30 – 13:45	Community Planning on Permafrost in Nunavik – the case Study of Salluit, T. Gibéryen, M. Allard, C. Desbiens
13:45 – 14:00	Destruction of Buildings and Underground Constructions Caused by the Cryogenic Weathering in Cryolithozone V. I. Grebenets
14:00 – 14:15	Methods of Estimation of the Reliability of Oil-Trunk Pipelines in Permafrost Area M.Y.Cherbunina, L.N.Khrustalev
14:15 – 14:30	Effects of Climate Change on Substrate Bearing Capacity in Russian Permafrost Regions D.A. Streletskiy, N.I. Shiklomanov

Time	Monday, June 14
14:30 – 14:45	Forecast of Frost Heave Caused by Freezing Soil around Pipeline Based on Physical and Numerical Modeling Data N. Volkov, C. Johansen
14:45 – 15:00	Forecast of Changing of Main Engineering and Geocryological Parameters in Russian Arctic to 2030 and 2050 D.G. Shmelev
ORAL Parallel session: The Thermal State of Permafrost <i>co-chairs: Hanne Christiansen & Vladimir Romanovsky in Møysalen</i>	
13:00 – 13:15	Spatial Distribution of Permafrost in Hurd Peninsula (Livingston Island, Maritime Antarctic) G. Vieira, et al.
13:15 – 13:30	The Thermal State of Permafrost in Canada – Results from the International Polar Year S.L. Smith, A.G. Lewkowicz, C.R. Burn, M. Allard, J.L. Throop
13.30 – 13:45	Thermal State of Permafrost in the Northern Yakutia and Alaska, Regional Peculiarities and Response on Climate Changes A. L.Kholodov, D.A. Gilichinsky, D. Fedorov-Davydov, A. Abramov, V. Romanovsky
13:45 – 14:00	Setting up a Monitoring Network of Mountain Permafrost in the Alps D. Vonder Mühl, J. Noetzli, B. Naegeli
14:00 – 14:15	Analysis of Temperature Time Series Measured in the PERMOS Boreholes and Their Vicinity J. Noetzli, S. Gruber, W. Haeberli
14:15 – 14:30	Air and Ground Temperatures along Elevation and Continentality Gradients in Southern Norway H. Farbrot, T. Hipp, B. Etzelmüller, O. Humlum, K. Isaksen, R. Ødegård
14:30 – 14:45	Characteristics and Controlling Factors of Warming Mountain Permafrost in Jotunheimen and Dovrefjell, Southern Norway K. Isaksen, R. S. Ødegård, B. Etzelmüller, H. Farbrot, T. Hipp, T. Eiken, C. Hauck, C. Hilbich

Time	Monday, June 14
14:45 – 15:00	Examples of Rapid Permafrost Degradation in the Swiss Alps Induced by Lateral Thermal Disturbances M. Phillips, E. Zenklusen Mutter
ORAL Parallel session: Periglacial Processes and Landforms I <i>co-chairs: Reynald Delaloye & Isabelle Gaertner-Roer in Lassegrotta</i>	
13:00 – 13:15	The Late Holocene History of Peatlands and Permafrost East of Hudson Bay, Canada M. Allard, C. Marchildon
13:15 – 13:30	Long-Term Solifluction Response to Increasingly Arid Conditions in Sierra Nevada, Southern Spain M. Oliva
13.30 – 13:45	General Morphometric Description of Solifluction Landforms I. Berthling, F. Høgaas, Kielland, P.G.
13:45 – 14:00	Geodiversity across Elevation Gradient in Subarctic Landscape, Northern Finland J. Hjort, M. Luoto
14:00 – 14:15	Transferability of Statistical Models in Geomorphological Mapping M. Marmion, J. Hjort, B. Etzelmüller, J. Tolgensbakk
14:15 – 14:30	Classification of Lakes in Pan-Arctic Permafrost Regions G. Grosse, B. Jones, K. W. Anthony, V. Romanovsky, S. Marchenko
14:30 – 14:45	Characteristics of a High Arctic Snow Avalanche Climate in 2006-2009 – Central Spitsbergen, Svalbard M. Eckerstorfer, H. H. Christiansen
14:45 – 15:00	A Regional Inventory of Glacial and Periglacial Landforms Indicating Alpine Permafrost in Norway K.S. Lilleøren, B. Etzelmüller
15:00 – 15:15	COFFEE/TEA

Monday

Keynotes

In Møysalen and video streamed to Lassegrotta

11:00-11:30 Thermal State of Permafrost – An Overview and Status of the Activities in the Polar Northern Hemisphere

Vladimir E. Romanovsky & Sergey S. Marchenko, *Permafrost Laboratory, Geophysical Institute, University of Alaska Fairbanks, USA*

Hanne H. Christiansen, *Geology Department, University Centre in Svalbard, UNIS, Norway*

Sharon L. Smith, *Geological Survey of Canada, Natural Resources Canada, Ottawa, Ontario, Canada*

11:30-12:00 Permafrost research in Norway and Svalbard

Ole Humlum *Department of Geosciences, University of Oslo, Oslo, Norway & Department of Geology, The University Centre in Svalbard, Svalbard*

Thermal State of Permafrost – an Overview and Status of the Activities in the Polar Northern Hemisphere

Vladimir E. Romanovsky & Sergey S. Marchenko, *Permafrost Laboratory, Geophysical Institute, University of Alaska Fairbanks, USA*

Hanne H. Christiansen, *Geology Department, University Centre in Svalbard, UNIS, Norway*

Sharon L. Smith, *Geological Survey of Canada, Natural Resources Canada, Ottawa, Ontario, Canada*

1 INTRODUCTION

Permafrost is an important part of the cryosphere and is a key cryospheric indicator of climate change. During the International Polar Year (IPY) 2007-2009, a global snapshot of the permafrost thermal state was obtained through a coordinated field campaign. This paper focuses on the information on the permafrost thermal state obtained during the IPY in all parts of the polar Northern Hemisphere through several regional and national research projects. The campaign was the key component of the IPY research project, “Permafrost Observatory Network: A Contribution to the Thermal State of Permafrost (TSP)”.

2 METHODS

The snapshot was obtained by continuing measurements at existing permafrost observatory sites, by re-occupying older sites where permafrost temperatures were measured in the past but were interrupted lately, and by drilling new boreholes and establishing new observatory sites with long-term ground temperature monitoring. Different equipment and techniques were used for borehole temperature measurements in different countries and at different time. The earliest systematic measurements in the European North of Russia go back to the 1930s. During that initial period, temperatures in the boreholes were measured using mercury thermometers with a scale factor from 0.05 to 0.1°C. Starting from the 1950s and especially in the 1960s, semi-conducting temperature sensors (thermistors) became more common in permafrost geothermal studies. Since then, most of the boreholes at the permafrost research stations were equipped with permanently or temporary installed thermistor strings and temperatures were measured periodically. During the last 20 years, digital data loggers have been used more and more commonly for ground temperature automatic data acquisition and storage.

The diversity of past measuring techniques could lead to uncertainty when comparing data obtained using these different sensors. Special field experiments were performed during the 2007 and 2008

field seasons to address this concern. These experiments assure the comparability of all measurement techniques at an overall accuracy of 0.1°C.

Even the longest records of the permafrost temperature dynamics are still very time-limited. To extend the knowledge on changes in the permafrost thermal state into the past and to project possible future changes, various numerical permafrost models with different levels of complexity are usually implemented. In this presentation we will give a short review of existing models and discuss the results of some of these modeling efforts.

3 RESULTS

Looking back into the last three years of international permafrost research activities, we can definitely conclude that the IPY-TSP was a success. The major part of the success was due to significantly increased international scientific cooperation which led to development and operation of the TSP project. Data collected through the TSP project have enabled, for the first time, an overall Northern Hemisphere synthesis of the current permafrost thermal state, which will provide a baseline against which future change may be measured. The addition of new monitoring sites in areas that were previously under-represented has resulted in new information on permafrost thermal state for regions where little or no recent information was available.

Most of the permafrost observatories in the Northern Hemisphere show substantial warming of permafrost during the last 20 to 30 years. The magnitude of warming varied with location, but was typically from 0.5 to 2°C at the depth of zero annual amplitude. The main exceptions are those sites with ice-rich fine-grained sediments where ground temperatures are within a few tenths of a degree below 0°C where ground temperature profiles are isothermal, indicating that phase change is occurring within the permafrost.

Permafrost is already thawing in specific landscape settings within the southern part of the permafrost domain. Formation of new closed taliks and an increase in depth of pre-existing taliks has been observed in this area during the last 20 to 30 years.

Permafrost Research in Norway and Svalbard

O. Humlum

Department of Geosciences, University of Oslo, Oslo, Norway & Department of Geology, The University Centre in Svalbard, Svalbard

1 PERMAFROST RESEARCH

1.1 Svalbard

The existence of permafrost in Svalbard has been common knowledge at least since the first International Polar Year in 1882 and the first coal mining operations in 1898. In 1883 ground temperatures were measured to 2 m depth at Kap Thordsen, and in 1913 studies on ground ice in central Spitsbergen (Colesdalen) were initiated. Rapidly a late Holocene age of low-altitude permafrost in Svalbard was suggested by multiple observations on ground ice at several sites below the upper marine limit.

1922 saw the first review of frozen ground phenomena in Spitsbergen published. Other early scientific observations relating to Svalbard permafrost was published between 1924 and 1937 by scientists of various nationalities, describing fine examples of patterned ground. Based on measurements of firn temperatures at Fjortende Julibreen, a publication in 1935 presumably was the first ever to demonstrate that not all bedrock below glaciers remain in a permafrozen condition. In 1941 observations from Spitsbergen on solid bodies of ground ice (presumably ice wedges) emphasised the importance of topography, soil type and moisture supply over long time to understand the distribution of ground ice. A few years later also the apparent paradox of finding permanent springs in a region with extensive perennial frozen ground was addressed in a publication.

In the following years, most studies relating to permafrost in Svalbard had a geomorphological focus. However, a major change in permafrost related research in Svalbard was introduced by the European PACE research project in 1998, where a borehole to 100 m depth was established at Jansonhaugen, central Spitsbergen. Several new boreholes to 20-30 m depth were established during the IPY period 2007-09 by the TSP-Norway project.

1.2 Norway

In mainland Norway permafrost research began later than in Svalbard. Although the Scandinavian mountains represent one of Europe's largest highland areas, and extends beyond the polar circle, permafrost research had a late start. Presumably one of the first publications referring to permafrost in Norway was a paper in 1957 on water resources in northern Sweden and Norway. Here the existence of modern permafrost in northern Scandinavia was suggested by

combining a climatic approach with a model for permafrost development. In addition, 20 m thick permafrost was described from mining activities in Lyngen peninsula, Norway, at an altitude of 750 m a.s.l.

Despite this publication, knowledge and research on permafrost remained sparse in all Nordic countries for the following years, at least until the mid-sixties, where a study of permafrost in ice-cored moraines in Norway was published by Gunnar Østrem (1964). This was followed by several Swedish investigations of landforms indicating the former existence of permafrost, e.g., a special type of circular lake, and fossil polygon patterns on raised beach ridges, both features described from northern Norway by Harald Svensson (1969).

Following the papers by Østrem and Svensson, a suite of other investigations were published from Norway and other Nordic countries during the following 25 years. During the initial 10 years of this significant development most investigations had their research focus on periglacial landforms such as, ice wedges, palsas, and pingos. Often permafrost was addressed only indirectly.

This changed in 1984, where a German scientist (like Østrem in 1964) began to use geophysical methods in the Norwegian periglacial environment. The successful introduction of this new technology resulted in a gradual move of the research focus from periglacial geomorphology to permafrost temperatures studied by geophysical means. After 1998 researchers involved in the European PACE program have greatly contributed to the recognition and description of permafrost in Norway and other parts of Scandinavia. In Norway a 100 m permafrost borehole was drilled at Juvvasshøe in Jotunheimen. Several new shallow permafrost boreholes were established during the 2007-09 IPY period, by the TSP-Norway and the CRYOLINK research projects.

References

- Svensson, H. 1969. A type of circular lakes in northernmost Norway. *Geografiska Annaler* 51A, 1-12.
- Østrem G. 1964. Ice-cored moraines in Scandinavia. *Geografiska Annaler* 46 A (3), 282-337

Monday
13:00-15:00

ORAL Parallel Session

Permafrost Foundation Behavior in a Warmer Climate

Co-chairs: Sarah Springman & Gisle Håland

In Kapp Mitra

Thermal Modeling of Variations in the Depth of the Frost Table Caused by Increasing Temperatures in Kangerlussuaq Airport, Western Greenland

Anders Stuhr Jørgensen

Department of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

1 INTRODUCTION

Kangerlussuaq Airport is located at 67°00' N and 50°42' W in the zone of continuous permafrost in western Greenland. During the period 1992-2007 the mean annual air temperature in the area has increased with approximately 2.5°C.

A thermal model of the embankment of the southern parking area in Kangerlussuaq Airport has been used to study the changes in the thickness of the active layer during the period 1992-2007. The modeling was carried out with the finite element software TEMP/W from GEO-SLOPE International Ltd. The thermal model is based on results from a previous borehole drilling, a trench excavation and climate data. Finally the model was compared with results from Ground Penetrating Radar (GPR) investigations, which have been used to study the annual variations of the frost table underneath two different surfaces, a normal dark asphalt surface and a more reflective surface (white paint), on the southern parking area in the summer periods of 2005-2008.

2 RESULTS

Figure 1 shows the calculated maximum thaw depths underneath the two investigated surfaces. The maximum modeled thaw depths generally occur in September or October. The modeling results show a clear correlation between the annual variation in the thaw and freeze indices, and the maximum annual thaw depth. The modeled results have shown a progressive lowering of the frost table as a consequence of the increase in air temperatures during the investigated period. The average modeled maximum thaw depth underneath both surfaces has increased with approximately 0.5-0.7 m from 1992-2007.

The modeled thaw depths compare with the results from the GPR investigations carried out during the thawing periods in 2005-2008. The GPR results from this period have shown that the maximum thaw depth underneath the reflective surface is approximately 3.1 m, whereas the maximum thaw depth is approximately 4.0 m underneath the normal dark asphalt surface (Jørgensen & Andreasen, 2007; Jørgensen & Ingeman-Nielsen, 2008)

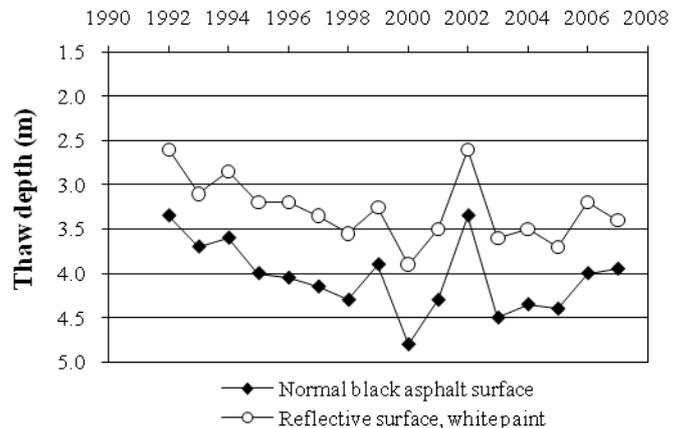


Figure 1. Modeled thaw depths underneath the southern parking area in Kangerlussuaq Airport, 1992-2007.

3 CONCLUSION

Thermal modeling have been carried out to get insight into the possible impact of climate warming on the thaw depth penetration underneath the southern parking area at Kangerlussuaq Airport, western Greenland. The results have shown a clear correlation between the annual variation in thaw and freeze indices, and the maximum annual thaw depth. During the studied period the mean annual air temperature in the area has increased with approximately 2.5°C. The increase in air temperature has led to an increase in the maximum annual thaw depth underneath the two investigated surfaces of approximately 0.5-0.7 m. The results have also shown that the use of a more reflective surface will reduce the maximum thaw depth with up to 1.0 m. This constitutes a major difference in the thermal regimes below the two kinds of surfaces.

References

- Jørgensen, A. S. & Andreasen, F. (2007): Mapping of permafrost surface using ground-penetrating radar at Kangerlussuaq Airport, western Greenland. *Cold Regions Science and Technology*, Vol. 48, pp. 64-72.
- Jørgensen, A. S. & Ingeman-Nielsen, T. (2008): The impact of light-colored pavements on active layer dynamics revealed by Ground-Penetrating Radar monitoring. *Proceedings, Ninth International Conference on Permafrost*, Fairbanks, Alaska, USA, pp. 865-868.

Foundation Behavior in Longyearbyen, Svalbard

Marie Nokken

Sweco Norway

Lars Grande

Norwegian University of Science and Technology, NTNU, Trondheim, and UNIS, Longyearbyen, Norway

1 AIM OF THE PROJECT

1.1 *General*

This project was carried out in spring 2009, with the aim to gather experience data from the different foundation principles utilized during the last 50 years in Longyearbyen. Buildings, roads and pipeline design were addressed, where building foundations had the main focus. The work was done as a master thesis at NTNU.

1.2 *Method*

Buildings in Nybyen, Haugen, Lia and Gruvedalen have been levelled by use of a laser leveller and photographs. Features on the facades as bottom sill and window lines are used as reference lines.

The measuring method has proven capable to identify level differences on building facades. Its strength lies in the possibility of comparing several reference lines as well as quick and easy execution of the measurements.

The fact that not all buildings have usable reference lines, and the assumption that windows and base of panelling originally are exactly in level, both add to the level of insecurity in the measurements.

2 FINDINGS

2.1 *Foundation principles*

The oldest buildings is characterized by shallow foundations, either concrete soles or piles of 1-2 metres. Newer building trends make use of deeper piles or other ways of controlling the soils thermal regime as insulation or artificial refrigeration.

2.2 *Measuring results*

Buildings approaching 50 years age and older generally show severe level differences. The evaluated buildings in this group all have shallow foundations, and building heat have been allowed to penetrate the subsoil.

The Nybyen Barracks and Haugen houses are lighter buildings with piles of 1-2 metres depth and ventilation space. The Barracks have displacements of 3-5

cm which is modest considering their age. No common trend in the displacement pattern could be identified. The Haugen Houses show a distinct pattern of deflection in the middle.

The newer buildings founded on about 4-6 m deep wooden piles generally show modest level differences. Only one measured building shows clear signs of uphill tilt, and should be looked into more closely.

The Blåmyra buildings make use of deeper concrete piles, and the experience from these is very good.

Buildings with artificial freezing have shown to be very stable, but care should be taken on influencing neighbouring buildings as well as energy consumption and technical surveillance.

2.3 *Conclusions*

Some movements occur even in new buildings on deep foundations. These small displacements can possibly be subscribed to some movement in the initial building phase, before conditions stabilise and movements terminate. Furthermore can these small level differences be due to natural creep processes, at some places accelerating from small increases in permafrost temperatures.

The wooden piles represent a cheap and effective design, but with limited maintenance-free life expectancy. More durable designs less exposed to freeze-thaw-cycles could be obtained by means of alternative designs as gravel pads with or without ventilation, deeper concrete piles and ground freezing through natural convection.

3 FURTHER WORK

To fully document the performance of the current foundation practise in Longyearbyen, more measurements on the newer buildings should be carried out. Not only should even more buildings be levelled, but development should be monitored over time and with seasonal changes. As only differential settlements can be detected by the used levelling method also more detailed methods also enabling monitoring of total settlement could be useful.

Community Planning on Permafrost in Nunavik – The case Study of Salluit

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1 PREMISE

Salluit is a village that lies in the continuous permafrost zone in Nunavik (Northern Québec). It is located in the bottom of a narrow valley with limited space for expansion and built in large part on ice rich silty permafrost. With recent climate warming, geotechnical problems have been encountered, such as some instabilities of several building foundations as well as increased risks of active layer slides on slopes. These geomorphic processes are expected to intensify with future climate changes, creating an additional challenge for the land-use management of this expanding community. To support the development of the community an interdisciplinary study, which combines elements from physical geography, human geography, civil engineering, economics and politics has been produced.

2 METHODOLOGY

In order to best identify local vulnerability and capacities for adaptation, geoscientific and climatic data are integrated with policy analysis and community perspectives. Public community hearings organized by Quebec's Ministry of Municipal Affairs and regular meetings with the decision makers were held in order to identify specific needs that have to be addressed. Maps integrating the collected data and the forecasted permafrost conditions have been produced. The identification of adequate adaptive measures asks also for a better understanding of the interaction between permafrost and the different types of foundations for buildings and municipal infrastructures.

A specific experiment was established in town to measure settlement and effectiveness of embankments for permafrost recovery. Thermistors and settlement plates are installed in an experimental pad and down into the underlying permafrost. The intent is to assess the best design parameters to provoke the recovery of permafrost in the newly installed pad to support the new house for a long period. An economic analysis of the possible choices of adaptation solutions will complete this study and cost-benefit analysis will be used to draw recommendations for local and regional land-use planners.

3 RESULTS

Information gathered from the policy makers and the local Inuit population show community based preferences and dislikes on the possible sites of expansion, as well as technical and geophysical constraints. These important results lay the basis for future master plans.

As for the experimental pad, the data clearly show that the ground has cooled in 2009 compared to 2008. Where there used to be a thermokarst pond, the cooling was much faster than in the surrounding less perturbed area, and after only one year of cooling the two areas have almost an identical thermal profile. This means that not only the cooling is making up for the extra thermal perturbation, but there is also a tendency of temperatures to come back towards the original unperturbed thermal profiles. Given the present data, we can expect to see the cooling trend to pursue itself during the coming years, maybe even reestablishing the natural thermal profile of the lot. This positive outcome of the experiment indicates that some disturbed terrain affected by past human activity and the presence of obsolete buildings can be restored in order to optimize the use of space within the community.

4 DISCUSSION

This leads us to the suggestions that the foundation technique of padding will not only help to restore already thermally disturbed grounds, but will also serve as a buffer zone to absorb increased air temperatures and hence help to protect, to some extent, the permafrost from global warming. This knowledge, combined with the local inuit preferences, will allow to optimize pad geometry for reclaiming degraded permafrost in the community.

In a further step this conclusion will be compared to other foundation methods, like piles, and a cost-benefit analysis will determine which method suits best not only in terms of permafrost recovery, but respects also local inuit cultural needs for future community planning.

Destruction of Buildings and Underground Constructions Caused by the Cryogenic Weathering in Cryolithozone

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Mass deformations in Northern Russia settlement's objects have been observed recent decade. They have been caused with: the changes in ground's bearing capacities reasoned by permafrost base's degradation due to the global climate fluctuations and the local technogenic influence; the activation of foundation's material and other artificial medium's cryogenic shattering in this region.

Theoretical mineralogical investigations of rock and material cryogenic weathering mechanism has been carried out. Field inspection of foundations, asphalt-concrete road covers, reinforced concrete underground collectors for communications undergone the frost weathering in Norilsk, Dudinka, Ust-Port have been made pass.

Theoretical and field investigations gave a possibility to obtain an objective picture of the foundations state, operating in different engineering-geocryological conditions, different technogenic loading on bases as well as different period of operation.

In order to detect main reasons causing the premature destruction of footings concrete, and to develop measures preventing this destruction in Norilsk industrial region (Norilsk, Talnakh and Dudinka), in Khatanga, Dixon and Igarka, special long-term research have been carried out to definite thermo-humidity conditions of seasonal freezing/ thawing in ground beneath footings. As objects to study have been singled out those footings built on permafrost ground with conservation of permafrost during various term of operation (from 3 until 40 years) and other geotechnical objects have been selected. For example, wear of footings in active layer (in Norilsk industrial region) is from 15-20 % up to 70-80 % from planned values that depends on frozen ground characteristics, conditions and duration of operation. From 20 inspected underground double-deck Ferro-concrete collectors for communications 30 km long only 20 % were in emergency and 60% were unsatisfactory.

The analysis of concrete foundations state for 14 constructions in Dudinka undergone the frost weathering have been completed. The pattern of footings destroying is rather variegated. Sometimes, there are about 5-8 zones in ventilated cellar with various state of footing. Thus, average value of concrete strength in one zone can be 2-3 times more or less than in other one. However, even inside the chosen

zones separate piles can have considerable wear extent (strength of concrete is about 10-20 % from designed) whereas others are very poor subjected to the corrosion. This can be explained by cumulative influence of a set of factors and different degree of negative actions. Mostly destroyed piles and supports located in the central part of ventilated cellars near gutters and communications and on water-saturated sites. Next zone on the destruction intensity is an angle bases zone under heat centers. Peripheral and inner footings near dry ventilated cellars are less destroyed.

Main reasons causing the concrete destruction have been divided into 4 general groups:

a) climate and geocryological conditions, e. g.: a repeated freezing-thawing process, high amplitude, ground humidity, etc.;

b) technogenic impact on geocryological-geological processes: seasonal thawing depth increased in the technogenic inundation, growth of the ground water aggression due to technogenic salinisation, etc.;

c) technological reasons (methods of the foundation structuring, the foundation loading, etc.

d) operation conditions (ventilated cellar's activity, time of operation, etc.). General most destructive zones of foundations in plain and vertical projections have been determined.

Methods of Estimation of the Reliability of Oil-Trunk Pipelines in Permafrost Area

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1 INTRODUCTION

Current state of knowledge of frozen ground and material status of building allows us to talk about possibility of resource development nearly any area. The difference of engineering geotechnical conditions causes only different cost. So it is very important to make good faith estimation of the reliability of structure base and make the optimization of the reliability. The paper is concerned with probabilistic –statistical approach for oil pipelines designing. The method of reliability estimation of oil-trunk pipelines within different types of pipe laying is introduced. The assessment of danger of failure and cost of risk was given.

2 NOMENCLATURE

Reliability ($R(t)$) is simply a measure of the probability of no failure occurring. We define risk as the probability of pipeline failure. So The reliability and the risk function ($P(t)$) are linked :

$$R(t)=1-P(t)$$

Risk function allows us to estimate the material loss which occurs with pipeline failure. This loss is called Cost of risk (C)

3 OPTIMIZATION OF OIL-TRUNK PIPELINES

The existing optimization studies of engineering constructions stabilization on frozen ground is based on deterministic model and has some substantial defect-this model can't compute the reliability of system and the variants can be compared just with theirs initial cost. So it is necessary to use probabilistic approach using the analytical method of estimation of pipelines reliability and cost of risk in the context of different types of pipelines.

4 ESTIMATION METHODS

Proposed methods of estimation of oil-trunk pipelines in permafrost area let us consider stochastic heterogeneity of the geotechnical system «pipeline-

permafrost» and actual loadings, to manage system quality, make emergency situations forecast , and the financial estimation of the consequences (in standard units). After getting the information about material costs it gives us an option to represent the optimization problem- cost rate for system implementation and cost of risk goes to lower limit.

5 RELIABILITY MANAGEMENT

We can manage the system reliability and cost of risk by changing the construction solutions, e.g. for above-ground pipeline it's modifying the length of piles, for buried pipelines modifying the thickness of radial heat-insulation.

6 CONCLUSIONS

A Solution of the problem allows to make a choice of optimum design decisions - trace the optimum pipeline route, optimum way of its laying and appropriate design values in different geological environmental conditions in permafrost area.

References

Khrustalev L.N., Pustovojt G.P. 1988. Probabilistic-Statistical estimation of foundations in permafrost zone. Novosibirsk

Effects of Climate Change on Substrate Bearing Capacity in Russian Permafrost Regions

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More than 75% of engineering structures on permafrost in Russia are built according to the "First Construction Principle," which relies on the freezing strength (bearing capacity) of the frozen ground to support structures. Bearing capacity, defined as the maximum load (in kN/m²) for a standard foundation pile embedded in permafrost, is used in Russia as a primary variable for engineering assessments in permafrost-affected territories. According to Russian construction rules and regulations, the bearing capacity of permafrost soils is estimated from the mean decadal values of air and ground temperature, with adjustment factors used to account for interannual climatic variability. For given surface and subsurface conditions, the bearing capacity depends strongly on the active-layer thickness (ALT) and the temperature of the permafrost, both of which are strongly affected by atmospheric climate. Increases in permafrost temperature and ALT resulting from climatic warming can significantly reduce the bearing capacity of the frozen soil and the stability of engineered structures.

Intensive industrial development of West Siberia began during the late 1960s and early 1970s. We assume that the engineering designs for infrastructure constructed during that period were developed based on 1960-1970 climatic conditions. Our research is driven by the hypothesis that by the year 2000 the bearing capacity had changed significantly as a result of observed climatic change. To evaluate this hypothesis we have developed a set of parameterizations to estimate the bearing capacity of frozen soils as functions of permafrost temperature and ALT, according to construction rules and regulations. The effect of climate on permafrost temperature and ALT was estimated by an equilibrium permafrost model.

Here, we present results from a geographic assessment of changes in the bearing capacity of permafrost soils attributable to observed climatic change in Siberia. Changes in bearing capacity for the last forty years were evaluated for several large settlements and industrial centers, representing different

geographical conditions of the Russian Arctic. Calculated changes in bearing capacity for some of the major settlements on permafrost show that those foundations built according to the first (passive) principle during the 1960-1970 period are most likely to experience deformation at Nadym and Salekhard, and are quite likely in Yakutsk, Anadyr, Chersky and Noviy Port. Generally, areas located in the southern permafrost zone are likely to experience more pronounced decreases in bearing capacity under warming of the magnitude predicted by climatic models.

A GIS-based landscape approach was used to apply the model at regional and continental scales to assess geographic changes in permafrost temperature, active-layer thickness, and bearing capacity in the North of West Siberia, and for the entire Russian continuous permafrost zone. Substantial (up to 25%) loss in the bearing capacity of frozen soils is evident throughout this zone. This situation has potential to cause deformation and damage to structures on permafrost, which can have severe socio-economic consequences.

Forecast of Frost Heave Caused by Freezing Soil around Pipeline Based on Physical and Numerical Modeling Data

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1 INTRODUCTION

Frost heave represents a significant thermo-mechanical problem for pipelines that are buried in frost-susceptible soils. This paper outlines the work that has been done on physical and numerical modeling of frost-heave issues related to chilled gas pipelines.

2 MODELING

2.1 Physical modeling

The physical modeling data falls into two groups: 1) One-dimensional “open system” freezing of a saturated mix of silt and kaolin to define the segregation potential and to investigate the water content redistribution in the frozen zone as well as the integral and differential frost heave displacement values at 1g ($g=9.89 \text{ m/s}^2$) 2) Centrifuge physical modeling at 50g in order to assess scaling effects (Taylor R.N., 1994). Freezing of initially unfrozen soil ($+2^\circ\text{C}$) caused by a chilled pipeline (-6°C) has been modeled and temperature field dynamics and vertical displacements have been measured.

2.2 Numerical modeling

A numerical model which simulated the frost heave action has been developed by N. Volkov and C. Johansen using the commercially available Finite Element program, ABAQUS. This model is capable of simulating the thermo-mechanical behavior of the frost-heave issue. The model is based on the Fourier equation (conductive heat transfer) and uses a lumped parameter methodology for characterizing the freezing and frozen zones. A phenomenological expansion function is applied in order to achieve the thermal expansion characteristics observed in physical experiments.

The expansion parameter incorporates: 1) Volume expansion of in-situ water. 2) Volume of migrating water into the frozen zone caused by the temperature gradient inside the freezing zone (or “frozen fringe”). This calculation is based on a segregation potential parameter (Konrad J.-M., 1983). 3) Migration of unfrozen water inside the frozen zone caused by the temperature gradient in the frozen zone, di-

rected towards lower temperatures and calculated with the help of a frozen permeability parameter.

3 RESULTS

The numerical model was applied in order to analyze a pipe embedded in heaving soil. Fig. 1 shows an example of the numerical modeling efforts that have been conducted to date. Comparisons between numerical and physical data have been completed. The numerical model provided reasonable comparisons to physical test data on the temperature field dynamics around the pipeline and on frost heave displacements. As such, the numerical model is considered a viable tool for forecasting frost heave caused by freezing soil around pipelines which are situated in semi permafrost areas.

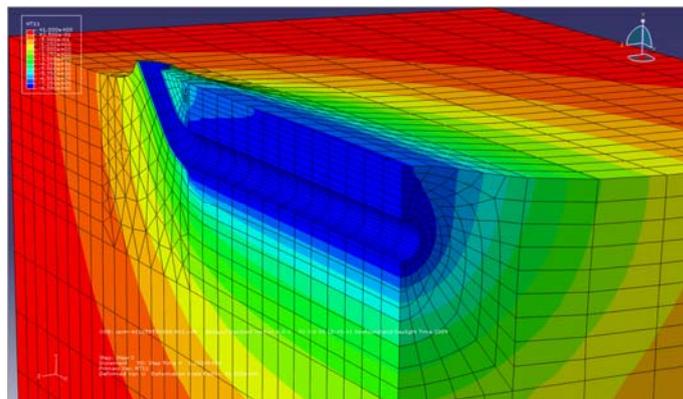


Figure 1. Vertical heave and temperature field around the pipeline physical model.

References

- Taylor R.N., 1994, Geotechnical Centrifuge Technology.
- Konrad J.-M., Morgenstern N.R., 1983. Frost heave prediction of chilled pipelines buried in unfrozen soils.

Forecast of Changing of Main Engineering and Geocryological Parameters in Russian Arctic to 2030 and 2050.

D.G. Shmelev

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Climatic fluctuations affect on nature and anthropogenic systems and lead to change of environmental, especially cryolithozone. 2/3 area of Russia locate in zone of permafrost, here main oil and gas, coal, ferrous and non-ferrous metals field, railroad and pipelines. Stability of these systems depends from stability of engineering-geocryological conditions.

Significant part of basement of buildings and pipelines in North establish by means pipes, which was freeze in permafrost; because estimating of dynamic of bearing capacity of freezing pipe and inclined forces of frost heaving stand be important.

Most development territory of Russian Arctic includes Bolshzemelskaya tundra, West Siberia and lowers of Yenisei. Opening up of this area was begun already in 30-s years of XX century. Here we can observe all types of areal extent of permafrost – sporadic type on south and continues on north, turf moss, massive ground ice and cryopegs are meeting. Natures zones: from north boreal forest to arctic tundra. These regions can be typical for cryolithozone on North hemisphere, modeling of main engineering and permafrost parameters is representative.

For modeling series of one-dimensional problem of non-stationary heat-conducting with moving boundary of division of phases was solved for definition of temperature regime and thickness of active layer. For modeling grid (size $2^{\circ} \times 2^{\circ}$) with three types of ground (sand, loam and turf with mineral substrate) into each fine was used. After modeling of changeable geocryological parameters, calculation by means standard scheme of bearing capacity of freezing pipe (length 10m, section 30x30cm) and inclined forces of frost heaving within active layer (diameter 210mm) was made.

Climatic forecast was created by Department meteorology and climatology of Lomonosov Moscow State University. Model assume positive trend of air temperature, increasing of mean annual air temperature will be 0,5-1,5°C to 2030 and 2-3°C to 2050. Forecast includes increasing of summer, warming of winter and shift of most cold month from January to February for North part of European Russia.

For 2030 and 2050 changing of complex parameters (inclined forces of frost heaving, which pull out of piles and bearing capacity of freezing piles) was calculated. In different types of ground increasing in-

clined forces of frost heaving on 20-300% and decreasing of bearing capacity on 30-50%. In large part of Bolshzemelskaya tundra permafrost will thaw on more 15-20m from the top, what will be cause of “fundament failure”. For these three regions (Bolshzemelskaya tundra, West Siberia and lowers of Yenisei) maps of changing of these complex parameters was made.

Monday
13:00-15:00

ORAL Parallel Session

The Thermal State of Permafrost

Co-chairs: Hanne H. Christiansen & Vladimir Romanovsky

In Møysalen

Spatial Distribution of Permafrost in Hurd Peninsula (Livingston Island, Maritime Antarctic)

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The Antarctic Peninsula is one of Earth's regions experiencing a faster increase on temperatures, with Mean Annual Air Temperatures (MAAT) rising ca. 2.5 °C in the last 50 years. The northerly location of the Antarctic Peninsula in respect to the Antarctic and its oceanic setting originate a milder and moister climate than in the Antarctic continent. The Northern Antarctic Peninsula is roughly located between the isotherms of MAAT of -1 °C to -8 °C at sea-level and therefore the northern tip and especially the South Shetlands are close to the limits of permafrost occurrence. If the observed warming trend is to continue in the near future, the region might suffer widespread permafrost degradation.

Research on the permafrost environment of Hurd Peninsula (Livingston Island, Antarctic Peninsula region) has been taking place with systematical ground temperature monitoring since 2000 and currently we are able to provide a good overview of the spatial distribution and characteristics of permafrost in Hurd Peninsula. Our research is based on:

1) shallow boreholes (<2 m) with a time series of 9 years (30 and 275 m asl);

2) a more recent set of boreholes with 1-3 years data, which include a 25 m borehole at Reina Sofia Peak (275 m a.s.l.), a 15 m borehole in the vicinity of Reina Sofia Peak near Hurd Glacier (269 m a.s.l.), a 4 m borehole at Papagal (147 m a.s.l.), a 5 m borehole at the Ohridski CALM-S (136 m a.s.l.), and a 8 m borehole near the St. Kliment Ohridski station at ca. 30 m asl.

3) Other shallow boreholes (1.5 m) at Nuevo Incinerador (25 m a.s.l) and Collado Ramos (115 m a.s.l.).

4) Electrical Tomography Resistivity and refraction seismic profiles providing a good overview of the general conditions of the permafrost terrain;

5) A network of air temperature dataloggers;

6) A network of snow thickness poles with miniloggers and digital time-lapse cameras;

7) An automatic meteorological station;

8) Remote sensing of snow cover;

9) Detailed geomorphological mapping of periglacial features at a scale 1:5,000.

The location of the boreholes along an altitudinal gradient from non-permafrost to permafrost terrain allows us to model ground temperatures. This data is integrated with geomorphological and geophysical information and is synthesized in the Map of Permafrost of Hurd Peninsula – Livingston Island. The available temperature data also allows to an evaluation of the climatic sensitivity of permafrost in a region of fast atmospheric warming.

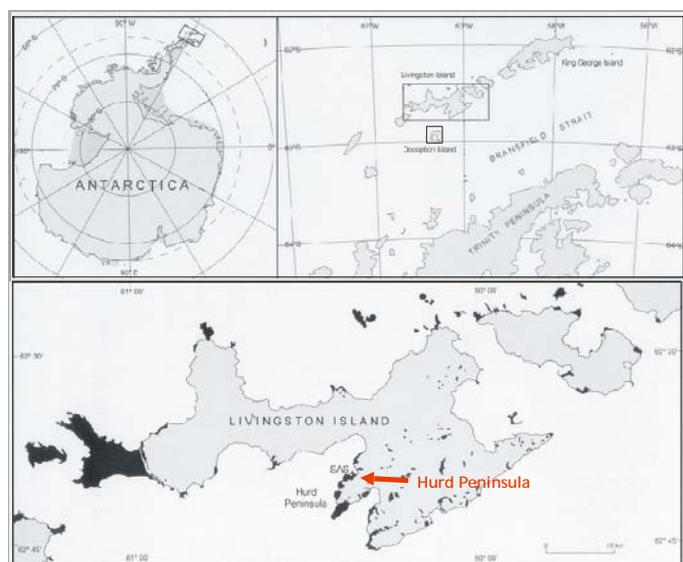


Figure 1. Location of Hurd Peninsula in Livingston Island

The Thermal State of Permafrost in Canada – Results from the International Polar Year

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1 INTRODUCTION

The International Polar Year (IPY) provided the opportunity for the Canadian permafrost community to conduct a coordinated program of permafrost observations in order to define present permafrost conditions and their spatial and temporal variability. Canada's contribution to the multinational Thermal State of Permafrost project examines the ongoing impacts of climate change on permafrost conditions.

2 CURRENT THERMAL STATE OF PERMAFROST

The Canadian permafrost monitoring network currently consists of about 170 sites, with almost half of these established during the IPY to address geographical gaps such as the eastern Arctic and the mountains of the Yukon Territory. The measurement sites span a diverse range of ecoclimatic and geological conditions across northern Canada. An updated snapshot of the thermal state of permafrost was developed that indicates permafrost temperatures range from warmer than -2.5°C in the discontinuous zone to as cold as -15°C in the continuous zone (Table 1).

Table 1. Summary of mean annual ground temperatures (MAGT) at depth of zero annual amplitude (or depth closest to it) in different regions of the Canadian permafrost zone during IPY (from Smith et al., accepted).

Region	MAGT ($^{\circ}\text{C}$) Discontinuous	MAGT ($^{\circ}\text{C}$) Continuous
Western Canada (lowland 59.5 - 70 $^{\circ}\text{N}$)	>-2.2	-0.3 to -8.1
Western Canada Mountain (60 - 63 $^{\circ}\text{N}$)	>-3.6	-2.2 to ?
Central Canada (lowland 57-75 $^{\circ}\text{N}$)	NA	>-12.3
Eastern Canada (lowland 55.5-82.5 $^{\circ}\text{N}$)	>-2.6	-2.4 to -14.9

3 RECENT CHANGES IN PERMAFROST THERMAL STATE

Ground temperature records 20 to 30 years long, available for a number of sites, indicate that permafrost was generally warmer during IPY than the average ground temperature for the entire record. In concert with regional air temperatures, permafrost has been warming across Canada for the past several decades with later warming occurring (since the early 1990s) in the eastern Arctic. Rates of permafrost temperature increase are variable and are generally greater in colder permafrost north of treeline where the upper 15 m of permafrost has warmed by up to 0.1°C per year. Latent heat effects in the southern discontinuous zone dominate the permafrost thermal regime close to 0°C and allow permafrost to persist for decades under a warming climate. Consequently, the spatial diversity of permafrost thermal conditions is decreasing over time.

4 SUMMARY

The snapshot of permafrost thermal state generated by this project provides an improved baseline against which change can be measured. Essential information has been generated for improved assessments of climate change impacts and predictions of future conditions. The project has also provided information that can be utilized for: engineering design of northern infrastructure; informed landuse planning decisions; development of adaptation strategies to deal with climate change.

Reference

Smith, S.L., Romanovsky, V.E., Lewkowicz, A.G., Burn, C.R., Allard, M., Clow, G.D., Yoshikawa, K. and Throop, J.L. accepted. Thermal state of permafrost in North America – a contribution to the International Polar Year. *Permafrost and Periglacial Processes*.

Thermal State of Permafrost in the Northern Yakutia and Alaska, Regional Peculiarities and Response on Climate Changes.

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1 INTRODUCTION

Permafrost temperature is not a direct reflection of the air temperature regime; it is also affected by the landscape and soil conditions at local measurement site. Landscape conditions can influence permafrost temperature through the snow cover redistribution, vegetation, and hydrology. Differences in the mean annual ground temperature (MAGT) due to differences in landscape settings can reach several degrees C. Local geology may affect MAGT through the thermal properties of soils. Current research was focused on the study regional permafrost feedbacks associated with climate change in the North-eastern Asia and Alaska.

2 RESULTS AND DISCUSSION

2.1 Investigation area

The investigated region covers the territory of eastern Siberia and Alaska. It is the most ancient permafrost area in the Northern Hemisphere; it is characterized by varied climate zones, from a maritime (the Pacific coasts of Alaska) to a continental zone (interior Alaska and the Tiksi area). It covers different landscape zones, including mountains, boreal forest, and tundra. So, this region is a good to study the influence of landscape conditions and atmospheric circulation peculiarities on permafrost temperature dynamics.

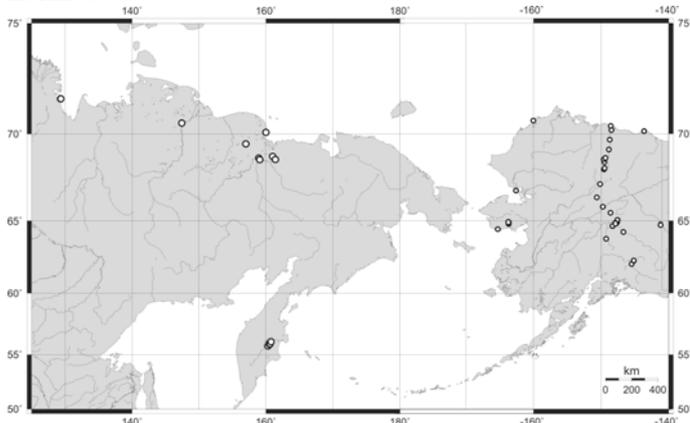


Figure 1. Map of the investigated region.

2.2 Methods of research

Observations have been conducted in this network since the 1980s. In Alaska this network has been monitored continuously; in the western part of the region (Siberia) the observations were mainly occasional (once or twice per year) until 2006. During the International Polar Year (2007-2008) a number of key boreholes in Siberia were instrumented for continuous monitoring.

2.3 Modern thermal state of permafrost

Modern thermal state of permafrost in this region is following: Siberian part characterized by the mean annual ground temperature on the top of rest of Late Pleistocene accumulative planes varies in the range from -12.3°C on the latitude $72^{\circ}50'$ north to -9.9°C on the latitude $69^{\circ}30'$ north. Within the alas depression mean annual ground temperature is a little bit warmer (-10°C on the $71^{\circ}40'$ north and -7°C on the $68^{\circ}50'$ north).

In the tundra zone of Alaska peninsula (North slope borough) MAGT varies from -8.6°C at the north shore to -4.6°C near the Brooks range. Interior Alaska characterized by the most variable permafrost temperature: from -3 to -0.5°C depending on landscape conditions.

2.4 Response of permafrost thermal state on the climate changes.

During the 1990s thermal state of permafrost in the Siberian part of region was stable. Since the 2000th permafrost temperature increase on $1.5-2^{\circ}\text{C}$ on the Kolyma lowland. At the same time thermal state of permafrost in the western part of region was stable until the last years. Noticeable increasing of ground temperature was recorded only recently. Also there are some sites where modern landscape changes (vegetation succession) leads to the stabilization of permafrost temperature.

On the contrary, Alaskan permafrost was warming up at the end of XX century. During the last 10 years it was not recorded significant changes of permafrost temperature.

Setting up a Monitoring Network of Mountain Permafrost in the Alps

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1 FIRST STEPS

The core drilling in 1987 through the active Murtèl-Corvatsch rock glacier initiated a number of permafrost research activities in Switzerland. Besides understanding of governing and involved processes, documentation of long-term behavior of Alpine permafrost was a clearly stated goal from the very beginning (Haerberli et al., 1993). This, in turn, motivated Swiss research groups to contribute, and they chose topics of their projects accordingly. However, the close link between process understanding and long-term monitoring has always been key.

2 HOW TO MONITOR ALPINE PERMAFROST?

The initial three items to be recorded with the “Permafrost Monitoring Switzerland (PERMOS)” were (i) borehole temperature, (ii) permafrost distribution pattern test regions and (iii) aerial photographs of specified rock glaciers. This concept was approved for a pilot phase by the responsible committee of the Swiss Academy of Sciences (SCNAT) in the year 2000. Only then, some funds to coordinate monitoring activities were made available. Before, the activities were exclusively funded through research projects (e.g. PACE) of contributing institutions.

2.1 Refinement by evaluation

Swiss permafrost research community continued on the one hand providing data of the monitoring sites, and sophisticated the parameters on the other. After evaluation of both, parameters and PERMOS elements, a standard was defined that serve now as a solid basis with three types of observations:

- (1) borehole sites, where ground and borehole temperatures as well as a few climate parameters are recorded,
- (2) changes in subsurface ice and water content at these borehole sites are inferred by repeated electrical resistivity tomography (ERT) surveys, and
- (3) movements of permafrost creep determined by geodetic surveys and/or photogrammetry on rock glaciers (kinematics). In addition, documentation of fast mass movements (in particular rock falls and debris flows) from permafrost areas is being established (dynamics).

Since 2000, PERMOS publishes bi-annual reports about recorded data and used methodology (e.g. Noetzli et al., 2009).

2.2 For example: rock fall observations

Rock falls have been observed and filed by various institutions in Switzerland, in particular those that caused damages. PERMOS compiled and standardized existing questionnaires in collaboration with mountaineering associations and authorities.

The inventory contains presently more than 150 events originating mainly from areas with potentially warm permafrost, some of them reaching back more than 100 years. First analysis indicate that large rock falls ($> 100'000 \text{ m}^3$) occurred more frequently since the 1990-ies, and that detachment zones are located markedly more often underneath ridges and peaks than in steep walls.

3 IMPLEMENTATION INTO THE NATIONAL MONITORING UMBRELLA

Most importantly, PERMOS has been successfully implemented into both the international permafrost monitoring (GTN-P) and the Swiss GCOS-activities, which coordinates the monitoring of all essential climate variables (ECV).

From 2011 onwards, PERMOS will be funded through GCOS Switzerland with additional contributions from the Federal Office for the Environment (FOEN), the Swiss Academy of Sciences (SCNAT), and the Federal Institute for Meteorology and Climatology MeteoSwiss. Maintenance of field sites and data acquisition will be continued to be done by the six partner institutes, the Universities of Berne, Fribourg, Lausanne, and Zurich, the ETH Zurich, and the WSL Institute for Snow and Avalanche Research SLF.

References

- Haerberli, W., Hoelzle, M., Keller, F., Schmid, W., Vonder Mühll, D. and Wagner, S. (1993): Monitoring the long-term evolution of mountain permafrost in the Swiss Alps. *Sixth International Conference on Permafrost, Beijing, Proceedings 1*, 214-219.
- Noetzli, J., Naegeli, B. and Vonder Mühll, D. (ed.) 2009. *Permafrost in Switzerland 2004/2005 and 2005/2006*. Glaciological Report (Permafrost) No. 6/7 of the Cryospheric Commission (CC) of the Swiss Academy of Sciences (SCNAT), 100 pp.

Analysis of Temperature Time Series Measured in the PERMOS Boreholes and Their Vicinity

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1 INTRODUCTION AND BACKGROUND

Warming of permafrost as a consequence of increasing air temperatures has been demonstrated for sites in Scandinavia and in polar regions. Changes in atmospheric conditions are also likely to affect subsurface temperatures in mountain permafrost regions in the European Alps. Here, ground temperatures at and below the surface have been monitored in the scope of the Swiss Permafrost Monitoring Network (PERMOS) for more than ten years. The first permafrost borehole in the Swiss Alps has been drilled on the Murtèl rock glacier in the Engadine in 1987.

Although a large number of studies exist on individual sites, temperature time series in the Alps have not yet been analyzed in a more comprehensive way. In this presentation, we statistically analyze all available types of time series of surface and subsurface temperatures measured in the scope of PERMOS. This synopsis is aimed at investigating the questions as to if, where, when, and in what magnitude a warming has been measured in Alpine permafrost during the past decade.

2 STATISTICAL ANALYSIS OF PERMAFROST TEMPERATURE TIME SERIES

At seven PERMOS sites borehole temperatures have been measured for ten or more years, at two sites for seven years, and at five sites for one to five years. In addition, near-surface temperature series in the areas of the drill sites exist for many years and for different typical Alpine surface types (i.e., steep rock, flat rock, loose material, coarse blocks).

Changes in permafrost conditions are mainly driven by changes at the ground surface. Therefore, we concentrate first on the evolution of near-surface temperatures and the most important factors determining their changes over time. This also allows for an estimation of the influence of the differing surface cover types, as well as the spatial variability of the changes. The temperature changes at depth, in contrast, integrate and filter the signal from the surface and reflect trends delayed, but more clearly. Temperatures at depth are additionally altered by effects of latent heat and 3D topography.

First results reveal that annual changes in near-surface temperatures follow the general pattern of air

temperatures, even where a considerable snow cover exists in winter. The variability in the magnitude of the changes, however, is high. Active layer thicknesses reflect seasonal variations in air temperatures and snow conditions for most boreholes and are increasing at some sites. Temperatures at depth of 10 m and more do not show a clear warming signal for the past decade in most of the boreholes. This may be explained by the fact that the connection between air temperatures and permafrost temperatures at depth is not straightforward for sites in high mountains, where effects of winter snow conditions, surface cover, subsurface ice content, and mountain topography mask changes in atmospheric conditions when they propagate into the subsurface.

In order to get a more comprehensive picture of changes in mountain permafrost than by analyzing ground temperatures alone, additional methods can be included into the interpretation. For example, ground temperatures little below the melting point may remain constant for a period because of effects of latent heat. Corresponding changes in unfrozen water content can be detected by electrical resistivity tomography monitoring. Further, numerical modeling can serve as a tool for the extrapolation to locations and times where no data exists or for the separation of transient and topographic effects in borehole temperature profiles in mountain topography.

ACKNOWLEDGEMENTS

The temperature time series used in this study are provided by the Swiss Permafrost Monitoring Network (PERMOS). These data have been collected and processed by the PERMOS partners, which we would like to sincerely thank: R. Delaloye (University of Fribourg), C. Lambiel (University of Lausanne), M. Hoelzle (University of Fribourg), M. Phillips (WSL Institute for Snow and Avalanche Research SLF), and S. Springman (ETH Zurich).

Air and Ground Temperatures along Elevation and Continentality Gradients in Southern Norway

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1 INTRODUCTION

The modern southern boundary for Scandinavian permafrost is located in the mountains of southern Norway. The three-year research project CRYOLINK (“Permafrost and seasonal frost in southern Norway”) aims at improving knowledge on past and present ground temperatures, seasonal frost, and distribution of mountain permafrost in Southern Norway by addressing the fundamental problem of heat transfer between the atmosphere and the ground surface. Hence, several shallow boreholes have been drilled, and a monitoring program to measure air and ground temperatures was started in August 2008. These data will be used to calibrate and validate distributed transient models of snow cover, ground surface temperature and ground temperatures in southern Norway.

Here we present the first two years of air and ground temperatures from the sites and discuss the influence of air temperature and ground surface characteristics (snow conditions, sediments/bedrock, vegetation) on ground temperatures.

2 SETTING

The borehole areas (Juvvass, Jetta and Tron) are situated along a west-east transect and, hence, a continentality gradient, and each area provides boreholes at different elevations (Table 1). At Jetta all boreholes are drilled in bedrock, at Tron at Tron in in situ weather material or ground moraine, and at Juvvass in different ground surface materials, ranging from block fields via coarse ground moraine to bedrock. The uppermost borehole at Juvvass (Juv-BH1, 1771 m a.s.l.) is situated close to the Juvvasshøe PACE borehole (1894 m a.s.l.). At the PACE borehole air and ground temperature measurements exist since 1999, and the Norwegian Meteorological Institute has recently opened a full meteorological station there. At this site mean annual air temperature is estimated to -4.5 °C and mean annual precipitation 800 mm (Isaksen et al. 2001).

3 RESULTS

In all areas the measured annual mean air temperatures (2008-2009) ranges from ~ -3.5 to ~ 0 °C between the borehole sites, however, the mean altitudinal lapse rate of air temperature differs. At Juvvass the transect goes from shallow seasonal frost to continuous permafrost, at Jetta and Tron from deep seasonal frost to marginal permafrost (Table 1). This pattern is mainly due to differences in snow conditions. At Juvvass the upper parts of the transect (Juvflya and Juvvasshøe) are fairly bare-blown during winter, whereas the upper parts of Jetta and Tron have a well developed snow pack. Further, solar radiation is more important for ground temperatures further east, so more continuous permafrost may be experienced at the upper, northern slope of Tron (transect in the south slope).

Table 1. Site information and ground temperature characteristics for the boreholes used in this study. Sed.Cov: Thickness of sediment cover, PF: Permafrost, ALT: Active Layer Thickness; SFT: Seasonal Freezing Thickness; MGT: Mean Ground Temperature at ~ 10 m depth. All thicknesses in m, temperatures in °C, for the period 01.09.2008-31.08.2009.

Borehole	Altitude	Depth	Sed.cov.	PF?	MGT	ALT/ SFT
PACE-31	1894	20	3-4	Yes	-	-
Juv-BH1	1861	10	4.5	Yes	-1.6	~ 1.5
Juv-BH2	1771	10	2	Yes	-1.1	< 2
Juv-BH3	1561	10	2	Yes	-0.3	~ 8
Juv-BH4	1559	15	0	Yes	-	-
Juv-BH5	1468	10	4.5	No	1.3	~ 4
Juv-BH6	1314	10	> 10	No	1.6	< 1
Jet-BH1	1560	19.5	0	Yes	-0.7	~ 8
Jet-BH2	1450	10	0	No	0.6	~ 7
Jet-BH3	1218	10	0	No	1.7	~ 6
Tro-BH1	1640	30	3.3	Yes	0.0	~ 10
Tro-BH2	1589	9.5	2	No	0.9	< 2
Tro-BH3	1290	10	9.5	No	1.4	~ 2

References

Isaksen, K., Holmlund, P., Sollid, J.L. & Harris, C. 2001. Three deep alpine permafrost boreholes in Svalbard and Scandinavia. *Permafrost and Periglacial Processes* 12: 13-26.

Characteristics and Controlling Factors of Warming Mountain Permafrost in Jotunheimen and Dovrefjell, Southern Norway

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1 INTRODUCTION

A large number of complex processes control changes in mountain permafrost temperatures. The great variability in surface characteristics, snow cover and lithology in Alpine slopes may result in highly variable ground thermal regimes. In addition mountain permafrost is often discontinuous, thin and warm, thus permafrost decay and disappearance may be more variable compared to Arctic lowlands.

In this study evidence for variable warming and first signs of degrading mountain permafrost in southern Norway is presented, together with an analysis of factors controlling the rate of warming.

2 STUDY SITES, DATA & METHODS

Long-term ground thermal data are derived from a 129 m deep borehole in Jotunheimen (61°40'N, 8°25'E), established within the PACE-project (Permafrost and Climate in Europe) and 11 shallow (9 m deep) boreholes on Dovrefjell (62°20'N, 9°20'E), in along a transect from deep seasonal frost to discontinuous mountain permafrost (Ødegård et al. 2008). In addition, data series from several miniature temperature dataloggers (MTD), situated in different aspects and settings were used to study the local variability in Mean Ground Surface Temperature (MGST). The temperature monitoring programs were started in 1999 in Jotunheimen and in 2001 in Dovrefjell. All data were compared with climate data from nearby weather stations and gridded data of snow. Recently established 10-15 m deep boreholes in Jotunheimen, within the Norwegian founded CRYOLINK-project were used as validation.

Time-lapse inversion of repeated electrical resistivity tomography (ERT) between summer 1999 and 2009 crossing the expected lower altitudinal limit of permafrost in Jotunheimen allowed changes in permafrost conditions to be delineated. The results from the repeated ERT were evaluated on the basis of local seasonal resistivity variations and compared to results from the MTD's, borehole- and climate data.

Data from the PACE-borehole show a significant warm-side deviation in the ground thermal profile to 70 m depth, associated with surface warming of ~1.0 °C during 1970-2000. Observations since 1999 indicate that present decadal warming rates at the permafrost surface are 0.04-0.05 °C/yr (Isaksen et al. 2007).

Previous results from the study areas, based on data from ERT, MTDs, BTS and ground temperatures, were highly consistent. New results from the 10 year MTD-series show significant trends of warming, but with high variability within the two study areas. Results from the repeated ERT-data show substantial increase in the resistivity of the upper surface layers, and a general decrease in the ground below. The resistivity changes suggest marked decrease in soil water content in the upper layers, possibly due to permafrost degradation. Results from calibrated heat conduction models that include phase changes and use realistic thermal parameters taking into account site specific conditions, produce promising agreement between calculated and measured permafrost temperatures within the zone of degrading permafrost in Jotunheimen.

Probable causes of the warming include increased air temperatures (primarily in winter), a general increase in snow amount, including interannual variability in the redistribution of snow by wind, and combinations of these. Within the two study sites, at flat and convex areas exposed to strong winds, snow cover is thin or absent until March or April, with a maximum snow cover of less than 0.5 m in May, while snow cover accumulation at east and north facing slopes east and north may be substantial, but highly variable from year to year.

References

- Isaksen K, Sollid JL, Holmlund P & Harris C. 2007. Recent warming of mountain permafrost in Svalbard and Scandinavia, *J. Geophys. Res.*, 112.
- Ødegård RS, Isaksen K, Eiken T & Sollid JL. 2008. MAGST in Mountain Permafrost, Dovrefjell, Southern Norway, 2001-2006. In Proceedings Volume 2, Ninth International Conference on Permafrost, University of Alaska Fairbanks. ISBN 978-0-9800179-3-9: 1311-1315.

3 RESULTS

Examples of Rapid Permafrost Degradation in the Swiss Alps Induced by Lateral Thermal Disturbances

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1 INTRODUCTION

The first decade of this millennium was marked by several exceptionally warm events in the Swiss Alps. At some permafrost monitoring sites a temporary deepening of the active layer was registered, with no other discernible effects. At two sites however, lateral thermal disturbances led to rapid permafrost degradation and a substantial thinning of ground ice.

2 TWO SITES WITH LATERAL THERMAL DISTURBANCES

2.1 Permafrost degradation at Flüela Pass

At Flüela Pass (Eastern Swiss Alps, 2394m asl) ground temperatures from a 20m deep borehole in a scree slope indicate that the permafrost at the base of the slope is thinning from below (Fig. 1a) despite a constant active layer thickness of 3m. The process is triggered by air circulating within the blocky scree underneath the permafrost due to a lateral ‘chimney’ effect within the slope. Intra-talus ventilation generally cools scree slopes, but at this site the lake at the base of the slope induces heat into the system. Warm, moist air rises along the temperature gradient between the water table (constantly $\geq 0^{\circ}\text{C}$) at the level of the lake and the colder ventilated voids under the ground ice. The moisture condenses at the base of the ice, releasing latent heat. The rate of ice melt is estimated to be approximately 1-2 mm/day (Phillips et al. 2009). Warming of the lake water may accelerate this phenomenon.

2.2 Permafrost degradation at Distelhorn

On Distelhorn above Grächen (Southwestern Swiss Alps, 2450m asl) ground temperatures from a 25m deep borehole near a concrete structure indicate that the permafrost has almost completely thawed since summer 2003. Excavations for and the construction of a specially designed, flexible and adjustable concrete structure for ice-rich terrain (a chair-lift midway station) were carried out in 2003 (Phillips et al. 2007). Subsequently, a supra-permafrost talik and an intra-permafrost talik formed, inducing rapid permafrost melt (Fig. 1b). The influence of hydration heat from the concrete structure was limited by the presence of a layer of insulation but the presence of an open excavation pit during the exceptionally hot summer months in 2003 most likely accelerated the formation of these taliks and modified the local hydrology.

frost melt (Fig. 1b). The influence of hydration heat from the concrete structure was limited by the presence of a layer of insulation but the presence of an open excavation pit during the exceptionally hot summer months in 2003 most likely accelerated the formation of these taliks and modified the local hydrology.

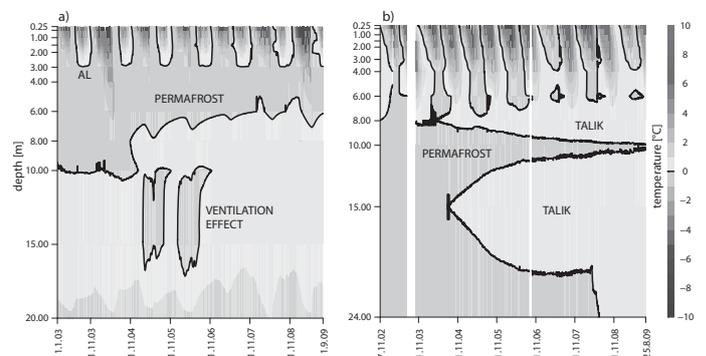


Figure 1a. Ground temperatures measured in a 20 m borehole at Flüela Pass (2003 – 2009), and (Fig 1b) in a 25m borehole at Distelhorn (2002 – 2009). 0°C isotherms are shown (black lines). Permafrost and taliks are labeled.

3 CONCLUSIONS

These examples illustrate that lateral thermal disturbances can cause permafrost to thaw within short periods of time. Non-conductive heat transfer and physical perturbations played an important role in accelerating ground ice melt at both sites. Permafrost degradation can have both natural and artificial causes and the driving mechanisms are not exclusively limited to warming air temperatures and thawing from the surface downwards.

References

- Phillips, M., Ladner, F., Müller, M. Sambeth, U., Sorg, J., Teyssiere, P. 2007. Monitoring and reconstruction of a chairlift midway station in creeping permafrost terrain, Grächen, Swiss Alps. *Cold Regions Science and Technology*, 47, 32-42.
- Phillips M., Zenklusen Mutter E., Kern-Luetschg M., Lehning M., 2009. Rapid degradation of ground ice in a ventilated talus slope: Flüela Pass, Swiss Alps. *Permafrost and Periglacial Processes*, 20, 1-14.

Monday
13:00-15:00

ORAL Parallel Session

Periglacial Processes and Landforms I

Co-chairs: Reynald Delaloye & Isabelle Gaertner-Roer

In Lassegrotta

The Late Holocene History of Peatlands and Permafrost East of Hudson Bay, Canada.

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1 INTRODUCTION

The discontinuous permafrost region east of Hudson Bay contains one of the largest concentration of palsas and lithalsas in the World. Those landforms were heaved as abundant ice segregation formed in the post-glacial marine clays of the Tyrrell Sea (Calmels and Allard, 2008). During past studies, it appeared that palsas are widespread below the treeline while lithalsas and other peat-less mounds are found principally beyond the tree line, in the shrub tundra. A gradient of peat cover denudation exists from below the tree-line where wider peat covers are still present on palsas to beyond the tree line where only minimal peat caps a few square meters in size are scattered here and there on mound tops. Finally, in the context of climate warming, all of these landforms are currently thawing and progressively disappearing. This study aims first as verifying to what extent some lithalsas in the landscape owe their origin to the erosion of the peat cover on palsas. Second, as the minerotrophic peatlands into which palsas formed are biogeographically associated with the forest tundra zone, we wanted to quantify the apparent erosion of peat covers on both sides of the tree line. Finally, through observations, we wanted to assess if there are differences in the disintegration process of peat covered mounds and the non-peat covered mounds and if they leave distinctive relict features in the landscape after their final disappearance.

2 METHODS

We mapped the permafrost, which appears exclusively in mounds, in six test areas 1 X 1.5 km in size and distributed many kilometers apart. Two of the test areas are beyond the tree line, two actually straddle the tree line and two are below it. Mapping was also done of the extent of peat cover on all the mounds in the test areas, as well as of thermokarst hollows and ponds. The mapping was done both on air photographs dating back to 1957 and on Ikonos images purposely acquired in July 2005. In each test area, one core was drilled through the peat cover on a mound down into the ice rich silt. All basal peat samples were radiocarbon-dated to date peat inception and near surface peat samples were also care-

fully cleaned and dated in order to estimate surface drying due to frost heave of the peat and, therefore, the likely date of permafrost inception. All other dates associated with palsas from other studies in the larger region were also compiled from the literature.

3 RESULTS

All over the region, inception of the peatlands started on the poorly drained valley floors between 6975 and 5465 cal. BP. Near surface peat dates indicate that the permafrost formed within three periods, i.e. 2300-1900, 1500-1000 and since 500 cal BP (Little Ice Age). Intact residual caps of peats on eroded mounds have the same thickness (≈ 1.2 m) and age as on fully covered mounds. The map patterns illustrate that peat from one mound to the next belongs to the remnants of a formerly continuous geologic surface layer. Therefore, widespread erosion of the peat cover on the permafrost occurred. This erosion was more intense in the actual shrub tundra zone than in the forest tundra. The total permafrost area in mounds was reduced by 43% since 1957, while the area covered by thermokarst ponds was increased by 65 % and by shrublands by 12%. The peat covered and the non-peat covered mounds currently thaw at the same rate. However, the degradation process generally differs between peat covered mounds which tend to be more affected by the backwasting of steep slopes from the periphery inwards and purely mineral mounds which tend to collapse internally and leave a residual rampart circling a thaw lake. This study generally indicates that the past climatic and morphological evolution of landforms of the "palsa family" in the region exerted a large influence on the actual pattern of spatial distribution of palsas and lithalsas. At the current rate of degradation, the remaining permafrost in the region will disappear in a matter of several decades.

References

- Calmels, C. and Allard, M (2008) *Segregated ice structures in various permafrost landforms through CT Scan*. *Earth Surface Processes and Landforms*, 33: 209-225.

Long-Term Solifluction Response to Increasingly Arid Conditions in Sierra Nevada, Southern Spain

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1 INTRODUCTION

Periglacial research has developed significantly over the last decades with an exponential increase of the studies focused on the past activity of contemporary periglacial landforms. But less effort has been addressed to the understanding of the complex interactions between geomorphological processes in periglacial environments from a Holocene perspective.

We provide a reconstruction of past slope activity in the massif of Sierra Nevada from two sedimentary records situated at the present-day periglacial belt: solifluction lobes and mountain lake sediments.

Sierra Nevada is a high semiarid range in southern Iberian Peninsula with peaks exceeding 3000 m a.s.l. Our study area is located at elevations ranging from 2500 to 3000 m.

2 METHODS

We examined sections from 32 solifluction lobes. Samples were extracted from each lithostratigraphic unit for standard laboratory analyses (texture, organic matter content, iron fractions, X-ray fluorescence). On the other hand, five lakes were sampled and cores were analyzed at 1 cm interval resolution (magnetic susceptibility, texture, organic content, X-ray fluorescence). In total, we performed 25 AMS datings to establish the chronological framework of environmental changes deduced from both records.

3 SEDIMENTARY RECORDS

3.1 Solifluction landforms

Chronostratigraphic studies of present-day weakly active solifluction lobes reveal several periods with enhanced periglacial activity in Sierra Nevada, with an approximate timing of: 5-4, 3.6-3.4, 3-2.8, 2.5-2.3, 1.8-1.6 ka BP, 850-700 and 400-150 a BP.

3.2 Mountain lake sediments

Geochemical and texture properties of lake sediments show evidence of phases with more intense geomorphic activity between 6.2?-6, 5.8-5.6, 5.3-4.6, 3.7-3.1, 2.5-2.2, 1.8-1.6, 1.2-0.9 ka BP and 650-200 a BP (Oliva et al., in press). Moreover, lake sediments record an increasing arid trend in Sierra Nevada starting ca. 4.2 ka BP.

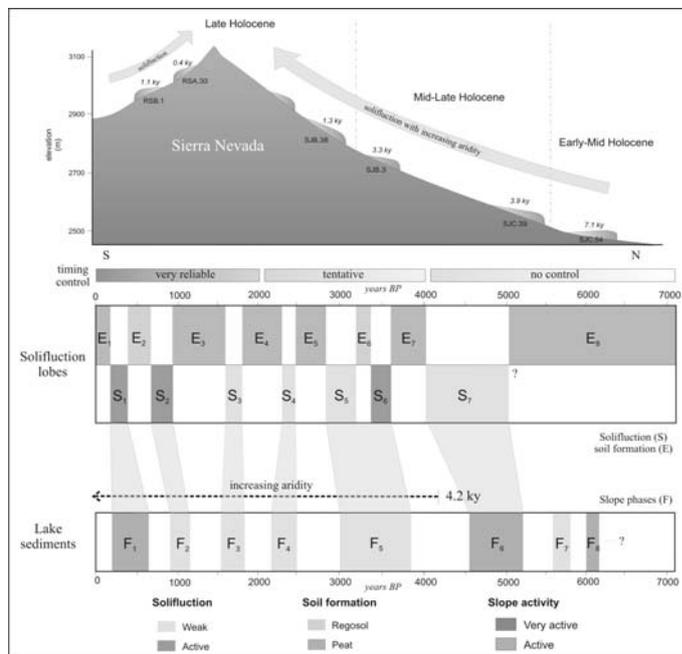


Figure 1. Geomorphic phases inferred from both records and solifluction response to increasingly arid conditions.

4 DISCUSSION AND CONCLUSIONS

A clear synchrony is detected between these two records, especially during the last 2.5 ka BP when chronologies are more precise: periods with enhanced solifluction activity correlate with phases of higher coarse-grained input into the lakes (figure 1). The distribution pattern of solifluction lobes in relation to altitude may also reflect the increasingly aridity trend inferred from lake sediments dominating in Sierra Nevada since the Mid Holocene (Oliva, 2009): solifluction has migrated progressively to higher elevations where more late-lying snow patches remained longer. Therefore, water availability was higher, which is crucial for solifluction movements in Sierra Nevada (Oliva, 2009).

References

- Oliva, M. 2009. Holocene alpine environments in Sierra Nevada (Southern Spain). PhD thesis, University of Barcelona.
- Oliva, M., Gómez Ortiz, A. & Schulte, L. in press. Tendencia a la aridez en Sierra Nevada desde el Holoceno Medio inferida a partir de sedimentos lacustres. Boletín de la Asociación de Geógrafos Españoles, 52.

General Morphometric Description of Solifluction Landforms

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1 INTRODUCTION

The process of solifluction will through time often lead to the development of a variety of landforms. These landforms are in general characterized by a riser which delimits their front and sides. Depending on the plane geometry of this riser, solifluction landforms have been categorized as tongue-shaped, lobe-shaped, terraces or sheets. As noted by Hugenholtz and Lewkowicz (2002), there is a clear lack of knowledge regarding dimensions and shape of solifluction features, and apart from Matsuoka et al. (2005) the process-form relationship remains little studied.

A possible hypothesis regarding the process-form relationship for solifluction landforms would be to regard the landforms an emergent property of the solifluction process, due to spatially distributed differences in the parameters that influence solifluction debris transport rates.

This study will attempt to describe the general shape of solifluction landforms. The purpose is (1) to test if a more precise description of solifluction morphology than the L/W index of Hugenholtz and Lewkowicz (2002) and Matsuoka et al. (2005) provide relevant additional information on solifluction characteristics, (2) to investigate the distribution of dimensional characteristics within a slope and between slopes, (3) to quantify the specific volume of debris that is or has been in transport on a slope and (4) to provide typical envelopes of solifluction dimensions enabling comparison with other areas.

2 METHODS

Our morphometrical measurements utilize the orthophotos and tools available on the freely accessible 'Norgei3D' and 'Norgebilder' internet sites (www.norgei3d.no and www.norgebilder.no). This method allows parameters to be collected in a consistent manner on a substantial selection of solifluction lobes at various locations. We have selected the parameters both to fit earlier studies and so that lobes that are skew in length and/or width can be characterized. The measurements are currently ongoing.

The accuracy of the digital measurements is not as good as for field-based methods. On the other hand, the possibility of quantifying large populations probably more than compensates for these errors. Field measurements on a number of these lobes will be performed to quantify the errors involved. Field areas are selected according to picture quality and the two environmental parameters geology and slope direction.

3 SOLIFLUCTION MORPHOLOGY

Both Hugenholtz and Lewkowicz (2002) and Matsuoka et al. (2005) investigate simple, but typical, lobe-shaped features where width (W) and length (L) of the solifluction tread and height (H) of the riser describe the morphometry. In such cases the L/W ratio distinguishes tongue-shaped forms ($L/W \geq 1$) from lobate forms ($L/W < 1$). In many cases, however, solifluction morphometry is significantly more complex. Hugenholtz and Lewkowicz (2002) consequently avoided complex lobes in their study to maintain consistency in field measurements. Our field areas include slopes on which lobes appear to be systematically skew. Quantifying such characteristics may uncover possible external controls on solifluction, such as wind transport. One area also shows lobes that seem to have disproportionately high frontal risers. If typical envelopes of solifluction dimensions or dimensional relations can be established, solifluction-like landforms outside these envelopes could be related to other processes, such as permafrost creep.

References

- Hugenholtz, C.H and Lewkowicz, A.G. 2002. Morphometry and Environmental Characteristics of Turf-Banked Solifluction Lobes, Kluane Range, Yukon Territory, Canada. *Permafrost and Periglacial Processes* 13: 301- 313.
- Matsuoka, N., Ikeda, A. and Date, T. 2005. Morphometric Analysis of Solifluction Lobes and Rock Glaciers in the Swiss Alps. *Permafrost and Periglacial Processes* 16: 99 - 113.

Geodiversity across Elevation Gradient in Subarctic Landscape, Northern Finland

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1 INTRODUCTION

Geodiversity (i.e. variability of abiotic nature) is a new, emerging topic in earth science. There is now increased awareness of our need to understand patterns of geodiversity in different high-latitude landscapes facing global change. In periglacial regions, there is a high risk of losing geodiversity with a warmer climate (e.g. Hjort and Luoto, 2009). Even though many have acknowledged the importance of geodiversity, studies that have explored the determinants of geodiversity are still largely lacking, particularly for polar and alpine landscapes (Hjort and Luoto, 2010). The aim of our study was: (1) to map geodiversity in a subarctic landscape; (2) to describe the variation of geodiversity across elevation gradient [490–1030 m above sea level (a.s.l.)]; and to (3) explore the relationship between geodiversity and periglacial process activity.

2 MATERIAL AND METHODS

The study area is located in Kilpisjärvi, NW Finnish Lapland (ca. 69°N, 20°50'E). The mean annual air temperature was -2.3 °C, and the mean annual precipitation was 459 mm (Kilpisjärvi Meteorological Station; 480 m a.s.l.; 1971–2000). The tree line occurs at ca. 600–650 m a.s.l. and discontinuous permafrost is present above 700–750 m a.s.l.

The elements of geodiversity and periglacial activity (% cover) were mapped applying the systems of Hjort and Luoto (2009, 2010) in August 2009. As a spatial study design, we used a grid system at a mesoscale (100 x 100 m, $n = 166$). The mesoscale approach was chosen based on the size range of the detectable elements of geodiversity. We used a correlation analysis (Spearman's rank order correlation, R_s) to explore the relationship between the variables.

3 RESULTS

A total of 53 different types of elements of geodiversity were mapped in the study area. The R_s between geodiversity (total number of different elements per grid) and elevation (0.53, $p < 0.001$) and periglacial activity (0.55, $p < 0.001$) were positive and moderately strong. It should be noted that the relationships were nonlinear with a leveling off effect (Fig. 1).

Geodiversity increased from the zone of subarctic forests to the alpine zone characterized by permafrost conditions. However, the rate of change decreased at the higher elevations. Moreover, the results indicated that the increasing process activity does not necessarily mean increasing geodiversity.

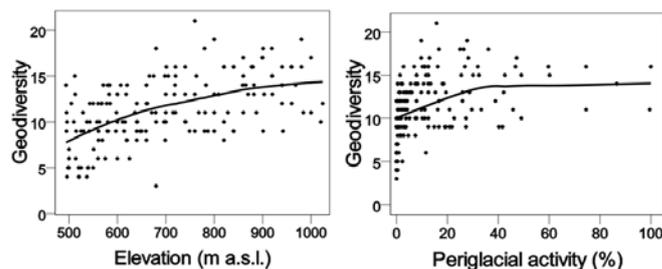


Figure 1. Relationship between geodiversity (total number of elements per grid) and elevation (m a.s.l.) and periglacial process activity (% cover). The curves were derived using Loess smoothing technique due to the nonlinear nature of the relationships (cf. Hjort and Luoto, 2009).

4 CONCLUSIONS

Our results revealed highly interesting linkages between geodiversity and elevation as well as between geodiversity and periglacial process activity in subarctic landscape. To deepen the theoretical knowledge of abiotic nature, studies scrutinizing the geodiversity-environment relationships are urgently needed. The exploration of geodiversity-landscape linkage may open new insights into the landscape development in geomorphology. Thus, we recommend that further studies focus on: (1) quantifying spatial patterns of geodiversity in different regions and (2) determining the key drivers that control the variability of abiotic nature. Moreover, the mapping of geodiversity may be indicative not only in the context of earth science, but also provide a focus for conservation initiatives and biodiversity assessments.

References

- Hjort J, Luoto M 2009. Interaction of geomorphic and ecologic features across altitudinal zones in a subarctic landscape. *Geomorphology* 112: 324–333.
- Hjort J, Luoto M 2010. Geodiversity of high-latitude landscapes in northern Finland. *Geomorphology* 115: 109–116.

Transferability of Statistical Models in Geomorphological Mapping

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1 INTRODUCTION

Currently, spatial models, which relate occurrences of periglacial landforms and processes with environmental conditions, are increasingly used in geomorphology. Among other applications, models can offer new insights into investigate the distribution of geomorphological features and provide scientists with valuable maps of periglacial landscapes. In geomorphology, numerous areas have a lack of data, and such predictive maps can be used to fill these shortcomings in order to create more complete datasets. For such applications, transferable models are needed. Many different modelling algorithms are available and several recent studies have shown that derived models have unequal predictive performance (e.g. Marmion et al. 2008). However, to the best of our knowledge, no one of these studies has thoroughly tested the spatial transferability of different models. Here, we attend to fill this lack by comparing the spatial transferability of geomorphological models based on five representative modelling techniques, following in one hand an interpolative study design and on another hand an extrapolative study design.

2 MATERIAL AND METHODS

Based on a calibration dataset, the spatial distribution of sorted circles, solifluction lobes and ice wedges was related with seven environmental variables in North-Western Spitzbergen at a 100 x 100 m spatial resolution. Models were based on two machine learning methods [Artificial Neural Networks (ANN) and Random Forest (RF)], two regression methods [Generalized Additive models (GAM) and Generalized Linear Models (GLM)] and an information theory based technique (Maxent). Once build, models were then transferred to two evaluation datasets which were spatially mixed and independent from the calibration dataset. The predictive accuracy of the models was evaluated on each dataset by Area Under the receiver operating Curve (AUC) values. Besides, a transferability index derived from AUC values (i.e. AUC_{extra}/AUC_{inter}) was computed.

3 RESULTS

On average, models interpolated better the distribution of the landforms than they extrapolated it (Table 1). Mean AUC values based on the interpolative dataset ranged from 0.776 (GLM) to 0.877 (ANN), whereas based on the extrapolative datasets these values varied from 0.627 (GLM) to 0.718 (RF). According to mean transferability indices, models based on Maxent and GLM transferred the most equally on both evaluation areas, whereas ANN and GAM produced models with the highest transference asymmetry.

Table 1. Mean transferability index and AUC values based on the interpolative and extrapolative evaluation datasets of the five modelling techniques.

models	AUC _{int}	AUC _{extra}	Transferability
ANN	0.877	0.659	0.753
GAM	0.844	0.636	0.762
GLM	0.776	0.627	0.852
RF	0.862	0.718	0.838
Maxent	0.798	0.686	0.873

4 CONCLUSIONS

Results obtained in this study underline that models based on different algorithm may have unequal predictive performance, which makes echo to the work presented by Marmion et al. (2008). Predictive modelling in geomorphology can help scientists to map poorly surveyed areas, however, our results shows that depending on the study design, some modelling algorithms are more appropriate than others. In the context of global change, transferrable models are needed, and our results encourage the utilization of predictive mapping in geomorphological hazard assessment.

Reference:

Marmion, M, Hjort, J, Thuiller, W & Luoto, M 2008. A comparison of predictive methods in modelling the distribution of periglacial landforms in Finnish Lapland. *Earth Surface Processes and Landforms* 33: 2241 - 2254.

Classification of Lakes in Pan-Arctic Permafrost Regions

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1 INTRODUCTION

Arctic thermokarst lakes tap the large carbon pool in permafrost sediments and release carbon into the atmosphere as methane, a potent greenhouse gas. Hence, thermokarst lakes are an important component of the northern carbon cycle, with potential global implications for climate (Walter et al., 2007). A major research question now is how current and future warming of the Arctic impacts permafrost stability, thermokarst lake dynamics, and methane emissions from thermokarst lakes.

In a first step towards quantifying a more accurate thermokarst lake carbon budget, a classification of lakes in permafrost regions needs to be achieved that allows characterization of lakes and their potential for methane emissions.

2 METHODS

A desktop Geographic Information System (GIS) was used to extract lake polygons from the Global Lake and Wetland Database (GLWD) (Lehner & Döll, 2004) falling into the permafrost boundaries as defined by the IPA permafrost map. We manually corrected the resulting lake dataset by removing non-lake features such as lagoons and river segments. Centroids from lakes >10ha were then used to populate feature attribute tables by extracting additional information from other datasets: permafrost type, ice content and sediment cover thickness from the IPA permafrost map; Land surface elevation from the Etopo dataset; Late Pleistocene glaciation extent from global datasets on Quaternary glaciations; Soil carbon content from the circumarctic soilmap; climate parameters from various sources; and near future permafrost characteristics as predicted with spatially distributed numerical permafrost models. The lake dataset was then analyzed using GIS-based tools for spatial data analysis.

3 RESULTS

About 155,000 lakes >10ha occur in Pan-Arctic permafrost regions based on the GLWD (ca. 63% of

global lake population). Their lake area amounts to about 690,000 km², excluding extremely large outliers such as Lake Baikal or Great Bear Lake. In general, lakes are concentrated in continuous permafrost regions with thick ice-rich sediments. About 86,000 lakes (330,000 km²) were found in such regions. A vast majority of these lakes are found in elevations <50 m asl. Core regions of occurrence are the Yamal Peninsula, the Khatanga and Anabar river lowlands, Lena river valley and delta, the Yana-Indigirka-Kolyma river lowlands, the Alaska North Slope, the northern Seward Peninsula, the lower Kobuk river lowland, northern Yukon and Northwest Territories, and parts of Baffin Island.

4 DISCUSSION

GLWD used in this study only allows for a first-order assessment of lakes types, i.e. for thermokarst regions. A comparison of detailed water body datasets in 3 thermokarst lake regions of North Siberia with the GLWD reveals that the limnicity in thermokarst lake regions is reduced in GLWD by up to 6.5% for lakes >10ha. Lake area (incl. lakes <10ha) not inventoried in GLWD accounted for 21.6 to 82.2% of the total lake area in the study regions. Global lake datasets derived from remote sensing data currently under processing will be highly useful to refine this classification and reduce uncertainties.

5 CONCLUSIONS

Detailed lake characterization in Pan-Arctic permafrost regions will help assessing carbon cycling in permafrost regions, i.e. as related to thermokarst lake dynamics.

References

- Walter, K.M., Edwards, M.E., Grosse, G., Zimov, S.A. & Chapin, F.S., III. 2007. Thermokarst lakes as a source of atmospheric CH₄ during the last deglaciation. *Science* 318: 633-636.
- Lehner, B. & Döll, P. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. *Journal of Hydrology* 296: 1-22.

Characteristics of a High Arctic Snow Avalanche Climate in 2006-2009 – Central Spitsbergen, Svalbard

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1 MOTIVATION & PURPOSE

In this study, systematic observational snow avalanche, meteorological and snow pack data from a small High Arctic mountain area during a 3 year period is analyzed, to characterize the properties of a High Arctic snow avalanche climate in Svalbard. The data was collected during the Cryoslope Svalbard project (2006-2009, funded by the Norwegian Research Councils Norklima program 2006-2009), building the basis of a geographical analysis (timing, location, extent) of the snow avalanche activity around Svalbard's main settlement Longyearbyen, marking the first attempt of such a detailed analysis in the High Arctic. A main focus lies also on the influence of the underlying continuous permafrost on the snow stability. We also quantified the sedimentation rates of dirty spring snow avalanches to analyze the geomorphologic impact of snow avalanches.

2 STUDY AREA

The High Arctic study area is located around Longyearbyen, in central Spitsbergen at about 78° N. Infrastructure and traffic takes place in a mountainous landscape affected by periglacial slope processes, especially snow avalanches. Plateau shaped mountains dominate with no high vegetation, thus wind plays a major role in redistributing snow. Mean annual precipitation at sea level is around 200 mm, mostly solid precipitation.

3 METHODS

Geographical, meteorological and snowpack observations were carried out along a 70 km long snowmobile track in the study area, resulting in 137 fieldwork days over 3 years. All observations were recorded in the field and stored in a database.

4 RESULTS

731 avalanches were recorded in the 3 years, 423 avalanches further analyzed. Cornice fall avalanches were most observed with almost 50 % of the total. Most avalanches released in the sector WSW-NWN

and over 40 % stopped at a slope inclination between 21-30°.

109 snow pits were dug in 3 years with an average snow depth of 130 cm. Snow pack temperatures reached -20 °C in the coldest periods. Most common grain type was mixed forms, followed by depth hoar

and ice masses. The snow pack in general was rather hard, with weak layers inside.

Rock debris was weighted in dirty spring snow avalanches. Up to 45 kg per m² of sediments were eroded and accumulated on the avalanche fans.



Figure 1. Study area around Longyearbyen with all snow avalanches observed in the 3 years.

5 DISCUSSION

Southeasterly prevailing winter winds over the plateau mountains significantly redistribute the snow, building cornices on the crests, resulting in many cornice falls. Slab avalanches as the second major avalanche type released due to the occurrence of weak layers, mainly depth hoar, resulting in 8 large avalanche cycles in 3 years. Over 50 % of all slabs were triggered after a snow storm with threshold values of 8 m/s wind velocity and 20 cm snow precipitation per day. Avalanche activity increased towards the end of all three snow season, as temperatures and direct solar radiation increased. The snow pack around Longyearbyen is a thin and cold snow pack, with a persistent structural weakness, and a significant amount of ice layers. It represents an early season snow pack with a weak base that forms due to the temperature gradient between the permafrost and the atmosphere.

Snow avalanches have a significant geomorphologic impact in the study area originating avalanche fans.

A Regional Inventory of Glacial and Periglacial Landforms Indicating Alpine Permafrost in Norway

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Department of Geosciences, University of Oslo, Norway

1 INTRODUCTION

1.1 *Scope*

An inventory of permafrost-related landforms in Norway was compiled using pre-existing maps, aerial photos and field observations. Such a systematic inventory does not exist for Norway, and is needed e.g. as an independent validation of numerical permafrost distribution models. In this presentation, the inventory was used for statistical purposes to examine possible relationships between landforms, climate and topography.

1.2 *Methods*

The landforms were divided into two major groups; landforms of southern and northern Norway, and internally divided into either 'active/inactive', or 'fossil' landforms. These groups were further classified, sorted by shape (lobate or tongue-shaped), or landform origin (ice-cored moraines, talus-derived rock glaciers, and moraine-derived intermediate landforms). Statistical *t*-tests were applied to examine class-dependent trends in parameters such as area, mean annual air temperature (MAAT), elevation and aspect.

By combining gridded maps of MAATs (© met.no) and DEMs (© Norwegian Mapping Authorities), a down-scaling algorithm was developed, and MAAT was included in the further analyses.

2 RESULTS AND DISCUSSION

2.1 *Activity and origin*

In northern Norway, most of the mapped landforms are fossil (155 of 215), while in southern Norway, there is a slight overweight of active/inactive landforms (42 of 73), as a result of higher concentration of ice-cored moraines. Also, the majority of the landforms in northern Norway are talus landforms, which are mainly fossil features.

All together, there are only a few active talus-derived rock glaciers in Norway today, while the intermediate moraine-related landforms show a higher degree of activity. Also, all the landforms in south-

ern Norway are situated inside the traditional interpretation of the Younger Dryas glaciation limit, while the landforms in northern Norway are mainly situated outside the YD limit, but inside the limit of the assumed Weichsel maximum.

The concentration of fossil talus-derived landforms in northern Norway can be interpreted to reflect a former dry, periglacial climate that favored their formation, while no areas today are favorable for the development of these landforms. The intermediate moraine-derived landforms and ice-cored moraines then reflect a more modern climate where glaciers and permafrost co-exist, and at one point during the Holocene, the dominating process creating permafrost landforms must have changed.

2.2 *Aspects, temperatures and permafrost limits*

The active landforms in southern Norway are to a much higher degree dependent on aspects than the fossil, and show a preferred direction towards north (18°). In northern Norway, the fossil landforms are also depending on aspect, and have a preferred orientation towards NW (301°), while the active landforms have shifted slightly towards north (325°).

The mean MAAT of the active permafrost landforms for southern and northern Norway are -4.4 and -1.3 °C, respectively, and the fossil -1.3 and 1.5 °C.

Based on the presence of landforms, the lower limit of permafrost in southern Norway is close to 1600 m a.s.l., and sporadic permafrost down to 12-1500 m a.s.l. depending on aspect. Corresponding values for northern Norway are 650 and 350 m a.s.l. These results correspond well to previous studies.

3 CONCLUSIONS

Permafrost-related landforms in southern Norway are mainly ice-cored moraines and intermediate, moraine-derived landforms, connected to present glacial activity. In northern Norway, the majority of the landforms are fossil talus rock glaciers, related to a different thermal regime than present. The inventory of active landforms indicates a lower limit of mountain permafrost distribution, which largely corresponds to previous studies.

Time	Monday, June 14
15:15 – 17:00	<p>POSTER SESSIONS</p> <p># 1-24 in UNIS Entrance</p> <p># 25-45 in Kapp Lee</p> <p># 46-67 in Kapp Schultz</p> <p># 68-83 in Templet</p> <p># 84-99 in Festningen</p>
18:00 – 19:00	<p>OPEN PUBLIC LECTURE</p> <p><i>in Møysalen and video streamed to Lassegrotta</i></p> <p>“The Unintended Research Legacy of John Munro Longyear” Frederick E. Nelson University of Delaware</p>
19:00 – 21:00	PYRN SOCIAL EVENT <i>in UNIS Canteen</i>
19:00 – 21:00	IPA COUNCIL MEETING <i>in Kapp Mitra</i>

Posters Monday

Periglacial Processes and Landforms:

in UNIS Entrance Hall

1. **Correlation between Process of Frost Heave and Climatic Factors**
D. Ablyazina, G.Yampolskiy
2. **A Provisional Method for Assessing the Impact on, and Recovery of, Antarctic Desert Pavements from Human-Induced Disturbances**
T.A. O'Neill, M.R. Balks, J. López-Martínez
3. **Recent (2004-2010) Variations of Surface Displacements in an Andean Permafrost-Glacier Environment (Chile, 33° S.)**
X. Bodin, G. F. Azócar, A. Brenning
4. **Active Layer Processes on a Solifluction Slope at Endalen, Svalbard**
C. Harris, M. Kern-Luetschg, H.H. Christiansen, F. Smith
5. **New Rock Glaciers Inventory of Aosta Valley, Italy**
M. Curtaz, M. Vagliasindi, U. Morra di Cella, P. Pogliotti, S. Letey
6. **Laser Scanning of a Small Patterned Ground System,**
R.P. Daanen, W. Cable, G. Grosse, D.A. Walker, V.E. Romanovsky
7. **Hydrochemical Response of a Polar Glacier Facing the Recent Climate Changes (Austrelovenbre, Svalbard, 79°N)**
E. Delangle, C. Marlin, M. Griselin, D. Laffly, E. Bernard, J.M. Friedt
8. **Slope Morphodynamics in Periglacial Environments: Data from Physical Modelling**
M. Font, E. Védie, J.-L. Lagarde
9. **Snow-Push Activity at a Seasonal Snowpatch Site, Sierra De Ancares, Northwestern Spain**
P. Carrera-Gómez, M. Valcárcel-Díaz, R. Blanco-Chao
10. **Spatial Distribution of Pingos in Northern Eurasia**
G. Grosse, B. Jones
11. **Formation and Dynamics of Holocene Syngenetic Ice-Wedge Polygons in Adventdalen, Svalbard**
S. Härtel, H.H. Christiansen
12. **High-Resolution Digital Elevation Models (DEM) and Orthoimages of Permafrost Landforms in Svalbard (Norway) from HRSC-AX Data**
E. Hauber, F. Preusker, F. Trauthan, R. Jaumann, D. Reiss, M. Zanetti, H. Hiesinger, M. Ulrich
13. **Sediment Quantification and Ground Water Storage in an Alpine Permafrost Catchment**
H. Hausmann, E. Brückl, R. Illnar, S. Eipeldauer, K. Krainer, G. Blöschl, J. Komma, G. B. Chirico
14. **Permafrost and Karst Landscapes Development in Mezenskaja Tundra (Archangelsk Area, Russia)**
S.A. Iglovsky

Posters Monday, cont.

15. **Possible Freeze/Thaw Landforms on Martian Slopes: Using Svalbard Advent Valley as an Analogue to Mars**
A. Johnsson, L. Johansson, M. Zanetti, D. Reiss, E. Hauber, M. Ulrich, H. Hiesinger, M. Olvmo, E. Carlsson, H.A.L. Johansson
16. **The Project ANAPOLIS: Analysis of Polygonal Terrains on Mars Based on Earth Analogues**
P. Pina, J. Saraiva, L. Bandeira, C. Lira, N. Benavente, G. Vieira, C. Mora, M. Neves, M. Oliva, M. Jorge, A. Ferreira, H. Christiansen
17. **State and Evolution of the Bérard Rock Glacier (Southern French Alps) after Its Collapse in 2006: Insights from Geophysical, Geodetic and Thermal Datasets**
J.M. Krysiecki, O. Leroux, X. Bodin, P. Schoeneich
18. **Stratigraphy of an Ice Wedge Cast on the Northern Seward Peninsula, Alaska, and Implications for Paleo-Thermokarst Lake Development**
M. LaDouceur, G. Grosse
19. **Kinematics and Morphological Characteristics of a Destabilized Rock Glacier, Swiss Alps**
C. Lambiel
20. **Future Glaciations and the Challenges Related to Long Time Management of Nuclear Waste: Greenland Analogue Project**
A. Lehtinen, L. Claesson Liljedahl, J-O. Näslund, T. Ruskeenieni
21. **A New Method to Monitor Solifluction on Permafrost Slopes Using Magnetic Targets, Svalbard, Norway**
A.G. Lewkowicz, H.H. Christiansen
22. **Integrating Ice Sheet, Bedrock and Surface Systems in a Periglacial Environment by Modeling Water and Chemical Fluxes**
T. Lindborg, J. O. Näslund, S. Berglund
23. **Thermal and Dynamic Characteristics of the Small Valley-Side Huset Rock Glacier in Longyeardalen, Svalbard**
N. Matsuoka, A. Ikeda, T. Watanabe, O. Humlum, H.H. Christiansen, H. Juliussen
24. **A Historical Approach to Solifluction in the Longyearbyen Area**
J. R. Mertes, H.H. Christiansen, M. Sigurðardóttir

Periglacial Processes and Landforms:

in Kapp Lee

25. **Thermokarst in Siberian Ice-Rich Permafrost – Characteristics and Potential Evolution**
A. Morgenstern, F. Guenther, L. Schirrmeister
26. **Periglacial Investigations in Louise Arner Boyd’s American Geographical Society Expeditions to East Greenland, 1933 and 1937**
F.E. Nelson, S.M. Peschel

Posters Monday, cont.

27. **“A Characteristic Periglacial Landscape”**: Cryoplanation Landforms of Beringian Uplands
F.E. Nelson, A. Campbell
28. **Hiorthfjellet Rock Glacier – towards an Understanding of Geomorphology**
R. S. Ødegård, K. Isaksen, T. Eiken, J. L. Sollid
29. **Holocene Solifluction Processes in a Mediterranean Mountain Environment (Sierra Nevada, Spain)**
M. Oliva, A. Gómez Ortiz
30. **Stratified Slope Deposits in Cold Maritime Environments in the Mountains of Tierra Del Fuego (Argentina)**
A. Perez Alberti, J. Lopez Bedoya, P.P. Cunha
31. **Rock Glacier Kinematics in the Central and Southern Swiss Alps**
G. Ramelli, S. Mari, C. Scapozza, D. Abbet, R. Delaloye, C. Lambiel
32. **Annual Ring Studies on Plants in Permafrost Areas of the High Arctic**
F.H. Schweingruber, H.H. Rump
33. **Stone Fields and Patterned Ground Development on Platforms in Elephant Island, Maritime Antarctica**
E. Serrano, J. López-Martínez, A. Navas
34. **Protalus Lobe Dynamic on Pyrenean High Mountain**
E. Serrano, J.J. Sanjosé, M. Del Río, M. González-García, J.J. González-Trueba, R. Martín-Moreno
35. **Frost Mounds Morphodynamic in Marginal High Mountain (Picos De Europa, NW Spain): a Geomorphological and Environmental Approach**
J.J. González-Trueba, E. Serrano, J.J. Sanjosé, M. Del Río
36. **Glacially-Derived Permafrost**
Y. Shur, T. Jorgenson, M. Kanevskiy
37. **Glacial and Periglacial Modification of Impact Craters in Utopia Planitia, Northern Plains of Mars**
G. Pearce, G. R. Osinski, R. Soare, L. Thomson
38. **Assessing the Impacts of the Hydrological Drainage Networks upon the Characteristics of Permafrost in the Upper Kuparuk Region**
E.D. Trochim, A. Prakash, D.L. Kane
39. **Geomorphometric Analysis of Patterned Ground on Svalbard from High Resolution Stereo Camera (HRSC-AX) Data: Analogue Studies for Mars**
M. Ulrich, L. Schirrmeister, E. Hauber, D. Reiss, M. Zanetti, H. Hiesinger
40. **Consequences on Groundwater Discharge Pattern in a Permafrost Region due to Continental Ice Sheet**
P. Vidstrand, S. Follin
41. **Mud-Boil Dynamics in Adventdalen, Svalbard: High-Resolution Monitoring of Frost Heave and Active Layer Dynamics**
T. Watanabe, N. Matsuoka, H.H. Christiansen

Correlation Between Process of Frost Heave and Climatic Factors

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Changes of air temperature meaning are closely interconnected with distribution of permafrost. The frosts heave process in spite of the widespread distribution is most dangerous in areas of borders of permafrost distribution..

State estimation of permafrost condition according to data from meteorological stations haven't show direct correlation, but allows capturing data bulk from meteorological stations, rather than from geocryological stations. Connection between climatic factor and geographical distribution of permafrost was supposed in the beginning of XX-th century. We used permafrost coefficient A.A. Grigoriev who assumed that neither the average annual temperature, nor average temperature of three winter months in itself are not factors which could be direct correlated and functional communicated with permafrost development.

When we used the given coefficient we were remember: 1) that it does not consider geological conditions of character of the geothermal gradient, which in other cases, for example at presence juvenile waters, can strongly change all picture; 2) that it does not consider degree of heat conductivity of rocks and a vegetative cover; the last is especially essential, if the vegetative cover consists of the sphagnum; 3) that it does not consider microhydrological (bogging) conditions. Each of these local factors could change picture of climatic factors influence and consequently should be considered for each point especially [Grigoriev, 1930]. In 1930 this coefficient has been calculated for 114 meteorological stations, in our work it was recalculated for the period since 1930 to 2004 (fig.1).

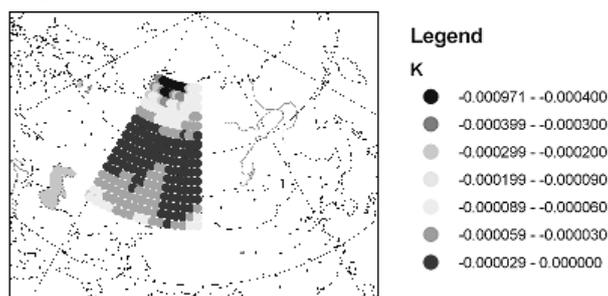


Figure 1. Permafrost coefficient for the West Siberia

In the calculation formula were used the basic climatic parameters which, according to researchers, show the greatest impact on process, the formula does not include only interrelation with soils. The results of calculation for CALM points have shown that the direct correlated between climatic parameters and value of seasonal variation changing of day surface level of is absent. The permafrost coefficient belatedly responds to the climatic variation, but we couldn't categorically point on non effect from climate because frost heave is highly "scaling" process.

When we using regional type we could include global climate parameters for general assessment, for specification and data qualification the scale is enlarge and microclimate conditions make a figure. Nonetheless this permafrost coefficient could guide for appraisal of potential frost heave and pointed to frost heave value

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References

Grigoriev A.A. 1930 Vechnaya merzlota. Leningrad: Academy of science.

A Provisional Method for Assessing the Impact on, and Recovery of, Antarctic Desert Pavements from Human-Induced Disturbances

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1 INTRODUCTION

A set of criteria were developed to quantify the relative stage of desert pavement recovery in the Ross Sea region of Antarctica. The desert pavement recovery assessment system was formulated based around a number of distinguishing morphological features that change over time as the pavement re-establishes and stabilises. Features included clast characteristics, such as embeddedness, impressions and attributes to describe clast characteristics (e.g. ventifacted, pitted); surface colour contrast; degree of deflation; varnish; pavement crust coherence and thickness; nature of pavement armour (packing and % of surface armoured); presence of salt coatings on rock undersides, as well as general surface stability (e.g. evidence of subsidence, melt, recent disturbance, and concentrations of salt).

2 METHODS

Twenty-eight sites across a range of soil landscape units were investigated. Sites included areas disturbed by activities such as bulldozer scraping for road-fill, contoured for infrastructure, geotechnical and treading trial experimental sites; disturbed at timescales ranging from one week to 50 years prior to assessment. A relative % recovery for each parameter was calculated for each site - based on the deviation of that parameter relative to a control or undisturbed equivalent surface. An overall Mean Recovery Index (MRI) was then assigned to each pavement surface, and is expressed as pavement Rehabilitative Stage (RS) one through five (Table 1).

Table 1. Mean Recovery Index (MRI)

MRI (%)	RS	Description
0	1	Newly disturbed
25	2	Incipient pavement
50	3	Intermediate recovery
75	4	Advanced recovery
100	5	Indistinguishable from undisturbed site

3 RESULTS AND DISCUSSION

The rate of desert pavement recovery is a function of the level of disturbance (low level footprints versus high level bulldozer cut surfaces) and the environmental conditions of the site. Table 2 highlights some of the sites investigated.

Table 2. Mean Recovery Index (MRI) and Rehabilitative Stage (RS) of selected Ross Sea Region sites

Site Description	Time since Disturbance	MRI (%)	RS
K123 04/05 campsite [#]	5 years	100	5
Cape Roberts ice-free storage	9 years	100	5
Former Greenpeace base [^]	10 years	100	5
Former Vanda Station court [#]	15 years	91	5
Vanda Fan treading trial [#]	17 years	67	3
Bulldozed track [*]	>30 years	52	3

[#] Wright Valley, McMurdo Dry Valleys; [^] Cape Evans, Ross Island; ^{*}Marble Point

Highly active surfaces, such as the Greenpeace World Park Base site at Cape Evans, recovered relatively quickly as wind, water, and wave action provided the necessary energy to regenerate pavement surfaces. Alternatively in less active sites such as the bulldozer tracks at Marble Point our recovery assessment shows only intermediate recovery 30 years post-disturbance. Desert pavements disturbed by randomly dispersed footprints, such as the K123 2004/2005 campsite, recover to be undetectable within five years. Raking to re-contour tracked areas, such as the ice-free storage area at Cape Roberts, led to full recovery of the desert pavement within 10 years. Site remediation, such as raking larger clasts from outer track margins; widespread trampling over confined traffic; and concentrating activity to more resilient active environments where recovery is aided by wind, water action, and freeze-thaw cycles, will assist pavement recovery.

Recent (2004-2010) Variations of Surface Displacements in an Andean Permafrost-Glacier Environment (Chile, 33° S.)

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1 INTRODUCTION

In the semi dry central Andes (Chile, 33° S.), glaciers, debris-covered glaciers and rock glaciers constitute the three main components of the cryosphere (except snow). Recent studies in the Laguna Negra area (Bodin *et al.*, acc.) have shown, for the last 50 years, a shrinkage of uncovered glacier leading to an extension of debris-covered glacier area, frequently associated to thermokarst development.

This work intends to present the main results of a 6-year GPS monitoring (measurements in Apr. 2004, Apr. 2009, Apr. 2010) of the annual ground surface displacement of a debris rock glacier and a debris-covered glacier and a 2-years GPS monitoring (measurements in Dec. 2008, Apr. 2009, Jan. 2010 and Apr. 2010) of seasonal surface displacement of a talus rock glacier.

2 INTRA- AND INTERANNUAL KINEMATICS OF A TALUS ROCK GLACIER (2008-2010)

The horizontal surface velocities measured on Punta Negra Bajo rock glacier range from 0.13 to 0.58 m/y, whereas the mean vertical displacement is -0.08 m/y (sd = 0.03).

The part of the austral summer component (from Dec. 2008 to Apr. 2009) in the total oblique displacement reaches on average 27-31% which, reported to a daily basis (taking account of the duration of the two measurement periods) yields 2 to 5 times more movement during austral winter (from Apr. 2009 to Jan. 2010) period.

Furthermore, it appears that on average the ratio between vertical and horizontal movement is 4.7 at an annual timescale but reaches 9 during summer (and 4.4 during winter).

3 INTERANNUAL KINEMATICS OF A DEBRIS ROCK GLACIER AND A DEBRIS-COVERED GLACIER (2004-2010)

The mean horizontal surface velocity on the debris rock glacier (lines A, B and C) of the Punta Negra Alto complex between (Fig. 1) April 2004 and April 2009 reached 0.32 m/y and the mean vertical displacements -0.07 m/y. On the same period, the de-

bris-covered glacier (line D) shows slightly higher horizontal velocities (0.48 m/y) but a clearly distinct vertical component (-0.16 m/y).

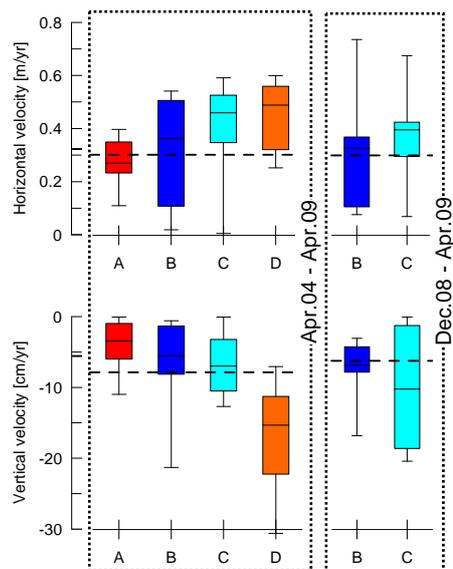


Figure 1. Box-and-whisker plot of the vertical and horizontal displacements (left box: annual; right: summer) of the ground on the 4 transverse lines of Punta Negra Alto complex.

4 DISCUSSION

The high vertical velocities recorded on the debris-covered glacier are most probably related to the melting of the quasi-stagnant glacier ice covered by a thin debris mantle, as attested by the presence of numerous thermokarsts.

The talus rock glacier combines winter horizontal velocity 1.1 times higher compared to summer with comparatively 1.5 times higher vertical velocity. Although the limited number of measurement dates impedes to have a good temporal resolution, such high vertical component in the total movement of the rock glacier might be due to a delayed thermal propagation of the summer heat wave associated to fusion of the ice-rich permafrost.

Reference

Bodin, X., Rojas, F. & Brenning, A. accepted. State and recent evolution of the cryosphere in the Andes of Santiago (Chile, 33.5°S). *Geomorphology*, accepted.

Active Layer Processes on a Solifluction Slope at Endalen, Svalbard

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1 INTRODUCTION

Here we present a continuous record over the period 2005-8 of active layer processes at Endalen, Svalbard, (78° 11' N, 15° 44' E), a tributary valley of Adventdalen, some 4 km SE of Longyearbyen. The monitoring station lies on a widespread gently concave lower valley side slope of gradient around 7°, at an elevation of 75m a.s.l. (Harris et al. 2007). The mean annual air temperature at Svalbard Airport, Longyearbyen (approximately 8 km from the study site), is -6.8°C (1961-90), and mean annual precipitation is 190mm. However, the last decade, including the period of field monitoring reported here, has been characterised by higher temperatures than the long-term average. Drilling has proved an ice-rich transient zone extending at least 1 m below the active layer base into the upper permafrost.

2 RESULTS

2.1 Active layer freezing and thawing

Annual variations in active layer temperatures were associated with warmer than average air temperatures in 2005-6, and prolonged duration of thicker than average snow in 2007-8. Active layer depth was slightly less than 1m in 2005, but thaw penetration increased this by around 100 mm over the three year period, most of the increase occurring in summer 2006. Frost heave was 42 mm in 2005-6, 66 mm in 2006-7 and 32 mm in 2007-8, but thaw settlement exceeded frost heave in each year, giving a net ground surface lowering of 62 mm (Fig. 1). Time series data of thaw settlement and ground temperature indicate that segregation ice was concentrated in the uppermost 30 cm and towards the base of the active layer, leaving the central parts relatively ice-poor. Positive pore pressures were recorded during thaw settlement in the ice-rich zones and in 2006, thawing of the ice-rich transient zone was associated with artesian pore pressures at 90 cm depth.

2.2 Solifluction

Solifluction occurred during thaw settlement, and resulted in downslope surface displacements of 25

mm in 2005-6, 12 mm in 2006-7 and 12 mm in 2007-8. Time series of movement and thaw penetration allowed the distribution of shear strain to be calculated and synthetic profiles of movement to be constructed. In 2006, shearing occurred both in the uppermost 30 cm of soil, and in the basal 10 cm, the latter associated with the high pore pressures recorded during rapid active layer deepening. However in 2007, with no active layer deepening, only near-surface solifluction was observed. In 2008, shear strain once again occurred both in the near-surface and at the base.

3 CONCLUSION

Annual variations in active layer thermal regime, frost heave, thaw settlement, pore pressure and resulting solifluction reflected yearly air temperature and snow depth variations. It is hoped that long term monitoring will allow the establishment of clearer relationships between annual solifluction mass transport and meteorological conditions, including the effects of any long-term climate warming.

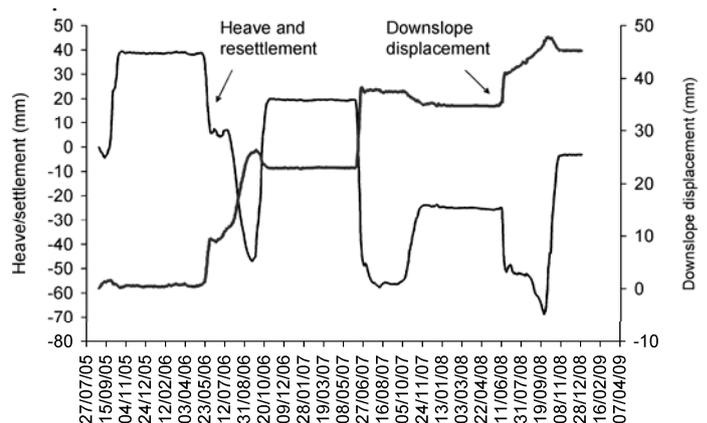


Figure 1. Continuous record of ground surface heave/settlement and associated downslope movement due to solifluction.

References

Harris C, Luetschg M, Davies MCR, Smith FW, Christiansen HH, Isaksen K. 2007. Field instrumentation for real-time monitoring of periglacial solifluction, Permafrost and Periglacial Processes 18, 1, 105-114. DOI: 10.1002/ppp.573

New Rock Glaciers Inventory of Aosta Valley, Italy

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1 INTRODUCTION

A new rock glaciers inventory of Aosta Valley region is presented. Some data already exist in the Rock Glacier Inventory of the Italian Alps (data collection of the Italian Glaciological Committee, edited by Smiraglia and Guglielmin, 1997), but a census based on the new cartographic products available has been performed for the entire region. Realized in the frame of the project PermaNET – Longterm Permafrost Monitoring Network (Alpine Space program), the new inventory is part of the Permafrost Evidences Database of the work package 5 (WP5 - Permafrost and Climate Change) as rock glaciers are considered an indirect evidence of permafrost. The evidences collected by the project partners are used for the construction and for the validation of a permafrost distribution map, common for the whole Alpine Space.

2 CONSTITUTION OF THE NEW INVENTORY

2.1 Study area

The Aosta Valley is a small alpine region in the Alps in the North West of Italy, at the corner with France and Switzerland. Its surface (about 3300 km²) is prevalently mountainous with more than 50% of the territory above 2000 m asl and about 5% of glaciated areas.

2.2 Methods

The inventory is carried out by the analysis of aerial photographs (ortophotos 0,5 m resolution), DTM (2 m grid) and IRFC (15 cm resolution). Each rock glacier is identified and manually bounded inside a GIS environment crossing the visual informations coming from the stereoscopic vision of IRFC images, hillshade effect derived from DTM and ortophotos. For each deposit the main geomorphic parameters as area, length, width, slope, aspect, elevation of the front, elevation of the upper part and altitude of the relief from which they originate are mapped and quantified by the DTM.

For each rock glacier a detailed table is filled and stored in the inventory database. Such form is constructed following the example of existing rock gla-

cier inventories (Seppi et al. 2005; Guglielmin & Smiraglia 1997). In addition to geomorphic parameters previously described, the fields are: (i) state of activity (classified in intact, that includes active and inactive rock glaciers, and relict), (ii) geometry (lobate, tongue shaped or equi-dimensional), (iii) shape (simple or complex, with the specification of complexity typology: multipart, multiroot, multilobe, multiunit), (iv) alimentation (morainic-derived or talus-derived), (v) location, (vi) relations with glacial forms and with vegetation limits, (vii) morphological features such as longitudinal or transverse ridges, swollen or hollow body and the presence of conic pits.

Quality of the information which includes the certainty in the deposit boundaries, the definition of the state of activity and the detection of morphological features is evaluated. In addition possible interferences with human structures (e.g. cableways, roads, ski tracks, huts, etc) are mentioned for the analysis of risks deriving from permafrost degradation. Also potentially dangerous positions of the deposits in relation to the inhabited valley floors are pointed out, considering the possibility of loose material release from rock glaciers. Furthermore surveying or monitoring activities are specified in dedicated fields.

3 RESULTS AND FUTURE STEPS

Geostatistics analysis were performed in order to assess which are the main characteristics of the rock glaciers in Aosta Valley and to evaluate the distribution of such deposits in relation to topography.

A data validation campaign, by means of specific field surveys, is planned for Summer 2010 in sample areas of the region.

References

- Seppi, R., Carton, A., Baroni, C. 2005, Proposta di una nuova scheda per il censimento dei rock glaciers da fotografie aeree: applicazione sull'Alta Val d'Ultimo (Gruppo Ortles-Cevedale), *Geogr. Fis. Dinam. Quat. Suppl. VII*
- Guglielmin, M., Smiraglia, C. (eds.) 1997, Rock glacier inventory of the Italian alps, *Arch. Comit. Glaciol., GNGFG.*, 3, Torino

Laser Scanning of a Small Patterned Ground System

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1 INTRODUCTION

Non-sorted circles are a ubiquitous patterned ground formation in the arctic tundra (Walker et al., 2008). These features are not always visible at the surface due to vegetation cover. Research has shown that frost heave plays a major role in evolution of these features over time. The interaction of frost heave, hydrology and vegetation is a concept that is currently being researched (Daanen et al., 2008). During freezing of the active layer water migrates from warm regions to cold regions in the active layer during freezing. These regions are generated by snow and insulating vegetation. This water migration leads to differential heave in the landscape. For this study we use a field site near Franklin Bluffs Alaska.

2 METHODS

Differential heave has been measured with a total station at a resolution of 25cm in the same grid for the period 2007-2008. To measure differential heave we have applied a terrestrial laser scanner in spring and fall to understand frost heave and vegetation distribution in these systems. We use a Leica ScanStation 2 scanner and we processed the scan data with Cyclone. Due to vegetation and small topographical irregularities we scan the area from four different directions and integrate these scans into one point cloud using targets at each corner of our 10X10 meter research area. The large point cloud is then analyzed with our own software designed to sort the point cloud into layers and boxes.

In order to measure the smooth frost heave pattern we subtract datasets after aligning them in space. Vegetation cover density was calculated using the vertical distribution of the point cloud. Relative cover density is calculated as the number of points above the ground surface (2cm) divided by the total number in that subplot.

3 RESULTS

The data suggests that frost heave is greatest in regions with least vegetation cover surrounded by high

vegetation cover and partially vegetated non-sorted circles show subdued frost heave (Figure 1). The overall heave in the non-sorted circles is between 15 and 20 centimeter using the inter-circle area as reference point with no frost heave.

4 FIGURES

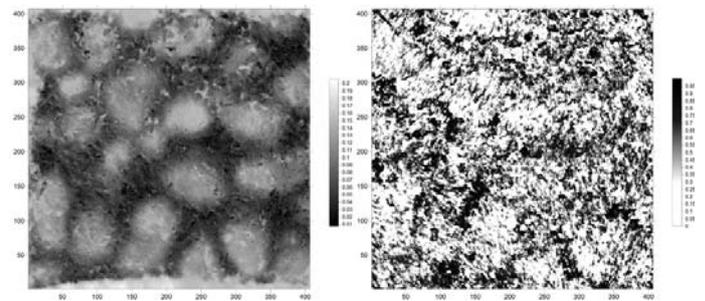


Figure 1. Differential Frost heave (left) and vegetation canopy density (right) measured with a Terrestrial Laser Scanner on a 10X10m grid near Franklin Bluffs Alaska.

References

- Daanen, R.P., Misra, D., Epstein, H., Walker, D. and Romanovsky, V., 2008, Simulating nonsorted circle development in arctic tundra ecosystems. *Journal of Geophysical Research-Biogeosciences*, 113: Artn G03S06.
- Walker, D.A., Epstein, H.E., Romanovsky, V.E., Ping, C.L., Michaelson, G.J., Daanen, R.P., Shur, Y., Peterson, R.A., Krantz, W.B., Reynolds, M.K., Gould, W.A., Gonzalez, G., Nicolsky, D.J., Vonlanthen, C.M., Kade, A.N., Kuss, P., Kelley, A.M., Munger, C.A., Tamocai, C.T., Matveyeva, N.V. and Daniels, F.J.A., 2008, Arctic patterned-ground ecosystems: A synthesis of field studies and models along a North American Arctic Transect. *Journal of Geophysical Research-Biogeosciences*, 113: Artn G03s01.

Hydrochemical Response of a Polar Glacier Facing the Recent Climate Changes (Austrelovenbre, Svalbard, 79°N)

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The Brogger-peninsula glaciers (Svalbard, 79°N) like many glaciers have been shrinking for the past century since the end of the Little Ice Age due global warming. However, the freshwater fluxes flowing from glaciers are not simple functions of climatic indicators (T, P). They also depend on other parameters (proglacial moraines, glacier structure, permafrost distribution). Few Arctic catchments display hydrological networks suitable for accurate quantification of freshwater volumes. The Austrelovenbre glacier basin has two well-defined outlets that concentrate all water fluxes: one connected to the glacier, the other only to proglacial moraine. The hydrological response of this river-system has been studied, since 2007, by continuous monitoring of climate (T, P) and hydrological parameters (Q, T, EC). Geochemical measurements have conducted on water samples (anions, ¹⁸O, ²H).

The outlet of the glacier shows hydrographs with two dynamics: daily cyclicality and isolated flood events. The daily fluctuations are induced by air-temperature variations with a mean delay. Most flood events mainly result from rainfall events. When they occur during warm periods, the floods may be amplified. However, all warm and/or rainy events do not influence the hydrographs. On the contrary, the hydrographs may present variations during periods without any particular meteorological events. The other outlet displays a monotonous hydrograph, reflecting (1) the discharge of the supra-permafrost aquifer within the proglacial moraine, (2) the snow melting and (3) the permafrost thawing. The Q curve obtained do not show any significant variation linked to atmospheric conditions. The geochemistry has been successfully used to identify the different water end-members in the basin.

Slope Morphodynamics in Periglacial Environments: Data from Physical Modelling

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Here we describe a full-scale laboratory simulation experiment designed to investigate the influence of rainfall induced erosion of stony slope underlain by permafrost.

1 EXPERIMENTAL DESIGN

Two identical 30° slope models were constructed adjacent to each other within a 3 m square freezing chamber (Fig. 1). Models were 2 m long, 0.55 m wide and 50 cm thick and constructed using a natural Weischelian periglacial slope deposit soil from La Hague area (Western Normandy, France).

Air temperatures were lowered to -8°C to simulate winter freezing, and were subsequently raised to +20°C to simulate the summer thaw period. The two-sided freezing model was constructed above a refrigerated plate that maintained a 15 cm thick permanently frozen layer (permafrost). The maximum thaw depth was around 15 cm. A total of 31 cycles of freezing and thawing were undertaken.

The soil material was initially water saturated. When the active layer had reached 5 cm of thickness, water was added at the surface via a ramp with 10 calibrated nozzles that equally distribute simulated rain on the soil surface.

The initial morphology of the two models is characterised by a regular slope (30°). One of the model has a steeper part (45°), one metre below the top of the model, to analyse the behaviour of the soil when the dip of the slope increases as often observed in the field (Fig. 1).

In the present paper we present data from the experiments relating to two different situations, firstly with moderate rainfall, and secondly with heavy rainfall during the thaw period.

2 INSTRUMENTATION

The models were instrumented with platinum resistance thermometers Pt100 to follow the freeze advance and control the permafrost thickness. Sensors were positioned at depths of: -30 cm, -20 cm, -15 cm, -10 cm, -5 cm, at the surface of the soil and 15 cm above soil surface.

Digital elevation models of the surface were computed using an ultrasound sensor. At the end of each freeze-thaw cycle phase, the sensor was deployed on a graduated metal structure to obtain coordinates and altitudes of a regular grid. These grids are useful to quantify heave, longitudinal and transversal topographies, surface and volume of eroded zones.

Markers were used to measure downward displacements of the soil. Vertical profiles were obtained by measuring displacements of columns of tiles and along the lateral side made of synthetic glass.

3 RESULTS

These experiments bring new data that can help the understanding of periglacial slope development related to an increase in precipitation rate and variations of active layer texture and thickness.

When moderate rainfall is applied, erosion processes involve frost jacking of the coarse blocks, frost creep and gelifluction that induce slow and gradual downslope displacements of the active layer, but also small landslides leading to large but slow mass movements with short displacements. With such boundary conditions, water supply is insufficient to evacuate downslope the whole of the eroded material and a topographic smoothing is observed.

When heavy rainfall is applied, rapid mass wasting become prominent. Slope failures are largely controlled by the water saturation of the active layer and by the occurrence of steeper slopes.

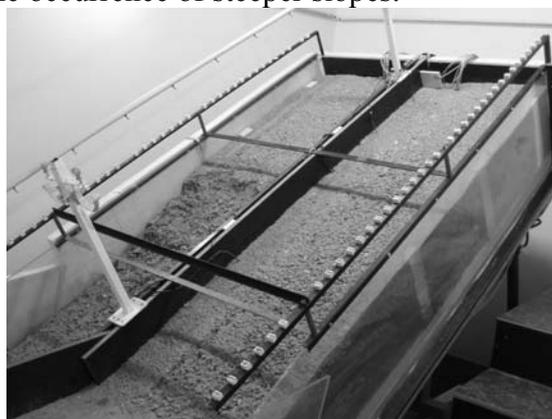


Figure 1. Two parallel slope models, far side, irregular slope model, near side, regular slope model.

Snow-Push Activity at a Seasonal Snowpatch Site, Sierra de Ancares, Northwestern Spain

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The push action associated with the basal movement of the snow cover has been identified as a major mechanism in the origin of subnival geofoms, developed not only on a substrate composed of deformable sediment, but also on hard bedrock surfaces. In this contribution we present the results of a geomorphological survey carried out in the backwall of the Cuiña Cirque, Sierra de Ancares, northwestern Spain (latitude 42° 50' N, longitude 6° 49' W; 1.860 m a.s.l.), focussed on the identification and description of nival geofoms whose origin is attributed to snow-push mechanisms.

The site comprises an upper sector formed by stepped, sub-horizontal bedrock benches and small steep walls, and a lower sector formed by a gently sloping surface covered by fines-rich diamicton and loose clasts.

The seasonal snow cover begins to form by mid-autumn and disappears by early July. Snow thickness is uneven, reflecting the irregularities of the underlying substrate. Maximum snow depths up to 4-6 m occur at the cirque edge, where drifted snow builds up thick cornices. Snow density measured during the ablation season attains mean values of 570 kg m³, peaking to 640 kg m³ in the basal section of the snow cover. The temperature at the snow/substrate interface remains at 0°C throughout the winter and spring periods, allowing the presence of free water at the base of the snow cover.

At Cuiña Cirque the snow cover is affected by mass movements such as snow glide and full-depth avalanches, in which the entire snow profile down to the substrate is mobilized. Observed field evidence of snow glide are tensile fractures or glide cracks formed in spring in the thick snow cornices accumulated at the cirque edge. Usually, an increase in the glide rate, evidenced by the rapid widening of the tensile fracture, causes the release of a full-depth avalanche. Such kinds of movements can generate considerable push and dragging forces on the underlying substrate and on loose clasts, thus creating distinctive geofoms.

A wide array of micro- and meso-forms have been found on rock slopes comprising plucked steps, polished surfaces, abrasion tracks, striae, grooves, crescentic marks and asymmetric rock bumps.

Distinctive features have also been identified in areas covered by deformable, fines-rich diamicton, including displaced blocks embedded in the substrate with characteristic upslope furrows and downslope mounds; small pronival ramparts; fines-rich diamict micro-ridges, showing worn-edged clasts with scratched and striated surfaces; nearly flat bulldozed surfaces; embedded blocks occurring in the proximal slopes of pronival ramparts and diamicton micro-ridges; and strongly compacted fines-rich diamicton sheets, pressed against rock outcrops.

Taken as a whole the field observations suggest that snow-push is a particularly effective geomorphic process in the subnival environment.

Key words: seasonal snow cover, snow-push, subnival environment, Sierra de Ancares, Spain.

ACKNOWLEDGEMENTS

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Spatial Distribution of Pingos in Northern Eurasia

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1 INTRODUCTION

Pingos are prominent periglacial landforms in vast regions of the Arctic and Subarctic. A general knowledge about their distribution exists based on detailed field studies of many workers in permafrost research. Pingos and pingo scars are often used as indicators for certain modern as well as past climate and permafrost conditions. However, detailed databases based on Geographic Information Systems (GIS) are lacking. GIS-based spatial analysis tools could help in analyzing the environmental significance of pingos in the northern hemisphere and better define their role as an indicator land surface feature for climate, hydrology, and permafrost conditions.

In this study we analyze a newly generated dataset of pingo locations for a large region in northern Eurasia.

2 METHODS

We manually extracted pingos from 675 Russian medium-scale (1:200,000) topographic maps of northern and central Siberia and created a comprehensive GIS-based dataset of pingo locations. Using this point dataset and additional thematic datasets with climatic, permafrost and other environmental parameters, we analyzed the spatial distribution of pingos in our study region and discuss relationships between these parameters and pingo occurrence. We also compared modern pingo distribution with modeled near-future permafrost distribution.

3 RESULTS

More than 6000 pingo mounds were identified in a land area of about 3.5 million km² (Fig. 1). Pingo height was provided for approximately half of the features in the database. Heights identified in the maps ranged from 2 to 37 m, with the majority of pingos ranging from 2-6 m.

The majority of pingos likely formed through closed system freezing, typical of those located in thermokarst lake basins of northern lowlands with continuous permafrost. Nearly 98% of mapped pingos were found in the continuous permafrost zone. About

64% of all pingos occur in continuous permafrost with high-ice content and thick sediments; another 19% in continuous permafrost with moderate ice content and thick sediments. About 82% of the pingos are located in the tundra bioclimatic subzone. Most pingos were found in mean annual ground temperatures between -3 and -11°C, with a population peak between -9 and -11°C. Main distribution of pingos by mean annual air temperatures is between -7 and -18°C. Based on model predictions for near-future (2100) permafrost distribution, hundreds of pingos in NW Siberia, central Siberia around Yakutsk, and the pacific region of Far East Siberia will be impacted by thickening active layers and increased permafrost degradation.

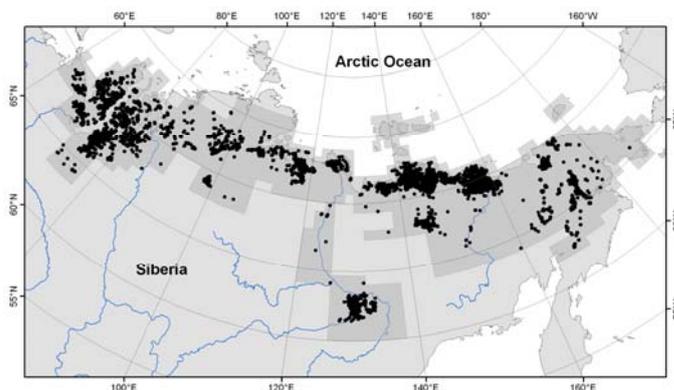


Figure 1 Spatial distribution of pingos in northern Eurasia (black dots: pingos; dark grey: mapped area).

4 CONCLUSIONS

The presented dataset is a subset of the pingo population in North Eurasia. Including other available pingo counts for various regions of the northern hemisphere (Alaska, NW Canada, Greenland, Svalbard), we conclude that there are about 10,000 or more pingos on Earth today. This new estimate roughly doubles previously published numbers. The main pingo provinces on Earth are N Alaska, NW Canada, and N Siberia, totaling ca. 90% of all pingos. Detailed GIS pingo databases may also prove useful for characterizing thermokarst lake drainage history and analyzing the distribution of pingo-like features on submarine shelves and extra-terrestrial planets.

Formation and Dynamics of Holocene Syngenetic Ice-Wedge Polygons in Adventdalen, Svalbard

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INTRODUCTION AND METHODS

Ice-wedge polygons are a widespread periglacial landform used as a key climatic indicator. The understanding of the dynamics and formation of ice-wedges is a prerequisite for their application in palaeoenvironmental reconstructions. To improve the understanding of the Holocene dynamics of the ice-wedge activity, four ice-wedge sites in Adventdalen, Svalbard (Table 1) have been studied in combination with stratigraphic investigations.

Table 1. Site characteristics and applied methods for the four ice-wedge study sites in Adventdalen, Svalbard.

Site	site A	site B	site C	site D
activity	inactive	active	active	active
polygon morph.	flat terrain	low-centr.	low-centr.	high-centr.
polygon type	orthog.	hexag.	orthog.	orthog
crack mapping	-	x	-	x
central pit	x	x	-	x
trench/width i-w	x / 1m	x / 3m	-	-
exposure	x	-	-	-
cliff section	x	x	-	-
permafr.core	1.75m	1.79m	-	-
network mapping	x	x	x	x

During summer 2009, soil pits were dug in the centre and across the troughs of the four ice-wedge polygon sites to study the sediments and for soil sampling. Crack mapping performed in the field, combined with the analysis of stratigraphical data from site B (Christiansen manus), contribute to the understanding of local cracking dynamics. Two permafrost cores from central ice-wedge polygons were collected by hand drilling and sampled at 10 cm intervals. Two river cut cliff sections, exposing ice-wedge host sediments, allowed detailed studies of the sediments and one ice-wedge (Fig.1). 53 samples were analysed with respect to ice content, magnetic susceptibility, pH-value, electric conductivity and grain-size. High resolution remote sensing data were used to map and study the crack network.

RESULTS AND DISCUSSION

Significant variations between the ice-wedge study site were detected, regarding ice-wedge morphology, network geometry and the host sediment stratigraphy, soil moisture and active layer depth. The ice-wedges found from the base of the active layer

indicate either recent syngenetic activity or recently increasing active layer depths. The general stratigraphy shows a glacio-fluvial or organic unit covered by a 1.5 m loess unit. OSL dates (UNIS report) suggest that loess sedimentation continued during the Late Holocene with higher rates at site A than at site B. The ice-wedge exposure shows intensively deformed host sediments except for the upper 10-30 cm of undisturbed loess. Desiccation crack structures are found in the upper 50 cm of the studied active layer pits. An OSL age from the bottom of the loess unit indicates that drier soil conditions prevailed since the onset of the Little Ice Age (LIA). Cooler temperatures, as existing during the LIA, appear favourable for thermal contraction cracking, followed by a period of reduced ice-wedge activity.

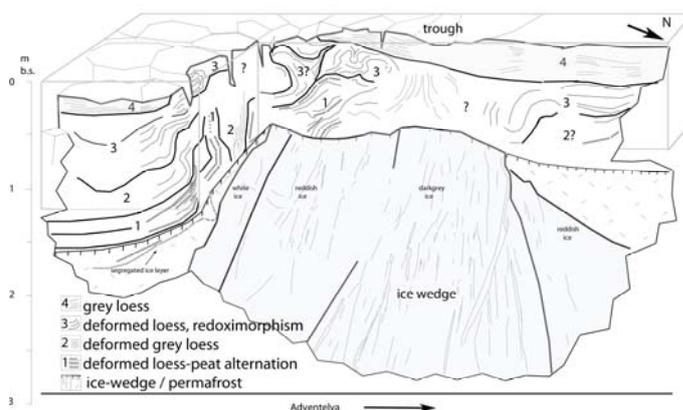


Figure 1. Ice-wedge exposure along the cliff at site A

The observation of modern nearby inactive and active ice-wedges suggests that site-specific conditions such as primarily soil moisture are decisive for the ice-wedge dynamics in a maritime arctic environment. For a more comprehensive understanding of the key climatic/meteorological ice-wedge controlling factors, further site-specific studies are necessary.

References

- Christiansen, H.H., Hormes, A., Snowball, I. (manus) High resolution Late Holocene loess record with syngenetic ice-wedges in Adventdalen, Svalbard
 UNIS report 2008 *The International University Course on High Arctic Permafrost Landscape Dynamics in Svalbard and Greenland AG 333 2008 - final report.*

High-Resolution Digital Elevation Models (DEM) and Orthoimages of Permafrost Landforms in Svalbard (Norway) from HRSC-AX data

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1 INTRODUCTION

Morphometric investigations of landforms based on remote sensing techniques require the availability of reliable topographic information. Ideally, additional high-resolution images provide textural context for interpretation. Unfortunately, such data are often missing for geomorphologically interesting, but remote study areas. Here we present Digital Elevation Models (DEM) and corresponding orthoimages of permafrost landscapes in Svalbard (Norway). The data were acquired for analogue studies of Martian landforms (Hauber et al., 2010), but should be useful for terrestrial permafrost studies as well.

2 DATA

An airborne version of the HRSC camera was used for the acquisition of stereo and colour images. HRSC (High Resolution Stereo Camera) is a multi-sensor push broom instrument with 9 CCD line sensors mounted in parallel. It simultaneously obtains high-resolution stereo, multicolour and multi-phase images. Based on five stereo channels, which provide five different views of the ground, digital photogrammetric techniques are applied to reconstruct the topography. The four colour channels are used to make true orthoimages in colour and false-colour. HRSC is in orbit around Mars since January 2004, and as for February 2010, high-quality DEM and corresponding orthoimages are available for more than 30% of the Martian surface. The particular value of HRSC is the stereo capability, which enables the systematic generation of high-resolution DEM with grid sizes between 50 and 100 m. Since 1997, different airborne versions of HRSC have been developed. The principles of HRSC-AX data processing are described by Gwinner et al. (2006). The orientation data of the camera is reconstructed from a GPS/INS (Inertial Navigation System). HRSC-AX has been applied in diverse technical and scientific applications and was also successfully used to investigate rock glacier activity. The flight campaign in July/August 2008 covered a total of seven regions in Svalbard: (i) Longyearbyen and the surroundings of Adventfjorden, (ii) large parts of Adventdalen, (iii) large parts of the Brøggerhalvøya

in western Spitsbergen, (iv) the Bockfjorden area in northern Spitsbergen, (v) the northeastern shore of the Palanderbukta and the margin of the adjacent ice cap in Nordaustlandet, (vi) an area on Prins Karls Forland, and (vii) the area of the abandoned Russian mining settlement of Pyramiden together with the nearby Ebbedal. The landforms presented as examples in this study are located on the Brøgger peninsula and in Adventdalen and its vicinity.

3 RESULTS

The DEM derived from HRSC-AX stereo images has a grid cell size of 50 cm, a vertical resolution of 10 cm, and an absolute vertical accuracy of ~20 cm. The map-projected HRSC-AX true orthoimages (panchromatic and colour) have ground resolutions of 20 cm per pixel. We will present examples of HRSC-AX data showing the detailed topography of pingos, polygons (Fig. 1), and rock glaciers.

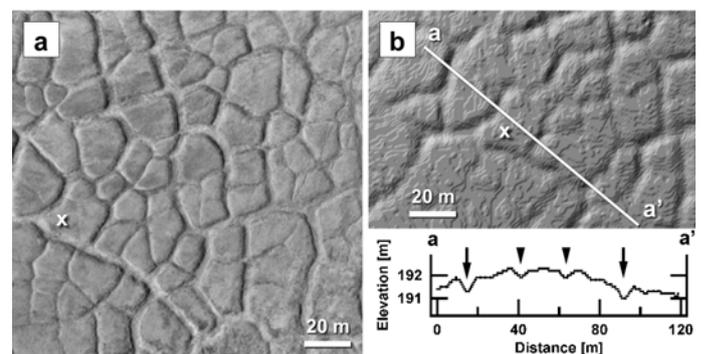


Figure 1. Example of HRSC-AX data of polygons in central Adventdalen. (a) Panchromatic image. (b) Shaded version of gridded DEM ("x" marks identical location in a and b). a-a': Topographic profile. The troughs delineating the polygons are clearly resolved in the DEM (black arrows).

References

- Hauber, E. et al. 2010. Periglacial landscapes on Svalbard: terrestrial analogues for cold-climate landforms on Mars. *Geol. Soc. Amer. Spec. Publ.* (submitted)
- Gwinner, K. et al. 2006. The HRSC-AX Mt. Etna Project: High-Resolution Orthoimages and 1 m DEM at Regional Scale. *International Archives of Photogrammetry and Remote Sensing*, v. XXXVI (Part 1), <http://isprs.free.fr/documents/Papers/T05-23.pdf>.

Sediment Quantification and Ground Water Storage in an Alpine Permafrost Catchment

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Changing permafrost may have significant consequences on the hydrological regime of an alpine catchment. For an area abundant in unconsolidated sediments model parameters such as the spatial distribution of the effective storage volume, the permafrost distribution and the hydraulic conductivity are essential. In this work the first steps such as the quantification of the effective storage volume, the detection of permafrost, and the estimation of ground water storage are presented.

The study area (Krummgampen Valley, Ötztal Alps, Austria) is located at altitudes between 2400 and 3300 m.a.s.l and covers an area of 5.5 km². The mean annual precipitation is ~1500 mm and the mean annual air temperature at a nearby meteorological station (2500 m.a.s.l) is ~ -0.7 °C. Active rock glaciers, fissure ice in bedrock and patterned ground indicate the presence of extensive alpine permafrost. Predominant subsurface classes are talus slopes (17%), pre-LIA lodgement and meltout till (18%), LIA lodgement and meltout till (27%), rock glacier (5%), and bedrock (33%). Geophysical methods (seismic refraction, georadar) along numerous profiles are applied to estimate the sediment volume. Statistic correlations between the subsurface class's thickness and their geomorphometric surface characteristics were used to extrapolate for the entire valley. The permafrost distribution was assessed by seismic methods and evaluated by continuously recorded BTS-temperatures. Discharge data is available for 2008 and 2009 for the main catchment and for 2009 for three sub-catchments. Base flow recession analysis was applied to separate the ground water flow from surface and subsurface runoff.

Permafrost with active layer depths of up to ~ 3 m was detected above 2500 m.a.s.l (north facing). Estimated mean sediment thicknesses (disregarding the impermeable permafrost) are 8 m (talus slopes), 6 m (pre-LIA till), 5 m (LIA till), and 20 m (rock glacier). The flow data recorded by the hydrograph at

the main outlet is characterized by processes such as snow melt, ground water flow, subsurface and surface run off with peak flows of up to 2000 l/s. The hydrologic data from 2009 show a recharge of ground water lasting from late April to early August. According to recession analysis the ground water system has a response time larger than 30 days. The ground water storage computed from recession analysis and the effective water storage estimated from the sediment volume by geophysical investigations show similar values. Finally we discuss how permafrost degradation could affect the hydrological regime.

Permafrost and Karst Landscapes Development in Mezenskaja Tundra (Archangelsk area, Russia)

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1 ABSTRACT

Researches were carried out in Mezenskaja tundra in s. Koida (Arkhangelsk area, Russia) in 2000-2009. Were made measurements of temperature of grounds, depth of a seasonally-thawed layer, spatial structure frost heavy migratory, coastal crioturbation and pseudomorphozes on ices wedges, thermokarst lakes and karst landscapes. The Mezenskaya tundra is located near to southern boundary of permafrost. Therefore, areas of permafrost of researches it is presented island and rare island by types of distribution which are dated first of all for files peat ground by depth up to 15 m. Here permafrost settles down locally in peat deposits tundra bogs. Mid-annual temperatures of frozen ground of Mezenskaja tundra make nearby – 0,5 - – 1,0 ° C. From cryogenic processes for area most typical thermokarst, frost heavy, thermodenudation. As a result of frost heavy in territory of Mezenskaja tundra it was generated characteristic hill shape of tundra landscapes. The opposite type of natural complexes is developed on left coast of r. Koida. Here there is a local site intensive karst processes which changes habitual hill landscape of Mezenskaja tundra. Because of development of a karst by virtue of the raised drainage of waters, practically there is no development of cryogenic processes on this site. Such conditions are favorable for development birch «drunk» forest and a juniper. The zone of intensive development of a karst coincides with a zone of development birch «drunk» forest and has the oval form and from northwest is surrounded by hills. In 7 km to northwest from s. Koida where the zone of development of the karst landscapes comes to an end, again essential share of a relief cryogenic forms – frost heavy hills, «mochagini», thermokarst lakes. At coast lakes mixed (karstic and cryogenic) genesis which are subject to an opportunity of descent are developed. page. Clipping may occur during reproduction.

Possible Freeze/Thaw Landforms on Martian Slopes: Using Svalbard Advent Valley as an Analogue to Mars

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1 INTRODUCTION

Stripes and gelifluction lobes are common slope features in polar regions on Earth where freeze and thaw processes occur. Mars is currently a cold and barren planet with its water resources locked up as ice caps and ice-rich permafrost. However, features resembling stripes and gelifluction lobes have been observed on high-latitude slopes on Mars and in most, but not all, cases in close proximity to gullies (Fig. 1). Stripe width typically ranges from ~50 cm to 1.5 m, and their orientation is consistently down slope, although it can not be excluded that it sometimes slightly deviates from the steepest topographic gradient. Lobes are found on steep inner crater walls and display similar dimensions as terrestrial gelifluction lobes. These observations may point to a late phase in Mars history with transient melt water in local niches. In our study we have examined sorted and non-sorted stripes as well as gelifluction lobes on slopes in Svalbard in order to test the working hypothesis of a freeze and thaw origin of the Martian landforms.

2 MATERIAL AND METHODS

The analysis on Svalbard is based on high resolution imagery with the High Resolution Stereo Camera (HRSC-AX), an airborne counterpart to HRSC on Mars Express. For comparison we use satellite imagery (n=85) of Mars obtained by the High Resolution Imaging Science Experiment (HiRISE) which has a similar spatial resolution of 25 cm/pxl. Image analysis is complemented by field work for ground truth.

3 DISCUSSION

The occurrence of stripes and lobe features on Mars raise the question if they are periglacial in origin. The presence of a moist active layer requires the surface layers ice content to be recharged as ice is continuously lost by the progressive desiccation of the ground. However, seasonal thaw may have

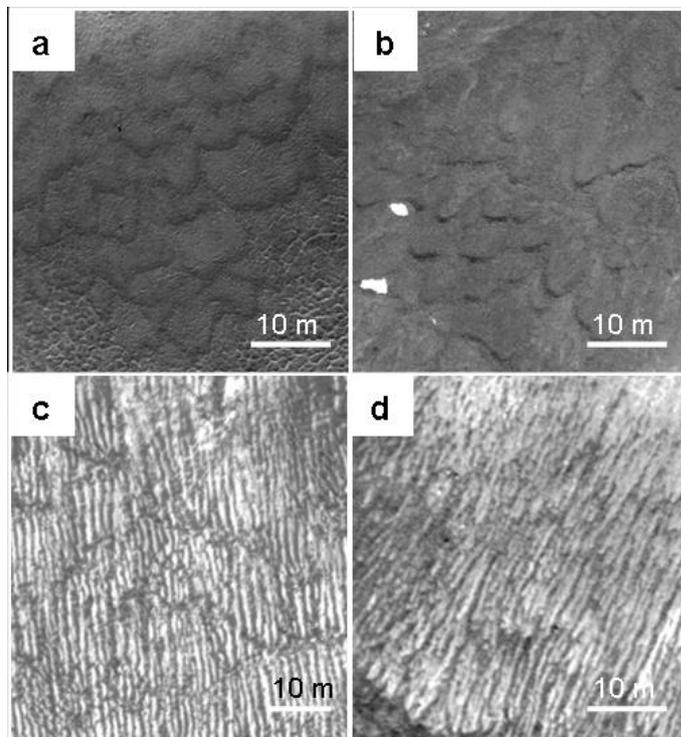


Figure 1. Mars (left) and Svalbard (right). Mars images: HiRISE, Svalbard images: HRSC-AX. (a) Lobe-like feature on crater wall. (b) Gelifluction lobes. (c) Stripe-like pattern on crater wall. (d) Non-sorted stripes.

existed in microenvironments such as the interior of craters or on hillslopes. In recent models crater floors or poleward facing slopes have been identified as specific locations for water ice stability and deposition of ice. One proposed model state that liquid water in the ground could be stable for enough time before being sublimated. In this case the winter CO₂ frost may protect ground ice from sublimation before thawing. A plausible mechanism for recharge is top-down melting of snow packs, which could be a viable mechanism to supply moisture for freeze and thaw cycles. In this case the stripe patterns and lobes are possibly linked to the formation of gullies since both landforms are favored by similar conditions. The presence of stripes and lobes on Mars may be an indicator of a freeze/thaw process which in turn has implications for our understanding of near surface water dynamics and local climate. However, further work is needed to constrain the processes and timing of formation.

The Project ANAPOLIS: Analysis of Polygonal Terrains on Mars Based on Earth Analogues

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1 SYNOPSIS

Polygonal networks are a much more common surface feature on Mars than on Earth. Detailed images have shown large areas covered by widely diverse polygonal terrains, a fact that highlights the ubiquity of the presence of ice in the Martian ground. There is still much to be learned about the conditions that give rise to such a variety of morphologies and dimensions. Thus, a full understanding of their origin, age and evolution requires that their thorough characterization is attained. The number of polygons in a given network can be very large, depending on their average dimensions and the area occupied by the network. Collecting quantitative data on these networks can be a daunting task that can be avoided through the use of an automated procedure. This takes advantage of the characteristics presented by the networks on digital images to map the edges of the polygons. Application of this methodology to the surface of Mars raised the possibility of using it to map and characterize the same type of feature on Earth. The advantages can be clearly seen: the automated results can be compared with a real ground-truth (and thus provide clues for refinement of the methodology when strictly applied to remotely sensed data, such as in the case of Mars), and some measure of comparison can be established between Martian polygons and terrestrial analogues, illuminating some issues and probably raising many interesting new questions.

The results obtained in the previous project focusing on Mars polygonal networks (TERPOLI - Pina et al. 2008, Saraiva et al., 2009) support the continuation of this research through the project ANAPOLIS.

In TERPOLI we were able to map and collect geometric and topological parameters from extensive Martian polygonal networks, thus taking an important step into their characterization and comparative study, in an attempt to understand their

origin, evolution and relation with climate change on the planet.

In the framework of ANAPOLIS, Earth's polygonal networks will be studied at test sites in Svalbard. Field survey is crucial for gathering accurate data on the geometry of the polygons. Combining DGPS measurements, aerial photography and VHR satellite imagery will enable better understanding of the relation between in situ measurements and the appearance of the networks on images at various scales, allowing for the improvement and validation of the algorithm for the automatic extraction of networks. Knowledge on the specific environmental conditions related to the genesis of the networks shall contribute to inferences about the past and present environmental conditions related to the Martian polygonal networks. Ground truthing also allows for a better discrimination between the strictly periglacial polygonal networks and the features with other origin. In this way, a more sustained interpretation on the past and present environmental significance of the polygonal networks of Mars can be made. Furthermore, the significance of the geometric and topological properties of terrestrial polygonal networks has not been properly acknowledged yet, so that the use of an algorithm for the extraction of the networks from remote sensing products can also be of great use for studies in the harsh access areas of Earth's periglacial domain.

References

- Pina, P., Saraiva, J., Bandeira, L., Antunes, J. 2008. Polygonal terrains on Mars: A contribution to their geometric and topological characterization. *Planetary and Space Science* 56(15): 1919-1924.
- Saraiva, J., Pina, P., Bandeira, L., Antunes, J. 2009. Polygonal networks on the surface of Mars; applicability of Lewis, Desch and Aboav-Weaire laws. *Philosophical Magazine Letters* 89(3): 185-193.

State and Evolution of the Bérard Rock Glacier (Southern French Alps) After its Collapse in 2006: Insights from Geophysical, Geodetic and Thermal Datasets

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1 INTRODUCTION

In the French Alps, the summer 2006 has been marked by the sudden collapse of the Bérard rock-glacier, a rare event, exceptional by the quasi complete destabilization of the landform. This case raises questions on the evolution of mountain permafrost under warming conditions, especially those ice-rich debris accumulations located close to the altitudinal and/or latitudinal limits of permafrost and that may be experiencing morphogenetic crisis (e.g. Harris et al., 2003). The Bérard site (2500-2900 m asl; 44°26' N. – 6°40' E.) is located in the Parpaillon range, near the Southern limits of the Alpine permafrost and under Mediterranean climatic conditions. The objectives of our study are to analyse the present state of the Bérard rock glacier (collapsed and non-collapsed mass) and its evolution after the major movements of summer 2006 that mobilized 1.5 millions m³ of material. In this purpose, electrical resistivity and seismic refraction tomographies were repeated along two profiles in summers 2007 and 2009, GPS survey of 40 points was initiated in summer 2007 and a thermal monitoring, composed of 6 miniature temperature dataloggers and an automatic weather station was installed on the site on summer 2007.

2 RESULTS

2.1 *Thermal and geodetic data*

The combination of the thermal and geodetic data allows us to distinguish three areas:

- 1) the unstable but non-collapsed upper part of the rock glacier, characterized by creeping signs and which displays surface velocity between 0.1 and 0.6 m/yr and WEqT (Winter Equilibrium Temperature) values < - 2°C in 2008 and 2009;
- 2) the highly unstable but non-collapsed median part, characterized by destabilization signs like wide fractures and which displays surface velocity between 0.8 and more than 8 m/yr (no ground temperature available);

- 3) the collapsed mass, characterized by strong morphological changes (rapid downwasting of ice/debris packets) just after the deposition but no visible signs of evolution since 2007 and which displays surface velocity below 0.1 m/yr and WEqT around 0°C.

2.2 *Geophysics survey*

The electrical resistivity tomographies confirmed partly the observations made on open cuts just after the collapse, but don't reveal the 1-2-m thick layer of quasi pure ice (suspected to be a relict of LIA conditions) observed in the detachment cut in 2006 and 2007. Similarly to measurement on other pebbly rock glaciers, the resistivity of the Bérard rockglacier internal structure ranges from 0.2 to 25 kΩ.m. These low values may reflect the presence of warm permafrost or permafrost at the melting point. The seismic data indicate a seismic interface on average at 3-4 m depth and mean velocity V_p of the ice-rich level around 1800-2000m/s.

3 DISCUSSION

The collapse of the Bérard rock glacier in 2006 may be representative of the consequences of mountain permafrost degradation under warming climate. Nevertheless, a first assessment of the possible triggering chain of factors (climatic conditions of the last decades, meteorological events –storms and heavy rains– during summer 2006, geological and topographic contexts) shows the high complexity of such events and the further need to study and monitor mountain permafrost, especially in populated regions where its degradation may generate hazardous situations.

Reference

Harris C., Vonder Mühl D., Isaksen K., Haeberli W., Sollid J.L., King L., Holmlund P., Dramis F., M. Guglielmin and Palacios D., 2003. Warming permafrost in European mountains. *Global. Planetary Change* 39 (2003) 215Y225.

Stratigraphy of an Ice Wedge Cast on the Northern Seward Peninsula, Alaska, and Implications for Paleo-Thermokarst Lake Development

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1 INTRODUCTION

Thawing permafrost is a natural environment for carbon dioxide or methane production. Thermokarst lakes provide one of the most active modes of permafrost thawing in arctic and sub-arctic regions making thermokarst environments a potentially important factor for climate change feedbacks. Paleo-environmental records stored in lake sediments are key evidence for Late Quaternary paleoclimatic conditions and for identifying past climate changes. Ice wedge casts formed in thermokarst lakes are indicators of permafrost degradation and their stratigraphy can be a valuable paleoclimate record. An ice wedge cast located at 66.55N/164.45W on the Seward Peninsula, Alaska, was investigated. The ice wedge cast, three meters tall by five meter wide, was formed under the now drained Lake Pear and later exposed by erosion on the north facing shore of Lake Claudi. The refrozen sediments in the cast are well laminated lacustrine mineral- and organic-rich sediments with some re-worked tephra layers. A remnant ice wedge was found below the ice wedge cast. Stratigraphy and lithological composition of the ice wedge cast were studied to derive information about the paleo-environment during formation of the ice wedge cast. Sedimentation processes observed within the modern thermokarst lake environment were also found in the ice wedge cast sediments. The fine lamination potentially indicates an annual lacustrine layering.

2 RESULTS

The stable lacustrine part of the ice wedge cast consists of 174 fine peat/silt layers. Assuming that these represent annual lamina, we calculate that 174 years cover the sediment record for stable lake sedimentation above the ice wedge cast.

The distance of the exposure from the paleo-margin of Lake Pear is about 82 m. By relating this distance to the time represented by the layers, we calculate an annual paleo-erosion rate for Lake Pear of 0.47 cm/yr. This rate is comparable with modern rates measured at Lake Claudi.

Kinematics and Morphological Characteristics of a Destabilized Rock Glacier, Swiss Alps

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1 INTRODUCTION

Destabilized rock glaciers refer to active rock glaciers that have experienced for the last years or decades a landslide-like development and a strong increase of the velocities (Roer et al. 2008). 15 destabilized rock glaciers have been hitherto detected in the Alps. One of these landforms, the Tsaté-Moiry rock glacier, is found on a north-east slope of the Anniviers valley (Valais Alps), at an elevation of 2750 m a.s.l.

2 MORPHOLOGICAL CHARACTERISTICS

Only the lower part of the rock glacier is clearly discernable from the surrounding debris slope. Lateral crests line the central part of the landform. In their internal flank, fine-grained sediments outcrop clearly, contrasting with the blocky surface of the rock glacier. Several scars 2-3 meters high cut the landform between the two crests, in particular in the lower part. Blocks are very unstable in this area. These morphological characteristics are the consequence of sliding processes.

3 KINEMATICS

Since summer 2005, the position of about 50 blocks is measured with differential GPS around mid-July and early October each year. The measurements show the quasi absence of movements on the lateral crests, whereas the inner part moves very quickly. During the year 2008-2009, horizontal surface velocities of the destabilized part were 8 m a^{-1} (Fig. 1). The rooting zone moves much more slowly (vel. around 1 m a^{-1}). Summer velocities are 2-3 times faster than winter velocities. Maximal velocities of 16 m a^{-1} were measured during summer 2009. An increase of the annual velocities is observed since 2005. This can be related to a general warming of the ground surface (Fig. 1). In summer 2006 velocities were at least 2 times slower than during the three following summers. Mean annual ground surface temperature (MAGST) was at that time very cold. Then, the ground surface began to warm. The extreme velocities of summer 2007 coincide with abundant precipitation. Despite a slight decrease,

MAGST remained then quite warm. In addition, winter 2007-2008 was snowy and summer 2008 rainy. These conditions were favourable to high velocities. After that, MAGST increased dramatically. The snow cover was thick again in winter 2008-2009 and following summer was dry and hot. Again, summer velocities were very high.

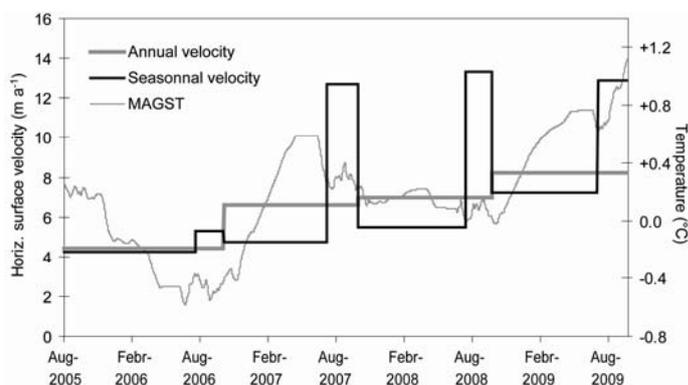


Figure 1. Annual and seasonal velocities of the destabilized part of the Tsaté-Moiry rock glacier and MAGST measured on the Mont Dolin West rock glacier (Arolla, 2770 m a.s.l.)

These data shows that the velocity of destabilized rock glaciers is controlled, at least partly, by the evolution of MAGST. Despite very warm MAGST and the thick snow cover of winter 2008-2009, velocities of summer 2009 were not higher than those of the two previous summers. The extremely low amount of precipitation of summer 2009 may be an explanation to that. It would confirm the importance of water infiltration for deformation and sliding processes at depth (Ikeda et al. 2008).

References

- Ikeda A., Matsuoka N., Käab A. 2008. Fast deformation of perennially frozen debris in a warm rock glacier in the Swiss Alps: An effect of liquid water. *J. Geophys. Res.*, 113, F01021, doi:10.1029/2007JF000859.
- Roer I., Avian M., Delaloye R., Lambiel C., Haeberli W., Käab A., Kaufmann V. 2008. Observations and considerations on collapsing active rockglaciers in the Alps. *Proceed. 9th Int. Conf. Permafrost, Fairbanks 2008*, 1505-1510.

Future Glaciations and the Challenges Related to Long Time Management of Nuclear Waste: Greenland Analogue Project

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1 INTRODUCTION

A deep geological repository for nuclear waste is designed to keep radiotoxic material separated from mankind and the environment for hundreds of thousands of years. Within this time perspective glacial conditions are expected in high latitudes in Canada and Northern Europe. Climate induced changes, such as the growth of ice sheets and permafrost will influence and alter the ground surface and subsurface environment, which may impact repository safety. The study of present-day analogues helps to reduce the uncertainties in our understanding of processes relevant to long-term repository performance and to support the assumptions made in safety assessments.

2 OBJECTIVES

The impact of glaciations on any planned repository at high latitudes is a key consideration when performing safety assessments as it is one of the strongest perturbations related to climate change in the long term. Some of the uncertainties related to glacial conditions concern hydrological and hydrogeochemical processes. The main aspects that need to be further investigated include: 1) the pressure conditions at the base of an ice sheet and how they drive ground water flow; 2) the depth and distribution of meltwater that may penetrate into the bedrock; 3) the chemical composition such water has when/if it reaches repository depth; and 5) role of taliks as potential concentrated discharge points of deep groundwater.

Field data is needed in order to achieve a better and integrated understanding of the conditions and processes discussed above and of the stability of hydrogeological system. Thus, research in a natural analogue site in Greenland has been planned and initiated by the Finnish (Posiva), Swedish (SKB) and Canadian (NWMO) nuclear waste management companies.

2.1 Study Area

The Greenland ice sheet and the Kangerlussuaq area (west Greenland) provide a good analogue for this research effort due to similarities in geology (in the selected study area) and the climate conditions expected to be seen in Fennoscandia/Canada during future glaciations. Furthermore, the ice sheet size in Kangerlussuaq resembles the expected conditions in Fennoscandia during future glaciations. In 2005 and 2008 reconnaissance field trips were made to Kangerlussuaq, which confirmed the suitability of the area for the planned studies. The Greenland Analogue Project started in 2009 and will continue until 2012.

2.2 Project description

The project is divided into three subprojects (SPA, SPB and SPC) addressing specific topics at or in relation to the ice margin: SPA studies ice sheet hydrology and glacial meltwater formation; SPB studies subglacial ice sheet hydrology and SPC studies hydrogeochemical and hydrogeological processes in the bedrock.

The multi-year project will acquire the necessary data and improved understanding of ice sheet processes such that better conceptual and numerical models for quantitative analysis of ice sheet hydrology and dynamics, groundwater flow, groundwater chemistry and hydro-mechanical couplings during glacial periods. A particular focus is placed on, reducing uncertainties and better constraining the boundary conditions used in the models. This project involves the first in situ investigation of the vital parameters needed to achieve a holistic and realistic understanding of how an ice sheet may impact a deep geological repository for spent nuclear fuel. It will provide the necessary integrated view of ice sheet hydrology and groundwater flow/chemistry required for refining safety assessments for deep geological repositories in Sweden, Finland and Canada.

A New Method to Monitor Solifluction on Permafrost Slopes Using Magnetic Targets, Svalbard, Norway

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1 INTRODUCTION

Solifluction is typically the most important slow mass-movement process on periglacial slopes, but to date, no ideal field monitoring technique has been developed. Complex equipment can usually be installed only at a single site in a given area because of time and cost; simple methods generally cannot track the intra-annual or inter-annual variability needed to link the process to meteorological conditions.

The goal of this research was to develop and test a method that could track movements within the active layer at sub-annual time-scales so that the influence of seasonal factors could be evaluated, but at low cost allowing numerous sites to be monitored.

Here we report on our experience with two prototype installations on Svalbard, one in Endalen adjacent to the site monitored by Harris *et al.* (2007) and the second in Adventdalen. The Endalen site is expected to be presented to participants during the EUCOP III Conference.

2 METHOD

The monitoring method uses 25 mm diameter rare-earth ring magnets embedded as free-floating markers at multiple depths within the active layer, and tracks soil movements by repetitive manual monitoring of their magnetic fields. The location of the centre of a ring magnet in the vertical plane can be determined using a reed switch to detect the top and bottom of the magnetic field (Mackay and Leslie, 1987). However, the centroid of its downslope position can be calculated only if a vertical section through the magnetic field is traced, requiring multiple measurements along a plane trending downslope. Measurements were made within a rectangular panel of double-walled polycarbonate equipped with a series of cross-dividers spaced at intervals of about 1 cm. When installed upright through the active layer in an upslope-downslope plane and anchored in permafrost, the panel provided a series of evenly spaced near-vertical access tubes. Lowering and raising a calibrated marker rod tipped with a reed switch within the tubes permits a magnet's field to be traced at multiple points, and its centroid to be calculated.

3 RESULTS

Magnets spaced through the active layer show heave in winter and up to 8 cm of thaw settlement in summer. In the near-surface, settlement is apparent during the early part of the thaw season, there is little change in mid-summer and settlement then recommences in August. In contrast, heave near the base of the active layer occurs in the early part of the summer, presumably because of infiltration into still-frozen ground, and settlement takes place only at the end. The timing of these movements suggests that in the autumn, ice lenses develop in both the near-surface and at the base of the active layer, but that the former are more important than the latter at the study sites. After two years of monitoring, the magnets had not regained their original level within the active layer, either because of progressive heave of the polycarbonate panel or because of overall loss of ice from the transient layer.

Downslope movements proved more difficult to discriminate than vertical ones. Preliminary results suggest that the magnets moved by 1-2 cm over two years which is less than expected. This may be because the panel itself is being displaced downslope, because movements of soil immediately adjacent to the panel in which the magnets are embedded are reduced by its presence, or because soil particles move more than the magnets. Further analysis of the data is required to examine these possibilities.

Despite the challenges, the measurement technique appears promising and further testing is planned. Multiple measurements undertaken through the year, including in winter, have given a good indication of active layer processes. No other method is currently available to directly measure independent soil movements within the active layer.

References

- Harris, C., Luetschg, M., Davies, M.C.R., Smith, F., Christiansen, H.H., Isaksen, K., 2007. Field instrumentation for real-time measurement of periglacial solifluction. *Permafrost and Periglacial Processes* 18: 105-114.
- Mackay, J.R. and Leslie, 1987. A simple probe for the measurement of frost heave within frozen ground in a permafrost environment. *Current Research, Part A, Geological Survey of Canada Paper* 87-1A: 37-41.

Integrating Ice Sheet, Bedrock and Surface Systems in a Periglacial Environment by Modeling Water and Chemical Fluxes

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1 ABSTRACT

The Swedish Nuclear Fuel and Waste Management Co. (SKB) currently investigates one site in Sweden (Forsmark) as a potential location for a geological repository for spent nuclear fuel (SKB 2008). The site investigations cover geology, chemistry, hydrology, climate and ecology, among several other disciplines. Strong emphasis is put on the characterization of properties and processes affecting the water-born hypothetical transport and retention of radionuclides along flow paths from repository depth (c. 500 m) to ground surface, and the subsequent dispersal and accumulation in the surface system. An important aspect of the characterization is the influence of climate change on repository performance. The modeling performed to support the site descriptions utilizes a wide range of modeling tools focusing on couplings between climate, bedrock and near surface hydrology, and the surface ecosystems.

In order to exemplify the Forsmark site under possible future climate conditions (figure 1) we have developed a methodology using site specific information from Forsmark as well as data and models from relevant analogue sites.

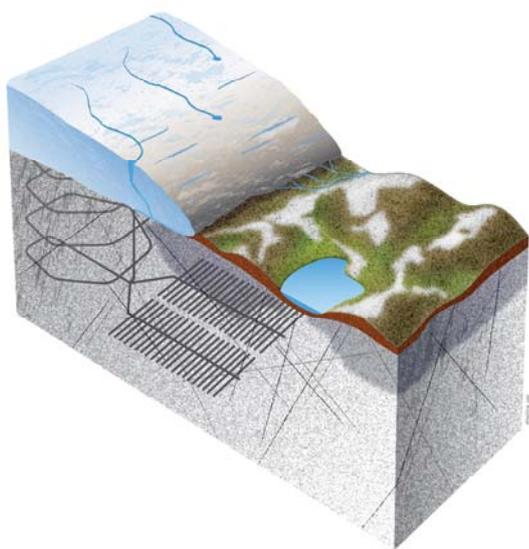


Figure 1. A conceptual model describing the ice sheet, bedrock and surface systems. Properties and processes affecting the repository and the fate of potential radionuclides released are analyzed in this integrated system

The methodology for describing the sites can be divided into four steps:

i) to describe the glacial hydrology down to the ice sheet bed

ii) to model the water flux and chemical conditions from the ice bed interface down to repository depth at ~500 m depth in bedrock

iii) to model particle transport from repository depth up to and within the surface system (via e.g. taliks) and iv) to synthesize the models into a conceptual understanding of the integrated ice sheet, bedrock and surface systems. The last step includes using the hydrology, chemistry and catchment physiography together with output from a chemical mass balance model to demonstrate the nature of transport and accumulation in a periglacial environment. In addition to extensive field investigations of the hydrological processes of the ice sheet and in the geosphere, this methodology focuses on processes and properties in the periglacial environment. These surface system investigations use site specific properties of selected pro-glacial catchment areas with lakes not affected by surface ice sheet melt water and with presumed presence of through taliks. The aim is to identify and quantify glacial melt water composition in surface system discharge areas from the deep groundwater system (see figure 1).

As a final step, the chemical conceptual model, the hydrological model and the mass balance models of transport and accumulation in the catchment areas are combined into a system description. This description is divided into the main functional units and features identified in the drainage area ecosystems, describing the pools and fluxes of matter. The system description defines and quantifies the important processes that govern transport and accumulation from the deep groundwater to the surface and out of the catchment. A synthesis of all information is made and the possibility to upscale the identified processes to the landscape level is discussed. Finally, the system descriptions of the analogue sites are compared with the present (temperate) Forsmark site, for which extensive site specific information is available. This comparison focuses on the main differences that can be identified between a periglacial and a temperate climate in terms of system functions and fluvial transport of matter.

References

SKB, 2008. Site description of Forsmark at completion of the site investigation phase. SDM-Site Forsmark. SKB TR-08-05, Svensk Kärnbränslehantering AB.

Thermal and Dynamic Characteristics of the Small Valley-Side Huset Rock Glacier in Longyeardalen, Svalbard

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1 INTRODUCTION

In contrast to mid-latitude alpine rock glaciers, polar rock glaciers have rarely undergone intensive observations of thermal and dynamic characteristics. Here we report the first four years of monitoring of the small Huset rock glacier that constitutes a bulge toward the bottom of the Longyeardalen valley. Snow avalanches supply coarse debris constantly, which supports the advance of valley-side talus-derived rock glaciers (Humlum et al., 2007).

A 15-m borehole was drilled into the top surface of the Huset rock glacier in August 2005. Thermal probes were installed at 0.02, 1, 2, 3, 5, 7, 9, 11, 13, 15 m depths and inclinometers at 5, 9 and 13 m depths. These sensors provide data on ground temperature and internal deformation. Air temperature and snow depth are also monitored. Now four years of data have been obtained at 1–6 h intervals. In addition, differential GPS has provided movements of surface benchmarks from August 2009.

2 INTERNAL STRUCTURE

The borehole shows that the upper 2 m consists of a blocky active layer (composed mainly of platy sandstones), below which an ice-rich layer occurs down to 6 m depth with a layer of frozen blocks further down to 15 m. Two-dimensional geoelectric tomography displayed a variation in the thicknesses of the active layer and ice-rich layer along the slope, showing that the ice-rich layer is a few meters thick near the borehole, but thickening upslope to about 10 m.

3 2005–2009 THERMAL REGIME

The mean annual surface temperature fluctuated between -1.9°C (2005/06) and -3.5°C (2008/09) with overall cooling during the observation period, basically reflecting the air temperature. The cooling trend was followed by subsurface temperatures at depths shallower than 2 m, while it contrasted with continuous gradual warming from -4.3°C (2005/06) to -3.6°C (2008/09) at 9–15 m depths (Fig. 1). Snow depth also showed an interannual variation, exceeding 1 m in late winter of 2006 due to a snow avalanche, but rarely exceeding 0.3 m when snow avalanches did not reach the monitoring site.

The thermal data imply gradual warming of the permafrost irrespective of interannual fluctuation in air temperature, but further monitoring is needed before temperature trends can be identified.

4 INTERNAL DEFORMATION

The inclinometers installed in permafrost showed very small, but continuous tilting indicative of internal deformation. The largest tilting (0.07° in 4 yrs) occurred in the ice-rich layer at 5 m depth, while much smaller deformation (0.01° – 0.02° in 4 yrs) was recorded in the underlying frozen blocks at 9 and 13 m depths (Fig. 1). The tilting was two orders of magnitude smaller than that recorded in a small rock glacier located near the lower limit of permafrost in the Swiss Alps (Ikeda et al., 2008). Such minor deformation despite relatively steep slope (i.e., large shear stress) may suggest that permafrost temperature around -4°C is too cold to promote deformation, but in case of sustained high future air temperature movement may be accelerated.

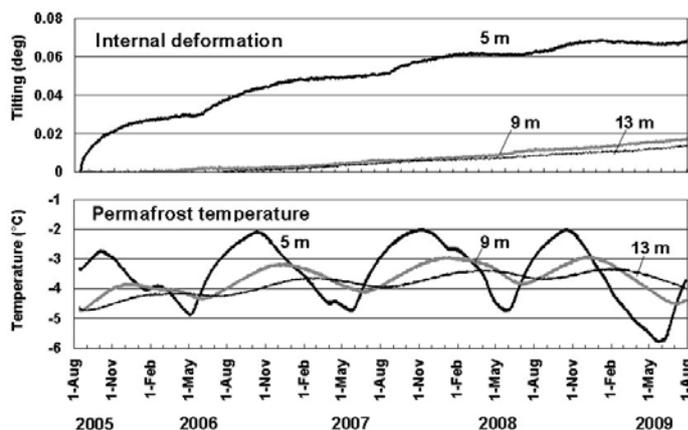


Figure 1. Permafrost deformation and temperature in Huset rock glacier 2005–2009.

References

- Humlum, O., Christiansen, H.H. and Juliussen, H. 2007. Avalanche-derived rock glaciers in Svalbard. *Permafrost and Periglacial Processes*, 18: 75–88.
- Ikeda, A., Matsuoka, N. and Käab, A. 2008. Fast deformation of perennially frozen debris in a warm rock-glacier in the Swiss Alps: An effect of liquid water. *Journal of Geophysical Research*, 113, F01021.

A Historical Approach to Solifluction in the Longyearbyen Area

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1 AIM

1.1 Introduction

During the last few years two solifluction monitoring stations have been installed on Svalbard. The first station is located outside the town of Longyearbyen between Adventdalen and Endalen (Harris et al 2007). The second station was recently installed on the west coast in the Kapp Linné area. These stations give us a clear picture of what rate solifluction is working at today. In addition, here we determine the average rate for the past 50-100 years involving not high tech equipment but a historical approach.

1.2 Objective

During spring 2009 a study was undertaken to measure numerous relict mining structures and buildings built during the initial mining boom (circa 1910-1912) and the later growth of Longyearbyen. These structures, being constructed on pillars, have been subjected to solifluction for their whole existence therefore they, in their current positioning, provide us with valuable long term data on solifluction direction and possibly speed.

1.3 Study Area

The total study area is comprised of three different locations. The oldest structures are believed to be the telegraph poles leading down the NW Longyeardalen valley wall from the remains of Mine 1. These were built in 1909-1910. Closer to the church in Longyearbyen there are remnant pillars from buildings burnt during the attack by the German army in September of 1943. The year of construction for these buildings, while yet still unverified, is assumed to be around 1912 (LAPISHA 2006). There are more pillars around these areas from other taubane routing buildings.

The other two study areas are located east of Longyearbyen where there's a line of cable car towers running eastward towards Endalen and mine 5, which join with towers coming from mine 5 at a hub at the opening of Endalen. From this hub more towers run south to mine 5 through Endalen. All of the tower posts are assumed to have been imbedded to the bottom of the active layer.

1.4 Methods

Collection of data consisted of measuring the amount and direction of the tilt and the coordinates of each pillar. This was done using a GEOClino digital GPS+Inclinometer. A standard Silva compass/inclinometer was also used to verify accuracy of the GEOClino.

The GPS points were then gathered into ARCGIS and plotted over some recent LIDAR DEMs at which time it was possible to extract local terrain slope and aspect information.

2 CONCLUSION

Under the assumption that the pillars can freely move above the permafrost while subjected to the solifluction of the active layer, using simple trigonometry we found for the Longyearbyen, Adventdalen and Endalen sites, solifluction rates of 1.50 cm y^{-1} , 0.78 cm y^{-1} and 1.60 cm y^{-1} respectively. Previously found values in Adventdalen (2 year study) 1.1 cm/yr and 3.2 cm/yr (Matsuoka and Hirakawa 2000) and in Endalen 1.2 cm/yr for 2006-07 (Harris et al 2007).

2.1 Further Work

More research into the building methods and dates is needed to more accurately determine which, if any, other processes may be affecting the movement of the pillars.

References

- LAPISHA (2006). Industrial Heritage in the Arctic: Research and Training in Svalbard, August 2004, Final Report. P. Martin, MTU.
- Matsuoka, N. and K. Hirakawa (2000). "Solifluction resulting from one-sided and two-sided freezing: Field data from Svalbard." *Polar Geoscience* **13**: 187-201.
- Harris C, Luetsch M, Davies MCR, Smith FW, Christiansen HH, Isaksen K. 2007. Field instrumentation for real-time monitoring of periglacial solifluction, Permafrost and Periglacial Processes 18, 1, 105-114. DOI: 10.1002/ppp.573

Thermokarst in Siberian Ice-Rich Permafrost – Characteristics and Potential Evolution

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1 INTRODUCTION

Thermokarst is one of the most obvious types of permafrost degradation in arctic landscapes. Its role in a changing climate system has been addressed in many recent studies focusing on carbon release, changes in water and energy balances, etc. Some of them point out an especially high relevance of thermokarst processes in ice-rich permafrost sediments (Ice Complex) of the Yedoma landscape in Siberia.

The modern inventory of thermokarst landforms in these landscapes comprises different evolutionary stages with characteristic morphometry. Evolving thermokarst on Yedoma uplands is represented by circular lakes completely filling their basins. As these thermokarst lakes grow, they eventually coalesce with neighboring lakes and/or drain partly or completely. The remaining thermokarst basins (alasses) feature steep slopes, flat floors, and smaller alas lakes. Permafrost aggradation and subsequent degradation can lead to multiple cycles of secondary thermokarst within alasses accompanied by modifications of initial alas and lake morphology.

Thermokarst lakes on Yedoma uplands have a stronger transformative impact on permafrost sediments, landscape character, and environmental processes than thermokarst lakes in alasses. Taliks forming underneath thermokarst lakes on Yedoma uplands allow for the activation of physical and biochemical processes in the Ice Complex sediments altering their structure and composition that had been conserved for thousands of years. The sediments in alasses, however, have already been reworked and do not represent the characteristics of the very ice-rich permafrost of the surrounding Yedoma uplands. We investigate the characteristics of different stages of thermokarst landforms in Ice Complex deposits of the Siberian Lena River Delta regarding their morphometry and spatial distribution using remote sensing and GIS. Based on this inventory we assess the potential extent of future thermokarst evolution in the study area.

2 DATA AND METHODS

A Landsat-7 ETM+ image mosaic of the Lena River Delta served as a basis for the automatic extraction of water bodies and manual digitization of alasses within the Ice Complex extent. Subsequent analyses of all thermokarst features were performed in ArcGISTM. Elevation data were extracted from a Digital Elevation Model derived from an ALOS PRISM triplet for the key site Kurungnakh Island. The resulting dataset was statistically tested for morphometric and spatial characteristics.

3 SOME PRELIMINARY RESULTS

22.3% of the Ice Complex area in the Lena River Delta is affected by thermokarst features. Lakes on Yedoma uplands account for a much lower proportion than lakes in alasses (2.3% and 20.0% of the Ice Complex area, respectively). Lakes on Yedoma uplands are on average an order of magnitude smaller than alasses. This suggests that drainage occurs in an earlier stage under current conditions than in the past when lakes were able to form large basins before they drained.

Larger lakes on Yedoma uplands reach greater depths and form deeper taliks. On Kurungnakh Island, 28% of the Ice Complex area is covered by thermokarst features with surfaces below 17 m asl. This contour level is the approximate boundary between Ice Complex deposits and underlying fluvial sands. Hence, the Ice Complex sediments in these thermokarst features should be completely depleted. In regions of higher relief energy, thermoerosion limits the extent of thermokarst by drainage, which is reflected in a much lower areal percentage of thermokarst features in these regions. Calculations for Kurungnakh Island show that only 33.9% of the area within the limits of Ice Complex sediments represent flat Yedoma uplands unaffected by thermokarst or thermoerosion. As distances to existing degradational features and fluvial channels become shorter the potential for considerable thermokarst activity before drainage occurs decreases substantially.

Periglacial Investigations in Louise Arner Boyd's American Geographical Society Expeditions to East Greenland, 1933 and 1937

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Polar exploration has been characterized as a “cult of masculinity.” Unlike many societies and clubs concerned with exploration and field research, the American Geographical Society (AGS) welcomed women into its ranks, from its inception in the early 1850s. Perhaps the most extraordinary woman of long-standing AGS affiliation was Louise Arner Boyd, described by the historian of geography J.K. Wright as “the world’s most enterprising woman explorer.” Boyd contributed substantially to polar science through her seven expeditions to the Arctic, most of them under AGS sponsorship. Several geographical features in East Greenland were named for her, including “Miss Boyd Land,” “Cape Louise,” “Louise Boyd Bank,” and “Louise Glacier.” “Geographical Society Land” was so-named because of Boyd’s work in the area under the auspices of the AGS.

Boyd’s extensive correspondence in the AGS Archives and elsewhere leaves no doubt about her ability to exercise authority over well-credentialed male scientists. Her expeditions employed scientists who eventually became highly influential in their respective fields. Among others, Boyd employed the renowned earth scientists J Harlan Bretz, Richard Foster Flint, A. Lincoln Washburn, and Noel E. Odell. Also on Boyd’s expeditions were AGS staffers O.M. Miller and W.A. Wood, who developed and applied innovative ground-based survey and photogrammetric techniques. Periglacial features formed an important part of the investigations on Boyd’s expeditions to East Greenland in 1933 and 1937. Documented features included talus slopes, ice-wedge polygons, nivation hollows, protalus ramparts, rock glaciers, and sorted patterned ground. Washburn, who later became the first Director of the Arctic Institute of North America, received his introduction to Arctic work on the 1937 expedition, on which he served as Flint’s graduate-student research assistant. He returned to the fiord region of East Greenland in the 1950s to conduct an award-winning program of research on periglacial weathering and mass wasting, eventually published in *Meddelelser om Grønland*.

Boyd’s expeditions to East Greenland in the 1930s were predictive of the type of collaborative campaign that after World War II would characterize government-sponsored and international scientific

efforts. “Planned as a unit,” Boyd’s expeditions were thoroughly integrated scientific enterprises that investigated a wide variety of natural phenomena within representative areas. The volumes resulting from this work, published as AGS Special Publications (Boyd, 1935; 1948), contain large-scale hydrographic and topographic maps, high-resolution glacier maps, extended treatments of East Greenland’s geology, glacial history, botany, hydrology, and a wealth of Boyd’s own stunning photographic work..

In 1955, Boyd became the first woman to fly over the North Pole. She was the first woman to serve as an AGS Councilor, was a signer of the Society’s Fliers’ and Explorers’ Globe, and received the Society’s Cullum Geographical Medal in 1938.

Boyd, an accomplished photographer, was responsible for the majority of the photographic documentation on her expeditions. Thousands of the images she created, never used in publications, are in the AGS Library in Milwaukee and the AGS Archives in New York, and are currently being cataloged. This presentation is the first public display of many of Boyd’s images of periglacial features. They provide detailed documentation of the historic periglacial investigations of Bretz, Odell, Flint, and Washburn.

References

- Boyd, L.A. (1935). *The Fiord Region of East Greenland*. American Geographical Society Special Publication 18, 369 pp. + slipcase containing maps, profiles, photos, data tables.
- Boyd, L.A. (1948). *The Coast of Northeast Greenland*. American Geographical Society Special Publication 30, 339 + slipcase containing maps, profiles, photos, data tables.

“A Characteristic Periglacial Landscape”: Cryoplanation Landforms of Beringian Uplands

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1 INTRODUCTION

Periglacial geomorphology has been described as “the study of surface decorations” in cold regions. Although features such as patterned ground, pingos, blockfields, rock glaciers, and solifluction lobes are common geomorphic elements in periglacial environments, they are relatively small landforms and the ability of associated processes to create a “characteristic periglacial landscape” has been questioned. Partially on this basis, some authors have even questioned whether periglacial geomorphology can continue as a relatively independent subdiscipline. A positive answer to this question depends to a large extent on whether periglacial processes can be shown to create extensive, visually and morphometrically distinctive landscapes.

2 THE CONCEPT OF CRYOPLANATION

Earth scientists conducting surveys of Beringian uplands in Alaska, Yukon, and Siberia during the early 20th century were perplexed by vast areas exhibiting flattened summits and sharply angled breaks in slope that give landscapes the appearance of giant stair steps. Geological surveys showed that the features are conspicuous throughout the unglaciated uplands of central Alaska, from the Canadian border to the Seward Peninsula. These landforms extend well into Canada’s Yukon Territory. Russian scientists found similar landforms in uplands throughout much of unglaciated Siberia. These features were not consistent with theories of landscape development extant at the time, such as those of William Morris Davis.

North American and Russian scientists developed similar hypotheses for the features’ formation, attributing their origin to the effects of late-lying snowbanks, described as a suite of geomorphic processes under the collective term “nivation.” Over the years a morphological classification and descriptive explanation of their genesis evolved.

The topic of cryoplanation lost popularity during the 1970s and 1980s, as geomorphologists focused attention on “process studies” that were necessarily concerned with relatively small study areas. Small-scale field experiments by Thorn, Hall, and others brought some of the assumptions about the efficacy of nivation into question, and the entire concept of cryoplanation has been questioned by some authorities.

Perhaps the most geographically extensive investigation of cryoplanation was undertaken in a doctoral dissertation by Reger, who collected data on nearly 700 cryoplanation terraces in unglaciated central and western Alaska. Unfortunately, except for a small summary paper, this study remains unpublished. Application of elementary spatial-analytic techniques to Reger’s data set by Nelson (1989, 1998) led to the conclusion that the geographic distribution of the features is to a large extent climatically determined, and that cryoplanation terraces can be considered as periglacial analogs of glacial cirques.

3 LOOKING FORWARD

With the reemergence of interest in broad-scale geomorphic landscapes, the development of tectonic geomorphology, and the increasing sophistication of data-logging and cosmogenic dating capabilities, re-focus of scientific interest on cryoplanation is appropriate. For the first time since development of the theory of cryoplanation, the tools necessary for rigorous testing of the concept are available. The authors of this presentation have begun a reexamination of the theory of cryoplanation using contemporary analytic methods, including cosmogenic dating, geographic information science, remote sensing, and high-resolution field data loggers. Unglaciated Beringia provides opportunities for the study of cryoplanation landforms that are unsurpassed anywhere else in the world.

References

- Nelson, F.E. (1989). Cryoplanation terraces: periglacial cirque analogs. *Geografiska Annaler* 71A(1-2): 31-41.
- Nelson, F.E. (1998). Cryoplanation terrace orientation in Alaska. *Geografiska Annaler*, 80A(2): 135-151.

Hiorthfjellet Rock Glacier – towards an Understanding of Geomorphology

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1 SVALBARD ROCK GLACIERS

Mapping of Svalbard rock glaciers have revealed more than 500 rock glaciers on the archipelago. Most rock glaciers are found in coastal areas, situated below the escarpment that delimits the inner part of the strandflat. Svalbard rock glaciers are assumed to be less than 60 m in thickness and a length less than 500 m. The permafrost base is probably far beneath the base of the rock glaciers.

The geomorphology of these features has been discussed since Olav Liestøl (1962) linked them to slope processes, but the development and processes are not known in detail. This is partly due to uncertainty in the extent of the late Weichselian ice sheet in the area and partly due to few detailed process studies. The geomorphology of Svalbard rock glaciers varies considerably, and there is obviously a complex interaction of processes forming them.



Figure 1. View of the Hiorthfjellet rock glacier from Longyearbyen in June 1998. The rock glacier is situated on the south-western slope of Hiorthfjellet (905 masl.). The total length of the rock glacier is 400 m and maximum depth is estimated to less than 50 m. Parts of the steep front is at the angle of repose of approx. 40°. This site is part of the excursion program for EUCOPIII (Photo: J.L. Sollid).

The Hiorthfjellet rock glacier is one of the few Svalbard rock glaciers that have been investigated measuring surface velocities and inner structures using georadar and resistivity measurements (Ødegård et al 2003). This paper presents new data on surface velocities and discusses these data related to previous field data and interpretations. A revised concep-

tual model is discussed with emphasis on the complexity of the front processes.

2 SURFACE VELOCITIES

Surface velocities on Hiorthfjellet rock glacier have previously been measured using traditional geodetic methods. Surface velocities were found to on the range 9-10 cm year⁻¹. In a cross profile with 5 measurements there were no significant differences between velocity vectors (length and direction). The measured surface strain is very small on the order of 4-8 x 10⁻⁵ year⁻¹ (Ødegård et al 2003).

New surface velocity data are based on air photo interpretation with scale 1:5000 from 1995 and 2006. The new results show a larger spread in surface velocities, but generally confirm the previous results. The surface layer of the rock glacier has a sheet-like flow with minimal drag from the sides. It is not possible from the air photos to clearly identify a shear zones on the slopes of this rock glacier due active gravitational processes. However, the front of the rock glacier shows interesting variations in surface slope that could be linked to a shear zone.

3 DISCUSSION

Understanding the complexity of the front processes is of crucial importance in understanding the development and geomorphology of the Hiorthfjellet rock glacier. There is a decreasing surface gradient towards the front, which most likely is caused by an increasing accumulation of debris at the base as the glacier progress. The rigid surface layer resists longitudinal compression. A combined interpretation of georadar-, resistivity and surface velocity measurements suggests a thickness of the supersaturated surface layer of 25-30 m.

References

- Liestøl, O. 1962. Talus terraces in Arctic regions. *Norsk Polarinstituttets Årbok 1961*: 102-105.
- Ødegård, R.S., Isaksen K., Eiken T., Sollid J.L. 2003. Terrain Analyses and Surface Velocity Measurements of the Hiorthfjellet Rock Glacier, Svalbard. *Permafrost and Periglacial Processes* 14: 359-365.

Holocene Solifluction Processes in a Mediterranean Mountain Environment (Sierra Nevada, Spain)

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1 INTRODUCTION

Numerous papers have focused on the present-day activity of solifluction processes (Matsuoka, 2001), but only a few of them have been addressed to reconstruct the past activity of solifluction landforms. Most of these studies have been undertaken in mid and high latitudes. We provide a chronological framework for Holocene solifluction processes in a semiarid mountain environment from the Mediterranean region.

Sierra Nevada is a high massif located at 37°N that contains the highest peaks in Western Europe outside the Alps. Terrain above 2500 m a.s.l. is strongly shaped by the Pleistocene glaciations. During the Holocene, periglacial processes have been dominant at elevations between 2500 and 3000 m, where our study area is located. Hundreds of solifluction landforms are distributed in San Juan and Rio Seco valleys.

2 METHODS

We examined sections from tens of solifluction landforms. Samples were extracted from each lithostratigraphic unit for standard laboratory analyses: grain size measurements, organic matter content, iron fractions and X-ray fluorescence. Pollen grains from organic layers were concentrated for dating purposes. Up to 17 AMS datings provide a tentative framework for solifluction activity in Sierra Nevada.

3 SOLIFLUCTION CHRONOLOGY

Present-day geomorphological monitoring has recorded very low solifluction displacements in Sierra Nevada (Oliva et al., 2009), which suggests that solifluction landforms must have generated under more propitious climate conditions than present. The stratigraphy of solifluction landforms shows an alternation between organic layers and coarse-grained clastic sediments. Organic layers are characterized by high organic matter contents, a silty matrix and low gravels content. Mineral units are composed basically of gravels and sands, with low organic proportions and are interpreted as solifluction deposits.

The most intense solifluction phases during the Mid-Late Holocene in Sierra Nevada correspond to the Neoglacial period (3.6-3.4 ka BP) and the Little Ice Age (850-700 and 400-150 a BP). Other solifluction advances occurred between 5-4, 3-2.8, 2.5-2.3 and 1.8-1.6 ka BP (Oliva et al., 2009).

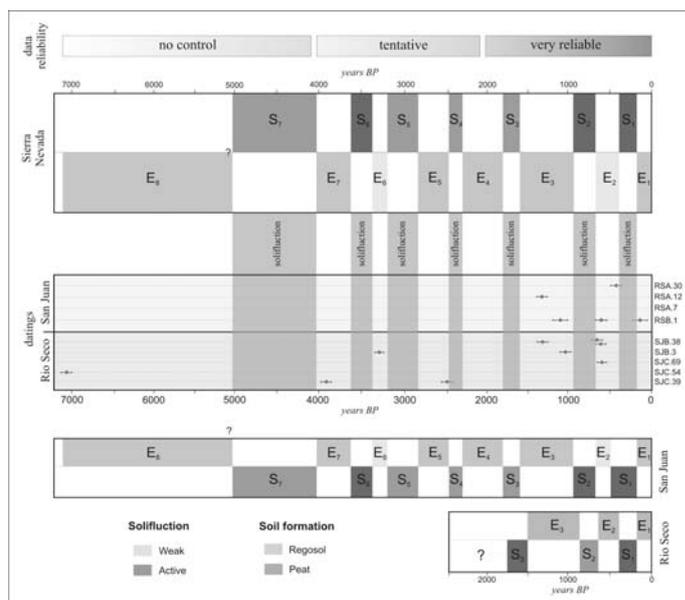


Figure 1. Solifluction/soil development chronology.

4 DISCUSSION AND CONCLUSIONS

Seven solifluction/soil development cycles have been determined in Sierra Nevada for the last 7 ka BP. Cold and/or wetter phases during the Holocene triggered solifluction whereas warm periods were propitious for soil development. According to moisture availability, soils were more or less developed: wet phases favoured peat growth and arid periods induced regosol formation.

References

- Matsuoka N. 2001. Solifluction rates, processes and landforms: a global review. *Earth-Science Reviews* 55: 107-134.
- Oliva, M., Schulte, L. & Gómez Ortiz, A. 2009. Morphometry and Late Holocene activity of solifluction landforms in the Sierra Nevada (Southern Spain). *Permafrost and Periglacial Processes* 20(4): 369-382.

Stratified Slope Deposits in Cold Maritime Environments in the Mountains of Tierra Del Fuego (Argentina)

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Stratified slope deposits have been studied in Tierra del Fuego (Fueguian Andes), at 800-1100 m asl. The study consisted of detailed geomorphologic mapping of selected areas and sedimentology of the deposits. These were analyzed at the surface and in several pits ≤ 1.5 m deep. Selected samples were analyzed in the laboratory in order to obtain a characterization of texture and composition. The Fueguian Andes are characterized by wide, locally straight, valleys with steep margins (slopes sometimes $\geq 40^\circ$) and primarily alluvial floors. The general morphology of the landscape mainly results from the distribution of different lithological units, outcropping in E-W oriented bands. The rock types consist of volcanoclastics, slates, philytes, amphibolites, slightly metamorphosed sandy mudstones and quartz veins. The region is located in the Sub-Antarctic zone and has an annual average atmospheric temperature of about -2°C , with a temperature maximum $\leq 15^\circ\text{C}$ and the minimum not lower than -11°C . Ground temperature varies largely annually, seasonally, and daily.

The results of this study indicates that generation, transport and sedimentation of clasts are affected by topography, but also by the existence of snow cover. A thick snow cover provides estabilization of the ground temperatures during the winter, but as it forms and melts during the fall and spring, respectively, numerous freeze and thaw cycles are generated that lead to fragmentation of the rocky substratum. The difference in slope inclination is of major importance. It was observed a change in the sedimentary characteristics between steepy slopes (more than 40°) that typically show unsorted solifluction deposits, and those of slopes between 15 and 30° characterized predominantly by stratified deposits. In stratified deposits, the difference in particle size is influenced not only by the steepness of slope but also by the type of active process, such as debris flow, solifluction or snow flow. Some sorting is also due to frost heave that, is greatly influenced by the deposit grain-size distribution and is progressively less effective as the steepness of the slope increases. This sorting is less effective in deposits developed on a slaty substratum.

Rock Glacier Kinematics in the Central and Southern Swiss Alps

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1 INTRODUCTION

Permafrost is a widespread phenomenon in the Alps. In Switzerland, it covers approximately 5% of the country's area. Due to the sensitivity of rock glacier creep to ground temperature evolution, the understanding of rock glacier dynamics and creep represents a major interest in periglacial geomorphology (e.g. Käab et al. 2007).

In the Central and Southern Swiss Alps, only few studies have been carried out on rock glacier dynamics and knowledge on permafrost distribution is still limited. The goal of this study is to contribute to the research on permafrost in these areas by measuring surface movements on several selected rock glaciers.

2 STUDY AREA AND METHOD

For this study, ten rock glaciers have been selected between the Gotthard massif and the Cima di Gana Bianca massif (Lepontines Alps of the Tessin). All landforms are located at elevations comprised between 2300 and 2600 m a.s.l.

The method used is the Real-Time Kinematics GPS. This technique provides measurements of displacement rates with accuracy often better than 3 cm (Lambiel & Delaloye 2004). Two field campaigns have been conducted between June and October 2009. 20 to 40 points have been measured on each rock glacier. Annual horizontal surface velocities have been calculated on the basis of the measured movements.

3 RESULTS AND DISCUSSION

The fastest movements are encountered on the Monte Prosa-N rock glacier, where annual horizontal surface velocities raise 0.65 m a^{-1} . The slowest movements have been measured on the Klein Furka and Blauberg rock glaciers, where annual horizontal surface velocities remain below 0.1 m a^{-1} . For the other rock glaciers, horizontal surface velocities are comprised between 0.15 and 0.55 m a^{-1} (Table 1).

For the moment, the length of the measurement sets is too short to make comparisons with other data of

the Swiss Alps. In order to better understand the dynamics of these rock glaciers across time, a monitoring should be undertaken annually. For the future, we plan to continue the GPS monitoring and to implement other survey methods (e.g. geophysical prospecting and ground surface temperature monitoring) to improve the knowledge on rock glaciers internal structure and provide information on the permafrost state in the Southern Swiss Alps.

Table 1. Maximal horizontal surface velocities measured on the different rock glaciers.

Rock glacier	Horiz. surf. velocity m a^{-1}
Monte Prosa-N	0.65
Cavagnoli	0.55
Piancabella	0.50
Pièi	0.30
Cadlimo	0.30
Monte Prosa-S	0.20
Pizzo Nero	0.15
Gütsch	0.15
Klein Furka	0.10
Blauberg	0.10

References

- Käab A., Frauenfelder R. Roer I. 2007. On the response of rockglacier creep to surface temperature increase. *Global and Planetary Change* 56: 172-187.
- Lambiel C. & Delaloye R. 2004. Real-time Kinematic GPS of creeping Mountain Permafrost. *Permafrost and Periglacial Process* 15: 229-241.

Annual Ring Studies on Plants in Permafrost Areas of the High Arctic

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1 GROWTH OF ARCTIC HERBS AND SHRUBS

Most perennial plants in the high arctic develop annual rings with a width from 0.05 mm/y to a maximum of 0.3 mm/y. Dwarf shrubs reach an age of 50 to 140 years (e.g. *Betula nana*, *Salix arctica*, *Salix polaris*, *Empetrum nigrum* or *Cassiope tetragona*) whereas herbs of various families with distinct rings live between 3 and 35 years. Table 1 illustrates the age structure of 36 high arctic zone herbs and dwarf shrubs which varies from 2 to 26 years (the latter: *Melandrium triflorum*) in herbs and from 4 to 145 (the latter: *Dryas octopetala*) years for shrubs.

The analysis of annual rings in plants of the high arctic is a scientific challenge: Most plants are creeping, form eccentric stems/rings, and growth occurs only on the protected side near or in the soil. During years with extremely cold summers they do not form rings at all or rings exist only on small parts of the stem. Processes of mass movement on permafrost ground like (episodic) solifluction and continuous soil creeping may injure the stem and destroy locally living tissue and/or induce scars. All these signs of disturbances can be used for the reconstruction of summer temperatures, the intensity of soil movement and even rare mechanical events like landslides. (Figure 1)

Table 1. Age of 29 arctic herbs and 7 dwarf shrubs from Svalbard (1), Yamal (12), NE Greenland (18) and Banks Island (5)

Group	Age (y)			
	1-5	6-10	11-20	21-145
Herbs	18	9	1	1
Dwarf shrubs	1	1	2	3

2 ENVIRONMENTAL FACTORS

A better understanding of solifluction and creeping processes influenced by climatic change is crucial. Predictor variables describing and modelling them have already been identified from morphology, exposition, soil mechanics, and microclimate of each site within arctic research programmes supported by sophisticated instrumentation. Standardised networks for continuously recording the data together with the results of mass movement are still lacking due to the complex technology and high costs.

3 INDICATORS FOR CLIMATE CHANGE MODELLING

As a proxy for climate variation annual tree rings have frequently been evaluated whereas the potential of arctic herbs and dwarf shrubs has not yet been explored in detail.

The productivity of arctic plants responds mostly to summer temperature and soil water content with clear effects on cell size and cell wall thickness. Therefore we suggest the use of appropriate herbs and shrubs as a supplemental information source for mass movement processes where data gaps between well-equipped monitoring stations otherwise cannot be filled. Averaged variation of soil displacement including flow anomalies could be analysed much easier. Additionally, the development, calibration and reliability of deterministic or multivariate statistical models describing slow rhythmic processes could be improved as well.

Once the steering variables of permafrost active layer dynamics in solifluction sheets or nonsorted circles/stripes are found, annual ring analysis of herbs and shrubs could improve the explanatory power of models, e. g. when searching for discriminant functions during dichotomic yes/no-decisions.

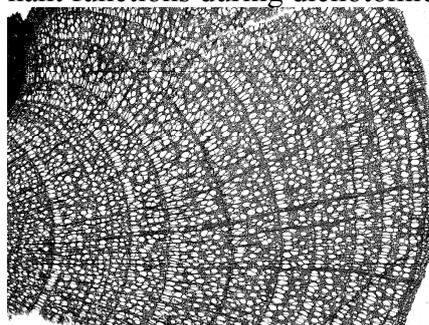


Figure 1. Annual rings in the dwarf shrub *Dryas octopetala*, indicating some environmental influences

References

- Schweingruber, F.H., P. Poschlod 2005. Growth rings in herbs and shrubs: life span, age determination and stem anatomy. *Forest Snow and Landscape Research* 79(3), 195-415.
- Harris C. et al. 2008. Solifluction processes on permafrost and non-permafrost slopes: Results of a large-scale laboratory simulation. *Permafrost and Periglac. Process* 19, 359-378.

Stone Fields and Patterned Ground Development on Platforms in Elephant Island, Maritime Antarctica

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1 INTRODUCTION AND STUDY AREA

In the ice-free areas of the South Shetland Islands there is a wide typology of periglacial landforms, being patterned ground and stone fields the most common. The studies about the origin and evolution of stone fields in Antarctica are scarce. In this work a detailed study has been carried out in the area of Stinker Point, located in the western coast of Elephant Island (aprox. 61°10'15''S-55°19'44''W). Main elements of the relief in this area, as in many other places in the South Shetland Islands, are a succession of raised marine platforms at different altitudes between the sea level and more than 140 m a.s.l. In the studied area the mentioned landforms have been studied at altitudes between 40 and 90 m a.s.l.

2 OBJECTIVE AND METHODS

The aim of this work is to determine the key elements controlling the development of patterned ground and stone fields on platforms of the South Shetland Islands, Studying also their characteristics and geographical distribution.

A detailed geomorphological map of the Stinker Point area has been compiled to study the landforms spatial distribution. The surface formations types, their internal structure and texture, vegetation cover, slope, drainage, bedrock, and active layer have been analysed in 32 sites with patterned ground and stone fields in Stincker Point. The results of the study carried out in the study area has been compared with our observations in different sites of the archipelago.

3 RESULTS AND CONCLUSIONS

The most common periglacial landforms in ice free areas of the South Shetland Island are patterned ground, in all its varieties. In the whole archipelago the stone fields occupy 47% of the surface with periglacial features. Patterned ground and stone fields are the most extensive periglacial landforms and together account for about 80% of the area occupied by landforms of periglacial origin on platforms in the South Shetland Island. Patterned grounds shows a wider altitudinal rank, occurring between 10 and 140 m a.s.l. The stone fields have been mapped between 20 and 50 m a.s.l. In all cases the mentioned landforms are mainly related to platforms, planes and low-gradient slopes.

Stinker Point area is located in a permafrost environment with an active layer 15-55 cm depth. Patterned ground is mainly generated on relatively deep surface formations, primarily till, with well classified mainly sandy textures. They are located on poorly drained areas with constant feed snow melt and water saturated in summer. The stone fields are generated on minor watersheds, in well drained or dry areas, and mainly on weathering poorly sorted clast mantles. Snow cover, substrate lithology and thermal regime have similar involvement in the presence of both studied landforms types.

Protalus Lobe Dynamic on Pyrenean High Mountain

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1 STUDY SITE

On the northern side of Western Maladeta Peak, (3,185) closed to the granite cliffs, protalus lobe have developed placed joint Maladeta rock glacier. The protalus lobe is located 2,900 m a.s.l. in the massif of Maladeta, the highest massif of the Pyrenees (Aneto peak, 3,404 m a.s.l.). It is a small feature, 113 m length x 80 m width, characterised by big blocks without fines in surface and a talus of >40° with fines in the front.

Protalus lobes have been defined as nonglacier in origin, although the ice genesis could have originated from buried snowpatch, buried icepatch or segregated and interstitial ice. Protalus lobe have also been described as embrionic rock glaciers and it is not conclusive whether permafrost conditions are necessarily required for its development (Barsch, 1996; Whalley and Azizi, 2003). But the thermal conditions definitely required for the development of active protalus lobe are soil temperatures below zero for several years, and a local permafrost environment. Currently there are not many observations on protalus lobe and they are from both Arctic and Antarctic environments mainly.

2 OBJECTIVE AND METHODOLOGY

The aim of this work is to know about the surface dynamic and the structure of protalus lobe. These landforms can be used as indicators of mountain permafrost and permit us to know the activity of cryospheric processes at the recently deglaciated high mountain. They also are useful indicators of the effectiveness of sediment transfer from the high mountain in temperate environments.

To know the surface dynamic of the Maladeta protalus rampart we must approximate to the thermal regime of the feature, in order to increase the knowledge about the geomorphic site and environmental setting, the inner structure and the surface displace-

ment. A detailed geomorphological map with dynamic information on wall, debris slopes and surface of the protalus lobe have been made. On the protalus lobe we have placed eight points surveyed by Differential Global Positioning System since 2008. Thermal conditions of soils have been established by BTS measurements and datalogger. Finally GPR sounding have been carried out on the surface of the protalus lobe.

3 RESULTS

The rock glacier is located in a permafrost environment as it has been registered by the soil thermal regime. The DGPS survey on the Maladeta protalus lobe have permit us to know about the surface movement of the protalus lobe. It is slow, a medium advance of 7 cm yr⁻¹, homogeneous on the surface and with the same direction, NE, on all control points. The body of protalus lobe is thinning, with a small vertical movement of 5 cm yr⁻¹. The data on both horizontal and vertical movement point to low rates but continuous activity in accordance with the protalus lobe root feed processes. The studied feature is active, and one of the most important, joint rock glaciers and debris talus, for the debris transfer system of the Iberian high mountain environment. We need further studies on protalus lobe to improve the knowledge on processes related to frozen bodies in the temperate high mountain.

References

- Barsch D. 1996. Rock Glaciers. Indicators for the Present and Former Geocology in High Mountain Environment. Springer Verlag; Heidelberg.
- Whalley, W. B., and F. Azizi, 2003. Rock glaciers and protalus landforms: Analogous forms and ice sources on Earth and Mars, *Journal of Geophysical Research*, 108(E4), 8032, Doi:10.1029/2002 JE001864.

Frost Mounds Morphodynamic in Marginal High Mountain (Picos de Europa, NW Spain): a Geomorphological and Environmental Approach

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1 STUDY SITE

Picos de Europa is the highest massif of the Atlantic Mountains of SW Europe (Torre Cerredo, 2.648 m), only 20 km to the Cantabrian Coast. It was the only high mountain area glaciated during the Little Ice Age in the Cantabrian Range (40°N-5°S, NW Spain). Nevertheless, the response of the historical glaciers to the climate changes of the last century has meant the deglaciation of the massif. Important differences in melt speed of ice bodies according to the topographic character of glacial cirques have been noted. These glaciers have turned into debris-covered ice patches, so at present there are no glaciers in Picos de Europa. Nival and periglacial processes in the cirques have changed the glacial landscape into a rocky high mountain landscape. The cryonival belt (above 2,300 m), is characterised by a thermal conditions that imply gelifraction, gelifluction and cryoturbation processes limited to the more favourable areas. On these places are located frost mounds and patterned grounds.

2 OBJECTIVE AND METHODOLOGY

The aim of this work is to know the surface dynamic and structure of frost mounds in this marginal high mountain environment. These landforms can be indicators of a sporadic and semi-temperate mountain permafrost and permit us to know the activity of cryospheric processes in relation with buried ice patches inherited from the Little Ice Age. The interactions exist between the ice bodies and the periglacial processes and landforms, active and sensitive to the current environmental changes, are analyzed. They are a privileged “indicator of changes”, point to the morphogenetic answers of marginal mountain environment in warming environments, and the importance of the local topoclimatical factors.

Different techniques have been implemented in this work: topographical survey, terrestrial photogrammetry, GPR surveys, ground thermal measurements (datalogger), debris surface analysis and geomorphological mapping.

3 RESULTS

In the cirque of Jou Negro, Traslambrión, Palanca and Forcadona, between 2,200-2,300 m a.s.l. there are gelifluction lobes and frost mounds. The largest frost mounds examples are located over the Jou Negro buried ice patch. In the mass of clasts covering this ice patch, epigenic ice has been observed under a clasts cover to 30-60 cm depth.

According to the thermal records from the most favourable, northern orientation and highest summits (Peña Vieja Goup: 2,510 m.a.s.l., 2,600 m.a.s.l.; Llabrión Group: 2,535 m.a.s.l.), the current environmental conditions are not cold enough to bear the development of mountain permafrost. Nevertheless, thermal records with mean annual temperatures of below 0°C on the moraines of Jou Negro and the surface of buried ice patches at altitudes of around 2,200 m a.s.l. testify to the existence of an local permafrost environment.

The preservation of ice remnants and intense periglacial processes as cryoturbation indicate a mean annual temperature of about 0°C and a clear disequilibrium of these phenomena with the present-day environmental conditions. The low rate of solar radiation, the consequent snow protection during the summer and the presence of buried ice are the keys to explaining the thermal ground regime. All of them permit the preservation of the ground ice and the development of frost mounds.

Glacially-Derived Permafrost

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The two well-known types of permafrost are syngenetic and epigenetic. Syngenetic permafrost is formed through a rise of the permafrost table during the deposition of additional material on the ground surface, while epigenetic permafrost is formed through penetration of the permafrost base in previously deposited sediment. Besides these two main types, permafrost can form by incorporating glacier ice during and after glaciation. Yet, the current definition of permafrost specifically excludes glacier ice (IPA Multi-language glossary on permafrost and related ground-ice terms 1998) and there lacks a formal recognition of transformation glacier into permafrost. The Late Pleistocene was extremely favorable to formation of syngenetic permafrost and glaciation. With rapid warming during the Pleistocene–Holocene transition most glaciers in Northern Hemisphere melted and a big part of permafrost degraded. In the contemporary permafrost region however, most permafrost that had formed during the Pleistocene persisted. Although the Pleistocene–Holocene transition led to disappearance of most glacier ice in the contemporary permafrost region, some of them has persisted in a buried state. Before the 1950s, most massive ice in permafrost was believed to be the buried glacier ice. Later studies showed that many large bodies of massive ice that previously had been identified as buried glacier ice were actually syngenetic permafrost ice-wedges. This fact and the contemporary concept of segregated ice formation, which does not set a limit to formation of massive tabular ice, practically exclude wide involvement of glacier ice in permafrost development.

Our work in Alaska (Shur et al. 1994, Jorgenson and Shur 2008, Kanevskiy et al. 2008) and studies in Canada (Murton 2004, 2008), Russia (Kaplyanskaya and Tarnogradskiy 1976, Astakhov et al. 1996, Solomatin, 1986), and Kazakhstan (Gorbunov 1970) show that buried glacier ice is more common in permafrost than it is recognized in the permafrost literature. In Alaska, we have observed processes of incorporation of glacier ice in permafrost at terminal moraines. Buried ice bodies are represented often by basal ice because upon thawing, debris from glacial ice accumulates at the surface, provides insulating soil material, and prevents further thawing. Thus, soil-rich basal ice

has greater potential to persist in a buried state than does englacial ice with little debris. In the discontinuous permafrost zone of Alaska Range, we have observed several hundred years old permafrost presented mainly by buried englacial and basal ice and permafrost with buried basal ice of Pleistocene age in the continuous permafrost zone.

We propose to consider the *glacially-derived permafrost* as a special type of permafrost and to differentiate it from syngenetic and epigenetic permafrost. It forms by incorporation of thick masses of already frozen material. Consequently, the glacially-derived permafrost is characterized by buried englacial ice or (and) by basal ice. Glacially-derived permafrost degrades very differently from typical syngenetic and epigenetic permafrost. Upon its thawing, the material typically collapses into deep kettle lakes, or forms large retrogressive thaw slumps caused by the flow of collapsed soils at very low gradients across a well lubricated thawing surface. Glacially-derived permafrost in the discontinuous permafrost zone of Alaska was encountered at different depth and in some cases it was too late to take it into account during design of roads. Thawing of such permafrost under structures leads to their unbearable settlement.

Glacial and Periglacial Modification of Impact Craters in Utopia Planitia, Northern Plains of Mars

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1 INTRODUCTION

A variety of landforms possibly indicative of late-Amazonian glacial activity have been identified on Mars. These include lineated fill in mid-latitude valleys, lobate debris aprons on the flanks of Tharsis Montes and within the Hellas impact basin, morainal and esker-like features in valleys and craters, and finally, concentric fill craters (Colaprete & Jakosky, 1998, Levy et al., 2009). On local to regional scales, impact craters are useful in studying glacial processes since their initial geometry is relatively predictable from their diameter. This facilitates the identification of post-impact modifications.

We present a case study in which we describe and discuss evidence of glacial flow having been initiated on the floor of an 11.5 km diameter crater (39.50°N, 105.6°E) in Utopia Planitia, Mars. The arcuate ridges, putative end moraine, and glacial-like flow lobe that we identify provide evidence for geologically recent glacial activity in the central region of the Utopia Planitia Basin.

2 TARGET CRATER CHARACTERISTICS

The crater has a depth/diameter ratio of ~ 0.1 , consistent with it being relatively young in age when compared with other craters in this region, many of which have been filled near to their rims and often exhibit concentric fill patterns. Gullies that exhibit the classic morphology (i.e., alcoves, channels, debris aprons) and whose source region is near the top of the inner wall are abundant within the crater.

The crater floor is marked by an arcuate structure near the base of the southern wall that has a long axis of ~ 6 kilometres, a width that varies between 50 and 500 metres and a height that varies between 20 and 50 metres based on photoclinometric measurements derived from images taken by the High Resolution Science Imaging Experiment (HiRISE) aboard the Mars Reconnaissance Orbiter and elevation data obtained from the High Resolution Stereo Camera (HRSC) aboard the Mars Express satellite. The structure is oriented concave towards the southern crater wall, has a sinuous, ridge-like morphology and has sharp crests across much of its length.

3 PROPOSED MORPHOLOGY

A variety of processes considered for the origin of the crater floor features but ultimately refuted include crater central uplift, aeolian, and gully and debris flow processes.

3.1 *Glacial Origins*

We suggest that the arcuate feature was emplaced by glacial processes based on the following observations: 1. the morphology of the feature is comparable with that of end moraines at the head of piedmont glaciers on Earth; 2. the geometry and morphology of the crater is consistent with glacial flow having occurred across its floor in a north-south direction; and, 3. there is substantial evidence for glacial-like flow having occurred within other craters in the region surrounding it.

3.2 *Regional Evidence*

As part of an ongoing study of crater modification by glacial and periglacial processes in the Utopia Basin, we have completed a survey of high resolution images within the coordinates 30-60°N, 75-120°E. Among our results is the identification of a region that contains features consistent with intra-crater glacial flow between 35-40°N and 100-115°E an area that includes the two previously discussed craters. We focus on this region because there has yet to be a systematic study of glacial processes within the Utopia Basin, and the craters that we discuss have yet to be presented in a glacial context.

References

- Colaprete, A., Jakosky, B. M., 1998. Ice flow and rock glaciers on Mars. *Journal of Geophysical Research-Planets* 103: 5897-5909.
- Levy, J., Head, J.W., Marchant, D.R. 2009. Concentric crater fill in Utopia Planitia: History and interaction between glacial "brain terrain" and periglacial mantle processes. *Icarus*, 202: 462-476.

Assessing the Impacts of the Hydrological Drainage Networks Upon the Characteristics of Permafrost in the Upper Kuparuk Region

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1 INTRODUCTION

1.1 Water track definition

Water tracks are saturated linear-curvilinear features which rapidly and efficiently transport surface runoff downslope through a surficial organic layer; where the flow is confined to the near surface by an impermeable layer (Figure 1). In the foothills of the Alaskan Arctic, continuous permafrost is the impermeable layer that creates drainage networks which are much more immature and spatially extensive than those in more temperate regions. They are a unique hydrologic feature that over time transports water through the same pathway. This continual process also thermally impacts the underlying ground regime, causing subsidence and a slight depression to form as the channel (Jorgenson et al., 2008). The movement of water also results in a higher proportion of nutrients to accumulate which provide favourable conditions for vegetation growth. Previous research demonstrate that the shrub vegetation is related to the quantity of water typically present/adjacent to the channel (Walker et al., 1994).



Figure 1. Surficial drainage network with water tracks, northern foothills of the Brooks Range, Alaskan Arctic.

1.2 Thermal erosion

Some water tracks have undergone extensive thermal erosion when runoff flowed over massive ice under water track due to either an extreme precipitation event or the influence of warmer ambient temperatures. Understanding and categorizing different types of water tracks will assist in predicting which are more vulnerable to thermal erosion and under

which conditions the rate may be accelerated. Water tracks are also an important feature as they tie climate, soil, hydrology and biota to permafrost in an interdisciplinary fashion.

2 METHODOLOGY

Fieldwork carried out in the summers of 2008 and 2009 involved differential GPS measurement to establish a network of ground-verified points where vegetation and soil characteristics were quantified. Over 500 points were distributed throughout the headwaters of the Kuparuk Basin. Water tracks were then classified into four different categories based on vegetation and soil moisture: moist *Betula nana*; wet and wet non-satiated *Betula nana* and *Salix pulchra*; wet satiated *Salix pulchra*; and saturated *Eriophorum sp.* and *Augustofolium sp.* Analysis involved comparing the organic layer depth & composition, active layer depth and shrub heights in each category to estimate the impact of the drainage network on the underlying permafrost characteristics.

3 CONCLUSIONS

Preliminary analysis showed the deepest active layers (at time of measurement) occurred where water tracks were classified as saturated *Eriophorum sp.* and *Augustofolium sp.* The water track category wet satiated *Salix pulchra* was not always associated with an increase in active layer depth likely due to high gravel content as these features may represent a remnant of the old glacial drainage network.

References

- Jorgenson, M.T., Shur, Y.L., and Osterkamp, T.E., 2008, Thermokarst in Alaska, in Kane, D.L., and Hinkel, K.M., eds., Ninth International Conference on Permafrost, Volume 4: Fairbanks, AK, Institute of Northern Engineering, p. 869-876.
- Walker, M.D., Walker, D.A., and Auerbach, N.A., 1994, Plant communities of a tussock tundra landscape in the Brooks Range Foothills, Alaska: Journal of Vegetation Science, v. 5, p. 843-866.

Geomorphometric Analysis of Patterned Ground on Svalbard from High Resolution Stereo Camera (HRSC-AX) Data: Analogue Studies for Mars

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1 INTRODUCTION AND BACKGROUND

Because the landscape of Svalbard is under the influence of a dry and cold climate it is a good analogue for comparative Martian studies. The mean annual air temperature is about -5°C at the sea level in central Svalbard and the mean annual precipitation is about 180 mm. One of the most widespread landforms within the periglacial landscapes of Svalbard are polygonal structures formed by thermal contraction cracking of the ground. Furthermore, stone circles and nets are particularly well developed on flat areas indicating cryoturbation (i.e. freeze-thaw cycles).

A variety of similar shaped surface features on Mars has been interpreted as periglacial in origin. The study of their characteristics, distribution and spatial associations would therefore allow conclusions on the climate history of Mars. Particularly, polygon patterns are well explored and used to infer the presence of permafrost on Mars.

Dedicated studies of terrestrial analogues, however, are required to obtain reference information needed to interpret remote sensing data of Mars. Successful analogue studies involve field investigations providing information about subsurface conditions and physical properties of periglacial structures. In addition, terrestrial remote sensing data are necessary that have a quality and scale comparable to that of planetary data.

2 DATA AND METHODS

Extremely high-resolution images and topographic information of periglacial landforms on Svalbard were acquired in summer 2008 with HRSC-AX an airborne version of the HRSC camera currently orbiting Mars. Color orthoimages (20 cm/pixel) and corresponding Digital Elevation Models (DEM) with a cell size of 50 cm and a vertical accuracy of 20 cm are available for a total of seven regions on Svalbard. HRSC-AX data from western and central Svalbard were used for quantitative terrain and remote sensing analyses.

In July/August 2009, a field campaign was conducted on Svalbard at two study areas. The main objectives were the description and analysis of periglacial landforms by measurements and observations of geomorphological characteristics, soil properties, and collection of soil samples. The observed parameters are used as ground truth dataset for the HRSC-AX measurements. One study area is situated on Kvadekusletta in western Svalbard. The site is renowned for its well-developed sorted stone circles. A second study area is the Adventdalen valley in central Svalbard. It offers a variety of periglacial landforms and particularly thermal contraction crack polygons in different settings.

3 FIRST RESULTS AND DISCUSSION

Stone circles, nets, and labyrinths were observed on Kvadehuksetta inside of comparably moist and shallow depressions dammed by beach ridges. Diameters are ranging from 0.5 m to 5 m. Raised rims (up to 50 cm high) consist of stones with diameters of a few centimeters. Sorted structures on Kvadehuksetta are always located in areas in which adequate water supply exists. Recently observed sorted circles on Mars show significant differences to the structures on Svalbard with respect to shape and dimension, and stone ring particle size. Maximum diameters of individual Martian stone circles range to 23 m and stones within the rings have diameters of 1 – 2 m.

Ice wedge polygons were analyzed on many flat and inclined surfaces in the Adventdalen. High center polygons in the upper valley appear inactive as frost cracking could not be observed. They have diameters of 10 – 20 m and are separated by well-developed wide and deep troughs. Various polygons on Mars share the characteristics of the high center polygons in the upper Adventdalen. HRSC-AX data have sufficient spatial and vertical resolution to enable the three-dimensional geomorphometric analysis of polygonally patterned ground and the interpretation of small-scale variation in periglacial environments.

Consequences on Groundwater Discharge Pattern in a Permafrost Region due to Continental Ice Sheet

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1 INTRODUCTION

1.1 Reasoning

The assessment of groundwater flow models that includes the physical aspect of permafrost as well as continental ice sheets with basal melting is a very large, however immensely important, issue in order to fully understand the long-term performance of a geological repository for spent nuclear fuel.

1.2 Strategy

The strategy has been to use simplified top boundaries e.g. glacial melt water and surface temperatures) in groundwater flow simulations to provide the performance assessment with relative values and uncertainty ranges on e.g. discharge patterns.

As permafrost is conceptually viewed upon as a tight layer inhibiting recharge as well as discharge; the general expectancy of the discharge pattern of groundwater in a permafrost environment are associated with taliks, available at a site.

The ice sheet is simulated with theoretical ice elevation models with melt water beneath so that subglacial pressures equalise the floatation pressure.

2 PERMAFROST TREATMENT

2.1 Property change

Typically in groundwater flow modelling permafrost is treated by a reduction in permeability related to the temperature below the freezing point. The values for a frozen ground are based on material estimates using the values found by Burt & Williams 1976. In our model the reduction in frozen ground is typically ten orders of magnitude; resulting in that frozen ground being less permeable than 10^{-20} m^2 .

3 RESULTS

3.1 Discharge pattern

As expected, the main discharge is found to be associated with the lake taliks at the simulated site. However, some groundwater also discharges

through the frozen ground along some of the defined fracture zones.

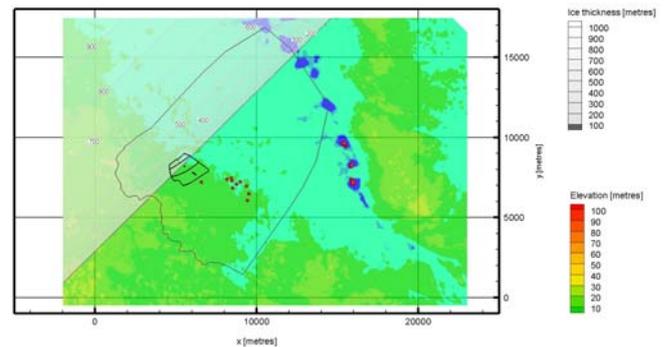


Figure 1. Discharge pattern associated with an ice sheet in permafrost environment. Ice sheet advances from northwest towards southeast.

In Figure 1 a dot illustrates a discharge location from one of a total of 6916 possible release locations within the repository at 465 mbsl, some 350 meters beneath the base of the permafrost. Approximately 98% of these released particles discharge in taliks marked as darker.

Are the 2% discharging through permafrost only a numerical effect of flow through a very low-permeable porous media? Or maybe such discharge is plausible as an ice sheet generate a sub-permafrost over-pressure of some 3-4 MPa.

Field reports of fracture zones discharging in deep permafrost regions where high sub-permafrost pressures exist have been reported, e.g Fengton & Guangzhong 1988.

Hence, although a result of the porous media flow it is also suggested that high sub-permafrost pressures may maintain open fracture systems or even open-up such systems during glacial melt water discharge.

Reference

- burt T.P., Williams P.J. 1976. Hydraulic conductivity in frozen soils. *Earth surface processes* Vol. 1: 349-360
- Fengton L., Guangzhong T. 1988. Hydrogeological features in Huolahe Basin of North Daxinganling, Northeast China. *In: Fifth international conference proceedings on permafrost* Vol. 1 ISBN 82-519-0863-9.

Mud-Boil Dynamics in Adventdalen, Svalbard: High-Resolution Monitoring of Frost Heave and Active Layer Dynamics

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1 INTRODUCTION

Patterned ground is the representative-feature in Arctic periglacial landscapes. Flat tundra surfaces composed of fine-grained soils are generally dominated by ice- and soil-wedge polygons, hummocks and mud-boils. The formation of mud boils is related to various mechanisms including but not limited to differential frost heave, convection cell-like circulation, diapirism and load casting. However, there have been few detailed observations highlighting mud-boil dynamics. We report one year of monitoring data (2008–2009) on movement, structure, thermal and hydrologic conditions at a mud-boil site in Adventdalen, Svalbard.

2 METHODS

Automatic monitoring stations were installed in August 2008. The monitored parameters are vertical soil displacement on the center of a mud-boil and the surrounding vegetation trough, soil temperatures and volumetric soil moisture contents at different depths, all of which were recorded every three hours. Five frozen soil cores (70–102 cm long) were collected in May 2009 to observe frozen structure in active layer and measure ice content. In addition, DC resistivity tomography monitoring was applied to understanding active layer freeze-thaw dynamics from June to early October in 2009.

3 RESULTS

3.1 Frost heave and thaw settlement

Figure 1 shows the first year monitoring data of frost heave and soil temperature. Frost heave differed in the amount, timing and rate between mud boil and vegetation trough. However, the total heave amount was not registered because it exceeded the upper limit of extensometer at the mud-boil. A longer extensometer installed in the summer of 2009 guarantees a more precise measurement of frost heave. The mud boil and vegetated trough also showed differential thaw subsidence in summer. The subsidence almost completed by the end of June when the active layer reached about 40 cm depth, which implies that ice lenses accumulated within the upper 40 cm of the

active layer. However, subsidence was also observed in the late summer of 2008. This movement may have originated from thawing of ice lenses at the bottom of the active layer, which possibly developed during upward freezing from the permafrost table (cf. Mackay, 1980).

3.2 Frozen soil structure and ice content

The frozen soil cores showed thin ice lenses (< 3 mm) had developed both in the upper 40 cm below mud-boils and in the transient layer (ca. at 80–90 cm deep). Similar volumetric ice contents were observed in mud-boils and vegetation troughs, which decreased from about 60% near the surface to about 30% at the lower part of the active layer (40–80 cm deep), and increased again to about 60% at the transient layer.

3.3 DC resistivity tomography

Resistivity profiles in summer displayed a distinct boundary propagating downward with time, which was consistent with the thaw depth measured by mechanical probing. In early winter, a high resistivity zone slowly descended from the ground surface, which is likely to reflect a decrease in the unfrozen water content and the growth of ice lenses. Furthermore, low resistivity spots appeared just below the near-surface high resistivity zone, implying that migration of unfrozen water promote ice segregation.

Reference

Mackay, J. R. 1980. The origin of hummocks, western Arctic coast. *Canadian Journal of Earth Sciences* 17: 996–1006.

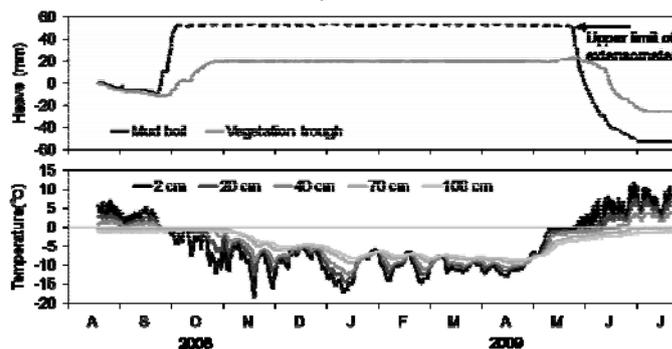


Figure 1. Vertical displacement at the surface and soil temperatures at the mud boil site, 2008–2009.

Posters Monday, cont.

Soils in Periglacial Regions:

in Kapp Lee

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DEM Based Analysis of Soil Cover in Discontinuous Permafrost Zone on Landscape Level (the European North-East)

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1 INTRODUCTION

Satellite images in soil mapping couldn't be interpreted directly upon color pixels corresponding to definite vegetation classes. So groundtruth field survey based on vegetation contours is conducted before mapping procedure. Topographic pattern should be accounted during soil mapping. In present-day GIS Digital Elevation Model (DEM) is considered to be as a basis of topographic information. Computer-based analysis of DEM is used to reveal different features of landscape components including soils.

2 OBJECTS AND METHODS

Under Carbo-North research activities digital soil maps of intensive key sites were compiled using ArcGis 9.2. and ERDAS IMAGINE 9.0. software. During our research we used ASTER GDEM GeoTIFF images (coordinate system WGS84/EGM96, pixel resolution 20 m) as a digital representation of ground surface topography.

3 GEOGRAPHICAL BACKGROUND

Field study was conducted in the European North-East. The area is predominantly classified as discontinuous permafrost zone and (forest)-tundra region. Cryosols and Cambisols are typical soils on the drained terrain. Peat accumulation on high-lying topographic positions favors permafrost preservation in the soils (Cryic Histosols and Histic Cryosols). Low-lying topographic positions favor accumulation of insulating snow in early winter, creating local scale conditions unfavorable for permafrost formation (Hugelius & Kuhry, 2009).

4 RESULTS

DEM images were used for correction and analyses of large-scale digital soil maps. The comparison of soil polygons with DEM information allowed us to calculate such averaged values as drainage coefficient, altitude, aspect and slope degrees for major soil groups (table 1).

Table 1. Topographic parameters of the soil groups under study (Middle Rogovaya site)

Soil groups	Altitude, m asl	Slope, degrees	Drainage coefficient	Aspect, degrees
Fluvisols	66,58	5,12	1,0047	184,17
Histic Fluvisols	69,38	4,29	1,0035	171,99
Cryosols	72,79	4,01	1,0029	201,33
Cambisols	72,79	3,39	1,0021	184,19
Cryi-Folic Histosols	72,32	3,36	1,0020	192,94
Histic Cryosols	72,37	3,20	1,0020	193,71
Fibric Histosols	70,30	3,18	1,0019	195,83
Histic Gleysols	71,86	3,10	1,0018	178,95

DEM analysis of the site revealed that soils of the terrain are predominantly of south windward aspect (avg. 188°) which favors additional ground cooling in winter and permafrost preservation. Soils of fluvial terraces are classified as well-drained (slope degree $4 - 5^{\circ}$) and poorly drained soils ($3.1 - 3.2^{\circ}$) are occurred in low-lying positions on watershed terraces. Averaged slope degree for upland mineral soils ranges from 3.4 to 4° .

DEM files were used as a basis of topographic information during soil mapping of definite terrains such as peat plateaus, fluvial terraces and others. DEMs were created from isohypse digitizing upon topographic maps. It is shown organic layer thickness and permafrost depth still depend on topography.

5 RESUME

DEM based analysis of soil cover in discontinuous permafrost region allows to analyze influence of topographic pattern on soil formation. DEM appears to be as a digital topographic basis in present-day soil mapping based on interpretation of multi-spectral satellite images.

References

Hugelius G. and Kuhry P. 2009, Landscape partitioning and environmental gradient analyses of soil organic carbon in a permafrost environment. *Global Biogeochemical Cycles*, 23, GB3006, doi:10.1029/2008GB003419.

Periglacial Activity Controls Plant Biomass Patterns in Subarctic Landscapes

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1 INTRODUCTION

High-latitude ecosystems are characterized by low air and soil temperatures, permafrost, a short growing season, and limited vegetation productivity. These ecosystems are considered to be particularly sensitive to disturbance which is a “partial or total destruction in vegetation or the underlying substrate caused by some external factor”. Physical disturbances associated to soil instability and other periglacial processes have viewed as important driver of vegetation dynamics and productivity. These disturbances cause changes in resource availability and biomass losses. Geomorphologic disturbances such as avalanches on mountain slopes have particularly strong effects on tree-line vegetation, but very few quantitative studies have examined the role of periglacial disturbance on high-latitude vegetation biomass. In this study we explore the role of four key periglacial processes on the plant biomass distribution in high-latitude mountain landscape of northernmost Fennoscandia using novel multivariate statistics.

2 MATERIAL AND METHODS

The study sites are in NW Finnish Lapland (ca. 69°N, 20°50'E), in the subcontinental northern Scandes. The altitude of the mountains ranges from 460 to 1030 m above sea level (a.s.l.). The biomass sampling was made along 15 altitudinal transects on five mountain massifs (n=200). To quantify the rate of physical disturbance, percentage cover of different geomorphologic processes was mapped for each study site. Generalized Linear Mixed Model (GLMM) with random effects was built to explain observed variation in biomass in relation to periglacial process variables. To overcome the problems of spatially clustered data points, we fitted the mountain massif and transect as two categorical random terms into the GLMMs.

3 RESULTS

The effects of cryoturbation, solifluction and nivation were negative and fluvial activity positive on the biomass pattern. All four explanatory variables were statistically significant ($p < 0.05$) in GLMM

analysis, the effect of cryoturbation was strongest followed by solifluction and nivation (see Fig. 1). In areas with high cryoturbation activity the biomass values were typically lower than 100 g/m², whereas the values were often above 2000 g/m² in sites without any active cryoturbation.

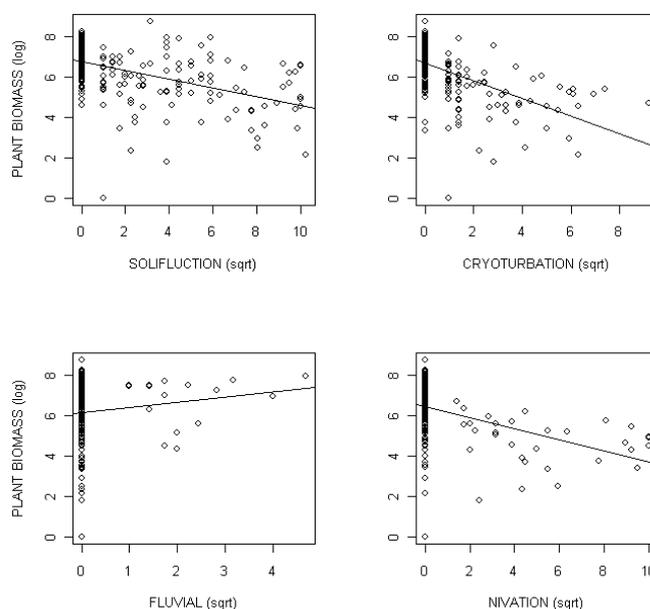


Figure 1. Relationship between above-ground plant biomass (log-transformed grams per square meter) and process activity of solifluction, cryoturbation, fluvial and nivation (square-root transformed percentage values).

4 DISCUSSION

We consider that cryoturbation, nivation and solifluction are important negative drivers of landscape level plant biomass patterns, whereas fluvial activity has a positive role in biomass distribution. Our findings suggest that disregarding physical disturbance in climate change impact models may cause a significant source of error in global biomass scenarios. These results are important given the need for improved mapping of high-latitude vegetation, associated periglacial processes, and to predict patterns of carbon flux.

Imprints of Permafrost and Cryogenic Processes Preserved in Paleosols in Europe

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1 INTRODUCTION

One of the factors that determine soil formation is climate. Paleosols, either buried or exposed under changing surface conditions, preserve evidences of environmental conditions under which they were developed (Retallack, 2002). The study and interpretation of features preserved in paleosols are complementary parts of the paleo environmental reconstruction. The climatic fluctuation of the Quaternary Glaciation Age (Pleistocene) largely influenced the development of soils. The paper will discuss the evidences, recording and interpretation problems of permafrost and cryogenic processes in soils formed mainly in periglacial areas adjacent to the past ice sheets in Europe.

2 EVIDENCES OF PERMA-FROST AND CRYOGENIC PROCESSES IN PALEOSOLS

The most common processes that influence landforms and soil processes are cryoturbation, cryosuction, frost heave, gelifluction, and solifluction. The common results of the processes are pattern ground, polygonal icewedges, deformation of sediments and horizons, soil crack formation, fragipan formation, matrix veins and lenses (Washburn, 1969).

3 EXAMPLES FOR PRESERVED PALEO FEATURES IN SOILS OF EUROPE

Examples for evidences of permafrost and cryogenic features have been reported by many authors from almost all countries influenced by quaternary glacial and periglacial environment. The poster will illustrate some of the most striking features of permafrost and the listed cryogenic features from different locations of Europe. The documented features are important scientific evidences in the reconstruction and timing of paleoclimatic environments and the understanding the polygenetic nature and sequences of soil formation processes of the studied soils.

4 RECORDING AND CLASSIFICATION OF PRESENT AND PAST CRYOGENIC FEATURES

In the most commonly used guidelines for soil descriptions published by FAO and USDA, the permanently frozen layers are indicated by “f” after the capital letter of the master horizon. Buried layers are designated with “b”, and the cryoturbed layers with “@”. The paleo nature of those features can not be indicated in the current genetic horizon designation systems, and should be elaborated. However the buried paleosols can be described with full classification in the WRB (World Reference Base for Soil Resources). If the overlying recent soil is classified at the first level (according to WRB rules), the name of the buried soil is placed after the name of the overlying soil adding the word “over” in between (eg. Technic Umbrisol over Rustic Podzol). If the buried soil is classified at the first level, the overlying material is indicated with the Novic qualifier.

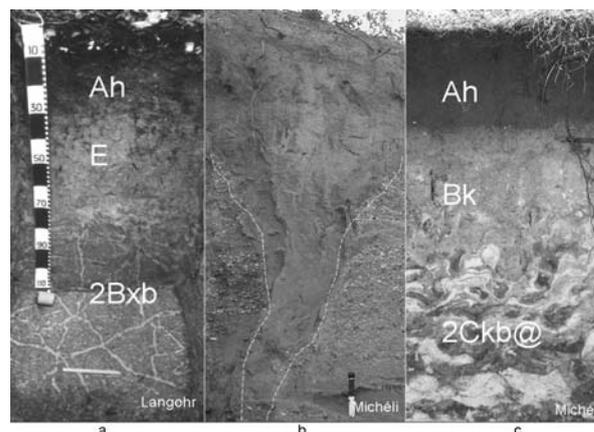


Figure 1. Examples for cryogenic processes preserved in soils. a. cracking, fragipan formation b. ice wedge c. cryoturbation

References

- Retallack, G.J., 2001. *Soils of the Past*. 2nd ed. New York, Blackwell Science, p.365.
- Washburn, A. L. 1969. *Periglacial Processes and Environments*. Edward Arnold, USA p.172.

Temperature Regime of Soils in the Kolyma Lowland

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In the Kolyma Lowland (North-Eastern Yakutia), we study the temperature regime of the zonal soils using temperature loggers from 1998 in a frame of the International Project "Circum Polar Active Layer Monitoring" (CALM). The observation net consists of seven sites in the Lowland: five sites in the Tundra zone and two ones in the Northern Taiga sub zone. Following parameters were calculated using the temperature monitoring data: mean annual soil temperature (MAST), mean summer soil temperature (June-August) (MSST), accumulated positive soil temperature (APST), accumulated ecologically sufficient soil temperature (AEST), mean twenty-four-hours soil temperature (MDST), durability of the ecologically sufficient soil temperatures ($\tau_{\geq+5}^{\circ\text{C}}$, DEST), durability of the active soil temperatures ($\tau_{\geq+10}^{\circ\text{C}}$, DAST), and positive temperature heatturn through the soil surface (PTHS).

The temperature regime of loamy tundra cryozems is varied with latitude in tundra. In the Typical Tundra (site R13, 70° 05' N), MSST is 2.3° C at the 20 cm depth and 0.2° C at the 50 cm depth. The mentioned parameter is 3.8° C (20 cm) and 0.4° C (50 cm) in the Southern Tundra (site R22, 69° 19' N), and 4.6° C and 1.1° C in the Northern Taiga (site R18, 68° 45' N) respectively. The APST increases from 250° to 430° (20 cm) and from 40° to 175° (50 cm) in last-mentioned row. The DEST at the 20 cm depth is 7-30 days in the Typical Tundra, 20-40 days in the Southern Tundra, and 40-50 days in the Northern Taiga. The ratio AEST/APST increases also: 41% in the Typical Tundra, 59% in the Southern Tundra, and 74% in the Northern Taiga.

Winter soil temperatures are varied in a zonal row sharper than summer ones. A steep increase of the winter soil temperature is a result of the warming effect of plant and snow cover in the zonal row. The warming effect is higher in the taiga landscapes than in tundra. A sharp increase of MAST takes place between Southern Tundra (MAST=-7.0...-7.2° C) and Northern Taiga (MAST=-2.5...-2.8° C) as a result of MAST change under the impact of winter temperature.

Equally with the site latitude, snow cover and vegetation type, the soil granulometric composition is an important factor which controls a soil temperature regime. During the summer season, the drained sandy podbur (site R21) is a most warm soil among all soils we study. The sandy podbur is characterized with the MSST = +6.4° C (20 cm depth) and MSST = +3.8° C (50cm). It is the highest MSST among any tundra soils also among any loamy soils in the North Taiga sub zone. The DEST is equal 50-85 days (20 cm depth) for tundra sandy podbur, and the DAST reaches 25 days. No increasing the MDST upper 10° C was observed at other sites.

PTHS we calculated is a quantity of heat energy which is spent to heat the soil from zero temperature (C) to maxima positive temperature. To compute the PTHS, the temperature curves enveloping were calculated using the soil temperature monitoring data. The PTHS values increase in the following row: tundra cryozems (PTHS = 3600-3700 kCal/m²*year), taiga grey soil (5200 kCal/m²*year), tundra podburs (6000...6200 kCal/m²*year). This row shows that formation of different soil profiles is controlled by the quantity of heat energy which is spent for the soil heating.

This work is supported by US NSF (project CALM) and RF RFBR (project 08-05-00175).

Posters Monday, cont.

The Thermal State of Permafrost:

in Kapp Schultz

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Permafrost Response to Climate Change at Illisarvik, Western Arctic Coast, Canada.

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1 INTRODUCTION

Canada's western Arctic coastlands have experienced climatic warming of about 0.8°C/decade since 1970. Two boreholes were drilled to 50-m depth in frozen sandy sediments of undisturbed permafrost near the Illisarvik field site on Richards Island, N.W.T., to determine the response of ground temperatures to this warming. The second borehole was completed as part of activities for the Canadian contribution to the Thermal State of Permafrost project of the International Polar Year.

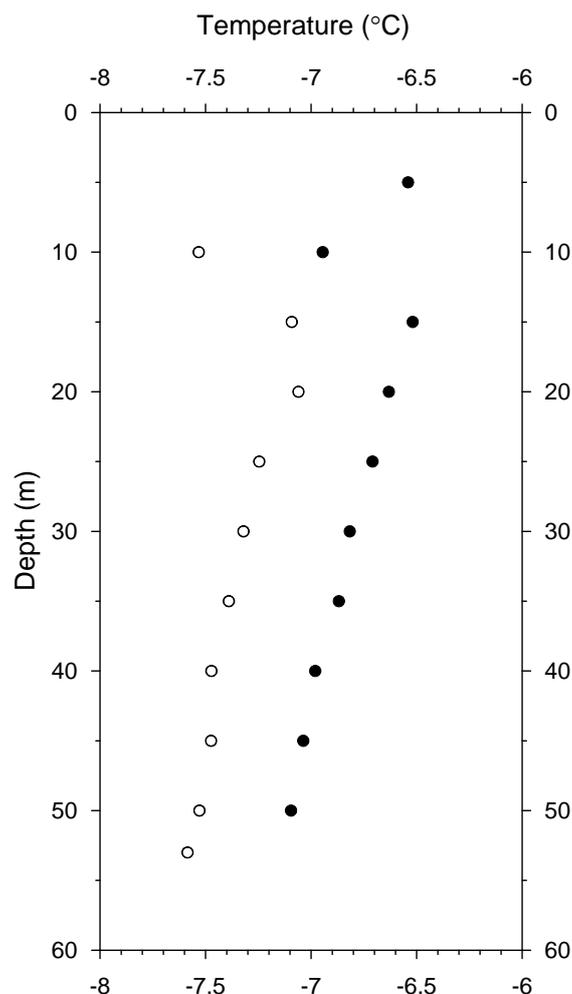
2 METHODS

The two sites are about 1 km apart, and are to the north and to the south of Illisarvik. The boreholes were drilled by water jet. The first hole, drilled in August 2006 was completed to 50-m depth in 2.5 hours. The second, drilled in July 2008 to 53 m, was completed in 4 hours. A casing of 1-inch steel pipe was installed in each hole, into which was placed a cable, with calibrated thermistors at 5-m intervals. The drill holes were filled with water, which froze around the casings. The casings were filled with non-convective fluid to provide contact between the sensors and the surrounding ground.

3 RESULTS

The temperature profiles from both boreholes collected on 22 August 2009 are presented on the figure. These profiles show seasonal variation in the upper 15 m, but below this they indicate long-term warming of permafrost. The mean temperature at 20-m depth of about -7°C is 1.5°C higher than data collected in this area in the 1970s. The parallel profiles from the two sites indicate a consistent thermal history for the area, although the near-surface temperatures are about 0.5°C higher at one site. A simulation of the ground thermal regime at Illisarvik has been completed, using the climate record from Tuktoyaktuk, about 50 km from the site, which is representative of conditions at Illisarvik. Surface temperatures were calculated with an n-factor of 0.9 in summer, and conduction through a 20-cm thick snow pack in winter. Near-surface

ground thermal properties were calibrated from soil conditions at the sites, and ground temperatures obtained to 5-m depth by data logger over two years. The geothermal flux was the regional value of 0.05 Wm⁻². The simulation was equilibrated with the climatic regime of 1925-71, and this provided a deep temperature profile congruent with data from central Richards Island. Subsequently the simulation reproduced the temperature profile presented below. Thus validated, the simulation has been used with climate scenarios for the region to demonstrate that widespread permafrost degradation is not currently projected to occur before 2100.



Spatiotemporal Variability of Permafrost Degradation on the Qinghai-Tibet Plateau

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1 ABSTRACT

Based on the analyses of data from five major meteorological stations in the permafrost regions, 60 boreholes for long-term monitoring of permafrost temperatures, and 710 hand-dug pits and shallow boreholes, the spatiotemporal variations of the responses of permafrost on the Qinghai-Tibet Plateau to climate change was examined through the relationships of the rising rates in air, ground surface and ground temperatures. The decadal averages of and the increases in the mean annual air temperatures during the past 45 years (1961-2005) were the largest and most persistent during the last century. The mean annual air temperatures rose by 1.12°C , with an average increase rate of 0.025°C/a , in which the increase rate was 0.012°C/a in the 1980s, 0.034°C/a in the 1990s, and 0.039°C/a during 2001-2008. The mean annual ground surface temperature increased by 1.34°C at an average rate of 0.030°C/a , in which the warming rate was 0.03°C/a in the 1980s, 0.035°C/a in the 1990s, and 0.048°C/a during 2001-2008. The rates of changes in ground temperatures were -0.01 to 0.015°C/a during 1976-1985, 0.01 - 0.032°C/a during 1986-1995, and 0.016 - 0.07°C/a during 1996-200.

The change rates in the depths of the permafrost table were -1 to 2 cm/a during 1976-1985, 1 - 3 cm/a during 1986-1995, and 2 - 10 cm/a during 1996-2008. The areal extent of permafrost on the Qinghai-Tibet Plateau shrank from 1.50×10^6 km² in 1975 to 1.2583×10^6 km² in 2006, i.e. an reduction of about 0.2417×10^6 km² (16.1%), in which about 0.14×10^6 km² (or about 60% of total reduced area of permafrost) occurred during the period from 1996 to 2006. Due to the climate warming beginning in the late 1980s, warm permafrost started to degrade, and degradation gradually expanded to the areas of transitory and cold permafrost, and the rising in temperatures penetrated deeper with damped amplitudes with depth, as deep as 50-70 m at present. Persistent climate warming has resulted in the transition of the permafrost degradation from the relatively stable phase to the gradual degrading phase. In particular, regional degradation of permafrost has been accelerated due to the pronounced rising in air temperatures during the past 10 years. It is projected that, under a persistent warm climate during the next few decades, the degradation of permafrost would accelerate, and apparent changes in the distributive features of permafrost should be anticipated.

Permafrost Thermal Conditions in Periglacial Landforms in Svalbard during IPY 2008-2009

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1 INTRODUCTION

During IPY 2007-2009 the Nordenskiöldslund Permafrost Observatory was established in central and western Svalbard as part of the Norwegian IPY 'Permafrost Observatory Project: A contribution to the Thermal State of Permafrost in Norway and Svalbard (TSP NORWAY) research project, containing 12 new boreholes drilled into different periglacial landforms for continuous long-term ground thermal observations. The shallow permafrost boreholes installed during IPY are mainly located in the Longyearbyen and Kapp Linne areas in continental and maritime parts of central Nordenskiöldslund. In addition also a new borehole was drilled in Ny Ålesund, and an earlier established borehole in Svea, are presented here together with the boreholes from Nordenskiöldslund. All data are available through the Norwegian permafrost database NORPERM developed during IPY.

Here we present the different permafrost borehole sites and installations, which were operational during the IPY in Svalbard with respect to periglacial landforms, instrumentation and resulting data.

2 BOREHOLE INSTRUMENTATION AND SITES

All the 12 new boreholes were drilled in spring 2008 and instrumented in summer and autumn 2008 primarily with GeoPresicion thermistor strings with 10 sensors, and some with high resolution Campbell equipment with up to 25 sensors covering up to 38 m. The drilling was performed with a weasel-based hammer drill rig, and samples were taken regularly of the drill dust to determine mineral content. All holes were cased with PVC-tubes.

The boreholes are drilled one in a meltwater plain, 3 in a strandflat, one in an ice-cored moraines, one in a rock glacier, one in a block-field, one in loess, one in a solifluction sheet, one in a pingo and two in different parts of a snowpatch site and across regional climatic gradients to cover the variation of permafrost conditions in the Svalbard landscape. The borehole depths range from 5 to 38 m. Several boreholes are only in sediment, but 4 extend into bedrock below sediments.

3 RESULTS

The permafrost thermal IPY snapshot in Svalbard show permafrost temperatures at the depth of zero annual amplitude, or at the lowermost sensor located as high as at 5 m depth, ranging from as high as -2.3°C to -3.5°C in the boreholes in the most maritime west coast in Ny-Ålesund and at Kapp Linne, to as low as -5.2°C to -5.6°C at the borehole sites in the continental Adventdalen and Svea areas.

In the Adventdalen area (Fig. 1), permafrost temperatures at 5-15m depth vary between -3.2°C at the solifluction sheet in Endalen, -5.2°C at the mountain top at Janssonhaugen, -5.3°C at the blockfield at Gruvefjellet and -5.6°C in the loess terrace at the Old Auroral Station. The Endalen solifluction borehole has the highest permafrost temperature, due to a relatively thicker snow cover, reaching 50 to 60 cm during the IPY winters, and moister summer ground conditions. No significant difference appear between permafrost temperatures along the altitudinal transect from the bottom of the Adventdalen valley at 9 m a.s.l. via Janssonhaugen at 270 m a.s.l. to the summit of Gruvefjellet at 464 m a.s.l. Clear local warming of a thick snowpatch is shown with the top permafrost temperature being close to 0°C, and clear winter reduction in the ground temperature (Fig. 1).

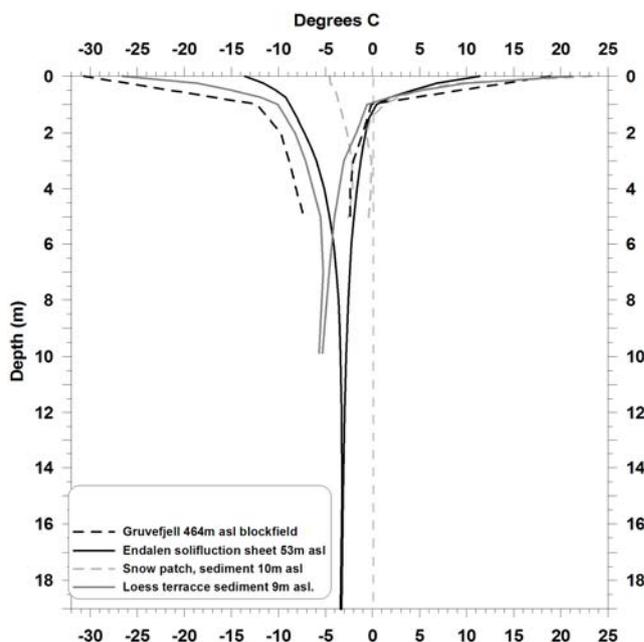


Figure 1. Permafrost trumpets for the year 2008-2009 from selected boreholes in the Adventdalen area.

Characterization of the Thermal Regime of the Upper Levels of the Active Layer along an Altitudinal Transect in the Sierras de Alvear, Fuegian Andes, Southern Argentina

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The thermal evolution of the uppermost 50 cm of the active layer was monitored over a one-year period at three sites located above tree line in the Monte Alvear region of the Sierras de Alvear, Fuegian Andes, Tierra del Fuego, southern Argentina (latitude 54° 40' 30'' S; longitude 68° 02' 30'' W).

The sites represent a range of elevations, ground materials and snow cover depths. Site 1 was established in a small, talus-derived rock glacier located at 797 m a.s.l., composed of angular blocks embedded in finer debris. Site 2 was set up in a solifluction sheet located in a mid-slope position at 975 m a.s.l. The ground material is a frost-weathered regolith composed of coarse sand and gravel, embedded in a matrix of fines. Site 3 was installed in a gently sloping surface from a summit area located at 1050 m a.s.l. At this site sorted stripes have formed on a regolith composed of coarse sand embedded in a matrix of fine sediment.

Boreholes 50 cm deep were drilled at each of the sites. These were equipped with four thermistor-type temperature probes connected to a multi-channel data logger. Probes were placed at the ground surface and at depths of 5, 20 and 50 cm. Hourly temperature data were collected continuously from February 1, 2008 to January 31, 2009.

An air temperature record covering an identical time span was obtained in the vicinity of Site 3. Mean annual air temperature was $-1,5^{\circ}\text{C}$.

Mean ground surface temperatures were $1,3^{\circ}\text{C}$ at Site 1, $0,4^{\circ}\text{C}$ at Site 2 and $0,6^{\circ}\text{C}$ at Site 3. The absolute amplitudes at the surface were $49,5^{\circ}\text{C}$ at Site 1, $37,7^{\circ}\text{C}$ at Site 2 and $26,9^{\circ}\text{C}$ at Site 3. At the 50-cm level mean ground temperatures were $1,1^{\circ}\text{C}$ at Site 1, $0,5^{\circ}\text{C}$ at Site 2 and $0,4^{\circ}\text{C}$ at Site 3. The absolute amplitudes at this level were $13,6^{\circ}\text{C}$ at Site 1, $9,5^{\circ}\text{C}$ at Site 2 and $8,5^{\circ}\text{C}$ at Site 3.

Five seasonal temperature regimes were identified: Positive temperatures of the active layer with occasional daily subzero events, occurred from early spring to early autumn at Site 1, and from late spring to early autumn at Sites 2 and 3; Cooling of the active layer beneath a thin, discontinuous snow cover, characterized by subzero active layer temperatures coupled with air temperatures. This regime occurred from early autumn to early winter at Sites 1 and 2, and from early to late autumn at Site 3; Subzero ac-

tive layer temperatures beneath a shallow, continuous snow cover. The connection between the atmosphere and the active layer was not blocked, but the atmospheric signal was attenuated. This regime occurred from early winter to early spring at Sites 1 and 2. At Site 3 it occurred from late autumn to early winter and from late winter to late spring; Subzero active layer temperatures beneath a thick, continuous snow cover. The connection between the atmosphere and the active layer was interrupted. This regime occurred in mid-winter, only at Site 3. A zero curtain regime occurred from early to mid-spring in the 50-cm level of Site 1. At Site 2 the whole active layer experienced this regime from early to late spring.

The timing and duration of seasonal regimes show a well-defined inter-site variation. The duration of the positive temperatures regime was maximum at Site 1 (6 months). The duration of the cooling beneath a discontinuous snow cover regime was similar at Sites 1 and 2 (3,5 months), reaching a minimum at Site 3 (1,5 months). Subzero temperatures beneath a continuous snow cover regime reached a maximum duration at Site 3 (4 months). The duration of the zero curtain regime was maximum at Site 2 (2 months). The seasonal snow cover at the three sites was shallow enough to allow the connection between the atmosphere and the active layer, except for Site 3 where a thick snow cover blocked this connection in mid-winter.

Key words: active layer, thermal regime, Fuegian Andes, Argentina.

ACKNOWLEDGEMENTS

This work was funded by the research projects CGL2004-03380/BOS and POL2006-PC091 (Ministerio de Educación y Ciencia, Spain), PGIDIT06PXIB239226PR (Xunta de Galicia, Spain) and BIOCON05/103-CARBOCLIM (BBVA Foundation).

Active Layer Thermal Regime at a Mountain-top Site from the Sierras de Alvear, Fuegian Andes, Southern Argentina

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A multiannual record of active layer temperature data, obtained in a monitoring site located in a mountain summit from the Monte Alvear region, Sierras de Alvear, Fuegian Andes, Tierra del Fuego, southern Argentina (latitude 54° 40' 30'' S; longitude 68° 02' 30'' W), is discussed.

The instrumented summit is a sub-horizontal, broad surface, covered by a mantle of angular rock fragments composed of Late Jurassic basalts and porphyrites. An extensive network of polygons up to 5 m wide enclosed by shallow trenches has formed in the underlying bedrock, presumably either by thermal-contraction cracking or by fracture widening. The centers of the polygons are occupied by sorted circles, consisting of an inner sector of sand and silt and a surrounding ring of large angular clasts. The degree of present-day activity of the bedrock polygons remains unknown. The inner sectors of the sorted circles experience heave displacements due to seasonal freezing.

A shallow borehole 130 cm deep was drilled in the centre of a sorted circle, located at an elevation of 1057 m a.s.l. The borehole was instrumented with eight thermistor-type temperature probes connected to multi-channel data loggers. Probes were placed at the ground surface and at depths of 5, 10, 20, 35, 70, 100 and 130 cm. Temperature data were recorded continuously at hourly intervals from mid-February 2006 to the end of January 2009.

In addition to ground temperatures an incomplete record of air temperature was obtained in the summit area. Mean air temperature from February 2008 to January 2009, the longest continuously recorded period available, was $-1,5^{\circ}\text{C}$.

Mean ground surface temperature during the ground recording period was $-0,5^{\circ}\text{C}$ and maximum and minimum absolute surface temperatures were $23,5^{\circ}\text{C}$ and $-9,5^{\circ}\text{C}$ respectively. At a depth of 100 cm mean ground temperature was $-0,5^{\circ}\text{C}$, maximum and minimum absolute temperatures were $1,1^{\circ}\text{C}$ and $-3,4^{\circ}\text{C}$ respectively, and absolute amplitude was $4,5^{\circ}\text{C}$. The lowest level (130 cm) experienced continuous subzero temperatures throughout the recording period. Mean ground temperature at this level was $-0,6^{\circ}\text{C}$ and absolute amplitude was $3,1^{\circ}\text{C}$.

Four main seasonal thermal regimes or temperature patterns have been identified in the active layer:

Positive temperatures pattern with occasional daily subzero events in the superficial levels. This regime attains its maximum annual duration in the upper 20 cm of the active layer, where it develops from mid-October to early April; Cooling of the active layer beneath a very thin, discontinuous snow cover, characterized by subzero active layer temperatures coupled with air temperatures. This pattern develops from early April to early June; Subzero active layer temperatures beneath a shallow, continuous snow cover. The connection between the atmosphere and the active layer is not interrupted, but the atmospheric signal is damped. This regime develops from early June to mid-October; A zero curtain develops between the levels of 35-cm and 100-cm. It attains a maximum annual duration of three months (from mid-October to mid-January) at the 100-cm level.

The upper permafrost (130-cm level) experiences sustained negative temperatures close to 0°C from mid-October to June, interrupted by a cooling regime from June to September, followed by a short-lived subzero warming period.

At this site the maximum thickness of the active layer is estimated to be in the close vicinity of 130 cm.

The obtained multiannual ground temperature record has enabled to confirm the occurrence of permafrost on the higher summits of the Sierras de Alvear.

Key words: active layer, permafrost, thermal regime, Fuegian Andes, Argentina.

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This work was funded by the research projects CGL2004-03380/BOS and POL2006-PC091 (Ministerio de Educación y Ciencia, Spain), PGIDIT06PXIB239226PR (Xunta de Galicia, Spain) and BIOCON05/103-CARBOCLIM (BBVA Foundation).

Ground Temperature Regime at Three (Sub-)Alpine Permafrost Sites in the Swiss Alps – Analysis of Perennial Minilogger and Borehole Data

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1 MOTIVATION

At the University of Würzburg the working group “Mountain and Subarctic Environments (MouSE)” is dealing with questions concerning permafrost sensitivity and dynamics (e.g. degradation/aggradation) in alpine and subalpine environments. One approach is the comparison between temperature data from five shallow boreholes. An analysis of the perennial record of these data is presented, focusing on the interannual variability and the differences between the three sites.

2 FIELD SITES AND INSTRUMENTATION

All three borehole sites are located in the Upper Engadin (Swiss Alps). Since 2006 five boreholes were drilled in different permafrost environments and geomorphological settings. In addition 1 m snow poles were installed at the drill sites equipped with 4 miniloggers each. Further information on the site characteristics is specified in Tab. 1.

Table 1. Characteristics of the 3 borehole sites.

	Muragl	Bever Valley	Murtèl
<i>Field site</i>	Glacier forefield	Talus slope	Glacier forefield
<i>Boreholes</i>	BH1: July 2006 BH2: Sept. 2006	BH1: Sept. 2006	BH1: Oct. 2008 BH2: Oct. 2008
<i>Depth</i>	8 m	8 m	10 m
<i>Elevation</i>	BH1: 2670 m BH2: 2756 m	BH1: 1806 m	BH1: 2682 m BH2: 2710 m
<i>Instrumentation</i>	12 sensors	12 sensors	14 sensors
<i>Substrate/Grain size</i>	BH1: boulders BH2: sand/gravel	BH1: boulders	BH1: boulders BH2: sand/gravel
<i>Vegetation</i>	BH1: lichens BH2: scattered pioneer species	BH1: moss, shrubs, larch and pine	BH1: --- BH2: scattered pioneer species

3 RESULTS AND DISCUSSION

A distinct difference in the annual temperature signal can be observed between sites located in coarser substrate consisting of gravel and blocks (> 20 cm) compared to boreholes drilled in finer debris. While the cold wave at BH1 reaches down to -8 m, at BH2

it ends at -5 m (Muragl). In contrast, the active layer depth varies between 5 m (BH1) and 2 m (BH2). Both boreholes in the Murtèl forefield show a larger variation: active layer depth at BH1 is about 2.5 m, whereas BH2 is only affected by seasonal frost (1.5 m deep).

The influence of meteorologic variables such as temperature and solid precipitation on the thermal state of the ground varies considerably between the sites. The winter 2006/2007 was the warmest winter recorded in Switzerland so far. In the Bever Valley its impact is well reflected in the temperature data with cold wave penetration reduced by about 4 m. However, the boreholes at Muragl do not show any substantial anomaly. The snow-rich winter 2008/2009 is more pronounced at the alpine boreholes at Muragl, whereas at the subalpine site Bever an almost identical signal as in the previous winter is visible.

Beside these seasonal variations in atmospheric conditions that are reflected in ground temperatures, the intra-annual variance between all three sites is shown (Fig. 1). The difference in substrate (fine-coarse) as well as the elevation (alpine-subalpine) is identified by the thermal envelope.

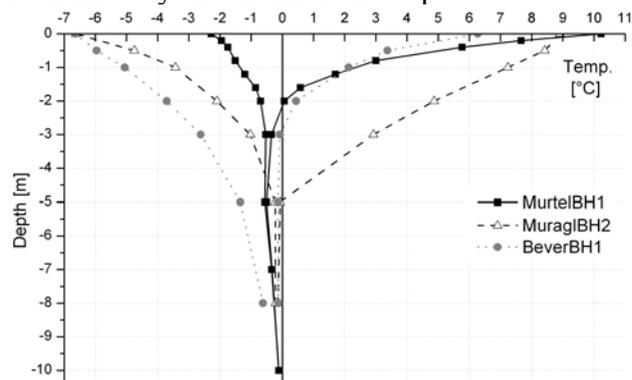


Figure 1. Thermal envelope (10/2008-09/2009).

The thermal regime at the borehole sites can be used as a first indication for the characterization of different heat conduction processes within the ground in respect of substrate and vegetation cover. While the alpine sites are influenced by the variability of the annual snow cover and its redistribution due to wind as well as substrate type, the subalpine site is less affected by the snow cover, whereas air ventilation through the talus voids is more relevant.

Pluriannual Thermal Behavior of Low Elevation Cold Talus Slopes – Western Switzerland

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1 BACKGROUND

In the Alps, discontinuous mountain permafrost is currently encountered above about 2'400 m.a.s.l. Nevertheless, abnormally cold ground conditions pointing out to the possible occurrence of isolated permafrost patches have also been reported at much lower elevation in porous debris accumulation, despite a mean annual air temperature (MAAT) definitely higher than 0°C. These observations have been attributed to an internal and reversible mechanism of air circulation, the so-called “chimney effect” (Wakonigg 1996, Morard et al. 2008).

In order to document and better understand the ventilation process causing the strong overcooling observed in the lower part of debris accumulations, ground surface temperature (GST) monitoring has been carried out on numerous sites located below the timberline in western Switzerland, since 1997 for the longest time series. In November 2004, two boreholes were drilled in Dreveneuse d'en Bas (DrB) talus slope (1'600 m.a.s.l.). Climatic variables, such as radiation, air temperature and snowcover evolution were also measured in-situ.

2 RESULTS

(1) The same seasonal thermal signal was observed in all the investigated sites. In winter the decreasing trend of positive GST in the upper part of the slope illustrates the evacuation of the heat out of the ground (fig.1). As a consequence, air is aspirated in the lower part of the talus slope cooling deeply and strongly the ground interior, even after the onset of a thick snowpack (fig.1). During summer, the GST remains remarkably cool and stable from year to year, providing favorable conditions for azon alpine ecosystems.

(2) Ground temperature monitoring has pointed out the main role played by the winter air temperature conditions to drive the thermal regime of low elevation talus slopes. The thermal conditions observed at the ground surface and in the shallow sub-surface in summertime are mainly influenced by the intensity of winter cooling and the recharge of the cold reservoir. Snowcover and summer temperatures play thus

a less significant to insignificant role. This statement contrasts with controlling factors of classical permafrost terrain.

(3) According to the observations of two boreholes in DrB, thin talus permafrost forms just a few meters below the surface in the lower part of the slope. This frozen ground extends to greater depth until the middle part of the slope. At this place, it is found at 11.5m depth directly beneath the blocky material in finer sediments (moraine), although the minimal MAGST was recorded at 8.5m depth.

This advective-induced extra-zonal permafrost is mainly temperate and its geometry and occurrence have suffered very rapid changes: responding directly to contrasted interannual winter coldness conditions, its growth has been reported between 2004 and 2006 and its thaw in 2007. Since the exceptional mild winter 2006-2007, only seasonal freezing has been observed.

However, depending in particular on the size of the debris accumulation, characteristics of the DrB extra-zonal permafrost cannot be completely generalized to other low elevation talus slopes.

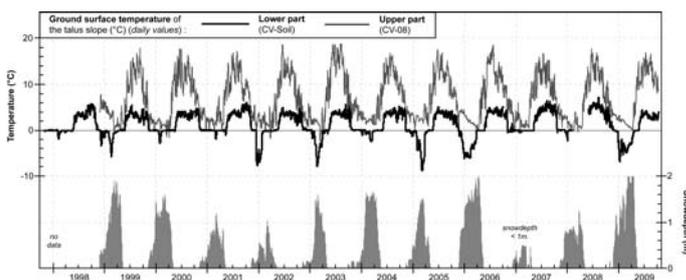


Figure 1. Daily air and GST evolution in the Creux-du-Van talus slope (1'200 m.a.s.l.) (black curve: lower part of the slope, dark gray: upper part of the slope, light gray: atmospheric air temperature) and evolution of the snowcover since December 1997.

References

- Morard, S., Delaloye, R., Dorthe, J. 2008. Seasonal thermal regime of a mid-latitude ventilated debris accumulation. *Proc. 9th Int. Conf. Permafrost, Fairbanks*: 1233-1238.
- Wakonigg, H. 1996. Unterkühlte Schutthalden. *Beiträge zur Permafrostforschung in Österreich. In: Arbeiten aus dem Inst. f. Geogr. Karl-Franzens-Universität Graz* 33 : 209-223.

Thermal State of Permafrost at Mount Reina Sofia, Livingston Island (Antarctica)

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1 ABSTRACT

1.1 Introduction

Two new boreholes 25 m (Permamodel-Gulbenkian; PG-1) and 15 m (PG-2) deep were drilled at Mount Reina Sofia (275m a.s.l.) (628390S, 608210W, UTM), Livingston Island. The drilling process was done during the Antarctic campaign 2007-08 as an International Polar Year (IPY) activity. Air temperature measurements from the Spanish Antarctic station at 15m a.s.l., show MAAT from 2000 to 2006 between -3.2 °C and -1.5°C. From April to November, the average daily temperatures at sea level are generally below 0 °C and from December to March they are generally positive. The MAAT (2003–06) at the borehole site on Mount Reina Sofia (Figure 1) was -4.2 °C (Ramos et al., 2008) and mean annual ground temperatures measured since 2000 at 15, 25, 40 and 90 cm depth in a 1.1m borehole varied between -2.6 °C and -2.1 °C. The active layer thickness, based on direct observations in pits and temperature data, was approximately 70 cm but has increased to 90 cm since 2003.

1.2 Methods

A thermistor chain and a CR1000 Campbell data logging system were installed in the deepest borehole (PG-1) with air temperature and relative humidity, heat flux and ground surface temperature. Data are measured every 5 min and hourly means, maxima and minima are stored each hour. PG-2 was equipped with single-channel miniature temperature loggers (iButtons) (type DS1922L, precision -0.5°C) sampling each hour.

Data collected during the first two years of monitoring (2008 and 2009) for the 25 and 15 m depth boreholes are presented. They provide a first insight into the thermal state of permafrost and will enable following its temporal evolution.

1.3 Results

Initial data indicates a permafrost body several decametres thick with a temperature bellow of the depth of the Zero Annual Amplitude (ZAA) of -1.9 °C in 2008 and -1,8 °C 2009 in PG-1. PG-2

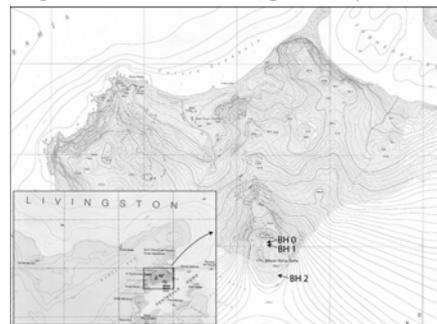
showed -2.1 °C in 2008 and -1.9 °C in 2009. ZAA is approximately at 9 m depth. Table 1 shows the mean temperatures at different depths at PG-1 and PG-2 boreholes and the mean air temperature in 2008 and 2009. Future data from these boreholes is expected to provide insight into ground temperature evolution in maritime Antarctica.

Key words: Permafrost borehole, ground temperature monitoring, maritime Antarctica.

Table 1. We can see in the table the mean temperatures in different depth of the PG-1 and PG-2 boreholes and the mean air temperature (2m up to the soil surface). The mean periods was 2008 (8/03/2008 to 17/01/2009) and 2009 (6/02/2009 to 8/01/2010).

Temp (°C)	PG1(2008)	PG1(2009)	PG2(2008)	PG2(2009)
Air	-3,2°C	-3,4°C		
0,20m	-1,7°C	-1,8°C	-2,2°C	-3,0°C
2,5m	-1,8°C	-1,9°C	-2,0°C	-2,1°C
15,0m	-1,9°C	-1,8°C	-2,1°C	-1,9°C
25,0m	-1,8°C	-1,8°C		

Figure 1. Location of the study area on the top of the Sofia mount (275 m a.s.l) in the surroundings of the Spanish Antarctic Station Juan Carlos I, Livingston Island. BH1 and BH2 are the corresponding to PG1 and PG2 respectively.



References

- Ramos M, Vieira G, Blanco JJ, Gruber S, Hauck C, Hidalgo MA, Tome D. 2008. Thermal active layer monitoring in two different sites on Livingston Island during the last seven years: a comparative study. In Proceedings of the Ninth International Conference on Permafrost, Fairbanks, Alaska. Institute of Northern Engineering, University of Alaska Fairbanks: Alaska; 1463–1467.
- Ramos M, Hasler A, Vieira G, Hauck C and Gruber S. 2009. Drilling and Installation of Boreholes for Permafrost Thermal Monitoring on Livingston Island in the Maritime Antarctic. *Permafrost and Periglacial Processes*. 20: 57–64, DOI: 10.1002/ppp.635

Temperature Studies in a 1084 Meter Deep Borehole in Southern Spitsbergen

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A 1084 m deep borehole was drilled and logged at 408 m asl in the lateral ice-cored moraine of the glacier Sysselembreen close to Zimmerfjellet between the fjords Van Keulenfjorden and Van Mijenfjorden in Nathorst Land, at approx. 77°N in southern Spitsbergen. The drilling was performed by Store Norske Spitsbergen Kullkompani (SNSK) and LNS Spitsbergen in the course of a cooperation project between the Norwegian oil companies StatoilHydro and DetNorske, the Norwegian Petroleum Directorate and SNSK. Borehole logging parameters were temperature, water conductivity, rock resistivity, natural gamma radiation, seismic velocity, caliper, relative density, and borehole deviation. The borehole was also investigated by acoustic televiewer. The aim of this scientific drilling project was to get a better 3D understanding of the clinoform development of the Eocene foreland basin at Svalbard.

Due to perturbations related to drilling operations, and, in particular, the fact that heated salt water was used to prevent freezing, temperature logging performed immediately after drilling was expected to give unreliable temperature data especially at relatively shallow depths. For the Geological Survey of Norway it was of interest to obtain reliable ground thermal gradient recording for heat flow calculations, and at the same time to establish permafrost monitoring all the way through the permafrost. It was therefore decided to especially construct a 1000 m long thermistor string, which could be installed in the borehole before freezing.

A string with altogether 20 thermistors was constructed by the Swiss company Alpug. For the permafrost thermal studies 12 thermistors were more or less logarithmic distributed in the upper 200 meter, while the remaining ones were mounted at 100 meter interval down to 1000 meter. Unfortunately, the borehole was blocked at 850 meters when the installation was done, and we had to install the thermistor string only down to that depth with a loop in the upper 50 m.

Immediately after installation, it was clear that the string suffered from incorrect data at depths deeper than 50 meters. During logging, the groundwater table was at 65 meters, and we concluded that the thermistors were not insulated to stand the water pressure in the borehole. The next step was therefore to uninstall the string, and

open the borehole for temperature logging after temperature stabilization. However, by then the string was stuck, most likely due to rockfall in the borehole, and it broke when we tried to lift it up.

Because of these problems, the very first borehole logging data were analysed and modelling suggested that the logged temperatures in the borehole, at least for its deeper levels, were close to stabilisation, allowing for some heat flow studies. Thermal conductivity was measured on ~140 core samples evenly distributed in the borehole. A preliminary estimate for the heat flow at the deepest levels of the well yields uncorrected values of ~70 mW/m². Further corrections involving topographic and paleoclimatic effects are expected to result in a higher heat flow value. A permafrost thickness of 250 m has been calculated assuming a mean annual ground surface temperature of -5°C and using the mean thermal gradients from the upper borehole.

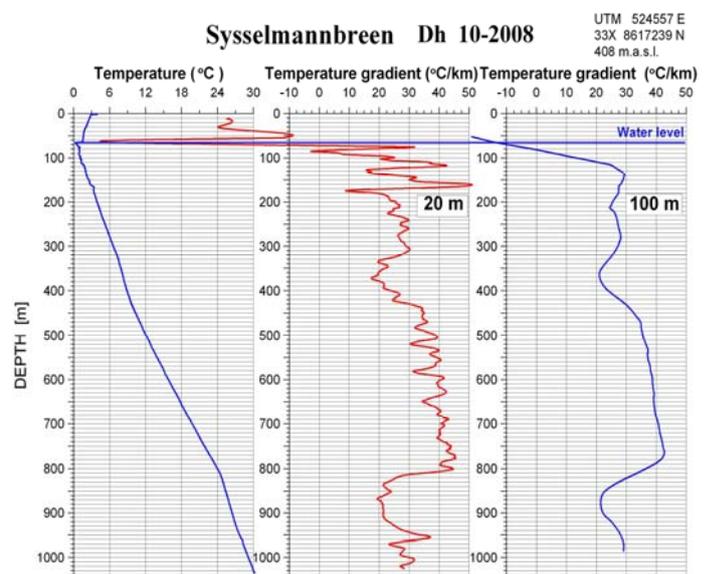


Figure 1: Temperature and thermal gradients through the Sysselembreen borehole recorded 5 days after terminated drilling, 17th June 2008.

Reference:

Elvebakk, H., Rønning, J.S., Jochmann, M., Henningsen, T., Johannessen, E.P., Bering, D. & Elvebakk, G.: Geophysical borehole logging in Dh 10-2008 at Sysselembreen, Svalbard. NGU Report 2008.090, 45 pp.

Posters Monday, cont.

Circumpolar Arctic and Antarctic Active Layer Monitoring:

in Kapp Schultz

55. **Diversity of Ground Temperatures on the Kaffiøyra Plain (NW Spitsbergen) in the Summer Period (1975-2009)**
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Diversity of Ground Temperatures on the Kaffiøyra Plain (NW Spitsbergen) in the Summer period (1975-2009)

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The ground thermal conditions in Spitsbergen are shaped by a variety of factors, including the inflow of solar energy, the advection of air masses, atmospheric precipitation, the albedo, the extent of surface vegetation, snow cover, and the earth's inclination in relation to solar exposure. Furthermore they are also dependant on the thermal properties and moisture level of the ground itself, as well as the depth of the permafrost.

Research into ground temperatures on the Kaffiøyra Plain (NW Spitsbergen, Fig. 1) was conducted over 17 summer seasons (with "summer" here being taken as July 21st to August 31st) in the years 1975, 1977-80, 1982, 1985, 1989, 1997, 1998, 2000, 2005-09. The study was conducted as part of the Toruń Polar Expedition organized by the Institute of Geography at the Nicholas Copernicus University in Toruń. Among the studies investigating ground temperature in Kaffiøyra are Wójcik & Marciniak (1987) and Wójcik, Marciniak & Przybylak (1988). During all the research periods measurements were always taken in the same locations and the same measurement techniques were used. Ground temperatures were measured using mercury thermometers placed at depths of 5, 10, 20 and 50 cm. An additional measurement of ground temperature was taken at a depth of 1 cm was taken using a regular thermometer. Thermometer readings were taken 1⁰⁰, 7⁰⁰, 13⁰⁰ and 19⁰⁰ local mean time (LMT) (UTC + 1 hour). Measurement sites were selected with reference to three ecotypes: a sandy beach, the flat frontal-lateral summit moraine of the Aavatsmark Glacier, and the tundra (Fig. 1).

- ◆ the beach site (B) is located on the flat shoreline away from the range of influence of the Greenland Sea. The ground here is mostly sand and gravel and the surface layer is dry and free of vegetation.

- ◆ the moraine site (M) is situated on the flat frontal-lateral summit moraine of the Aavatsmark Glacier composed of sandy clay, gravel, mud, and sand. About 20% of the moraine has vegetation cover.

- ◆ the tundra site (T) is situated on the cone of the glacial outwash (sandur) emerging from the moraine of the Aavatsmark Glacier. The cone is largely made up of sand / gravel deposits with large quantities of rock scree. Around 70% of the surface is covered with tundra vegetation. There is a high level of moisture content in the ground at this site.

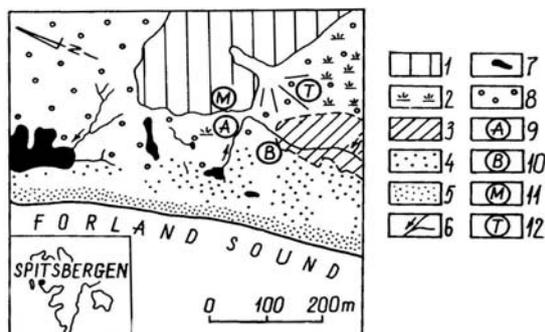


Fig. 1. A morphological sketch of the area of the Nicolaus Copernicus University Research Station and the location of the measurement sites. Key: 1- moraine, 2- tundra, 3- area subject to occasional flooding during high tides, 4- storm ridges, 5- beach area subject to occasional flooding during high tides, 6- currents, 7- lake, 8- glacial outwash (sandur), 9- research station, 10, 11, 12- ground temperature measurement sites: Beach (B), Moraine (M), Tundra (T).

The smallest differences between the readings for the different ecotypes are those recorded at 1⁰⁰ LMT, while the greatest are observed in the afternoon. In the surface ground layer (1-20 cm) at 1⁰⁰ LMT at all sites there appears an inverse pattern between measurements, which diminishes away from the surface. At 7⁰⁰ LMT the pattern begins to appear more normal, and becomes most clearly defined at 13⁰⁰ LMT. At 19⁰⁰ LMT a normal course develops in the isotherms, moving towards inversion. At the deeper ground layer (20-50 cm) there is a normal course throughout the day.

Long-term analysis of the ground temperature data confirms that the coolest site at all depths (1-50 cm) is the measurement point on the sandy beach; the tundra is warmer, and the warmest is the moraine site. The ground temperature in Kaffiøyra, similar to most meteorological elements, is subject to considerable variability from year to year. In the period analysed a rising ground temperature trend was noted during the summer seasons, e.g. at the beach site (50 cm) where an increase of 0.98°C/10 years was recorded.

References

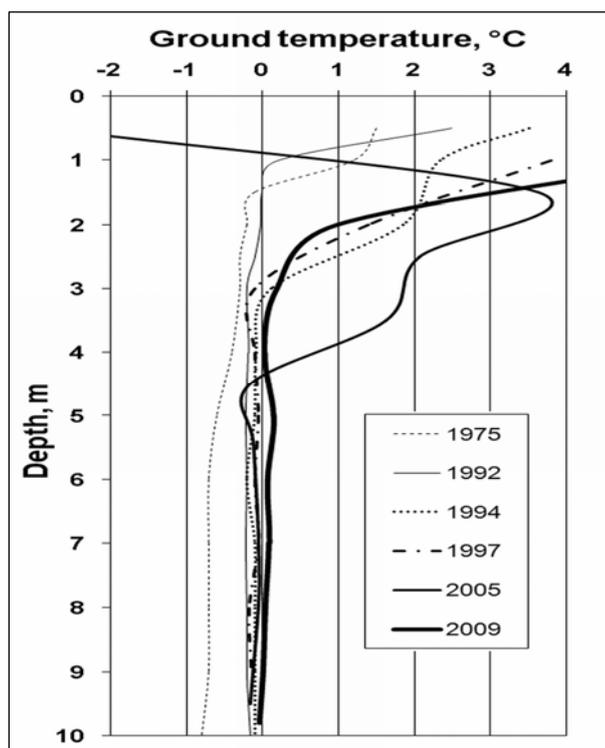
- Wójcik G., Marciniak K., 1987, Ground temperature of main ecotypes of Kaffiøyra, Spitsbergen, summer 1978; *Polish Polar Research*, 8 (1): 25-46.
- Wójcik G., Marciniak K., Przybylak R., 1988, Time and spatial variation of temperature of active layer in summer on the Kaffiøyra Plain (NW Spitsbergen), *V International Conference on Permafrost, Proceedings volume 1*, Trondheim, Norway: 499-504.

Active Layer and Permafrost Table Lowering in the Tundra/Forest-Tundra Transition Zone at Urengoi Oil-Gas Field (West Siberia)

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Within the tasks of the international project CALM three regime observations sites are in use for several years in the northern part of Western Siberia. The dynamics of active layer depth is investigated there. Two sites are situated at Yamal peninsula in the typical tundra (continuous permafrost) where the seasonal thawing occurs. The third site is placed nearby Nadym city in the northern taiga (discontinuous permafrost) where both the seasonal thawing and frizzing occur. So different active layer conditions are examined along this transect. But the southern tundra / forest-tundra transition zone was not involved in this investigation in spite it occupies considerable areas in Western Siberia and has specific features of active layer.



In order to improve the complex Western Siberian zonal transect of the active layer monitoring the Earth Cryosphere Institute SB RAS have equipped two new regime sites in 2008. They are placed at the left bank of Pur river in landscape sub-zones of the southern tundra and southern forest-tundra. Both regime sites are located at the natural

undisturbed areas within the territory of Urengoi oil-gas field. The regime sites are combined with the geocryological key-sites already organized in 1974-75 for the observation temporal and spatial variability of ground temperature at little landscape units, so called urochishches: tundra, bog, peat bog, forest, open forest, etc.

The annual measurements in the special bore-holes of approximately 10 m depth made it possible not only to reveal trends and oscillations of the frozen ground temperature, but to also to obtain background for evaluating the changes in the thickness of active layer. The ground temperature measurements were hold all over the period of climate and frozen ground warming and it made it possible to fix the moment of the substitution of seasonal thawing by seasonal frizzing of soil.

Positive temperature trend at the period of 1974-2009 is generally confirmed everywhere; however the temperature increase is uneven both temporally and spatially. Somewhere the cycles of "warming up and temperature drop" are revealed. Active layer depth is correlated with these cycles. In the southern forest-tundra sub-zone the permafrost table lowering is observed widespread. At the first stage of this lowing it looks like as the gradual increase of thawing depth.

So in the open forest with the sandy frozen substratum at first (since 1975 until 1992) the depth of thawing had not exceed 1.5 m. During 1993-1997 the frozen ground table have descended to the depth of 3 m, later in 2005-2009 it have lowered to the depth of 5-8 m (Fig.). This data is confirmed by microseismic survey. The seasonal freezing depth detected here by probe in August 2009 varies from 0.8-1 to 1.4-1.6 m.

The new areas with lowered permafrost table are indicated by appearance of open forest which advance to the north is about 30-40 km since 1974. In the southern tundra permafrost is stable and seasonal thawing does not exceed 0.4-1.1 m.

Supported by CALM, TSP, RFBR (08-05-00872a; 09-05-10030κ), RAS projects №13 «Cryosphere evolution at climate changes».

Results of Monitoring of Active Layer on CALM Grid, Talnakh, R-32 CALM Grid.

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The Circumpolar Active Layer Monitoring (CALM) site was established in Norilsk region, North part of Middle Siberia. Mean annual temperature of air in this region is $-11,3^{\circ}\text{C}$. Temperature at depth of zero annual amplitudes (temperature of permafrost) vary from -2 to -5°C . Deposits from surface presents by loam and silt. The regular active layer measurements were operated since 2005 followed by detailed characterization of landscapes and surface conditions. For studying of frost heaving and surface subsidence were made measurements by optical leveling in 2007 and 2009.

We observe of positive trend of annual GRID depth of active layer (from 81,3 to 93,8 cm) and the grid-average ALT for the study period is 89,4 cm. We have good correlation between depth of seasonal thawing and thawing index (sum of positive daily temperature) – 0,56 (for studying period thawing index vary from 927 to 1107, but more warm summer no correspond more thawing, see fig.1. In different landscapes best correlation (0,64) in bogs was observed. This result of sum of some factors: different temperature of rain, different term of snow covering and different moisture of ground in different years.

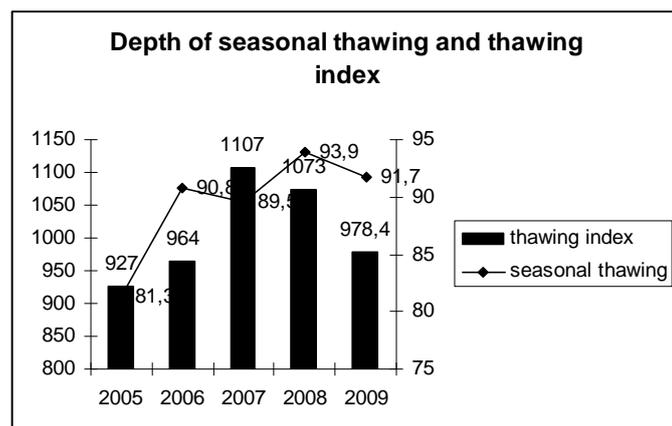


Figure 1 Diagrams changing of depth of seasonal thawing and thawing index for CALM grid in 2005-2009.

The thickness of the active layer varies from 45-50 cm to 150 cm, depending from landscape-specific conditions. The maximum thickness of the active layer was observed at landscapes represented by sparsely-vegetated patterned ground and dry hill-ocks. The minimum ALT was found in the polygon peatlands. Additional, we use standard deviation

from middle depth of season thawing for characteristics resistance of landscapes for environmental (climate) change. Most standard deviation (and the least resistance) for studying period was observed on bogs. Most stability landscape – pingo.

In whole, trend of increase of seasonal thawing is occurring. But short term of monitoring don't allow to speak about definiteness of recent change. For example, in 2007 and 2009 decrease of thickness of active layer was observed. In 2007 it was result of more "cold" precipitation of summer (in 2007 main rains was in second half of august with low temperature of air, but in 2008 main quantity of precipitation was occur in "warm" Julie). Summer of 2009 is more cold, than previous, and this cause of decrease of thickness of active layer. In whole, correlation coefficient between depth of seasonal thawing and thawing index for 2005-2009 form 0,56. It's relativity steady relationship between this parameters. In addition, summer of 2009 (to time of measure) was more dry, than in 2008 (100 mm precipitation in 2009 and 130mm in 2008). Additional drainage provided additional thawing.

Short-term record on this grid show increasing of active layer and depending of active layer from landscapes and climate conditions.

Active Layer Freeze and Thaw Dynamics Revealed by Year-Round Electrical Resistivity Tomography in Svalbard

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1 INTRODUCTION

Information on the active layer freeze/thaw dynamics is important for periglacial, biological and hydrological studies and for engineering purposes. We have tested electrical resistivity tomography as a tool in studying active layer freeze and thaw dynamics at four sites with differing soil moisture conditions in Svalbard. The electrical resistivity in the ground is largely dependent on the unfrozen water content, making resistivity monitoring a valuable tool to delineate freeze and thaw extent.

The results presented here are part of the IPY research project 'Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost in Norway and Svalbard' (TSP NORWAY) and the IPA periglacial working group project on 'High-Resolution Periglacial Climate Indicators'.

2 FIELD SITES

Electrode arrays were installed permanently at four sites in the Adventdalen area; a wet solifluction slope in May 2007, a dry loess terrace (the UNIS-CALM site) in September 2007, a mudboil site and an ice wedge site in June 2009. The arrays are 16m long, giving maximum profile depths of 2m, and electrodes were installed with 0.2m spacing. Measurements were made at an irregular but approximately two-week time interval, depending on weather conditions and instrument availability. Data are available until autumn 2009. Ground temperature and soil moisture was monitored at all four sites, and mechanical probing of the thaw depth progression was performed along with the resistivity measurements for three of the sites, but only a few times at the Endalen site due to the presence of rocks in the ground here.

3 RESULTS

The apparent resistivity raw data error is low in the summer, but in the wintertime 40 to 50% of the data was excluded in the worst cases. The errors are higher for the dry loess site also in the summer compared to the three wetter sites.

After inverting the raw data to give subsurface models of the specific resistivity (Fig. 1), depth of investigation (DOI) mapping was made to identify

model areas that are not well constrained by the data. The models show good reliability except at the model edges and in some cases of steep resistivity gradients and at local maxima and minima.

The thaw depth progression could be followed through the summer at all sites as a distinct resistivity boundary propagating downward with time and reaching a depth of about 1m at the end of the thaw season (Fig. 1). At the dry loess site, however, the resistivity contrast between thawed and frozen areas disappears in the late summer (Fig. 1), probably due to increased unfrozen water content in the upper permafrost as the temperature increases, while the active layer dries up. The thaw depths obtained at the remaining three sites is in agreement with those from the temperature data and probing.

In autumn, the advance of the freezing front can be imaged. In the wintertime the frozen active layer has a high-resistive layer near the surface (Fig. 1), indicating low temperatures and possibly that ice lenses have formed. At intermediate depths the resistivity values are moderate due to higher temperatures and possible desiccation as water was drawn to the freezing front during freezing.

In summary, the electrical resistivity tomography revealed active layer freezing and thawing well at moderate to wet sites, but less so at the dry site.

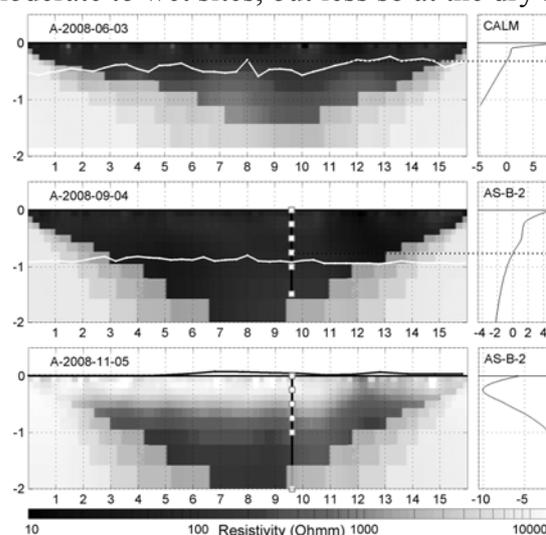


Figure 1. Selected tomograms from the dry loess terrace site. The recording dates are given (YYYY-MM-DD). Probed thaw depths are given by the white line and snow cover depth by the black line (lower panel only). The vertical array marks the position of the borehole where temperature recordings were made. The ground temperature profiles are shown in the right panels.

Active Layer Monitoring at the Bolvansky Site: Ground Temperature and Thawing Depth

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Active layer monitoring at the site R24 Bolvansky (68°17.3'N, 54°30.0'E) using CALM-project carry out since 1999. The similar regime supervision on the same area was carried out earlier with 1983 for 1993. The site R24 is located at the hill top occupied dry tundra. Such landscape is typical for this area. The significant climate variability and positive mean annual (MAAT), mean winter and mean summer air temperature trends is characteristic in a given functioning time. The long-term linear trend of MAAT increase is equal 0,07°C/year. The greatest impact in total climate warming is making by air temperature rise during the winter period (0,14°C/year) while summer changes appear not so appreciable (0,03°C/year).

Years 2005 and 2007 were anomalously warm (MAAT=-0.8°C), when the MAAT was 5 times higher than the climatic norm. According to our forecast a maximum of warming has been passed and in the coming years the colder climate is expected.

Average long-term snow depth for this area is equal 61 cm. The most snow years were 2004, 2008 and 2009, when the maximum snow depth exceeded 80 cm. Snow density varies during the winter period from 0,19 to 0,39 g/cm³ and an average measured in 0,25-0,28 g/cm³ at this CALM site.

Ground temperature and thawing depth dynamics of active layer is due to the modern climate changes.

In the past 10 years a very quick increase of average thaw depth (2.5 cm per year) has observed. The average annual ground temperature at the base of the active layer also distinctly increased from -3.1 to -0.4°C (trend of temperature rise is equal 0.27°C/year) – (fig. 1).

Some conclusions may well do concerning the active permafrost degradation on the site Bolvansky. But over a longer period of observation, such trends are lost, because relevant trends to the sharp decline (fig. 1).

Ground temperature and the thaw depth is a good correlation with the change of climatic parameters [Malkova, 2008; Mazhitova and all., 2004]. The thaw depth is increased when increasing the amount of positive air temperatures.

The mean annual ground temperature most dependent on snow cover and air temperature in winter.

Highest ground temperatures observed in years with warm and snowy winter.

Active layer condition is now a transient. The mean annual ground temperature at the base of the active layer reached the critical value. Two ten-year cycles observation combining allows adjusting the findings of the dynamics of the thawing depth and ground temperature. The precarious state of permafrost was observed in previous years. If such warm and snow winter will not be repeated, then the permafrost state begins to stabilize.

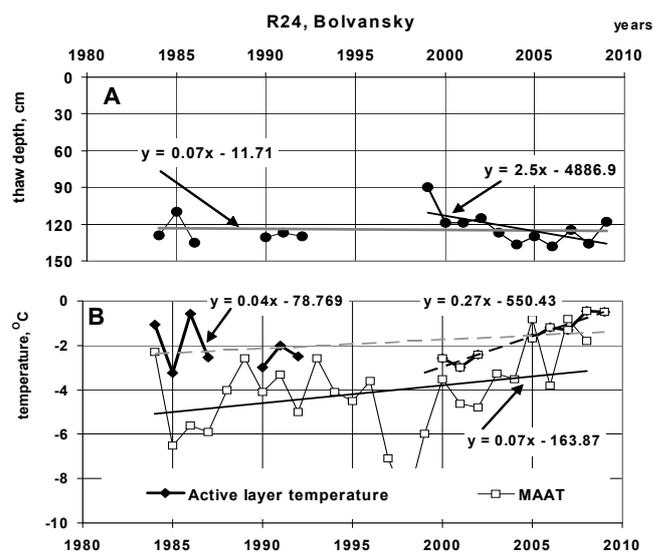


Figure 1. The dynamics of the thawing depth (A) and mean annual temperature of air and active layer (B) and linear trends of their change

References

- Malkova G.V. Last twenty-five years of changes in permafrost temperature of the European north of Russia // Proceedings of the Ninth International Conference on Permafrost. University of Alaska Fairbanks, June 29–July 3. Edited by Douglas L. Kane and Kenneth M. Hinkel, 2008. V.2, pp. 1119-1125.
- Mazhitova G., Ananjeva-Malkova G., Chestnykh O.V., Zamolodchikov D. D. Active layer spatial and temporal variability at European Russian Circumpolar Active Layer Monitoring (CALM) sites // Permafrost and periglacial processes. 2004, 15, pp. 113-139

Relation of Vegetative Cover and Active Layer Depth in the Arctic Tundra of Bely Island on New CALM Grids

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1 INTRODUCTION

Bely Island is located in the southern part of the Kara sea and is separated from Yamal peninsula by Malygin strait 19-23 km wide. It belongs to the northern belt of the Arctic tundra subzone, or in terms of CAVM Team (2003) to zone B. Two CALM grids were established on Bely Island in 2009. CALM-1 grid 25x25 sq.m, and CALM-2 grid 50x50 sq.m.

2 VEGETATION

Grid CALM-1 is located on a flat top of a sandy terrace of a small stream with polygonal microrelief with flat hummocks, mostly bare surface occupied by polygonal dwarf-willow-moss (*Gymnomitrium corallioides*, *Racomitrium lanuginosum*) tundra. Dwarf-willow (*Salix nummularia*) occupies ca 5%, and it grows in the micro-troughs and edges of micro-polygons. Moss (*Racomitrium lanuginosum*) is dominating in the troughs (90%), its total coverage being ca 30-35%. Hummocks are 20-40 cm in diameter, cracks are about 5 cm deep and about 10 cm wide. Micro-polygons are covered with the crust of the liverwort (*Gymnomitrium corallioides*), with total coverage up to 40%.

CALM-2 grid is set up at the gentle slope of the low marine terrace on the clayey soils. Polygonal microrelief is hidden by dense vegetation and is recognized through the water plane on the surface. Plant cover is a mosaic of few different communities depending on the drainage/moisture content. Poorly drained wet sites with cotton-grass dominating (70-90%), occupying troughs and polygon centers, with less developed moss cover are alternating with little better drained polygons with thicker and denser moss cover (grass-cotton-grass-moss and *Salix polaris*-sedge-moss communities). Total coverage is 100%. Considerable amount of litter (up to 50%) is very characteristic.

3 ACTIVE LAYER DEPTH

Depth of seasonal thaw on the CALM grids of Bely Island was measured at the end of July, in mid-September and in mid-October, 2009. Maximum was observed on September 15. In October 15 refreezing of the active layer started though air temperature was above zero yet, thus, mid-September data is considered. Average depth on CALM-1 grid in mid-September is 99,7 cm ranging at 89-115 cm.

On CALM-2 grid average thaw depth is 54,3 cm which is almost twice less in comparison with CALM-1. It is explained by thick dense vegetative cover, clayey soils and poor drainage at CALM-2.

4 DISCUSSION AND CONCLUSION

Correlation was analyzed between active layer depth and various features of vegetation, such as coverage, thickness, density, species and complexes.

Dense cotton-grass sod has approximately the same insulation ability regardless of drainage and moss diversity, thaw depth reaches 50-55 cm in such sites. The lowest and the deepest values were recorded in the moss-dominated communities with sparse (or absent) graminoid-layer. The lowest values were observed in wet sites with thick and dense *Dicranum* (usually with liverwort *Sphenolobus minutus*), whereas the highest thaw depths were observed in better drained sedge-moss communities with *Salix polaris* dominated by *Aulacomnium turgidum* and *Hylocomium splendens*. Surprisingly thaw was deeper under *Sphagnum*-dominated moss cover (58 cm) than under *Drepanocladus s.l.*-dominated cover (49 cm).

References

CAVM Team 2003 Circumpolar Arctic Vegetation Map. Conservation of Arctic Flora and Fauna (CAFF) Map No. 1 US Fish and Wildlife Service, Anchorage, AK

Active Layer Response to Biomass and Soil-Vegetative Cover Changes at CALM-Site in the Tundra/Forest-Tundra Transition Zone (West Siberia, Urengoi Oil-Gas field).

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As an elaboration of CALM program (circumpolar active layer monitoring), Earth Cryosphere Institute SB RAS have equipped two new regime CALM-sites situated in Western Siberia in the landscape sub-zones of southern tundra and southern forest-tundra (the undisturbed areas at the Urengoi oil-and-gas field).

In southern forest-tundra the CALM-site is placed on the watershed surface of the IV lacustrine-alluvial plain. The ice-rich continuous and discontinuous permafrost (total water content of sand is 22-25%, of loam – 35-50%) is overlapped by peat here. The watershed peat-land predominates at the site. At periphery of the site is occupied by the near-valley larch/lichen open forest. According to the temperature and geophysical measurements the permafrost table under the larch open forest have been lowered to the depth of 5-8 m since 1980-th.

In the southern tundra the CALM-site is situated on the III marine plain predominantly formed by loam deposits. Ice-rich continuous permafrost could be found here (total water content of loam is up to 60%, of sand – 21-28%). The grass-herbaceous shrub-moss-lichen tundra with scarce spot medallions predominates on the surface.

The complex landscape-geochemical investigations have been carried out in order to reveal the influence of the soil-vegetable cover upon the thawing depth. The natural waters, moisture, soils, plants from the active layer and permafrost upper horizons have been examined. The chemical features and phytomass density have been determined. The typification of the natural geosystems of the local level (the facies rank) has been carried out. The large-scale (1:5000) maps of the natural geosystems have been made up.

According to the landscape-indicative conception (geosystem conception), such maps can be used as a base for estimates of the local irregularity of the thawing depth and for making up of geospatial models. The series of geospatial models have been created with the use of the geoinformation technique (GIS). These models demonstrate the

clear correlation between the active layer thickness and the geosystem facial structure.

The landscape (facial) structure at the CALM-site in the southern forest-tundra is mosaic: open forest, small-hilly tundra's, ravines with shrubs, peat-lands, bogs. The reserves of the top phytomass reach 3-4 kg/m², the peat thickness makes up 2-3 m on the peat-lands, 25-30 cm in the ravines and small-hilly tundra, 5 cm in the open forest. Local irregularity of the thawing depth depends significantly on the thickness of the organic soil horizon (peat). Thus the vegetation in southern forest-tundra affects considerably the depth of permafrost thawing; it can also cause the alternation of sites with the lowered permafrost table (larch light forest) and with the stable permafrost (peat-lands, small-hilly tundra). According to Y.L.Shur and M.T.Jorgenson this is an ecosystem-driven permafrost [2007].

The role of the soil-vegetable cover in the distribution of the permafrost temperature and of the seasonal layer depth is sharply decreases in the southern tundra. The reserves of phytomass is 1,5-2,5 kg/m², the thickness of the organic soil horizon is rather uniform and makes up 4-10 cm. The exclusive phytomass (4-5 kg/m²) could be found at south-face slopes with dense long-boled 3-4-m alder. The seasonally thawed layer thickness following the isotropic landscape structure varies in narrow limits: 0.4-0.7 m at the lowered places and 0.8-1.1 m at the watershed. So the CALM-site at the southern tundra represents the features of climatic-driven ecosystem-modified permafrost. Also, the complex landscape-geochemical investigation reveals new factors of interrelation of soils and vegetation verse active layer thickness cross different natural zones.

Supported by CALM, TSP, RFBR (08-05-00872a; 09-05-10030-к), RAS projects №13 «Cryosphere evolution at climate changes».

Posters Monday, cont.

Education and Outreach:

in Kapp Schultz

62. **PYRN – the Future in Permafrost Research**
I. Gaertner-Roer, P.P. Bonnaventure, A.K. Liljedahl, S. Hachem, A.A. Abramov
63. **International Permafrost Field Courses TEPO-Yamburg (2007–2009) in the Network International Polar Year**
V.I. Grebenets
64. **PYRN-Bib: the Permafrost Young Researchers Network Bibliography of Permafrost-Related Theses**
G. Grosse, H. Lantuit, I. Gärtner-Roer
65. **NORPERM, the Norwegian Permafrost Database – a TSP NORWAY IPY Legacy**
H. Juliussen, H.H. Christiansen, G.S. Strand, S. Iversen, K. Midttømme, J.S. Rønning
66. **Permafrost! Polar Science at 62° South: an Education and Outreach Short Film**, G. Vieira, C. Teixeira
67. **Permafrost Research in the New Generation of Polar Scientists Program Caixa Carbono Zero**
G. Vieira, C. Mora, A. Ferreira, A. Correia, P. Amaral

PYRN – The Future in Permafrost Research

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An increasing number of young permafrost researchers from all over the world are represented by the four letters: PYRN (Permafrost Young Researchers Network). Currently more than 760 members are active in PYRN, communicating with other young scientists via our website, at international and regional conferences, workshops or in national groups. In addition, PYRN members' have worked to generate the over 700 references-strong PYRN-Bib, a bibliography of theses completed in the field of permafrost science and engineering.

Beside the objective to increase contact across our network of young researchers within the permafrost field as well as to encourage transdisciplinary research, PYRN's aim is to provide methodological skills through scientific workshops and joint projects, such as the PYRN drilling project (Part of the IPY project "Thermal State of Permafrost" or PYRN TSP). In this context, it is important to learn how to design and organize field campaigns, how to set up and apply permafrost distribution models as well as how to drill a borehole, etc. A major goal of the PYRN drilling project is to educate the newest and younger generation while stimulating future projects. These efforts we hope will guarantee long term monitoring of permafrost attributes all over the world. Thus, PYRN directs the multi-disciplinary talents toward global awareness, knowledge and response to permafrost-related challenges in a changing climate.

This report examines a sample of some of the research currently being conducted by PYRN members with respect to the PYRN drilling project as well as other ongoing independent projects.

International Permafrost Field Courses Tepo-Yamburg (2007 – 2009) in the Network International Polar Year

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During the summers 2007-2009 three International University Courses on Permafrost (IUCP) were conducted in West Siberia, Russia, as part of the IPA's IPY activities, and in this time more 70 students, masters and postgraduate students from Russia, USA, Germany and other countries participated in practice on permafrost. Studying regions are the polar and sub-polar territories in the tundra and forest tundra (Yamalo-Nenetsky Autonomous region). The course addressed three major topics of permafrost-related research:

- a) permafrost environments characteristic of the discontinuous and continuous zones;
- b) field instrumentation and techniques;
- c) permafrost engineering and problems of development in permafrost regions.

The course consisted of systematic permafrost investigations at long-term monitoring sites (30-m deep temperature boreholes) and survey-type expeditions (CALM grids). The sites and boreholes represent diverse landscapes characteristic of West Siberia. Another emphasis lay on the study of characteristics of permafrost. Other main item of our field courses is studying Quaternary history and sediments for understanding forming and development of permafrost on this area. Thanks to our courses students got to know a wide range of field techniques, including surveying, coring, geothermal monitoring, thaw-depth measurements, landscape characterization, geomorphologic investigations, soil description and classification according to International, Russian, German, and U.S. classification systems.

Three major gas fields (Yamburg, Yubileinoe, and Zapolyarno) and associated industrial complexes and settlements were visited. In the course of several excursions students knew about searching for gas and oil, extraction, cleaning and preparation for transportation and transportation itself. The field work was complemented by daily lectures prepared by instructors and students, covering a wide range of topics. Analysis of the diverse data sets obtained during the course is underway at Moscow State University, and a detailed report is in preparation.

International Field Courses gave the valuable experience as exchange of knowledge between representatives of different national geographic schools.

PYRN-Bib: The Permafrost Young Researchers Network Bibliography of Permafrost-Related Theses

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1 INTRODUCTION

PYRN-Bib is an international bibliographical database aiming at collecting and distributing information on all theses submitted for earning a scientific degree in permafrost-related research. PYRN-Bib is hosted by the Permafrost Young Researchers Network (PYRN, <http://pyrn.ways.org>), an international network of early career students and young scientists in permafrost related research with currently more than 750 members. The fully educational, non-profit project PYRN-Bib is published under the patronage of the International Permafrost Association (IPA).

The bibliography covers all theses as long as they clearly treat aspects of permafrost research from such diverse fields as: Geophysics, Geology, Cryolithology, Biology, Biogeochemistry, Microbiology, Astrobiology, Chemistry, Engineering, Geomorphology, Remote Sensing, Modeling, Mineral and Hydrocarbon Exploration, and Science History and Education.

The specific goals of PYRN-Bib are (1) to generate a comprehensive database that includes all degree-earning theses (e.g. Diploma, Ph.D., Master, etc.), coming from any country and any scientific field, under the single condition that the thesis is strongly related to research on permafrost and/or periglacial processes; (2) to reference unique but buried sources of information including theses published in languages other than English; (3) to make the database widely available to the scientific community and the general public; (4) to solicit PYRN membership; and (5) to provide a mean to map the evolution of permafrost research over the last decades, including regional trends, shifts in research direction, and/or the place of permafrost research in society.

PYRN-Bib is available online and maintained by PYRN (<http://pyrn.ways.org/resources/pyrn-bib-permafrost-bibliography>). The complete bibliography can be downloaded at no cost and is offered in different file formats: tagged Endnote library, XML, BibTex, and PDF. The full pdf document is also available via an internet permanent handle (Grosse & Lantuit, 2008). New entries are continuously pro-

vided by PYRN members and the scientific community. PYRN-Bib currently contains more than 1000 references to theses covering the period 1947-2009 and includes degree-earning theses from bachelor to doctoral and even some professorial habilitation theses. The increasing number of thesis references starts to reflect the diversity as well as focus regions in permafrost-research. Theses currently originate from 22 countries and 10 languages. All references in PYRN-Bib are translated into English to guarantee a wider distribution. PYRN-Bib opens the door to assess to highly valuable scientific work previously hidden either by language barriers or archive dust. PYRN-Bib is a unique tool for finding information about previous student research on permafrost topics. Such theses, often the backbone of modern research, are otherwise spread over hundreds of university libraries and hard to find or even know about.

We encourage students who do research in a permafrost-related topic to submit their thesis after graduation.

Reference

Grosse, G., Lantuit, H. 2008. PYRN-Bib: The Permafrost Young Researchers Network Bibliography of Permafrost-Related Theses. Permafrost Young Researchers Network, 72 pp. (Permanent handle: <http://hdl.handle.net/10013/epic.31101>)

NORPERM, the Norwegian Permafrost Database – A TSP NORWAY IPY Legacy

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1 INTRODUCTION

NORPERM –The Norwegian Permafrost Database– (www.ngu.no/norperm) was developed at the Geological Survey of Norway during IPY 2007-2009 as the main data legacy of the IPY-project *Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost in Norway and Svalbard* (TSP NORWAY). It follows the IPY data policy by giving open, free and full access to all the temperature time series and manual temperature logs collected by TSP NORWAY during IPY. Gradually, also all other ground temperature data collected in Norway and Svalbard will be included. The TSP NORWAY permafrost observatories and the structure and technical aspects of NORPERM are presented, as is also possible future developments of NORPERM.

2 TSP NORWAY DATA INFRASTRUCTURE

TSP NORWAY established two permafrost observatories during IPY. In the North Scandinavian Permafrost Observatory in northern Norway ground temperature monitoring was started in 15 boreholes and at 46 sites outside boreholes (in the air, snow, ground-surface and upper ground) to study climate-permafrost relationships, and manual temperature logging was made in three boreholes. In the Norden-skiöld Land Permafrost Observatory in Svalbard temperature monitoring was made in 17 boreholes and at 52 sites outside boreholes. Temperature was manually logged in three deep boreholes (440-900 m) by the Longyearbyen CO₂ Lab research project and made available for TSP NORWAY. Through NORPERM there is online access to near real-time permafrost temperatures in two TSP NORWAY boreholes in Svalbard (Fig. 1). The monitoring continues after the IPY for future assessment of long-term trends in permafrost temperatures.

3 NORPERM DESIGN

NORPERM is built on Oracle database tools (Oracle RDBSM), georeferenced through an ArcSDE geodatabase and made publically available in map format on the internet through a WMS server. Background maps of topography, superficial deposits, orthopho-

tos, place names and administrative borders are available through the public national co-operation on digital data, Norge Digital (www.norgedigitalt.no). Because of differences in background maps and the distance between the two areas, the database has separate interfaces for Norway and Svalbard.

NORPERM is structured into four levels with decreasing spatial scale. At the uppermost level are the entire land areas of Norway and Svalbard, at the second level is the permafrost observatories followed by what we have called permafrost areas at the third level. A permafrost area is at the scale of an individual mountain or valley where measurement sites are clustered, and provide overview information and photographs of the area. Finally, the individual measurement sites (boreholes, sites with miniature temperature dataloggers outside boreholes) are at the finest level of detail. Metadata information follows the GTN-P standard, and links to detail photographs, the full datasets and standard data plots is provided in fact sheets.

4 POSSIBLE FUTURE DEVELOPMENTS

Following the increased permafrost collaboration in the Nordic area during IPY, and particularly with the PYRN-TSP project collecting permafrost borehole temperatures in Finland, Norway and Sweden, we aim at expanding NORPERM into a regional Nordic database.

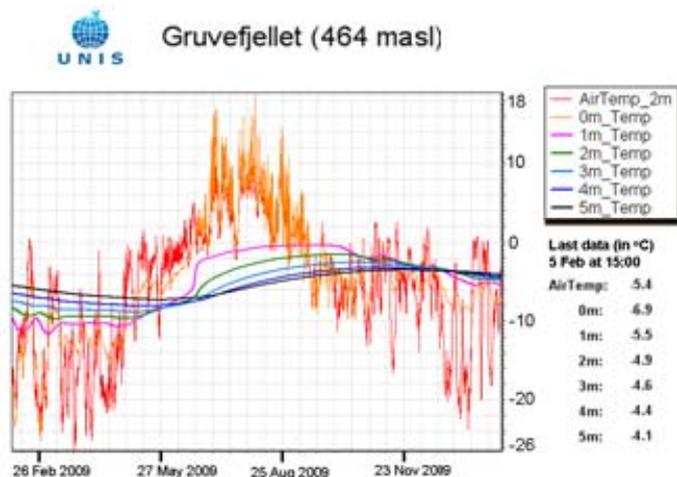


Figure 1. Near real-time temperature time series from the Gruvefjellet borehole in Svalbard. The data was downloaded 5 February 2010 at 16:00 and showing values measured until one hour before. The period is 5 February 2009 to 5 February 2010.

Permafrost! Polar Science at 62° South: an Education and Outreach Short Film

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1. ABSTRACT

The International Polar Year education and outreach project LATITUDE60! was a large success in Portugal with worldwide impacts. It included a large number of activities, such as conferences, seminars, exhibitions, theatre plays for kids, polar festivals, national contests, scientists go to school initiatives, students in Antarctic expeditions, educational materials and also short films. The project counted with the involvement of over 8,000 students from kindergarten to the University level and more than 400 teachers from all over Portugal. In this framework 4 educational films on Portuguese Polar Science were prepared and distributed freely in schools and in the Internet. Two of these films focus on permafrost and the more recent one – Permafrost! Polar science at 62° South – is presented here.

Permafrost! Polar science at 62° South is a 16-minute long, amateur film, in Portuguese with English subtitles, aiming at Secondary school and University students and shows the current scope of Portuguese research on Antarctic permafrost. It focuses on the activities of the Research Group on Antarctic Environments and Climate Change (ANTECC) at the Centre for Geographical Studies – University of Lisbon, as well as on its national and international collaborations. Permafrost is framed in the context of climate change and Earth system sciences and its Global importance is explained. Emphasis is given to the interdisciplinary character of permafrost research, as well as to the importance of field work and application of new technologies for research. At the same time as permafrost science is explained to students, we also intend to show the enthusiasm of researchers, the interest of field research and capture the interest of students for this amazing research field.

2. ACKNOWLEDGEMENTS

Permafrost! Polar science at 62° South was funded by Agência Ciência Viva (FCT/MCTES), POCI 2010 Ciência e Inovação, FEDER in the framework of the IPY educational project LATITUDE60! Fundação para a Ciência e a Tecnologia and Programa Gulbenkian Ambiente funded the Antarctic Campaigns. Câmara Municipal de Almada and DEGAS funded the publication of the DVD. Image by Alexandre Trindade, Andreas Hassler, António Correia, Cristina Teixeira, Gonçalo Vieira, Jorge Alves, Mário Neves, Patrick Blètry, Raquel Melo, Vanessa Batista, Vladimir Romanovsky. Subtitles by Ana Salomé David, Alice Ferreira and Cristina Teixeira. Music by João Lucas.

The authors thank: Armada Argentina, Armada Española, Base Antartica Española Gabriel de Castilla, Base Antartica Española Juan Carlos I, Base Argentina Decepcion, Bazar do Video, Bulgarian Antarctic Institute, Bulgarian Base St. Kliment Ohridski, Comité Polar Español, Dirección Nacional del Antártico – Argentina, Ejército de Tierra Español, International Permafrost Association, Hilti, Honda Portugal, Pixilart, Programa Nacional de Investigaciones Antártidas – España, Russian Academy of Sciences, Russian Antarctic Station Bellingshausen, Russian Antarctic Program, Unidad de Tecnología Marina, Universidad de Alcalá de Henares, Universidad de Buenos Aires, University of Sofia.

Research in the film was conducted in the framework of PERMADRILL 2007, PERMANTAR, PERMAMODEL-IPY and SHALLOWDRILL.

Permafrost Research in the New Generation of Polar Scientists Program Caixa Carbono Zero

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The New Generation of Polar Scientists is a multidisciplinary grant program promoted by the Portuguese Committee for the International Polar Year and by the bank *Caixa Geral de Depósitos* through its environment program *Caixa Carbono Zero*, that funds the initiative. The program comprehends a set of six grants of up to 24 months that fund full-time research students at the master's level in biological sciences, cryospheric sciences and atmospheric sciences. It involves five research institutions, all of them running IPY projects funded by the FCT – Portuguese Foundation for Science and Technology. The projects are focusing in the Antarctic and sub-Antarctic and deal with climate change-related topics. Some of the students are involved in formal Master programs and the grants provide the framework for the development of their theses, participation in national and international conferences, and publication of results in peer-reviewed papers. An annual subsidy for stages abroad and conference participation is also included.

Besides their own research, students and their supervisors are actively engaged in outreach activities: public talks, blogs directly from the Antarctic, classroom activities and hands-on demonstrations of polar science in museums. A website about the program is frequently updated with input from the research students (<http://www.cgd.pt/Site/Ano-Polar-Internacional/Pages/Jovens-Cientistas-Polares.aspx>). CGD is a Portuguese major bank and its commitment, regarding *Caixa Carbono Zero*, has provided a high visibility to the program and to the International Polar Year activities in Portugal, through the homepage of its website. The very close collaboration between polar scientists and bank is generating also new ideas for outreach that have been developing with the bank's involvement and empowerment. The New Generation of Polar Scientists Program is an excellent example on the importance to foster relationships between science and society and on alternative ways to gather funding for polar research in a non-polar country.

Two grants to young permafrost researchers have been attributed in the framework of the New Generation of Polar Scientists Program: Alice Ferreira (CEG-UL) and Paulo Amaral (CGE-UE). These are a reflex of the overall importance of permafrost research within the Portuguese strategy for polar science. Both grants focus on the PERMANTAR and PERMANTAR-2 projects focusing on Permafrost and Climate Change in the Maritime Antarctic. The grants are contributing to the strengthening of the critical mass on permafrost research, a country where permafrost science has developed essentially after the late 1990's:

- Alice Ferreira is studying ground and air freezing indexes in Livingston and Deception Island (Maritime Antarctica), with the objective of evaluating the influence of microscale controls, such as snow cover and topographical factors, on ground thermal regimes. Her research is based on the analysis of air and ground surface temperature data from several sites, as well as on meteorological and snow cover data.

- Paulo Amaral is analyzing the thermo-physical properties of rock cores from boreholes from Livingston Island (thermal diffusivity, thermal conductivity). This data contribute to the implementation of the Portuguese Antarctic bedrock and soil characteristics database that will be made available online for the international community.

Posters Monday, cont.

Geophysical Monitoring in Permafrost Regions 1: *in Templet*

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A. Bast, C. Kneisel
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75. **Rapid Response of Active Layer Thickness and Vegetation Greenness in Subarctic Sweden to Experimentally Increased Snow Cover**
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G. Peter Kershaw
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79. **Climate Conditions of the Permafrost Active Layer Development in Petuniabukta, Billefjorden, Spitsbergen**
K. Láská, D. Witoszová, P. Prošek
80. **Recent Changes of Permafrost Active Layer on the James Ross Island, Maritime Antarctic**
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81. **Permafrost Monitoring Network in Northeastern China**
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82. **Permafrost Monitoring in West Siberia Subarctic**
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83. **Monitoring Mountain Permafrost in Switzerland – Strategies and Experiences from 10 Years PERMOS**
PERMOS Scientific Committee: J. Noetzli, R. Delaloye, I. Gaertner-Roer, S. Gruber, C. Hauck, C. Hilbich, M. Hoelzle, M. Phillips, D. Vonder Muehll

Snowdrift as an Important Factor in the Water Balance of the Fyrsjöen Catchment, Kapp Linné,– Svalbard, Norway

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1 INTRODUCTION

The investigated catchment is situated on the west coast of central Spitsbergen. It is a small catchment (282ha) situated on the strandflat area south of Kapp Linne' (78°04'N, 13°38'E) draining into the ocean through a short river where the discharge is measured. The catchment has no connection with higher levels (the water divide is only 12-14 m. a. s. l.) nor has it connection with any glacier.

2 WATER BALANCE

An attempt to quantify the water balance of the catchment has been performed. A formula of the water balance equation can be expressed as:

$$P - Q_{\text{river}} - Q_{\text{ground}} - ET \pm \Delta S = \epsilon \quad (1)$$

Where the P is precipitation, Q_{river} is the river discharge, Q_{ground} is the groundwater discharge, ET is the evapotranspiration, ΔS is the storage changes and ε is the error, all expressed in mm water. The error should end up close to 0 if all variables are measured correctly. Regarding evapotranspiration the figure (80mm/year) used by Killington et al.

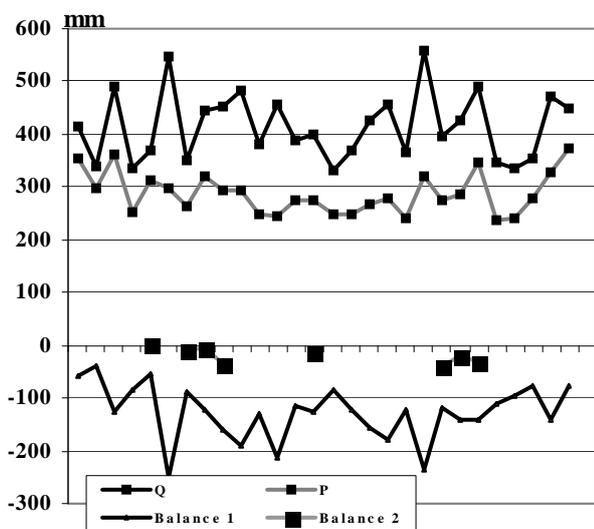


Figure 1. Runoff, precipitation and hydrological balance for the FYRSJÖEN lake catchment area the hydrological years (Sept-Aug) 1973/74 to 1999/2000. (Q) =Discharge, (P)= Precipitation-ET, water balance 1= P-Q, and (balance 2)=Corrected water balance (considering the snow drift import) in mm

2003 has been adopted. The storage component S is considered to be constant as the water level in the lake at the end of the drainage season is down to a constant level. The balance for each and every hydrological year was found negative - on an average - 127mm (Figure 1 & Table 1). The reasons for this obviously lie in the precipitation or discharge figures, which may have some built in errors. But there is one factor not considered, which became evident during the snow cover surveys within the catchment. Snow cover surveys (water equivalents) have been performed in late winter during 9 different years.

In Fig. 1 & Table 1 is shown that the catchment contain on an average 100 mm more water equivalents than the measured "traditional winter precipitation" indicates. The reason for this is the large amount of drifting snow that is accumulated in drifts mainly along the eastern "slopes" of the basin. The shallow basin gets a "precipitation import" through snowdrift mainly from the prevailing easterly winter winds.

Table 1. Corrected hydrological balance for the FYRSJÖEN lake catchment area based upon snow surveys. In mm.

Hydrological year	Vinter Precipitation	P-Q	Snow	Diff.	Corrected. Balance
1977/78	267	-55	326	59	4
1979/80	292	-86	368	76	-10
1980/81	261	-123	378	117	-6
1981/82	304	-161	429	125	-36
1986/87	278	-125	391	113	-12
1993/94	298	-119	379	81	-38
1994/95	282	-141	402	120	-21
1995/96	287	-142	397	110	-32

References

- Killingtonveit, Å., Pettersson, & Sand, K. 2003. Water Balance investigations in Svalbard. Polar Research 22(2), 161-174Last name.
- Akerman, H. Jonas, 2008, Coastal Processes and their influence upon discharge characteristics of the Strokdammane plain, West Spitsbergen, Svalbard. P:19-24 (eds. Kane & Hinkel). *Proceedings NICOP*. Fairbanks: Univ. of Alaska.

Small-Scale Permafrost Distribution and the Influence of Surface Substratum in Alpine Periglacial Environments: a case Study from the Muragl Glacier Forefield/Swiss Alps.

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1 INTRODUCTION

Permafrost is a widespread phenomenon in alpine environments. Mountain permafrost is special because of its often extreme heterogeneity concerning different parameters such as ice content, temperature etc. Besides climate, elevation, topographic aspect (incoming solar radiation), mountain permafrost occurrence depends strongly on surface characteristics (snow cover, vegetation, sediments), that often act as a buffer-system in the energy balance between atmosphere and subsurface.

2 STUDY SITE AND OBJECTIVES

The investigated glacier forefield, ranging in elevation from 2650 to 2900 m a.s.l., is located in the Muragl Valley, Swiss Alps. Its geomorphology is characterized by a complex glacier-permafrost interaction (e.g. thrust-moraine, glacial flutes) due to the polythermal regime of the former Muragl glacier.

The aim of this contribution is to show the small-scale variability of surface substratum and its influence on ground surface temperature regimes as well as on permafrost distribution in the subsurface.

3 METHODS

In summer 2008 geomorphological mapping of the surface substratum was performed for the whole glacier forefield. Furthermore, a 175 x 175 m grid, consisting of 10 parallel ERT (electrical resistivity tomography) profiles and 12 perpendicular tie-lines, was used to establish a high resolution quasi-3D resistivity image of the subsurface structure. Within the grid, surface substratum was mapped at 792 (electrode) points resulting in a detailed map of its distribution. To measure ground surface temperatures 15 MTDs (miniature temperature data logger) were placed throughout the glacier forefield; 3 MTDs were placed inside, 12 outside the ERT measurement grid. In addition 2 boreholes (8 m depth, 8 sensors) were drilled in summer 2006 to log ground temperatures. One is located in coarse blocky mate-

rial inside the ERT-grid, one outside in fine-grained substratum.

4 RESULTS AND DISCUSSION

Surface substratum was categorized in five substrate classes ranging from coarse blocks (>630mm, often 1000-2000 mm) at the thrust-moraine, to fine-grained, detritus-sandy to loamy substrate particularly within the streambeds of the glacier run-off. A high variability in grain-size is noticeable within short distances.

The 3 MTDs inside the ERT-grid reflect the different temperature regimes of the substrate classes. In 2006-2007 MAGST (mean annual ground surface temperature) range from -1.3°C in the coarse grained, to 1.06°C in the finer-grained substrate; resulting in an offset larger than 2.3°C within approx. 100m. Likewise, similar values are observed also in other measurement periods as well as in the MTDs outside the ERT-grid.

Results of the quasi-3D image enable a link between the subsurface structure and the substrate maps. Resistivities >100 kOhm.m below the coarse blocky material indicate higher ice contents in the voids between the blocks of the subsurface. In the marginal areas of that high resistivity anomaly, where also surface substratum changes to more fine-grained particles, resistivities decrease to values around 12 kOhm.m. This suggests a lower ice content of the permafrost body. Active layer thickness increases simultaneously from 2 m to 5-7 m. In case of the finest substrate class as well as in areas with streambeds, resistivities < 10 kOhm.m in the subsurface indicate permafrost-free conditions.

Borehole temperature logging prove permafrost occurrence at both sites. MAGT (mean annual ground temperature) in 5 m depth of -0.59 °C (2008/09) at the site, which is characterized by coarse blocky material, is slightly colder in contrast to -0.10 °C (2008/09) at the site with the fine-grained substratum.

Hence, the blocky surface substratum causes a cooling effect due to advective heat transport.

Thermo-Physical Properties of Rocks from Livingston Island, Maritime Antarctica

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1 INTRODUCTION

Thermal conductivity and thermal diffusivity of rocks are two physical parameters that are essential to understand and interpret heat transfer phenomena in rocks. That is particularly important in areas where permafrost is suspected to exist; knowledge of those properties can shed light to phenomena such as permafrost and active layer evolution as well as to the distribution of temperature with depth in those areas. There are a few methods to determine those properties, some indirect and some laboratorial. We report here the values for the thermal conductivity and the thermal diffusivity measured in cores collected from two boreholes drilled in the Hurd Peninsula of Livingston Island in Maritime Antarctica. These values constitute an attempt to construct a database of thermal properties of rocks for Livingston Island, which, in the future, can incorporate other data from other areas of Antarctica.

The work was performed under the framework of the PERMANTAR (Permafrost and Climate Change in the Maritime Antarctic) project which constitutes one of the Portuguese contributions to the core projects ANTPAS (Antarctic and Sub-Antarctic Permafrost, Soils and Periglacial Environments) and TSP (Permafrost Observatory Project – Thermal State of Permafrost) of the International Polar Year.

The cores that were used to determine in laboratory the thermal conductivity and the thermal diffusivity were obtained in two boreholes drilled in Livingston Island near the Bulgarian Antarctic Base (BAB) in the Hurd Peninsula. One of the boreholes was drilled in the CALM site near the BAB, reached a depth of 5 m, and has coordinates 60°21'44.3''W, 62°38'48.5''S; the other was drilled near the CALM site in a place called PAPAGAL, reached a depth of 6 m, and has coordinates 60°21'49.3''W, 62°38'54.2''S.

2 RESULTS

In a first stage all the cores were measured in a TCS Lippmann & Rauen GbR which allows the simulta-

neous measurement of the thermal conductivity and the thermal diffusivity of rocks. The measurements were performed in dried cores and along three perpendicular directions to study possible thermal conductivity and the thermal diffusivity anisotropy in them.

For the borehole in the CALM site the average measured thermal conductivity is 3.14 W/mK, with the values ranging from 2.78 and 3.33 W/mK; for the borehole in the PAPAGAL site the average measured thermal conductivity is 3.17 W/mK, with the values ranging from 3.00 and 3.57 W/mK. As for the thermal diffusivity, the borehole in the CALM site has an average measured value of $1.58 \times 10^{-6} \text{ m}^2/\text{s}$, with the values ranging from 1.49 and $1.61 \text{ m}^2/\text{s}$; the borehole in the PAPAGAL site has an average measured thermal diffusivity of $1.52 \times 10^{-6} \text{ m}^2/\text{s}$, with the values ranging from 1.50 and $1.62 \text{ m}^2/\text{s}$. For both boreholes it was also possible to calculate the heat production; the value of $1.30 \mu\text{W}/\text{m}^3$ was obtained for the borehole in the CALM site, while the value of $0.70 \mu\text{W}/\text{m}^3$ was obtained for the PAPAGAL site. The work is far from being complete and so porosities are being estimated so that thermal conductivities and thermal diffusivities can be measured and/or estimated with the cores filled with water and ice.

3 FUTURE WORK

These first results reported here will incorporate a database of bedrock and soil properties that will be made available online for the international community. Other boreholes have been drilled in Livingston Island and cores have been collected to measure their thermal conductivity and thermal diffusivity, which will be done in the near future.

A Geoelectrical Survey to Study Permafrost in the Hurd Peninsula of Livingston Island, Maritime Antarctica

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1 INTRODUCTION

Under the framework of the project PERMANTAR (Permafrost and Climate Change in the Maritime Antarctic) a geoelectrical survey has been performed on January and February of 2009 in Livingston Island in Maritime Antarctica. The PERMANTAR project is a contribution of several Portuguese research institutes to the International Polar Year core projects ANTPAS (Antarctic and Sub-Antarctic Permafrost, Soils and Periglacial Environments) and TSP (Permafrost Observatory Project – Thermal State of Permafrost).

Permafrost is a key component to understand the global climate system because of its influence on energy exchanges, hydrological processes, natural hazards and carbon budgets. Therefore, it is not surprising that the Intergovernmental Panel on Climate Change has advocated that research on climate change should also consider the climate-permafrost relation. As a matter of fact, permafrost has been identified by World Meteorological Organization as one of the six cryospheric indicators of global climate change (Brown *et al.*, 2008). Here we report the results of a geoelectrical survey that has been performed in the Circumpolar Active Layer Monitoring (CALM) site near the Bulgarian Antarctic Base (BAB) in the Hurd Peninsula of Livingston Island.

2 RESULTS

The main objective of the geoelectrical survey was to identify and assess the depth of the permafrost in two areas: one in the NW slope of a hill, and another in a CALM site, both near the Bulgarian Antarctic Base (BAB) of St. Kliment Ohridski in the Hurd Peninsula in Livingston Island, in Maritime Antarctica. Only the results of the survey performed in the CALM site are reported here. Electrical methods are particularly well suited for permafrost studies because of the increase of electrical resistivity in structures containing frozen material. In the study area three electrical resistivity tomography (ERT) pro-

files, with different orientations, were implemented. In each ERT profile 40 electrodes 2 meters apart were used and the measured apparent electrical resistivities were inverted using the inversion scheme RES2DINV (Loke and Baker, 1995). The geoelectrical data collected during the field work have high quality because of their stability and very low electrical noise, which was verified by performing repeated measurements at different times. The geoelectrical models obtained from the inversion of the apparent resistivities indicate that there are sections of very high electrical resistivity (of the order of 10^{-4} ohm.meter) along the geoelectrical profiles. The interpretation of those electrical resistivity models is that the high electrical resistivity areas are associated with superficial frozen patches of soil and not permafrost.

References

- Brown J, Smith SL, Romanovsky V, Christiansen HH, Clow G, Nelson FE. 2008. Global Terrestrial Network for Permafrost. In: *Terrestrial Essential Climate Variables for Assessment, Mitigation and Adaptation*, WMO Global Climate Observing System report GTOS-52, Sessa, Dolman (eds). Food and Agriculture Organization of the United Nations (UN FAO), Rome; 24–25.
- Loke, M.H. and Barker, R.D., 1995. Least-squares deconvolution of apparent resistivity pseudosections, *Geophysics*, 60, 1682-1690.

The Aiguille du Midi (Mont Blanc massif, European Alps): a Unique High-Alpine Site to Study Bedrock Permafrost

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1 INTRODUCTION

Permafrost and its change in steep high-Alpine rockwalls remain poorly understood because of the difficulties of *in situ* measurements. A large proportion of permafrost studies are mainly based on modelling, with a few existing instrumented sites and a resulting lack of process understanding.

Yet, a number of rockfalls that occurred in the last decade in the Alps (e.g. 2003 Summer rockfalls; 2004 Thurwieser rock avalanche) are likely related to climatically-driven permafrost degradation, as suggested by interstitial ice in the starting zones, increased air temperature, and modelling studies.

2 MONITORING AT AIGUILLE DU MIDI

2.1 A remarkable Alpine site at 3842 m a.s.l.

Starting off in the framework of the French-Italian *PERMAdataROC* project and presently under development within the EU co-funded project *PermaNET* (*Permafrost long-term monitoring network*: www.permanet-alpinespace.eu), our investigations at the Aiguille du Midi began in 2005. The summit is accessible from Chamonix, France by a cable car which was built at the end of the 1950s. Half a million tourists visit the site each year.

Besides its easy accessibility, the site was chosen for its elevation, geometry, and year-round accessibility to rock slopes of diverse aspects and to galleries inside the rock mass.

2.2 Monitoring methods

The rockwall temperature is measured by a network of mini-dataloggers at a maximal depth of 55 cm, and by three 15-nodes thermistor chains in 10-m-deep boreholes, covering diverse slope angles and expositions. The permafrost body at depth in the rock mass and the seasonal evolution of the active layer are monitored by repeated ERT (electrical resistivity tomography) on fixed electrodes.

An automatic weather station records air temperature and humidity, incoming and outgoing short- and long-wave radiation as well as wind speed and direction perpendicular to the rockwall surface. A 3D-high-resolution DEM of the Aiguille (outside and tunnels) was obtained by terrestrial laser scanning (TLS). TLS is also used to monitor instability in the SE face.

3 PROSPECTS

During the next months, two complementary studies will be accomplished: (i) numerical modelling of the transient 3D subsurface temperature fields, combining a distributed energy balance model with a 3D heat conduction scheme, and (ii) numerical modelling of water flow in rock fractures.

The combination of process understanding, statistical analyses and/or modelling will help to improve our understanding of the characteristics of the mountain permafrost degradation. Secondly, we are interested in how a reduction in the uncertainty of data, process understanding and models may contribute to our predictive skill of corresponding effects.



Figure 1. Summit of the Aiguille du Midi (3842 m a.s.l.). In the background, right: North face of the Grandes Jorasses.

References

Deline, P. *et al.* 2009. L'AdM, un site remarquable pour l'étude du permafrost. *Collection EDYTEM* 8: 125-146 [in French].

Air Circulation and Cooling Effect through Artificial Screens: a case Study (Fribourg, Switzerland)

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1 INTRODUCTION

Occurrences and thermal impacts of air circulation throughout a natural porous medium have been detected and investigated for the last decade in many talus slopes. The process makes frozen sediments to occur far below the regional lower limit of discontinuous permafrost (Delaloye & Lambiel 2007). It is commonly accepted that connected systems of large voids facilitates the movement of air. Which boundary conditions (e.g. volume, grain-size, porosity) do prevent the circulation of air and the significant cooling of the ventilated terrain? The investigation of artificial gravel heaps consisting each of material of different grain-size could provide key data to solve the problem.

2 PRELIMINARY RESEARCH

During the 2008/2009 winter, a preliminary research was carried out on 8 artificial gravel heaps. These heaps have various grain-sizes and volumes. They are located in a gravel pit close to Fribourg (620 m a.s.l., Switzerland). The first results of the investigations have pointed out no visual evidences of air circulation (Morard & al. 2008) in heaps with a volume smaller than 30m^3 or/and a grain-size under 4mm. Conversely, three gravel heaps with a volume bigger than 900m^3 and a grain-size larger than 8mm showed visual evidences of air circulation. Ground surface temperature measurements on these gravel formations confirmed the occurrence of air circulation and its impact on the thermal regime of the artificial screens (overcooled base and warm top). As these investigations were only superficial, direct information was collected by digging. The excavation revealed that the material was frozen deep inside the heap. In the frozen section, the grains were ice cemented together or not, leaving the porosity open for air to circulate. Gravels stalactites (ice cemented) were also found near the top of the heap. This probably occurs when water percolation (from snowmelt or rain) comes in contact with the cooled gravels.

3 CASE STUDY

Through the last winter (2009/2010) and spring, a pile (P1) of gravel was equipped with thermistors

and temperature – humidity mini-loggers. The size of the gravels is between 11 and 16mm and the volume of the pile is 1500m^3 . The instruments are spread inside the pile. The goal of this distribution is to better define the thermal regime of a porous formation (compared with external meteorological conditions) during the winter and the beginning of the warm season. In the same time, two other piles (with a smaller volume (150m^3 each) were also equipped with temperature loggers. The grain-size of one of them is the same as P1, in order to measure if a different volume involves a change in air circulation efficiency and duration. The grains of the other small pile are calibrated between 8 and 11mm. Therefore the two small piles could provide information on the air circulation and its behaviour with a change of gravel size.

Ground surface temperature measurements were also made several times during a month to map the thermal impact caused by the air circulation and its evolution on P1. Thermal imaging was also used as a tool to measure the air circulation's thermal effect on P1 (fig.1).

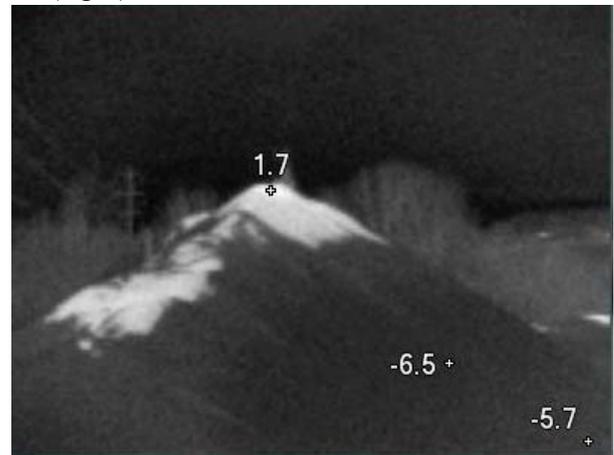


Figure 1: Thermal imaging of P1. Temperature are in °celsius.

References

- Delaloye, R. & Lambiel, C. 2007. *Drilling in a low elevation cold talus slope (Dreveneuse, Swiss Prealps)*. *Geophysical Research Abstracts*, 9 10907.
- Morard, S., Delaloye, R., Dorthe, J. 2008. Indices de fonctionnement de la ventilations des éboulis froids. Proceedings of the Swiss Geomorphological Society (SSGm) Annual meeting 2007, 12-14 July, Samedan.

CRYOLINK: Monitoring of Permafrost and Seasonal Frost in Southern Norway

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1 INTRODUCTION

The modern southern boundary for Scandinavian permafrost is located in the mountains of southern Norway. The three-year research project CRYOLINK (“Permafrost and seasonal frost in southern Norway”) aims at improving knowledge on past and present ground temperatures, seasonal frost, and distribution of mountain permafrost in southern Norway by addressing the fundamental problem of heat transfer between the atmosphere and the ground surface. Hence, several shallow boreholes have been drilled, and a monitoring program to measure air and ground temperatures was started in August 2008. These data will be used to calibrate and validate distributed transient models of snow cover, ground surface temperature and ground temperatures in southern Norway.

This poster will focus on the field setup and give examples of data obtained from the sites.

2 SETTING

The borehole areas (Juvvass, Jetta and Tron) are situated along a west-east transect and, hence, a continentality gradient, and each area provides boreholes at different elevations. At Jetta all boreholes are drilled in bedrock, at Tron in situ weather material or ground moraine, and at Juvvass in different ground surface materials, ranging from block fields via coarse ground moraine to bedrock.

3 FIELD SETUP

The following loggers are in use for borehole temperature measurements (Table 1): Hobo U22 miniloggers, Geoprecision thermistor strings and thermistor chains connected to Campbell loggers. The first two devices have an accuracy of roughly $\pm 0.2^\circ\text{C}$ and the latter $\pm 0.1^\circ\text{C}$.

On most borehole sites air temperatures are measured. Further, vertical arrays of Miniature Temperature Dataloggers (MTDs; Thermochron iButtons®) at fixed heights above the ground surface have been

installed to roughly determine the snow depths at the sites, which is also indicated by digital cameras providing daily pictures of snow and weather conditions. Four boreholes are provided with close by probes measuring soil moisture in the upper 65 cm. This is an important parameter for heat flow models. The uppermost borehole at Juvvass (Juv-BH1, 1771 m a.s.l.) is situated close to the Juvvasshøe PACE borehole (1894 m a.s.l.). At the PACE borehole air and ground temperature measurements exist since 1999, and the Norwegian Meteorological Institute has recently opened a full meteorological station there. For Jetta and Tron such longtime observations are absent. At the uppermost borehole at Tron (Tro-BH1) an automatic weather station was installed September 2008.

On most borehole sites electrical resistivity tomography (ERT) data has been obtained. At Juvvass BH3 three ERT profiles have been obtained so far on a fixed electrode setup, and these measurements will continue for monitoring of active layer dynamics and longer terms changes in ice content of the subsurface.

In addition individual MTDs have been placed out to measure ground surface temperature at different aspects and snow settings.

Table 1. Site information and field setup for the boreholes used in the Cryolink project. AH: relative Air Humidity, AT: Air Temperature, BI: Borehole Installation, OM: Other Measurements, PF: Permafrost, RF: Radiation Fluxes (short and long waved), SD: Snow Depth thickness, SM: Soil Moisture content, W: Wind speed and – direction. All thicknesses in m.

Borehole	Altitude	Depth	PF?	BI	OM
PACE-31	1894	20	Yes	Campbell	AT,RF,W
Juv-BH1	1861	10	Yes	Campbell	AT,SD,SM
Juv-BH2	1771	10	Yes	Campbell	AT,SD
Juv-BH3	1561	10	Yes	Campbell	-
Juv-BH4	1559	15	Yes	Geoprecision	AT
Juv-BH5	1468	10	No	Geoprecision	AT,SD
Juv-BH6	1314	10	No	Geoprecision	AT,SD,SM
Jet-BH1	1560	19.5	Yes	Geoprecision	AT,SD
Jet-BH2	1450	10	No	Hobo U22	AT,SD
Jet-BH3	1218	10	No	Hobo U22	AT,SD
Tro-BH1	1640	30	Yes	Campbell	AT,RF,SD,SM,W
Tro-BH2	1589	9.5	No	Geoprecision	AT,SD
Tro-BH3	1290	10	No	Geoprecision	AT,SD,SM

Rapid Response of Active Layer Thickness and Vegetation Greenness in Sub-Arctic Sweden to Experimentally Increased Snow Cover

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1 INTRODUCTION

Snow depth increases observed and predicted in the sub-arctic are of critical importance for the dynamics of lowland permafrost and vegetation. Snow acts as an insulator that protects vegetation but may lead to permafrost degradation. In the Abisko area, in northernmost Sweden, there has been an increasing trend in snow depth during the last Century. Downscaled climate scenarios predict an increase in precipitation by 1.5-2% per decade for the coming 80 years. The observed changes in snow cover have affected peat mires in this area as thawing of permafrost, increases in active layer thickness and associated vegetation changes have been reported during the last decade (Åkerman and Johansson, 2008; Malmer *et al.*, 2005). An experimental manipulation was set up at one of these lowland permafrost site in the Abisko area (68°20'48''N, 18°58'16''E) in 2005, to simulate projected future increases in winter precipitation and to study their effects on permafrost and vegetation.

2 EFFECTS OF SNOW MANIPULATION

The mean snow depth has during the period of observation (2005-2008) ranged from 7 to 9 cm (std error 0.94) for the six control plots and from 16 to 21 cm (std error 2.28) for six plots with a snow fence. After three years of treatment, statistically significant differences ($p=0.02$) in mean winter and minimum ground temperatures could be detected between the control and the manipulated plots. The control plots were between 0.5 and 1°C colder than the plots with snow fences at 15 cm depth during winter (Oct-Apr).

At the outset of the experiment (2005) there was no statistically significant difference in active layer thickness between the control plots and the plots with snow fences (Figure 1). For the second and third years of treatment, there was a statistically significant difference between the active layer thicknesses in the control plots compared to the plots with a snow fence ($p=0.03$). The active layer thickness decreased for all three years of measurements in the control plots (from 67 to 58 cm) but remained around 66 cm for all years apart from 2007 when it increased slightly to 68 cm in the plots with snow fences.

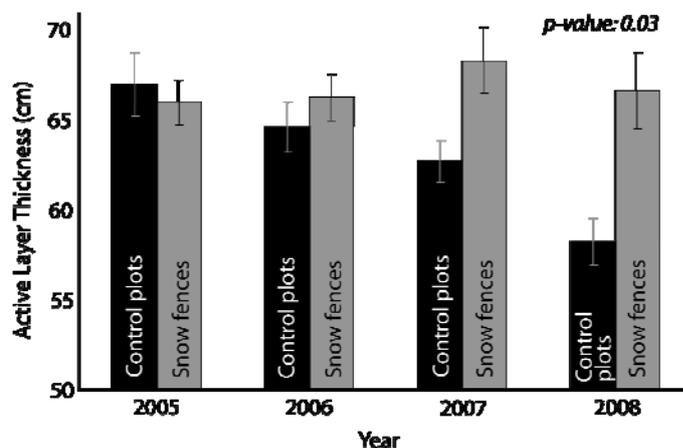


Figure 1. Statistically significant differences in active layer thickness were detected between the control plots and the plots with a snow fence after only three years of treatment.

No statistically significant difference was found in the abundance of species between the different treatments. However, in the manipulated plots, the vegetation remained greener until later in the autumn. In August 2008, the vegetation was between 140-145% greener in manipulated plots compared to the control plots. Increased snow may increase the average annual drawdown of atmospheric CO₂ due to an increase in the duration of green, photosynthesizing leaves in the autumn. However, we acknowledge that a prolonged growing season could result in increased frost damage to some species and create a complex dynamic in the long term uptake of CO₂ due to increased snow cover.

According to past, century-long patterns of increasing snow depth and projections of continuing increases, it is very likely that the changes in permafrost and vegetation that have been demonstrated by the experimental treatments presented here will continue in the future under natural conditions and will be a non-reversible process in this region.

References

- Åkerman HJ, Johansson M, 2008. Thawing permafrost and thicker active layers in Sub-arctic Sweden. *Permafrost and Periglacial Processes* 19 (3): 279-292.
- Malmer, N., Johansson, T., Olsrud, M., and Christensen, T.R., 2005: Vegetation, climatic changes and net carbon sequestration in a North-Scandinavian subarctic mire over 30 years. *Global Change Biology* 11, 1895-1909.

High-Mountain Permafrost Temperature Monitoring in Central Svalbard – Implications for Arctic Coal Mining

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1 INTRODUCTION

While permafrost temperatures has been monitored at 270 m asl at Janssonhaugen in central Svalbard for a decade (PACE project), and extensive monitoring, mainly in the lowlands, started during IPY 2007-2009 in western and central Svalbard (TSP NORWAY project), there is no information on the mountain permafrost thermal regime above 464 m asl in Svalbard. Such information is particularly relevant for the coal mining industry in Svalbard, and temperature monitoring was thus initiated in two mountains by UNIS and the local mining company Store Norske Spitsbergen Grubekompani (SNSG). At Breinosa (677 m asl), where the SNSG coal mine *Gruve 7* is located, a borehole made for coal prospecting was instrumented for ground thermal measurements to 10 m depth in March 2009. At Lunckefjellet (901 m asl), where SNSG makes plans for a new coal mine, another prospecting hole was instrumented to 90 m in June 2009.

Here we present the two sites and the preliminary results.

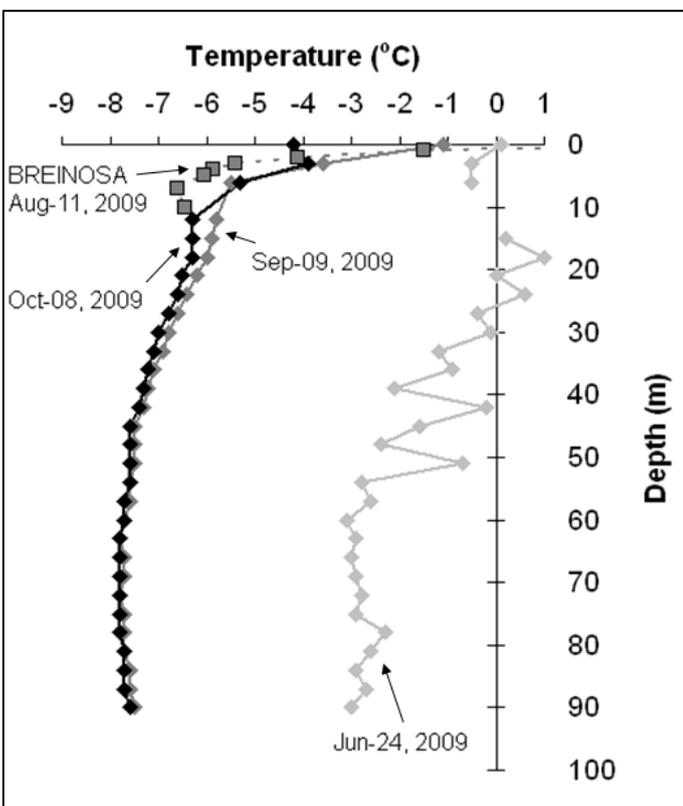


Figure 1. Ground temperatures in Lunckefjellet (24 Jun, 9 Sep and 8 Oct. 2009) and Breinosa (11 Aug, 2009).

2 BOREHOLE SITES AND INSTRUMENTATION

Breinosa and Lunckefjellet are located in the most continental, central part of Svalbard. The annual mean air temperature 2009 at Breinosa 520 m asl. was -6.9°C . Both borehole sites are located at mountain plateaus where the ground surface consists of block fields with little interstitial fine material. The Lunckefjellet site has a more or less perennial snow cover.

Salt-water was injected in the boreholes during drilling, so some thermal disturbance should be expected until this water is frozen or drained. The holes were cased with a PVC-tube in the upper 12 m at Lunckefjell and 16 m at Breinosa. The Breinosa hole was instrumented with a GeoPrecision M-Log7 (accuracy $\pm 0.2^{\circ}\text{C}$), recording data every second hour. The Lunckefjellet hole was instrumented with a thermistor-string connected to a Campbell data-logger (accuracy $\pm 0.1^{\circ}\text{C}$), recording data once a day.

3 PRELIMINARY RESULTS

The Lunckefjellet borehole temperatures recorded at the first day of monitoring, 24 June 2009, are noisy and influenced by the drilling that ended only a few days before (Fig. 1). The recordings of 9 September and 8 October shows that the temperature is about to stabilize in the lower half of the borehole at this time. Above 40-50 m, the borehole is, however, still cooling (Fig. 1). The Breinosa borehole temperatures stabilized by July 2009.

While the temperature in the upper part of the permafrost in the lowland areas of Svalbard are in the range -2.3 to -5.7°C , the high-mountain permafrost temperatures are at -6.5°C at 10 m depth in the Breinosa borehole, and as low as -7.8°C at 63-78 m depth in the Lunckefjellet borehole (Fig. 1).

The low temperatures recorded at Lunckefjellet may partly be explained by the topography around the hole, enabling cooling also from the mountain sides. Ignoring this, and assuming a linear temperature gradient with depth from 78 m depth and downwards, the permafrost thickness at Lunckefjellet is estimated to about 550 m.

Permafrost Warming in the Discontinuous Permafrost Zone, Northwestern Canada

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1 INTRODUCTION

1.1 Study area

The study was established in August 1990 on the border of the Selwyn and Mackenzie Mountains west of the Continental Divide and the Yukon/Northwest Territories, Canada border. The initial four sites were selected along a ~300 m elevation gradient with dominant vegetation varying from erect shrub tundra to lichen-graminoid tundra.

1.2 Objective

Evidence of palsa degradation in the region (Kershaw and Gill, 1979) prompted questions as to the processes responsible. Consequently, a network of microclimate stations was established to monitor near-surface conditions in an attempt to quantify factors affecting the features.

2 METHODS

Automated microclimate dataloggers were installed with a variety of sensors. The focus of this paper is the results from type T thermocouples used to monitor air, surface and near-surface permafrost temperatures. Only the 24h mean values were used in this analysis.

Manual measurements were conducted in the late thaw season to monitor thaw layer depth. The frost probing method was employed at each study feature on a permanently marked sampling grid which varied in size ($n=85$ to 23 in 1990) with the feature. As features degraded, lost sampling points varied from 5 to 65% of the original number.

3 RESULTS

3.1 Microclimate

Records have been interrupted due to animal damage and the extent of disruption differs among the sites. Air temperature has varied from a mean annual low near -9°C to a high of -4.5°C . The most complete records vary from a cooling at one site of 0.25°C to warming at two sites of 0.75°C over the 19-year record period.

Mean annual near-surface permafrost (1.5m depth) temperature has risen at all sites with the most com-

plete records rising from approximately -2.25°C to -1.0°C (Figure 1). Recent cooling has reduced the magnitude of this trend.

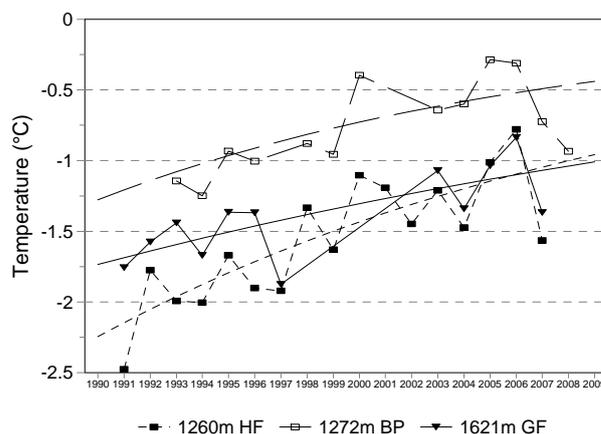


Figure 1. Mean annual near-surface permafrost temperature trends at the sites with the most complete records.

3.2 Active layer

Thaw layer depth has varied little over the record period. However the number of sampling points has been reduced by perimeter reduction in the features with the result that some probe points are now off-feature. No palsas were unchanged over the study period and one has lost $>50\%$ of its surface area since 1990. Despite this the mean thaw depth is unchanged except at the site that has degraded the most and thaw depth here has thinned with the recent cooling.

4 CONCLUSIONS

Palsas and peat plateaus in the discontinuous permafrost zone of Northwestern Canada are degrading despite conflicting air temperature changes. Near-surface permafrost warming reflects significant areal reductions which are primarily around the features' perimeters.

References

Kershaw, G.P. and Gill, D., 1979. Growth and decay of palsas and peat plateaus in the Macmillan Pass-Tsichu River area, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 16(7): 1362-1374.

Ground Surface Temperature Monitoring in the French Alps (2003-2009)

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1 INTRODUCTION

Ground surface temperature (GST) monitoring has been initiated in the French Alps at one site in 2003 and on three additional sites in 2007. All sites are situated on active rockglaciers.

The surface displacements of the Laurichard rockglacier are measured geodetically since 1983, providing one of the longest rockglacier displacement records of the Alps (Bodin *et al.*, 2009). GST monitoring has been initiated in 2003.

The other sites are monitored for GST and surface displacement by DGPS since 2007. On both the Deux-Alpes-Bellecombes and the Orelle-Plan Bouchet sites, a cable car is partly installed on the rockglacier. The Berard rockglacier front collapsed in 2006, and measurements are performed on the residual upper part of the landform.

All GST measurements are performed with UTL-1 mini temperature loggers, associated with an annual BTS survey. Surface displacements are monitored once a year with a single band DGPS.

We present here the results of the GST measurements.

2 RESULTS

2.1 GST evolution (2003-2009) at Laurichard

GST monitoring was set on in autumn 2003, just after the summer 2003 heat wave. The following winter was characterized by an early and thick snow cover. Both resulted in higher GST values.

The two following winters, 2004-2005 and 2005-2006, were snow poor and cold, allowing a strong cooling of the soil during autumn and early winter. This resulted in a drop of 3-4°C in winter temperatures. Summer and autumn 2006 were unusually hot and followed by a snow rich winter. GST rose again by 2-3 °C. This trend continued for 2007, before a moderate cooling in 2008.

The 12 month running mean of GST (fig. 1) illustrates the cumulated effects of: 1) hot summers and early and high snow cover, 2) moderate summers and snow poor winters.

2.2 GST evolution (2007-2009) on others sites

For the two winters 2007-2008 and 2008-2009, GST records are available at the four monitoring sites.

Both winters were snow rich and provided a good isolation of the ground against atmospheric temperature variations, but differed in the time of onset of the snow cover. In winter 2007-2008, the snow cover developed from ca. the 20th of November. Thus the ground could have cooled during the late autumn, and GST remained moderately cold.

In winter 2008-2009, the snow cover set on much earlier and provided a good isolation from the 20th of October. Thus the GST remained warmer on most sites. At the Berard site, the registered WEqT are 0.2 to 0.8°C higher than the previous year.

3 DISCUSSION

The results show that each site has its own thermic evolution which is governed by topo-climatic factors and ice content of the ground. If the mini-dataloggers disposed outside the rock glaciers have on the whole the same behaviour, those which are on rockglaciers are divergent. As outlined above, the results show also that the evolution of GST is strongly dependent on the time of onset and the thickness of the snow cover.

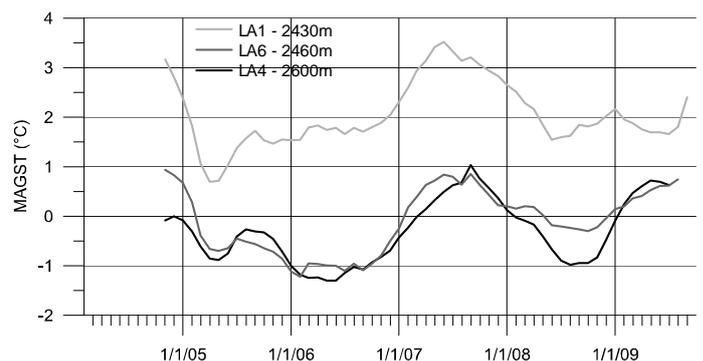


Figure 1. 12 month running mean of GST at Laurichard.

References

Bodin X., Thibert, E., Fabre, D., Ribolini, A., Schoeneich, P., Francou, B., Reynaud, L. & Fort, M. – 2009. Two decades of responses (1986-2006) to climate by the Laurichard rock glacier, French Alps. *Permafrost and Periglacial Processes*, 20 : 331-344. DOI : 10.1002/ppp.665

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Climate Conditions of the Permafrost Active Layer Development in Petuniabukta, Billefjorden, Spitsbergen

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In high Arctic, both vegetation cover and soil organism biodiversity depend mainly on the local climate, substrate as well as the permafrost occurrence. Specific climate conditions and geographical location affect thermal regime of the active layer of permafrost and liquid water availability that allow plants and soil biota development. Therefore, detail knowledge on a seasonal variation of microclimate parameters and other environmental factors are essential for study of the permafrost active layer and other constituents of terrestrial polar ecosystems. The research presented here is conducted under the framework of the “Biological and climate diversity of the central part of the Svalbard Arctic archipelago” project funded by the Ministry of Education, Youth & Sport of the Czech Republic, INGO - LA 341 (2007 - 2010).

The investigated area is located in the coastal zone of Petuniabukta, north-western branch of Billefjorden, Spitsbergen. The most part of Petuniabukta is covered with cement type of the permafrost. During summer season, the permafrost table is located in the depth of 40-120 cm depending on the altitude, slope and relief exposition. Since 2008, fourth automatic weather stations (AWS) have been operated along the northern coast of Petuniabukta at different altitudes ranging from seashore level to the mountain ridge up to 500 m a.s.l. All AWS are equipped with an identical set of sensors to measure air temperature and relative air humidity at a height of 2 m. Furthermore, the soil temperature and volumetric water content (VWC) are measured at the depths of 5 and 15 cm. Apart from that, an extended monitoring program is carried out at a single station (AWS1) located on the south-eastern slope at an altitude of 15 m (Fig. 1). It consists of sensors for the measurement of shortwave net radiation, PAR, air pressure, air temperature and humidity, surface temperature of tundra vegetation, wind speed and direction. In addition, platinum resistance thermometers depths of 2, 5, 15, 30, 50, and 75 cm are installed near the AWS1 location to measure soil temperature profile.

It can be concluded that climate conditions in Petuniabukta slightly differ from the rest of the Svalbard archipelago, Isfjorden in particular (Hanssen-Bauer *et al.*, 1990). In the period of 21 July 2008 to 13 August 2009, mean air temperature at Petuniabukta (AWS1) was -4.5 °C. The air temperature reached absolute minimum of -32.6 °C and maximum of

16.2 °C. For the whole investigated period, mean global shortwave radiation was 85.9 W/m². However, daily maximum intensity of global radiation reached 360 W/m². We found that mean soil temperatures at depths of 5, 15, 30, 50 and 75 cm were -3.5 , -3.2 , -3.3 , -3.4 , and -3.5 °C, respectively. Freezing of the permafrost active layer between at depths of 5 to 15 cm was closely related to air temperature drop below -10 °C, which occurred during snow fall events in the period of 1-7 October 2008.

Permanent snow cover established on 2 October 2008 and melted out on 16 June 2009 after 6-days of thermal advection and direct solar radiation. After that event, thermal regime of the permafrost active layer at depths of 5 to 15 cm changed rapidly under the influence of melting water. It was clearly seen also in the VWC increase from 0.12 to 0.42 m³/m³ which happened within 68 hours. In summer 2009, mean air temperature was 5.5 °C, while mean/max. surface temperature of tundra vegetation reached 7.8 and 26.5 °C, respectively. The increase in surface and substrate temperatures was accompanied by an increase in the mean VWC at depths of 5 and 15 cm that ranged from 0.29 to 0.32 m³/m³. Then, within the following 41 days, continuous warming of the permafrost active layer brought a slow decrease of the VWC from 0.40 to 0.33 m³/m³ at 5 cm, while other depths remain unchanged.

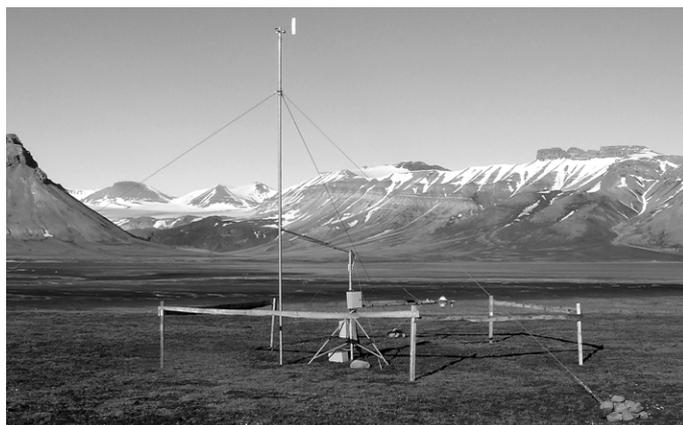


Figure 1. General view on the automatic weather station (AWS1) in Petuniabukta, Billefjorden, Spitsbergen.

References

- Hanssen-Bauer I., Solås, M.K., Steffensen, E.L. 1990. The Climate of Spitsbergen. DNMI-Report 39/90 KLIMA, Norwegian Met. Inst. 40 pp.

Recent Changes of Permafrost Active Layer on the James Ross Island, Maritime Antarctic

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Permafrost distribution and temperature belong to key indicators of climate change as they react sensitively to climate variations. The mean annual air temperatures rose substantially in the Maritime Antarctic during past 50 years (Turner *et al.*, 2005). This trend has caused warming of solid earth and increase of permafrost active layer thickness. At the Ulu Peninsula, the northern part of the James Ross Island, we started to examine variations of permafrost thawing depth and processes in the active layer in 2005.

Permafrost active layer thickness is investigated along a 5.4 km long transect ranging from the altitude of 4 to 323 m a.s.l. (Figure 1). Climate conditions and altitude are the main factors, which control the thickness of active layer at 12 study sites (P-1 to P-12). Mean depth of permafrost table changed from 0.75 m in 2009/2010 to 0.55 m in 2010/2011 following the interannual decrease of mean air summer temperature from 0.8 to -1.8°C . Similarly, the changes were found in incoming solar radiation during summer season which decreased from 1738.2 to 1632.6 $\text{MJ}\cdot\text{m}^{-2}$. Depth of permafrost thawing (DPT) ranged from 22 to 93 cm depending on altitude. The negative correlation between the DPT and altitudes was modified by water content in regolith and deflation processes, which reduced the downward propagation of active layer.

Temperature conditions in the active layer have been measured by platinum resistance probes close to the Mendel Station located on marine terrace (10 m a.s.l.) and at the Johnson Mesa (323 m a.s.l.). Furthermore, ground heat flux at the depth of 2 cm was monitored at both sites. We found that the annual mean temperatures of the regolith at depths of 5, 10 and 20 cm at the Mendel Station were -8.0 , -7.7 , and -7.5°C , while at Johnson mesa they reached -8.8 , -8.6 , and -8.5°C . Similarly, summer mean temperatures at the Mendel Station were higher by 0.8°C that at Johnson mesa. However, difference between the two sites was not reflected in heat flux measurements.

Predominant periglacial processes in the active layer are strongly influenced by site characteristics. Two main periglacial processes affect the active layer evolution. Among these, patterned grounds and solifluction landforms are the most common. Patterned grounds cover almost continuously summit

plateaus and slightly inclined surfaces on weathered volcanic bedrock. The shape of these sorted landforms is controlled by inclination of slopes changing from isometric polygons to elongated stripes with high inclination of slopes. Temperature variations in the ground reflect the intensity of sorted landforms development as indicated by measurements of regeneration cycles at five sites (GT-1 to GT-5) in 2009. Moreover, the solifluction process was monitored from January 2005 to February 2010 at eight sites (S-1 to S-8). The most intense solifluction can be observed in areas underplayed by sedimentary rocks, which disintegrate into fine-grained waste. The mean annual rates of solifluction ranged in order of centimetres with the highest annual values up to 120 mm.

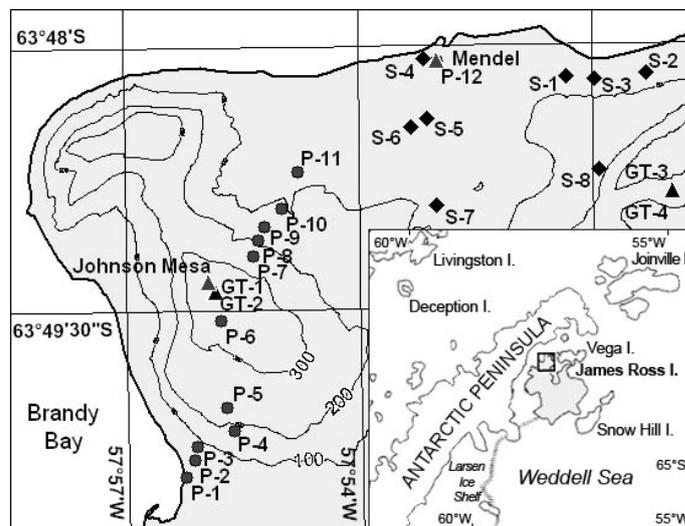


Figure 1. Map of the northern part of the James Ross Island with locations of meteorological stations (triangle) and sites of permafrost depth (circle) and solifluction movement (diamond) measurements.

References

- Turner, J. *et al.* 2005. Antarctic climate change during the last 50 years. *International Journal of Climatology*, 25: 279-294.

Permafrost Monitoring Network in Northeastern China

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During the past 40 years, due to climate warming and rapid deforestation, and other human activities, permafrost in the Da and Xiao Xing'anling (Hinggan) Mountains in northeastern China has been degrading, as shown by the deepening active layer, thinning permafrost, rising ground temperatures, expanding talik, and the disappearance of permafrost patches (Jin *et al.*, 2007).

activities represented by rapid urbanization and extensive deforestation on the permafrost and cold regions environments, additional 15 boreholes were drilled from Yekeshi to Mo'he on the western flank of the Da Xing'anling Mountains from October to December 2009, and the measurements of ground temperatures will start in 2010 (Figure 1).

Therefore, so far there are about 58 boreholes, and more than 50 will be added in the near future to establish and maintain of the monitoring network of permafrost, which will play important roles in multidisciplinary research in the cryospheric sciences, as the northern parts of the Heilongjiang Province and northeastern part of the Inner Mongolia Autonomous Region (IMAR) have undergone the warming of 0.9-2.2°C during the last 40 years, the most striking in China.

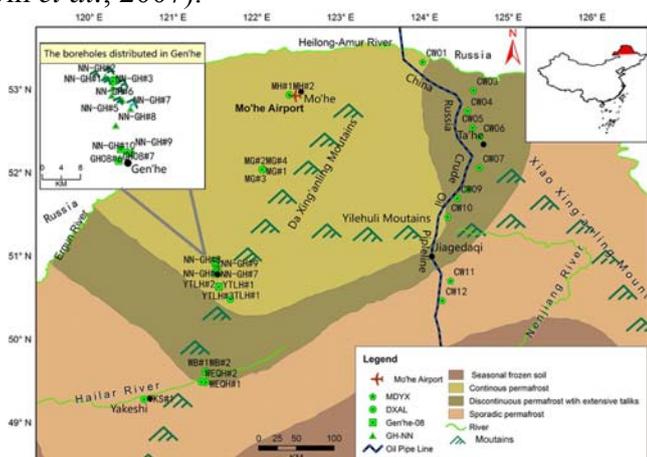


Figure 1. Map of boreholes for monitoring permafrost temperatures in Northeastern China.

There are no extensive monitoring boreholes for ground temperature in northeastern China before 2004. In October to December 2004, and April to August 2005, 10 boreholes were drilled at Mo'he Airport to monitor the permafrost risks and unfavorable geology. From July to August 2007, 8 boreholes were drilled at Gen'he and Yituli'he to study the effects of vegetation on the active layer processes, thermal offsets and ground temperatures, as well as the symbiosis of wetlands and permafrost (Jin *et al.*, 2008). In October to December 2007, 15 boreholes were drilled and installed along then to-be-built China-Russia Crude Oil Pipeline (China segment) from Lianyin, Mo'he to Jiagedaqi (PetroChina Daqing Oilfield Engineering Co. Ltd., 2008), later the data were used in assessing the thermal regimes of permafrost at various segments of the pipeline route. In June to August 2009, 10 boreholes were drilled by Inner Mongolia Agricultural University at the CFERN Gen'he for studying the relationships of permafrost, vegetation, ecology, micrometeorology and micro-topography. In order to study the impacts of anthropogenic

References

- Jin HJ, Yu QH, Lü LZ, Guo DX, Li YW, 2007. Degradation of permafrost in the Xing'anling Mountains, Northeastern China. *Permafrost and Periglacial Processes*, **18**(2), pp. 245-258. DOI: 10.1002/ppp.589.
- Jin HJ, Sun GY, Yu SP, Jin R, He RX, 2008. Symbiosis of marshes and permafrost in the Da and Xiao Hinggan Mountains in Northeastern China. *Chinese Geographical Science*, **18**(1): 62-69. DOI: 10.1007/s11769-008-0062-0.

Permafrost Monitoring in West Siberia Subarctic

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Permafrost monitoring is carried out since 1970 at the Nadym site in the West Siberia North. The observation site is located in 30 km south from the Nadym town on a flat boggy surface of the fluvial-lacustrine plain. Permafrost underlies the area sporadically. Patches of permafrost are closely associated with peatlands, tundras, mires, and frost mounds.

Observations are included measurements of permafrost temperature and active layer thickness, microrelief leveling, soil and vegetation descriptions on fixed plots (10x10 m), CALM grid (100x100 m) and transects.

According to the Nadym weather station for 1970-2008 the trend rise of air temperature has made 0.04°C in a year. The rise in air temperature caused increase in active layer thickness and permafrost temperature.

On CALM grid during 1997-2009 periods maximum active layer thickness (143 cm) was registered in 2002 with warm summer and big quantity of summer precipitation (table 1).

Table 1. Active layer thickness (cm) in different natural complexes on CALM grid

Years	natural complexes *			Mean on CALM grid
	A	B	C	
1997	57	120	147	121
1998	73	170	166	137
1999	66	130	144	123
2000	73	154	147	126
2001	81	157	159	134
2002	86	148	170	143
2003	85	155	143	126
2004	83	167	148	134
2005	95	170	149	141
2006	99	143	147	129
2007	99	153	140	129
2008	115	143	148	136
2009	83	111	109	101
mean	84	148	147	129

*A – flat peatland, B – bog, C - hummocky tundra

Minimum active layer thickness is observed on flat surface of peatland (84 cm). Areas with deep thaw are confined to dwarf shrub-sedge-moss bogs (148 cm) and to hummocky tundra (147 cm).

The ground temperature in different landscape conditions for the investigated period has increased for 0.4-1.4°C. Minimum temperature increase from -0.5 up to -0.1°C was observed on mineral frost mounds, composed by sands, underlying by icy clay. Maximum temperature increase from -1,8 up to -0,4 °C was registered on palsa peatland.

The annual course of ground temperature on different depths on palsa peatland for 2008 is resulted in Figure 1. During the autumn period on depths of 2-5 m gradual increase of temperature which maximum falls at December is marked. Since January - February temperature of the upper ground layers start to go down under influence of low air temperature. The lowest temperatures are observed on depth 1 m. The maximal winter temperature gradient is registered in March and makes 1,7 degrees/m. In March influence of air temperatures reaches depths of 4-6 m, and deeper downturn of temperatures begins only since April and comes to an end in June. Since May temperatures of the upper ground layers again raise, and increase of temperature deeper than 5 m is traced only in July - August.

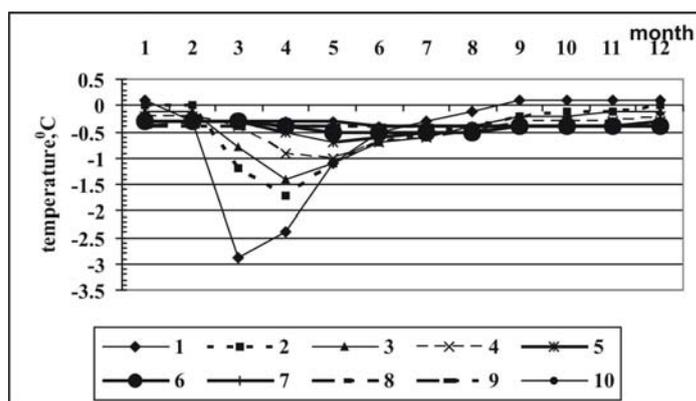


Figure 1. Mean monthly temperature in 2008 at the depth 1-10 m on palsa peatland

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Monitoring Mountain Permafrost in Switzerland – Strategies and Experiences from 10 Years PERMOS

PERMOS Scientific Committee

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1 INTRODUCTION

The Swiss Permafrost Monitoring Network (PERMOS) was initiated as a research-oriented network in the 1990ies, and officially started with a pilot phase in 2000. It is currently developing towards an operational monitoring service. Monitoring techniques have been and still are subject to changes and adaptations based on new experiences and findings. In this contribution, we present the monitoring strategy of PERMOS after its first ten years of operation, together with the most important experiences and results gained during this period. The questions we address refer to the general problem of how to monitor permafrost at high altitude: Which parameters and measuring techniques are suitable? What insight can be gained from which parameter, and how do they complement each other in order to get a comprehensive picture of the state and changes of mountain permafrost? Although general observation parameters and methods of lowland permafrost also apply for monitoring of permafrost at high altitude, several specific aspects need to be considered. Further, the organization of the network is described, as well as its integration into national and international monitoring programs and into research and academia.

2 MONITORING STRATEGY AND MEASURED PARAMETERS

The main objectives of the PERMOS network are: (a) the long-term documentation of the state and changes of mountain permafrost in Switzerland, and (b) the maintenance of a research network to identify suitable monitoring parameters and techniques. Today, PERMOS is based on three types of observations: (1) ground temperatures measured at and below the surface at borehole sites, (2) changes in subsurface ice and water content at these sites inferred by geoelectrical surveys, and (3) velocities of permafrost creep determined by geodetic surveys and/or

photogrammetry. In addition, standardized documentation of fast mass movements from permafrost areas (e.g., rock fall) is being established.

The three observation elements complement each other in order to deliver a comprehensive picture that cannot be achieved without their joint interpretation. The connection between air and subsurface temperatures is not straightforward in high mountains since snow conditions, surface characteristics and cover, subsurface ice content, and mountain topography mask changes in atmospheric conditions when they propagate into the subsurface. Complementing the borehole data by geoelectrical surveys, which can be linked to changes in unfrozen water content, show the potential of a combined approach compared to thermal monitoring alone. Similarly, changes in creep velocities during the past years can be interpreted together with changes in unfrozen water content or subsurface temperatures.

Due to the dynamic of the research field, it is important that the network develops in close contact with academia. In order to fulfill requirements of an operational monitoring service, however, the development of a sound strategy and standards for data acquisition, processing, quality control, archiving, and reporting is crucial. Further, integration into both, national and international monitoring programs is required.

ACKNOWLEDGEMENTS

The Swiss Permafrost Monitoring Network (PERMOS) is funded by the Federal Office for the Environment (FOEN), the Swiss Academy of Sciences (SCNAT), and the Federal Institute for Meteorology and Climatology MeteoSwiss. Maintenance of field sites and data acquisition is mainly done by the six partner institutes, the Universities of Berne, Fribourg, Lausanne, and Zurich, the ETH Zurich, and the WSL Institute for Snow and Avalanche Research SLF.

Posters Monday, cont.

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The Permafrost Monitoring Site of Cime Bianche Pass (3100 m, Aosta Valley, Italy)

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1 INTRODUCTION

The Aosta Valley is a small alpine region in the NW corner of Italy surrounded by the highest peaks of the Alps. Since 2005 a permafrost monitoring program is started in order to understand the impacts of climate change on the cryosphere in the regional territory. Here the characteristics of Cime Bianche Pass site are presented and first monitoring results discussed.

2 SITE DESCRIPTION

The Cime Bianche Pass (45°55'N 7°41'E, 3100 m a.s.l.) is located at the head of the Valtournenche Valley (Fig 1). The site is characterized by bare fractured bedrock mainly consisting of garnetiferous micaschists and calcschists, locally mantled by shallow coarse-debris deposits. Several gelifluction lobes, terracettes and sorted polygons occur on the deposits.

3 SITE INSTRUMENTATION

Two boreholes respectively 6 and 41 m deep were drilled during autumn 2004. Temperature measurements are continued since January 2005 in the shallow one and since August 2008 in the deeper. Actually both boreholes are equipped with two thermistor chains (sensor YSI 44031 $\pm 0.1^\circ\text{C}$) cabled on a common Campbell Scientific CR800 datalogger. A small CALM grid with (40x10 m wide) is active since January 2005. The monitoring grid is composed by 5 nodes where ground temperature is measured at 2cm and 30cm of depth by PT1000 sensors. Moreover, air temperature, relative humidity, incoming and outgoing solar radiation, wind speed and direction, snow depth and atmospheric pressure are measured since March 2006. Precipitation monitoring (both solid and liquid) started in January 2009 by an OTT Pluvio² precipitation gauge. All instruments are powered by solar panels and temperature-resistant buffer batteries.

4 RESULTS AND DISCUSSION

At the Cime Bianche Pass the combined effect of irregular morphology and strong wind action lead to an high variability of snow cover thickness within few meters. In such context the shallow borehole is drilled on a convex coarse-debris land-form highly subject to wind erosion which usually avoids thick snow covers while deep borehole is located in a small depression which promotes snow accumulation.

Crossing boreholes and meteorological data an high correlation between mean seasonal snow depth and ground temperatures have been found. Different snow thickness due to the morphological differences strongly affect the ground thermal regime indeed active layer thickness in the deep borehole is almost twice than in the shallow. Even if less strong also the air temperature contribute to modify ground thermal regime mainly influencing duration of snow cover at both the beginning and end of the seasons. The temperature profiles of the deep borehole allow to identify the depth of zero annual amplitude at around -17 m. The mean permafrost temperature at this depth is about -1.36°C . Within the CALM grid nodes the spatial variability of mean annual ground surface temperature is at least 2°C . This value is nearly double in comparison with the mean inter-annual variability of a single node. These results suggest that a single point of measure is not enough to define permafrost occurrence and its thermal regime over complex alpine morphologies.



Figure 1. Overview of the Cime Bianche site.

The Aiguille du Midi (3842 m a.s.l., Mont Blanc Massif, European Alps): Monitoring of Rock Temperatures and Meteorological Parameters

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1 INTRODUCTION

During the last decades, the European Alps have shown to be extremely sensitive to climate change. The numerous instability events occurred during the hot summer 2003 in the Alpine high-mountain regions are a clear example of the potentially fast response of steep bedrock slopes to climate forcing. In the last years, several sites have been equipped for the monitoring of rock surface temperature in the Alps with the purpose to collect data for calibration and validation of permafrost and rock temperature models in such complex morphologies. In this context the Aiguille du Midi can be considered one of the most advanced sites in high-mountain permafrost research having several differing instrumental approaches but also a close collaboration between different research groups.

2 SITE DESCRIPTION

Located in the Mont Blanc massif, the Aiguille du Midi is a beautiful summit composed by two granite towers. The location is easily accessible all around the year by cable car from Chamonix, France. All instruments are installed on the south tower (*Piton Central*, 3842 m a.s.l.), which has been chosen for its “cigar” shape and fast access to its top by elevator. This morphology allows complete availability of all slope expositions within few meters and near-vertical faces. The rock mass is only little fractured and characterized by widely spaced, persistent closed discontinuities. Rockwall accessibility is very easy thanks to a summit panoramic terrace.

3 INSTRUMENTS AND METHODS

The rock surface temperature is measured over all faces since 2005 by mini-dataloggers with thermistors placed at depths of 3, 10, 30 and 55 cm below the surface. Deeper measurements are performed in three 10 meters-deep boreholes drilled during 2009 in the lower section of the Piton Central. The boreholes are equipped with thermistor chains having 15-

nodes. Air temperature and relative humidity are measured only on south and north faces by means of mini-dataloggers placed inside radiation shields. On the south face, meteorological parameters are measured by an automatic weather station adapted and installed directly on the rockwall. Incoming and outgoing solar radiation are measured parallel to the rock face in both shortwave and longwave bands. Wind speed and direction are measured perpendicular to rock face with the anemometer orientation giving 0°-North values for vertical wind. All parameters are logged each 10 minutes.

4 RESULTS

All the data are collected mainly for initialization, calibration and validation of rock temperature and permafrost distribution models. However their statistical analysis allow to quantify the great spatial variability of near- and sub-surface temperatures in such complex morphologies. Preliminary results shows that: (i) the mean annual ground surface temperature can vary of more than 5-6 °C within few meters; (ii) freeze-thaw cycles on southern aspect are nearly twice as frequent than in the north but markedly shallower; (iii) a significant thermal-offset exist despite the compact rock mass and the absence of ground covers (e.g. debris, snow); (iv) the active layer thickness varies from few centimeters to some meters. Meteorological data on the rockwall shows that: (i) the peak of SW radiation occurs during the winter giving strong daily temperature excursions at rock surface; (ii) there is a clear prevalence of upslope winds with speeds ranging from 4 to 9 m/s; on average the mean annual air temperature is around -7°C, with 5 to 6 °C of daily excursion and an absolute temperature range between -25 to 12 °C.

Permafrost Thermal Regime Monitoring in an Active Volcano, Deception Island (Antarctica).

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1 ABSTRACT

1.1 Introduction

Deception Island is an active volcano with a high geothermal heat flux, located in the Maritime Antarctic region at 62°43'S, 60°57'W. Its climate with Mean Annual Air Temperature (MAAT) close to -1.9 °C, are compatible with the existence of permafrost. On the other hand, the Antarctic Peninsula region showed very strong atmospheric warming in the last 50 years, with MAAT increasing approximately 2.5 °C. Given these conditions the study of the thermal regime of permafrost and its active layer becomes especially interesting, allowing comparing its evolution with the regional climatic variability and the anomalous geothermal flux effects.

1.2 Methods

During the last years we have installed in Deception Island a CALM-S (Circumpolar Active Layer Monitoring - Southern Hemisphere) in the surroundings of Crater Lake (S62.98333°; W060.66667°; 85 m a.s.l). The following parameters are monitored: maximum active layer depth (mechanical probing and thermal monitoring), active layer temperatures in shallow boreholes (under 1.8 m depth), snow distribution and depth, air and soil surface temperatures.

In the framework of a collaboration between Spain, Portugal and Russia, in order to better analyse the permafrost thermal regime, during the Antarctic campaign 2008-09, three new boreholes were drilled: STS-1; 4.5 m depth (62°59'07.7"S, 60°40'42.9"W, 97 m a.s.l), STS-2; 5.0 m depth (62°59'07.5"S, 60°40'48.1"W, 85 m a.s.l) and STS-3; 6.0 m depth (62°59'08.0"S, 60°40'48.5"W, 88 m a.s.l). These boreholes were instrumented with temperature chains composed by i-Button DS1922L miniloggers with an accuracy of 0.1°C for measuring temperatures at different depths (see table 1).

1.3 Results

In this work we show the first results for 2009 year. Permafrost is 4.5 m thick at borehole STS-2 and 3.5 m at STS-3, with an active layer depth of 30-40 cm. At borehole STS-1, permafrost

reaches over 4.5 m depth, with the temperature in the deepest sensor is below zero, but close to it, see table 1. Figure 1 shows 2009 mean thermal profiles at STS-1, STS-2 and STS-3 boreholes, four months later its mechanical drilling was done to prevent the first step of influence or the heat dissipated by the drilling process.

Keywords: Permafrost, Boreholes, Maritime Antarctica.

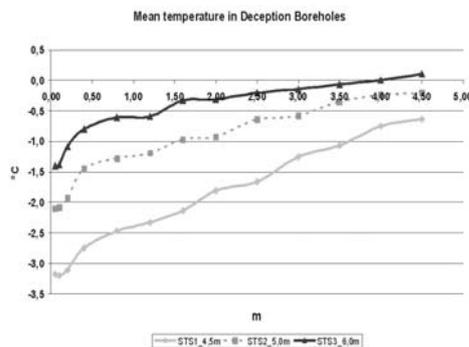
Table 1. Characteristics of the measurements protocols used at the Crater Lake boreholes.

Borehole	Sensor position (cm)	Period	Max./mean temperature at 4,5 m depth.
STS_1	5, 10, 20, 40, 80, 120, 160, 200, 250, 300, 350, 400, 450	1/06/2009 to 19/01/2010 (each 4 hours)	-0,5°C/-0,6°C± 0,15 °C
STS_2	Equal and 500	Equal	-0,1°C/-0,2°C± 0,05 °C
STS_3	Equal and 500	Equal	0,2°C/0,1 °C ± 0,05 °C

References

- Ramos M, Vieira G, Gruber S, Blanco JJ, Hauck C, Hidalgo MA, Tomé D, Neves M, Trindade A. 2007. Permafrost and active layer monitoring in the maritime Antarctic: Preliminary results from CALM sites on Livingston and Deception Islands. *U.S. Geological Survey and the National Academies*; USGS OF-2007-1047, Short Research Paper 070, doi:10.3133/of2007-1047.srp070
- Vieira G, Lopez-Martinez J, Serrano E, Ramos M, Gruber S, Hauck C, Blanco JJ. 2008. Geomorphological observations of permafrost and ground-ice degradation on Deception and Livingston Islands, Maritime Antarctica. In *Proceedings of the 9 th Conference on Permafrost, Fairbanks, Alaska June 29 - July 3 2008*, Kane DL, Hinkel KM (eds.). University Alaska Press: Fairbanks: 1839-1844.

Figure 1- In the figure we show the mean thermal profile of the temperatures registered during the winter of 2009 on the STS-1, STS-2 and STS-3 boreholes.



The PermaFRANCE Network

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and PermaFRANCE network partners

1 INTRODUCTION

A French long term monitoring network of permafrost and frost related processes, named PermaFRANCE, is being built since two years. It will represent the French contribution to the Alpine wide PermaNET network and to the global GTN-P network.

2 SCIENTIFIC GOALS

The PermaFRANCE network will focus not only on permafrost, but on all frost related phenomena at different altitudinal levels, including both thermal monitoring and process observation and monitoring. The scope is to gain a complete view of frost related phenomena, of their distribution over altitude, and of their evolution at different altitudinal levels. It is actually expected that some phenomena will migrate to higher altitudes and evolve accordingly in intensity and frequency.

2.1 *Continuous and discontinuous permafrost in rock walls*

Thermal monitoring is mainly performed at the Aiguille du Midi (Mont Blanc massif) and includes rock surface temperature (RST) and temperature profiles in medium depth boreholes (10 m).

Inventory and observation of rockfall activity in high mountain rock walls: this action concerns the whole Mont Blanc area and is based on a historical inventory and an observation of current activity based on a network of observers and contributors.

2.2 *Discontinuous permafrost in surficial deposits and flat bedrock*

Thermal monitoring is performed on five rockglacier sites and includes ground surface temperature (GST) and annual BTS campaigns on some sites. Two medium depth boreholes (15 m) have been made in 2009 on one site, and equipped for thermal profile monitoring. A deep borehole (100 m) will be made in 2010 at 45° N latitude.

Geophysical monitoring is performed on 4 sites: repeated vertical electrical soundings exist for some sites since 20 years, and have been complemented

since 2007 by electrical resistivity tomography (ERT) and refraction seismics.

Surficial displacements of rockglaciers : surficial displacements are measured either by classical geodesy or by DGPS on 6 rockglaciers.

2.3 *Sporadic permafrost at middle altitudes*

An inventory of cold scree slopes and biological investigations on soil and tree growth (dendrogeomorphology) have already been achieved.

A thermal monitoring should be initiated on selected sites in 2010.

2.4 *Seasonal frost and frost/thaw cycles at middle and low altitudes (infra-periglacial belt)*

The effect of frost/thaw cycles on rock weathering is monitored on 3 sites on various lithologies.

A network of seasonal frost monitoring sites (frost occurrence and frost depth) at different altitudes is not yet implemented, but is in discussion.

2.5 *Status of data acquisition*

The longest time series amount to 25 years for displacement of one rockglacier, 7 years for GST monitoring on one site, 5 years for RST, but most time series have only 2 years or less. The first monitoring report should be printed in the mean time and presented at the conference.

3 NETWORK PARTNERS

The PermaFRANCE network is mainly supported by three research laboratories: PACTE/Institut de Géographie Alpine at the Université de Grenoble, EDYTEM at the Université de Savoie, and PRODIG at the Université Paris 7. Several other partners (labs, private companies, individuals, institutions) will be associated. Financial support is provided by several research projects: the Interreg PermaDATARock project for the permafrost in rockfaces, a Fondation MAIF project for the monitoring of rockglaciers, and now mainly the ETC Alpine Space PermaNET project until 2011. For further financing, the scope is to be recognized as a long term observation service (SOERE), a status that would ensure financing for several years.

Permafrost of the Sub-Polar and Polar Ural Eastern Slope Piedmont

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The projected railway 885 km long nearby the eastern slope of Sub-Polar and Polar Ural Mountains connects the Polunochnoe station (60°26' N, 60°51' E) and the city of Salekhard (66°43' N, 66°31' E). During the engineering-geological survey along the railway line, the geocryological research of this poorly investigated and difficult of access region have been carried out.

The geocryological zonation is shown accurately in the region: from continuous permafrost in its northern part to sporadic at the southern border of the permafrost zone (see fig. 1).

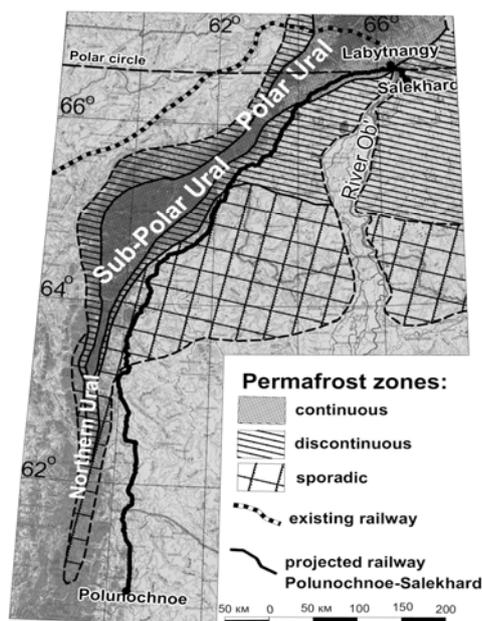


Figure 1. Permafrost zones of the western part of West Siberia and Ural Mountains

The sub-zone of continuous permafrost spreads to 66°30' N. The area occupied by permafrost is more than 90 % of the terrain. Just under large lakes, exceeding in the diameter thickness of permafrost as well as under Ob' River, the existence of talics is probable. Permafrost thickness in the vicinity of Salekhard is 250-300 m. Mean annual ground temperature (MAGT) changes from -2.0...-2.5°C up to -0.1°C. The lowest temperature is characteristic for the surfaces composed of peat 0.5-1.0 and more metres thick underlayed by lacustrine-alluvial, lacustrine-glacial deposits. In flood-lands of rivers and streams, in leeward feet of hills and ridges, with

shrub vegetation up to 1.0-1.5 m high, MAGT increases up to -0.1...-0.5°C. The least depth of active layer (0,4-0,6 m) is characteristic for flat peatlands and the surfaces combined with mineral ground lying down under a layer of a damp moss 15-20 cm thick. The depth of active layer in glacial and marine-glacial deposits on the watersheds is 0.8 - 1.5 m.

The sub-zone of discontinuous permafrost is stretched to 65° N. The area occupied by permafrost decreases to the south from 80-90 to 50-60 % of the terrain. A prominent feature of this zone is a presence of two frozen layers separated by the unfrozen massif. Thickness of the upper layer of permafrost varies from 40-50 up to 100 m. The lowest MAGT is characteristic for masses of frozen peatlands (-1.5...-2.0°C, sometimes slightly lower). The mineral ground temperature depending on a number of factors (a relief, structure, natural ground humidity, etc.), ranges from ±0°C (sites of deepened permafrost table) to -0.5...-1.0°C (shrub tundra, coniferous forests).

The depth of seasonal thawing changes from 0.4-0.6 m in peatlands and moss covered surfaces up to 1.8-2.5 m on the drained slopes and watersheds composed of sandy, gravel-loamy deposits of Ural Mountains slopes and foothills and tops of fluvial-glacial hills and ridges).

The sub-zone of scattered and sporadic permafrost (10-50% of area) has a southern limit at the latitude about 63°20' N. Permafrost islands are common for flat-topped peatlands and dark coniferous forests with moss cover of more than 10-15 cm thick. Permafrost thickness here is 20-40 m, MAGT is -0.6...-0.8°C in peat massifs and -0.1...-0.5°C in loamy ground at watersheds. Some separate islands of permafrost up to 8-10 m thick can be found in peatlands and mossy coniferous forests down to 62°40' N. The depth of seasonal thawing is 0.6-1.0 m in peat, 1.0-1.5 m in loam and 1.5-2.5 m in sandy ground. The depth of seasonal freezing outside of permafrost patches is from 0.8-1.0 m in peat bogs up to 2.0-2.5 m in sandy-loamy ground composing watersheds with negligible snow cover.

In the Ural Mountains, all the boundaries between permafrost zones listed above, are shifted to the south for a distance about 250-300 km.

Snow Cover and Shallow Ground Temperature Regimes in Hurd Peninsula, Livingston Island, Antarctic

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1. INTRODUCTION

The Antarctic Peninsula region has experienced a major warming trend in annual mean air temperatures over the last 50 years (King, 1994). This region is located near the latitudinal limit of permafrost and increasing air temperatures may cause its degradation.

The limited knowledge of the impact of climate change on permafrost led to an effort to increase research in the Antarctic. Two core projects of the International Polar Year 2007–2008 were approved: ANTPAS – Antarctic and Sub-Antarctic Permafrost, Soils and Periglacial Environments and TSP – Thermal State of Permafrost. The present research is integrated in these projects and intends to monitor the ground temperature regime in several shallow boreholes.

Hurd Peninsula is a mountainous area located in the south coast of Livingston Island (South Shetlands, Antarctic). About 90% of the island is glaciated and the rest shows a seasonal snow cover and coincident with periglacial domain. The study focuses on the ice-free areas of the north western part of Hurd Peninsula in the vicinity of the Spanish Antarctic Station “Juan Carlos I” and Bulgarian Antarctic Station “St. Kliment Ohridski”.

This paper aims to characterize the shallow ground thermal regimes (active layer and seasonal frost) in different places with similar climatology and soil composition, with special reference to the understanding of the influence snow cover in permafrost spatial distribution.

2. METHODOLOGY

This study focus on data from air and ground temperature and snow thickness data for 2007 and 2008 from Incinerador (25 m a.s.l), Collado Ramos (110 m a.s.l), Ohridski (140 m a.s.l) and Reina Sofia Peak (275 m a.s.l). At each study site, data loggers were used for the monitoring of air temperatures (150 cm high), for the ground (5, 20 and 40 cm deep) and mini loggers for the snow depth (2, 5, 10, 20, 40, 80 and 160 cm high) (Lewkowicz, 2008). Ground and air temperatures and snow thickness are monitored at 4-hour intervals.

The analysis of the ground and air temperature together with snow cover enabled the detection of ten

types of daily regime. They were identified according to the depth and cyclicity of freeze–thaw on a thermal basis. A freeze–thaw cycle was considered when temperature crossed 0°C, a definition with some limitations, because it does not reflect a direct relationship with the formation of ice in the ground. This allowed identifying the controls of air temperature and snow cover on ground temperatures.

3. RESULTS

Ten types of daily ground temperature regime were identified: 1) isothermal unfrozen 2) non-isothermal unfrozen, 3) surficial freeze–thaw, 4) surficial freeze–thaw and subsurficial frost, 5) surficial and subsurficial freeze–thaw, 6) subsurficial frost, 7) surficial and subsurficial frost with short-term fluctuations, 8) surficial frost but no daily rhythm, 9) surficial and subsurficial frost with stable temperatures and, 10) isothermal surficial and subsurficial subfreezing regime.

Shallow ground thermal conditions are marked by irregularity. The summer shows very little snow cover and similar regimes at all sites, with unfrozen ground, and freeze–thaw regimes prevailing. In the other seasons a spatial and temporal control of snow cover on ground thermal regimes is clear. Sites with thicker seasonal snow cover showed higher ground temperatures and more frequent occurrence of two daily regimes: surficial and subsurficial frost with stable temperatures and isothermal surficial and subsurficial subfreezing regime. Sites that experienced thinner seasonal snow cover showed lower ground temperatures and the regime with surficial and subsurficial frost with short-term fluctuations occurred more frequently.

The differences observed are particularly significant in a marginal permafrost terrain, where snow cover becomes a critical factor for determining the presence or absence of permafrost.

References

- King, J.C. 1994. Recent climate variability in the vicinity of Antarctic Peninsula, *Int. J. Climatol.*, 14 (4), 357-369.
- Lewkowicz, A. 2008. Evaluation of Miniature Temperature-loggers to Monitor Snowpack Evolution at Mountain Permafrost Sites, Northwestern Canada. *Permafrost and Periglacial Processes*, 19(3): 323-331.

Normal-Reciprocal Error Models for Quantitative ERT in Permafrost Environments: Bin Analysis versus Histogram Analysis

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1 INTRODUCTION

Electrical resistivity tomography (ERT) has been used for the monitoring of permafrost-affected rock walls for some years now. To further enhance the interpretation of ERT measurements a deeper insight into error sources and the influence of error model parameters on the imaging results is necessary.

Here, we present the effect of different statistical schemes for the determination of error parameters from the discrepancies between normal and reciprocal measurements – bin analysis and histogram analysis – using a smoothness-constrained inversion code (CRTomo) with an incorporated appropriate error model.

2 STUDY SITE AND DATA ACQUISITION

The study site is located in galleries adjacent to the Zugspitze North Face (2800 m a.s.l.) at the border between Austria and Germany. A 20 m * 40 m rock permafrost body and its surroundings have been monitored along permanently installed transects – with electrode spacings of 1.5 m and 4.6 m – from 2007 to 2009. For data acquisition, a conventional Wenner survey was conducted as this array has proven to be the most robust array in frozen rock walls. Normal and reciprocal data were collected directly one after another to ensure identical conditions.

3 ERROR MODEL PARAMETERS

The ERT inversion results depend strongly on the chosen parameters of the employed error model, i.e., the absolute resistance error and the relative resistance error. These parameters were derived (1) for large normal/reciprocal data sets by means of bin analyses (Koestel et al. 2008) and (2) for small normal/reciprocal data sets by means of histogram analyses (Slater and Binley 2006). Error parameters were calculated independently for each data set of a monthly monitoring sequence to avoid the creation

of artefacts (over-fitting of the data) or unnecessary loss of contrast (under-fitting of the data) in the images.

4 INVERSION RESULTS

The inversion results are assessed with respect to (1) raw data quality as described by the error model parameters, (2) validation via available (rock) temperature data and (3) the interpretation of the images from a geophysical as well as a geomorphological perspective. Our study highlights the importance of carefully chosen error parameters for a reliable interpretation of ERT images in permafrost environments.

References

- Koestel, J., et al. (2008), Quantitative imaging of solute transport in an unsaturated and undisturbed soil monolith with 3-D ERT and TDR, *Water Resources Research*, 44.
- Slater, L., and A. Binley (2006), Synthetic and field-based electrical imaging of a zerovalent iron barrier: Implications for monitoring long-term barrier performance, *Geophysics*, 71, B129-B137.

PERMANTAR-2. A New Project for Monitoring Permafrost in the Antarctic Peninsula Region

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Permafrost influence on climate has been largely neglected in the past, but research in the last decade emphasizes on its major significance as a component of the cryosphere. In the recent climate change assessments by the Intergovernmental Panel on Climate Change, Arctic Climate Impact Assessment and United Nations Environment Program, reference to present-day and future responses of permafrost terrain to climate have already been included.

There is a widespread trend towards warming of permafrost on Earth, with significant influences on the climate system (carbon fluxes), terrain stability, ecology and hydrology. Permafrost research as a long tradition in the Northern Hemisphere, especially in the circum-Arctic region and there are hundreds of boreholes and active layer monitoring sites focusing on the evolution of the thermal state of permafrost. However, Antarctic permafrost is still poorly characterized and the borehole and active layer monitoring network is scarce. The International Permafrost Association (IPA) maintains the Global Terrestrial Network for Permafrost (GTN-P), as well as the Circumpolar Active Layer Monitoring Network (CALM). During the International Polar Year, the IPA conducted a significant effort in developing the permafrost and active layer monitoring networks in the Antarctic and coordinated two IPY core projects: The Thermal State of Permafrost (TSP) and Antarctic and sub-Antarctic Permafrost, Soils and Periglacial Environments (ANTPAS). Portugal participated in these projects with PERMANTAR - Permafrost and climate change in the Maritime Antarctic, funded by the FCT. Current

activities are framed within the new project PERMANTAR-2.

A major objective of PERMANTAR-2 is to bridge the gap in monitoring through installing and upgrading permafrost boreholes and CALM-S sites in the Antarctic Peninsula region, with a focus in the South Shetlands. Together with this objective, improving knowledge on permafrost distribution and characteristics, with a modeling component, and also the implementation of sites for monitoring the periglacial geomorphodynamics in relation to climate change are important goals. PERMANTAR-2 also includes a task on snow cover monitoring using field data, as well as ASAR satellite imagery. Following the IPA guidelines for the implementation of a permafrost monitoring transect along the Antarctic Peninsula, a new site will be tentatively implemented in collaboration with the University of Wisconsin-Madison in Anvers or Brabant islands constituting an important node in the GTN-P.

PERMANTAR-2 will take place from 2010 to 2012 and is organized according to the following tasks:

Task 1 – Permafrost, active layer and geomorphodynamics monitoring;

Task 2 – SAR analysis of the snow cover;

Task 3 – Permafrost modelling

Ground Temperature Modeling Using ERA-Interim Forced H-TESSEL Scheme. Results for Livingston Island (Antarctic Peninsula)

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This study focus on Livingston Island (South Shetlands, Antarctic Peninsula), one of the Earth's regions where warming has been more significant in the last 50 years. Our work is integrated in a project focusing on studying the influence of climate change on permafrost temperatures, which includes systematic and long-term terrain monitoring and also modeling using land surface models. A contribution will be the evaluation of the possibilities for using land surface modeling approaches to areas of the Antarctic Peninsula with lack of data on observational meteorological forcing data, as well as on permafrost temperatures.

The climate variability of the Antarctic Peninsula region was studied using the new reanalysis product

from ECMWF Era-Interim and observational data from boreholes run by our group. Monthly and annual cycles of near surface climate variables are compared. The modeling approach includes the H-TESSEL (Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land) forced with ERA-Interim for modeling ground temperatures in the study region (Fig. 1). The simulation results of runs of the land surface model compared with observational data of ground temperatures have shown significant results with R correlation up to 0.91 and bias of -1. The use of different forcing parameters is compared and the model vs. observation results from different results is analysed. The main variable needing further improvement in the modelling is snow cover.

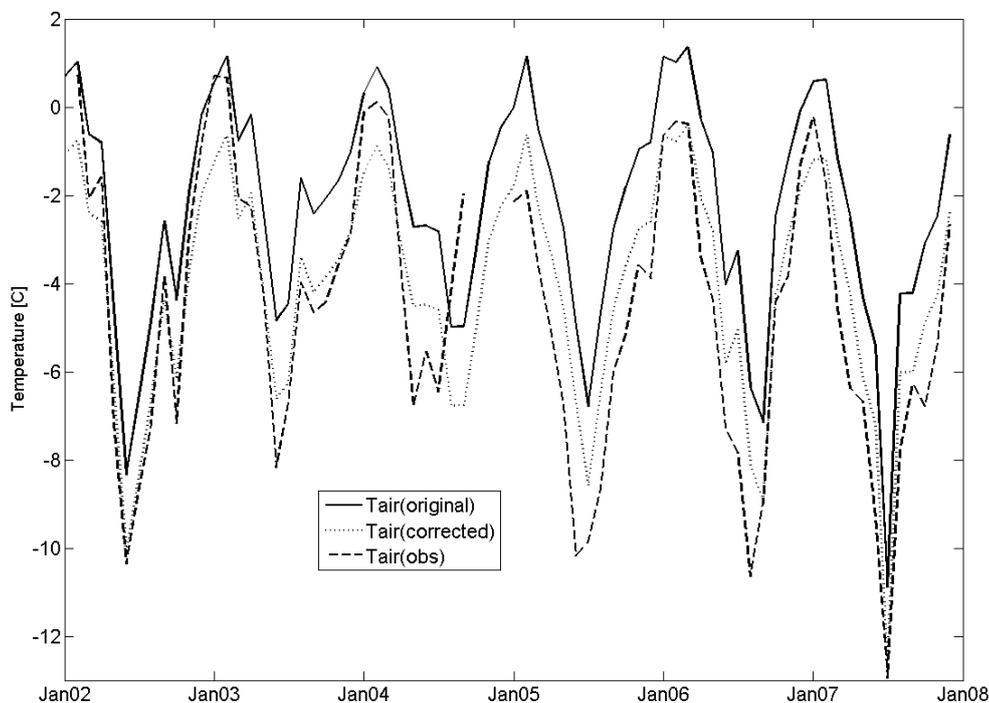


Figure 1 - Modelled and observed air temperatures series from the ERA-Interim reanalysis and Reina Sofia Hill. Tair(Original) - ERA Interim, Tair(corrected) - ERA-Interim corrected for altitude, Tair(obs) - Temperature at Reina Sofia Peak.

Controlling Factors of Permafrost Temperatures at a High-Arctic Site on Svalbard

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1 INTRODUCTION

The temperature distribution in permafrost soils is affected by a wide variety of parameters, which can vary over small distances and on short timescale. An adequate representation of these small-scale heterogeneities in permafrost models remains a challenging task. Energy balance models calculate the surface temperature based on the partitioning of energy at the surface. The surface temperature is then projected into deeper soil layers. In principle, such permafrost models can account for small-scale spatial heterogeneity, if only a sufficiently resolved set of all input parameters is provided. In practice, such data sets rarely exist, so it is necessary to identify the crucial parameters and the spatial and temporal scales, over which they must be accounted for to achieve a satisfactory accuracy of the model. For this purpose, a detailed understanding of the surface energy budget is indispensable.

2 SITE

The study site is located between the glacier Brøggerbreen and the Kongsfjorden at 78° 55'N, 11° 50'E, approximately 2km SW of the village of Ny-Alesund on Svalbard. It is situated in hilly tundra at the foot of two major glaciers at elevations of 15m to 25m above sea level and is characterized by sparse vegetation alternating with exposed soil and rock fields.

3 METHODS AND RESULTS

We present continuous measurements of all components of the surface energy budget at a high-arctic permafrost site on Svalbard over the course of one year (Westermann et al. 2009). An eddy covariance system is used to determine the turbulent land-atmosphere exchange processes. Our results highlight the importance of sensible and latent heat fluxes for the formation of the surface temperature. During the snow-free period, the surface temperatures of an area of about 100 x 100 m² have been monitored at spatial resolutions below one meter us-

ing a thermal camera system. Strong temperature differences between wet and dry areas are found on short timescales of a few hours. Using an energy balance approach, this can be explained by different evaporation rates and hence a different energy partitioning between the sensible and the latent heat flux. However, on timescales of one week to one month, the differences between wet and dry areas widely average out, so that they are negligible for the formation of spatial differences in subsurface temperature.

During winter, an average temperature difference of more than 3K is found between the air temperature at 10m height and the surface temperature. This strong near-surface temperature inversion is a striking feature, which clearly limits the use of air temperatures as surrogate for the temperature of the snow surface.

Furthermore, the temperature at the snow-soil interface and the temperature profile to a depth of 1.5 m have been monitored at 14 different locations within an area of half a square kilometre. In contrast to summer, sustained average temperature differences of up to 6 K between different locations are found at the snow-soil interface, although energy balance calculations and direct measurements suggest little spatial variation of the temperature of the snow surface. The temperature differences is directly related to the thickness of the snow cover and possibly also its history of formation. They result in strong site-to-site variations of the soil temperatures at 1.5 m depth, which range from -6°C to -0.3°C in March. The snow cover is therefore found to be the prime source of spatial variability of the permafrost temperatures at the study site.

References

- Westermann, S., Lüers, J., Langer, M., Piel, K., and Boike, J. The annual surface energy budget of a high-arctic permafrost site on Svalbard, Norway, *The Cryosphere*, 3, 245–263, <http://www.the-cryosphere.net/3/245/2009/>, 2009.

Snow Cover Measurements around the Permafrost Boreholes at the PACE-Site Stockhorn Plateau

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1 GENERAL INFORMATION

The Stockhorn plateau (3410 m asl) is located in the southern Swiss Alps and is part of the Matter Valley. The site has a MAAT of -5.5 °C, a mean annual precipitation of 1500 mm and is within the zone of discontinuous permafrost. Here, two PACE-boreholes (depth: 30 m and 100 m), a meteorological station and a geoelectric monitoring profile have been installed for permafrost research. Additionally, measurements of the near-surface ground temperatures were made during different years. The effects of topography cause a complex temperature regime at this site (Gruber et al. 2004).

2 SNOW COVER

2.1 *Snow cover and permafrost*

Permafrost distribution and evolution is influenced by snow cover duration, snow depth and ablation timing due to the high insulation and albedo of snow. Especially in complex topography, small scale differences in snow cover conditions can diminish or amplify the effect that colder or warmer air temperatures have on the ground. Hence, the snow cover is an important factor for the interpretation of the temperature measurements made in permafrost ground.

2.2 *Data situation at the Stockhorn plateau*

Due to data gaps caused by lightning and a high frequency of errors, a rather discontinuous time series from the meteorological station seriously restricts the analysis of snow depth data from this station. Other data such as ground surface temperatures can be used as indicator to derive e.g. the end of the seasonal snow cover. Two data sets of the near-surface ground temperatures from the years 2004-2005 and 2007-2008 are available and have been analyzed.

3 RESULTS

Results show a strong spatial variation of the ablation timing at the Stockhorn plateau, which can vary

about 30 days during a single year even though the slope angle and orientation are the same.

These substantial small-scale variations indicate a limited representativeness of the snow depth measured at the meteorological station for the characterization of the permafrost conditions of the boreholes or even the whole Stockhorn plateau. The effects of differences in snow cover thickness and duration contribute, with other factors, to differences of up to 3 °C within the MAGST at this site.

4 CONCLUSIONS

The strong spatial variations in snow cover conditions on the Stockhorn plateau revealed by the presented analysis provide important information to support not only the interpretation of the two permafrost boreholes but also the heterogeneous resistivity distribution observed in the electrical resistivity monitoring profile. Moreover, the results from this analysis of the two short-term data sets from 2004 to 2005 and 2007 to 2008 clearly call for the installation of permanent ground surface temperature measurements across the plateau with respect to the variability of snow cover conditions and their influence on permafrost distribution and evolution. Within the PERMOS-network, the permanent measurement of the ground surface temperature has been a reliable method to derive the timing of snow cover disappearance (PERMOS 2009).

References

- Gruber, S., King, L., Kohl, T., Herz, T., Haeberli, W. & Hoelzle, M. 2004. Interpretation of the Geothermal Profiles Perturbed by Topography: the Alpine Permafrost Boreholes at the Stockhorn Plateau, Switzerland. *Permafrost and Periglacial Processes*, 15: 349-357.
- PERMOS 2009. *Permafrost in Switzerland 2004/2005 and 2005/2006*. Noetzli, J., Naegeli, B. & Vonder Muehll, D. (eds.), Glaciological Report (Permafrost) No. 6/7 of the Cryospheric Commission (CC) of the Swiss Academy of Sciences (SCNAT), 100 pp.

Permafrost in the Qilian Mountains, China – Report from Field Drill Survey

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1 INSTRUCTIONS

The Qilian Mountains (93°30'~103°00' E, 36°30'~39°30' N) which along the HeXi corridor strike northwest to southeast locate the north-east edge of the Qinghai-Tibet Plateau, where is confluence area of three macroclimate type (i.e. seasonal, inland arid and alpine climate) of China. The altitude of Qilian Mountains range from 3000 to 5800m, and the mean annual temperature of Muli (4000m a.s.l.) is about -5.8°C, the mean annual precipitation decline from about 600mm in east section to less than 200mm in west section of the Mountains.

Permafrost distribute widely in Qilian Mountains because of alpine cold climate. The discrepancy of local humidity between east and west section induce the differences of permafrost distribution and characters.

During 2004~2009years, a series of permafrost drilling programs have been carried along the Datong River, Buha River and Shule River valleys. Based on the information from field drilling survey, this paper describe the permafrost characters both east and west section of Qilian Mountains.

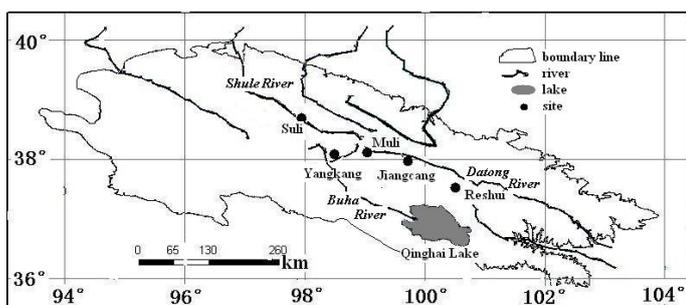


Figure 1. Location of Qilian mountains

2 PERMAFROST CHARACTERS

2.1 The lower limit of Permafrost

Datong River valley is in east section of Qilian Mountains, where have three sites (Reshui, Jiangcang, Muli). The precipitation is over 500mm, humid climate make marsh grow in bottom of valley. Under the ecosystem protected, the permafrost occurred in lower altitude local. In Reshui, the lower limit of permafrost is about 3550m, even lower altitude at about 3400m find permafrost too further to

east. To west, the precipitation decrease to 300mm in Yangkang and 250mm in Suli so that the vegetations deteriorate. The lower limit of permafrost raise to about 3670m and 3750m in Yangkang (Buha River valley) and Suli (Shule River valley) respectively.

2.2 Permafrost distribution

Distribution of permafrost in Qilian Mountains is controlled mainly by altitude. Because of discrepancy of humidity between east and west section, the occurrence of permafrost present the “longitudinal zonality”. But the “latitudinal zonality” is not obviously for the range of latitude being small.

In generally, the depth and mean annual ground temperature (MAGT) become deeper and colder respectively with the elevation increasing. The lapse rate of the MAGT is different between the east and west section in the mountains. The MAGT has dropped about 0.27°C when the elevation rise 100m in Datong River valley, there is 0.42°C in the Buha River valley, and 0.94°C in Shule River valley.

Because there are effects of ecosystem on the thermal regime of ground surface, and the effects differentiate in local. This induce the width of island permafrost zone is different between the east and west in Qilian Mountains. The width of island permafrost zone is 70km, the height scope is 200m in Datong River valley; in Buha River valley, these data are 40km and 100m respectively; there are not permafrost island in Shule River valley.

Monday
18:00-19:00

Open Public Lecture

The Unintended Research Legacy of John Munro Longyear

Frederick E. Nelson, University of Delaware

In Møysalen and video streamed to Lassegrotta

The Unintended Research Legacy of John Munro Longyear

Frederick E. Nelson

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BACKGROUND

Longyearbyen's namesake, John Munro Longyear, was born in Lansing, the capital of the USA's State of Michigan, in 1850. After attending schools affiliated with Olivet College in southern Michigan and Georgetown College in Washington, DC, Longyear embarked on a career of "landlooking" in Michigan's Upper Peninsula. He became an expert appraiser of mineral and timber resources and amassed a large amount of land during an economic downturn in the 1870s. The land was rich in iron ore, and Longyear eventually became the leader of an international conglomerate of mining and forest-products interests. He served as a member of the Board of Control of the Michigan School of Mines (now Michigan Technological University), was instrumental in developing Northern State Normal School (now Northern Michigan University), and was Mayor of the City of Marquette during the early 1890s.

In 1889, Longyear and several other prominent Michigan men founded the "Huron Mountain Shooting and Fishing Club" on a large tract of scenic land along the shore of Lake Superior. Currently known as the "Huron Mountain Club," this is one of the most extensive areas of old-growth forest in the eastern USA. While President of the Club, Longyear developed a gentleman's farm on land surrounding Ives Lake, just outside Club borders. Following the Longyear family's move to Brookline, Massachusetts in the opening years of the 20th century he built "Stone House," a large summer home on the shores of Ives Lake, to provide a setting suitable for transacting those of his business enterprises remaining in Michigan. The house was furnished exclusively with several consignments of furniture purchased in Norway. Following Longyear's death in 1922 the property, of which Stone House is part, was used in a variety of agricultural and resort schemes. It eventually was acquired by the Huron Mountain Club.

Several years after a family visit to Spitsbergen in 1901, Longyear and business partner Frederick Ayer purchased the operations of the former Trondheim-Spitsbergen Coal Company, establishing operations in "Longyear City" (the name was changed subsequently to *Longyearbyen*). Renaming the enterprise the "Arctic Coal Company," Longyear and Ayer set up mining operations that survive to the present time. Longyear also made contributions to the governance of Spitsbergen, which at the time was a *terra nullius* ("no man's land").

LONGYEAR'S SCIENTIFIC LEGACY

John M. Longyear's life is usually interpreted as that of a successful businessman and entrepreneur. It is important, however, to recognize his significant contributions to education and science, several of which were unintended:

(1) Following submission of a 1938 report by Aldo Leopold about integrated scientific land management in the Huron Mountains, the Club undertook a program of environmental conservation that ultimately resulted in the formation of the Huron Mountain Wildlife Foundation (HMWF) in 1955. This organization is concerned with the encouragement of scientific research on Club property. Today, HMWF oversees a burgeoning program of scientific research into a diverse group of topics, including forest and wildlife ecology, climatology, Quaternary geology and paleoecology, fisheries, and entomology. Hundreds of scientists have conducted research in the Huron Mountain Club while living in Stone House, the structure that was once Longyear's summer home.

(2) Through his advocacy and service to two fledgling universities, Longyear helped to ensure that scientific research and education would benefit the citizens of Michigan's remote Upper Peninsula region, in perpetuity.

(3) Longyear was deeply interested in historical topics and, following his death, his daughter donated his extensive collection of books, maps, photographs, and manuscripts to the Marquette County History Museum, where it now administered as the "J.M. Longyear Research Library." This facility is used heavily, and attracts both local and foreign researchers.

(4) Part of Longyear's "unintended research legacy," of great consequence to this conference, involves his activities in Svalbard. The mines developed by the Arctic Coal Company and its successors now function as a long-term permafrost observatory. Several geographic features named for Longyear have become the subjects of successful programs of research on permafrost and periglacial topics.

Longyear's activities early in the 20th century were an important factor that allowed Svalbard to eventually become a leading international center for research on permafrost and periglacial geomorphology. Without Longyear's contributions a century ago, it is highly unlikely that an international permafrost conference would be taking place in this location.

Tuesday

Time	Tuesday, June 15
8:00 – 13:00	Registration Desk Open <i>in UNIS Entrance Hall</i>
8:30 – 9:00	KEYNOTE <i>in Møysalen and video streamed to Lassegrotta</i> The Development of Infrastructure on Permafrost in Svalbard Arne Instanes
9:00 – 9:30	KEYNOTE <i>in Møysalen and video streamed to Lassegrotta</i> State of Periglacial Research at the End of IPY Norikazu Matsuoka
9:30 – 10:00	COFFEE/TEA
ORAL Parallel session: Periglacial Processes and landforms II <i>co-chairs: Michel Allard & Karianne Lilleøren in Lassegrotta</i>	
10:00 – 10:15	Mapping and Monitoring of Rock Glaciers in the Chilean Andes: a Progress Report A. Brenning, G.F. Azócar, X. Bodin
10:15 – 10:30	The Slump of the Grabengufer Rock Glacier (Swiss Alps) R. Delaloye, S. Morard, D. Abbet, C. Hilbich
10.30 – 10:45	Distribution and Structure of Permafrost in Two Alpine Talus Slopes, Valais, Swiss Alps C. Scapozza, C. Lambiel, L. Baron, L. Marescot, E. Reynard
10:45 – 11:00	Time-Lapse Electrical Resistivity Tomography (ERT) to Estimate Temperature Changes at Depth and Isolated Permafrost Patches in Two Low Elevation Ventilated Cold Talus Slopes – Western Switzerland S. Morard, R. Delaloye
11:00 – 11:15	Inhomogeneity of (Sub-)Surface Conditions at a Permafrost-Affected Glacier Forefield, Swiss Alps T. Rödder, C. Kneisel
11:15 – 11:30	Application of Lidar and GPR to Terrestrial and Martian Periglacial and Glacial Geomorphology L. Thomson, G. R. Osinski, T. Barfoot

Time	Tuesday, June 15
11:30 – 11:45	Permafrost Landforms on Spitsbergen (Svalbard, Norway) – Terrestrial Analogues for Martian mid-Latitude Landscapes E. Hauber, F. Preusker, F. Trauthan, R. Jaumann, D. Reiss, M. Zanetti, H. Hiesinger, M. Ulrich, L. Johansson, A. Johnsson, M. Olvmo
11:45 – 12:00	Investigation of Thermokarst Depression Asymmetry in Siberian Ice-Rich Permafrost in Comparison to Asymmetric Scalloped Depressions on Mars M. Ulrich, A. Morgenstern, F. Günther, L. Schirrmeister, D. Reiss, E. Hauber

ORAL Parallel session: Palaeo-Permafrost and Coastal Dynamics

co-chairs: Britta Sanell & Hugues Lantuit in Kapp Mitra

10:00 – 10:15	Evolution of Permafrost and Periglacial Environments in the Northeastern China since the Last Glaciation Maximum H. Jin, M. Wei, Q. Wu
10:15 – 10:30	Reconstruction of Late Quaternary Permafrost Distribution: Utilization of the Global Climate Models K. Saito, S. Marchenko, N. Bigelow, V. Romanovsky, K. Yoshikawa, J. Walsh
10.30 – 10:45	Holocene Climate Variability as Deduced from Radiocarbon-Dated Ice Wedges from the Central Lena Delta, Northern Siberia H. Meyer, T. Opel, A. Dereviagin
10:45 – 11:00	Quartz Weathering in Freeze-Thaw Cycles; Experiment and Application to El'gygytgyn Crater Lake Record for Tracing Siberian Permafrost History G. Schwamborn, B. Diekmann, L. Schirrmeister, A. Förster
11:00 – 11:15	Late Quaternary Sedimentation History of a Coastal Permafrost Landscape, Western Laptev Sea, NE Siberia M. Winterfeld, L. Schirrmeister, P.P. Overduin, M. Grigoriev, V. Kunitsky
11:15 – 11:30	The Nature and Origin of Massive Ground Ice on Herschel Island (Western Canadian Arctic) Deduced from Stable Isotope and Hydrochemical Investigations M. Fritz, S. Wetterich, H. Meyer, L. Schirrmeister, H. Lantuit, N.J. Couture, W.H. Pollard

Time	Tuesday, June 15
11:30 – 11:45	Fossil Organic Carbon in Arctic Permafrost Sequences of Northern East Siberia – Contents and Characteristics L. Schirrmeister, S. Wetterich, G. Grosse, C. Siegert, P.P. Overduin, H.-W. Hubberten
11:45 – 12:00	How Important Is Ground Ice in Coastal Flux Studies? N.J. Couture, W.H. Pollard
ORAL Parallel session: Mathematical and Physical Modelling of Permafrost <i>co-chairs: Nikolay Shiklomanov & Anna Klene in Møysalen</i>	
10:00 – 10:15	An Empirically-Based Permafrost Distribution Model for the Entire Alps L. Boeckli, S. Gruber, J. Noetzli, A. Brenning
10:15 – 10:30	Experimental and Numerical Modeling Studies of Pore Water Pressure Variations in Subpermafrost Groundwater A. Rivière, J. Goncalves, A. Jost, M. Font
10.30 – 10:45	Physical Modeling Approach of Thawing Permafrost B. Hurault, J.-L. Lagarde, M. Font
10:45 – 11:00	ERT Regularization Schemes for Improved Fracture Delineation in Alpine Permafrost Rocks: Results from Numerical Simulations and Measurements at the Aiguille Du Midi, France A. Kemna, M. Krautblatter, P. Deline, L. Ravanel, V. Coviello, E. Cremonese, P. Pogliotti
11:00 – 11:15	Modeling the Thermal Regime of Mountain Permafrost in Southern Norway with Respect to a Changing Climate T. Hipp, B. Etzelmüller, T.V. Schuler, H. Farbrot, K. Isaksen
11:15 – 11:30	Observed and Projected Changes in Climate, Permafrost, and Active Layer in Northern Eurasia and Their Relation to Permafrost Carbon Pool S. Marchenko, V. Romanovsky, O. Bulygina, V. Razuvaev
11:30 – 11:45	Size Matters - Very High Resolution Permafrost Simulations on the 4 Km Scale in Northeast European Russia M. Stendel, J. Hesselbjerg Christensen, S. Marchenko, R. Daanen, V. Romanovsky

Time	Tuesday, June 15
11:45 – 12:00	Modelling Mountain Permafrost Distribution above and below Treeline Using Empirical-Statistical Methods, Yukon Territory, Canada P.P. Bonnaventure, A.G. Lewkowicz
12:00 – 13:00	LUNCH
13:00 – 18:00	FIELD EXCURSION to infrastructure and permafrost research sites in and near Longyearbyen
18:00 – 22:00	BARBEQUE between SAS Hotel and UNIS

Tuesday

Keynotes

In Møysalen and video streamed to Lassegrotta

8:30-9:00 The Development of Infrastructure on Permafrost
in Svalbard

Arne Instanes, *INSTANES POLAR AS, Bergen , Norway*

9:00-9:30 State of Periglacial Research at the End of IPY

Norikazu Matsuoka, *Life and Environmental Sciences, university of Tsukuba, Tsukuba,
Japan*

The Development of Infrastructure on Permafrost in Svalbard

A. Instanes

INSTANES POLAR AS, Bergen, Norway

1 INTRODUCTION

The development of infrastructure on permafrost in Svalbard has gone through several stages during the last hundred years. This lecture aims at giving a historical background for engineering design on Spitsbergen and the development of foundation techniques that can handle challenging ground conditions such as warm, saline, ice-rich permafrost. The uncertainty related to future reliability of existing infrastructure caused by climate change will also be discussed.

2 INFRASTRUCTURE

The infrastructure associated with human settlements in Svalbard is rather limited compared to Alaska, Canada and Russia. There are only five main towns or settlements on the Spitsbergen island: Ny-Ålesund, Pyramid, Longyearbyen, Barentsburg and Sveagruva. Today only Sveagruva and Barentsburg are solely dependent on the traditional industrial activity on the island; coal mining. Ny-Ålesund, Longyearbyen and Sveagruva are Norwegian settlements, Longyearbyen being the principle one with close to 2000 inhabitants. The Russian settlements Barentsburg and Pyramid did both have more than 1000 inhabitants in the 1990-ties, but there has been some decline in population in Barentsburg the last couple of years and Pyramid was abandoned in 1998.

All these communities require infrastructure such as transportation facilities, power plants, water supply, waste-water treatment, sewage lines and buildings and man-made structures for various purposes.

In the Norwegian communities the buildings are seldom more than 2½-stories in order to reduce the loads and/or the necessary amount of foundation piles. In the Russian communities the buildings can be more than 4-stories high and may require a large number of piles to support the heavy structures.

The major parts of the engineering structures in the settlements have been designed and constructed during the last 30 years.

3 PERMAFROST ENGINEERING DESIGN

In permafrost regions, special foundation techniques have been developed in order to handle frozen ice-rich and saline foundation soils. However, conventional foundation design can be used if the foundation soils does not change volume or induce excess pore pressures upon warming or thawing. In these cases warming or thawing of permafrost is acceptable. Typically this is possible if the foundation soils consist of artificially crushed rock, gravel, coarse sand, or solid rock without ice-filled cracks and hollows. If the ground becomes unstable upon warming and thawing, the engineering design must ensure that the thermal stability of the foundation soils is intact during the construction work and service lifetime of the structure. When the ground conditions are characterized by high salinities and high ice-contents, it may be required to artificially cool the foundation soils to ensure the mechanical and thermal stability of the foundations and soil during the lifetime of the structure.

4 CHANGING CLIMATE

During the last two decades the mean annual air temperature has increased in Svalbard. This has caused some concerns related to the reliability of infrastructure in the region, and reduction of lifetime of existing structures.

The sensitivity of a particular infrastructure project to climate change is determined by a number of factors, including the initial soil/permafrost temperatures, the temperature dependence of the material properties, the project lifetime, and the existing safety margin that might be included in the design.

A risk-based approach should be used to evaluate engineering projects in terms of potential climate warming impacts. It is also important to combine engineering knowledge with socioeconomic development scenarios and environmental impact assessments in order to evaluate how projected climate change may affect human lives in the Arctic in the future.

State of Periglacial Research at the End of IPY

N. Matsuoka

Life and Environmental Sciences, University of Tsukuba, Tsukuba, Japan

1 INTRODUCTION

During IPY (2007-2009) intensive studies, including IPA-sponsored projects, promoted significant progress in understanding periglacial processes, landscapes and structures in polar regions. The progress is mainly achieved by advances in on-site and remote-sensing technologies. New or featured topics also widened research subjects as well as intensified understanding of specific problems. This report highlights some of the major topics in periglacial research during IPY and prospects next steps.

2 TECHNOLOGICAL ADVANCES

2.1 *Comprehensive monitoring of periglacial processes*

Intensive monitoring campaigns have progressed in Canadian Arctic and Svalbard. Solifluction monitoring involves 2D surface heave, internal deformation, soil temperature and moisture with various techniques. Ice wedge monitoring is enhanced by a combination of 2D movements of troughs and ramparts, breaking of subsurface cables and counting of acceleration events. Detailed monitoring also focuses on dynamics of polar rock glaciers.

2.2 *Visualizing surface morphology and subsurface structure*

Visual techniques permit detailed topographic mapping and thermal imaging of small-scale periglacial land surface (e.g. patterned ground, rock surface). High resolution geophysical soundings (e.g. GPR, ERT) also visualize 2D and 3D subsurface structures of ice-wedge polygons, pingos and smaller features, which display stratigraphy, wedge structure, ice distribution and soil moisture content. Time series of these images reinforce process monitoring.

2.3 *Thermal, geochemical and structural analyses of active layer-permafrost soils*

Geochemical analyses provide profiles of isotopes and dissolved ions in the active layer, as well as temporal change in electric conductivity of soil solutions below frost mounds (mudboils, palsas and li-

thalsas). The chemical data, combined with temperature, moisture, composition and structure of soils, imply mechanisms of frost heave or cryoturbation responsible for these periglacial features.

3 NEW OR FEATURED TOPICS

3.1 *Thermokarst and slope processes associated with global warming/forest fire*

Remote sensing and on-site investigations highlight a recent increase in thaw slumping and thermokarst features, associated with permafrost thawing due to climatic change or forest fires. Prediction of thaw slump generation requires mapping of ice-rich permafrost. Other features associated with permafrost degradation include block failures along coasts and riverbanks, differential ground settlement, ice wedge inactivation and, possibly, rock glacier activation.

3.2 *Polar landscape as Martian surface analogues*

High resolution images of the Martian surface have recently displayed small-scale landforms resembling polygons, pingos and rock glaciers. Their origins are discussed with terrestrial equivalents in the Arctic and Antarctica. Major debates concern the shape and dimensions, the presence and source of subsurface water and the timing and thermal condition for formation. The lack of subsurface information complicates the interpretation. A major question is whether polygon troughs are underlain by ice, sand, or sublimation wedges.

4 PROSPECTS FOR POST-IPY PROJECTS

Periglacial features have often been used as indicators of past climate, but mostly based on empirical rules. To appeal the significance of periglacial research to wide disciplines in geoscience requires establishments of more precise climatic indicators. This goal can be achieved by synthesizing the above techniques to evaluate the climatic thresholds and/or dependence on climatic variables of various periglacial features.

Tuesday
10:00-12:00

ORAL Parallel Session

Periglacial Processes and Landforms II

Co-chairs: Michel Allard & Karianne Lilleøren

In Lassegrotta

Mapping and Monitoring of Rock Glaciers in the Chilean Andes: a Progress Report

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1 INTRODUCTION

Rock glaciers, the geomorphological expression of creeping ice-rich mountain permafrost, exist in a variety of climatic conditions along the Chilean Andes from the arid Atacama into the humid Andes. We review recent studies investigating the significance of rock glaciers as water resources, and present first results from recently established rock glacier monitoring sites in Chile. Research on rock glaciers in Chile has strongly increased in recent years because of the impacts of mining on rock glaciers and the establishment of a National Glacier Policy.

2 REGIONAL DISTRIBUTION AND SIGNIFICANCE

Rock glaciers exist in three latitudinal zones along the Chilean Andes: (1) The dry tropical Andes north of the Arid Diagonal of South America (from 23.5°S northward into Peru at 15°S), (2) the arid-to-subhumid part of extratropical winter precipitation area (27-35.25°S), and (3) locally in the relatively dry, eastern part of the Patagonian Andes (~45-50°S). However, rock glaciers are best developed in the semi-arid Andes from Santiago (~33.5°S) northward to ~28°S. Statistical sample surveys combined with air photo analysis have been conducted to estimate the water equivalent of rock glaciers, indicating that rock glaciers in the semi-arid Andes (29-32°S) store approximately three times as much ice as glaciers in the same area (Azócar & Brenning, 2009). Overall, there are on the order of 4000-5000 rock glaciers in Chile between 27°S and 34.5°S, covering 460 km² and storing a water equivalent on the order of 3.3 km³ using very conservative assumptions (40% ice content by volume, fixed thickness of 20 m), and 7.9 km³ using more optimistic assumptions (60% ice content by volume, area-volume scaling methods). Rock glacier inventories are not yet available but are currently being prepared by the authors for three watersheds in the semi-arid Andes within a project funded by the Dirección General de Aguas (DGA) of Chile.

3 MONITORING ACTIVITIES

Continuous monitoring of ice-rich mountain permafrost in the Chilean Andes has been initiated in 2003/04 in the Laguna Negra area near Santiago, where geodetic GPS surveys are being conducted since then. GPS measurements and multitemporal air photo analysis (1956-1996) of an adjacent debris-covered glacier indicate a significant downwasting component and thus strikingly different dynamics than on the connected debris rock glacier (Bodin et al., in press). As a consequence of ice loss from retreat of the Echaurren Norte glacier (monitored by the DGA since the 1970s) and the downwasting of a debris-covered glacier, the amount of ice stored in rock glaciers is increasingly exceeding the amount stored in glaciers (current ratio: 1.5:1). A second focus of monitoring is on ground thermal conditions and snow cover. Active rock glaciers in this area often occur at elevations with positive current mean annual air temperatures (MAAT), suggesting a high sensitivity to climate change.

Since 2009, a second monitoring area is being set up in the semi-arid Andes at 30°S at and near Cerro Tapado on behalf of and with funding from the DGA. A high-elevation (4400 m a.s.l. at snout) debris rock glacier and a nearby lower-elevation (3750 m a.s.l. at snout, MAAT ~2°C) talus rock glacier have been instrumented with a geodetic GPS monitoring network and ground surface temperature sensors. Active-layer boreholes for thermal monitoring will be drilled in 2010 in cooperation with the IANIGLA (D. Trombotto, Mendoza, Argentina). This will allow for future comparisons with ongoing long-term monitoring activities in Argentina.

References

- Azócar, G.F. & Brenning, A. 2009. Hydrological and geomorphological significance of rock glaciers in the dry Andes, Chile (27°-33° S). *Permafrost and Periglacial Processes*, DOI: 10.1002/ppp.669.
- Bodin, X., Rojas, F. & Brenning, A. accepted. State and recent evolution of the cryosphere in the Andes of Santiago (Chile, 33.5°S). *Geomorphology*, accepted.

The Slump of the Grabengufer Rock Glacier (Swiss Alps)

R. Delaloye, S. Morard, D. Abbet, C. Hilbich

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1 INTRODUCTION

June 2009 the Grabengufer rock glacier – a steep 500 m long and 100 m wide rock glacier located close to the lower limit of the regional discontinuous permafrost belt in the Valais Alps (Switzerland) – exhibited several large transverse fresh scarps in its rooting zone as well as in its terminal section. The remnants of the winter snowpack were in many places heavily crevassed. Permafrost ice-rock mixture was outcropping in the uppermost cracks and in three zones at the front of the rock glacier. The rock-fall activity from the front was very high.

InSAR (synthetic aperture radar interferometry) analysis of 1-day ERS-1/2 scenes dating back to the years 1995-1997 allowed previously to identify the rock glacier as a potentially destabilised landform with displacement rate in the range of cm/day (Delaloye et al. 2008). However, the above depicted description of the rock glacier pointed out a stronger disturbance of the current creep processes. They suggested exceptionally high movement rate and even the possibility for the terminal part of the rock glacier – located on a 30-40° inclined slope – to collapse.

2 ROCK GLACIER SURVEY

Since July 2009, in agreement with the local and regional authorities, the surface motion of the still accessible sections of the rock glacier has been regularly surveyed by means of geodetic measurements (total station, DGPS). A camera has also taken daily one to several lateral pictures of the rock glacier. In September 2009 a permanent GPS was installed in the central part of the rock glacier and had to be replaced in February 2010. In addition, a ground-based InSAR survey was performed in August 2009 (Strozzi et al. 2009) with the support of the Federal Office for the Environment.

Geophysical investigation (electrical resistivity, refraction seismics and ground penetrating radar) was moreover conducted during three days in August

2009 in the central, still accessible part of the rock glacier.

3 PRELIMINARY RESULTS

After 8 months of survey (July 2009 – February 2010), exceptionally high surface velocities ranging from 30 to more than 200 m/year have been measured depending on the rock glacier sections. Despite a gentle acceleration the rock glacier motion rate did not change significantly for the whole period.

Mid-February 2010, there was still no collapse of the rock glacier tongue but a rapid erosion of the front has occurred for the previous months and a few new scarps has opened.

Beneath every scarp the surface tends to dip backwards evidencing the development of rotational failures through the rock glacier. Between the scarps the surface remains mostly undisturbed. Morphologically the current crisis of the rock glacier can be compared to a slump.

Geophysics suggests a total thickness of the rock glacier of about 15 to 25 m, with a basal layer containing much fine-grain material and unfrozen water and where a large part of the mass wasting is likely to occur.

Considering the measured velocities and their development, the involved volumes of material and their geometry, and so far there is no collapse, it can be foreseen that the slump should continue until 2011 or 2012 before to slow down gradually. A total amount of about 250'000 m³ of rocks is expected to be delivered in the gully beneath the rock glacier snout, of which about 3/5 until 2012.

References

- Delaloye, R., Strozzi, T., Lambiel, C., Perruchoud, E., Raetz, H. 2008. Landslide-like development of rockglaciers detected with ERS-1/2 SAR interferometry. *Proceedings of the FRINGE 2007 Workshop, Frascati, Italy, 26-30 November 2007 (ESA SP-649, February 2008)*.
- Strozzi, T., Delaloye, R., Raetz, H., Wegmüller, U. 2009. Radar interferometric observations of destabilized rockglaciers. *Proceedings of the FRINGE 2009 Workshop, Frascati, Italy, 30 November - 4 December 2009 (in press)*.

Distribution and Structure of Permafrost in Two Alpine Talus Slopes, Valais, Swiss Alps

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1 INTRODUCTION AND STUDY SITES

In order to determine the spatial extension and the characteristics of the permafrost within alpine talus slopes, geophysical measurements were carried out in several sites of the Swiss Alps, proposing a model of the permafrost distribution in talus slopes located within the Alpine periglacial belt (e.g. Lambiel and Pieracci, 2008). According to this model, permafrost appears likely in the lower part of the slope, whereas it is generally improbable upslope. In order to validate this model, two periglacial talus slopes located in the western part of the Swiss Alps (Valais) have been studied thanks to destructive borehole drilling and electrical resistivity tomography (ERT) profiles: Les Attelas talus slope, composed of paragneiss, (Verbier area, 2600-2800 m a.s.l.) and the Petit Mont Rouge talus slope, composed of dolomites and limestone (Arolla area, 2600-2700 m a.s.l.).

2 RESULTS AND DISCUSSION

Three boreholes have been drilled along an upslope-downslope transect in the two talus slopes. For both sites, frozen sediments are present only in the two lowest boreholes, whereas the upper borehole does not present ice (Fig. 1 – for more details, see Scapozza *et al.*, submitted). The stratigraphy is confirmed by ground temperatures registered in the boreholes.

In both sites, an upslope-downslope ERT profile has been measured in summer 2009. These two profiles show a difference in inverted resistivities between the lower and the upper part of the slope. In the Attelas talus slope, a resistive body with values higher than 15 k Ω m (with maximal resistivities higher than 50 k Ω m) and a thickness of about 15-20 m is present in the lower part of the slope, with resistivities that decreased with increasing elevation. In the Petit Mont Rouge talus slope, maximal resistivities are comprised between 100 and 200 k Ω m in the lower part of the talus slope (between 54 and 82 m), and higher than 200 k Ω m in the protalus rampart (between 88 and 116 m). In the uppermost part of the profiles, the resistivities are lower than 5 k Ω m for the Attelas talus slope, and lower than 15 k Ω m for the Petit Mont Rouge talus slope.

These results confirm that, in the two studied sites, the presence of permafrost is probable in the lower parts of the talus slope, whereas it appears to be improbable in the upper parts. The borehole data allowed validating the stratigraphy obtained from the ERT profiles, both for the distribution of frozen sediments in the talus slope and for the depth of the detected structures.

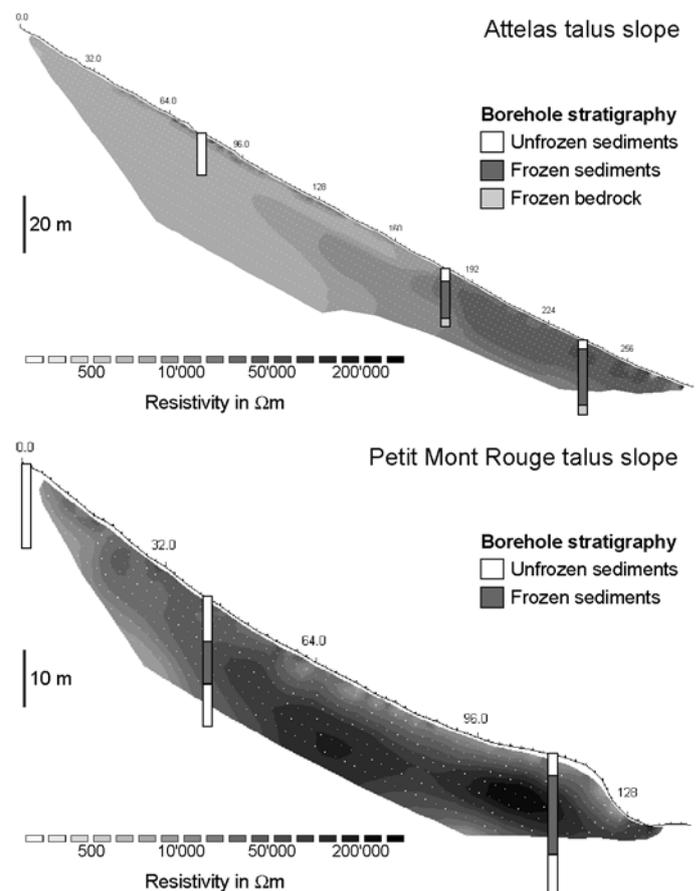


Figure 1. Inverted ERT profiles and boreholes with stratigraphy along an upslope-downslope transect.

References

- Lambiel, C., Pieracci, K. 2008. Permafrost distribution in talus slopes located within the alpine periglacial belt, Swiss Alps. *Permafrost and Periglacial Processes* 19: 293-304.
- Scapozza, C., Lambiel, C., Baron, L., Marescot, L., Reynard, E., submitted. Internal structure and permafrost distribution in two alpine periglacial talus slopes, Valais, Swiss Alps. *Geomorphology*.

Time-Lapse Electrical Resistivity Tomography (ERT) to Estimate Temperature Changes at Depth and Isolated Permafrost Patches in Two Low Elevation Ventilated Cold Talus Slopes – Western Switzerland

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1 INTRODUCTION

Seasonally reversible air circulation (the “chimney-effect”) throughout a whole talus slope plays a major role on its thermal regime (Morard et al. 2008). This process lead to abnormally cold ground conditions pointing out the possible occurrence of isolated permafrost patches.

2 ERT MONITORING

As the acquisition of temperature data is generally limited to the ground surface or – in more favourable situations – to borehole(s), the dependency of ground electrical resistivity to temperature makes the use of time-lapse ERT a promising tool for documenting more precisely the 2D spatial pattern of the seasonal temperature changes at depth (Hilbich et al. 2008). In particular, freezing phases can be detected with ERT, since resistivity increases exponentially below the freezing point.

A semi-automatic ERT monitoring system with 48 electrodes has been installed along a cross profile since 2007 in Dreveneuse d'en Bas (DrB) talus slope (1580 m.a.s.l.) and in Creux-du-Van (CV) talus slope (1200 m.a.s.l.). The ERT survey has been carried out with a monthly resolution.

3 MAIN RESULTS

(1) Despite differences in total resistivity due to site-specific characteristics in material properties, the occurrence of a resistive body, not restricted to the overcooled area (with summer ice and dwarf spruces) but extending towards the upper part of the slope, was detected in DrB and CV.

(2) In winter, resistivity increases strongly (about 4 to 12 times) at the ground surface in the lower part of the slope, as at depth in the lower half of the high resistive zone (fig.1). These modifications illustrate both the deep penetration of freezing and the (re)filling of a cold reservoir inside the porous talus slope.

(3) In CV, a deep resistive zone remains electrically stable during all year. It could be interpreted as a

permafrost ice body or an area not affected intensively by deep air circulation.

(4) Good relationship was founded between the observed resistivity and the ground surface/borehole temperature, demonstrating the ability of ERT monitoring to estimate relative 2D thermal changes, especially below freezing point.

(5) A particular fact is observed in spring, where resistivities are slightly lower than in fall for the same temperatures above the freezing point. This could be interpreted as an effect of higher unfrozen water content due to the percolation of snowmelt water.

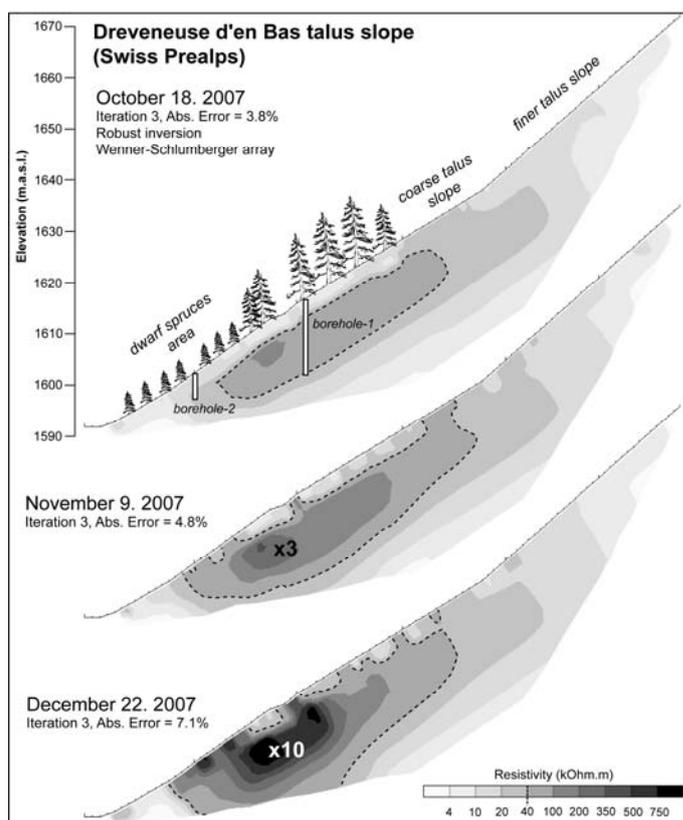


Figure 1. Freezing in early winter of the inside of Dreveneuse d'en Bas talus slope detected by ERT monitoring.

References

- Hilbich, C., Hauck, Ch., Delaloye, R., Hoelzle, M. 2008. A geoelectric monitoring network and resistivity-temperature relationships of different mountain permafrost sites in the Swiss Alps. *Proc. 9th Int. Conf. Permafrost, Fairbanks*: 699-704.
- Morard, S., Delaloye, R., Dorthe, J. 2008. Seasonal thermal regime of a mid-latitude ventilated debris accumulation. *Proc. 9th Int. Conf. Permafrost, Fairbanks*: 1233-1238.

Inhomogeneity of (Sub-)Surface Conditions at a Permafrost-Affected Glacier Forefield, Swiss Alps

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1 MOTIVATION

Within the project “Sensitivity of Mountain Permafrost to Climate Change” the SPCC 3-team is working on the spatial assessment of permafrost characteristics and dynamics in alpine periglacial environments. The main focus lies on the small-scale heterogeneity of substrate and subsurface conditions that is typical for the discontinuous permafrost-zone of the Alps.

Permafrost occurrence and its characteristics are investigated by a number of methods and techniques that will finally enable a detailed mapping and analysis of the internal structure (ice/unfrozen water content, porosity, active layer thickness, thermal envelope, thermal offset, rate of creep) of adjacent sites with and without permafrost.

2 SITE AND METHODS

In 2009 diverse methods were implemented at a glacier forefield below Piz Corvatsch in the Upper Engadin (Swiss Alps) such as temperature measurements at the bottom of the snow cover (BTS), borehole temperature logging, quasi-3D geoelectric resistivity surveying, DGPS and laserscanning.

Within the forefield a complex geomorphology with lateral moraines, coarse blocks and subsidence structures exists, offering a wide range in grain sizes from sand to boulders.

The quasi-3D electrical resistivity tomography (ERT) approach – established in environmental and archaeological studies – has been applied recently in periglacial research. For this study 23 two-dimensional ERT profiles (Wenner and Wenner-Schlumberger array) were collated into one grid. This configuration enhances the horizontal and vertical resolution using a 3D inversion algorithm in the software RES3DINV. An assessment of subsurface conditions is achieved in combination with borehole data from a 10 m deep borehole (BH 1) in the centre of the grid. A second borehole (BH 2) outside the grid suggests permafrost-free conditions.

3 RESULTS AND DISCUSSION

BTS data from winter 2009 indicate that permafrost is possible throughout the whole glacier forefield with temperatures at and below the $-3\text{ }^{\circ}\text{C}$ threshold temperature. Subsequent geoelectrical measurements across BH 1 show large contrasts in resistivity values ranging from around 1.000 Ohm.m up to more than 200.000 Ohm.m , the latter indicating ice-rich permafrost (Fig. 1).

Permafrost conditions in the high-resistivity region are confirmed by borehole temperature data (MAGT: $-0.5\text{ }^{\circ}\text{C}$ in 5 m depth). Information on active layer thickness (2.2 m) and thermal offset ($0.7\text{ }^{\circ}\text{C}$) are derived from the temperature records.

The combination of results from direct temperature measurements and ERT investigations demonstrate the inhomogeneity of the subsurface in a former glaciated area, concerning permafrost distribution.

Beside a high-resistivity body that indicates a high ice content and/or a low content of unfrozen water there is a sharp drop towards low resistivities. This decline coincides with a change in substrate at the surface from interlaced boulders towards sand and gravel covered sporadically with pioneer species.

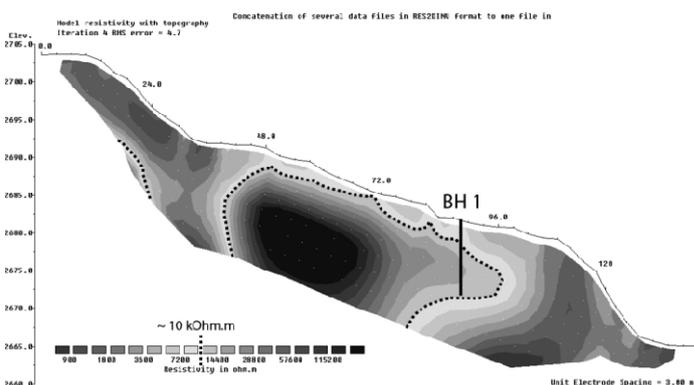


Figure 1. Electrical resistivity tomogram with borehole location of BH 1 (high resistivity body is highlighted by dotted line).

4 OUTLOOK

Ongoing research at this field site will include seismic tomography for crosschecking the ERT and repeated DGPS/laserscanning measurements to quantify the geomorphological dynamics.

Application of Lidar and GPR to Terrestrial and Martian Periglacial and Glacial Geomorphology

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1 INTRODUCTION

We explore the utility of lidar and ground penetrating radar (GPR) as scientific tools in the discipline of polar geomorphology. These techniques were integrated during a series of field tests in 2008 and 2009 on Devon Island in the Canadian Arctic. The two instruments were integrated on a rover-prototype test bed and tested for suitability as tools for both navigation and scientific investigation of the Martian surface (Barfoot et al. 2009; Osinski et al. 2009). This presentation discusses the scientific results of the study according to the sites of terrestrial geomorphic interest, including polygonal terrain, gullies and channels, and slump/collapse features.

2 TECHNIQUES

2.1 Lidar

Lidar (Light Detection and Ranging) scanning systems offer an alternative to in situ field surveying and stereoscopic aerial photography for the collection of three-dimensional data. In essence, a lidar system measures the signal reflection of near-infrared laser pulses off of a solid surface, acquiring a high-resolution spatial measure in three dimensions. When features of known coordinates are within the field of view, the lidar point cloud collected can be georeferenced and integrated into digital mapping media such as geospatial information systems (GIS). While more commonly used as an airborne method to collect digital elevation models (DEMs), recent advances in lidar technology have made portable ground-based surveys possible, as were used in this study.

2.2 GPR

GPR systems enable subsurface reflector dimensions to be resolved according to the relative dielectric properties of the buried materials. In periglacial geomorphology, GPR has been proven to be highly successful in its ability to detect buried ground-ice with sub-metre vertical accuracy. In this study we executed surveys with a 250 MHz hand-towed transceiver antenna system. Depth penetration was on the order of 5-10 metres, with a sub-metre horizontal resolution.

3 RESULTS

The lidar scans provided a wealth of geometric and structural information about a site, accomplishing the equivalent of weeks to months of manual surveying and with much greater accuracy than traditional tools (e.g., differential GPS) (Fig. 1). At the same time, the GPR surveys enabled two dimensional mapping of the underlying permafrost table topography and massive ice inclusions.

The two datasets combined provide insight to the processes linking permafrost table topography, ice inclusions, and subsequent landscape evolution. There is the potential for quantitative correlations to be made between surface feature dimensions and the strength and extent of reflectors found on the GPR profile.

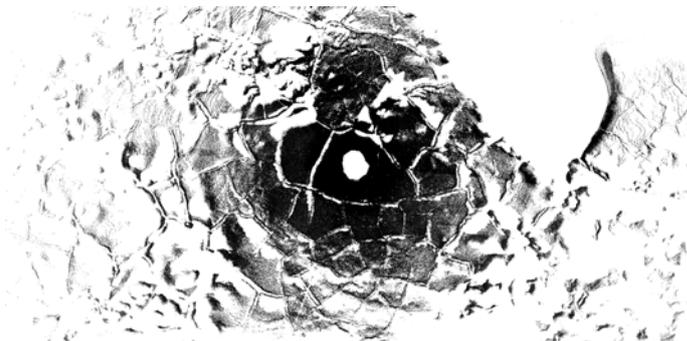


Figure 1. Bird's eye view of lidar scan taken on ground reveals polygon field. The lidar scan was taken at the centre; the dark central area reflects a high number of points in data. Lake Orbiter, Devon Island, Nunavut. Image ~1.6 km across.

References

- Osinski, G., Barfoot, T., Ghafoor, N., Izawa, M., Benerjee, N., Jasiobedski, P., Tripp, J., Richards, R., Auclair, S., Sapers, H., Thomson, L., and Flemming, R. 2009. Lidar and the mobile Scene Modeler (mSM) as scientific tools for planetary exploration. *Planetary and Space Science* doi:10.1016/j.pss.2009.08.004.
- Barfoot T., Furgale P., Osinski G. R., Ghafoor N., Williams K. 2009. Field testing of a mission concept to robotically prospect for ground ice in Martian polygonal terrain. *Planetary and Space Science* doi: 10.1016/j.pss.2009.09.021.

Permafrost Landforms on Spitsbergen (Svalbard, Norway) – Terrestrial Analogues for Martian Mid-Latitude Landscapes

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1 INTRODUCTION

Many landforms on Mars were probably formed by exogenic processes and show a latitude-dependent geographic distribution. They include surface mantling, lobate debris aprons, viscous flow features, gullies, and patterned ground. Collectively, these landforms are hypothesized to represent the surface records of Martian ice ages that were induced by astronomical forcing and associated climate changes.

Many previous studies of possible periglacial features on Mars, however, often considered just one of the features in isolation (e.g., polygons), without taking into account the geomorphologic or physical context. A more comprehensive investigation of the full assemblage of landforms (landscape analysis) has the potential to reduce the ambiguity in interpreting landforms (e.g., the problem of equifinality). Here we present permafrost landforms of Spitsbergen as useful terrestrial analogues for the suite of possible periglacial landforms that are typically found at mid-latitudes on Mars. Based on this comparison, we propose possible scenarios which may help to understand the evolution of these Martian landforms into their present state.

2 DATA

We investigate the morphology and topography of landforms on Mars and Svalbard using images and topographic data (Fig. 1). For Svalbard, orthoimages (20 cm/pixel) and corresponding Digital Elevation Models (DEM) with a cell size of 50 cm, a vertical resolution of 10 cm, and an absolute vertical accuracy of 20 cm were acquired in 2008 during a flight campaign with HRSC-AX, an airborne version of the High Resolution Stereo Camera (HRSC) on Mars Express. Field work was done on the Brøgger peninsula and in Adventdalen in summer 2008 and 2009, including sampling of patterned ground (stone circles, ice-wedge polygons), measurements of thermal conductivity and moisture content of soils, and acquisition of ground truth for HRSC-AX.

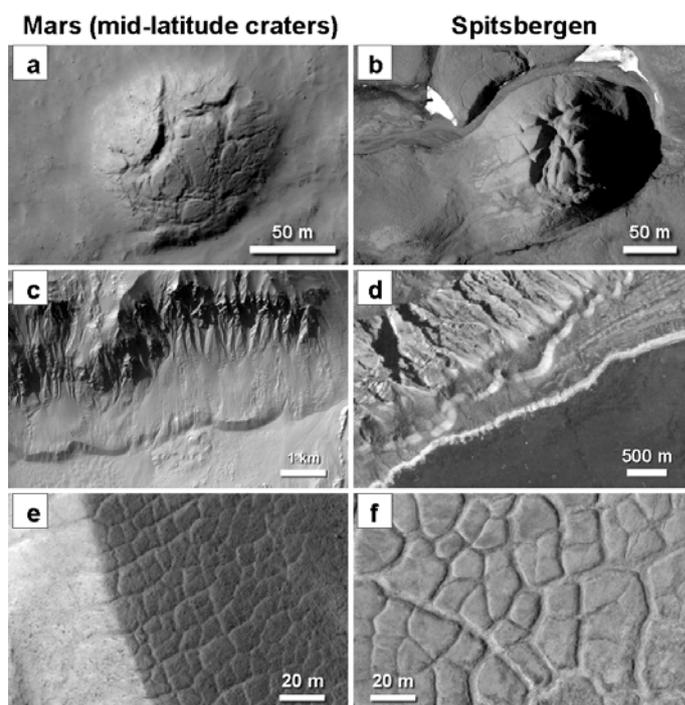


Figure 1. Cold-climate landforms on Mars (left) and Svalbard (right). Mars images: HiRISE, Svalbard images: HRSC-AX (except for d: part of aerial photo S 704128, Norsk Polarinstitut). (a) Fractured mound. (b) Pingo in Eskerdalen. (c) Inner wall of Hale Crater. (d) Protalus ramparts on Prins Karls Forland. (e) Polygons in Hale Crater. (f) Polygons in Adventdalen.

3 PRELIMINARY RESULTS

A suite of periglacial landforms on Svalbard are remarkably analogous to landforms at mid-latitudes on Mars. Not only are the scales very similar, but also the spatial proximity of different features within a few km or less. The climates on Svalbard and Mars, however, are distinctly different today (and likely in the past). Morphologic interpretations have to take this into account, and an identical formation of these landforms on Earth and Mars is far from being confirmed. Scenarios should be explored that involve different processes (e.g., no freeze/thaw on Mars), but similar resulting landforms.

Investigation of Thermokarst Depression Asymmetry in Siberian Ice-Rich Permafrost in Comparison to Asymmetric Scalloped Depressions on Mars

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1 INTRODUCTION AND BACKGROUND

Thermokarst landscapes are widely distributed on Northeast Siberian Ice Complex deposits. Large thermokarst depressions (0.5 – 3 km wide, 10 – 30 m deep) with steep slopes and flat bottoms have been formed by massive surface subsidence during Late Glacial to Early Holocene global warming. Particularly, the high ground ice content of Ice Complex deposits (up to 90 vol%) is a crucial factor for deep thermokarst formation. Lateral growth of thermokarst basins occurred due to thermoerosion and gravimetric mass wasting along the slopes. Preliminary studies indicate a specific asymmetric depression morphometry suggesting spatially directed thermokarst processes of still unclear reasons.

Comparable depressions can be observed in Mars' mid-latitude regions in close relation to a several meters thick water-ice-rich mantle layer, which was deposited during variations in orbital Mars parameters. These small (80 m – 2 km wide, 5 – 25 m deep), rimless, scallop-shaped depressions show a N-S asymmetry, which is opposed on both hemispheres with the steeper slopes pointing polewards. Formation hypotheses for these depressions include an asymmetric sublimation of ground ice with respect to the aspect (i.e. N-S) due to solar insolation and therefore a poleward migration.

We investigate a large thermokarst depression in Ice Complex deposits in the Siberian Arctic as terrestrial analogue for scalloped depressions in Martian ice-rich mantle deposits focusing on the influence of solar insolation on thermokarst morphology.

2 DATA AND METHODS

A Digital Elevation Model (DEM) of 3 m/pixel derived from geodetic measurements of thermokarst depression morphology was used for solar radiation modeling within ArcGISTM. Morphometric parameters (slope angle, aspect, elevation, curvature) were extracted for quantitative terrain analysis. Landsat-7 ETM+ thermal data were used for analyzing spatial patterns of thermal emittance within the thermokarst depression.

Comparative analyses of Martian scalloped depressions were conducted using data in high resolution (HiRISE, CTX) from the Mars Reconnaissance Orbiter (MRO). Topographic information was derived from a DEM of 1 m/pixel based on a HiRISE stereo pair. Brightness temperatures for a selected region were derived from Thermal Emission Imaging System (THEMIS) infrared data.

3 RESULTS AND DISCUSSION

Several asymmetries within the terrestrial thermokarst depression become obvious in the DEM showing steeper slope angles of the south-facing slopes. GIS based morphometric analyses confirm a spatially directed thermokarst development in ice-rich deposits. Based on the general basin form, slope asymmetry, lake location, and the lake terrace arrangement, we suppose a lateral thermokarst development in NNW direction. The results suggest solar insolation and surface temperatures as crucial factors controlling thermokarst slope instability and steepness. The highest amounts of solar insolation and temperatures on south-facing slopes are forcing lake migration and, therefore, lateral thermokarst development.

On Earth, the steeper south-facing thermokarst depression slopes are geomorphologically more active and therefore younger. By direct analogy, this would imply scallop development on Mars primarily forced on the steep pole-facing slopes in an equatorward direction, probably during high obliquity (>45°) periods with higher summer temperatures on the pole-facing slopes rather than current poleward migration. The morphometric characteristics of the equator-facing slopes imply the absence of strong erosional processes and current surface stabilization. Further, current thermal properties and albedo data show always lower temperatures and higher albedo of the scalloped terrain comparable to the adjacent non-degraded uplands within the investigated area. This would be in disagreement with areal heating and enhanced sublimation on the equator-facing slopes in the present stage.

Tuesday
10:00-12:00

ORAL Parallel Session

Palaeo-permafrost and Coastal Dynamics

Co-chairs: Britta Sannel & Hugues Lantuit

In Kapp Mitra

Evolution of Permafrost and Periglacial Environments in the Northeastern China Since the Last Glaciation Maximum

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1 ABSTRACT

Based on the sediment strata, relict permafrost evidence, pollen records, and TL and ^{14}C dating, the evolution of permafrost and periglacial environments in northeastern China was reconstructed. Four periods of cooling and warming periods, *i.e.*, prior to the Late Pleistocene, the Late Pleistocene (10~6 kaBP), the Megathermal in the mid-Holocene (8~3 kaBP), and the late Holocene (since 3 kaBP), were divided on the evidence of paleobiological successions. The paleotemperatures inferred from the relict permafrost and periglacial phenomena and those from pollen records agree well, and the southern limits of permafrost during each of the four periods were delineated. In the mid-Holocene warm period, permafrost retreated northwards to about 52°N . The permafrost north of the latitude was an overlapping of permafrost formed during the Last Glaciations Maximum and that formed during the cold periods in the late Holocene. To the south, the existing permafrost was formed during the the Neoglaciation in the late Holocene.

Reconstruction of Late Quaternary Permafrost Distribution: Utilization of the Global Climate Models

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1 INTRODUCTION

1.1 Background

Dynamics of freezing and thawing of the soil is a decisive factor in the eco-climate system in cold regions. Changes in the distribution of frozen ground in time and space are an important issue in understanding the attribution and consequence of Quaternary climate change. Land process models with physically-based freeze/thaw dynamics can serve as a strong tool for such investigation. We are to employ the permafrost dynamics models to the Quaternary conditions to shed light on the abovementioned issues from a climate modeling approach. This is a sub-project in the Paleoclimate Model Intercomparison Project 2 (Saito et al. 2009).

2 METHODOLOGY

2.1 Permafrost mapping by thermal indices

Firstly, the classification mapping was constructed based solely upon the present-day near surface air thermal (freeze and thaw) indices and the present-day distribution of the frozen ground. Then, this diagnosing analysis was applied to Quaternary climate conditions, i.e. the Paleoclimate Model Intercomparison Project 2 (PMIP2) output. The methodology showed reasonable capability for large-scale mapping when tested against the present-day conditions.

2.2 Global climate models and data

The outputs from the PMIP2 atmosphere-ocean coupling (AO) integrations are used in the analysis; nine models for 0ka, seven for 6ka, and six realizations for 21ka. Monthly data are analyzed both for the model outputs and the observational data (e.g. CTU temperature data).

3 RESULTS AND IMPLICATIONS

3.1 Reconstructed distributions

The frozen ground distribution was reconstructed for 0ka (pre-industrial), 6ka (mid-Holocene), and 21ka (the last glacial maximum; LGM) conditions (Figure 1). The Holocene simulations (0ka and 6ka) produced largely similar results. The LGM outputs showed substantial increase of the permafrost area

by 49.6% relative to the pre-industrial conditions in median among the models, but also showed insufficient cooling during the cold season in some regions.

3.2 Implications and next steps

Across-model variations illustrate the regions that need careful examination in using PMIP2 outputs for further subsurface thermal regime calculations. The simulated results of the land model with the permafrost dynamics (e.g. Romanovsky and Osterkamp, 1997) will also be presented.

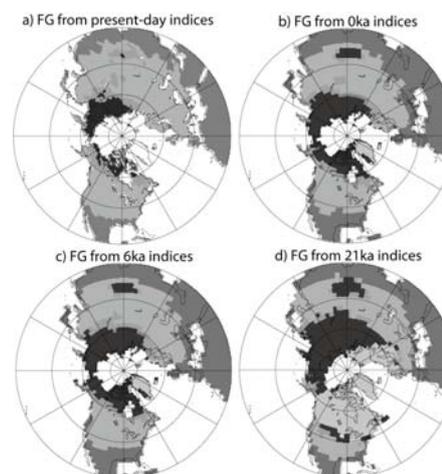


Figure 1. Frozen ground distribution (the mode among the models) classified by the freeze/thaw index combination a) derived from the NSIDC 1981-2000 monthly climatology for the current climate, and from the last-ten-year monthly climatology for PMIP2 outputs for b) 0ka, c) 6ka, and d) 21ka. The present-day coastlines are drawn commonly for reference in all the figures. The different zones are separated by grey scales (from high to low latitudes): the glacial ice sheet, permafrost, transitional, seasonal, and no frost zones.

References

- Romanovsky, V. E. and T. E. Osterkamp 1997. Thawing of the active layer on the coastal plain of the Alaskan Arctic. *Permafrost and Periglacial Processes*, 8(1), 1-22.
- Saito, K., Marchenko, S., Romanovsky, V., Bigelow, N., Yoshikawa, K., and Walsh, J. 2009. Thermally-Conditioned Paleo-permafrost Variations from Global Climate Modeling. *SOLA*, 5: 101-104.

Holocene Climate Variability as Deduced from Radiocarbon-Dated Ice Wedges from the Central Lena Delta, Northern Siberia

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1 INTRODUCTION

In the permafrost regions of Northern Siberia, paleoclimate investigations are mainly restricted to lakes and permafrost profiles and, in many cases, based upon paleoecological (thus, summer) indicators such as pollen. Stable water isotopes in ice wedges as direct paleoprecipitation proxies are considered to be excellent winter temperature tracers due to: (1) temperature-dependent water isotope fractionation during precipitation, (2) timing of frost cracking and of the infill of frost cracks, (3) no significant post-depositional modifications of the isotope composition. The organic matter in ice wedges can be dated by Radiocarbon methods, thus, allowing directly dating of discrete parts within an ice wedge.

In the frame of the field campaign "Lena Delta 2005, ten outcrops with Holocene ice wedges and enclosing sediments were studied and sampled in detail. Keysites of the first Lena River terrace were selected according to the following characteristics: (1) Holocene ice wedge activity, (2) height of > 10 m when possible to avoid river flooding processes influencing ice wedges during or after their growth. The objective of this project is to link the isotope composition of ice wedges (and by that the winter temperature) to the time of their formation by directly AMS-dating of organic matter enclosed in ice wedges, and hence, to establish a Holocene ice wedge-based winter isotope thermometer.

2 RESULTS & DISCUSSION

The ice wedges of the first Lena terrace are of milky-white appearance and display relatively high contents of organic matter. All studied outcrops with ice wedges are characterised by peat horizons of different thicknesses varying between 3 m and more than 10 m. However, since organic matter within the ice may be derived from either allochthonous or autochthonous peat, hence a careful selection of the samples to be dated is a prerequisite for a successful application of the ^{14}C dating to ice wedges.

The first results based upon 25 AMS-dates of organic matter in ice wedges show that the ground ice on the first terrace of the Lena Delta was mainly

formed in the second half of the Holocene between 5.5 kyr BP and today, thus mostly contemporaneously to sediment accumulation (Schwamborn et al. 2002). Different parts of the Lena Delta had different periods of ice-wedge activity. In general, ice wedge-growth was particularly active in the past 2000 years. At least three generations of ice wedges related to different stable surfaces were detected on the first Lena terrace (e.g. on Samoylov Island).

The sampled Holocene ice wedges are remarkably variable in their isotopic composition ($\delta^{18}\text{O}$ of around -26.8 to -22.8 ‰) reflecting highly variable winter conditions in the second half of the Holocene. Warmest winter conditions were observed in the most recent centuries and about 1000 years BP, whereas between 4000 – 5500 years BP winter climate was significantly colder.

Several signs of degradation of Holocene ice wedges systems were observed during our studies including thermokarst processes e. g. by water standing above the ice wedges, thermoabrasion forming deep gullies, but also changes in the hydrological regime leading to the formation of high-centre polygons and secondary ice wedge growth.

3 SUMMARY

Studying outcrops of the first terrace in the Central Lena Delta gave new insight to the understanding of the genesis of this terrace. A detailed ^{14}C -based study on the stable isotopic composition of Late Holocene ice wedges reveals the winter climate history of the last about 5,500 years. This is the first centennial-scale resolution winter temperature record in Northern Siberia, where up to now mainly summer proxies (bioindicators) are available as climate indicators.

References

Schwamborn, G., Rachold, V., Grigoriev, M. N. 2002. Late Quaternary sedimentation history of the Lena Delta. *Quaternary International* 89:119–134

Quartz Weathering in Freeze-Thaw Cycles: Experiment and Application to El'gygytyn Crater Lake Record for Tracing Siberian Permafrost History

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SUMMARY

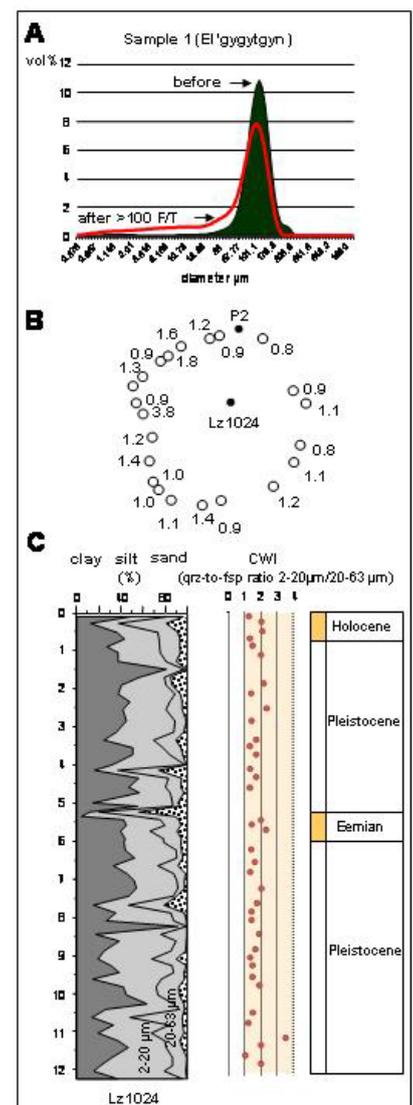
Brittle and fragile sand and silt is produced in near surface frozen ground. It makes up much of the regolith in permafrost areas such as Arctic Siberia. Microscopical grain features (e.g. angular outlines, surficial microcracks) illustrate grooves of cryogenic destruction in the course of numerous seasonal freezing and thawing events. Even after a grain is transported off place (i.e. in mobile slope material, in seasonal melt water run-off, into a lake basin), it still keeps the particular weathering traces.

This is also valid for a mineralogical peculiarity; quartz is more susceptible to frost weathering than e.g. feldspar, another ubiquitous mineral. Quartz quickly reacts to cryogenic break-up and small grains disintegrate due to thermal fluctuations and the explosive power of expanding ice in micro-meter scale fissures. Quartz enriches in the fines and this anomaly when compared to low latitude weathering is linked to cryogenic weathering. This is demonstrated in an experimental set-up, where after more than 100 freeze and thaw cycles quartz-rich silt is produced in initially fine sandy samples of permafrost and non-permafrost origins (Figure 1 A). The preferential crack of quartz grains (with reference to feldspar) can be expressed using the so-called Cryogenic Weathering Index (CWI). This quartz-to-feldspar ratio highlights quartz enrichment in the fines when values are >1 (Konishchev and Rogov, 1993) and marks a zone, which is indicative for material resulting from cryogenic break-up.

The combination of silt abundance, quartz grain micromorphology, and quartz enrichment is used as a proxy data set for frost weathering history in sedimentary archives. It has been examined in a 5 m core composed of frozen slope deposits and weathered bedrock (P2), in surface samples and along a lake sediment core from El'gygytyn Impact Crater, Central Chukotka (Figure 1 B+C). This site provides the longest continuous terrestrial archive available for the continental Arctic. The basin was non-glaciated in Quaternary times and studied layers are dating back 220.000 years according to the available age model (Juschus et al., 2007). All frozen ground samples and also the upper 12 meters of the lake sediment core are characterised by silt abundance,

cryogenic grain micromorphology, and quartz enrichment in the silt fraction. This argues for persistent permafrost conditions in the area as reflected by the continuous input of cryogenic weathering detritus into the basin. Even when periods were as warm as or warmer than today (i.e. during the Eemian Interglacial) the permafrost signal does not disappear according to the lake record.

Figure 1. A: Example of experimental grain break-up. "Before" marks the initial fine sand sample, whereas "after" shows the increase in the silt and clay portion after freeze-thaw (F/T) cycling. B: Display of the CWI as measured on surface sediments from El'gygytyn Crater lake inlets. The lake diameter is 11 km. Core P2 values are not displayed but likewise range around 1.3. C: The upper 12 m of lake sediment core Lz1024 stretch over 220.000 years and CWI values all fall into the range of cryogenic weathering.



References

- Konishchev, V.N., Rogov, V.V., 1993. Investigations of cryogenic weathering in Europe and Northern Asia. *Permafrost and Periglacial Processes* 4, 49-64.
- Juschus, O., Preusser, F., Melles, M., Radtke, U. 2007. Applying SAR-IRSL methodology for dating finegrained sediments from Lake El'gygytyn, northeastern Siberia. *Quaternary Geochronology* 2: 187-194.

Late Quaternary Sedimentation History of a Coastal Permafrost Landscape, Western Laptev Sea, NE Siberia

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1 INTRODUCTION

Palaeoenvironmental reconstructions of the landscape history of the western Laptev Sea are primarily based on studies of exposed cliffs and surface sediment cores. During the COAST drilling campaign in April 2005 a transect of deeper cores was drilled at Cape Mamontov Klyk in the western Laptev Sea. Here, we present the reconstruction of a coastal permafrost landscape including periods of permafrost aggradation and degradation and reaching back to at least the Eemian interglacial based on cryolithological, sedimentological, geochronological (^{14}C -AMS, OSL on quartz, IR-OSL on feldspars), and palaeoecological (pollen, diatoms) analyses.

2 STUDY AREA

The study area is located in the western Laptev Sea at the coastal cliff of Cape Mamontov Klyk (73.61°N, 117.18°E). The investigated borehole transect reached up to ~12 km offshore including 5 cores, one terrestrial (C1) and four marine cores (C2 to C5) at different distances from the coast. The most distant core (C2) reached the maximum depth of 77 m below sea level (b.s.l.).

3 PERMAFROST LANDSCAPE HISTORY

The lowermost unit I (figure 1) was only observed in core C2 (77 to 64.7m b.s.l.) and mainly consisted of silty sands with several clayey layers. The largely plastic-cryotic state (i.e. ice-bearing but not ice-bonded) was a result of pore water salinities of 11.7 to 30.8 ‰ depressing the freezing point, combined with temperatures of -1.0 to -1.4°C at these depths. Along with pollen data, pore water isotope values and one IR-OSL age of 111 ± 7.5 ka (at 77 m b.s.l.) a marine interglacial (Eemian) origin seems to be possible although the depth b.s.l. was unexpected, particularly when compared to marine Eemian deposits on the Taymyr Peninsula identified up to 100 m above sea level (a.s.l.). The subsequent landscape development was primarily governed by sea level changes. Aggradation of terrestrial permafrost (unit

II + III) on the shelf occurred during the Weichselian glaciation and the Holocene (unit IVa). The unfrozen, cryotic (<0°C) sediment unit IVb was a result of modern coastal erosion of unit III and IVa sediments and their re-deposition in the marine environment as well as thermal and chemical degradation of unit II from above.

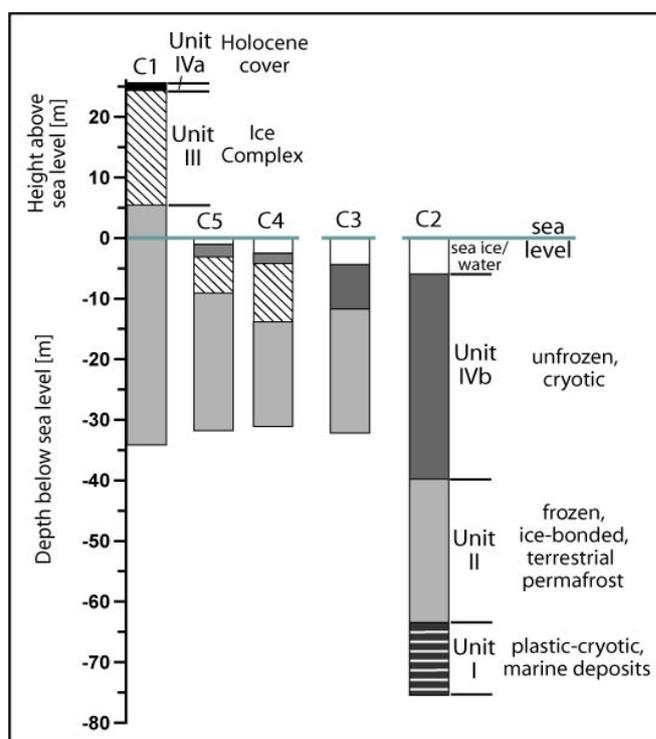


Figure 1. Proposed lithostratigraphical units representing different stages of landscape development. The distances between single cores are not to scale.

4 CONCLUSIONS

New marine sedimentological evidence adds to existing terrestrial records from exposures and surface sediments, showing strong late Quaternary landscape dynamics and coastal development in the western Laptev at least back to the Eemian. On-shore, terrestrial sediments were encountered down to 50 m b.s.l.; offshore, marine sediments lie deeper than 65 m b.s.l. beneath relict terrestrial permafrost. These results focus our line of questioning regarding the relative sea level, glacio-isostatic and neotectonic history of the region.

The Nature and Origin of Massive Ground Ice on Herschel Island (Western Canadian Arctic) Deduced from Stable Isotope and Hydrochemical Investigations

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1 INTRODUCTION

Herschel Island (69.58°N, 139.08°W) lies west of the Mackenzie Delta in the southern Beaufort Sea. It represents a terminal moraine resulting from the Laurentide Ice Sheet (LIS) during the Early to Middle Wisconsin and marks the northwesternmost extent of the LIS.

Massive ground ice bodies in the island's permanently frozen ground are ubiquitous and contribute to the shaping of the landscape since deglaciation. Stable water isotope studies ($\delta^{18}\text{O}$, δD) and hydrochemical investigations were applied on ground ice bodies on Herschel Island to unravel their genetic origin.

2 RESULTS & DISCUSSION

2.1 Stable isotope signatures

Massive ice bodies with a lateral extent of several hundreds of meters and up to 15 m thick are exposed along retrogressive thaw slumps within ice-rich permafrost sediments. One ice body (TSD) was discovered below an ice-rich diamicton with strong glaciotectionic deformation structures. Its isotopic composition is strongly depleted in ^{18}O and D (mean $\delta^{18}\text{O}$: -33‰ , mean δD : -258‰) thus suggesting a full-glacial climate and water source, respectively (Fig.1). The slope and d -excess lie near the Global Meteoric Water Line (GMWL) indicating that the moisture source is likely of meteoric origin without substantial alterations.

Other massive ice (HI-GI) of unknown but supposedly glacial origin was encountered adjacent to large, striated boulders. With a mean of about -37‰ for $\delta^{18}\text{O}$ (Fig.1), the ice exhibits extremely low isotopic values. The $\delta^{18}\text{O}$ -range of 18‰ is tremendous. A clear freezing slope is observed with progressive depletion in heavy isotopes towards the centre of the ice body. Strong kinetic fractionation must have taken place during the re-freeze of probably glacial meltwater.

The general question arises, whether the ice bodies aggraded before or after deglaciation as massive segregated ice or if the ice was originally basal glacier ice (regelation ice) buried by supraglacial till.

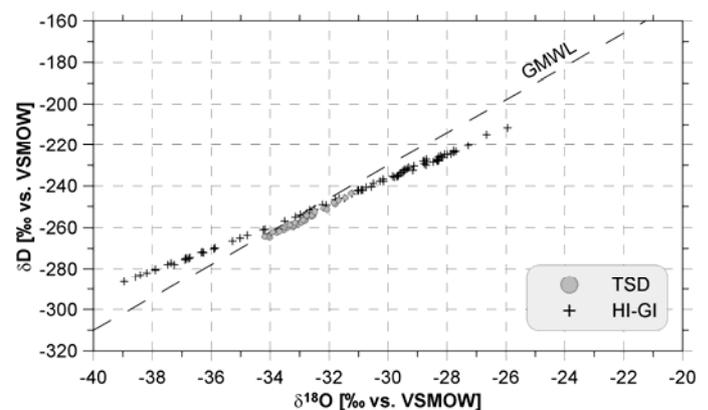


Figure 1. $\delta^{18}\text{O}$ - δD diagram for two massive ground ice bodies on Herschel Island. Both ice bodies show a strongly depleted mean isotopic signature but a completely different pattern. TSD has a narrow range and lies close to the GMWL. HI-GI exhibits a broad scatter while sample points lie on a freezing slope.

2.2 Hydrochemical signatures

Usually, buried glacier ice or lake ice tends to have low conductivity values as it derives from meteoric water. It is supposed to show a terrestrial water signature dominated by Ca^{2+} , HCO_3^- , and SO_4^{2-} . In turn, both massive ground ice bodies reveal a mixed ion composition of terrestrial waters and a marine influence by Na^+ and Cl^- . Frozen pore waters on Herschel Island reflect the sedimentary ion composition. Marine sediments are strongly enriched in solutes having high electrical conductivity values ($>1000\ \mu\text{S cm}^{-1}$) and ion peaks in Na^+ and Cl^- . Therefore, hydrochemical data of massive ice resemble the Herschel Island sediments that derive from near-shore marine deposits upthrust by the Laurentide Ice.

Either a prolonged contact between water feeding the ice bodies and the surrounding sediment is assumed. Or the incorporation of solute-rich debris at the glacier base by regelation and shear led to mixed hydrochemical signatures.

Fossil Organic Carbon in Arctic Permafrost Sequences of Northern East Siberia – Contents and Characteristics

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² Geophysical Institute, University of Alaska Fairbanks, , Alaska, USA

1 INTRODUCTION

Permafrost deposits constitute a large carbon pool highly sensitive to degradation and potential carbon release due to global warming. However, only a few detailed analyses have been made on the character of this carbon pool, its spatial variability, and its availability for decomposition. Most important and highly sensitive to degradation are the ice-rich deposits (Ice Complex) of the Yedoma Suite. Fifteen permafrost sections at coast and river bank sections on the Laptev and East Siberian seas, in the Lena River Delta and in the Indigirka–Kolyma lowland region were studied for carbon contents (TC; TOC) and organic matter (OM) parameters (C/N, $\delta^{13}\text{C}$).

2 RESULTS

The studied permafrost sequences were formed under different climate and landscape conditions during the Late Quaternary climate cycles including the Saalian Glacial (Ice Complex deposits), the Eemian Interglacial (thermokarst lagoon, lacustrine and boggy alas deposits), the Weichselian Glacial (fluvial, flood plain and Ice Complex deposit), and the Holocene Interglacial (lacustrine and boggy alas deposits). Therefore, OM stored in these sequences grew, froze, partly decomposed and refroze under different periglacial environments reflected in specific cryolithological features and organic matter and carbon signatures (Figure 1).

The vertical distribution of TOC in 10 m to up to 100 m thick permafrost profiles is highly variable and TOC contents vary from 0.1 up to 40 wt% of the dry sediment. The frozen organic matter consists of well preserved plant remains like wood fragments of shrub twigs, roots, leaves, moss peat inclusions and layers as well as tree stems in interglacial deposits. In addition, numerous small filamentous grass roots and loosely distributed fine organic detritus are common.

The survival of pre-Holocene and sometimes even pre-Eemian ice wedges and their surrounding ice-rich sediments proves that despite sometimes high ice contents near surface permafrost was not totally degraded during the Eemian warm period and the early Holocene thermal maximum.

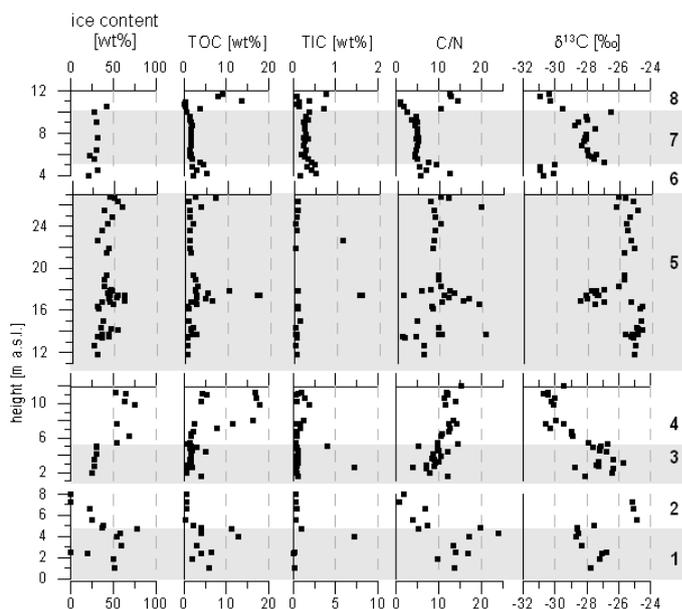


Figure 1: Exemplary compilation of ice content, carbon and OM signatures according to the general stratigraphic scheme of permafrost sequences at the Dmitry Laptev Strait (East Siberian Sea). 1 – Saalian Glacial (Ice Complex); 2 – Pre-Eemian flood plain deposits, 3 – Eemian ice wedge cast (lacustrine), 4 – Early Weichselian peat (alas), 5 – Weichselian interstadial (Ice Complex), 6 - Weichselian interstadial (taberite), 7 – Late Glacial-Early Holocene thermokarst lake, 8 – Late Holocene peaty deposits (alas)

3 CONCLUSIONS

Variations in TOC, C/N, and $\delta^{13}\text{C}$ are connected to changes in bioproductivity, intensity and character of cryosol formation, in OM decomposition, sedimentation rates, as well as in plant associations. High TOC, high C/N, and low $\delta^{13}\text{C}$ reflect less-decomposed OM under anaerobic conditions that is characteristic of interglacial and interstadial periods. Glacial and stadial periods are characterised by less variable, low TOC, low C/N, and high $\delta^{13}\text{C}$ indicating stable environments with reduced bioproductivity, stronger OM decomposition under relatively dry, aerobic conditions.

Due to the inhomogeneous vertical distribution of organic carbon and poorly mapped spatial distribution of organic-rich deposits estimations of carbon release from permafrost are somewhat speculative. The variable vulnerability of permafrost-stored carbon under warming climate conditions complicates modeling and quantification of climate change feedbacks with the permafrost carbon pool.

How Important is Ground Ice in Coastal Flux Studies?

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Coastal erosion research provides valuable information on sediment mobility, which can affect offshore hydrocarbon development activities and shipping, or present a hazard to onshore coastal infrastructure and heritage sites. In addition to sediment, contaminants and important chemical elements are also mobilized, and these fluxes can have significant implications for coastal ecosystems and human health, as well as regional and global biogeochemical cycling. In Arctic environments, ground ice plays a significant role not only in governing how much sediment and other material is contained within coastal bluffs, but also in controlling the rate at which these materials are eroded. This study examines how important ground ice is in estimates of the fluxes of sediment and soil organic carbon (SOC) from the Yukon Coastal Plain, an ice-rich region along the Canadian Beaufort Sea. It is a contribution to the Arctic Coastal Dynamics (ACD) project, a circum-Arctic study that seeks to develop not only a better understanding of the processes at work in Arctic coastal regions, but also how material fluxes are affected.

Measurements of soil density and organic carbon contents account for pore ice in the sampling procedure, but when scaling up from individual samples, ice wedges and massive ice within a terrain unit must be factored in separately. Ground ice is shown to account for a significant portion of earth materials in coastal bluffs along the Yukon Coastal Plain and the amount of it is related to different surficial materials and geomorphic histories along the length of the coast. Coarse-grained marine deposits in bars and spits have the lowest ice contents (3%), followed by fluvial materials, glacial outwash, morainic deposits, and finally, lacustrine materials with the highest ground ice content (54%). None of the marine or fluvial terrain units contain excess ice. Ground ice makes up almost half of the soil volume in formerly glaciated areas where bluffs are generally high, but only one third of the volume in unglaciated portions of the coast which consist of low bluffs.

Failing to account for the presence of ground ice results in significant overestimates of the total amount of material contained within a terrain unit and the annual flux of that material. Overall, this leads to errors of close to 19% and 16% in the assessment of

total organic carbon and mineral sediments, respectively. However, in terrain units with a high proportion of ground ice, errors can be as high as 88% for SOC and 146% for sediment. This underscores the importance of properly identifying and quantifying massive ice bodies in coastal deposits. Although wedge ice has been shown to account for just 3% of frozen materials along the Yukon Coastal Plain, it takes up 14% of the upper 7 m of soil, where the organic carbon-rich layers are found (Table 1).

Table 1. Volume occupied by wedge ice at different depth ranges within the soil column. These are averages for the entire Yukon Coastal Plain. Values differ among different terrain units based on the size and spacing of wedges.

Depth range (m)	Wedge ice (%)
0 – 1	31
1 – 2	26
2 – 3	19
3 – 4	11
4 – 5	9
5 – 6	8
> 6	6

It is not just the overall volume of ground ice but the stratigraphic relationship between wedge ice and organic carbon, in particular, that is important since they both vary with depth. This variation is not as significant in areas with low coastal bluffs; however, in regions with higher cliff elevations, a more detailed assessment of ground ice is warranted.

Tuesday
10:00-12:00

ORAL Parallel Session

Mathematical and Physical Modeling of Permafrost

Co-chairs: Nikolay Shiklomanov & Anna Klene

In Møysalen

An Empirically-Based Permafrost Distribution Model for the Entire Alps

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A. Brenning

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1 INTRODUCTION

Permafrost distribution modeling in highly populated mountain regions is an important task and different modeling approaches exist. Mountain permafrost distribution models are typically calibrated for a local region and only applicable for a specific area. To analyze the permafrost distribution and evolution on an alpine-wide scale, one consistent model for the whole domain is required, instead of differing and therefore incomparable models. In this paper, we present a newly developed statistical permafrost model for the entire European Alps, that is based on direct permafrost evidences as ground-truth information. The evidences were collected in the framework of the EU Alpine Space project PermaNET and contain different types of data (e.g., rock glacier inventories, borehole temperatures, ground surface temperatures).

Two models were developed: one for debris covered areas (*debris model*) and one for steep rock faces (*rock model*). In both cases, the predictor variables are mean annual air temperature (MAAT) and potential direct solar radiation (RAD). To distinguish between the two surface types a third model (*surface type model*) was introduced. Logistic and linear fixed-effects and mixed models are used to account for the different response variables and grouping structures.

2 DEBRIS MODEL

The debris model is based on a stratified random sample from the PermaNET rock glacier inventory, which consists of a total number of 1858 intact and 2573 relict rock glaciers, including inventories from Austria, France, Italy and Switzerland. The final generalized linear mixed-effects model takes into account random inventory effects and uses a logistic link function to predict the probability of a rock glacier as being intact (i.e. active or inactive) as opposed to relict.

The area under the receiver-operating characteristic curve (AUROC) was measured to summarize the model's goodness-of-fit. The debris-model achieved an AUROC of 0.85, which is a good value.

3 ROCK MODEL

Data from 42 temperature loggers located in steep rock walls in the Swiss and Italian Alps with a minimum slope inclination of 55° were used for the rock model. Mean annual rock temperature (MART) ranged from -9.2 °C to 6.5 °C, which corresponds to elevations of 2380–3965 m a.s.l. The MART was adjusted with long-term observations of climate records in order to correct short-term temperature fluctuations.

The final linear regression predicts rock surface temperatures based on MAAT and RAD; the R^2 is 0.82. The RAD was calculated using local slope and aspect values, but terrain shading has not yet been considered, which we expect would further improve the model.

4 SURFACE TYPE MODEL

The surface type model is based on a stratified random sample of 400 points above 2000 m a.s.l in the Swiss Alps and uses the following prediction variables: Soil adjusted vegetation index (SAVI), slope and curvature. The logistic regression describes rock against debris-covered surfaces and has an AUROC value of 0.81.

5 FINAL MODEL

The final output product combines the three models and provides alpine-wide permafrost probabilities. Areas of dense vegetation (i.e. no coarse debris) as well as glaciers will be masked using remote sensing products. In the future, interpretation guidelines will be devised to communicate model limitations and local deviations to potential users (e.g., thermal offset for rock wall temperatures or spatial displacement of permafrost probabilities in debris covered areas due to movement of rock glaciers).

Experimental and Numerical Modeling Studies of Pore Water Pressure Variations in Subpermafrost Groundwater

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1 OUTLINE

Development and degradation of permafrost directly affect numerous hydrogeological processes such as thermal regime, exchange between river and groundwater, groundwater flows patterns and groundwater recharge (Michel, 1994).

Groundwater in permafrost area is subdivided into two zones: suprapermafrost and subpermafrost which are separated by permafrost. As a result of the volumetric expansion of water upon freezing and assuming ice lenses and frost heave do not form in a saturated aquifer, the progressive formation of permafrost leads to the pressurization of the subpermafrost groundwater (Wang, 2006). Therefore disappearance or aggradation of permafrost modifies the confined or unconfined state of subpermafrost groundwater.

Our study focuses on modifications of pore water pressures of subpermafrost groundwater which could appear during thawing and freezing of soil.

Numerical simulation allows elucidation of some of these processes.

2 NUMERICAL MODELLING

Our numerical model accounts for phase changes for coupled heat transport and variably saturated flow involving cycles of freezing and thawing.

The flow model is a combination of a one-dimensional channel flow model which uses Manning–Strickler equation and a two-dimensional vertically groundwater flow model using Richards equations for saturated-unsaturated medium.

Numerical simulation of heat transport consisted in a two dimensional model accounting for the effects of latent heat of phase change of water associated with freeze/thaw cycles which incorporated the advection-diffusion equation describing heat-transfer in porous media.

The change of hydraulic conductivity and thermal conductivity are considered in our numerical model.

3 EXPERIMENTAL MODELLING

The model was evaluated by comparing predictions with data from laboratory experiments in a cold room.

Experimental design was undertaken at the Laboratory M2C (Université de Caen-Basse Normandie, CNRS, France). The device consisted of a Plexiglas box insulated on all sides except on the top.

Precipitation and ambient temperature are imposed. The Plexiglas box is filled with glass beads of which hydraulics and thermal parameters are known. The subpermafrost unfrozen zone is guarded by a heating cable.

All parameters required for our numerical model are controlled and continuous monitoring of soil temperatures and pore water pressure are reported.

4 CONCLUSION

Our results of experimental model allow us to test the relevance of the process described by our numerical simulation and to quantify the impact of permafrost on pore pressures of subpermafrost groundwater during a cycle of freezing and thawing.

References

- Michel, Frederick A. and Van Everdingen, Robert O. 1994. Changes in hydrogeologic regimes in permafrost regions due to climatic change. *Permafrost and Periglacial Processes*, 5: 191-195.
- Wang, Chi-yuen and Manga, Michael and Hanna, Jeffrey C. 2006. Can freezing cause floods on Mars? *Geophysical Research Letters*, 33

Physical Modeling Approach of Thawing Permafrost

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Laboratoire M2C, Université de Caen-Basse Normandie, UMR CNRS/INSU 6143, Caen, France

In the Northern Hemisphere permafrost occurs occupies approximately 25% (23 million km²) of the land area. In many regions of Alaska, Canada and Siberia, many features develop in response to freeze-thaw cycles (i.e. sorted and unsorted polygons, ice-wedges). A periglacial environment is cold but non-glacial. Frost-induced conditions, geomorphic processes and landforms typify a periglacial environments. Formation of some periglacial features are also accelerated by ice-rich permafrost thawing (i.e. thermokarst lakes and retrogressive thaw slumps) under the influence of global warming.

The objective of this work is to (i) identify the effect of global warming on the evolution of permafrost thermal state, (ii) examine the relationship between the thermal state and the vertical settlement of the active layer. This could have implications for thermokarst lakes formation.

This is done by means of a physical model using blocks made of experimental permafrost. Several sets of experiments have been conducted in a cold room to recreate a periglacial environment.

The experimental devices consist of small size blocks (57 cm x 37 cm) and can test the influence of many parameters, such as:

i) *lithology*: permafrost blocks are made of fine sand and loess mixed in different proportions,

ii) *moisture content*: sediments are saturated with water to make a water-rich permafrost. The water content is adjusted to the mixing of sediment. One model has also been supersaturated,

iii) *ice content*: ice flakes are added into the wet-sediment mixture. Different percentages of ice (30, 50, 80%) are tested to simulate an ice-rich permafrost or not. Some models also contain an ice sill to simulate the impact of massive ice during permafrost melting,

iv) *thermal regime*: freeze-thaw cycles were performed during one day, simulating a one-year period. As a representation of a thaw period, the cold room is off and an external infrared heat source allows a quick thawing of permafrost blocks. The devices of infrared radiant panels can be coupled to obtain or not a uniform heat distribution on the model surface. A heat monitoring system provides a temperature control.

For each cycle, surface thaw-settlement is monitored. Also, thermal profiles are obtained using 12 thermal sensors included on one vertical pipe near the model center (Fig.1).

Results from the 17 trials already made, show the predominant role of ice content, moisture content and lithology. The number of freeze-thaw cycles is not an influential factor in the collapse or the thermal state of the soil. Further experiments are being conducted in order to evaluate this observation.

In conclusion, our preliminary experiments should help to better constrain the parameters that control the permafrost evolution during freeze-thaw cycles in a context of climate warming. Many questions remain, for example, about replicating the concentration and distribution of ice in ice-rich permafrost.

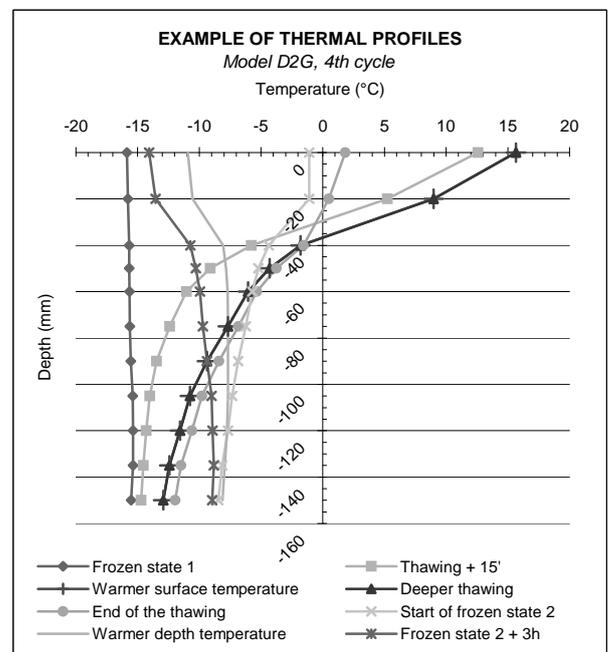


Figure 1. Example of thermal profiles obtained during a thawing cycle

ERT Regularization Schemes for Improved Fracture Delineation in Alpine Permafrost Rocks: Results from Numerical Simulations and Measurements at the Aiguille du Midi, France

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1 INTRODUCTION

Electrical resistivity tomography (ERT) is increasingly being used as a non-invasive imaging tool in alpine permafrost studies. Key objectives here are the mapping of temperature distributions inside the rock and the delineation of fracture zones given their influencing role on permafrost dynamics and stability. The imaging of fractures, however, is a notoriously difficult task using conventional ERT approaches which rely on smoothness-constraint regularization. We here investigate regularization schemes for improved fracture delineation by means of numerical simulations and field data collected at the Aiguille du Midi, France.

2 REGULARIZATION IN ERT

Due to inherent problems of non-uniqueness and ill-posedness some sort of regularization is required in ERT inversion. Regularization is commonly implemented as a model-smoothness constraint by minimizing the first- or higher-order roughness of the resistivity distribution. By evaluating the model roughness in different spatial directions, also an anisotropic smoothing, for instance aligned with the known direction of fractures in the study area, can be imposed. For structures where both sharp contrasts as well as smooth parameter variations coexist, as often being the case in alpine permafrost environments, more recently a regularization approach based on the so-called minimum-gradient-support (mgs) functional has been proposed.

3 NUMERICAL SIMULATIONS

ERT inversions with conventional isotropic smoothing are compared to inversions using anisotropic smoothing and mgs-based regularization for a synthetic model setup exhibiting a fracture zone in a permafrost rock body with irregular geometry. The

model geometry was adopted from the measurement geometry at the Aiguille du Midi.

4 AIGUILLE DU MIDI FIELD CASE

In 2008 and 2009, three ERT surveys were conducted at the Aiguille du Midi, France, as part of a geophysical monitoring which integrates into the framework of the French-Italian *PERMAdataROC* project and is part of the EU co-funded *PermaNET* project. Each ERT survey comprised the acquisition of more than 10,000 normal and reciprocal dipole-dipole data over three different arrays of altogether 144 electrodes. The electrodes of two arrays could be placed to almost surround the Piton Central and the Piton Nord in a horizontal plane, offering a favorable tomographic coverage. A vertical north-south transect across the summit was installed by abseiling on the almost vertical north and south face. The ERT data were inverted using isotropic smoothing, anisotropic smoothing, and mgs-based regularization, and employing a finite-element grid which captures the irregular geometry of the rock as well as the electrode layout.

5 RESULTS

The inversion results demonstrate the deficiency of conventional isotropic smoothing to delineate sharp features such as fractures in permafrost rocks. While anisotropic smoothing can be adjusted such as to allow a correct interpretation of the ERT image, inversion with mgs-based regularization provides most convincing results in terms of resolving sharp structural features associated with lithological changes but at the same time preserving smooth changes typical of temperature variations in the rock. At the Piton Nord low-resistivity zones could be delineated, which seem to coincide with water-containing fractures caused by artificial heat supply, while the continuation of these fractures outside the heated gallery indicates permafrost conditions.

Modeling the Thermal Regime of Mountain Permafrost in Southern Norway with Respect to a Changing Climate

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1 BACKGROUND

The modern southern boundary for Scandinavian permafrost is located in the mountains of southern Norway. The three-year research project CRYOLINK (“Permafrost and seasonal frost in southern Norway”) aims at improving knowledge on past and present ground temperatures, seasonal frost, and distribution of mountain permafrost in Southern Norway by addressing the fundamental problem of heat transfer between the atmosphere and the ground surface. Several shallow boreholes have been drilled, and a monitoring program to measure air and ground temperatures was started in August 2008.

In this study a 1-D transient heat flow model and a 2-D finite element heat flow model (GEOSLOPE TEMP/W) were applied to model the thermal regime of mountain permafrost. The special focus of this study was the modeling of the influence of different surface cover and bedrock types as well as the topographical effect. Further, the sensitivity of mountain permafrost to a changing climate (past and future climate change) was analyzed.

2 STUDY SITES AND DATA

The borehole areas (Juvvass, Jetta and Tron) are situated along a west-east transect along a continental-ity gradient providing boreholes at different elevations, bedrock types and overlaying sediments. A total number of 12 shallow boreholes to a depth of 30 m are located along altitudinal transects, thus showing both permafrost and seasonal freezing only. The boreholes along at Juvvass (Profile 1) range from 1771 m a.s.l. to 1200 m, where 5 of the 7 boreholes showing the presence of permafrost. The Profile 2 at Tronfjell ranges from 1640 m a.s.l. to 1300 m a.s.l. while only the uppermost shows permafrost. Air temperatures and snow depths are continuously monitored at each borehole site and a large number of miniature temperature loggers record ground surface temperatures (GST) along each profile.

This setting allows the detailed 2-D modeling of permafrost distribution as it is affected by altitude,

varying aspects as well as lateral thermal effects due to snow cover and block fields.

3 MODEL STUDIES

3.1 1D modeling for calibration and sensitivity analysis

The ground temperature data series of one year obtained from the borehole sites was used to calibrate a transient heat flow model, which solves the heat conduction equation including phase change. Modeling accuracies with a RMSE of <0.5 °C were achieved.

This model was used to model the effect of different ground properties and surface cover on the thermal regime. For this analysis the model was forced by measured GSTs. To estimate a possible impact of a future climate change on the stability of mountain permafrost, the model is forced by an ensemble of down-scaled climate scenarios.

3.2 2D modeling for investigating topographic impact

A 2-D finite element model (GEOSLOPE TEMP/W) was calibrated and run along Profile 1 and Profile 2. The model was driven using the measured GSTs along each transect and the permafrost temperatures measured at each borehole site could be reproduced satisfactorily. The past and current regional permafrost distribution could be reproduced as well as the lower limit of permafrost distribution along each transect.

In particular the effect of topography, aspect and the spatial variations in surface cover (coarse blocks and snow cover) were investigated in detail.

Observed and Projected Changes in Climate, Permafrost, and Active Layer in Northern Eurasia and Their Relation to Permafrost Carbon Pool

Sergey Marchenko & Vladimir Romanovsky

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Olga Bulygina & Vyacheslav Razuvaev

Russian Institute for Hydrometeorological Information, Obninsk, Russia

1 INTRODUCTION

During the past 128 years (since 1881), the annual surface air temperature in terrestrial Northern Eurasia has increased by 1.5°C and in the winter season by 3°C. In the nearby Arctic Ocean, the late summer sea ice extent decreased by 40% during the last 30 years exposing a source of water vapor for the dry arctic atmosphere in the early months of the cold season. As a result of these processes the maximum snow depth and snow water equivalent (SWE) have increased over most of Russia.

Recent observations indicate a warming of permafrost in many northern regions with the resulting degradation of ice-rich and carbon-rich permafrost. Permafrost temperature has increased by 1 to 2°C in northern Eurasia during the last 30 years. Warming in permafrost temperatures observed in the Russian North has resulted in the thawing of permafrost in natural, undisturbed conditions in areas close to the southern boundary of the permafrost zone. Thawing of Little Ice Age permafrost is ongoing at many locations. There are some indications that older late-Holocene permafrost has begun to thaw as well at some undisturbed locations in northeastern Europe and in northwest Siberia.

2 MODEL AND INPUT DATASET

To assess possible changes in the permafrost thermal state and the active layer thickness we implemented the GIPL2/MPI (Geophysical Institute Permafrost Lab) parallel transient model for the entire Northern Eurasia permafrost domain for the 1950-2100 time period. Input parameters to the model are spatial datasets of mean monthly air temperature, snow properties or SWE, prescribed vegetation and thermal properties of the multilayered soil column, and water content, which are specific for each soil classes and geographical location. For the period of 1950-2006 climatic conditions, the historic data set of observed surface air temperatures and snow derived from more than 300 weather stations across the entire Northern Eurasia permafrost domain was used. The future climate scenario was derived from the ensemble of five IPCC Global Circulation Models (GCM)

that performed the best in the Arctic and sub-Arctic; ECHAM5, GFDL21, CCSM, HADcm and CCCMA, compiled by the researchers from University of Illinois at Urbana-Champaign. The outputs from these five models have been scaled down to 0.5 degree latitude/longitude horizontal resolution. Each derived value represents a single month within a given year, based on the composite (mean) output of the five models, using the IPCC SRES A1B emission scenario with doubling gradual increase of atmospheric CO₂ concentration by the end of current century. According to this model, the globally averaged warming with respect to present-day climate is 3.5°C. Historic ground temperature measurements in shallow boreholes (3.2 m in depth) from more than 120 weather stations located within the continuous, discontinuous, and sporadic permafrost zones were available for the initial model validation and calibration. To prescribe the thermal properties we used the map of soil characteristics for all of Russia (Stolbovoi & Savin, 2002) and the map of Soil Carbon Pools, CO₂ and CH₄ Emissions (Tarnocai et al., 2009) and also the soil structure descriptions available for some locations.

3 RESULTS

According to this specific climate scenario, projections of future changes in permafrost suggest that by the end of the 21st century, late-Holocene permafrost in Northern Eurasia may be actively thawing at all locations and some Late Pleistocene carbon-rich peatlands underlying by permafrost also could start to thaw at some locations. At the same time, the modeling results show how different types of ecosystems affect the thermal state of permafrost and its stability.

References

- Stolbovoi, V. and I. Savin. 2002. Maps of soil characteristics. In Stolbovoi V. and I. McCallum. 2002. CD-ROM *Land Resources of Russia*. Laxenburg, Austria: International Institute for Applied Systems Analysis and the Russian Academy of Science. CD-ROM. Distrib. by NSIDC, Boulder.
- Tarnocai, C., J. G. Canadell, E. A. G. Schuur, P. Kuhry, G. Mazhitova, and S. Zimov (2009), Soil organic carbon pools in the northern circumpolar permafrost region, *Global Biogeochem. Cycles*, 23, GB2023, doi:10.1029/2008GB003327.

Size Matters - Very High Resolution Permafrost Simulations on the 4 km Scale in Northeast European Russia

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Permafrost Laboratory, Geophysical Institute, University of Alaska Fairbanks, USA

1 INTRODUCTION

Major climate changes in polar regions and a substantial reduction of the area of the Northern Hemisphere underlain by permafrost can be expected according to simulations with global circulation models (GCMs). However, thawing of permafrost, in particular if it is ice-rich, is subject to a time lag due to the large latent heat of fusion. State-of-the-art GCMs are unable to adequately model these processes because (a) even the most advanced subsurface schemes rarely treat depths below 5 m explicitly, (b) soil thawing and freezing processes cannot be dealt with directly due to the coarse resolution of present GCMs, and (c) due to the underestimation of orographic variance, simulated GCM precipitation is often underestimated and the proportion of rain and snow is incorrect.

One possibility to overcome resolution-related problems is to use regional climate models (RCMs). Such an RCM, HIRHAM, has until now been the only one used for the entire circumpolar domain, and its most recent version, HIRHAM5, has also been used in the high resolution study described here. Instead of the traditional degree-day frost index approach, we make use the regional model itself to create boundary conditions for an advanced permafrost model. This implies that the permafrost model can be run on the RCM grid, i.e. in a considerably higher resolution than in previous approaches.

2 MODEL HIERARCHY AND DOWNSCALING

The driving GCM is ECHAM5/MPI-OM1 at T63 resolution ($\sim 1.8^\circ$ by 1.8°). The RCM is HIRHAM5 with the physical parameterization of ECHAM5, so that HIRHAM5 can be thought of as a high resolution limited area version of ECHAM5. The boundary forcing from the global model is updated every six hours in a region 10 grid points wide with a relaxation of all prognostic variables.

Varying concentrations of well-mixed greenhouse gases, ozone and sulphate aerosol have been prescribed from observations prior to 2000 and following the SRES A1B scenario thereafter. According to this scenario, the CO_2 concentration in 2100 is near

700 ppm, and the globally averaged warming with respect to present-day climate is 3.5°C .

As the final step for regional permafrost modelling we have used the GIPL model of the University of Alaska Fairbanks, which is a spatially distributed, physically based analytical model for the calculation of active layer thickness ALT and mean annual ground temperature MAGT. The input data for GIPL, mean annual air temperature and its seasonal amplitude, average winter snow depth and density, composition, water content and thermal properties of soils and characteristics of vegetation cover and geomorphologic features, are obtained from the RCM output.

3 RESULTS

We present results from new time-slice integrations for the 20th and 21st centuries with an unprecedented horizontal resolution of only 4 km, covering part of northeast European Russia. According to this specific climate scenario, projections of future changes in permafrost suggest that by the end of the 21st century, permafrost in the Russian North may be actively thawing at many locations of the Pechora River watershed. This simulation has served as basis for an assessment of the carbon balance within the EU-funded project Carbo-North.

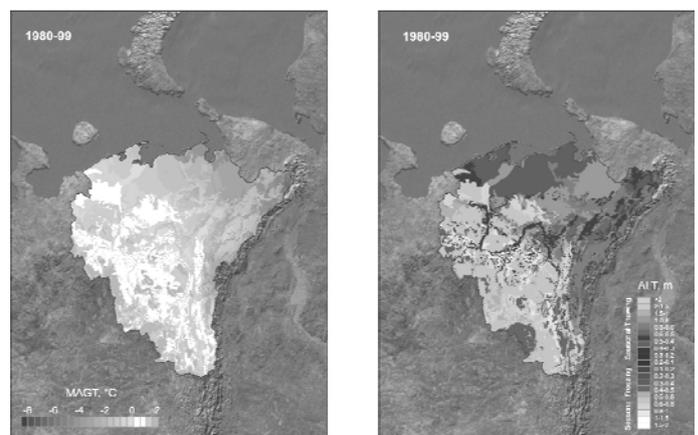


Fig. 1 Modeled MAGT (left) and ALT/ depth of the seasonal freezing (right) for 1980-99 derived from the GIPL-1.3 equilibrium permafrost model run using the 4x4 km HIRHAM output.

Modelling Mountain Permafrost Distribution above and below Treeline Using Empirical-Statistical Methods, Yukon Territory, Canada

Philip P. Bonnaventure & Antoni G. Lewkowicz

Department of Geography, University of Ottawa, Ottawa, Canada

1 INTRODUCTION

Empirical-statistical methods were used to model mountain permafrost probability for five widely separated study areas within four different climatic boundaries in the southern half of the Yukon Territory (60-65°N). These areas differ from those usually modeled using the Basal Temperature of Snow (BTS) method, as much of the modeled terrain is covered by boreal forest but still can exhibit permafrost. An added complication is that measurements of air temperatures over several years have shown that lapse rates are gentle, nonexistent or inverted in the forest zone, but become normal above treeline. This pattern of air temperatures means that the usual primary dependence of mountain permafrost distribution on elevation is not present.

2 METHODS

BTS values were measured in mid-March 2007 and 2008 in all of the locations except one where readings were taken only in the latter year due to a general lack of snow in 2007. Field verification of the presence or absence of permafrost was performed by probing and/or excavating pits in the study areas during August 2007 and 2008, and by using annual ground temperatures recorded at logger sites.

Multiple regression analyses using BTS points as the dependent variable were performed for each area with independent variables of elevation, Potential Incoming Solar Radiation (PISR), slope and Normalized Difference Vegetation Index (NDVI). These largely failed to produce statistically significant relationships until elevation was replaced by equivalent elevation, a newly conceptualized variable that adjusts elevations below treeline in relation to lapse rates. For example, in an area with an annual inverted lapse rate, the equivalent elevation of a BTS sampling site in the forest is actually above treeline. Final modelled BTS values were similar to those collected in the field (Figure 1).

The probability of permafrost for each of the five study areas was then calculated using logistic regression based on the relationship between modeled BTS values and observed presence or absence of late-summer frozen ground at the ground-truthing sites

(e.g. Lewkowicz and Ednie, 2004; Bonnaventure and Lewkowicz, 2008).

3 RESULTS

Estimates of the percentage of each study area underlain by permafrost from the permafrost probability modelling ranged from 29% for Johnson's Crossing in the southern Yukon to 79% in the Keno area. The spatial distribution of permafrost in each area depends on the combination of variables used in the modelling. However, at four of the five areas where equivalent elevation is significant, high probabilities of permafrost emerge in low-lying areas and in topographic hollows such as U-shaped valleys below treeline, as well as on the highest and steepest peaks above treeline. These results illustrate the complexity of mountain climates and hence permafrost distribution in this part of northern North America.

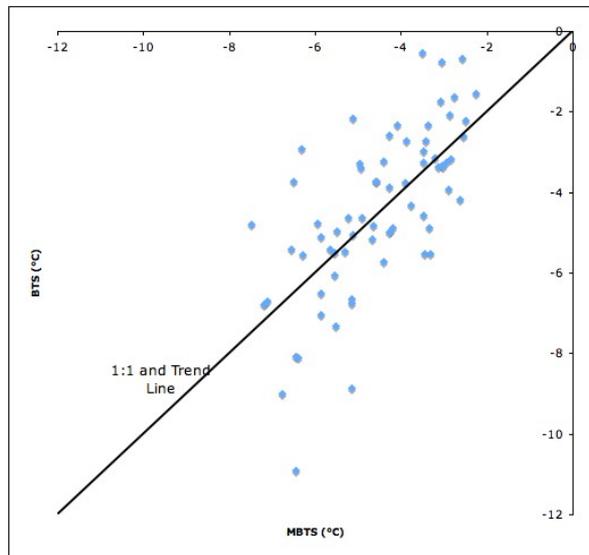


Figure 1. Scattergram of measured BTS versus modeled BTS (MBTS) for the Keno Area in the central Yukon. The modeled values were predicted using equivalent elevation.

References

- Bonnaventure P.P. and Lewkowicz A.G., 2008. Mountain Permafrost Probability Mapping Using the BTS Method in two Climatically Dissimilar Locations, Northwest Canada. *Canadian Journal of Earth Sciences* 45:443-455.
- Lewkowicz, A.G. and Ednie, M., 2004. Probability mapping of mountain permafrost using the BTS method, Wolf Creek, Yukon Territory, Canada. *Permafrost and Periglacial Processes* 15: 67-80.

Wednesday

Time	Wednesday, June 16
8:00 – 17:00	Registration Desk Open <i>in UNIS Entrance Hall</i>
8:30 – 9:00	KEYNOTE <i>in Møysalen and video streamed to Lassegrotta</i> Where, How Fast, and Why Arctic Permafrost Coasts Undergo Coastal Erosion? Hugues Lantuit, P. Overduin, N. Couture
9:00 – 9:30	KEYNOTE <i>in Møysalen and video streamed to Lassegrotta</i> Remaining Challenges in Permafrost Carbon Research—a Status at the End of IPY Peter Khury
9:30 – 10:00	COFFEE/TEA
ORAL Parallel session: Soils in Periglacial Regions <i>co-chairs: Jerry Brown & Tina Sanders in Kapp Mitra</i>	
10:00 – 10:15	Soil Atlas of the Northern Circumpolar Atlas A. Jones, V. Stolbovoy, C. Tarnocai, G. Broll, O. Spaargaren, C-L Ping, L. Montanarella
10:15 – 10:30	Permafrost-Affected Soils – a Challenge for Soil Classification! O.C. Spaargaren
10.30 – 10:45	Permafrost-Affected Soils in Russia V.S. Stolbovoy, S.V. Goryachkin
10:45 – 11:00	Permafrost-Affected Soils in Mountains of Northern Circumpolar Region S.V. Goryachkin, D.E.Konyushkov
11:00 – 11:15	Soils at the Treeline in Northern Fennoscandia G. Broll
11:15 – 11:30	Soils of the Northern Alaska Low Arctic C.L. Ping, G.J. Michaelson, M.T. Jorgenson, M.Z. Kanevskiy, Y.L. Shur
11:30 – 11:45	Soils of the Canadian High Arctic C. Tarnocai
11:45 – 12:00	Hyper-Arid Ecosystems of Antarctica J.G. Bockheim

Time **Wednesday, June 16**

ORAL Parallel session: Remote Sensing Techniques and Geohazards

co-chairs: Birgit Heim & Lothar Schrott in Lassegrotta

- 10:00 – 10:15 Radar Interferometric Observations of Permafrost Related Surface Deformation
T. Strozzi, U. Wegmüller, R. Delaloye, H. Raetzo, A. Kos, A. Bartsch, C. Lambiel
- 10:15 – 10:30 A Multi-Satellite Concept in Support of High Latitude Permafrost Modeling and Monitoring - the ESA DUE Permafrost Project
A. Bartsch, V. Naeimi, D. Sabel, W. Wagner, B. Heim, J. Boike, T. Opel, T. Strozzi, A. Wiesmann, C. Duguay, S. Hachem, C. Schmullius, S. Hese, M. Herold, S. Pöcking, M. Urban, F. M. Seifert
- 10.30 – 10:45 Using in-Field and D-InSar-Techniques for the Monitoring of Seasonal Lithalsa Dynamics in Northern Quebec
I. May, J. S. Kim, K. Spannraft, R. Ludwig, I. Hainsek, M. Bernier, M. Allard
- 10:45 – 11:00 PermaSAR – Permafrost Monitoring Using Imaging Satellite Radar (SAR) and Ground Based Techniques in Svalbard
T.R. Lauknes, Y. Larsen, E. Malnes, H.H. Christiansen
- 11:00 – 11:15 High Resolution Remote Sensing Identification of Thermokarst Lake Dynamics (1954-2006) in a Subarctic Peat Plateau in West-Central Canada
A.B.K. Sannel, I.A. Brown
- 11:15 – 11:30 Planimetric and Volumetric Thermokarst Change Detection on Ice Rich Permafrost, Using Remote Sensing and Field Data
F. Günther, M. Ulrich, A. Morgenstern, L. Schirrmeister
- 11:30 – 11:45 Permafrost Influence on the Active Nordnes Rockslide
L.H. Blikra, H. H. Christiansen, Håvard Juliussen, B. Etzelmuller, O. Humlum, K. Isaksen, J.S. Rønning
- 11:45 – 12:00 A Rock-/Ice Mechanical Model for the Destabilisation of Permafrost Rocks and First Laboratory Evidence for the “Reduced Friction Hypothesis”
M. Krautblatter, D. Funk

Time **Wednesday, June 16**

ORAL Parallel session: Analysis of Sensitivity of Permafrost Modelling

co-chairs: Wilfried Haeberli & Megan James in Møysalen

- 10:00 – 10:15 Permafrost Monitoring in Northwestern Russia and a Methodology of the mid-Range Projections of Its past and Future Degradation in Natural Conditions
N. Oberman, I. Derevyanko, V. Romanovsky, H. Vanhala, P. Lintinen
- 10:15 – 10:30 Interaction between the Accelerated Thaw of Discontinuous Permafrost and Drainage Network Organization, Northern Quebec
M.-É. Larouche, M. Allard, L. Gosselin
- 10.30 – 10:45 Monitoring and Process Analysis of Permafrost Creep and Failure in Changing Temperature Regimes
I. Gaertner-Roer
- 10:45 – 11:00 The Sensitivity of Mountain Permafrost to Climate Change (SPCC) Project: Influence of Substrate and Morphology
C. Hauck, I. Gärtner-Roer, C. Hilbich, C. Kneisel, M. Krautblatter, T. Rödder, M. Scherler, S. Schneider, S. Verleysdonk, R. Dikau, M. Hoelzle, R. Mäusbacher
- 11:00 – 11:15 Warming of Permafrost Temperatures on Svalbard - What Is the Effect of the Snow Cover?
J. Boike, S. Westermann, K. Piel, P. P. Overduin
- 11:15 – 11:30 Frozen Ground Conditions in Subarctic Mountain Environments, Northern Sweden Assessed by near-Surface Geophysics and Ground Temperature Regimes
C. Kneisel, H. Ridefelt
- 11:30 – 11:45 Spatial and Temporal Variability in Active Layer Thickness on the Qinghai- Tibet Plateau under the Scenarios of Climate Change
Q. Pang, L. Zhao, Y. Ding, S. Li
- 11:45 – 12:00 Impact of Infiltrating Melt Water on the Thermal Regime of Active Layer - a Comparison of PERMOS Sites with Different Subsurface Textures
S. Schneider, M. Scherler, C. Hauck, M. Hoelzle

12:00 – 13:00

LUNCH in UNIS Canteen

Wednesday

Keynotes

In Møysalen and video streamed to Lassegrotta

8:30-9:00 Where, How Fast, and Why Arctic Permafrost Coasts Undergo Coastal Erosion?

Hugues Lantuit & P. Overduin, *Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany*

N. Couture, *Geologic Survey of Canada, Ottawa, Canada*

9:00-9:30 Remaining Challenges in Permafrost Carbon Research—a Status at the End of IPY

Peter Khury *Department of Physical Geography and Quaternary Geology, Stockholm University, Stockholm, Sweden*

Where, How Fast, and Why Arctic Permafrost Coasts Undergo Coastal Erosion?

H. Lantuit & P. Overduin

Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany

N. Couture

Geological Survey of Canada, Ottawa, Canada

1 BACKGROUND

Permafrost coasts represent 34 % of the global coastline and are likely to become one of the most impacted environments of the Earth under changing climate conditions. The lengthening of the open-water season and the increasing open-water area, the warming of permafrost, the increasing occurrence of coastal thermokarst, and the increase in sea surface temperatures are all thought to impact the pace of coastal erosion. In particular, storms are predicted to hit the coasts later in the fall season. These storms are thought to bear staggering threats to the coasts in the form of destruction of community and industry infrastructure as well as dramatic changes in sediment and nutrient pathways in the nearshore zone. Alas, there is little data available to provide a circumarctic picture of coastal erosion and to indicate erosion trends. Indeed, arctic coasts remain largely unknown and unexplored, which puts current adaptation and mitigation strategies in northern communities into jeopardy.

2 THE ACD PROJECT OUTCOMES

2.1 *The ACD classification*

In this presentation, we present the latest results from the Arctic Coastal Dynamics project, initiated by the International Permafrost Association and the International Arctic Science Committee in 1999. A classification, built to consistently describe the geomorphological characteristics and processes observed at the coast along the arctic rim, indicates that the geomorphological setting of arctic coasts is highly spatially variable. This dataset highlights the major influence of this setting on the erosion rates observed and the *in fine* difficulty in providing statistics at the global level. It shows, however that some striking regional traits can be deduced from the dataset. Alaskan and Canadian coasts in the Beaufort Sea are characterized by larger ground ice contents but also by much smaller cliff heights than other arctic coasts. Overall it shows that circumpolar coastal erosion is on average 0.5 m/yr, but again with strong differences between arctic regions, with rates close to 10 m/yr in some areas and stable

coasts in others. The rates of erosion along the arctic coast are illustrated in Figure 1.



Figure 1. Coastal erosion along the arctic rim

2.2 *Trends in arctic coastal erosion*

A second outcome of the ACD project is a recent assessment of erosion rates and their evolution throughout the second half of the twentieth century and the beginning of the twenty-first century. Despite the recent media attention to coastal erosion, reliable long-term datasets asserting an increase in coastal erosion are scarce in the Arctic. This presentation will present the latest datasets published in the literature and compare their spatial coverage to the extent of permafrost coasts at the arctic scale.

Remaining Challenges in Permafrost Carbon Research – a Status at the End of IPY

P. Kuhry

Department of Physical Geography and Quaternary Geology, Stockholm University, Stockholm, Sweden

Recent years have shown a dramatic increase in permafrost carbon studies. A significant milestone has been the publication of a new estimate of below-ground organic carbon in the northern circumpolar permafrost region, which includes most pools but also avoids double accounting. The high storage of 1672 PgC highlights the potential role of permafrost carbon in the Earth System. Recent findings provide strong evidence that the deeper soil carbon in thawing permafrost terrain is starting to be released. However, significant research challenges still lay ahead to quantify the thawing permafrost carbon feedback.

Uncertainties in the new storage estimate remain due to relatively few available pedon data for certain geographic sectors, such as the High Arctic and northern Eurasia, and for deeper cryoturbated soil horizons. Upscaling of individual pedon data is difficult due to the large spatial variability in landscape partitioning of the permafrost carbon pool and the large polygon size in regional soil maps.

An important issue is the lability of soil organic matter stored in permafrost. Frozen conditions largely inhibit decay and, therefore, the long-term permafrost history is critically important. Most permafrost peatlands first developed as permafrost-free fens under the Early-Middle Holocene Hypsithermal, and peat deposits underwent normal anaerobic decay before permafrost aggraded in the Late Holocene. Similarly, Yedoma has undergone repeated cycles of thermokarst exposing its deposits to decay. These decomposition trajectories are important because part of the permafrost carbon pool might be more refractory limiting future decomposability under thawing conditions. To date, there has been no attempt to define or map lability of the permafrost carbon pool at regional to northern circumpolar scales.

Future permafrost dynamics and periglacial processes are key to understanding the fate of the perennially frozen carbon pool. A gradual deepening of the active layer is expected but more rapid changes associated with thermokarst and erosion will quickly thaw out the ground over a much greater depth. The total and relative contributions of gradual and abrupt processes to permafrost thawing need to be quantified. Permafrost thawing and collapse could create both ponding as well as drying of the landscape.

This will dictate whether thawed carbon will be released through aerobic (CO₂) or anaerobic (CH₄) pathways. Permafrost models at the landscape level are needed that are able to predict changes in surface hydrological and drainage conditions taking into account differential ground subsidence.

The permafrost carbon pool is not yet fully integrated in climate and ecosystem models. It is unlikely that circumarctic and global models will ever achieve the spatial resolution needed to address key periglacial processes and carbon pool partitioning at the landscape level. Therefore, an important objective should be to parameterize transient landscape changes and define typical ground schemes appropriate for different model setups. The thawing permafrost carbon feedback needs to be included in model projections of future climate and environmental change.

**Wednesday
10:00-12:00**

ORAL Parallel Session

Soils in Periglacial Regions

Co-chairs: Jerry Brown & Tina Sanders

In Kapp Mitra

Soil Atlas of the Northern Circumpolar Atlas

A. Jones¹, V. Stolbovoy², C. Tarnocai³, G. Broll⁴, O. Spaargaren⁵, C-L Ping⁶ & L. Montanarella¹

1. European Commission Joint Research Centre, Ispra, Italy; 2. Institute of Geography, Moscow, Russia; 3. Agriculture and Agri-Food Canada, Ottawa, Canada; 4. Institute of Geography, University of Osnabrück, Germany; 5. ISRIC – World Soil Information, Wageningen, The Netherlands; 6. University of Fairbanks, Alaska, USA

1 NORTHERN SOILS

Soil is a unique substance that is often overlooked in discussions on climate change. As the second largest terrestrial sink of carbon dioxide on the planet, soil contains nearly double the amount stored by vegetation. Understanding how soil characteristics affect the fluxes of carbon dioxide and other greenhouse gases into and out of the ground, is particularly important in understanding climate change processes and responses. A key consideration that must be addressed is the role of permafrost-affected soils from the northern latitudes of the planet.

The cold climate of the northern circumpolar region and the association with near-surface permafrost reduces microbiological activity in the soil thus inhibiting the decay of organic remains. As a result, significant accumulations of peat can occur. These organic soils, together with the organic matter found in mineral soils, account for about 50% of the global soil carbon pool. The current environmental conditions keep this carbon locked in the ground. Consequently, northern soils can be regarded as an asset in the struggle to combat climate change. However, the same soils could dramatically affect global climate if existing environmental controls are altered.

2 THE SOIL ATLAS OF THE NORTHERN CIRCUMPOLAR REGION

The European Commission's Joint Research Centre has just completed a comprehensive three year project to produce the first ever Soils Atlas of the Northern Circumpolar Region. The scope of the Atlas is educational: raising awareness amongst the public, politicians, decision makers and the scientific community of the importance of northern soils.

Undertaken under the auspices of the International Polar Year, the atlas is a novel and unique publication that positively showcases collaboration between the European Union and internationally renowned soil scientists from Norway, Iceland, Greenland, Canada, USA and Russia.

The Atlas uses striking maps, informative texts and stunning photographs to explain and illustrate vividly the great diversity of soils in northern landscapes. The Atlas explains the origin and character-

istics of the different soil types that can be found in this environment and their relevance for global issues. The Atlas discusses the possible impacts of climate change on permafrost-affected soils and the important role that they play in global climate dynamics and the carbon cycle.

For the first time, the distribution of soil types for the entire northern circumpolar region has been presented in detail on twenty six map plates (A2 format) using the World Reference Base for Soil Resources as a framework for correlating knowledge from diverse soil classification systems. The maps and supporting explanations allow the reader to visualize the variations in major soil characteristics and associated landscapes that are found above a latitude of 50° N. The Atlas also presents a series of local soil perspectives from around the northern circumpolar region.

While the Atlas is primarily an educational and instructive document, its publication is geared to stimulate discussion at all levels and to encourage the development of policies and strategies for the protection and sustainable management of these fragile regions.

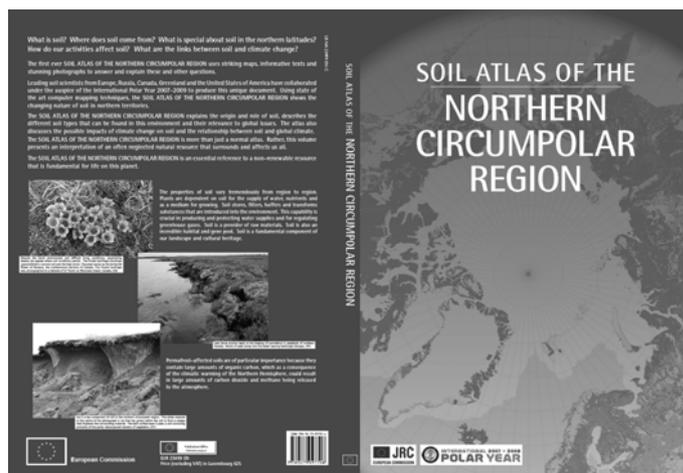


Figure 1. The cover pages of the soil atlas of the northern circumpolar region.

References

Jones, A., V. Stolbovoy, C. Tarnocai, G. Broll, O. Spaargaren and L. Montanarella (eds.), 2010, Soil Atlas of the Northern Circumpolar Region. European Commission, Office for Official Publications of the European Communities, Luxembourg. 142 pp.

Permafrost-Affected Soils – a Challenge for Soil Classification!

O.C. Spaargaren

Chair IUSS Working Group WRB, The Netherlands

Permafrost-affected soils have long been deprived of proper recognition and place in soil classifications. Older classification systems were built on zonal concepts or vegetational relations; names like desert soils, steppe soils, tropical soils, forest soils, or tundra soils are quite common in the older literature. These names do not convey much information about the processes in and properties of such soils. In addition, much of the soil research was focussed on agricultural land, forestry or rural development, mostly in temperate, sub-tropical and tropical regions, thus neglecting the soils of the polar regions.

Even in the '60s and '70s, when globally important new classification systems emerged, such as the FAO-UNESCO Legend of the Soil Map of the World and the US Soil Taxonomy, cold soils were only distinguished by their soil temperature regime, or the presence of permafrost, not by the unique properties and processes that characterize the permafrost-affected soils. Also in the twentieth century Russian system of soil classification evidence of, for example, gleying or podzolisation prevails over effects of cryoturbation.

It was only at the end of the '70s, under the impulse of soil research in Canada and Alaska, that permafrost-affected soils gained a mature status in soil classification, for example by the recognition of the Cryosolic Order in the Canadian system. This was followed in the '90s by Soil Taxonomy in establishing the Gelisol Order, and in the World Reference Base (WRB) for Soil Resources [1] – a sequel to the FAO-UNESCO Revised Legend of the Soil Map of the World – through the introduction of Cryosols.

Still no uniformity has been reached between major soil classification systems that recognize permafrost-affected soils at the highest level. The US and Canadian systems more or less treat them alike, Gelisols and the Cryosolic Order encompass both organic and mineral soils. On the other hand, WRB, through its historical roots, separates at the highest level organic soils (Histosols) from mineral soils. Consequently, Cryosols in WRB are mineral soils; the influence of cryogenic processes in organic soils is treated at a lower level.

Soil classification only makes sense if it can be put to service to society. Most criteria used in WRB to separate soils at the highest level and subdivisions at

the lower level are related to land use and management, mainly for agriculture and land development. This approach is less appropriate for soils in the circumpolar regions; they require other criteria to be recognized. Such criteria may be related to ecosystem services, engineering, or threats to soil, in the light of increased human presence in polar regions and the potential effects of man's activities on the fragile ecosystem. The challenge to soil classifiers will be to find and define these criteria, and to apply them in a sensible way in their classification system.

References

- [1] IUSS Working Group WRB. 2007. *World Reference Base for Soil Resources 2006, first update 2007*. World Soil Resources Reports 103. FAO, Rome. 112pp.

Permafrost-Affected Soils in Russia

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1 INTRODUCTION

About 60% of Russia (960 million ha) has permafrost. This huge area is varied by principle soil-forming factors such as climates, relief, geological substrata, vegetation and land use. All the above-mentioned diversity does result in a considerable variety of soils which is relatively well documented by soils maps in Russia and is summarized by national genetic soil classification.

2 OBJECTIVES

The overall aim of the presentation is to demonstrate a diversity of the permafrost-affected soils in Russia. The presentation is based on aggregated data presented in "Soil Atlas of the Northern Circumpolar Region".

3 MATERIALS

Seven soil divisions (Table 1) occupy about 100% of the area with continuous permafrost, nearly 95% of the zone with discontinuous and some 90% of sporadic permafrost zones. These soil divisions cover about 60% of the zone with seasonally frozen soils.

Table 1. Area (million ha) of main soil divisions by thermal zones in Russia..

Divi- sion	Seasonally frozen	Zones with permafrost			Total soil
		Spora-dic	Discon- tinuous	Continu- ous	
Al-Fe- Humic	60.1	53.6	88.4	173.5	375,6
Texture- differen- tiated	214.0	47.0	7.2	1.0	269,3
Gley-zems	6.4	18.4	20.3	199.9	245,0
Meta- morphic	45.0	32.2	32.0	56.0	165,2
Sod- organic- accumu- lative	10.1	11.6	43.2	45.0	109,9
Peaty	35.7	36.0	8.8	10.5	91,0
Cryo-zems	no	<0.1	15.3	59.0	74,4
Total zone	371,5	198,8	215,2	544,9	1330,4

Al-Fe-humic permafrost-affected soils predominate in the permafrost zone of Russia. These soils are coarse textured, well drained and manifest clear accumulation of total and amorphous organo-mineral

iron and aluminum. Permafrost table is usually found within the upper 2 m of the soil profile.

Texture-differentiated soils are seldom in permafrost zone. These soils have strongly bleached topsoil and argic B horizon with deep tonguing of the bleached material.

Gleyzems occupy considerable area in the permafrost zone. These are poorly drained soils with re-doximorphic features. The lack of oxygen reduces the rate and degree of organic matter decomposition leading to accumulation of peaty and muck topsoil organic horizons. Ice-rich permafrost is common within upper 100 cm.

Metamorphic permafrost soils cover are common in the permafrost zone. These soils have profile identified by differentiation in color or structure with uniform distribution of clay, sesquioxides and SiO₂. Ice permafrost is usually observed within upper 200 cm in the zone of continuous permafrost.

Sod-organic-accumulative soils are common in the permafrost zone. These soils have dark-coloured humus horizon. Often these soils originate from calcareous rocks. The presence of calcareous rock debris shifts pH to neutral supporting formation of organic muck horizon. These soils have mostly dry permafrost.

Peat permafrost soils are characterized by accumulation of under decomposed vegetation residues. Deep peat (more than 50 cm thick) has limited area in the zones of continuous and discontinuous permafrost in Russia. It is caused by limited vegetation production and organic input into soils and shallow permafrost table. The permafrost zone is dominated by shallow peat (30-50 cm peat thickness) or soils with peaty (less than 30 cm thick peat) horizons.

Cryozems are specific soils for permafrost area. These soils are characterized by intensive cryoturbation which leads to a totally mixed soil profile. Cryozems have lack of genetic horizons apart from a litter or shallow peaty layer on the surface.

4 CONCLUSIONS

The permafrost does not alter principle soil-forming processes and coexists with characteristics observed in seasonally-frozen soils. However permafrost-affected soils have a specific hydro-thermic regime which deteriorates a majority of soil processes including the intensity of C-turnover.

Permafrost-Affected Soils in Mountains of Northern Circumpolar Region

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1 INTRODUCTION

Mountains in (perma)frost-affected zone of the Northern Circumpolar region occupy huge area, where principle soil-forming factors such as climates, relief, geological substrata and vegetation vary greatly. It results in a considerable diversity of mountainous soils in zone with permafrost.

The main distinction of mountainous soils from plain ones in the permafrost-affected regions is their shallowness because of a close lithic contact or permafrost tables. That is why the often problem of mountainous cold soil correlation is to evaluate whether they are lithologically shallow enough to have features of Leptosols (in case of shallow permafrost table) or whether they cold enough to be correlated as Cryosols (in case of shallow lithic contact).

2 OBJECTIVES

The overall aim of the presentation is to demonstrate a diversity of the permafrost-affected soils in mountainous regions of the Northern Circumpolar area. The presentation is based on the data presented in "Soil Atlas of the Northern Circumpolar Region" and the field experience of the authors.

3 MATERIALS

The predominant feature of the surface of Arctic mountainous archipelagos is surely outcrops of barren substrates, mainly cobbly and rocky ones. The most common soils are reported to be Turbi-Leptic Cryosols on cobbly parent material. They form patterned ground with barren cryogenic spots in centers of polygons. On calcareous material Turbi-Leptic Cryosols (Humic and/or Calcaric) are developed. Hydromorphic non-gleyic soils Oxyaqui-Leptic Cryosols or Oxyaquic Leptosols can be widely met in the hollows of running melting water. In local places under continuous vegetation cover and overmoistening the cryosols with stagnic features are reported Stagni-Leptic Cryosols.

The main soils of the tundra mountains besides rock outcrops are: Lepti-Entic Podzols on stony material with shallow lithic contact and Hapli-Leptic

Podzols with shallow bedrock. Entic Podzols, lacking the Albic horizon is connected with Fe-rich parent materials (gabbro and basalts of some alpine tundras) and cryogenic disturbances, preventing of E horizon formation. Genuine permafrost-affected soils appear only in peatlands - (Cryic Histosols) and on loamy substrates (Turbic Cryosols) and sands Spodi-Turbic Cryosols).

Most of mountainous permafrost-affected areas are in boreal forest of humid and semihumid climates. In cryogenic mountainous stony organic soils the peat cover is usually 25-30 cm and more, and permafrost table lies at 40-100 cm as aquiclude (Cryic Histosols and Turbi-Histic Cryosols). The predominant soils of both mountainous and plain territories are Oxyaquic and Reductaquic Turbic Cryosols both in North America and Asia.

The most specific soil cover is in the mountains of central parts of the continents with continental climates. A lot of arid soil features are reported in these areas. Calcaric Leptic Cryosols alternating with rock outcrops and Oxyaquic Turbic Cryosols of overmoistened places are typical here. In places with calcareous bedrock, Calcaric Leptosols are developed. Finally, it should be indicated that the altitudinal zonality in continental regions is complicated by the effect of slope aspect. In particular, the areas with steppe vegetation are widespread on southern slopes (Mollic Cryosols and Leptosols), whereas the northern slopes at the same altitudes are covered by taiga forests with Spodi Cryosols or Turbic Cryosols.

4 CONCLUSIONS

The mountainous regions of the permafrost-affected zone have the same spectrum of soils as the plain ones, however, they have less imperfectly drained soils and more Leptosols in soil covers as they usually have deeper thawing due to stony substrate. Cold stony soils having no permafrost table within their profiles because of shallow control section should have special thermic regime, as it have been proposed by C.L.Ping and colleagues.

Soils at the Treeline in Northern Fennoscandia

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The treeline is the most conspicuous vegetation boundary in the mountains and in the North. In the northern hemisphere, the treelines are caused by decreasing temperature associated with elevation and latitude. If warming continues the forest will advance to greater altitudes and more northerly latitudes. How fast and to what extent this will happen is depending on many factors including the soil properties. Thus, one objective of our studies at the treeline in northern Fennoscandia is the characterization of soils in order to understand the interaction with vegetation, microclimate and topography. Permafrost occurs in peatlands. Mineral soils are frozen for most time of the year.

Large areas in Lapland, the northern part of Norway, Sweden, Finland and northwestern Russia, are characterized by undulating peneplains located at altitudes between 250m and 350m, overtopped by rounded mountains (Finnish: tunturi, Norwegian: fjell), reaching several hundred metres in height. Sandy-skeletal deposits left by the inland ice cover the bedrock. Erosion has dissected the sediments; what is left is a diversified mosaic of small hilltops, ridges, valleys and shallow depressions. Wind blown areas with little snow often alternate with snow-rich sites, sheltered from the wind. In most cases the mountain birch is the only tree species at the northernmost tree line in Lapland.

Beside Leptosols, Podzols are the dominating soils at well drained sites in the treeline ecotone, exhibiting small eluvial horizons. In wet depressions Histosols dominate. Mineral or peaty hummocks can be found in depressions and stream valleys, in many cases they are cryoturbated. The cryoturbation was most intensive during the Little Ice Age. Patterned ground occurs in some valleys with loamy sediments.

The variable relief and soil permeability are key factors controlling the distribution of water in the soil. The mosaic of vegetation clearly reflects the given soil moisture conditions. On windswept hilltops, where the wind and over-grazing by reindeer have exposed the highly permeable glacial deposits, lack of water and nutrients impedes the growth of birch seedlings. Because such sites have only little or no winter snow the soil is frozen to great depth for many months. Soil frost may seriously affect sensitive roots of tree seedlings. Profiles are eroded to the B horizon or even to the C horizon. Reindeer grazing also influences the soil microclimate. Without the insulating effect of the vegetation cover, bare soil shows very high temperatures in summer and very low temperatures in winter. Due to these effects a delayed response of the birch forest boundary to climate change can be observed.

Soils of the Northern Alaska Low Arctic

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Arctic Alaska, climatically classified as Low Arctic, includes areas north and west of the Brooks Range and the northern Seward Peninsula. It lies in the zone of continuous permafrost. In northern Alaska there are two major physiographic regions: the Arctic Foothills and the Arctic Coastal Plain. In the northern Arctic Foothills, most soils form in carbonate-rich loess of Pleistocene age. Syngenetically frozen silt-rich loess includes large ice wedges. Soil drainage ranges from moderately well to somewhat poor. Vegetation is nonacidic tundra (MNT) dominated by *Dryas*, herbs and low shrubs. Dominant soil types are Aquic Molliturbels (Mollic Turbic Cryosols) and Ruptic-Histic Aquiturbels (Histic Turbic Cryosols). In the southern Arctic Foothills, parent materials change from loess dominated to an increased occurrence of gravelly loamy moraines accompanied by an increase in precipitation and temperature. Vegetation changes to moist acidic tundra (MAT) with poor soil drainage. The dominant soil type is Ruptic Histoturbels (Histic Turbic Cryosols). The Histels (Cryic Histosols) formed along the narrow stream banks and are limited to depressions. Soils under both the MNT and MAT are highly cryoturbated, mainly caused by the activity of non-sorted circles (frost boils), which churn the surface organic layers downward into the lower active layers and upper permafrost. The presence of organic matter concentrations observed at depth in soil profiles indicates that cryoturbation usually occurs down to 1.3 m, except on exposed hilltops

The flat landscape of the Arctic Coastal Plain is characterized by low-center polygons on the western part and high-centered polygons on the eastern part caused by ice-wedge formation. Most of the soils on the coastal plain are ice-rich, averaging of 80% ice by volume. Nearly 60% of the area is on the western part of the coastal plain with landforms dominated by thaw lakes and drained-lake basins with vegetation dominated by wet nonacid tundra (WNT). Parent materials are dominated by glaciomarine and eolian deposits, with lesser amounts of alluvium and sandy diamicton. The volume of wedge-ice averages 20% and field evidence shows frost churning of organic matter reaches 2 - 3 m. Thus, the cryoturbation

process in the thaw-lake landscape is a result of combined effects of ice-wedge polygon formation, mixing through thaw-lake development, and frost boil formation. The dominant soil types are Ruptic-Histic Aquiturbels (Histic Turbic Cryosols), Ruptic Histoturbels (Histic Turbic Cryosols), Glacistels (Cryic Glacic Histosols), and Glacic Historthels (Histic Glacic Cryosols). In the eastern part of the coastal plain, the dominant parent material is sandy diamicton, followed by eolian and alluvial deposits. Average volume of wedge-ice is about 10%. The dominant soil types include Ruptic-Histic Aquiturbels and Ruptic Histoturbels.

Delta deposits occupy nearly 25% of the coastline in northern Alaska. Soils formed in newly deposited sediments with an active layer exceeding one meter lack cryoturbation and are classified as Gelaquents (HaplicGleysols). Those with the permafrost table within one meter are Typic Aquorthels (Cambic Cryosols (Reductaquic)) and Sulfuric Aquorthels (Cambic Cryosols (Reductaquic)).

Soils of the Alaska Low Arctic store high amount of carbon on the average, the coastal plain soils store 68 kgCm² and the Arctic Foothills store 48 kgCm² with nearly 50% of this carbon sequestered in the upper permafrost. In response to climate warming, the Low Arctic is likely to become a carbon source because of an increased organic matter decomposition rate and release of the sequestered carbon in upper permafrost. On the average the frozen soils of the Low Arctic release 1.5 g CH₄ m² and 150gCO₂ m² upon thawing. In addition, the Arctic Coast Plain of Alaska is greatly affected by global warming; the coastal erosion rate averaged -1.1 m yr⁻¹ over the past 50 years, but recent erosion rates as high as 18 m yr⁻¹ have been observed in extremely ice-rich glaciomarine sediments. The eroding Beaufort Sea coastline exports 160,000 tons of carbon and associated nutrients into the Arctic Ocean annually.

Soils of the Canadian High Arctic

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1 DESCRIPTION OF THE AREA

The High Arctic in Canada, which encompasses part of the mainland and all of the Canadian arctic islands except for the very southern tip of Baffin Island, covers a land area of approximately 1157×10^3 km². This region contains a large variety of landscapes, from low-lying to hilly and mountainous terrain, the latter of which is commonly associated with polar glaciers and ice fields. The climate is severe, with short, cold summers and extremely cold and dark winters. Daily winter temperatures average -30 °C or colder while mean daily temperatures are warmer than 0 °C only in July and early August. Mean annual precipitation is less than 200 mm, with approximately 70% occurring as snow. The vegetation cover, which is generally sparse and discontinuous, is composed of low-growing (less than 10 cm) herbs and shrubs. Nearly continuous vegetation cover occurs only on the wet areas. Permafrost is continuous, reaching thicknesses of up to 500 m, and the soil surface is generally associated with patterned ground.

2 RECENT SOILS

Cryosols (Gelisols), the dominant soils of the High Arctic, developed during the Holocene Period. They have active layers that are 30–60 cm deep and are strongly affected by cryogenic processes such as cryoturbation, frost heave, cryogenic sorting, thermal cracking and ice build-up in the subsoil. These cryogenic processes result in unique macromorphologies and micromorphologies, thermal characteristics, and physical and chemical properties. These processes also translocate non-living biomass into the subsoil and are responsible for the high carbon content in these soils and for the fact that these soils are carbon sinks containing approximately 9–34 kg C/m² in a 1 m depth. Other soil-forming processes, such as gleying, salinization and weak brunification, are minor but can also leave an imprint on these soils.

Soils developed on moderately calcareous glacial till or marine parent materials, such as those occurring on Bathurst, Banks and Victoria islands, have thin,

brownish, cryoturbated B horizons. On the other hand, soils developed on strongly calcareous parent material, such as those on Cornwallis Island, are also strongly cryoturbated but usually lack B horizon development. Soils developed on noncalcareous glacial till parent materials, such as those on Boothia Peninsula, usually have brownish B Horizons. All of these soils are classified as Turbic Cryosols. Soils developed on coarse-textured sandy and gravelly parent materials are usually not cryoturbated and are classified as Static Cryosols. Some of these soils, such as those on Cameron Island, have thin, leached Ae horizons. Organic Cryosols are uncommon in the High Arctic region. Soils that occur in association with wet meadows have thin organic layers and seldom meet the criteria for Organic Cryosols. However, deep (>1 m) Organic Cryosols do occur in association with eroded high-centre polygons that developed during the Hypsithermal maximum, about 7–8 thousand years ago, and are found even at very high latitudes.

3 PALEOSOLS

Although soils in the Canadian High Arctic are dominated by Cryosols, this area is also rich in paleosols that developed under very different climatic conditions, indicating that climate change was very much a part of the past history of this region. One of the most outstanding of these paleosol areas is the fossil forest site located on Axel Heiberg Island, approximately 10° south of the geographic North Pole. Its well-preserved fossiliferous beds contain Podzols and deep organic paleosols together with logs and stumps up to 1 m in diameter. The preserved flora, and subsequent dating of the Buchanan Lake Formation, indicate that these paleosols formed approximately 45 million years ago, during the Middle Eocene Epoch of the early Tertiary Period. At that time, this high latitude was experiencing a warm and wet temperate climate with a landscape covered by tall coniferous forests on well- and imperfectly-drained sites and forested swamps with deep peat deposits on poorly-drained areas.

Hyper-Arid Ecosystems of Antarctica

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With a mean annual water equivalent precipitation of <50 mm and a mean annual air temperature ranging from -20 to -35 °C, Antarctica is referred to as a cold desert. Although only 0.36% (49,800 km²) of the continent is ice-free (Ugolini and Bockheim, 2008), Antarctica has contributed substantively to our understanding of Earth's systems, particularly the cryosphere. Land life in Antarctica generally is restricted to the hyporheic zone, which until recently was limited to streams and ponds that thaw during the austral summer. Soils of continental Antarctica are underlain by permafrost, which is often "dry-frozen" (Bockheim et al., 2007; 2008), and have low concentrations of organic C (<0.05%) and moisture (<5%), and have abundant water-soluble salts (>5 dS/m) (Fig. 1). Soils have played important roles in Antarctica in (i) understanding the behavior of dry-based glaciers, (ii) relative dating of glacial deposits, (iii) correlation of drift sheets, and (iv) testing of hypotheses such as whether there were high-level lakes in the McMurdo Dry Valleys following the last glacial maximum. Soils in the Transantarctic Mountains are classified as Anhyturbels, ca. permafrost-affected mineral soils with anhydrous conditions that feature cryoturbation, or Anhyorthels, ca. related soils that do not feature cryoturbation. Miocene-aged soils in Antarctica contain a salt-cemented horizon and are classified as "Petrosalic," "Petronitric," or Petrogypsic Anhyorthels (Fig. 2). An international organization, known as ANTPAS (Antarctic Soils and Permafrost; <http://erth.waikato.ac.nz/antpas>) is coordinating the mapping of soils and permafrost in Antarctica. Soil evidence suggests that warming is occurring in continental Antarctica, including an expansion of the hyporheic zone, exposure of nivation hollows from sublimation of long-term snow patches, and flushing of salts from high-elevation soils. Cold desert soils are important for studying extremophiles such as endolithic lichens and microorganisms in 2-8 million-year-old permafrost. Antarctic soils have been used for interpreting features and processes on Mars, including patterned ground, thermokarst, and rock glaciers. Finally, Antarctic soils are an important component of environmental observatories and provide a data repository for studying environmental change (Bockheim, 2010).

References

- Bockheim, J.G. 2010. Soil mapping in Antarctica. Atlas of Northern Soils. Joint Research Centre of the European Commission.
- Bockheim, J.G., I.B. Campbell, M. Guglielmin, and J. Lopez-Martinez. 2008. Distribution of permafrost types and buried ice in ice-free areas of Antarctica. In: Proc. 9th Internat. Conf. on Permafrost, University of Alaska Press, Fairbanks, pp.
- Ugolini, F.C. and J.G. Bockheim. 2008. Antarctic soils and soil formation in a changing environment: a review. *Geoderma* 144:1-8.
- Bockheim, J.G., I.B. Campbell, and M. McLeod. 2007. Permafrost distribution and active-layer depths in the McMurdo Dry Valleys, Antarctica. *Permafrost & Periglacial Processes* 18:217-227.



Figure 1. Image of hyper-arid soil from Antarctica.



Figure 2. Salt pan from hyper-arid soil in Antarctica.

**Wednesday
10:00-12:00**

ORAL Parallel Session

Remote Sensing Techniques and Geohazards

Co-chairs: Birgit Heim & Lothar Schrott

In Lassegrotta

Radar Interferometric Observations of Permafrost Related Surface Deformation

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ABSTRACT

In recent years we successfully applied radar interferometry to measure surface deformation over permafrost areas. The first investigations concerned the estimation of the surface deformation of rockglaciers in the Swiss Alps between 1995 and 2000 using Synthetic Aperture Radar (SAR) data of the European Remote Sensing Satellites ERS-1 and ERS-2. Based on ERS differential interferograms, with a ground spatial resolution of about 20 m and a radar wavelength of 5.6 cm, an inventory of mass moving objects could be elaborated over a large part of the Swiss Alps. Rockglaciers were classified into the four displacement rate classes: cm's/day, dm's/month, cm's/month and cm's/year (Lambiel et al. 2008). More recent satellite SAR images of the ENVISAT ASAR, ALOS PALSAR and TerraSAR-X sensors permitted updating the inventory with respect to the more recent rockglacier activity, the spatial resolution (which is 3 m in the case of TerraSAR-X), and the detection of displacement at more densely vegetated lower altitudes (higher coherence of 23 cm wavelength of ALOS PALSAR). Considering that the quantifica-

tion of displacement rates larger than about 0.5 cm/day is currently limited by the orbit repeat time interval of the satellites, radar interferometric observations with a ground-based instrument were also performed. Our ground-based radar interferometer operates from a tripod with a signal wavelength of 1.8 cm and a temporal interval of about 15 minutes (Werner et al. 2008), permitting the detailed survey of mass movements with displacement rates of cm's/day like destabilized rockglaciers and rockwalls. Furthermore, preliminary encouraging results using TerraSAR-X data for the monitoring of Arctic permafrost subsidence over an area around Tuktoyaktuk near the Mackenzie River Delta in Canada will be presented.

References

- Lambiel, C., Delaloye, R., Strozzi, T., Lugon, R., Raetzo, H. (2008). ERS InSAR for detecting the rockglacier activity. Proceedings of the Ninth International Conference on Permafrost, July 2008, Fairbanks, Alaska, 1, 1019-1024.
- Werner, C., Strozzi, T., Wiesmann, A., Wegmüller, U. (2008). GAMMA's portable radar interferometer. Proceedings of IAG/FIG, Lisbon, Portugal.

A Multi-Satellite Concept in Support of High Latitude Permafrost Modelling and Monitoring - The ESA DUE Permafrost Project

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1 INTRODUCTION

A number of remotely sensed products have been developed in the past which provide information relevant to permafrost distribution on circumpolar scale. They comprise parameters such as land surface temperature, land cover, soil moisture, disturbances, snow, terrain and methane. A monitoring system of high latitude permafrost requires regular and multiscale observation of all these parameters. Further on, the datasets need to meet requirements of permafrost models as well as support related research in geomorphology, botany and hydrology.

Such a comprehensive database is setup within the framework of the European Space Agency's (ESA) Data User Element (DUE) program. The ESA DUE Permafrost project establishes a monitoring system on local to pan-boreal/arctic scale based on satellite data. Within this project permafrost relevant remotely sensed products are assessed and eventually provided to users. The complexity of the phenomenon permafrost requires the close cooperation with the scientific community working in this field.

The consortium is led by I.P.F, Vienna University of Technology and supported by four partners: Gamma Remote Sensing, University of Waterloo, Friedrich Schiller University Jena and the Alfred Wegener Institute for Polar and Marine Research.

2 SATELLITE DATA PRODUCTS

Permafrost is a subsurface phenomenon and cannot be directly observed with satellite data. Yet, monitoring can be done based on indicators and via permafrost models. Indicators are especially thermokarst lake dynamics and surface elevation changes.

Those phenomena need to be observed on a local scale. Regional to circumpolar monitoring requires the use of permafrost models for which the following dataset will be provided:

- Land surface temperature is available from passive sensors such as MODIS, AATSR, and AMSR-E. It can be used as a forcing parameter for all permafrost models.
- The amount of snow determines insulation properties. An operational monitoring service for snow extent and SWE is currently being set up within the ESA DUE project GlobSnow.
- Vegetation layer also insulates the ground. A number of global and regional land cover maps are available (e.g. from GlobCover). They need to be merged and assessed for the purpose of modelling of permafrost and fluxes.
- Thermal conductivity is influenced by soil moisture. A near real-time (NRT) product based on METOP ASCAT is available from EUMETSAT. This service will be improved within the project under the viewpoint of frozen ground conditions.

3 OBSERVATION STRATEGY

The circumpolar datasets will be provided weekly to monthly with a spatial resolution of 25 km x 25 km. Selected areas will also be monitored at 1 km x 1 km for snow extent (SE), LST, soil moisture, and vegetation. High resolution satellite data are used at selected local sites. All satellite data products will eventually be made freely available via a WebGIS.

Further Information:

www.ipf.tuwien.ac.at/permafrost

Using in-Field and D-InSAR-Techniques for the Monitoring of Seasonal Lithalsa Dynamics in Northern Quebec

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1 BACKGROUND

The discontinuous permafrost zone of the Northern Hemisphere is one of the most unique and sensitive ecosystems of the world. It operates as a vast ecosystem and is home for a large fraction of the Inuit people. But during the last decades several research teams observed severe changes in the landscape of this region. Typical observations are the collapse of distinct permafrost landforms such as lithalsas, subsiding areas and the expansion of wetlands. These alterations are all accompanied by impacts for the local habitants as well as for the ecosystem. As they can be attributed to permafrost thawing due to warmer climate conditions, it is very likely that they will occur even more strongly and frequently in the future.

In order to reduce the effects for human beings, a high demand for adaptation and management strategies arose in the recent years. The basis for such decision support always is the profound knowledge about the processes themselves and the different methods and approaches that may be useful to evolve convenient strategies.

The international collaboration project Nunavik between LMU, INRS, DLR and UL within the framework of ArcticNet tries to address this issue by developing a monitoring system able to understand, visualize and potentially project such climate induced changes. In order to establish a spatially efficient technique, the system will be strongly based on remote sensing imagery and GIS-based data analysis.

The presented research is a proof-of-concept whether the interferometric products from the German TerraSAR-X sensor can contribute to the envisioned system by detecting the mentioned topographical changes at the object-scale.

2 IMPLEMENTATION AND RESULTS

2.1 Implementation

The investigation was conducted near the Inuit village Umiujaq (56°33' N, 76°33' W), located in Northern Quebec. The idea was to figure out if the data delivered from the TerraSAR-X sensor is actu-

ally suitable to deliver information about small-scale topographical deformation and displacement. Focus is given to an attempt to see if seasonal dynamics between winter and summer are detectable in the interferometric products.

For this purpose, three lithalsas were surveyed by high-precision d-GPS, during field campaigns in April and August of 2009. TerraSAR-X imagery from the same time period with multiple acquisition parameters (asc/desc, polarizations (VV, HH, VH)) were analyzed and phase-interferograms from multi-temporal image pairs were computed.

The results of the interferogram analyses were then compared to field-measurements for validation.

2.2 Results

First results are surprising but promising: The in-field measurements as well as the interferograms show corresponding topographical deformation. But in contrast to the expected decrease during the summer, the geodetic measurements reveal an uplift in topography of about 14 cm in average. After some initial analysis of the images showing the phase difference of the TerraSAR-X products, the firstly doubtful results were confirmed in the image analyses. These very interesting outcomes may be traceable to a combination of the annual thermal regime of lithalsas in the discontinuous permafrost zone, namely the delay of temperature waves while penetrating into the ground.

The presentation will depict the measurement methods, the discovered seasonal dynamic of the surveyed lithalsas as well as a possible explanation for the movements. Besides a summary of research findings and methodological detail from the image analysis process will be given.

PermaSAR – Permafrost Monitoring Using Imaging Satellite Radar (SAR) and Ground Based Techniques in Svalbard

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1 INTRODUCTION

Permafrost landform monitoring at landscape scale is important to achieve, when assessing the effects of climate change on periglacial landscapes. Here we demonstrate how this hopefully can be developed using Synthetic Aperture Radar (SAR) remote sensing techniques.

Imaging SAR is a key instrument onboard many Earth observation satellites. Due to the insensitivity of SAR to light and meteorological conditions, it is a very valuable tool for studies of dynamic processes of periglacial landscapes. In 2009, Norut and UNIS initiated a project *PermaSAR* where SAR satellite remote sensing data are used directly in a study of periglacial landform dynamics.

2 METHODS

Differential SAR interferometry (InSAR) is a method that can be used to detect fine-scale surface displacements.

In this study, we investigate the effects of different radar wavelengths, as well as spatial resolution, using data from multiple sensors and acquisition modes, to detect and quantify landscape displacement related to permafrost.

The very high spatial resolution of new SAR instruments, like the Ultrafine mode of Radarsat-2 and the stripmap and spotlight modes of TerraSAR-X, combined with the relatively short repeat cycle of these instruments (11 and 24 days), makes them well suited for monitoring the fine-scale seasonal displacement that happens during the thawing and freezing of the active layer [Larsen et al., 2009].

Furthermore, we have measured since 2005 the near-daily temporal development of radar backscatter using wide swath data from the Envisat ASAR sensor. The backscatter is a proxy for the amount of liquid water in the top surface layer, which is related to freezing and thawing of the active layer. The time series allow studies of the spatial distribution of different permafrost regions in Svalbard.

Starting in the snow-free season of 2009, we are acquiring both Radarsat-2 Ultrafine and TerraSAR-X stripmap and spotlight mode SAR data over two 25 x 25 km study areas in Longyearbyen and at Kapp

Linné on Svalbard. In both study areas ground based field monitoring allows for comparison between the SAR results and in situ measurements.

3 RESULTS

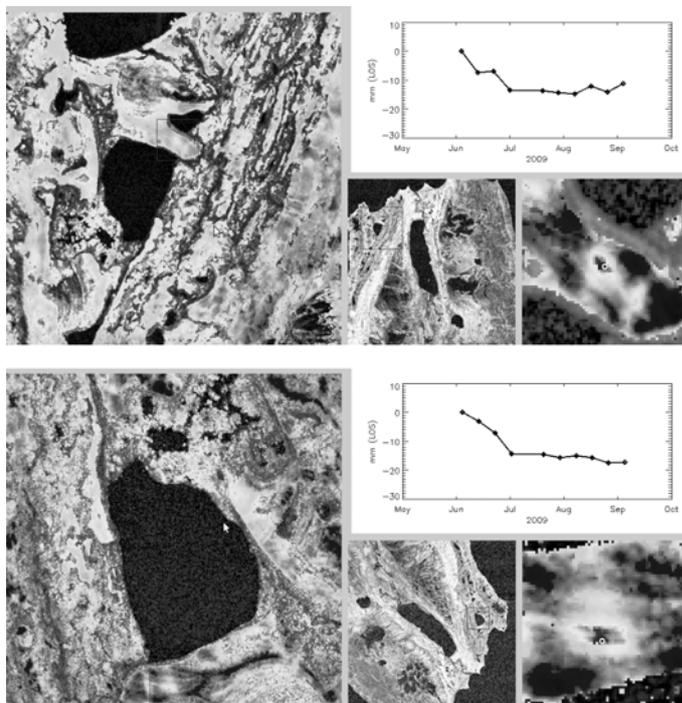


Figure 1. We have analyzed TerraSAR-X data from overlapping ascending (upper figure) and descending (lower figure) passes. The time-series analysis is preliminary, but the level of agreement between the two independent datasets is remarkable.

From the InSAR results in Fig. 1 a settlement of about 20 mm in the (radar line of sight) can be observed in the period from mid June until mid July. This corresponds very well with field observations recorded by the Kapp Linné solifluction station located inside the SAR study area.

References

- Larsen, Y., et al., 2009. High-resolution InSAR analysis of Radarsat-2 Ultra-Fine mode and TerraSAR-X data for measuring fine-scale landscape changes due to permafrost activity. Abstract for 6th International Workshop on SAR Interferometry (FRINGE 2009).

High Resolution Remote Sensing Identification of Thermokarst Lake Dynamics (1954-2006) in a Subarctic Peat Plateau in West-Central Canada

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1 INTRODUCTION

1.1 Peat plateau/thermokarst lake complexes

Peatlands in the northern circumpolar permafrost zone are important reservoirs of soil organic carbon, containing ~277 Pg carbon (Schoor et al., 2008). In the subarctic, peat plateaus dotted with numerous thermokarst lakes are common landscape features. In a future warmer climate permafrost thawing in these peatlands might result in increased thermokarst lake formation, lateral expansion and/or increased lake drainage. A better understanding, and quantification, of thermokarst dynamics is important for predicting future greenhouse gas emissions from these ecosystems under changing climatic conditions.

2 SPATIO-TEMPORAL VARIATIONS IN LAKE EXTENT

2.1 Aim and study area

The aim of this study has been to enhance methods to quantify thermokarst lake dynamics in subarctic peat plateau/thermokarst lake complexes on decadal time-scales. The study area (57°53'N, 94°10'W, 85 m a.s.l.) is located in the southernmost part of the continuous permafrost zone in the Hudson Bay Lowlands, northeastern Manitoba.

2.2 Methods

For the time-series analysis panchromatic aerial photographs from 1954 and 1974 and a QuickBird registration from 2006 were used. To perform land-water separation several semi-automatic remote sensing techniques such as unsupervised and supervised classification and texture and high-pass filtering were tested, evaluated and rejected. Instead a combination of manual delineation and binary encoding of transects perpendicular to the shoreline was tested as a method to more accurately differentiate the land-water boundaries. According to a test with multiple interpreters the relative uncertainty when manually delineating lake margins was reduced to ± 0.6 m when binary encoding of spectral profiles was used.

2.3 Results and conclusions

Manual delineation, employing binary encoding of transects perpendicular to the shoreline, proved to be the best method to identify lake dynamics at metre-resolution (Sannel & Brown, in press). Two main types of landscape changes were identified; erosion along thermokarst lake shorelines and infilling with fen vegetation along lake margins (Figure 1). Between 1954 and 2006 the highest recorded erosion rate was 0.73 m/yr and the highest rate of infilling was 1.25 m/yr, but most shorelines showed very little change over time. During the same period no new thaw ponds formed and lake drainage was very limited, indicating relatively stable permafrost conditions in the peat plateau. More long-term spatial analysis of thermokarst features are needed to better understand future responses to the predicted wetter and warmer conditions in subarctic peatlands, and their consequences for the global carbon cycle.

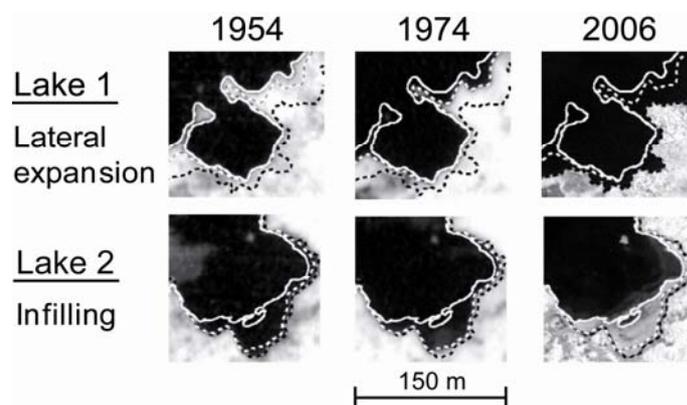


Figure 1. Examples of lake expansion and infilling with fen vegetation in a peat plateau/thermokarst lake complex in the Hudson Bay Lowlands from 1954 to 2006.

References

- Sannel, A.B.K. & Brown, I.A. in press. High resolution remote sensing identification of thermokarst lake dynamics in a subarctic peat plateau complex. *Canadian Journal of Remote Sensing*.
- Schoor, E.A.G., Bockheim, J., Canadell, J.G., Euskirchen, E., Field, C.B., Goryachkin, S.V., Hagemann, S., Kuhry, P., Lafleur, P.M., Lee, H., Mazhitova, G., Nelson, F.E., Rinke, A., Romanovsky, V.E., Shiklomanov, N., Tarnocai, C., Vernevsky, S., Vogel, J.G. & Zimov, A. 2008. Vulnerability of permafrost carbon to climate change: Implications for the global carbon cycle. *Bioscience* 58: 701-714.

Planimetric and Volumetric Thermokarst Change Detection on Ice Rich Permafrost, Using Remote Sensing and Field Data

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1 INTRODUCTION

An expected increase of thermokarst activity will lead to a further degradation of ice rich permafrost. Lakes formed by thermokarst processes are known to be a spatially and temporally variable feature indicative for surface wetness and drainage conditions. In order to investigate recent cryomorphogenesis this study is aimed to determine lake and terrain height changes in an ice rich arctic landscape.

The investigation area is located in the south of the Lena Delta (Russia). Average sediment discharge of the Lena River is about 21 mil. t/a. In comparison to the whole catchment river bank erosion in the area of the delta contributes to the riverine sediment input to the Arctic Ocean above average. Ice Complex (IC) permafrost deposits of the third geomorphological terrace cover large areas of the southern Lena Delta, which is exceptionally exposed to an increasing river discharge and strong flood waters along the largest delta channels. On Kurungnakh Island belonging to the third terrace a well pronounced alas-Yedoma thermokarst relief is developed. Undissected Yedoma uplands (< 55m high) alternate with large thermokarst depressions (alasses, < 30m deep) formed by thawing of ground ice since the Bølling interstadial. Lakes can be found here within alasses and on the Yedoma uplands (see Morgenstern et al., this conference).

Using photogrammetric principles, GIS, and geodetic measurement techniques a geometric consistent dataset was created for monitoring purposes.

2 DATA AND METHODS

Digital Elevation Models (DEM) were developed from a triplet set of ALOS PRISM imagery (2006), a CORONA stereo pair (1968) and a tacheometric field survey of a thermokarst depression (7,5 km²), conducted in summer 2008.

Due to suboptimal imaging conditions, such as snow, large shadows in steep thermoerosional valleys, low-contrast in the tundra environment, compression artifacts and striping the PRISM data were resampled to 5m ground resolution. In comparison to the processing of separate image tiles and piecewise DEM generation, the combination of three possible PRISM epipolar pairs with various overlap

ratios allow higher measurement accuracy and the immediate generation of one DEM over the whole investigation area. Accurate processing of CORONA data, which included the correction of several overlapping image distortions, allowed for the minimization of wrong height parallax measurement and led to the generation of a 5 m DEM, representing the relief situation in 1968.

The DEMs then were used for orthoimage generation to allow distance and area measurements. For 2D-change detection purposes another historical dataset (1964) consisting of two adjacent CORONA filmstrips was used. The extent of Ice Complex deposits (260 km²) served as an analysis mask for digitizing thermokarst lakes at a large scale.

3 RESULTS AND DISCUSSION

The DEMs could be used effectively for 3D-change detection. For the alas investigated in detail in the field various expansion rates up to 9 cm/a depending on exposition could be determined through differencing the CORONA and the field survey DEM. A comparison of the CORONA and the PRISM DEM shows negative terrain height changes within alasses, along thermoerosional valleys, and shores.

Along the two river bank sections Olenyokskaya (IC thickness < 15 m) and Buor Khaya (IC thickness < 30 m) a detected volume loss of 5.5 mil. m³ sands and 14.5 mil. m³ of the overlying Ice Complex equals an input of 0.4 mil. t sediment per year. Erosion at the Buor Khaya section (-13 mil. m³) exceeds the values at Olenyokskaya (-7 mil. m³) by about 90%. Because of the different Ice Complex thickness a comparison of planimetric erosion rates leads to a different evaluation of the dimensions of erosion. The Buor Khaya section retreats at rates of 2.9 m/a, which is only 60% higher than the 1.8 m/a retreat at the Olenyokskaya section.

Over the period 1964-2006 a decrease in water area (2291 to 2216 ha) about -3.5% could be observed, caused mainly by 45 catastrophic lake drainage events while persistent lakes increased about 2%. These parallel processes of lake drainage and expansion well detectable with high resolution data reveal ongoing lake dynamics that are not reflected in the overall limnicity change (8.7 to 8.5%).

Permafrost Influence on the Active Nordnes Rockslide

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The Nordnes rockslide is located along a fjord margin on a rockslope stretching up to about 800 m asl. It is characterized by large open fractures, which in the upper part are 1-10 m wide and 1-10 m deep. Periodic displacement measurements have documented that 12-22 million m³ of rock are moving up to 5 cm/year. The present intermunicipality monitoring program includes displacements measurements using GPS, crackmeters, tiltmeter and lasers.

In addition to the monitoring program, an IPY research project, TSP NORWAY, has instrumented the upper parts of the unstable Nordnes rockslide to study the thermal regime of the upper part of the rock surface, the temperature in open fractures and the regional permafrost distribution in the area. This instrumentation allows detailed studies of the relationships between deformation in the slopes and possible meteorological controlling factors.

2D resistivity measurements and seismic refraction data indicate that the depth of the instability can be more than 100 m. High resistivity levels potentially indicating permafrost conditions have been measured both on the higher mountain areas and as local patches within the unstable rock mass. The mean annual surface temperatures at different elevations and temperature data from 2,5 m deep boreholes demonstrate permafrost conditions at elevations above 700-800 m asl.. In addition, relict Little Ice Age (LIA) permafrost may exist at lower altitudes. Modelling suggests that during cold LIA intervals permafrost may have been forming down to 550-650 m asl. Air temperature data from the open fractures in the active rockslide also strongly indicate local cooling during winter, when the cracks have a thick snow cover, thus demonstrating the potential existence of permafrost in deeper part of the cracks. Visual observations of late summer ice in narrow parts of the crack further stress this possibility.

The displacement data from continuous lasers and crackmeters from 2007-2010 show the following characteristic temporal pattern (Figure 1):

1. Displacement from late summer (August- September) until early winter (January-March).
2. Stable conditions from early winter until late summer.

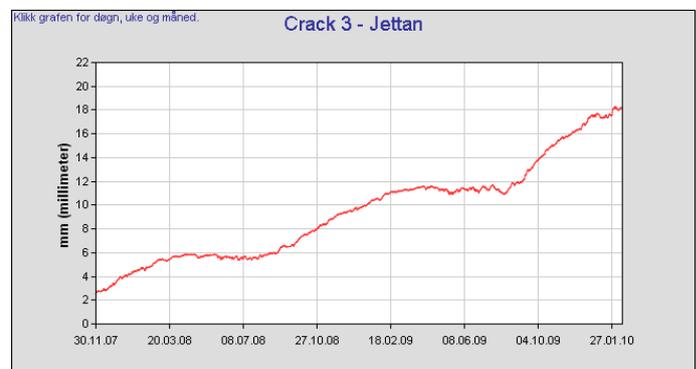


Figure 1. Displacement measured by a crackmeter across one of the main fractures at Nordnes.

The timing between displacement and stability is slightly different from one sensor to another. This seasonal characteristic is different from what has been documented from other large rockslides in Norway and elsewhere. Normally, the displacement of large rockslides increases during heavy rainfall and extensive snowmelt, increasing the water level in fractures in non permafrost areas. In Nordnes, there is no displacement during the snowmelt season, indicating other controlling factors.

The documented temperature regime both regionally and within the unstable Nordnes rock mass strongly indicate that processes linked to the existence of permanent ice in the narrow, but open cracks are an important factor for the stability of the rockslide. The deformation is interpreted to be an effect of expansion/contraction of bedrock, seasonal freezing and thawing and ice accumulation forming patches of ice/permafrost in fractures. However, these processes are not well understood, and there is a need for investigations and instrumentation of deep boreholes to fully understand the deformation process, including the effect of permafrost conditions in highly fractured rock masses.

A Rock-/Ice Mechanical Model for the Destabilisation of Permafrost Rocks and First Laboratory Evidence for the “Reduced Friction Hypothesis”

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1 INTRODUCTION

The destabilisation of permafrost rocks is commonly attributed to changes in ice-mechanical properties (Davies et al. 2001). The effect of low temperatures on intact rock strength and its mechanical relevance for shear strength and brittle fracture propagation has not been considered yet. But this effect is significant since compressive and tensile strength are reduced by up to 50% and more when intact rock thaws (Mellor, 1973). Here we show, that the reduction of the shear resistance of rock-rock contacts in discontinuities may play a key role for the onset of larger instabilities in thawing permafrost rocks.

2 MODEL DESIGN AND LABORATORY METHODS

Based on a Mohr-Coulomb assumption, we defined a failure criterion of an ice-filled rock fracture, with cohesive rock bridges, contact of rough fracture surfaces, ductile creep of ice and with a representation of rock-ice “failure” mechanisms along the surface and inside the ice body. The synoptic models are based on the principle of superposition, i.e. that shear stress “absorbed” by one component reduces the amount of shear stress applied to the other components.

To test the importance of reduced friction, we conducted shearing tests on homogeneous fine-grained limestone specimen taken from a permafrost site (Zugspitze, Germany). In a temperature-controlled shearing box, we repeatedly tested mechanical properties of identical sand-blasted surfaces between +5° and -7°C. Normal stress was set to a level that equals 4 m rock overburden and promotes the shearing of the asperities on the fracture surface.

3 MODEL AND LABORATORY RESULTS

Failure along existing sliding planes can be explained by the impact of temperature on shear stress uptake by creep deformation of ice, the increased propensity of failure along rock-ice fractures and reduced total friction along rough rock-rock contacts. This model may account for the rapid response of rockslides to warming occurring along existing planes of weakness (reaction time). In the long term, brittle fracture propagation is initialised. Warming reduces the shear stress uptake by total friction and decreases the critical fracture toughness along rock bridges. The latter model accounts for slow subcritical destabilisation of former permafrost rock slopes over decades to millennia, subsequent to the warming impulse (relaxation time). Both models underline the importance of reduced total friction from the onset of the destabilisation.

We could show for the first time, that the shear resistance of ice-free smoothed rock-rock surfaces decreased by a mean value of approximately 30 % subsequent to thawing. This occurred even after enhanced fracture smoothing due to repeated shearing experiments.

4 CONCLUSION

Thawing-related changes in rock-mechanical properties may significantly influence early stages of the destabilisation of larger thawing permafrost rocks irrespective of the presence of ice in the system. The models imply that only after the deformation accelerates to a certain velocity level (where significant strain is applied to ice-filled discontinuities) ice-mechanical properties outbalance the importance of rock-mechanical components. We present two quantitative models that relate the destabilisation of thawing permafrost rocks to temperature-related effects on rock- and ice-mechanics.

**Wednesday
10:00-12:00**

ORAL Parallel Session

Analysis of Sensitivity of Permafrost Modeling

Co-chairs: Wilfried Haeberli & Megan James

In Møysalen

Permafrost Monitoring in Northwestern Russia and a Methodology of the mid-Range Projections of Its past and Future Degradation in Natural Conditions

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1 INTRODUCTION

International Polar Year became a catalyst that dramatically increased research activities in the region. Due to efforts from the Russian Federal Agency for Mineral Resources (MIREKO Company), from the Geophysical Institute, University of Alaska, and from Geological Survey of Finland permafrost temperature observations were resumed at six stations in this region. In this paper the major results of these activities and the results of uninterrupted long-term observations at two other stations will be presented.

2 RECENT CHANGES IN PERMAFROST AND A METHODOLOGY OF THE PROJECTIONS OF ITS

Air temperature data collected at meteorological stations in the region show a warming trend during the last 30 to 40 years; the rate of warming was different for different stations. The positive trend in the maximum for the winter snow depth is not observed at all stations. In the eastern part of the region, ground temperature at 10 to 15 m depth increased by 0.7 to 1.6 C within the coldest peatland sites and by 0.9 to 1.0 C within the warmer sand-dominated areas. This warming penetrated down to 30 m into the permafrost, down to 80 m into the open taliks. Under favorable conditions, the 9 to 15 m deep new closed taliks developed, the pre-existing taliks became deeper. The ice content has been decreasing in warming permafrost. These changes were detected by the temperature measurements and by indirect surface geophysics data (Vanhala et al., 2008), as well as by observed to 0.6 m long-term subsidence of the ground surface.

We developed a methodology of the projections is based on assumption that the relationship between changes in the air and permafrost temperatures established at the long-term monitoring sites may be applicable for the other areas with the identical geologic and geomorphologic conditions. Using these relationships and comparing corresponding changes in the measured or predicted air temperatures at the long-term observation sites and within the area of interest, it is possible to estimate the past and future changes in permafrost at locations where only short-term or occasional observations were made. A map of near-term past changes in permafrost in the region

was developed. This map shows that during the last 35 years the southern boundary of the Holocene age permafrost shifted by 30 to 80 km northward. The boundary between continuous and discontinuous permafrost moved northward at 15 to 20 km within the lowland and up to several tens of kilometers in the foothills.

3 SUMMARY

The direct ecological and economical damage from the degrading permafrost is just started to be recognized. Even less thought is the indirect threat to the Arctic, for example, a possible contamination of the Arctic and Atlantic Oceans and possible damage to the fishery there from the damaged oil pipelines as a impact from the thawing permafrost in the discussed region. To mitigate this impact, an accurate and timely forecast of changes in permafrost should be established. To make it possible at least two or three new long-term observational sites should be established in the central and western parts of the region where no permafrost observation sites. We call up the Arctic international community to join our forces in developing a mutually scientific collaboration in developing mid-range permafrost forecasts for this region.

References

- Vanhala, H., Lintinen, P., Oberman, N. & Suppala, I. 2008. Modelling discontinuous permafrost using geophysical data – a case from Vorkuta, Komi Republic, Russia. *Abstracts. Congress of the International Polar Year 2007/2008, Espoo. November 12-13. Espoo, p.53.*

Interaction Between the Accelerated Thaw of Discontinuous Permafrost and Drainage Network Organization, Northern Quebec

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1 RESEARCH HYPOTHESIS

Permafrost plays an important role in tundra hydrology. Climate warming has a major impact on subarctic ecosystems as more heat is being transferred into the ground. Thawing of the ice-rich permafrost ultimately occurs, which results in the formation of hollows and ponds, which can disturb drainage networks. In regions where no structured stream channel network is available to evacuate the excess water generated by snowmelt and permafrost thawing, more water stagnates on the terrain and could transfer additional heat into the ground. Furthermore, across the landscape, the creation of new thermokarst ponds and taliks likely leads to increased groundwater movement and storage capacity in the soils. Moreover, it is likely that the hydraulic conductivity of thawed permafrost is increased as the original, sedimentary, structure of soils is modified by freeze-thaw cycles, cryosuction, melting of ice lenses and thaw consolidation of soil aggregates. The aim of this research is to determine to what extent drainage network organization influences degradation of discontinuous permafrost in a region of rapid thermokarst. Particularly, we assessed how newly acquired hydraulic properties of thawing soils can participate in the further degradation of discontinuous permafrost close to the freezing point.

2 METHODS

2.1 *Study area*

The study area is located near the Hudson's Bay coast, 40 km north of Umiujaq. The analysis is performed on two adjacent watersheds, which flow into the Nastapoka river; one has an organized stream network of the second order, the other has no structured drainage pattern.

2.2 *Landforms and processes versus model*

We used a systems approach to correlate watersheds' structure and impacts of excess water stored in thermokarst ponds on ground thermal regime. Mapping of thermokarst ponds and stream networks was used to understand the watersheds' organization. We also used a 2D heat conduction model (fi-

nite volumes), elaborated in MATLAB© language, to simulate the thermal impact of water stored in a shallow thermokarst lake on an adjacent permafrost mound in order to assess the importance for permafrost decay. Hydraulic conductivities required for heat convection in thawing permafrost are estimated through successive model runs.

3 RESULTS AND DISCUSSION

3.1 *Dynamics of drainage patterns in subarctic watersheds*

The drainage network in watershed 1 is mature. Few thermokarst ponds are present. The organized stream network drains water efficiently. However, in watershed 2 the drainage network is not very developed. Thermokarst ponds in the watershed are more numerous because the drainage basin does not have the capacity to evacuate the excess water efficiently. Water storage in thermokarst ponds in watershed 2 has a thermal impact on permafrost.

3.2 *Water thermal impacts on simulated permafrost mound*

Numerical simulation results indeed suggest a quick talik formation under the thermokarst ponds. The permafrost mound besides the pond had large thermal amplitude but a small lateral talik. Nevertheless, this talik possibly extends laterally inside the permafrost from the warm lake into the ice-rich core of the mound. Lateral water flow during meltdown in the crack network would allow an additional warming of the soil through convective heat transport. However this particular thermal effect requires mass flow conditions that have not yet been observed or measured.

4 CONCLUSION

Subarctic watersheds are transitional environments in which water is abundant. This research shows the importance of taking into account the water dynamics in degrading discontinuous permafrost zones.

Monitoring and Process Analysis of Permafrost Creep and Failure in Changing Temperature Regimes

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1 MOTIVATION

The motivation for current and future research on creeping permafrost landforms, such as rockglaciers, is to understand the pathways from an atmospheric forcing, its influence on surface and subsurface characteristics to the point of a rheological response. Within the research bundle “Sensitivity of mountain permafrost to Climate Change” (SPPC), funded by the Deutsche Forschungsgemeinschaft (DFG), this study aims at the monitoring and process analysis of permafrost creep and failure in response to changing temperature regimes. In this context, the particular challenge is to define the sensitivity of creeping permafrost landforms. Therefore, it has to be distinguished between “normal” process regimes and disturbed ones, and thresholds have to be described.

2 METHODS

Kinematics (horizontal and vertical displacements) as well as spatio-temporal variations thereof are quantified for several representative rockglaciers and frozen talus slopes in the Alps by means of digital photogrammetry (based on aerial photographs from the last 5 decades) as well as annual geodetic surveys. Detailed investigations are performed on landforms showing instabilities and failures and thus indicate high sensitivities. In order to analyse the measured kinematics in a rheological context, temperature data (ground surface temperatures (GST) and borehole temperatures from different depths) as well as data on subsurface characteristics (from geophysical soundings) are implemented. The coupled analysis in a numerical model approach will allow for an assessment of how temperature changes will be translated into a rheological response.

3 RESULTS

Extraordinary high velocities or distinct temporal changes in kinematics within the monitoring period (from ~ 1970 – 2009) indicate a response to certain changes within the permafrost system and thus indicate a high sensitivity of the system. Existing data series from annual terrestrial surveys (total station) in the Turtmann Valley (Switzerland) show strong temporal changes in horizontal velocities.

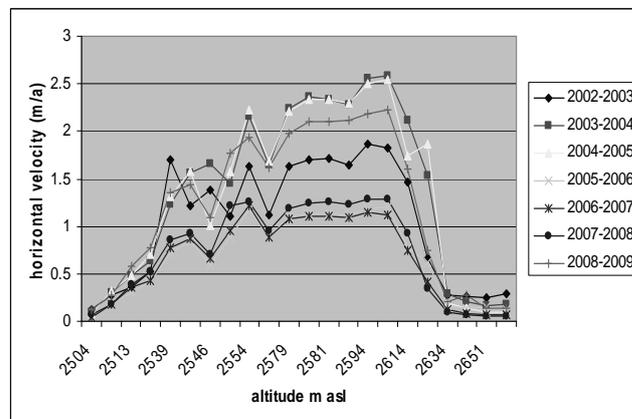


Figure 1. Annual horizontal velocities of single blocks at the surface of rockglacier HuHH3, Turtmanntal, Switzerland

Highest values are related to thermal anomalies like the hot summer of 2003 as well as the warm winter of 2008 (see figure 1) and indicate a direct response. At a first glance, this signal seems to be related to changes in water content or availability thereof, rather than to increasing permafrost temperatures. In addition, at least two rockglaciers in the same region indicate strong accelerations in combination with failures, such as cracks and collapsed tongues. Beside a general concept on rockglacier sensitivity, first results from different monitoring sites in Switzerland will be presented and discussed.

The Sensitivity of Mountain Permafrost to Climate Change (SPCC) Project: Influence of Substrate and Morphology

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1 INTRODUCTION

The DFG-funded project cluster “Sensitivity of Mountain Permafrost to Climate Change” (SPCC), consisting of 5 collaborating individual projects at German and Swiss Universities, aims at bridging the gap between climate simulations and the analysis of surface and subsurface characteristics for an assessment of the sensitivity of permafrost dynamics in mountainous terrain (see also www.spcc-project.de). The sensitivity is among others characterised by components of the geosystem, in this context lithology, substrate, terrain parameters, ice and water content, insulating covers etc. The investigation of sensitivity includes both, types of disturbance (e.g. climate) and types of reaction (e.g. permafrost degradation) of the different subsystems.

In this contribution, first results will be presented regarding the physical properties (e.g. pore volume, ice/water content, temperature, creep velocity) of typical permafrost occurrences at the main study site Murtèl, their temporal changes as well as their potential influence on the permafrost sensitivity.

2 STUDY SITES, DATA & METHODS

Field sites are located in different climatic regions of the Swiss and German Alps (Fig. 1) and consist of typical mountain permafrost occurrences including rock glaciers, moraines, talus slopes, bedrock plateaus, unconsolidated sediments and rock walls. They are chosen due to availability of deep borehole information, geophysical data, energy balance data and spatial terrain parameters (high-resolution DEM). Two research sites are highlighted as main collaborative study sites: the Zugspitze and the Murtèl/Corvatsch region (Fig. 1); the latter being the focus of this contribution.

In addition to 3 boreholes on Murtèl rock glacier drilled in 1987 and 2000, 8 shallow boreholes with temperature logging are available in different substrates and on different morphologies, three of them drilled within the SPCC project. Ground surface temperature and snow height is continuously measured at several places; a micro-meteorological station on Murtèl rock glacier is in operation since 1997.

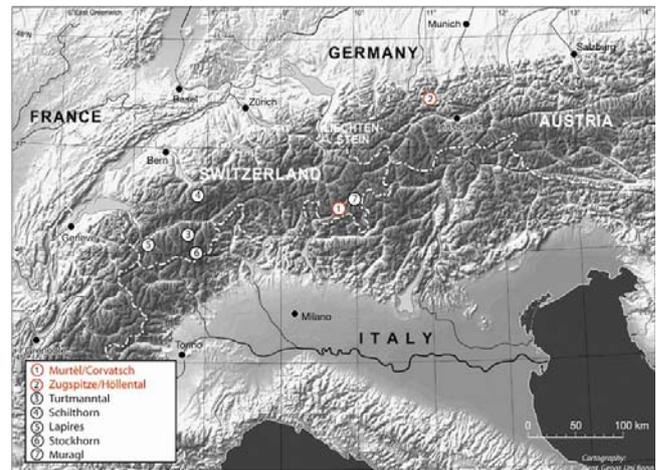


Figure 1: Overview of the study sites of SPCC.

Geophysical data comprise electrical resistivity tomography monitoring (ERTM) and refraction seismic tomography on many different landforms and substrates in the investigation area including several rock glaciers, where velocity data are available as well. On 4 of these landforms with different substrates and different morphological characteristics (rock glacier with coarse blocky material; steep rock face; bedrock/talus slope transition; glacier forefield) ERTM was recently installed to analyse changes in ice content in response to interannual variation of atmospheric forcing parameters (air temperature/radiation; snow height). Measurements on permafrost creep were conducted on several landforms using digital photogrammetry as well as geodetic surveys.

3 RESULTS

First results show a remarkable spatial variation in subsurface temperatures, depending on substrates and most probably on ice content. A preliminary comparison of ERT and rock glacier velocities shows a tendency of high resistivities for large and slowly moving bodies and smaller resistivity values for smaller but faster landforms. For seasonal changes in the active layer, ice content, substrate and availability of infiltrating melt water seem to be the governing properties and, on longer time scales, may constitute the dominant variables concerning the sensitivity of mountain permafrost.

Warming of Permafrost Temperatures on Svalbard - What is the Effect of the Snow Cover?

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1 MOTIVATION

This contribution investigates the warming of permafrost and potential causes: (i) snow cover and physical properties, (ii) soil thermal state before onset of snowfall (iii) climate parameters such as winter air temperatures and radiation balance. The main factors determining the permafrost's heat transfer are: (i) phase composition of soil (specifically available pore space) which enables vapor diffusion and/or water advection during all periods (ii) the temperature gradient between atmosphere and soil which is largely affected by the snow cover. The heat transfer into the ground is largely transmitted via conduction with the exception of snow melt and freeze back. The insulating capacity of snow dampens the effect of cold winter air temperatures on the soil. Winter warming events, rain-on-snow events, early-onset snow packs and warm end-of-summer soil conditions can contribute to warmer soil conditions throughout the winter. Warmer soils contain more liquid water and respond more slowly to increased heat loss to the atmosphere.

2 INVESTIGATION AREA AND METHODS

We use hourly data from automated weather and soil and snow temperature/volumetric water content stations from the Bayelva site near Ny-Ålesund. Auxiliary data include radiation balance data from the BSRN station network in Ny-Ålesund.

3 RESULTS

The 11-year permafrost temperature record from the Bayelva site shows a warming and thawing trend, especially pronounced over the last 5 years. In total, about 50 cm of upper permafrost has been lost at this site over the 11 year period since 1998. It is not clear yet what causes the observed warming trend. Factors considered include changes of the surface energy balance (radiation budget, atmospheric fluxes), changes of the surface characteristics (snow, vegetation cover, wetness), and changes in subsurface

composition (ice content, soil material). Furthermore, (warm) ocean currents and ice cover dynamics give Svalbard its relatively mild maritime climate. The hourly air temperature data from Ny-Ålesund southeast of the Bayelva site shows a long term pronounced winter warming trend (superimposed on strong interannual variability). From 1990 to 2009, the winter (Oct-Apr) temperatures increased by $0.13^{\circ}\text{C}/\text{year}$, whereas the summer temperatures (Jul-Aug) only increased by $0.05^{\circ}\text{C}/\text{year}$.

Frozen Ground Conditions in Subarctic Mountain Environments, Northern Sweden Assessed by near-Surface Geophysics and Ground Temperature Regimes

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Near-surface ground temperatures along an altitudinal transect and at different aspects and near-surface geophysics surveyed on typical periglacial landforms in subarctic Sweden have been applied in order to assess frozen ground conditions and the geomorphological significance of contemporary permafrost.

The investigated subarctic mountain environments are located south and south-west of Abisko, northern Sweden (68°10'N, 18°45'E). At the Abisko research station (385 m a.s.l.) the mean annual air temperature is -0.6°C. For the altitudinal zone of 1000-1400 m a.s.l. in which most of the investigation area is situated, the mean annual air temperature can be inferred to be about -2°C to -4.5°C. The subarctic mountain environments are characterized by well developed glacial and periglacial landforms including ice-cored moraines, gelifluction terraces, gelifluction/solifluction lobes and sorted and non-sorted polygons.

Miniature temperature loggers were placed near the surface to record year-round temperatures. From the latter data the mean annual ground surface temperature (MAGST) was calculated. The loggers were placed at different altitudes, at different aspects and along an altitudinal transect spanning from 660 to 1440 m a.s.l. Geophysical surveying included 2D resistivity tomography (ERT) and 2D seismic refraction tomography.

The results of the near-surface temperature measurements show at some sites no or only minor inter-annual variation in the MAGST, however, especially at wind-blown sites, significant temperature differences have been recorded. This also applies for the measurements at different aspects (cf. Tab. 1).

The ERT surveys performed along slopes with terraces and solifluction/gelifluction lobes show different subsurface resistivity patterns. In most cases permafrost and non-permafrost areas in the subsurface could be differentiated. The variable resistivity patterns point to small-scale variability of ice content and possibly also permafrost temperature within the investigated mountain periglacial environment. The results of the geophysical surveys indicate both shallow permafrost occurrences, and especially in the upper parts of the investigated sites, permafrost definitely thicker than the sounding depth of 30 m which was possible with the applied survey length. Based on the *MAGST* values (below -3°C) of the logger placed at the mountain pass (1440 m a.s.l.), a permafrost depth of more than 100 m can be assumed at this altitude.

The results of the temperature measurements together with those of the geophysical surveys, allow an interpretation of frozen ground conditions and permafrost characteristics in the investigated subarctic mountain environments. The near-surface ground temperature measurements show a small-scale variability and confirm the significant influence of the snow cover on the ground thermal regime, furthermore many loggers have MAGST around 0°C or even above.

The results show that widespread permafrost with significant impact on periglacial morphodynamics is encountered above an altitude of 1200 m a.s.l. Below this altitude the permafrost distribution is heterogeneous and topography, surface substratum and snow cover play an important role. In flat areas or in the valley floor with thick snow cover, permafrost can be either sporadic or marginal and the impact on contemporary periglacial processes is of minor importance. At lower altitudes isolated permafrost can occur if environmental factors are permafrost-favorable.

Table 1. Attributes of selected temperature monitoring sites.

Logger (Altitude m a.s.l.)	Site description	Year	MAGST [°C]
L1 (660)	Birch forest	07/08	0.8
		08/09	0.8
L3 (960)	Patterned ground	07/08	1.1
		08/09	1.0
L4 (1035)	Slope	07/08	0.6
		08/09	0.6
L8 (1320)	Solifluction Terrace	07/08	-2.4
		08/09	-1.5
L9 (1440)	Pass	07/08	-3.4
		08/09	-3.7
L10 (1000)	South-exposed	06/07	0.2
		07/08	1.4
		06/07	-1.1
	North-exposed	07/08	-0.7

Spatial and Temporal Variability in Active Layer Thickness on the Qinghai-Tibet Plateau Under the Scenarios of Climate Change

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1 ABSTRACT

Climate change has greatly influenced the permafrost regions on the Qinghai-Tibet Plateau. Most general circulation models (GCM) project that global warming will continue and the amplitude will amplify during the 21st century. Climate change has caused extensive degradation of permafrost, including thickening of the active layer. The changes in active layer thickness greatly impact the land surface energy balance, hydrological cycle, ecosystem and engineering in cold regions. A model based on Kudryavtsev's formulations was used to calculate the active layer thickness on the Qinghai-Tibet Plateau. The relative errors between the measured values and the calculated values are generally less than 15%, with others no larger than 20%. Potential changes of active layer thickness under the scenarios of climate change were also discussed. Maps of active layer thickness for the year 2049 and 2099 on the Qinghai-Tibet Plateau are projected under the scenarios of climate change. Simulations indicate active layer thickness in the permafrost regions on the Qinghai-Tibet Plateau will increase with the rising air temperature, especially in sporadic and discontinuous permafrost regions. Permafrost may degrade even disappear in some regions of the Qinghai-Tibet Plateau with the rising air temperature. Active layer thickness may increase by 0.2~0.7m for the year 2049 and 0.4~1.2m for the year 2099. The depth of thaw is a major factor controlling the amount of moisture content in the active layer. Recent study indicates that vegetation coverage decreases with the increase of active layer thickness for ecosystem of alpine meadow on the Qinghai-Tibetan Plateau. Ecosystem in permafrost regions is strongly coupled with thermal conditions of the active layer and permafrost degradation. Active layer changes may cause environmental deterioration, including the destabilization of buildings, impacted upon cold regions hydrology and water resources, and accelerated desertification in permafrost regions on the Qinghai-Tibet Plateau.

Table 1. Comparison between measured and calculated ALT

Station	Measured ALT, m	Calculated ALT, m
Beiluhe	2.0~3.2	2.12
Tanggula	1.5~2.5	1.98
Wudaoliang	2.0~3.5	2.13
Wuli	1.6~3.5	2.26
Tongtianhe	1.5~3.5	2.18
Mt. Kunlun	1.8~2.8	2.05
Mt. Fenghuo	1.3~2.5	1.82
Kekexili	1.8~3.5	2.2
Taoerjiu	1.3~2.5	2.1
Chumar	2.0~3.5	2.7

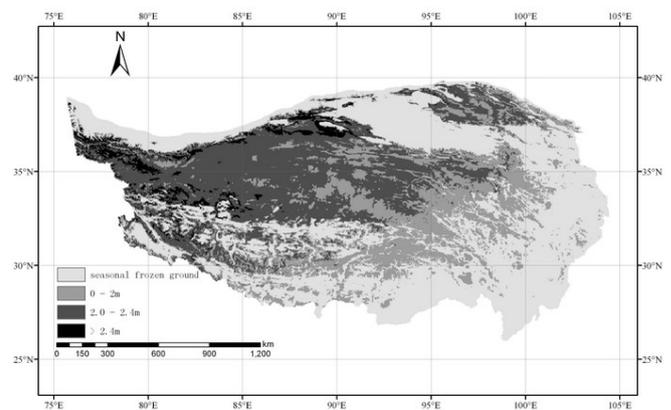


Figure 1. Distribution of ALT on the Qinghai-Tibet Plateau .

References

- Anisimov O.A., Shiklomanov N.I., Nelson F.E., 1997. Global warming and active-layer thickness: results from transient general circulation models. *Global and Planetary Change* 15:61-77.
- Pang Q, Cheng G, Li S, Zhang W, 2009). Active layer thickness calculation over the Qinghai-Tibet Plateau. *Cold Regions Science and Technology* 57: 23-28.

Impact of Infiltrating Melt Water on the Thermal Regime of the Active Layer – a Comparison of Mountain Permafrost Sites with Different Subsurface Textures

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1 THERMAL REGIME OF ACTIVE LAYER

Compared to polar regions permafrost in high mountain regions occurs in a large variation of surface and subsurface material and texture. Therefore, the thermal regime of the active layer strongly depends on site-specific factors like the grain size, the pore volume and type of material beside climatic factors such as air temperature, incoming radiation, precipitation and runoff.

The zero curtain in spring is very important for the thermal regime of the permafrost. It is characterized by the consumption of latent heat of fusion.

It is assumed that the main cause for the initialization of the spring zero curtain is the thawing of the snow pack and thus the infiltration of melt water into the frozen active layer (Hoelzle et al. 2003). Furthermore the influence of the subsurface texture on the evolution of the zero curtain is investigated.

2 INVESTIGATION SITES AND METHODS

Borehole temperature measurements from different PERMOS- sites (Permafrost Monitoring Switzerland) as well as ground surface temperature (GST) were used. All sites were classified respectively their subsurface texture (fine grained, gravelly, coarse blocky and bedrock). As far as available, the snow height and duration of the melting period was correlated with the starting time and duration of the zero curtain.

In addition a numerical heat and mass transfer model (COUP) was used to further investigate the snow melt infiltration processes on these different substrates.

3 RESULTS

3.1 Influence of the snow pack

The model results for different subsurface textures show a good agreement with the measured data. The correlation of the borehole temperature data with the snow height measurements as well as the model results confirm the hypothesis that the spring zero cur-

tain phase is mainly be driven by advection of the melt water of the snow pack (Fig. 1).

Superimposed ice seems to be important for the development and duration of the zero curtain, even more important than the temperature of the active layer at the onset of infiltration.

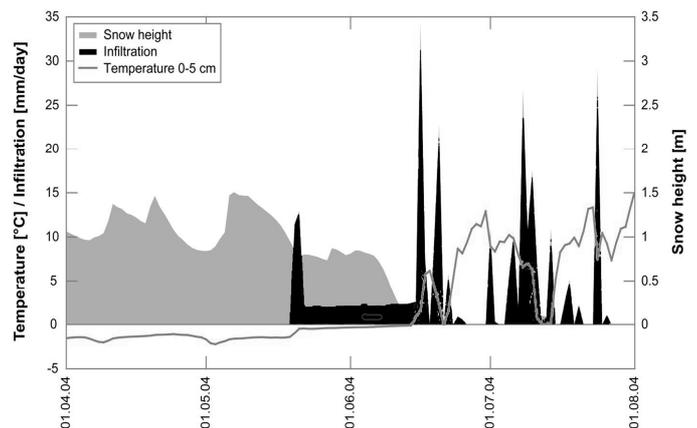


Figure 1. COUP model results showing the influence of the advection of the melt water on the onset of the zero curtain effect.

The onset of the zero curtain coincides with the time of the snowmelt, that is the infiltration of melt water from snow cover. Furthermore the height of the snow pack influences the duration of the zero curtain

3.2 Influence of the subsurface texture

The classification by subsurface texture shows that in fine grained material the isothermal region is much thicker than in coarse blocky material, whereas the duration of the zero curtain effect is the longer the coarser the material (Hanson and Hoelzle 2004). Basically the subsurface texture has insofar an influence on the zero curtain insofar as the existence of pore volume enables the formation of superimposed ice.

References

- Hoelzle, M., Haerberli, W. and Stocker-Mittaz, C., 2003. Miniature ground temperature data logger measurements 2000-2002 in the Murtèl Corvatsch area. In: M. Phillips, S. Springman and L. Arenson (Editors), *8th International Conference on Permafrost, Proceedings*. Swets & Zeitlinger, Lisse, Zürich, pp. 419-424.
- Hanson, S. and Hoelzle, M., 2004. The thermal regime of the active layer at the Murtèl rock glacier based on data from 2002. *Permafrost and Periglacial Processes*, 15(3): 273-282.

**Wednesday
13:00-15:00**

ORAL Parallel Session

**Soil Carbon Microbiology and Trace Gas Release in Permafrost
Environments**

Co-chairs: Charles Tarnocai & Gabriele Broll

In Lassegrotta

Estimating Soil Organic Carbon Storage in Periglacial Terrain at Very High Resolution; a case Study from the European Russian Arctic

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1 INTRODUCTION

While recent research advances have significantly increased our understanding of SOC storage in the periglacial landscape, there are still many uncertainties. Local scale studies have shown that the landscape distribution of SOC is highly heterogeneous (e.g. Hugelius and Kuhry, 2009). Some landscape components, such as peat deposits or cryoturbated soil horizons, can dominate local SOC storage. However, there are no clear trends in landscape distribution and regional differences emerge (Kuhry et al., *in prep.*).

We have conducted a very high resolution study of SOC storage in four study sites (Seida and Rogovaya 1-3) in discontinuous permafrost terrain, European Russian Arctic. Point pedon data is upscaled to areal coverage using two different upscaling tools, land cover classifications and soil maps.

2 METHODS

2.1 Soil sampling and upscaling

Soil sampling was performed (i) along landscape transects and (ii) according to a weighted, stratified random sampling program. Sampling was done in 10 cm increments to 1 m depth or to full depth of peat deposits in a total of 94 sites.

Point pedon data is upscaled to areal coverage using two different upscaling tools:

1. Thematic land cover classifications based on multiresolution segmentation of high-resolution Quickbird imagery (2.44 m raster resolution, 17 separate land cover classes, software Definiens Professional 5.0) and:

2. High resolution thematic soil maps following *World Reference Base for Soil Resources* terminology (20 distinct soil types, median polygon size 1960 m²).

Mean SOC storage for each land cover or soil type is multiplied by the areal coverage within the study areas to calculate total storage and landscape partitioning of SOC.

Figure 1 illustrates the spatial resolution of the two upscaling tools. It also shows 4 pixels of Landsat

TM resolution, representing the highest resolution of previous land cover based SOC storage studies in permafrost terrain.

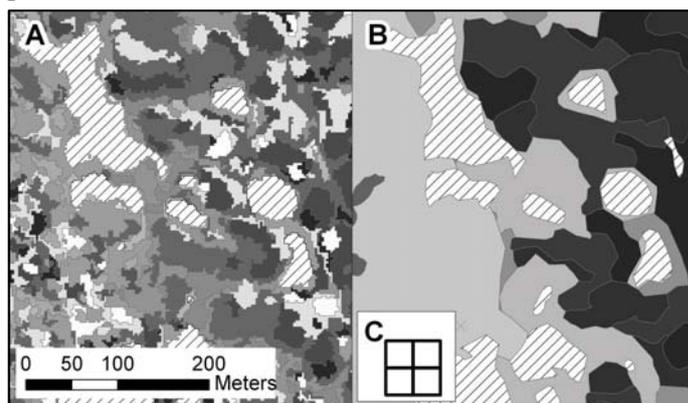


Figure 1. Resolution of upscaling tools for one section of the Seida study area: A= land cover and B= soil map. The squares at C are 30*30 m squares, simulating the resolution of Landsat TM pixels. Striped areas are thermokarst lakes.

3 RESULTS

Preliminary calculations show that the estimates in the four different areas are between 38-58 kg C m⁻² for land cover upscaling and between 37-49 kg C m⁻² for soil map upscaling. Both upscaling methods yield higher estimates than what has previously been reported for this area (Hugelius and Kuhry, 2009). A majority of SOC is stored in Cryic Histosols or Follic/Histic Cryosols. Contiguous permafrost peat plateaus are present in all study areas, covering ~20-30 % of the landscape. The mean depth of peat deposits in the four plateaus is between 150-250 cm, but it is highly variable (recorded range 30-420 cm). There is no evidence of any significant deep burial of SOC through cryoturbation processes.

References

- Hugelius G. and Kuhry P. 2009, Landscape partitioning and environmental gradient analyses of soil organic carbon in a permafrost environment. *Global Biogeochemical Cycles*, 23, GB3006, doi:10.1029/2008GB003419.
- Kuhry, P., Dorrepaal, E., Hugelius G., Schuur, E.A.G. and Tarnocai C., Potential remobilization of permafrost carbon under future global warming. *Permafrost and Periglacial Processes*, Submitted.

Methanogenesis in Cold Environments: Rates, Pathways, and Populations.

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1 INTRODUCTION

Methane is next to carbon dioxide the second most important greenhouse gas. Wetlands and Northern wetlands in particular, are among the most important sources of atmospheric methane. The effect of increasing temperature on all biological reactions is often claimed to initiate a feedback mechanism. However, a wide range of wetland emission estimates makes predictions difficult, and unknown physiological response of microbial communities further contribute to uncertainty. Here we report about an ongoing study on rates and controls of methane production in different organic soils (peat) and sediments from around the Arctic

2 SAMPLING SITES

Soils, sediments and peats were sampled from sites in Svalbard, Finland, West and East Siberia, and Alaska. Peat from the Boreal (Estonia) and soils from the subtropical Mediterranean served as references.

RESULTS

We studied the effect of temperature on rates of methanogenesis, on methanogenic populations, and on the microbial pathways that eventually supply methanogens with substrates. The influence of temperature on methanogenesis in the arctic and subarctic soils was similar: starting from a theoretical minimum temperature in the subzero range, methanogenesis was highly active just above zero and had its optimum in the range between 25 and 30°C. In contrast, the temperature optimum for soils from the temperate zone was around 40°C, while activities below 10°C were insignificantly low.

While in the Mediterranean samples a moderately thermophilic population co-existed with mesophils, no indication of such a population mix was so far detected in Arctic samples. While population change may happen on the long term, the reaction on increasing temperatures will depend on the yet

existing populations. In contrast to a consistent response to temperature, methanogenic populations and pathways were diverse.

3 CONCLUSIONS

The cold adaptation of Arctic communities does not exclude functioning up to 20°C and above. The extant populations in Arctic and Subarctic environments will be the main players in a warming environment, too, reacting sensitively even to a minor temperature increase.

Characterization of Permafrost Soils and Nitrifying Organisms on Island in the Lena River Delta, Siberia

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1 INTRODUCTION

Permafrost soils (Gelisols) cover about a quarter of the Earth's land surface. Gelisols are in subsoils continuously frozen throughout the year and only the active layers thaw during the short vegetation period. The main characteristic of these soils covered by polygonal carex-sedge tundra vegetation is the extreme soil moisture and temperature regime which ranges from -30°C to $+18^{\circ}\text{C}$. Element cycles like carbon (C) and nitrogen (N)-cycle, which are mostly driven by microorganisms, are influenced by these extreme environment parameters. In this study nitrification as one important part of the microbial controlled N-cycle, was investigated in typical wet arctic tundra sites of the Lena River Delta, Northeast Siberia, Russia. During nitrification ammonia is oxidized in two steps via nitrite to nitrate. These steps are catalyzed by two groups of organisms the ammonia and nitrite oxidizing bacteria (AOB and NOB). Recently it was shown that not only *Bacteria* but also *Archaea* of the group of *Crenarchaeota* (AOA) are able to oxidize ammonia to nitrite [1].

2 MATERIAL& METHODS

In this study different permafrost soils on the Island Samoylov in the Lena River Delta were analyzed: water saturated and organic rich soils of the polygonal tundra and dry sandy soils of the floodplain areas of the river Lena. Dissolved inorganic nitrogen (DIN, ammonia, nitrite and nitrate) were analyzed in different soil depths over the vegetation period, additionally potential nitrification rate were determined. For molecular biological analysis, DNA was extracted from each soil sample and DGGE and antibody methods were used.

3 RESULTS, DISCUSSION AND CONCLUSIONS

In soil samples from the river floodplain areas, characterized by neutral pH, high mineral content and aerobic conditions due to low water content, higher potential nitrification activities were found than in the water saturated peaty soils. In order to differenti-

ate *Bacteria* and *Archaea* ammonia oxidizing activities different antibiotics were tested. Only in soil samples taken from the beach, AOA activities dominated (Table 1). Via the functional gene of ammonia oxidation, the *amoA* (A subunit of ammonia monooxygenase), AOB are verifiable in nearly all soils of the Island Samoylov with exception of the water saturated peaty soils of the polygon center. In contrast AOA are only verifiable in the dry sandy soils of floodplain areas.

Table 1. Potential ammonia oxidation of *Bacteria* and *Archaea* (ng N-nitrite/g dry weight and hour), detection of *amoA* gene of *Bacteria* and *Archaea* per soil profile.

Site ID	Depth [cm]	AOB Activity	AOA Activity	Amo A Bacteria	Amo A Archaea	
Polygon rim	0 - 5	0	0	+	-	
	5 - 15	114	0	+	-	
	15 - 25	0	0	+	-	
Polygon center	0 - 5	33	0	-	-	
	5 - 15	0	0	-	-	
	15 - 25	0	0	-	-	
River terrace	0 - 5	103	0	+	+	
	5 - 15	78	3	+	+	
	150	197	0	+	-	
Cliff	250	571	0	nd	nd	
	Beach	0 - 5	186	356	+	+
		10 - 20	102	0	nd	nd
Floodplain	0 - 5	208	6	+	+	
	5 - 15	225	2	+	+	

In all investigated enrichment cultures of the soil samples the genus *Nitrosospira* (AOB) was detected using DGGE and polyclonal antibodies.

[1] Könneke et al. **2005**, Nature 437(22): 543-546

Peatland Exchanges of CO₂ and CH₄ - the Importance of Presence or Absence of Permafrost

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1 PERMAFROST AND THE CARBON CYCLE

Permafrost areas in the circumpolar North are estimated to hold more than 1600 Gt of organic carbon including almost 300 Gt in the form of peat most of which has accumulated since the last glacial maximum. In terms of atmospheric exchange of carbon, in the form of CO₂ and CH₄, the potential for additional releases are probably greater from these areas than anywhere else in the world. While the potential release from the huge stocks of carbon is significant, the actual data and year-round monitoring of atmospheric exchanges remain rare, and continuous flux measurements of CO₂ are limited to a handful of sites. Continuous monitoring of CH₄ fluxes is even rarer; the number of operational sites is less than five. Our empirically based understanding of what permafrost does to the dynamics and interannual variability in atmospheric (and dissolved run-off) fluxes of organic carbon is therefore still very poor. The longer-term dynamics on decadal to centennial timescales are even less well understood.

2 CARBON DYNAMICS

The interannual and across-site variability of CO₂ exchange in continuous permafrost ecosystems are driven primarily by growing-season dynamics and moisture conditions. Growing-season rates of CO₂ uptake by these ecosystems have been shown in several studies to be closely related to the timing of snow melt, with earlier snowmelt resulting in greater uptake of atmospheric CO₂. The annual C budget is not only controlled by growing-season exchange, but to a large extent by the losses during the shoulder (snow melt/soil thaw and senescence/soil freeze) and winter seasons. These more complex impacts on the annual budgets become more important outside permafrost regions, where warmer shoulder-season conditions prevail.

In northern Sweden we have documented changes in permafrost dynamics and effects on ecosystems and their feedbacks on climate in terms of methane emissions and in relation to catchment scale greenhouse gas exchanges (Christensen *et al.*, 2007). Here the thawing permafrost generally leads to wetter hydrological conditions and subsequently greater emissions at the landscape scale. The seasonal and inter-annual pattern at the subarctic site is predictable and

the emissions are stable from year to year. In contrast we observed some surprising autumn emission dynamics at our high-arctic measurement site in NE Greenland. These findings (Mastepanov *et al.*, 2008) show a second seasonal peak of emissions during the freeze-in. This distinct feature has been not previously observed, most likely because earlier flux studies in continuous permafrost regions have not extended into the frozen season. After further investigation in collaboration with atmospheric scientists, we have reached the preliminary conclusion that it may be a general feature of permafrost areas. This phenomenon helps to explain the observed seasonal dynamics in atmospheric methane concentrations during the autumn (Mastepanov *et al.*, 2008).

3 RECORDS OF CHANGES IN PERMAFROST

Longer records of peatland permafrost are available from the geographical margins of the permafrost zone. For example, in Abisko, northern Sweden permafrost has been monitored for decades. Here, the surface active layer has become thicker over the last three decades. In nine mires along a 100 km long transect the trend has been similar and in some mires the permafrost has even disappeared completely. This trend is also reflected in larger scale modeling of permafrost (palsa) peatlands in northern Scandinavia and from observations in North America. This prevalent trend towards transformation of permafrost landscapes calls for an understanding of ecosystem fluxes both where the permafrost is still present and where it has disappeared. This presentation will review the present state of understanding ecosystem-atmosphere fluxes in complex terrain influenced by the presence/absence of permafrost.

References

- Christensen, T.R., T. Johansson, M. Olsrud, L. Ström, A. Lindroth, M. Mastepanov, N. Malmer, T. Friberg, P. Crill & T.V. Callaghan (2007) A catchment-scale carbon and greenhouse gas budget of a subarctic landscape. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **365**, 1643-1656.
- Mastepanov, M., C. Sigsgaard, E.J. Dlugokencky, S. Houweling, L. Strom, M.P. Tamstorf, & T.R. Christensen (2008) Large tundra methane burst during onset of freezing. *Nature*, **456**, 628-U58.

Eight Years of Micrometeorological Land-Atmosphere Carbon Flux Measurements at a Northern Siberian Polygonal Tundra Site

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1 INTRODUCTION

High latitude ecosystems characterized by permafrost play an especially important role in the global climate system in general, and in the dynamics of relevant greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) in particular. They cover $\sim 25\%$ of the Northern Hemisphere's land surface and are estimated to contain ~ 1700 Gt of organic carbon while warming much faster than the global average. Due to their vastness and relative inaccessibility, current understanding of their CO_2 and CH_4 dynamics is based on an extremely limited dataset, mostly from very small-scale point measurements using closed-chamber techniques. Yet carbon fluxes are highly variable in space and time, which is especially valid for permafrost ecosystems characterized by strong small-scale heterogeneity. Very few studies in the Arctic provide integrated measurements over larger areas using the micrometeorological eddy covariance method. We have measured fluxes of CO_2 and CH_4 by eddy covariance from wet polygonal tundra in Northern Siberia during different periods since 2002.

2 MATERIAL AND METHODS

The study site is located at the Russian-German research station Samoylov Island in the Lena River Delta in Northern Siberia ($72^\circ 22'$ N, $126^\circ 30'$ E). The area is characterized by a polar and continental climate, very cold and ice-rich permafrost, and its position at the interface between the Eurasian continent and the Arctic Ocean. The soils are characterized by high organic matter content, low nutrient availability and water logging in low center polygons. The vegetation is dominated by sedges and mosses. Flux measurements started in 2002 and covered various parts of the following growing seasons. One "synthetic" growing season consisted of the periods July–October 2003 and May–July 2004 (Kutzbach et al., 2007) and a full growing season from June–September was covered in 2006 (Sachs et al., 2008). In 2005 and 2009, measurements were made

in July and August, while in 2007 and 2008 only CO_2 fluxes are available.

The eddy covariance system was set up in the center of the eastern part of Samoylov Island. The concentration of H_2O and CO_2 were measured with a closed-path infrared gas analyzer (LI-7000, LI-COR Inc., USA), and the concentration of CH_4 was measured with a tunable diode laser spectrometer (TGA 100, Campbell Scientific Ltd., USA).

3 RESULTS

The main carbon exchange processes - gross photosynthesis (GPP), ecosystem respiration (R_{eco}), and CH_4 emissions (F_{CH_4}) - were of low intensity and interannual variation (table 1). Day-to-day variations of photosynthesis were mainly controlled by radiation and hence by the synoptic weather conditions. Variations of ecosystem respiration were best explained by an exponential function of surface temperature, indicating the major role plant respiration plays within the tundra carbon balance.

Methane emissions were controlled by soil temperature and near-surface atmospheric turbulence. The strong influence of turbulence was attributed to high coverage of open water surfaces in the tundra. Total growing season CH_4 emissions were about 2 g m^{-2} . In 2003/2004 winter fluxes were estimated and accounted for 14 % of the annual ecosystem carbon balance. Considering the global warming potential of CH_4 the tundra was a greenhouse gas source.

Table 1. Seasonal R_{eco} , GPP , net ecosystem exchange (NEE), and CH_4 flux F_{CH_4} . All fluxes are given in g m^{-2} .

Growing season	R_{eco}	GPP	NEE	F_{CH_4}
2003/2004	327	-432	-105	2
2006	364	-471	-102	2

References

- Kutzbach, Lars et al. 2007. The exchange of carbon dioxide between wet arctic tundra and the atmosphere at the Lena River Delta, Northern Siberia. *BG* 4: 869-890.
- Sachs, Torsten et al. 2008. Environmental controls on ecosystem-scale CH_4 emission from polygonal tundra in the Lena River Delta, Siberia. *J. Geophys. Res.* 113 (G00A03).

Tundra Methane and CO₂ Bursts during Onset of Freezing: Does the Permafrost Matter?

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1 INTRODUCTION

The phenomenon of large tundra methane burst during onset of freezing was discovered during 2007 extended monitoring season in Zackenberg valley, NE Greenland (Mastepanov et al., *Nature*, 2008). Unnoticed before, this effect was found to double the annual methane flux from high arctic wet ecosystems. We hypothesize that the main mechanism of this burst is a physical squeezing out of the entrapped gas, remaining after growing season in active layer, due to gradual ice formation from the surface and rising pressure in the active layer. The permafrost “bottom” should be essential for this process, and some limitations to active layer thickness should apply.

However, another hypothesis was raised in the microbiological community, arguing that the late-season methane burst has a biological origin – deactivation of methanotrophic “filter” by low surface temperatures over continuing methanogenesis at lower horizons. This hypothesis does not imply any role of permafrost in the process, so according to it the late season methane burst can occur in any seasonally-freezing wetland.

Does the permafrost matter? Which mechanism is prevailing? Depending on the answer, the potential of the late-season methane emission for the global atmospheric budget may be estimated very differently.

2 METHODS

The study was carried on at two sites in Greenland:

1) Fen area of Zackenberg valley (74°28'N 20°34'W), North Eastern Greenland;

2) Fen area of Kobbefjord (64°07'N 51°23'W), South Western Greenland.

At each site CH₄ and CO₂ fluxes were monitored by 6 automatic chambers, giving 24 measurements per

day each. The active layer thickness, water table level and soil temperatures were logged as well.

3 RESULTS

The late season methane burst, first discovered at Zackenberg in 2007, was followed by CO₂ burst. Surprisingly, none of those were detected in 2008. In 2009 some high late season fluxes of both CH₄ and CO₂, were found again, however this was just for a few days before the end of the measurement campaign. Detailed data analysis show that every single episode of high methane emission during October-November was accompanied by a synchronous CO₂ emission.

CH₄/CO₂ ratio was changing over time, from higher CH₄ in the beginning of active layer freezing towards higher CO₂ in the end. Emission patterns, correlations with soil freezing and characteristics of CH₄/CO₂ ratio are all supporting the hypothesis of physical mechanism for late-season burst.

The same monitoring setup in Kobbefjord did not register any freezing-time CH₄ or CO₂ burst. The environmental conditions at the two sites were more or less comparable, except one important difference – the Kobbefjord fen had no permafrost underneath.

References

Mastepanov, M., C.Sigsgaard, E.J.Dlugokencky, S.Houweling, L.Strom, M.P.Tamstorf & T.R.Christensen (2008) Large tundra methane burst during onset of freezing. *Nature*, 456(7222): 628-U58

Permafrost Thawing and Long Term Greenhouse Gas Production Rates in Northeast Greenland

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1 INTRODUCTION

The part of the soil that thaws in the summer, the active layer, has become about 10 cm thicker the last decade in Zackenberg in Northeast Greenland (74°N). Consequently, the top permafrost has been thawing. Depending of the top permafrost characteristics, this will influence the water balance, the element cycling and not the least the net release of greenhouse gas to the atmosphere. The first permafrost samples from pits in Zackenberg were collected in 1996 and have been incubated at 7°C since. Based on regular measurements of carbon dioxide (CO₂) production rates (basal soil respiration rates), information about the long term effect of thawing permafrost on greenhouse gas production is now available. The spatial variation of the top permafrost characteristics in terms of carbon dioxide, methane and nitrous oxide production rates from two contrasting sites provides further insight into processes controlling subsurface greenhouse production following permafrost thawing. Finally, potential CO₂ production in relation to future thawing permafrost layers has been compared to current CO₂ effluxes.

2 RESULTS

2.1 *Permafrost characteristics*

Results from Zackenberg suggest that top permafrost characteristics cannot be predicted based on nowadays vegetation cover and that top permafrost layers typically have a greater potential release of carbon dioxide, methane and nitrous oxide production rates than bottom layers of the active layer (Elberling *et al.*, 2008; 2010). In some profiles at Zackenberg, the net production of greenhouse gasses, measured as CO₂ equivalent, from thawing top permafrost samples is higher than the top of the active layer. This is line with the burial of reactive organic matter as well as higher concentrations of total dissolved C and N in thawing permafrost layers.

2.2 *Long term incubation*

The long term incubation experiment indicates that the release of CO₂ from newly exposed permafrost layers can be expected to continue for decades after a burst as a result of initial thawing. After more than

14 years of incubation, some permafrost samples are producing CO₂ at rates similar to 15% of initial rates.

2.3 *Future CO₂ production from thawing permafrost layers*

Simulations based on future climate conditions in the Zackenberg area suggest a minimum additional thawing of 20-30 cm within the next 70-100 years for a typical tundra site. Simulated future soil temperatures and water contents are subsequently used in a respiration model to predict the corresponding depth-integrated CO₂ production from layers between 0.7 and 2 m below the surface. Results show an increase from present values of 40 gC m⁻² y⁻¹ to between 120 and 213 gC m⁻² y⁻¹ depending on the magnitude of predicted warming. These rates are about 50% of nowadays soil CO₂ efflux measured at the soil surface.

3 CONCLUSIONS AND FUTURE WORK

This study highlights the importance of top permafrost characteristics in future assessment of greenhouse gas budgets for arctic tundra ecosystems. Future modelling needs to account for snow, the overall water balance, shift in redox, vegetation and internal biological heat feedbacks to describe the entire ecosystem response.

ACKNOWLEDGEMENT

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References

- Elberling, B., Christiansen, H.H. & Hansen, B.U. (2010). High nitrous oxide production from thawing permafrost. *Nature Geoscience* (in press).
- Elberling, B., Nordstrøm C., Grøndahl, L., Søgaard, H., Friberg, T., Christensen, T.R., Stroem, L., Marchand, F. & Nijs, I. (2008) High Arctic Soil CO₂ and CH₄ Production Controlled by Temperature, Water, Freezing, and Snow. *Advances in Ecological Research* 40, 441-472.

Sensitivity of 21st Century High-Latitude CO₂ and CH₄ Balance to Frozen Soil Carbon Processes

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1 INTRODUCTION

Permafrost soils contain an enormous quantity of organic carbon, which has the potential to act as a positive feedback to global climate change due to enhanced respiration rates with warming. Here we report model-derived future greenhouse gas emissions resulting from anthropogenic climate change over the 21st century. We have added several processes — the effect of soil freezing on soil carbon decomposition rates (Khvorostyanov et al., 2008), insulation by soil organic material, vertical mixing of soil C by cryoturbation into permafrost layers (Koven et al., 2009), and microbial heat release during decomposition (Khvorostyanov et al., 2008) — to the ORCHIDEE terrestrial carbon cycle model to simulated soil processes relevant to the carbon cycle of permafrost regions.

2 RESULTS

We show that including insulation by soil organic material and vertical mixing of soil C by cryoturbation into permafrost layers together leads to up to 30% higher soil carbon stocks in the top meter of permafrost soils compared to a model version without these two specific processes, as well as large stocks of carbon below 1m in the upper permafrost soil layers. The vertical profile of partitioning of carbon between different lability pools is also affected, as the slower pools are more deeply mixed; also the time to reach equilibrium lengthens considerably. These effects are largest in the coldest regions such as Eastern Siberia. The inclusion of cryoturbative mixing and insulation by soil carbon leads to better agreement with estimates of

high-latitude soil carbon stocks, where substantial amounts of carbon are found in permafrost regions, to depths of three meters; however we do not include peat, Yedoma, or alluvial deposition processes here, so the total carbon stocks are still lower than observed.

Our results show that the addition of these soil processes changes the net carbon balance of terrestrial ecosystems north of 60°N due to warming during the 21st century from a net sink of 19 Pg C, which is in the central range of previous global carbon cycle model estimates (e.g. C⁴MIP), to a source in the range of 20 to 95 Pg C, depending on the specific processes included in the model. However, this CO₂ source resulting from warming is offset in the model in all but the final case due to increased carbon storage with CO₂ fertilization. Conversely, CH₄ emissions increase from ~40 Tg CH₄/yr to ~100 Tg CH₄/yr due to increasing CO₂ concentration but decrease to ~40 Tg CH₄/yr with warming due to drying and depletion of the carbon stock used as methanogenesis substrate, except in the extreme heating case in which thawing of deep permafrost deposits lead to large CH₄ emissions of ~90 Tg CH₄/yr.

References

- Khvorostyanov, D., G. Krinner, P. Ciais, M. Heimann, and S.A. Zimov, 2008. Vulnerability of permafrost carbon to global warming. Part I. Model description and role of heat generated by organic matter decomposition. *Tellus*, 60: 250-264.
- Koven, C., P. Friedlingstein, P. Ciais, D. Khvorostyanov, G. Krinner, and C. Tarnocai, 2009. The effects of cryoturbation and insulation by organic matter on the formation of high-latitude soil carbon stocks in a land surface model. *Geophys. Res. Lett.*, 36: L21501.

**Wednesday
13:00-15:00**

ORAL Parallel Session

Circumpolar Arctic and Antarctic Active Layer Monitoring

Co-chairs: Antoni Lewkowicz & Margareta Johansson

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The Circumpolar Active Layer Monitoring Program (CALM III): Long-Term Observations on the Climate-Active Layer-Permafrost System

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In August 2009 the National Science Foundation announced that it will fund a third five-year block of support for the Circumpolar Active Layer Monitoring (CALM) program, under the aegis of its "Arctic Observing Networks" (AON) administrative program.

CALM was established in the early 1990s to observe and document the temporal and geographic variability of active-layer thickness, active layer dynamics, near-surface permafrost characteristics, and the response of these factors to variations and trends in climatic conditions (Brown et al., 2000; Nelson et al., 2008). The CALM program involves 15 participating countries and approximately 175 sites distributed throughout the Arctic, parts of Antarctica, and several mountain ranges in the mid-latitudes. Groups of sites are used to develop regional maps of active-layer thickness. Data obtained from the CALM network are used to validate permafrost, hydrological, ecological, and climatic models, at a variety of geographic scales. In recent years considerable emphasis has been placed on obtaining records of frost heave and thaw subsidence from sites with ice-rich substrates. These observations are contributing to a reconceptualization of the role of the active layer in global-change studies.

CALM is, in the first instance, a global-change program. Its change-detection function remains a critically important part of its mission and CALM III continues to be concerned with observing the response of the active layer and near-surface permafrost to climate change at multi-decade time scales. CALM III and its companion borehole temperature program, *Thermal State of Permafrost*, are closely coordinated international observational networks devoted to permafrost (together, they comprise the Global Terrestrial Network-Permafrost, or GTN-P). The present active-layer network represents the only coordinated and standardized program of observations designed to observe and detect decadal changes in the dynamics of seasonal thawing and freezing in high-latitude soils. As part of this charge, the program is also concerned with differentiating between the impacts of long-term climate change and more localized anthropogenic effects. CALM III will con-

tinue existing partnerships and collaborations with other international organizations and programs. CALM II made significant contributions to International Polar Year 2007-08 in close collaboration with the *Thermal State of Permafrost* IPY project.

Reflecting its open, community-based structure, CALM III will hold annual meetings and roundtable discussions in connection with major scientific conferences. Educational and outreach activities are an integral part of the CALM III strategy. The project provides opportunities for field experience and educational participation at levels ranging from elementary school through postdoctoral studies. The circumpolar nature of the CALM network fosters extensive international collaboration between students involved in project activities. An outreach component of the project includes extensive involvement of local, predominantly indigenous population in observational program at remote Arctic sites. CALM will continue to incorporate data into its web-accessible database from existing and new sites. The program will maintain existing collaborative relationships and develop new ones with international observational networks and research programs. Further information about the CALM III program can be found at www.udel.edu/Geography/calm.

References

- Brown, J., Hinkel, K.M., & Nelson, F.E. 2000, The Circumpolar Active Layer Monitoring (CALM) program: historical perspectives and initial results. *Polar Geography* 24(3): 165-258.
- Nelson, F. E., Shiklomanov, N. I., Hinkel, K. M., & Brown, J. 2008. Decadal results from the Circumpolar Active Layer Monitoring (CALM) program. In: Kane, D.L. and Hinkel, K.M. (eds.). *Proceedings of the Ninth International Conference on Permafrost*. Fairbanks: University of Alaska Press, 1273-1280.

Spatial Distribution of the Active Layer Depth along the Yamal Transect

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1 INTRODUCTION

Five research polygons along the transect «Yamal» were under study in 2007-2009 (Fig. 1). Standard plots characterized by relief, lithology, surface properties and cryogenic processes were equipped for measurement of ground temperature and depth of seasonal thaw. The zonal pattern in the spatial distribution of various parameters of cryolithozone was analyzed using advantages provided by “transect” approach.

2 GROUND TEMPERATURE

Mean annual ground temperature at the active layer base is monitored at the Transect. It differs from that at the depth of zero annual amplitude by several points and can be considered representative in analysis of the zonal pattern. It follows zonal pattern when compared within similar landscape conditions. As a rule, on sandy plots temperature is lower, than on clayey ones. The reason lies in the specific geological construction of Yamal where hilltops are covered by sand and subject to wind action blowing snow away.

Snow is the main factor affecting ground temperature. That is why even within one subzone ground temperature range within a very wide interval. On leeward slopes, narrow valleys and concavities where snow accumulates, ground temperature may be 3-6°C higher compared to hilltops and windward convex slopes lacking snow in winter.

3 ACTIVE LAYER DEPTH

The basic well-known regularity of thaw depth is traced in all bioclimatic subzones: thaw depth in sandy environments essentially exceeds thaw depth in clay and peat. Average thaw depth on clayey plots decrease from south northward. On sandy plots this regularity is not that clearly traced. Discrepancy is noted on the sandy plots on low flat, and thus poorly drained, highly vegetated surfaces of sandy alluvial terraces. Active layer depth at such surfaces is less than expected zonal thaw.

Vegetation cover and lithology are the main factors affecting active layer depth. In peat and heavily vegetated clayey environments in the lake depressions and valley bottoms, active layer can be 2-3 times less (40-60 cm) than on sandy well drained hilltops and convex slopes (100-120 cm and more).



Figure 1. Yamal transect polygons.

4 CONCLUSIONS

It is established that, on the whole, consistent trend of bioclimatic subzones northward determines the consecutive change of various parameters of permafrost. However, local factors connected to relief, drainage degree, location of plots on different landforms, which determine snow accumulation and vegetation mat thickness, distort zonal pattern.

The zonal changes in the depth of thaw and ground temperature from south northward in similar landscape conditions are determined by the lower air temperature and reduction of vegetation mat in this direction.

Environments with lower ground temperature are characterized by higher active layer depth and vice-versa.

Correlation between Active Layer Depth and Vegetation Parameters at Vaskiny Dachi, Central Yamal, Russia

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1 INTRODUCTION

Active layer depth and vegetation indices (NDVI, LAI) were measured and correlated at Vaskiny Dachi polygon located on Central Yamal. NDVI and LAI could be used for analysis of relationship between vegetation cover and active layer depth because they quantitatively characterise vegetation cover affecting active layer depth.

Active layer depth was monitored according to the procedures accepted by the CALM program (Brown et al. 2000). Data of 2007 were used for correlation. The normalized difference vegetation index (NDVI) and the leaf area index (LAI) were measured at each grid point of a 100 x 100-m CALM grid in mid-August 2007. Active layer depths varied between 69 and 135 cm. The NDVI varied from 0,2 to 0,84, and LAI varied from 0 to 5,5.

2 METHODS

Active layer depth data were grouped into 3 categories: shallow, average and deep active layer. The average active layer depth and average value of vegetation indices for each group were calculated. As expected, the average values of active layer depth have an inverse relationship with average values of the vegetation indices because, as a rule, the higher vegetation indices are associated with higher insulating features of the vegetation. Then, to define degree of effect of different vegetation formations, vegetation indices, and formation parameters (height/thickness and coverage) were linearly correlated, for example, NDVI with moss coverage or LAI with shrub height.

3 RESULTS AND DISCUSSION

NDVI is directly related to moss parameters and sedge coverage; inversely related to shrub parameters and height of grass and sedge; there is almost non-pronounced relation to grass and lichen coverage. LAI is directly related to grass, shrub and sedge parameters; the inverse relation to lichen cov-

erage is observed, and almost non-pronounced relation to moss parameters.

The same formation parameters were correlated with active layer depth. Moss parameters were inversely correlated to active layer depth. On undisturbed wet slopes, moss cover is well-developed, and on slopes disturbed by cryogenic landsliding, dead moss and pioneering species were abundant. Shrub heights are directly correlated with active layer depth, probably indicating that the warmer soils are contributing to increased biomass production and thus shallower active layer. Very different shrub regimes occur on convex vs. concave landslide slopes. The tallest shrubs are linked to convex landslide bodies with disturbed ground cover; whereas densest shrub cover is characteristic of concave slopes with thick moss cover. Grasses are associated with areas of deeper thaw because grass cover is best developed on sandy hill tops with deep active layer and on landslide shear surfaces where grasses form pioneer plant communities. Sedge height was not significantly correlated to active layer depth, but sedge cover was inversely correlated to active layer depth because as a rule sedges occur in combination with moss cover. Lichen cover was directly correlated to active layer depth because lichens occur on sandy hill tops with deep active layer.

4 CONCLUSIONS

The inverse relationship between active layer depth and NDVI depends most strongly on moss thickness and coverage, grass height and coverage, and shrub and sedge height. Shrub, sedge and lichen coverage slightly distorts this relation. The fact that average values of active layer depth have the inverse relation to average values of LAI means that shrubs and lichens are more important factors controlling relation between active layer depth and LAI.

References

- Brown J., Hinkel K.M., Nelson F.E. 2000 The Circumpolar active layer monitoring (CALM) program: research designs and initial results // *Polar Geography* 24(3): 165-258.

The Active Layer Monitoring and its Recent Changes in the Northern Qinghai-Xizang Plateau

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1 ABSTRACT

Recent changes of active layer thickness (ALT) along Qinghai-Xizang highway were analyzed based on the monitoring data of the ground temperatures (GT) in active layer on the Tibetan Plateau in last 10 years. The results showed that ALTs were increasing, and were mainly resulted by climate warming. The observation consequences indicated that ALTs were thicker and GTs of active layer is higher during 2006/2007. GTs of active layer in low-temperature permafrost regions raised more than high-temperature permafrost regions, and thus more sensitive to climate change. The positive accumulated air and soil temperatures increased, and the increasing rate was decreasing with the depth. The beginning date of freezing and thawing of active layer changed obviously. The average of the former moved up about 16 days in advance, and the latter postponed for 14 days averagely. The ending date of freezing period moves up for 6 days, and starting date of thawing postponed about 9 days.

Landscape-Scale Thaw Subsidence in Permafrost Terrain: Results from Field Observations near Barrow, Alaska

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Thaw penetration into an ice-rich layer at the base of the active layer is accompanied by loss of volume (thaw consolidation) and results in subsidence at the ground surface. Differential thaw settlement occurs annually in permafrost environments as the layer of annual thaw (the active layer) develops. At longer temporal scales, changes in near-surface ground ice concentrations occur within the “transition layer” that alternates in status between seasonally frozen ground and permafrost over sub-decadal to centennial time scales, in response to changes in downward heat flux due to variations in surface energy balance. Significant ice segregation can occur within the transition layer during “cold” periods, due predominantly to freezing from below during the autumn and winter. During most “warm” periods this ice-rich layer protects underlying permafrost from thawing, thereby imparting non-linearity to the response of the permafrost system to climatic forcing. Substantial thaw settlement has been observed at sites where the surface energy balance was altered by human activities, primarily through disturbance or removal of vegetation cover. We sought to determine whether widespread thaw subsidence, possibly attributable to climatic variability and change, are occurring in natural, undisturbed landscapes, and if so, to estimate its magnitude and evaluate its role in overall response of permafrost to atmospheric forcing.

Field investigations to track interannual vertical movements associated with formation and ablation of ice near the permafrost table were initiated in 2003. Measurements continue annually at several 10 m x 10 m plots, established in early 1960s as representative of different elements of the polygonized tundra landscape near the village of Barrow, Alaska. Observations were made at the end of the thawing season using Differential Global Positioning Systems (DGPS) technology. During the initial years of the program DGPS observations were validated with optical (theodolite) surveys. Monitoring of the vertical position of the ground surface was accompanied by thaw-depth measurements involving mechanical probing.

The sampled areas showed net subsidence of the ground surface over the period of observation, re-

ducing average surface elevation by 0.11 m. The amount of winter heave did not compensate for summer ground subsidence during the observation period, except in 2005 and 2008, when net annual heave occurred in response to reductions in the depth of thaw propagation. These decreases were attributable to lower summer air temperatures than in the other years of observation. The largest net annual subsidence (0.08 m) was achieved in 2004, and resulted from thaw penetration into ice-rich soil material in the transition layer during this unusually warm summer. To quantitatively evaluate the relationship between the vertical movement of the ground surface and atmospheric forcing, annual changes in the position of the ground surface were correlated with annual changes in cumulative degree days of thawing (DDT).

To evaluate the integrated thermal response of this permafrost landscape to climatic forcing, site-average annual thaw depth values were correlated with the square root of DDT, estimated from site-specific air temperature records and accumulated by the date of thaw depth and surface elevation measurements. Analysis was performed using both measured values of thaw depth and values corrected for changes in the vertical position of the ground surface. Incorporation of changes in surface elevation provided significant improvements in linear regressions of thaw depth on the thawing index. It also resulted in changes in the slope of the regression line, indicating higher overall sensitivity of permafrost landscapes to climatic forcing than has been reported previously.

The linear best-fit regression equation was used, in conjunction with the DDT record, to estimate the vertical position of the ground surface years prior to 2003, when DGPS surveys were initiated. Results indicate that over the 18 year period the elevation of the permafrost table has decreased by 0.33 m. Only 36% (0.12 m) of this change is attributable to increased active-layer thickness, while 64% (0.21m) is attributable to subsidence of the ground surface.

Determining Microclimatic Controls on the Ground Thermal Regime Through the Evaluation of n-Factors (Deception and Livingston Islands, South Shetlands, Antarctic)

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1 ABSTRACT

The evidence of climate change in Antarctic Peninsula is now well known although its impacts on permafrost, active layer thickness and soil thermal regime are scarcely understood. In periglacial environments, at a local scale, microclimatic factors such as snow, solar radiation, soil physical properties, moisture and vegetation determine the spatial distribution of permafrost.

The n-factor is the ratio between the seasonal degree-day sum of ground surface and air temperatures (Lunardini, 1978) and it is used to assess the degree of coupling between soil and atmosphere, with regard to heat exchange. By analysing the freezing indexes and n-factors during the cold season we can evaluate the influence of microclimatic variables on soil thermal regime, particularly snow cover, which is of especial significance in permafrost regions. The snow pack season, snow thickness and physical properties are crucial in determining the thermal characteristics and spatial distribution of permafrost. In the Antarctic Peninsula region the knowledge about permafrost and its climatic sensitivity is still scarce and with average annual air temperatures

ranging between -4 to -2°C, therefore close to the climatic threshold of permafrost, the study of freezing indexes in key locations will help understanding the influence of snow cover on soil thermal regime.

We present the preliminary results from data collected in Livingston and Deception Islands in the last Antarctic campaign (2009/2010) and the comparison with previous years. We analyse data from distinct locations with different geographical settings to determine the site-specific ground thermal regime controls. This evaluation contributes to the understanding the spatial variability of the ground thermal regime and for the development of spatial models on the distribution of permafrost.

References

- Karunaratne, K.C. & Burn, C.R. 2003. Freezing n-factors in discontinuous permafrost terrain, Takhini River, Yukon Territory, Canada. In: *Proceedings of the 8th International Conference on Permafrost*. Zurich: University of Zurich-Irchel: 519-524.
- Lunardini, V. J. 1978. Theory of N-factors. In *Third International Conference on Permafrost*, Edmonton, Canada. pp. 4046.

Active Layer Depth and Moisture Content in Soils of the McMurdo Sound Region of Antarctica

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1 INTRODUCTION

The dry valleys in the McMurdo Sound region of Antarctica are a unique environment. Improved understanding of soil moisture and temperature are important for; monitoring changes over time, predicting effects of global changes on the Antarctic soil environment, and understanding the relationships between soil conditions and microbial diversity.

A soil climate monitoring network comprising seven automated weather stations was established between 1999 and 2003 (Figure 1) giving data from a range of soil environments in the McMurdo Sound Region.

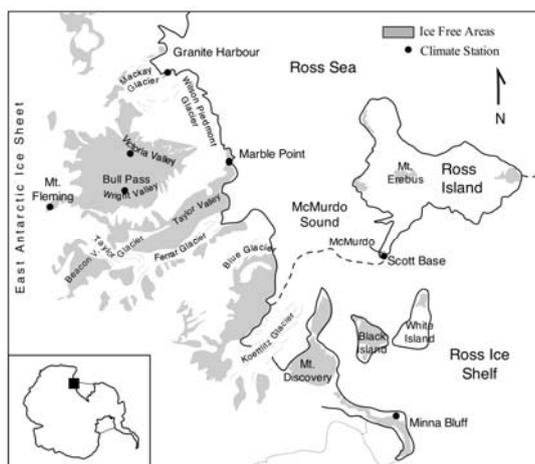


Figure 1. Location of soil climate monitoring stations in the McMurdo Sound region of Antarctica.

2 DATA COLLECTION

At each site, atmospheric and below-ground measurements, extending from the active layer into permafrost, were recorded hourly with a CR10X or CR1000 data logger (Campbell Scientific). Atmospheric measurements include air temperature, relative humidity, solar radiation, and wind speed and direction. Soil measurements include soil temperature and moisture in the active layer. Below ground sensors used include multiple thermistor temperature probes (Measurement Research Corporation), single thermistor temperature sensors (Campbell 107), and moisture probes (Stevens Hydra-probe type A) installed at depths from 2 cm to 1.2 m. Detailed descriptions are included in Adlam et al., 2010.

3 RESULTS

There are now 10 years of climate data from Marble Point, Scott Base, Wright Valley, and Victoria Valley; with seven years from Mount Fleming, and six years from Minna Bluff and Granite Harbour. Soil climate data and metadata are available on-line at <http://soils.usda.gov/survey/scan/antarctica/index.html>

Active layer depth, and duration of temperatures above 0°C, and hence potential liquid moisture availability, varied markedly between sites and seasons (Table 1). Mean volumetric moisture contents were lowest at Victoria and Wright Valleys (< 5%) and greatest at Granite Harbour (2-32%).

Table 1. Mean active layer depths and range of duration of temperatures >0°C within the top few cm* of soil for Antarctic soil-climate station sites.

Site	Active layer depth (cm)		Duration Temp > 0°C	
	Mean	Std dev	Range (hours/year)	
Marble Point	49	9	168-1656 (0-20)*	
Scott Base	32	6	0-1502 (0-25)	
Mt Fleming	6	2	0-115 (0-7)	
Wright Valley	46	7	1195-1858 (0-20)	
Minna Bluff	22	0.5	341-1103 (0-20)	
Granite Harbour	>90	-	1526-2112 (0-25)	
Victoria Valley	21	4	899-1756 (0-10)	

*Depth range in cm given in brackets

4 CONCLUSIONS

We are beginning to build a valuable data-base with up to 10 years of climate and soils information. There is marked variation in active layer depth between seasons and locations. Liquid moisture is only available for a limited time in most of these sites, due to cold temperatures and desert conditions.

References

- Adlam, L.S., M.R. Balks, C.A.Seybold, D.I.Campbell 2010. Temporal and spatial variation in active layer depth in the McMurdo sound Region, Antarctica. *Antarctic Science* 22(1): 45-52.

Active Layer and Air Temperature 1999 – 2009 in the Longyearbyen Area, Svalbard

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INTRODUCTION

Observations of active layer and air temperatures close to the ground surface, now is part of the Nordenskiöldslund Permafrost Observatory (Christiansen et al., in press), were started already in 1999. Air and active layer temperature recording have taken place at different periglacial landforms in the Longyearbyen area since 1999 located in a maritime high arctic climate. Data are collected at different heights above sea level. The monitoring was designed to improve the understanding of the interaction of atmosphere and ground surface/active layer thermal conditions in different landforms. Such knowledge is important as background for detailed modeling of the reaction of the different periglacial landforms to changes in air temperature, amount and timing of precipitation, and in wind speed and direction.

SVALBARD METEOROLOGY

The special characteristic of the geography of Svalbard is the combined maritime and high arctic setting. In addition one of the longest high arctic meteorological records (from 1912) is available. Within the last 10 years, with the operation of the University Centre in Svalbard, we have been able to use this unique climatic setting to collect temperatures from different parts of the Svalbard landscape, to improve the understanding of the sensitivity of the landscape and permafrost, with respect to climate change.

METHODS

Gemini Tinytag miniature temperature dataloggers of different types with external sensors have been used to establish more than 30 sites recording either 20-25 cm above ground, at the ground surface and/or in different depths in the active layer, all with an hourly recording frequency. Data have been downloaded at minimum annually. The study sites represent different landforms and heights above sea level. All data is included in the NORPERM database (Juliussen et al. submitted).

RESULTS

The maritime setting causes a relatively small annual air temperature amplitudes, but with significant interannual winter variation, and with relatively constant summer temperatures throughout the 1999 to 2009 period (Fig. 1). Particularly following the winter 2003-04 the active layer winter temperatures have warmed step like (Fig. 1), and the thickest active layers have occurred during the last 3 years. The active layer thickness in the UNISCALM site (Christiansen & Humlum, 2008) varied between 74 cm in 2005 and 110 cm in 2008. Because of the generally shallow snow pack, the air and ground temperatures correlate well, although less so in snow-patch sites. Snow distribution is recorded in several parts of the study area by continuous daily automatic digital photography.

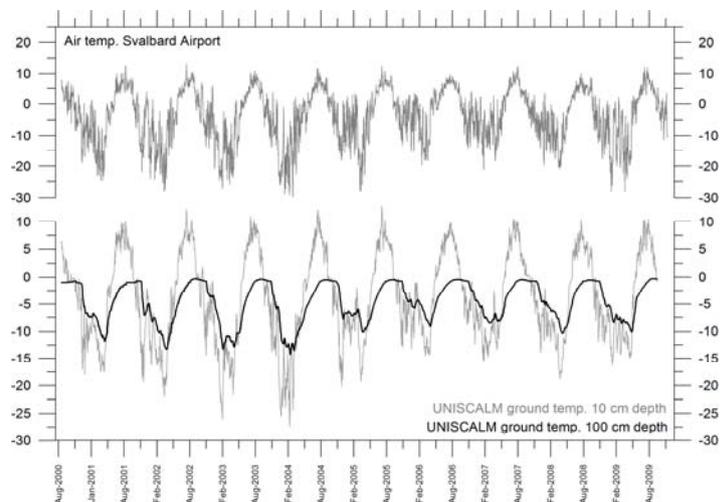


Figure 1. Air temperature at the official Svalbard Airport meteorological station (28 m asl) and UNISCALM ground temperatures in Advendalen 10 m asl, 1999-2009.

References

- Christiansen, H.H. & Humlum, O. 2008. Interannual Variations in Active Layer Thickness in Svalbard. In Kane, D.L. & Hinkel, K.M (eds.) Ninth International Conference on Permafrost Proceedings, Institute of Northern Engineering, University of Alaska, Fairbanks, USA, 257-262.
- Juliussen, H, Christiansen, H.H., Strand, G., Iversen, S., Midttømme, K. & Rønning, J.S. submitted. NORPERM: The Norwegian Permafrost Database – an important IPY TSP NORWAY legacy. Earth System Science Data.

**Wednesday
13:00-15:00**

ORAL Parallel Session

Geophysical Monitoring in Permafrost Regions

Co-chairs: Sharon Smith & Christian Hauck

In Møysalen

High-Resolution Electrical Resistivity Monitoring for Improved Process Analysis of Permafrost Evolution – A One-Year Time Series from Schilthorn, Swiss Alps

C. Hilbich^{1,2}, C. Hauck³ & C. Fuss⁴

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1 INTRODUCTION

Determining the subsurface ice and unfrozen water content in cold regions are important tasks in all kind of cryospheric studies, but especially on perennial (permafrost) or seasonal frozen ground, where little insights can be gained from direct observations at the surface. In the absence of boreholes, geophysical methods are often the only possibility to visualise and quantify the subsurface characteristics. Their successful applications in recent years lead to more and more sophisticated approaches including 2- and 3-D monitoring and even quantifying the ice and unfrozen water content evolution within the subsurface.

Due to the strong sensitivity of electrical resistivity to the phase change between unfrozen water and ice, the application of Electrical Resistivity Tomography (ERT) has been especially successful. This is supported by its comparatively easy and fast data processing, its robustness against ambient noise and its good performance even in harsh, cold and heterogeneous environments. Numerous recent studies have shown that ERT is principally suitable to spatially delineate ground ice, differentiate between ice-poor and ice-rich occurrences, and to monitor freezing, thawing and infiltration processes. However, resistivity surveys have still to be made manually, which poses large constraints concerning the comparability of measurements at specific time instances, e.g. the choice of the date for end-of-summer measurements, and/or the possibility for measurements during winter, when many locations are inaccessible. Furthermore, many climate studies require the analysis of statistically meaningful properties, such as maximum/minimum values and monthly or annual mean values, which cannot be determined using temporally sparse and irregularly spaced measurements.

2 AUTOMATED ERT MONITORING SYSTEM

As a new system for automated measurements with regular time interval, an automated ERT monitoring system for the use in cryospheric environments was recently developed in co-operation with the geophysical company Geolog (Starnberg, Germany).

The system is based on an existing multi-electrode resistivity instrument (Geotom) with up to 100 electrodes, a solar panel driven battery and wireless data transfer to a base station. A first prototype version of the system has been installed at Schilthorn (2970 m), a high-altitude permafrost site within the Swiss permafrost monitoring network PERMOS.

3 DATA SET

Starting in April 2009 a one-year time series of daily Wenner measurements of a 2 m spaced array of 30 electrodes is now available to investigate spatio-temporal resistivity changes. Apart from several data gaps caused by power failure due to lightning the system is running stable.

According to the large number of data, measurement errors had to be removed with a de-spiking filter prior to data analysis. After filtering of the raw data the time series was analysed concerning mean values and changes in 1D measured apparent resistivities as well as changes in the 2-D distribution of specific resistivities in the inverted tomograms. Additional data recorded at the Schilthorn site (borehole temperatures, soil moisture) were used to evaluate the significance of the ERT time series for the estimation of changes in ice and water contents in the subsurface.

4 FIRST RESULTS

First results show reproducible 2-D resistivity tomograms with small temporal changes during periods with snow cover, medium changes in summer and largest changes during snow melt in early summer and freezing in autumn. Temporal changes of the apparent resistivities are in phase with the change in near-surface soil moisture and subsurface temperature indicating the respective contributions of temperature changes and infiltration during the snow melt period to the thawing of the active layer. Singular events e.g. infiltration after heavy rain can be easily distinguished from freeze and thaw processes in the subsurface.

Near Surface Temperature Observations in the Russian Altay Mountains – Microclimatological and Surface Cover Effects and Their Impact on the Thermal Regime

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1 INTRODUCTION

1.1 General

Permafrost is widely spread in the Russian Altay Mountains with altitudinal ranges of 1800-2000m for the sporadic-patchy zone and above 2000m for the discontinuous-continuous permafrost zone. As different models report stronger permafrost degradation in those continental mountainous areas, temperature measurements are required to verify these statements.

Furthermore, typical for the Altay Mountains, permafrost degradation would lead to a loss of important cultural heritage, as several ancient Scythian burials are found in the area. Often these graves were found frozen, thanks to both the permafrost preservation, as their coarse blocks surface cover.

To model the thermal state of these graves (or kurgans in Russian) and make future predictions about their behavior towards a changing climate, at first the current permafrost distribution and thermal state of the permafrost in the Altay Mountains has to be examined

1.2 Study Area

An appropriate and accessible study area was found in and around the valleys of Dzhazator and on the Tarkhata plain (Kosh Agatch District), areas characterized by different types of permafrost (continuous/discontinuous/sporadic).

2 METHODS

2.1 Ground Temperature Measurements

96 iButtons and 19 Onset dataloggers were installed in order to cover surface temperatures and temperature profiles beneath a broad range of landcovers, different topographical positions and periglacial phenomena (e.g. rock glaciers). Some sensors were installed into the top of the permafrost, while the majority of the loggers were installed in the active layer or the seasonally frozen ground.

Temperatures were recorded between July 2008 and August 2009. MAAT in the Dzhazator Valley during this study period was -3.6°C .

2.2 Thermal Regime

For every logger, MAGT, seasonal n-factors and different offset values were calculated and compared. In addition, the specific thermal regime beneath the kurgans was examined in detail to study the temperature lowering effect of their blocky surface.

3 RESULTS

Results clearly show the dramatic topographical effect and resulting snow cover variance on the thermal regime in the study area. MAGT differences between sites separated not more than 200 meters, often exceed 4°C with both strongly divergent behavior in summer and winter

Furthermore, temperatures in kurgans and rock glaciers also show a strong negative anomaly, clearly indicating the convective cooling in winter times. This anomaly, present in the near surface, is also propagated with depth, as shown by figure 1.

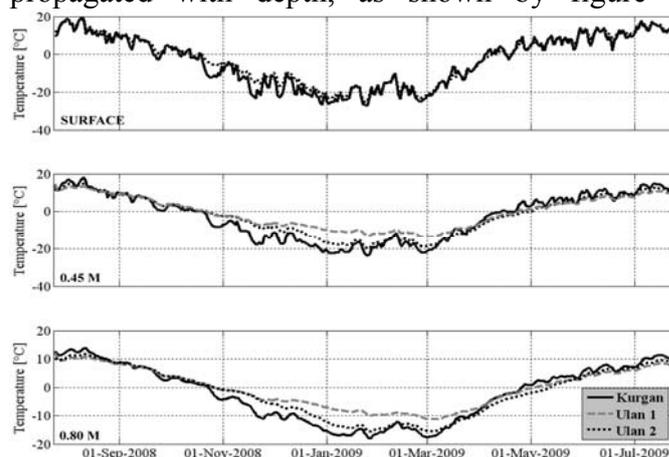


Figure 1. Temperatures at 0.10 m, 0.45m and 0.80m depth between 25 July 2008 and 25 July 2009 for 3 different boreholes. *Kurgan* represents a borehole in a reconstructed kurgan while *Ulan1* and *Ulan2* represent profiles from the surroundings.

4 CONCLUSIONS

This study emphasizes the large variation in thermal regime existing in the Russian Altay Mountains resulting in extreme permafrost zonation.

Characterizing Lowland Permafrost Using Electrical Conductivity Data – Results from Komi and Nenets Regions, NW Russia

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N. Oberman

MIREKO Mining Company, Syktyvkar, Russia

1 INTRODUCTION

Effects of warming and thawing permafrost, due to global climate warming, are of major concern in the extensive lowland permafrost areas in the northern Komi Republic and the Nenets Autonomous Area in northwestern Russia. Ground temperatures, monitored at several stations across the area since 1970's and 80's, show a warming trend (Oberman and Mazhitova, 2003). During the monitoring period the number and size of taliks have increased and permafrost disappeared from large areas at the southern limit of the permafrost zone.

The need for a flexible technique to monitor larger areas led us to start a pilot project to study the electrical properties of the Quaternary deposits of the lowland Bolshezemelskaya tundra. The objective of the project is to estimate the sensitivity of different geophysical electrical and EM techniques for imaging relevant permafrost-talik structures in different geological and morphological environments.

2 MATERIALS AND METHODS

We started the project in 2007 with a series of geophysical measurements and geological studies at the Lek-Vorkuta station (Fig. 1). The field work continued in 2009 at the Korotaikha station and will be continued 2010 at two new areas varying in geological characteristics and temperature regimes. 2D Resistivity sounding (ERT) has been the base technique for high-resolution characterization of the electrical conductivity of the sediments and structures and the effect of relevant physical factors (temperature, ice-content, etc) on the conductivity. The EM measurements have been made by a multi-frequency Max-Min Slingram and by a TEM-system. The MaxMin-soundings were made with 40m and 100m coil spacing and the TEM soundings with a transmitter (Tx) loop size 625m². In situ temperature and conductivity data were collected from surface waters and loose sediments. Minor tests with a VLF-R, TEM measurements with a larger 40000 m² Tx-loop, and soil sampling for laboratory studies were made also. All geophysical profiles were measured over representative sites where geology and sediment proper-

ties and temperature regime have been studied with logging of drill cores and temperature monitoring.

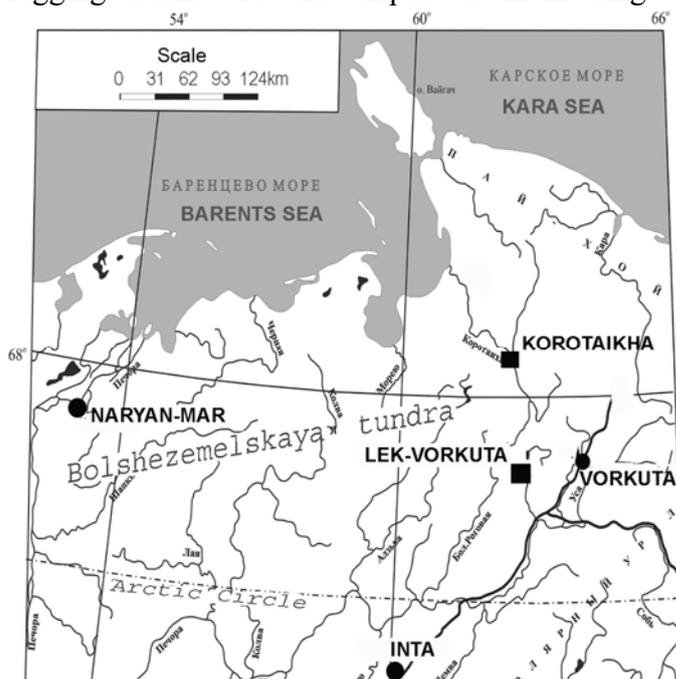


Figure 1. Study stations Lek-Vorkuta and Korotaikha are situated in northern Komi and Nenets (the Korotaikha site).

3 RESULTS AND CONCLUSIONS

In most profiles, we found a good conformity between the electrical conductivity and the geological sections. The conductivity data covering variety of deposits with varying physical properties, both in a frozen and in an unfrozen state, together with the results achieved with the EM techniques, form a basis when planning and modeling permafrost monitoring and mapping projects for larger areas in Komi and elsewhere in the same kind of lowland tundra areas.

References

- Oberman, N.G., Mazhitova, G.G., 2003. Permafrost mapping of Northeast European Russia based on the period of climatic warming 1970-1995. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, Vol 57, No 2: 111-120. *Geography*, vol. 57, No 2: 111-120.

Determination of Ice Contents in Greenlandic Permafrost Using Geophysical Measurements

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Asiaq, Nuuk, Greenland & Department of Civil Engineering, Technical University of Denmark, Copenhagen, Denmark

Thomas Ingeman-Nielsen and Niels Foged

Department of Civil Engineering, Technical University of Denmark, Copenhagen, Denmark

1 INTRODUCTION

Application of geophysics is a cost effective and less time consuming way of mapping and monitoring permafrost compared to geotechnical drilling. However, experience has clearly shown that results can be ambiguous due to inhomogeneous and anisotropic features of the permafrost.

Current research at ARTEK and Asiaq seeks to establish a set of geophysical survey schemes aimed at determination of ice contents through an integrated approach designed for different types of permafrost using DC resistivity, seismic refraction, FDEM, TDEM and GPR depending on the properties of the area. In this review focus will be put on seismic refraction and Electrical Resistivity Tomography (ERT).

2 METHODS AND DISCUSSIONS

2.1 DC Resistivity

DC Resistivity has been applied in Greenland by the Technical Organization of Greenland as early as 1969 for determination of permafrost boundaries. Measurements were made as 1D vertical electrical soundings (VES), typically in the Schlumberger configuration along with measurements in the Wenner configuration. Ingeman-Nielsen (2005) applied 2D Electrical Resistivity Tomography (ERT) in order to assess spatial distribution of permafrost and this method is currently the widest used by ARTEK.

2.2 Seismic Refraction

Ingeman-Nielsen (2005) applied seismic refraction in order to assess spatial distribution of permafrost. This was done through both tomography and through Hagedoorn's plus-minus method. The method has not been widely used by ARTEK, but is currently being explored more extensively for determination of ice contents in conjunction with DC resistivity profiles.

2.3 Combination of Methods

Through the combination of ERT and seismic refraction it is possible to set up a model which describes the possibility of high ice contents in permafrost. In general the possibility of high ice content increases as resistivity increases, particularly from 10-30 kOhmm, while it increases from approx. 1500 m/s peaks at around 3000 m/s and decreases towards approx. 4500 m/s when considering seismic velocity (Harris et al. 2009).

3 INITIAL FINDINGS

Data collected in an area with a transition from river gravel to ice rich silts and clays in a continuous permafrost zone in Kangerlussuaq seems to indicate a correlation between the seismic velocity and resistivity as described above. However, it does also seem that ice rich clays differ from the model discussed above in terms of resistivity as the data only indicates resistivity of 2-4 kOhmm in the upper ice rich clays. This might also be further influenced by high salinity in the marine clays overlain by river and meltwater deposits.

As the model described in Harris et al. (2009) is based on mountain permafrost with a substantially lower clay content this is to be expected. In order to establish a more suitable model further work is to be carried out during field season 2010. This work will be carried out in better known areas, i.e. areas in which geotechnical knowledge regarding grain size and ice content from drillings is better known.

References

- Harris, C., Arenson, L.U., Christiansen, H.H., Etzelmüller, B., Frauenfelder, R., Gruber, S., Haeberli, W., Hauck, C., Hölzle, M., Humlum, O., Isaksen, K., Käab, A., Kern-Lütschg, M.A., Lehning, M., Matsuoka, N., Murton, J.B., Nötzli, J., Phillips, M., Ross, N., Seppälä, M., Springman, S.M., Vonder Mühll, D. 2009: Permafrost and climate in Europe: Monitoring and modelling thermal, geomorphological and geotechnical responses. *Earth-Science Reviews* 92, pp. 117-171.
- Ingeman-Nielsen, T. 2005: Geophysical Techniques Applied to Permafrost in Greenland. Ph.D. Thesis. Arctic Technology Centre, Department of Civil Engineering, Technical University of Denmark, Copenhagen.

Instrumentation and Monitoring of a Talik in Kangerlussuaq, West Greenland

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1 ABSTRACT

The deep geologic repository concept for long-term storage of nuclear waste involves the containment and isolation of used nuclear fuel at depths of 500-1000 m within a suitable rock formation for hundreds of thousands of years. Glacial conditions with growth of ice sheets and permafrost will likely occur in Fennoscandia and Canada during this time perspective. To advance the understanding of the impact of glacial processes on the long-term performance of a deep geologic repository, the Greenland Analogue Project (GAP) has been established by the Swedish, Finnish and Canadian nuclear waste management organizations (SKB, Posiva and NWMO). The GAP is a field and modeling study utilizing the ice sheet and sub-surface conditions in West Greenland as an analogue for the conditions expected to prevail in Fennoscandia and Canada during future glacial cycles.

One of the main aims of the GAP is to improve the understanding of how groundwater flow and water chemistry is influenced by an existing ice sheet and continuous permafrost.

Given that taliks may provide hydraulic pathways through permafrost, they can potentially act as concentrated discharge points for radionuclides, in the case of release from the repository.

A 190 meter deep and inclined borehole was drilled beneath a lake, in the Kangerlussuaq area, West Greenland, to study a potential talik. The lake is located in a lineament structure and forms a 40 meter deep elongated basin (1200 x 300 meters). Continuous permafrost with measured depth of at least 300 meters characterizes the areas a few hundred metres from lakes. To prevent the hole from freezing, hot water drilling, using sodium fluorescein spiked lake water, was applied. In order to investigate if the talik is a through talik, and therefore potentially acting as a discharge point for deep groundwater, the borehole was packed off and instrumented with a U-tube system at a depth of 130 meters (in vertical depth). Sampling of downhole fluids is facilitated through the U-tube system (Freifeld, 2009), which is

equipped with sensors allowing monitoring of *in situ* pressure, temperature and conductivity. Water and gas is retrieved using N₂ forcing. Continuous temperature profiling from the surface down to a depth of 130 meters is enabled through the use of the installed fiber optical Distributed Temperature Sensing (DTS) cable.

Water samples were obtained from the borehole directly after drilling in June/July 2009 and again in September 2009. A total of 480 liters of water was purged out of the borehole during this time. Over the sampling period, significant decreases in the dye and tritium concentrations in accord with an increase in the TDS was observed, indicating that the drill fluid content is steadily decreasing and that groundwater is flowing into the borehole. Stable isotope analyses of ¹⁸O-²H compositions indicate that the borehole water is distinctly different from the lake water used for drilling.

Monitoring of *in situ* pressure, temperature and electrical conductivity during the same period showed a minor drop in pressure, a significant increase in the specific conductivity and a stabilization of the downhole temperature.

Based on the results from the DTS-profiling, the transition from permafrost to talik takes place at 20 meters depth i.e. at the shoreline of the lake. During the winter, when the shallow part of the lake freezes down to the bottom, the transition is expected to move further in under the lake.

2-dimensional steady-state conductive heat transfer modeling suggests that the lake generates a distinct anomaly in the subsurface temperature isolines, sufficient to support the existence of a through talik, under the lake. The effect of the lake talik extends several hundred meters landward from the lake-permafrost boundary.

References

Freifeld, B. 2009. The U-tube: A new paradigm for borehole fluid sampling. *Scientific Drilling*, 8: 41-45.

Change in Permafrost Distribution in Northern British Columbia and Southern Yukon, Canada from 1964 to the 2007-2008 IPY

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Geological Survey of Canada, Natural Resources Canada, Ottawa, Canada

1 ABSTRACT

1.1 Introduction

Numerous modelling studies have shown that permafrost extent should diminish as air and ground temperatures increase. However, there are few field-based studies of long-term permafrost change in Canada. The availability of early baseline permafrost data, rare in Canada, permitted this study to be conducted.

1.2 Objective

The goal of this study was to directly evaluate the impact of recent climate change on permafrost distribution as part of the IPY Thermal State of Permafrost in Canada project.

1.3 Methods

The 1964 survey of Roger Brown (1967) along almost 1500 km of the Alaska Highway from Fort St. John, British Columbia to Whitehorse, Yukon Territory was repeated in August 2007 and 2008 using archival maps and photographs to relocate 55 sites (Figure 1). Investigations were conducted manually to a depth of 2 m. Water-jet drilling of boreholes and EM-31 surveys were also used to gather information on permafrost conditions.

1.4 Results and Conclusions

The results show that: (1) significant degradation of permafrost has occurred over the past four decades, especially in the southernmost part of the route (Table 1); (2) where permafrost has persisted, it is thin and at temperatures just below 0°C and thus is sensitive to further warming; and (3) the active layer has generally increased in thickness. These results are consistent with the statistically significant increases in mean annual air temperatures that have occurred in the region since mid-1960s that especially relate to a reduction in the intensity of the freezing season. The results augment the very limited number of field studies of long-term change to permafrost in Canada, and are relevant to northern residents who must adapt to changing permafrost conditions.

Table 1. Permafrost conditions at sites investigated in 2007-2008 compared to 1964

Route segment	Total sites investigated	Permafrost sites	
		1964	2007-2008
Fort St. John to Fort Nelson	26	15 (58%)	5 (19%)
Fort Nelson to Watson Lake	11	6 (55%)	5 (45%)
Watson Lake to Whitehorse	18	10 (56%)	6 (33%)
Total	55	31 (56%)	16 (29%)

References

Brown RJE. 1967. Permafrost Investigations in British Columbia and Yukon Territory. Ottawa: National Research Council of Canada.

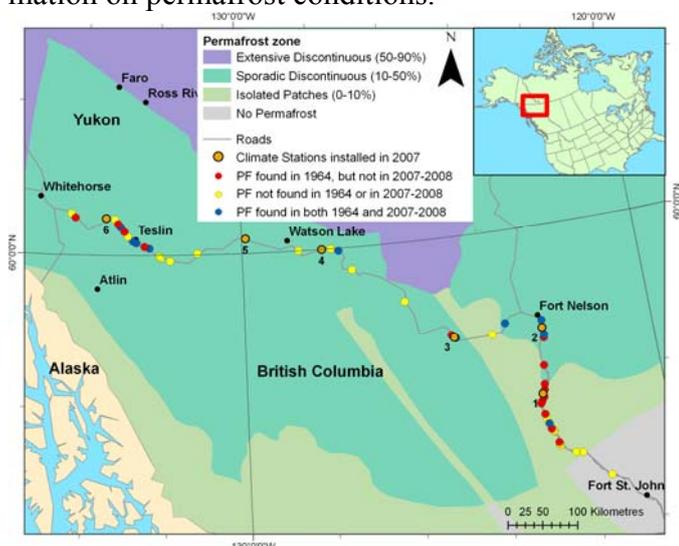


Figure 1. Study area showing field observations of changes in permafrost conditions

Interannual Variations of Ground Surface Temperatures in Sedimentary Deposits of the Alpine Permafrost Belt

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1 INTRODUCTION

Since the end of the 1990's ground surface temperatures have been measured during at least one year on about 400 sites in the Swiss Alps by the universities of Lausanne and Fribourg. The measurements have been concentrating on sedimentary deposits within the alpine permafrost belt, that is mainly rock glaciers, talus slopes and glacier forefields.

2 RESULTS

The monitoring carried out on the different sites shows that ground surface temperatures (GST) suffer strong inter-annual variations, in particular in winter (Figure 1). Mean annual ground surface temperature (MAGST) can for instance vary up to 3°C from year to year.

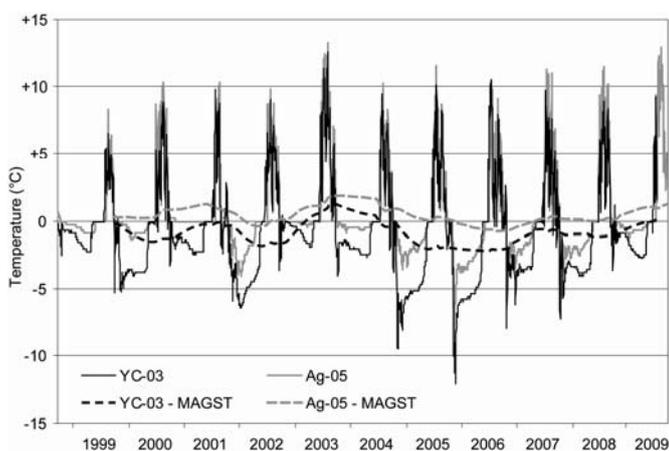


Figure 1. Ground surface temperatures and MAGST recorded in a blocky terrain (YC-03, Yettes Condjà C rock glacier) and in a fine-grained terrain (Ag-05, Aget glacier forefield). Both sites are located at around 2700 m a.s.l. in the Valais Alps.

Ground surface temperatures are essentially controlled by a set of factors related to terrain characteristics and by external factors (climate). The first set of factors refers to elevation, aspect and surface and sub-surface characteristics (roughness, porosity, active layer composition and thickness, permafrost, ice/water content). It is spatially heterogeneous and can change very rapidly over short distance. In particular, the grain size is a main factor as it controls

the porosity and thus characteristics of the active layer (for instance moisture). The external factors correspond mainly to the historical development of the snow cover for the winter GST (Delaloye & Monbaron 2003) and to the air temperature for the summer GST. Even if wind can also strongly modify the snow distribution pattern at the local scale, external factors are almost homogeneous at the regional scale, which implies that interannual variations in GST and MAGST behaviour are almost similar at the regional scale (Figure 1).

As terrain characteristics are not expected to change significantly over a short period, interannual variations of GST mainly depend on external factors and how they interact with the terrain characteristics. As illustrated on figure 1, our data show for instance that terrains with an open-work surface layer may experience stronger interannual temperature variations than fine-grained terrains. Due to the roughness of the ground surface, a thicker snow cover is necessary to insulate the ground in blocky terrains. Thus, GST in such environments is more influenced by air temperature in winter. Moreover less latent heat is produced by freezing in dryer coarse-grained terrain, permitting the temperature to drop much lower in wintertime. In addition, both air convection and advection within a porous active layer or in deeper layers (chimney effect) can strongly affect the ground surface thermal regime during cold winters (e.g. Lambiel & Pieracci 2008).

Further detailed results of the systematic analysis of GST time series at both local and regional scales will be presented at the conference.

References

- Delaloye R., Monbaron M. 2003. Snow effects on recent shifts (1998-2002) in mean annual ground surface temperature at alpine permafrost sites in the western Swiss Alps. *8th Int. Conf. Permafrost, Zurich 2003, Extended Abstracts Volume*: 23-24.
- Lambiel C., Pieracci K. 2008. Permafrost distribution in talus slopes located within the alpine periglacial belt (Swiss Alps). *Permafrost and Periglacial Processes*, 19: 293-304.

Temporal Permafrost Variability at Three Subalpine Talus Slopes in the Swiss Alps, by Geoelectrical Monitoring and Supplemental Methods

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1 INTRODUCTION

In the European Alps discontinuous alpine permafrost is expected to occur at elevations above 2400 m a.s.l. at mean annual air temperatures (MAAT) of less than -1°C . Below timberline only a few sites are known, where sporadic permafrost exists in vegetated talus slopes with positive MAAT. Aim of the study is to characterise the temporal permafrost variability in consideration of thermal site characteristics as influenced by humus, vegetation and snow cover as well as thermal effects inside the talus slopes.

ERT (electrical resistivity tomography) has been established as a suitable method for monitoring inter- and intra-annual variability of permafrost. In joint application with complementary methods (Quasi-3D ERT, refraction seismic tomography (RST), borehole data, temperature data loggers, BTS) an enhanced interpretation can be realised.

2 FIELD SITES

The investigated talus slopes are situated in the Swiss Alps and differ mainly in elevation, MAAT and parental rock material. All sites are characterised by a thick humus layer of up to 40cm, covered by mosses. Most of the trees at the field sites (*Larix decidua*, *Pinus cembra*, *Pinus mugo*, *Picea abies*) are dwarfed.

Table 1. Characteristics of the investigated talus slopes in the Swiss Alps.

	Bever Valley	Susauna Valley	Brüeltobel
Location	Engadin	Engadin	Appenzell
Elevation a.s.l.	1780 m	1663 m	1200 m
Aspect	NNE	NNE	NNW
MAAT	2.8°C	$\sim 3.2^{\circ}\text{C}$	$\sim 5.5^{\circ}\text{C}$
Parent material	granitic	dolomitic	dolomitic
Grain Size (ϕ)	>30 cm	5-20 cm	5-20 cm
Humus thickness	10-30 cm	30-50 cm	30-50 cm

3 METHODS

ERT-transects are installed at the three sites using 36 electrodes with a spacing of 3m (resp. 1.8m at Brüeltobel) and are measured once a month throughout the year. The measured Wenner and dipole-dipole

arrays are inverted as single datasets and merged datasets of both arrays, regarding error-proneness of different array types and to achieve higher resolutions of the subsurface model. Monthly time sections are compared using time-lapse inversion methods.

To enhance the interpretability of the ERT-monitoring supplemental methods are applied. RST is used to characterize permafrost properties. To define the ground thermal regime a number of temperature data loggers are installed within the humus layer and at different slope positions. Quasi-3D ERT is used for spatial interpretation of the subsurface conditions in contrast to the more punctual information of the ERT - monitoring data.

4 RESULTS & DISCUSSION

The permafrost occurrences show a high inter-annual variability at all three monitoring sites, where an exponential increase of resistivities has been measured between November and February, indicating a distinct decrease of unfrozen water content in the permafrost bodies, caused by a pronounced cooling in the lower parts of the slopes. During snowmelt the resistivities drop rapidly towards the autumn-values. In this case joint application of ERT and RST is of importance, as the P-Wave velocities between autumn (~ 1600 - 1800m/sec) and spring (~ 2600 - 3500m/sec) differ considerably, indicating higher ice contents in spring. During snowmelt ice is formed in the talus slopes under release of latent heat, resulting in warmer ice temperatures with higher contents of unfrozen water, hence, lower resistivities.

Results from ERT - monitoring and temperature data (MAGST, MAGT, MAAT, BTS) show an intra-annual variability of the permafrost bodies, with a cooling of the talus slopes in winter, permafrost aggradation during snowmelt and degradation in summer. The high insulation capability of the humus cover results in almost constant temperatures (1° - 3°C) at 30 cm depth in August and only slight permafrost degradation in summer. In winter the permafrost properties depend more on air temperature and air circulation inside the talus slopes (chimney effect) than on snow cover thickness, as the insulation capability of the snow cover is relatively low, due to high disturbance (vents, boulders, trees).

Time	Wednesday, June 16
15:15 – 17:00	<p>POSTER SESSIONS</p> <p># 1-24 in UNIS Entrance</p> <p># 25-45 in Kapp Lee</p> <p># 46-67 in Kapp Schultz</p> <p># 68-83 in Templet</p> <p># 84-99 in Festningen</p>
17:00 – 18:00	CLOSING CEREMONY in Møysalen and video streamed to Lassegrotta
19:00 –	CONFERENCE DINNER in UNIS Canteen

Posters Wednesday

Remote Sensing Techniques and Geohazards: in UNIS Entrance Hall

1. **Remote Sensing of Thermokarst Lake Dynamics and Implications for Carbon Fluxes, Northern Seward Peninsula, Alaska**
B.M. Jones, G. Grosse
2. **Temperature and Rockfalls Monitoring Activities at Aiguilles Marbrées North Face (Mont Blanc Massif, France)**
M. Curtaz, M. Vagliasindi, U. Morra di Cella, P. Pogliotti, R. Roncella, A.M. Ferrero
3. **RiskNat: a Cross-Border European Project Taking into account Permafrost-related Hazards**
The RiskNat B1-C1 team (RISKMAT)
4. **Rockfall Quantification in High-Alpine Rockwalls with Permafrost: Five Years of Survey with Laser Scanning in the Mont Blanc Massif**
L. Ravanel, P. Deline, S. Jaillot
5. **Movement Detection by InSAR in Permafrost Areas. Application to the Queyras Natural Regional Park, Hautes-Alpes, France**
T. Echelard, J.-M. Krysiecki, C. Barboux, M. Gay, P. Schoeneich
6. **The Modification of Criteria for the Natural Disasters Evaluation in Russia as an Impact of Climate Changing**
S.A. Gavrilova

Posters Wednesday, cont.

7. **Residual Strength of Ice Filled Rock Joints**
F.K. Günzel
8. **The ESA DUE Permafrost Project – Pan-Arctic Land Surface Temperature Products: Overview and Evaluation**
S. Hachem, C. Duguay, A. Soliman
9. **A Strategy for Assessing Risks Relating to Rock and Rock/Ice Avalanches from High-Mountain Permafrost Slopes**
W. Haeberli, L. Fischer, S. Gruber, A. Hasler, C. Huggel, J. Noetzli, D. Schneider
10. **The Lena River Delta, Arctic Siberia: an Arctic Ground Data Observatory of the due Permafrost Remote Sensing Project**
B. Heim, M. Langer, S. Muster, T. Opel, J. Boike, J. Sobiech, K. Piel, A. Morgenstern, M. Ullrich, A. Bartsch
11. **Landscape Pattern and Cryogenic Landsliding Hazard Analysis on Yamal Peninsula, Russia**
A.V. Khomutov, M.O. Leibman
12. **Warming-Induced Destabilization of Peat Plateau/Thermokarst Terrain**
A.B.K. Sannel, P. Kuhry
13. **Detecting and Quantifying Permafrost Creep with Space-Borne Radar Interferometry (Insar) in the Canton of Ticino (Southern Switzerland)**
S. Mari, R. Delaloye, C. Scapozza, T. Strozzi
14. **Northern Hemisphere Permafrost Changes Associated with GRACEderived Water Storage, MODIS-Derived Land Surface Temperature Changes**
R.R. Muskett, V.E. Romanovsky
15. **High Resolution Low Cost Ice-Wedge Mapping by Mini Unmanned Aerial System** U. Neumann, HH. Christiansen, S. Härtel
16. **Using AVNIR-2 and ETM+ Data to Detect Thermokarst Affected Surface Structures on Kurungnakh Island, Lena River Delta, Siberia**
S. Roessler, F. Guenther, A. Morgenstern, M. Ulrich, L. Schirrmeister
17. **Energy and Water Vapour Fluxes in the Arctic Tundra Landscape: How Can SAR Data Facilitate Upscaling?**
J. Sobiech, S. Muster, B. Heim, W. Dierking, J. Boike
18. **Remote Sensing and GIS Analysis of Spatial and Morphological Changes of Thermokarst Lakes: Kolyma Lowlands, Northeast Siberia**
A. M. Tillapaugh, G. Grosse
19. **Assessment of Temporal, Scale and Surface-Cover Effects on the GST-LST Relationship in the Russian Altay Mountains**
R. Van De Kerchove, R. Goossens
20. **Snow Cover in Livingston and Deception Islands (Maritime Antarctic). Multi-Temporal Analysis of ASAR Imagery of 2009**
C. Mora, G. Vieira, M. Ramos
21. **Cornice Development, Cracking and Failure and Triggering of Cornice Fall Avalanches on Gruvefjellet in Longyeardalen, Svalbard**
S. Vogel, M. Eckerstorfer, H. H. Christiansen

Remote Sensing of Thermokarst Lake Dynamics and Implications for Carbon Fluxes, Northern Seward Peninsula, Alaska

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1 INTRODUCTION

Quantifying changes in thermokarst lakes in a lake-rich, permafrost dominated landscape is of importance for understanding changes to the carbon budget due to the potential release or sequestration of carbon. Recent studies have documented increases in lake number and lake area in the continuous permafrost zone and decreases in lake number and area in the discontinuous permafrost zone (Smith et al., 2005).

2 STUDY AREA AND METHODS

Our study area of 700 km² is located on the northern Seward Peninsula, Alaska, USA in central Beringia. The study region is considered to be a Yedoma-like landscape with ice-rich permafrost, loess-like upland sediments with organic-rich horizons, large syngenetic ice wedges, and high segregated ice content. Nearly 70% of the landscape has been impacted by thermokarst lake processes.

We compared black and white aerial photography from the 1950s (Manley et al., 2007), color infrared aerial photography from 1978 (Manley et al., 2007), and IKONOS satellite imagery from 2006 and 2007 (Provided by the National Park Service). We used a semi-automated, object-oriented approach to classify waterbodies larger than 0.01 ha.

3 RESULTS AND DISCUSSION

3.1 Change in lake number and area

The number of lakes and ponds larger than 0.01 ha in the region have increased from 969 in ca. 1950, to 1,111 in 1978, to 1,189 in ca. 2007 or a 22.7% increase during the last 57 years. However, mean lake size over this same time period has decreased from 5.2 ha, to 4.6 ha, to 3.6 ha, respectively, indicating that the majority of the increase in lake abundance can be explained by the addition of several small lakes and ponds, which can either result from the formation of new thermokarst water bodies or the partial drainage of larger water bodies. In the case of our study area, it appeared that the latter was re-

sponsible for the large increase in lake numbers because total lake surface area decreased from 5,081 ha to 4,333 ha, or a 14.7% decrease in surface water area over the study period. Thus, we have identified an increase in lake number yet a decrease in total lake surface area for a region within the zone of continuous permafrost.

Table 1. Change in lake number and area between 1950 and 2007.

Time Period	Lake Number	Lake Area
1950 to 1978	+14.6%	+1.0%
1978 to 2007	+7.0%	-15.6%
1950 to 2007	+22.7%	-14.7%

3.2 Implications for carbon fluxes

Understanding landscape change with respect to lakes is important for up-scaling methane emissions. On this portion of the Seward Peninsula, lakes have typically expanded at ~0.3 to 0.4 m/yr. This expansion has resulted in lake disappearance due to the encountering of a sufficient gradient to promote lateral drainage. However, other factors may be contributing as well. Following drainage, peat accumulates and permafrost aggrades in the basin. While drained lake basins may remain a source for methane and carbon dioxide emissions during the thawed season, emissions from these terrain units may be several orders of magnitude lower than from thermokarst lakes on an annual basis.

References

- Smith, L.C., et al., 2005. Disappearing Arctic lakes. *Science*, 308, 1429.
- Manley, W.F., et al., 2007. High-resolution orthorectified imagery from approximately 1950 and 1980s for the coastal areas of Bering Land Bridge (NP) BELA, Northwest Alaska: Fairbanks, AK: National Park Service, Arctic Network I&M Program. Digital Media.

Temperature and Rockfalls Monitoring Activities at Aiguilles Marbrées North Face (Mont Blanc Massif, France)

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1 INTRODUCTION

On September 20th 2007 a small rockfall of about 125 m³ occurred at Aiguilles Marbrées North face leaving massive ice visible in the exposed detachment zone. Such ice evidences can be related to ongoing processes of permafrost degradation following climate change (Gruber & Haeberli 2007). With this awareness Fondazione Montagna sicura and ARPA Valle d'Aosta have started a project on this case study, in collaboration with GeoDigital Solutions (a University of Parma spin-off). The site was chosen to test innovative survey techniques with coupled monitoring of rockfall activity and surface rock temperatures. The aim is to analyze possible relation between rock face dynamics and temperatures and test survey techniques which can be useful to support risk management.

2 METHODOLOGY

2.1 Study area

The Aiguilles Marbrées is a granitic peak of 3535 m of elevation in Mont Blanc massif. The study area is located in the lower part of the North face, characterized by a mean steepness of about 70° and a mean aspect of about 320N. The slope is shaped by the crossing of 3 main discontinuities families which lead to the disjunction of big portions of rock face.

2.2 Photogrammetric surveys of rockfall activity

Periodical photogrammetric surveys have been done during Summer using a Nikon D700 digital camera with calibrated 20 mm lens. Georeferencing was made coupling the first survey to stop and go GPS measures of the camera positions (so-called photo-GPS technique). Control points were derived from the first block adjustment for use in next surveys. The images sequence is automatically processed with softwares using Structure and Motion and Dense Matching algorithms to obtain an high resolution Digital Surface Model (DSM) of the rockwall. The diachronic comparison of DSM models is per-

formed by the VRmesh software in order to detect geometry and volumes of eventual rockfalls.

2.3 Temperature monitoring

The surface rock temperature is measured since July 2008 at 3 different depths (3, 30 and 55 cm) with a logging frequency of 10 minutes. The instrumentation is installed in the upper part of the 2007 detachment zone. Air temperatures and humidity are measured in order to give a rough climatic characterization of the site. To reduce data loss due to damages or malfunctions in June 2009 a new system equipped with GPRS modem was settled down.

2.4 Other studies

To obtain a more complete knowledge of this site structural analysis were done both by traditional method and by computer using DSM and a specific software. Schematic back analysis of the 2007 rockfall were performed to study the relative influence of rock bridges, ice and melt water on the stability of the rock volume.

3 RESULTS AND FUTURE STEPS

So far the data collected by the two monitoring activities can't be compared because the only instability events identified by the photogrammetric surveys occurred before the installation of temperature sensors. For these reasons the two methodologies will be treated separately and preliminary results will be exposed.

Monitoring activities like these can give results only over a long term period: that's why Fondazione Montagna sicura and ARPA VdA have planned to continue their studies on this site for the following years.

References

Gruber S. & Haeberli, W. (2007). Permafrost in steep bedrock slopes and its temperature-related destabilization following climate change. *Journal of Geophysical Research*, vol 112.

RiskNat: a Cross-Border European Project Taking into Account Permafrost-Related Hazards

The *RiskNat* B1-C1 team

1 THE PROJECT *RISK*NAT

1.1 Introduction

In mountain areas natural hazards and management risks related to permafrost degradation are still poorly known and considered.

Alpine permafrost is rather different from permafrost in arctic or northern lands. Thermal regime largely depends on microclimate effects, dealing with altitude, aspect and geographic position; moreover, thermal regime inside of materials depends on material type itself (rock, debris, soil), slope steepness, exposure to solar radiation, water circulation and presence of snow. Because of the complexity of these parameters, permafrost distribution is discontinuous and difficult to detect. Furthermore, alpine permafrost affects areas traditionally characterized by few inhabitants and infrastructures. Thus, until now there has been no need of a good understanding of alpine permafrost-related phenomena from a practical point of view.

In the recent past, changes of climate are leading to permafrost degradation and to an increase in dynamics such as rockfalls in high elevation areas. The effects of these slope instabilities can expand downward to valley floors and populated areas (e.g. debris remobilized by debris flow). On the other hand, high elevation zones get more and more interested by human activities and structures (mainly for tourist trade).

That's why not only the scientific community but also public administrations involved in land use planning, in civil protection and in risk management had increased their interest to permafrost-related phenomena, becoming more important as strictly related to climate change. RiskNat project is an example of this increasing response to new needs.

1.2 *RiskNat* project

RiskNat is a cross-border project in the framework of the program Alcotra France-Italy (2007-2013), developed between 2009 and 2012. It focuses on natural hazards that concern mountain areas: earthquakes, landslides, torrent floods, snow avalanches and hazards related to permafrost degradation. All regions of Italy, France and Switzerland in the western Alps are involved.

RiskNat aims at the constitution of an interregional platform on natural hazards by means of (i) knowledge and experience exchange between

technicians, researchers and public administrations of the different regions and (ii) awareness programs about natural risks.

2 ACTIVITIES B1- C1: HAZARDS DERIVING FROM HIGH MOUNTAIN ENVIRONMENT EVOLUTION

2.1 Objectives

Activities B1 and C1 (*Hazards deriving from high mountain environment evolution*) focus on permafrost. Regions involved are: Autonomous Region of Aosta Valley (IT), Piedmont Region (IT), Department of Haute-Savoie (FR), Wallis Canton (CH). The aim is to define tools and procedures for (i) the assessment of hazards related to permafrost evolution in high mountain areas and (ii) the management of the risks resulting from its interaction with infrastructures located in permafrost areas. The understanding of the phenomenon is very complex and needs to be based on the knowledge of (i) meteorological conditions at high resolution, (ii) propagation mode of external thermal state inside the lithological materials and (iii) changes in geotechnical and mechanical parameters with temperature.

2.2 Methods

A first step is to define common criteria to assess permafrost distribution and to make thematic maps using both empirical and physically-based models.

Secondly, scenarios for permafrost evolution and related effects on natural hazards in response to climate change should be studied. These require to know: (i) how permafrost state of material reacts to increasing air temperature (by modelling); (ii) how mechanical characteristics of material (rock, debris) change with temperature rising (by laboratory tests); (iii) which are the effects on natural hazards like landslides and debris flows. In addition, the project analyses also interactions with human activities (infrastructures and inhabited areas) to define constraints and criteria for building in high mountain areas with definition of priorities for protection measures.

To test monitoring techniques and to improve the knowledge in permafrost-related risk management, several case studies have been chosen in Aosta Valley and Wallis.

Rockfall Quantification in High-Alpine Rockwalls with Permafrost: Five Years of Survey with Laser Scanning in the Mont Blanc Massif

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1 INTRODUCTION

In the last decade, major rockfalls occurred in high mountains around the world. If the hypothesis of a relationship between rockfalls and global warming through permafrost degradation gains force, frequency and intensity of rockfalls are still poorly known because of a lack of systematic observations. Here we present an applied methodology for the monitoring of high-elevated rockwalls in the Mont-Blanc massif.

2 STUDY SITES

The West face of the Petit Dru (3730 m a.s.l.) is located on the NW side of the Mont-Blanc massif; the six other study rockwalls are located on its SE side, along the boundary between France and Italy. Most aspects are represented, ranging in elevation from 2700 to 4600 m a.s.l., and in mean slope angle from 40 to 80° – with vertical or overhanging sectors. The granite of the different rockwalls can be massive (Petit Dru and Piliers du Freney), very broken (Aiguilles d'Entrèves), or even sheared (sectors of Tour Ronde, Grand Flambeau, Androsace).

3 SURVEY AND DATA PROCESSING

Surveys with Terrestrial Laser Scanning (TLS) in the Mont-Blanc massif began in June 2005. Helicopter or cable car is used to access to the sites. Data are acquired with an Optech ILRIS 3D laser scanner, and processed with InnovMetric Polyworks V10.1, to get 3D models of each rockwall at a high resolution.

A diachronic comparison of these models allows to map the topographic changes on each rockwall between two surveys, and detached rock volumes are calculated.

4 RESULTS

Approximately 30 rockfalls ranging in volume from 1 to 426 m³ were identified since 2005 thanks to TLS surveys. Their distribution suggests that the rockwalls morphodynamics depends of geological, topo-climatic and ice-cover factors. Except three small events that occurred just above 4000 m a.s.l.

(NW face of the Aiguille Blanche de Peuterey), no rockfall has been observed above 3720 m a.s.l. Rockwalls at very high elevation, with cold permafrost, are therefore very stable, while the ones below 3800 m a.s.l., with a likely degradation of the permafrost, are more or less affected by rockfalls – depending on geological structure and ice cover.

Among the largest (hundreds of m³) collapses observed, those which affected a compact spur at the Tour Ronde between 2005 and 2006 (volume: 382 + 154 m³) could result from the permafrost degradation (deepening of the active layer). By contrast, detachments at the Petit Dru during the same period are probably due to a mechanical adjustment after the rock avalanche of June 2005.



Figure 1. Detail of the map of the errors resulting from the comparison of the 3D models of July 2006 and July 2007, West face of the Grand Flambeau (3561 m a.s.l.). The notch is 15 m high and 4 m large, with a collapsed volume of 57 m³. Scale of grey on the right indicates changes in depth (in meters).

References

Ravanel L., Deline P., Jailliet S. (in press). Quantification des éboulements/écroulements dans les parois à permafrost de haute montagne : quatre années de relevés laser terrestres dans le massif du Mont-Blanc. *Revue Française de Photogrammétrie et de Télédétection*.

Movement Detection by InSAR in Permafrost Areas. Application to the Queyras Natural Regional Park, Hautes-Alpes, France

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Interferometric Synthetic Aperture Radar (InSAR) is a method of measurement based on the phase difference between two radar images, which represent the same area but at different time intervals. The technique generates interferograms, maps of surface deformation in two-dimensions allowing for the detection and quantification (in the centimetre range) of variations in distance between the target and the radar between two different data acquisitions. Recent research has shown that the InSAR technique can be used to quantify rockglacier deformation (under the assumption that certain conditions are respected with regard to generating and interpreting the interferograms) (Strozzi *et al.*, 2004).

The present study aims to detect and describe movements in permafrost. The radar images (dating from 1993 to 1999) were obtained by GIPSA-Lab (Grenoble, France) with the aim of generating interferograms. In contrast to previously used detection methods (Delaloye *et al.*, 2005), which follow an empirical analysis of the interferograms, the present study suggests a method of automatic detection of deformation zones (figure 1) through the use of confidence and coherence images (Barboux et Gay, 2009). The final product is a raster image representing the zones of movement.

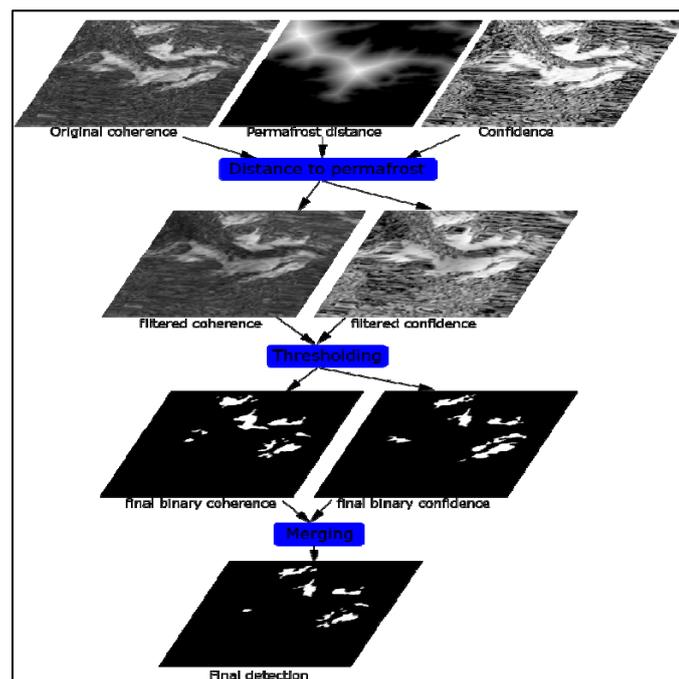


Figure 1 . Movement detection process (C.Barboux, 2009)

The research aims to validate the methodology used by analysing the movement polygons obtained. With the interferograms covering a considerable proportion of the Southern French Alps, an first study has been carried out which focused on the Queyras Natural Regional Park. Here, the topo-climatic conditions are conducive to the development of periglacial formations. Four different time scales are provided: one month, two months, one year and two years, allowing for the identification of four different movement rates (cm/month, cm/2months, cm/year and cm/2years respectively). A periglacial landform inventory was completed to provide a range of potentially creeping formations. For each landform several variables (aspect, minimum and maximum altitude, activity, potential received solar radiation, etc.) were described and collected in a data base. The aim was to compare the inventory with the detected movement zones by InSAR. Measurements of the movement on two rockglaciers were carried out in the field (DGPS). Using the results of this validation, statistical analyses were carried out to allow greater understanding of the limits of the InSAR method.

The ultimate objective of the study is to allow for the inventory of creeping landforms over vast areas (100 km width for ERS-1-2 by 100 km length making 10,000 km²) and to keep a record of their evolution.

This work is part of the Alpine Space PermaNET project.

References

- Barboux, C., Gay, M., Vasile, G. (2009). *Permafrost Detection in the French Southern Alps*, European PermaNET project of Alpine Space program, working paper (unpublished).
- Strozzi, T., Käab, A. & Frauenfelder, R. (2004). *Detecting and quantifying mountain permafrost creep from in situ inventory, space-borne radar interferometry and airborne digital photogrammetry*. International Journal of Remote Sensing, 25(15): 2919-2931.

The Modification of Criteria for the Natural Disasters Evaluation in Russia as an Impact of Climate Changing

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Russia is a very vast country, it covers areas with different kinds of landscape and climate – from subarctic tundra in northern parts to semideserts in southern, from arctic to subtropic climate. Of course, in different types of regions there are different types of natural hazards. But still some of them can be found in every region (eg. low temperatures or heavy showers). In Russia the words “natural disasters” are very closely connected to “material damage”. It means that every natural phenomenon that can cause a catastrophic situation should suit 2 types of criteria: geographical and social-economical. Geographical criteria can be meteorological or meteorological-hydrological, etc.

In 1990 the Ministry of Emergency situations and natural disasters was organized in Russia and these criteria were fixed. Since that time there were no modifications, although in all regulating documents state that “in face of rapid climate changes all criteria must be revised”.

The problem is that actually there is no spatial differentiation in geographical criteria of manifestation of natural hazards in Russia. In fact we have the same criteria in Yakutsk in Siberia and Sochi on the Black Sea coast, and these criteria are based upon the climate situation of 1990. This fact can cause many problems.

Statistics show natural disasters which were caused by natural hazards, which do not correspond with proper geographical criteria – but there is still material damage and even people’s death. These problem is all the more crucial in arctic and subarctic regions of Russia.

That’s why we propose to distinguish (according to statistics) different parameters of natural hazards, which can cause natural disasters and material damage in different parts and climatic zones of Russia. Also we have to reconsider these criteria according to today’s climate situation and try to predict the impact of global changes on natural hazards criteria.

Residual Strength of Ice Filled Rock Joints

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1 INTRODUCTION

A number of landslide and rock fall events in recent years have been connected with the warming permafrost in high mountain areas. This study investigates the shear strength of ice filled rock joints based on a series of direct shear tests. Artificial samples made of concrete with an idealised saw-tooth surface are used as described in detail by Günzel (2008). Two sample types are used: “concrete-ice” samples, simulating an infill thicker than the amplitude of the joint roughness and “sandwich” samples where the ice filling is equal to the amplitude of the surface roughness (1mm).

2 SHEAR STRENGTH OF ICE-FILLED JOINTS

2.1 Peak shear strength

At low normal stresses the peak shear strength of the concrete-ice samples was found to increase linearly with the normal stress (Figure 1); this is interpreted as sliding of the ice against the concrete surface. However, for higher normal stresses the relationship becomes parabolic. This is interpreted as plastic deformation of the ice itself. The sandwich samples yielded very scattered results with a trend of decreasing shear strength with increasing normal stress (Günzel, 2008).

The peak strength and the medium strength of the concrete saw-tooth surface without ice are also indicated in Figure 1.

2.2 Residual shear strength

It has to be noted that the ice temperatures at residual strength are slightly higher than at peak strength. This is due to the heat created by the motor of the shear box apparatus during experiments.

As shown in Figure 1, the residual strength of concrete-ice samples behaves differently to the peak strength. For both sample types the linear relationship continues throughout the whole series of experiments. Similarly, the angle of friction of the sandwich samples is 28° and 30° for ice temperatures of -1°C and -3°C respectively. Thus the residual strength appears to depend much less on the sample type or the ice temperature than the peak strength.

3 DISCUSSION AND CONCLUSIONS

The normal stresses used in the experiments were too small to erode the saw-tooth surfaces of the concrete in the samples without ice. Therefore the mean friction angle ($\phi_{\text{mean}} = 42^\circ$) of the saw-tooth surface is used instead of a true residual friction angle. The results show that unlike the peak strength, the residual strength of the ice-filled joints is always less than that of the unfilled joints.

The results of residual shear strength suggest that the residual strength is purely governed by friction between the ice and concrete surfaces rather than deformation of the ice itself. This interpretation is also supported by the fact that there is no significant difference in the residual strength of the two sample types despite their different behaviour at peak strength. However, the strongly reduced dilation of both concrete-ice and sandwich samples after peak suggests that there must be a combination of frictional sliding and deformation of the ice itself, which requires further investigation.

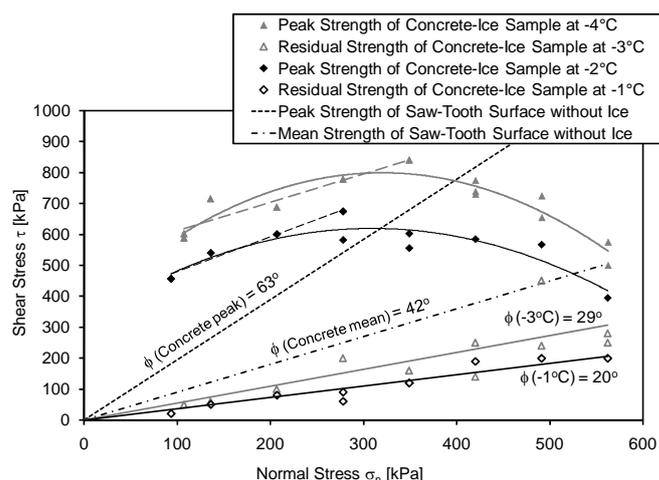


Figure 1. Peak shear strength and residual shear strength results of concrete-ice samples and saw-tooth surfaces without ice.

References

Günzel, F.K. 2008. Shear Strength of Ice-Filled Rock Joints. *Ninth International Conference on Permafrost, Fairbanks Alaska, 29 June–3 July 2008*: 581-586.

The ESA DUE Permafrost Project – Pan-Arctic Land Surface Temperature Products: Overview and Evaluation

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1 ABSTRACT

Land surface temperature (LST) is a critical parameter to measure for understanding biological, hydrological and climatological systems, and their interactions. Arctic and sub-Arctic regions merit particular attention in this respect since they are very sensitive to climate change. In these regions, permafrost (i.e. soil that is frozen for more than two consecutive years) is subject to thaw, which affects its stability. The rate at which permafrost evolves can be determined by studying its thermal regime, which is dependent on surface temperature. Surface temperature is a key parameter as it governs the surface energy budget and the thickness of the permafrost active layer. Given that the North covers a large area, and is remote and relatively unpopulated, the costs associated with the operation and maintenance of ground-based permafrost monitoring stations can be prohibitive. Satellite remote sensing sensors are a useful complement to ground-based monitoring networks since they can provide LST measurements over large areas on a regular basis.

Within the ESA Data User Element (DUE) Permafrost project, LST data from the MODIS (Moderate Resolution Imaging Spectroradiometer) are used to map/monitor the near-surface temperature of areas underlain by permafrost at the pan-boreal/arctic scales. For this purpose, it was decided to create pan-arctic products at the 25 km resolution. In this paper, we present an overview of the strategy of the DUE Permafrost project to develop pan-boreal/arctic scale LST-based products as required by the permafrost community (i.e. users). The products are then evaluated/cross-compared with near-surface air temperature measurements from a network of ground-based stations from the World Meteorological Organization (WMO) and other stations in North America, as well as with the North American Regional Reanalysis (NARR, 32 km) data over Canada and Alaska.

References

Hachem S., Allard M., Duguay C. (2009) Using the MODIS Land Surface Temperature Product for Mapping Permafrost: An Application to Northern Quebec and Labrador,

A Strategy for Assessing Risks Relating to Rock and Rock/Ice Avalanches from High-Mountain Permafrost Slopes

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Evidence is growing that ongoing atmospheric warming has the potential to reduce stability in steep perennially frozen and glacierised mountain flanks and that the frequency of large events may therefore be increasing already today (Fischer 2009). Resulting rock and rock/ice avalanches from high-mountain permafrost slopes can travel over large distances and cause process chains with devastating effects (extreme examples: Huascarán 1970, Kolka-Karmadon 2002). As a consequence and despite large uncertainties about details of the involved processes, reasonable risk assessment procedures must be envisaged and developed, especially for densely populated mountain regions or areas with important infrastructure (e.g., roads, pipelines, hydropower plants). The goal is to recognize critical situations and to enable appropriate measures to be taken in time.

A possible chain of reflections and actions starts with a spatial analysis of critical factor combinations with respect to slope stability (slope inclination, geological setting, warm permafrost, changes in glacier cover, de-buttressing through glacier vanishing). As a second step, flow trajectories of potential rock and rock/ice avalanches from identified sensitive sites can be modeled in order to define possibly affected zones (Figure 1; Noetzli et al. 2006)). A third step involves the investigation of possible process chains, which could amplify volumes or travel distances, especially in the case of impact waves in natural or artificial lakes. The fourth step then considers vulnerabilities and damage in the potentially affected zones. Based on such a knowledge basis, in-situ geological and rock-mechanical analyses as well as adequate monitoring (visual observation to high-technology surveying) can focus on a limited number of starting zones in the most severe situations, hopefully leaving enough time for useful hazard prevention measures where and when necessary (e.g. alarm systems, lake level lowering, blocking of traffic, evacuation - precursory signs are in most cases reported for large events).

Data (e.g., DEMs), models (e.g., permafrost occurrence, avalanche trajectories) and techniques (e.g. sensor networks, INSAR) are available or under de-

velopment to proceed along this sequence of steps. Implementation should, therefore, become possible within the coming years.

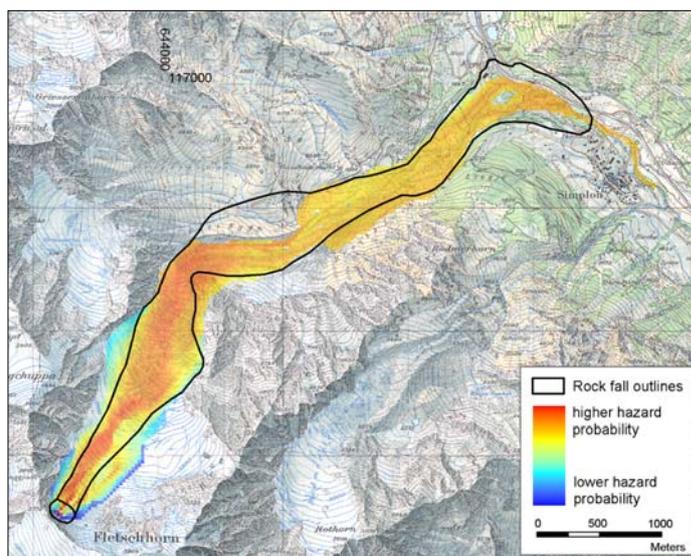


Figure 1. Modeled flow trajectories for the rock/ice avalanche at Fletschhorn (CH) in 1901, after Noetzli et al. (2006). Map and DHM25. Reproduced by permission of swisstopo (BA100040).

References

- Fischer, L. 2009. Slope instabilities on Perennially Frozen and Glacierised Rock Walls: Multiscale Observation, Analyses and Modelling. PhD thesis, Faculty of Science, University of Zurich.
- Noetzli, J., Huggel, C., Hoelzle, M., and Haeberli, W. 2006. GIS-based modelling of rock/ice avalanches from Alpine permafrost areas. *Computational Geosciences*, 10, 161–178.

The Lena River Delta, Arctic Siberia: an Arctic Ground Data Observatory of the DUE Permafrost Remote Sensing Project

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1 INTRODUCTION

1.1 ESA DUE Permafrost Remote Sensing Project

The major task of the European Space Agency ESA Data User Element DUE projects is to develop Earth observation services for specific user communities. Since June 2009, ESA DUE PERMAFROST develops a wide range of remote sensing services and remote sensing products for permafrost monitoring and modelling of permafrost, fluxes and climate.

1.2 Lena River Delta (Arctic Siberia)

The Lena River Delta (about 29,000 km²) located at the Laptev Sea coast in North-Eastern Siberia is a prime area for ESA DUE PERMAFROST. Since 1998, the Alfred Wegener Institute for Polar and Marine Research in collaboration with the Lena Delta Reserve in Tiksi has operated a German-Russian research station on Samoylov Island (72° 22' N, 126° 28' E), in the central delta. Samoylov Island (appr. 1200 ha) is part of the young Holocene delta. The measurement stations, experimental plots and installed sensors are located on the main terrace that is characterised by a wet polygonal tundra landscape with mossy tundra and wet fen and flooded sedge communities. The Kurungnakh Ice Complex is an adjoining Pleistocene geomorphological and stratigraphical ice-rich unit portraying different tundra moisture regimes and plant community structures. Since summer 2008, various surface characteristics have been mapped with wide-area coverage.

1.3 Diagnostic Ground Data

On Samoylov Island, automatic climate stations are continuously logging relevant parameters (air temperature, radiation, snow, soil temperature and moisture). The high landscape heterogeneity (wet polygonal centres, dry polygonal rims, ponds and lakes) may challenge that field observations of surface, soil and permafrost can be directly used to evaluate remote sensing products. Automatic thermal infrared TIR camera measurements mounted on 10 m masts provide high resolution surface temperature data, which can be used for upscaling techniques (Langer et al., submitted).

A land surface classification is obtained through high spatial resolution spectral imaging (VIS, NIR) using unmanned platforms (Muster et al., 2009).

1.4 Satellite Data Products

Operational NASA and ESA spaceborne missions provide multiyear remote sensing data to process optical, thermal and microwave products, such as averaged 'surface temperature', 'surface moisture' products, maps of vegetation and surface waters. The ESA DUE PERMAFROST datasets will be provided with weekly to monthly resolution. High-spatial resolution data are used at selected local sites. Further information is available at: www.ipf.tuwien.ac.at/permafrost

2 METHODS

Match-up data sets, i.e. field observations and satellite data coincident in time and location are being built up. Exclusion and selection criteria will be based on experience, especially the knowledge on parameter variability in time and space. This also will influence if point estimations or weighted averages, and a-priori logarithmic transformation are applied. Clustering and sub-setting of the match-up data will assess regional specific (e.g. vegetation and moisture dependent) and temporal specific (intra- and inter-annual) variations.

3 OUTLOOK.

We will identify systematic biases, conditions, for which the ESA DUE PERMAFROST products are invalid/valid, and provide an estimation of 'environmental' and 'thematical' accuracy to establish confidence in their utility.

References

- Langer, M., Westermann, S., Boike, J., Spatial and temporal variations of summer surface temperatures of wet polygonal tundra in Siberia-implications for MODIS LST based permafrost monitoring, *subm. to Remote Sensing of Environment*.
- Muster, S., Langer, M., Boike, J. 2009, Estimating seasonal changes of land cover, surface wetness and latent heat flux of wet polygonal tundra (Samoilov Island, Lena-Delta, Siberia) with high-resolution aerial and hyperspectral CHRIS Proba satellite imagery, AGU Fall Meeting 2009, San Francisco, USA, C51C-0491.

Landscape Pattern and Cryogenic Landsliding Hazard Analysis on Yamal Peninsula, Russia

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1 INTRODUCTION

Analysis of landscapes and cryogenic landsliding hazard at Vaskiny Dachi polygon located in the watershed of Se-Yakha and Mordy-Yakha rivers on Central Yamal in area of highly-dissected alluvial-lacustrine-marine plains and terraces is presented.

Landscapes of Vaskiny Dachi are represented by rolling hills, poorly drained, with prevailing herb-moss-shrub (up to 1,5 m high) tundra.

To analyse landscape pattern of Vaskiny Dachi, a landscape map was compiled. Mapped area (about 40 sq. km) is subdivided into 22 landscape complexes. Natural-antropogenic complexes (sandpit and vehicle tracks) are considered as well. Analysis of landscape map shows that potentially disturbed by cryogenic landsliding area is no less than 45% of total area of Vaskiny Dachi polygon.

2 LANDSLIDES DISTRIBUTION

On Central Yamal, cryogenic landsliding is a major surface process to control landscape dynamics.

Estimated is distribution of active layer detachment slides of 1989.

At Vaskiny Dachi most of the largest landslides (with area more 0,01 sq.km, and up to 0,08 sq.km each) are found on poorly drained lengthy gentle and concave landslide-affected slopes with ancient landslide shear surfaces, and subhorizontal hummocky-tussocky slopes adjacent to hilltops.

Landslides with area of 0,002 – 0,01 sq.km generally are linked to all the landscape units, more often to landslide-affected and concave shrubby slopes. Single landslides of this type occur on rather drained subhorizontal slopes with hummocky and tussocky tundra adjacent to hilltops, and drainage hollows, ravine, gully, and small stream valley slopes.

Small landslides (area less than 0,002 sq.km) are widely distributed on steep slopes of ravine and stream systems and frequently are linked to boundaries between these landscape complexes and rather drained edge parts of subhorizontal watersheds undercut by ravines and stream valleys. Sometimes such landslides occur on edge parts of rather drained subhorizontal hill tops near the lake depressions.

2.1 cryogenic landsliding hazard

To analyse cryogenic landsliding hazard of study area, landscape complexes are combined into 4 groups according to cryogenic landsliding hazard degree: minimal, average, high and maximal, based on estimation of geomorphic features, slope steepness, drainage, microrelief, vegetation associations and former landslide activity.

Landscapes with minimal and average hazard of cryogenic landsliding are low, mostly wet peatlands; gentle slopes adjacent to the higher geomorphic levels with well-developed moss cover; and khasyreis, lake terraces, beaches, and drainage hollows. Landslide shear surfaces of 1989 are also included in the group of minimal cryogenic landsliding hazard because of very low probability of repeated landsliding in nearest future. Probability of small-scale landsliding increases in immediate proximity of rather drained rolling hill tops, subhorizontal watersheds and lake depression slopes.

Lengthy slopes with small gradient rather favorable for vast landslides are also in high hazard group. Ravines, gullies and small river valleys are also included in the group of high hazard of cryogenic landsliding because of high potential of small-scale landslides on steep unevenly drained concave shrubby slopes with willows up to 1,5 m high.

Maximal hazard of cryogenic landsliding is assigned to concave shrubby slopes being ancient landslide shear surfaces; for landslide cirques and slopes, except landslide shear surfaces of 1989 where thermoerosion and thermokarst are developing after landsliding. Sandpit is not of a high landsliding hazard now because it is abandoned. There are only processes of bogging and thermokarst within excavations and deflation on surrounding sandy banks. Only steep slopes of these banks cutted by a river are favorable for small-scale landsliding. Also, cryogenic landslides could be triggered by vehicle tracks across slopes. Tracks crossing ravine heads could activate thermoerosion resulting in its turn in landsliding.

Warming-Induced Destabilization of Peat Plateau/Thermokarst Terrain

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1 INTRODUCTION

Large quantities of soil organic carbon are stored in northern peatlands located in the southern continuous and discontinuous permafrost zones, where permafrost degradation can be expected to occur as a result of changes in climatic conditions (Tarnocai, 2006). In this region, peat plateaus dotted with thermokarst lakes and fens are common landscape features. Permafrost thawing caused by warming or increased precipitation can result in increased thermokarst lake formation, lateral expansion and/or drainage. A better understanding, and quantification, of spatio-temporal variations in these landforms in relation to climate change is important for predicting the future thawing permafrost carbon feedback.

2 DYNAMICS IN THERMOKARST LAKE EXTENT

2.1 Aim, study area and methods

The objective has been to quantify dynamics in thermokarst lake extent in subarctic peat plateaus located along a climate/permafrost gradient during the last ~35-50 years. At three study sites; Hudson Bay Lowlands in west-central Canada, Rogovaya in east-European Russia and Tavvavuoma in northern Sweden, remote sensing time-series analysis of historical panchromatic aerial photographs and Quick-Bird/IKONOS scenes has been performed. For the land-water separation manual delineation in combination with binary encoding of transects perpendicular to the shoreline was used, as this method was identified to be most accurate for high spatial resolution mapping of thermokarst lakes (Sannel and Brown, in press).

2.2 Results

During the time period between image acquisitions in the mid 1970's and mid 2000's all three sites show similar trends with increasing mean annual air temperatures (MAAT) of 1-2°C, increasing winter precipitation (8-50%) and increasing ground temperatures (<1°C). In Hudson Bay Lowlands (located in the southern continuous permafrost zone with a MAAT of -6.6 to -4.9°C and ground temperatures

below -3°C) and Rogovaya (located in the discontinuous permafrost zone with a MAAT of -5.8 to -4.5°C and permafrost temperatures below -2°C) limited changes in lake extent have occurred. From the mid 1970's to the mid 2000's no lakes have drained and few new thermokarst ponds have formed. Conversely, in Tavvavuoma (located in the sporadic permafrost zone with a MAAT of -4.0 to -2.2°C and ground temperatures close to 0°C) lake drainage and infilling with fen vegetation has been extensive from 1975 to 2003 (~8% per decade), and 14 new small lakes have formed within a 1 km² area (Figure 1).

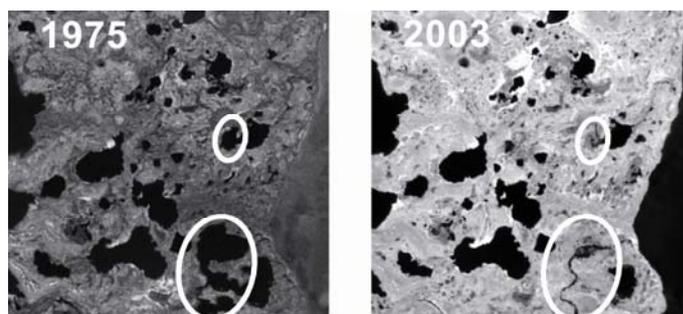


Figure 1. Examples of lake drainage and infilling with fen vegetation in a 1 x 1 km area in Tavvavuoma from 1975 to 2003.

2.3 Conclusions

Our results suggest that peat plateaus located in areas with MAAT below -4°C and with permafrost temperatures below -2°C have been stable during the last 35-50 years. In peatlands where ground temperatures are close to 0°C and the MAAT is warmer than -4°C, extensive lake drainage and infilling with fen vegetation has taken place and new thermokarst lakes have formed. In a future warmer and wetter climate, permafrost degradation will have a significant impact on landscape patterns and greenhouse gas exchange also in the extensive peat plateaus which are at present still relatively stable.

References

- Sannel, A.B.K. & Brown, I.A. in press. High resolution remote sensing identification of thermokarst lake dynamics in a subarctic peat plateau complex. *Canadian Journal of Remote Sensing*.
- Tarnocai, C. 2006. The effect of climate change on carbon in Canadian peatlands. *Global and Planetary Change* 53: 222-232.

Detecting and Quantifying Permafrost Creep with Space-Borne Radar Interferometry (InSAR) in the Canton of Ticino (Southern Switzerland)

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1 INTRODUCTION AND METHODOLOGY

The main goal of this research has been to obtain a regional overview, and data about permafrost creep in the Southern Swiss Alps, in particular in the Canton of Ticino. A large set of space-borne Synthetic Aperture Radar interferograms (InSAR) has thus been analyzed (with the support of the Swiss Federal Office for the Environment). The same methodology, as for researches carried out with InSAR in other regions of the Swiss Alps (e.g. Delaloye *et al.*, 2007), has been applied for inventorying land-movement polygons (i.e. InSAR-detected signals) and the corresponding alpine landforms in the whole study area.

InSAR investigations present intrinsic methodological limits due to the subjectivity of the interpretations by operators. In order to evaluate the quality of the results on the base of the specific characteristics of the studied region, particularly the land cover (presence of vegetation, lakes, snow, glaciers, etc.) and the regional climatic framework, our test area has been subdivided in 24 regions to have homogeneous morphological and climatological parameters.

2 RESULTS AND DISCUSSION

The analysis of the InSAR interferograms allowed us to inventory 177 polygons of land-movements, with displacement rates ranging from cm/d to cm/y. Most of the detected movements are the result of alpine permafrost creep (76 polygons have been identified as active rock glaciers) and glaciers movement (28 polygons have been attributed to debris-covered glaciers). The position of the detected movements attributed to permafrost creep shows a good correspondence with the regional model of potential distribution of discontinuous permafrost in the area (C. Scapozza, unpublished data).

At the regional scale, there is no observable difference in the frequency distribution of polygons between the western and the eastern part of Ticino. However a difference concerns the velocity of the inventoried landforms (in particular the rock gla-

ciers): in general landforms in the western Ticino Alps tend to move more rapidly than the landforms in the eastern part. This apparent difference could be attributed, on the one hand, to the more important occurrence of glaciers (which are almost completely covered by debris at present-day – if still subsisting) and their possibly former influence (in particular during Little Ice Age) on the structure and dynamics of several rock glaciers in the western Ticino Alps, and on the other hand to larger mean annual precipitations in the latter region.

In addition to the analysis of maps, aerial photos and field observations, the inventory of land-movements carried out with InSAR has been successfully used to elaborate a catalogues of rock glaciers in the Ticino Alps (Scapozza and Mari, 2010). The catalogues consists of 203 rock glaciers, of which 56 have been considered active, 35 inactive and 112 relict. Active and inactive/relict rock glaciers have been differentiated on the base of the analysis of InSAR interferograms, and inactive and relict rock glaciers have been differentiated on the base of their topographical and morphological characteristics.

In order to improve the InSAR displacement rate classification and to downscale from the regional to the local level, 10 rock glaciers in the Southern Swiss Alps have been selected on the base of the detected InSAR signatures. These rock glaciers are currently the object of thermal and geophysical prospecting for studying their internal structure and surface thermal regime, and of GPS monitoring for surveying their kinematics.

References

- Delaloye, R., Lambiel, C., Lugon, R., Raetzo, H., Strozzi, T. (2007). ERS InSAR for detecting slope movement in a periglacial mountain environment (western Valais Alps, Switzerland). *Proceedings HMRSC-IX, Graz, 14-15 Sept. 2006, Grazer Schriften der Geographie und Raumforschung* 43, 113-120.
- Scapozza, C., Mari, S. 2010. Catasto, caratteristiche e dinamica dei rock glaciers delle Alpi Ticinesi. *Bollettino della Societa ticinese di Scienze naturali* 98: in press.

Northern Hemisphere Permafrost Changes Associated with GRACE-Derived Water Storage, MODIS-Derived Land Surface Temperature Changes

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1 ABSTRACT

Climate-change driven changes in water storage and land surface temperature in the northern hemisphere have potential for wide reaching changes of permafrost. We investigate observations of water storage changes from the Gravity Recovery and Climate Experiment (GRACE) mission and land surface temperature changes from the Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature from August 2002 through 2009. We use satellite-derived snow water equivalent and in situ measurements of river runoff for comparisons of seasonal water mass changes. Trends of water mass storage are increasing in the watersheds underlain by continuous permafrost of the eastern Eurasian Lena, Yenisei and the western North American Arctic coastal plain. The Ob' watershed in western Eurasia is predominantly underlain by non-permafrost and while increasing in water mass storage it is a managed watershed for commerce and hydroelectric power generation (i.e. anthropogenic effects are present). Water mass storage is decreasing in watersheds underlain by discontinuous permafrost of the Mackenzie and Yukon in western North America. Land surface temperature changes show spatial correlation with water mass storage changes on the northern hemisphere. This suggests heat transfer by water is important in permafrost degradation and aggradation. Therefore, pathways within permafrost must exist, facilitating permafrost changes through negative and positive feedback mechanisms. We hypothesize that the development of new and increases of existing closed and open taliks are the pathways facilitating the changes of the northern hemisphere permafrost.

High Resolution Low Cost Ice-Wedge Mapping by Mini Unmanned Aerial System

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1 INTRODUCTION

Low altitude remote sensing using unmanned aerial systems (UAS) is a relatively new method and promises high resolution images on demand, cost effective and with low environmental fingerprint. The UAS technique thus overcomes major disadvantages of conventional manned aerial surveys or satellite missions. Both needs to be planned long in advance at high financial and environmental costs. With this in mind a mini UAS was deployed above ice-wedge polygons in Adventdalen, Svalbard during snow melt and summer of 2009.

2 METHODS

The UAS covered a 0.5km² study site, followed a predefined flight path (X,Y,Z). Flying at 380m above ground, the unmanned aerial vehicle obtained 75 overlapping images. By post processing the images were combined to a mosaic, georeferenced and ortho rectified.

Table 1. Technical data of the unmanned aerial system.

Wingspan	2.6m
Weight vehicle	2.2kg
Propulsion	electric
Range (horizontal)	5km
Range (vertically)	1000m
Endurance	30min / 30km / 1km ²
Weight system	30kg

3 RESULTS AND DISCUSSION

The resulting image mosaic features a large amount of surface details and has a pixel resolution of 4 cm. The image was used to create a base map of the study area, and to map the polygon extent and geometry of the ice-wedges. This was done in larger detail than possible before on standard aerial photographs. During snow melt the UAS was deployed right in time to accurately document the distribution of snow cover and bare ground. Compared to low flying airplanes and even though flying at low altitudes, no disturbance of wildlife were noticed during

the mission. Due to its small size and electric propulsion the UAS has a very low environmental impact locally and globally.

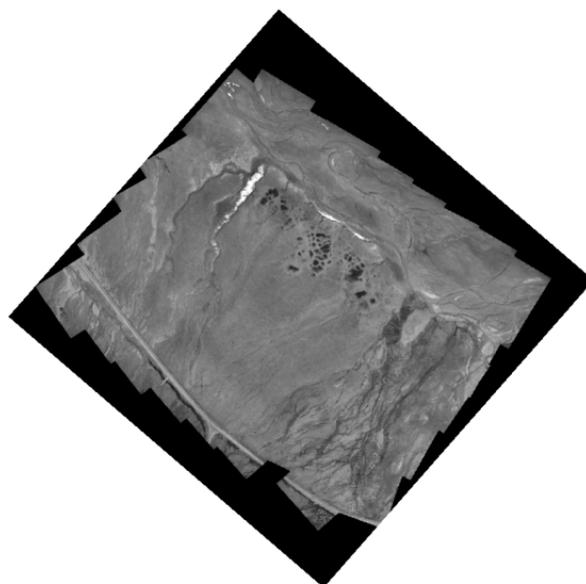


Figure 1. Aerial image mosaic of the ice-wedge study area in Adventdalen, Svalbard. The images were taken on 20th of June 2009 at 380m above ground from an mini unmanned aerial system. The mosaic is constructed out of 75 individual images. North is up.

4 CONCLUSIONS

With the use of UAS we were able to obtain high-quality images compared to most other remote sensing data currently available for the area, and at low cost and exactly at the demanded time and meteorological conditions. Especially when dealing with fast progressing and largely meteorologically controlled geomorphological processes, such as snow melt or surface water, the “on demand” service is a crucial advantage of the UAS service. Besides being a cost effective method, the UAS is well received by local authorities, and its development partly sponsored by the Svalbard Environmental fund. By overcoming many of the disadvantages which characterize conventional remote sensing techniques, the UAS enters a new and wide range of applications.

Using AVNIR-2 and ETM+ Sata to Detect Thermokarst Affected Surface Structures on Kurungnakh Island, Lena River Delta, Siberia

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1 INTRODUCTION

Thermokarst structures are common features in the ice-rich permafrost deposits of the arctic coastal lowlands. These deposits have been subject to extensive melting during warm periods since the Late Pleistocene – Early Holocene.

Thermokarst and thermo-erosion leads to a change in the drainage patterns which is reflected in different vegetation communities. The slope areas are dry compared to the moist to wet bottoms. The bottoms are either occupied by hydrophilic plants or – in thermokarst depressions – are filled by lakes or contain lake remnants.

Multispectral remote sensing methods (in combination with topographic data) are suitable to detect these surface types because of their distinct spectral properties and are therefore a useful tool to quantify the magnitude of permafrost degradation.

2 STUDY SITE AND METHODS

Investigations were carried out at Kurungnakh Island (72°20'N, 126°18'E) in the southern Lena River Delta (Russia).

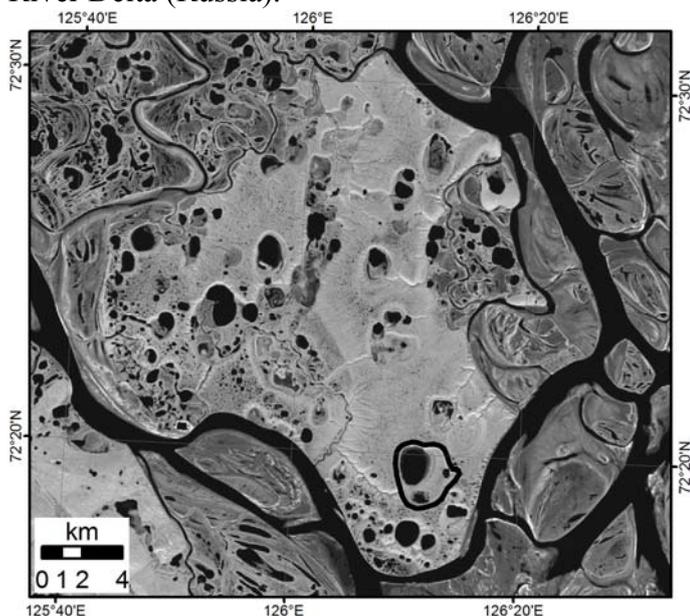


Figure 1. ETM+ subset (band 5) of Kurungnakh Island, the black frame marks the investigated thermokarst depression

The island belongs to the third geomorphologic terrace and is composed of ice-rich permafrost (i.e. ice-

complex deposits). The main research area (fig. 1) is a large (7.5 km²) thermokarst depression with the adjacent ice-complex uplands (i.e. Yedoma).

Various surface parameters (active layer depth, meso- and micro relief, water bodies and vegetation properties) were recorded at 284 sites during fieldwork in summer 2008. This dataset could be used for training in supervised maximum likelihood classifications of ALOS AVNIR-2 and Landsat-7 ETM+ data.

Digital Elevation Models (DEMs) derived from topographic data in different resolutions and sources (tachymetric surveys, topographic maps) as well as a soil adjusted vegetation index (SAVI) were considered in the classification approach.

3 RESULTS AND DISCUSSION

Following an upscaling approach, classifications were subsequently performed by enlarging the spatial scales (from the depression to the whole island) and by using coarser geometric resolutions (i.e. ETM+).

24 surface classes could be distinguished; including four water classes. Within the thermokarst depression, two additional classes were separated by using AVNIR-2 data and the very high resolution DEM derived from tachymetric survey.

Since the separation of the different classes was often only possible with the aid of digital elevation data or the derived slope map, the surface classes were merged into 13 “final” classes (10 land, 3 water classes). These classes were used to delineate typical thermokarst terrain types. Therefore, the class composition of manual mapped structures was compared and interpreted.

Within the thermokarst depressions, moist to wet surfaces (often with large water bodies) dominate. The vegetation consists of peat moss and sedges. On the Yedoma, drier surfaces are mostly occupied by mosses and dwarf shrubs. The slope areas are the driest surfaces in the investigated area.

Depending on the interpretation of the final classes in terms of thermokarst degradation, 56-75% of the ice-complex area of Kurungnakh Island is influenced by thermokarst.

Energy and Water Vapour Fluxes in the Arctic Tundra Landscape: How Can SAR Data Facilitate Upscaling?

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1 MOTIVATION

Energy and water vapour fluxes are important factors for the understanding of terrestrial ecosystems. While meteorological measurements provide necessary information for selected locations, an upscaling of the fluxes requires additional information, especially for heterogeneous environments like the polygonal tundra landscape. Spaceborne Synthetic Aperture Radar (SAR) is a valuable tool as it works independent from cloud cover and sunlight. SAR data can be used to determine spatial and temporal distribution of parameters such as soil moisture, changes in vegetation, timing of snowmelt during spring, freezing of active layer during autumn, and freezing and thawing of lakes, ponds and river arms.

2 INVESTIGATION AREA

The Lena Delta is located in Northern Siberia (72.0-73.8°N, 122.0-129.5°E). It covers 29000 km² and is the largest Arctic River Delta. The Delta consists of three different geomorphologic terraces. The first terrace is characterized by ice-rich deltaic sediments and consists of a polygonal tundra landscape dominated by sedges and a moss cover. The second terrace consists of mineral soils and is covered by dry tundra vegetation and thermokarst lakes. The third terrace is composed of so called Ice Complex deposits and dominated by moss carpets and dwarf shrubs. The Delta is characterized by a network of several river arms, countless channels and an innumerable amount of lakes. Approximately 30 % of the Delta is covered with water bodies.

3 METHODS

3.1 Climate data

On Samoylov, a small island located in the southern center of the Lena River Delta, a meteorological station is in operation since 1998. The climate data including soil moisture and temperature obtained from this station are used as reference for the satellite data.

3.2 SAR data

In order to cover the entire area of Lena Delta in one scene, images with a high spatial coverage are required. In this study ASAR Wide swath images are used to cover the entire investigation area (Figure 1). The effective spatial resolution of the images is 150 m, which is a suitable scale for such ecosystem analysis. Change detection algorithms are applied to a series of ASAR WS images all year round.

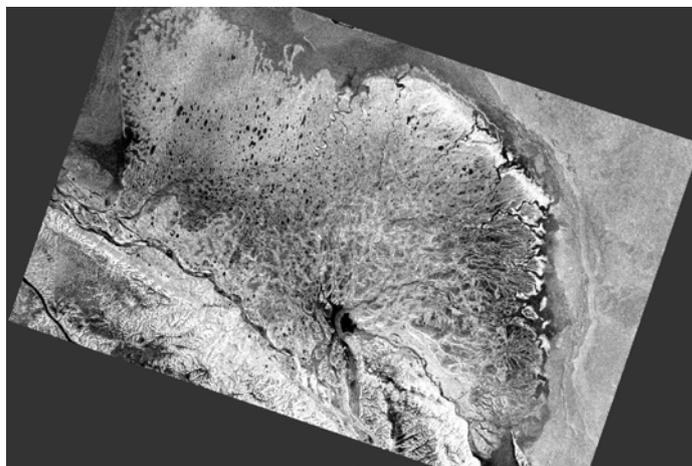


Figure 1. ASAR Wide Swath of the Lena River Delta. Image dated 29.05.2008.

4 FIRST ANALYSES

Open water surfaces play a significant role in the energy and water fluxes. Thus, the formation of ice on water bodies will change the distribution and quantity of fluxes. In this study the timing of thawing and freezeback is determined for selected water bodies of different sizes located in each of the geomorphologic units.

5 OUTLOOK

Future analyses will deal with the spatial distribution of thawing and freezing dates of the active layer at the land surfaces. We will also concentrate on the vegetation growth during summer month and the distribution of snow cover during winter month. Finally we will derive the spatial and temporal variations of soil moisture.

Remote Sensing and GIS Analysis of Spatial and Morphological Changes of Thermokarst Lakes: Kolyma Lowlands, Northeast Siberia

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1 INTRODUCTION

Understanding thermokarst lake changes is important because as lakes initiate, expand, and drain, these changes impact permafrost, hydrological patterns, vegetation cover, and carbon cycling. Permafrost soils contain large amounts of organic carbon and upon lake-driven thaw and decomposition, large amounts of carbon dioxide and methane are released. Ongoing climatic warming likely will impact permafrost stability and changes in thermokarst lakes distribution. This study examines spatial dynamics in lake distribution and lake area in the continuous permafrost zone of the Kolyma River Lowland in Northeast Siberia using high-resolution remote sensing data for the last 42 year period.

1.1 Study Regions

Two study regions in the Kolyma Lowlands of Northeast Siberia were selected based on available high-resolution imagery: Study region 1, Duvanny Yar, covers about 410 km²; Study region 2, Cherskii, covers about 340 km². Though both regions contain various permafrost types, they are dominated by relatively cold, continuous, ice-rich permafrost rich in organic carbon. The majority of the study region is less than 60 m above sea level. The climate is extremely continental with an average annual temperature between -10 and -15 Celsius.

1.2 Methods

To characterize spatial and morphological changes in thermokarst lakes GIS and remote sensing analysis was used. Lake polygon datasets were derived from high-resolution (2.5 m) ALOS Prism (2007) and Corona (1965) images allowing identification of lake changes over a 42 year period. A DEM and geological map were used for further lake analysis in a GIS environment.

2 RESULTS

2.1 Study Region 1 (Duvanny Yar: 65.3N/158.5E)

Study region 1 total lake area in 1965 and 2007 respectively is 42 740 ha and 40 502 ha. This region showed an overall decrease in lake area of 5.2%, ac-

counting for 2 238 ha. The limnicity (lake area per study region) of 10.4% in 1965 decreased to 9.9 in 2007.

Of the 3 129 lakes in 1965, 133 lakes showed drainage greater than 20% by area and 13 lakes drained completely by 2007. The highest normalized lake drainage values for 100 ha geological unit were located in the alluvial and loess-like lacustrine alluvial deposits with values of 0.6 and 0.7 ha respectively.

2.2 Study Region 2 (Cherskii: 68.4N/161.5E)

Study Region 2 total lake area for 1965 and 2007 respectively is 47 187 ha and 50 809 ha. This region showed an overall increase in lake area of 7.6%, accounting for 3 622 ha. The limnicity increased from 13.9% in 1965 to 14.9 in 2007.

167 lakes drained more than 20%, 14 lakes drained completely. Lake area drained amounted to 1 762 ha. This region is heavily influenced by the Kolyma River and therefore consists largely of alluvial deposits. The largest normalized increase in lake area for 100 ha geological area was in the lacustrine deposits and alluvial marine deposits; values ranged between 2.0 and 2.3 ha.

3 DISCUSSIONS AND CONCLUSIONS

Lakes in both study regions are expanding and draining. Both process are occurring simultaneously and appear to be caused by permafrost degradation. Location and factors like underlying geology, ice content and elevation likely determine the net result of lake changes. Many of the drained lakes drained catastrophically, as observed from the existence of drainage channels. Region 1 showed the most drainage in alluvial deposits. These deposits are heavily influenced by changes in river flooding and the creations of drainage channels. Region 2 showed the largest increase of lake area in older lacustrine deposits. These deposits consist mostly of smaller, silt sized particles.

Studies of thermokarst lake dynamics allow assessments of permafrost thaw, changes in arctic ecosystems, and permafrost carbon pool dynamics. Understanding thermokarst lakes is a crucial component to better understand arctic environments.

Assessment of Temporal, Scale and Surface-Cover Effects on the GST-LST Relationship in the Russian Altay Mountains

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1 INTRODUCTION

1.1 General

The Russian Altay Mountains are a challenging area for large scale permafrost modeling. The lack of meteorological data, strong temperature-inversions, rapid changing snow cover patterns and complicated landcover demand an in-depth approach. As a solution, time and spatially covering MODIS land surface temperature (LST) might be used as a proxy replacing the interpolated air and ground surface temperatures (GST).

Recent studies show the potential of this method on large areas (e.g. Canadian Arctic, Siberia), by using sinusoidal fits to eliminate the data-gaps both spatially as temporally out of the time-series. These studies use isotherms and analytical solutions for freezing and thawing to model permafrost distribution. However to use the LST-values as an upper boundary condition at heterogeneous mountain ranges as the Russian Altay, further research needs to be conducted. In detail the relation between this parameter and surface temperatures beneath areas covered with snow and vegetation requires more attention. In addition the effect of sub-pixel variability and topographic influence needs to be considered as the LST pixels come at 1km resolution.

1.2 Study Area

This study tries to answer these questions by showing results of 96 surface temperature time-series recorded in and around the valley of Dzhasator and on the Tarkhata plain (Kosh Agatch District) from July 2008 until July 2009, areas both characterized by discontinuous permafrost.

2 METHODS

2.1 Ground Temperatures

96 iButtons and 14 Onset dataloggers were installed in order to cover surface temperatures beneath a broad range of landcovers, different topographical positions and in grids to measure the sub-grid variability.

2.2 Satellite Imagery

At first the instant relationship between LST and GST was examined by using 60m resolution Landsat LST. Therefore LST was derived out of 6 atmospherically and topographically corrected Landsat scenes, obtained during cloud-free days and snow-free periods.

MODIS LST timeseries for the corresponding observation period were downloaded, cleaned up and interpolated by using air temperature.

2.3 Correlations

Firstly, for both the MODIS as Landsat LST, the instantaneous ratio with the corresponding GST was examined and correlations with NDVI (Normalized Difference Vegetation Index) were calculated to examine the vegetation offset.

Furthermore also the seasonal ratios (limited to the continuous MODIS LST timeseries) were calculated and again correlated to phenological parameters obtained out of the corresponding NDVI timeseries.

The resulted relationship was used to model snow-free GST solely out of LST and NDVI timeseries while these predictions were validated with certain loggers which had a small malfunction.

3 RESULTS

Correlations between NDVI and the GST/LST ratio are weak during the instantaneous moment of a satellite overpass while in contrast, relatively strong correlations (0.75) are shown when seasonal degree days (DDT_{GST}/DDT_{LST}) are related to phenological parameters.

4 CONCLUSIONS

This study shows the potential of this method, if temporal, scale and surface effects are considered.

Snow Cover in Livingston and Deception Islands (Maritime Antarctic). Multi-Temporal Analysis of ASAR Imagery of 2009

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ASAR images from Envisat are analyzed to map snow cover during 2009 in Deception and Livingston Islands (South Shetlands, Antarctic Peninsula). The study is part of the project PERMANTAR-2 focusing on monitoring and modeling the thermal regime of permafrost in the South Shetlands. Snow cover is one of the main environmental factors controlling ground temperature regimes and permafrost distribution. Therefore, mapping snow cover becomes of utmost significance for permafrost modeling and mapping.

For a GIS-based spatial modelling of snow cover distribution, spatially distributed data is required and the exploration of microwave remote sensing is a suitable technique for mapping the snow cover characteristics and regime. This becomes especially true due to the long winter night and unstable weather conditions of the northern Antarctic Peninsula region. For this purpose a multi-temporal ASAR imagery analysis was conducted. To distinguish wet snow cover from snow free terrain, we used the absorption dependency of the radar signal on the liquid water content of the snow to set a threshold on the differential backscatter between scenes. Snow depth can be obtained using polarimetric SAR using the differences between the VV – and HH polarized backscattering coefficients.

The imagery was analyzed using the processing chains from NEST (ESA SAR Toolbox). Preliminary results of the analysis of the time-series show strong seasonal changes in the backscattering due to the variations of liquid water content in snow (figure 1). Validation of the results obtained from the microwave imagery is done using the ground truth data: i) time-lapse cameras at key-sites, ii) ultra-sonic sensors of snow thickness and, iii) probes with snow temperature mini-loggers. This data is used for the calibration of the results and this poster shows the first results of image classification and validation.

Satellite imagery is provided by the European Space Agency in the framework of the Proposal Category-1: Snow cover characteristics and regime in the South Shetlands (Maritime Antarctic) - SnowAntar.

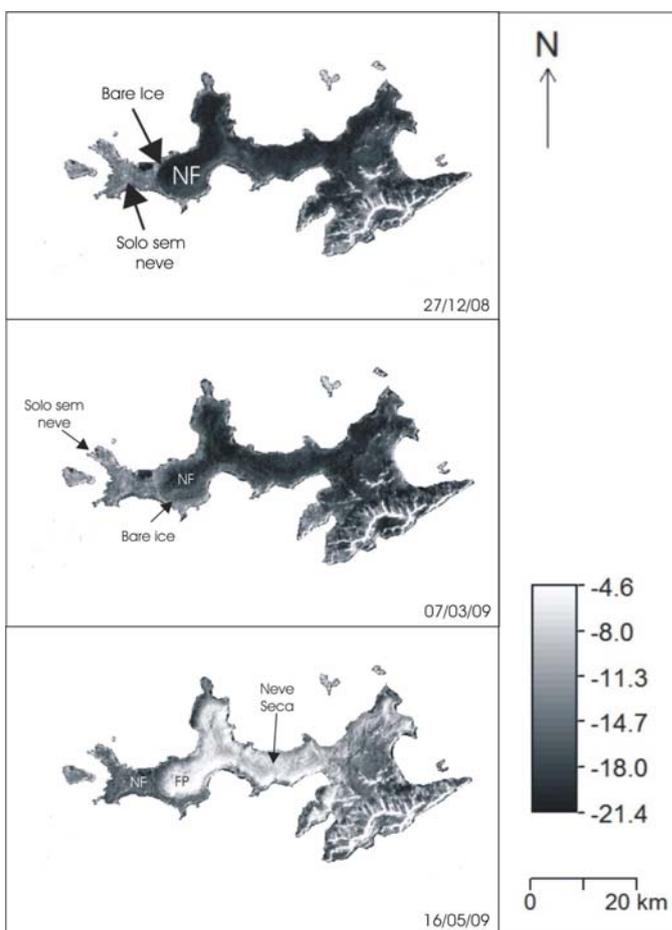


Figure 1. Backscattering for 27 December 2008, 7 March and 16 May 2009.

Cornice Development, Cracking and Failure and Triggering of Cornice Fall Avalanches on Gruvefjellet in Longyeardalen, Svalbard

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1 MOTIVATION & SCOPE

On 30 March 2009 a large snow avalanche was triggered by a falling cornice on Gruvefjellet, a plateau mountain representing the eastern limit of Longyearvalley. This avalanche crossed the street between Longyearbyen and Nybyen, one UNIS student had a narrow escape. It also destroyed two about 70 year old cable car towers from the old mine within the Gruvefjellet slope.

For a better understanding of these natural processes that endanger life and infrastructure in Longyearvalley, we investigate the cornice development, cracking and consequent failures that lead to cornice fall avalanches, the meteorological influence on these processes, their geomorphologic impact and the given topographic situation.

2 STUDY AREA

Nybyen as part of the main settlement Longyearbyen in Svalbard is situated at the southern end of Longyeardalen. Around a dozen houses are built on old avalanche deposits. During winter and spring, over 100 students and as many tourists live in these houses right underneath the Gruvefjellet slope. The plateau mountain Gruvefjellet rises to a maximum altitude of 525 m asl. its westfacing crest to about 460 m asl.. Nybyen is situated at about 125 m asl., which results in a vertical drop for potential cornice fall avalanches of nearly 335 m.

The prevailing winter wind direction is from SE, thus the cornices form along the ridgeline of the plateau. Additionally the westfacing slope is loaded by wind slabs right beneath the cornices due to its leeward position. These areas are prone for avalanche release.

3 CORNICE GENESIS

Cornices are a wedge-like projection of snow formed by wind deposition on the lee side of a ridgeline or slope inflection. Cornices form by downwind accretion of snow particles in successive outward as well as upward extending layers. Cornice growth is the result of a prevailing winter wind direction in combination with sufficient source area and the

geomorphological setting. Due to the plastic behavior of snow, cornices successively creep downwards with gravity as the primarily force. As these processes are proceeding, tension fractures tend to open between the cornice mass and the headwall of the plateau.

4 METHODS

Two automatic time lapse cameras take daily pictures of the whole Gruvefjellet slope, to observe avalanche activity, and on the ridgeline, to monitor the cornice development and cracking. Furthermore stakes on plateau are used to record snow depth distribution and cornice growth. Frequent field trips up the plateau are carried out to study the processes and to manually measure cornice crack opening rates.



Figure 1: Cracked and tilted cornice along Gruvefjellet ridge

Meteorological data are recorded at an automatic weather station situated on the Gruvefjellet plateau source area.

5 RESULTS & DISCUSSION

Cornices are found to have developed to distinctive size within a relatively short period, less than two month after the first snowfall. In 2009 the first cornice cracks were observed in mid April, while in 2010, probably due to persistent warm weather in combination with large precipitation, cornice cracks were already developing at the end of January. The cornice crack measurements of 2009 showed a linear development, indicating the major influence of gravity. Since 2006 more than 70 cornice fall avalanches have been recorded in the slope section above Nybyen, more than 15 reached the pronounced avalanche fans where the houses stand. Cornice blocks may tumble down the entire slope, or trigger slab avalanches due to their impact and fan out in the lower part of the slope. Cornice fall avalanche occur throughout the entire snow season, though the majority is released towards May/June due to warm temperatures and direct solar radiation.

Posters Wednesday, cont.

Mathematical and Physical Modeling of Permafrost: *in UNIS Entrance Hall*

22. **Longterm Monitoring of Permafrost Creep in Switzerland**
I. Gaertner-Roer, R. Delaloye, A. Kääh, C. Lambiel
23. **Regional Scale Mapping of Permafrost Distribution in Norway Using the TTOP Model**
K. Gislåås, H. Farbrot, B. Etzelmüller, T.V. Schuler
24. **Ground Temperature Trends in Alpine Permafrost**
E. Zenklusen Mutter, J. Blanchet, M. Phillips

Longterm Monitoring of Permafrost Creep in Switzerland

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During the last decade, an increasing number of studies quantified permafrost creep and investigated spatio-temporal variations thereof, in particular in the European Alps. The main purpose was and still is to better understand the dynamics of rockglaciers and creeping talus slopes, and to investigate how current atmospheric warming influences these landforms. This is of scientific interest, but also related to hazard potentials (e.g. rock fall from rockglacier fronts) as well as geotechnical problems (e.g. construction instabilities).

Within the PERMOS (Permafrost Monitoring Switzerland) network, rockglacier kinematics were analyzed right from its beginning 10 years ago at 8 different sites in the Swiss Alps. For the selected rockglaciers repeated aerial images from low flying height were used to measure surface displacements. With respect to the strong interannual velocity variations recently measured in other projects, PERMOS reacted and faced the challenging task to measure and document permafrost creep variations during the next decades. Existing and new data series from annual terrestrial surveys (dGPS and total station) are included in the monitoring strategy from 2007 on and actually 13 sites are monitored (PERMOS 2010). Nevertheless, repeated aerial surveys are conducted every 5 – 7 years.

Beside the general background and the monitoring strategy, we will introduce in this contribution the appropriate methods used as well as first results from different monitoring sites in Switzerland.

References

PERMOS 2010. *Permafrost in Switzerland 2006/2007 and 2007/2008*. Noetzli, J. , Naegeli, B. and Vonder Muehll, D. (eds.), Glaciological Report Permafrost No. 8/9 of the Cryospheric Commission of the Swiss Academy of Science.

Regional Scale Mapping of Permafrost Distribution in Norway Using the TTOP Model

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1 INTRODUCTION

Previous regional permafrost mapping in Norway has been based exclusively on mean annual air temperatures (MAAT). However, many other factors have a decisive importance for the ground temperature regime, as the distribution and duration of snow cover, vegetation and thermal properties in the active layer. The TTOP-model originally developed in Canada by *Smith & Riseborough (1996)* defines the temperature at top of the permafrost, based on annual freezing- and thawing degree days, seasonal n-factors parameterizing the vegetation and snow cover, and the conductivity ratio between frozen and thawed states in the active layer. A first implementation using the TTOP-model is now made with 1km resolution for a 100x100km area in central southern Norway.

The area has a complex topography, with alpine mountains up to 2500 m a.s.l. The regional lower limit of mountain permafrost is situated above 1400-1700 meters (east-west gradient; *Etzelmüller et al. 2003*), but palsas are also found at lower elevations. The model is based on operationally gridded temperature- and snow data from the period 1970-2000, provided by *senorge.no*.

2 FIRST RESULTS

The TTOP results in this study agrees relatively well with observations. Compared to estimates based on MAAT only, the TTOP-model shows a better representation of the observed east-west gradient mostly due to taking the snow distribution into account. Sporadic permafrost which is absent in previous regional modelling is now reproduced, mainly resulting from the integration of sediment conductivity data. However, the varying topography introduces challenges related to snow distribution and ground thermal properties. The largest error sources are n-factors for snow (nf-factors) and the thermal regime in block field areas. Nf-factors varying with annual average snow depth are not transferable from Canada, mainly because the climatic conditions and associated snow properties are different. Nf-factors based on Norwegian measurements are currently under development. Large parts of the permafrost

areas in Norway are covered by block fields. However, current available digital sediment maps do not cover block fields sufficiently well. New classifications are currently under development. Better models for the temperature regime in block fields are also necessary. Despite the above mentioned challenges the TTOP model shows promising results for simple regional scale mapping of permafrost in Norway.

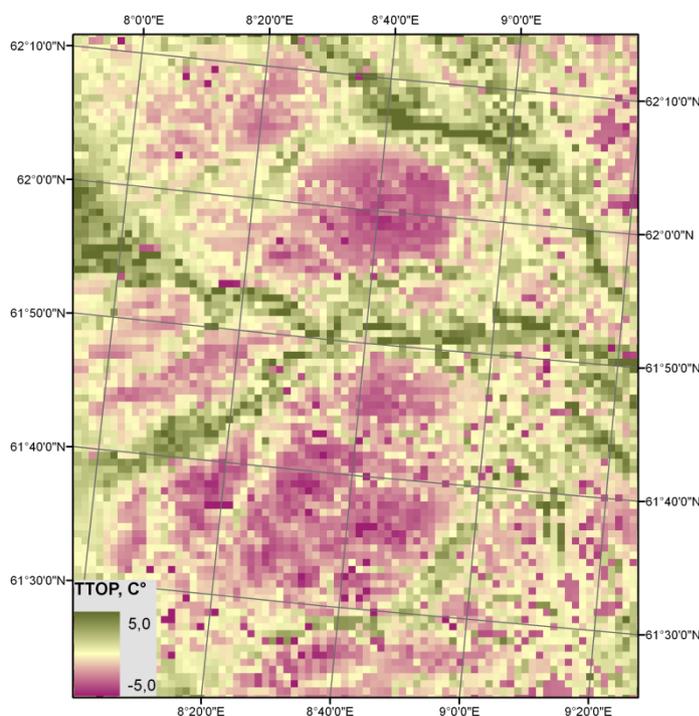


Figure 1. TTOP for an area of 100x100 km in central southern Norway.

References

- Etzelmüller, B., Berthling, I. & Sollid, J.L. 2003. Aspects and Concepts on the Geomorphological Significance of Holocene Permafrost in Southern Norway. *Geomorphology* 52: 87-104
- Smith, M., & Riseborough, D. 1996. Permafrost Monitoring and Climate Change. *Permafrost and Periglacial Processes* (7). 301-309.

Ground Temperature Trends in Alpine Permafrost

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1 INTRODUCTION

Varying snow depth, scree cover, complex topography and hydrology alter the ground thermal regime in Alpine permafrost. Furthermore ground temperature data series exhibit a pronounced annual cycle and are serially correlated. Trend estimation for such time series is not trivial and hence often only annual values are analyzed. However, linear trends estimated from annual temperatures are usually not robust for short measurement periods. To overcome these difficulties, we introduce different statistical models for trend estimation in time series with annual cycles and a daily data base.

2 TREND ESTIMATION

2.1 Model descriptions

Eight different models, able to fit overall trends as well as trends in the annual cycle amplitude, plus one model devoid of any periodicity have been proposed. Ordinary least squares model fitting should not be applied due to the serial dependence of ground temperatures. Generalized least squares fitting with autocorrelated errors is considered to account for this dependence.

Each model was fitted to each ground temperature time series separately and Akaike's Information Criterion was then used to select the model which best explains the data with a minimum of free parameters. For details, see Zenklusen Mutter et al. (submitted).

2.2 Results for one study site

Evaluation and comparison of the models is demonstrated using permafrost temperature series from the borehole MDP-B2 in the Muot da Barba Peider ridge in the Eastern Swiss Alps (Fig. 1).

The results for MDP-B2 are shown in Table 1. The detected trends show warming warm periods (crests) and cooling cold periods (troughs) to a depth of 10 metres. This increase in cycle amplitudes (i.e. increase in variability) mostly happens inside near-surface coarse-blocky layers. Deeper down in the solid bedrock where annual cycles are less pronounced an overall warming trend has been found.

Table 1. Trends [$^{\circ}\text{C}/\text{yr}$] for daily borehole temperature data at MDP-B2. Standard errors (s.e.) of the estimations are printed in brackets. All trends are significant on the 5%-level.

Depth	model R^2	Trend magnitudes [$^{\circ}\text{C}$]	
		Crests (s.e.)	Troughs (s.e.)
0.5 m	0.792	0.123 (0.048)	-0.123 (0.048)
1.0 m	0.799	0	-0.148 (0.055)
2.0 m	0.760	0	-0.094 (0.036)
3.0 m	0.736	0.042 (0.018)	-0.055 (0.025)
4.0 m	0.717	0.047 (0.014)	-0.047 (0.014)
6.0 m	0.683	0.035 (0.010)	-0.035 (0.010)
8.0 m	0.614	0.027 (0.006)	-0.024 (0.006)
10.0 m	0.508	0.023 (0.005)	-0.023 (0.005)
13.5 m	0.633	0.025 (0.004)	0.025 (0.004)
17.5 m	0.885	0.028 (0.003)	0.028 (0.003)

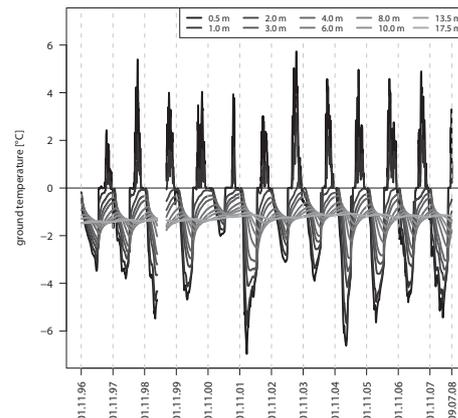


Figure 1. Ground temperature series measured at different depths between 0.5 and 17.5 m in borehole MDP-B2.

3 RESPONSIBLE PROCESSES

The decreasing temperature trends for the cold periods can be explained by different processes, such as the cooling effect of the scree itself, intra-talus ventilation or external influences like changes in the snow cover. The warming inside the deeper bedrock is more difficult to explain. It might be induced by increased intra-ridge heat transfer from the warmer southern flank towards the colder northern one.

References

Zenklusen Mutter E., Blanchet J., and Phillips M., (submitted). Analysis of ground temperature trends in Alpine permafrost using generalized least squares. Submitted to the *Journal of Geophysical Research*.

Posters Wednesday, cont.

Soil Carbon Microbiology and Trace Gas Release in Permafrost Environments:

in Kapp Lee

25. **Monitoring of Soil Temperature and CO₂ Emission from Tundra Soil in Nyålesund, Svalbard**
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Peter Frenzel, Stephanie Hainbuch, Alexandra Hahn, Mette M. Svenning
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M.L Geai, K.M. Walter Anthony, M. Engram
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Yoo Kyung Lee, Hye Min Kim
34. **Seasonal Variation in CH₄ Fluxes from a Greenlandic High Arctic Fen**
T. Tagesson, M. Mölder, M. Mastepanov, N. Pirk, A. Lindroth, T.R. Christensen, L. Ström, C. Sigsgaard, M.P. Tamstorf, J.M Falk, M. Lund
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36. **First Insights from Biomarker Composition & Compound-Specific ¹⁴C Analysis of Permafrost Soils, Suspended Particulate Matter and Sediments**
M. Winterfeld, J. Rethemeyer, G. Mollenhauer

Monitoring of Soil Temperature and CO₂ Emission from Tundra Soil in Ny-Ålesund, Svalbard

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1 INTRODUCTION

Northern ecosystems contain an estimated 25- 33% of the world's soil carbon (Oechel and Vourlitis, 1995). Due to the large quantities of carbon (C) stored in tundra, the Arctic plays an important role in global C budgets. The Arctic soil will influence how northern ecosystems respond to global warming by acting as a carbon source or sink to the atmosphere, controlling energy balance at the earth's surface and serving as a source of nutrients for plant growth (Marion et al., 1997). The study of soil CO₂ emission has been widely investigated through artificial control of the environment in the laboratory and in situ measurements in Norway, Alaska, Canada and Greenland. Soil temperature is one of the most important environmental factors for soil CO₂ emission. The objectives are to report the monitoring of soil temperature and soil CO₂ emission.

2 METHODS

Soil temperature was measured three depth points (0.15, 0.55 and 1.08 m) in three locations near Korean Dasan station (78° 55' N, 11° 55' E) in Ny-Ålesund in Svalbard from 2005 to 2009. Soil CO₂ emission measurement were conducted for 16 sampling points in the plot (30 m × 30 m) using a closed-dynamic chamber system for July 2007, 2008 and 2009 during summer.

3 RESULTS

Soil temperature for three points, 0.15, 0.55 and 1.08 m ranged from -14 to 11, -15 to 6 and -10 to 3, respectively. Period of the lowest temperature was from February to early April and highest temperature was from mid July to early August. Spatially averaged Soil CO₂ emission for 16 sampling locations ranged from 0.3 to 0.7 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and means of that were 0.56(± 0.07) $\mu\text{mol m}^{-2} \text{s}^{-1}$ (2007), 0.54(± 0.13) $\mu\text{mol m}^{-2} \text{s}^{-1}$ (2008), 0.51(± 0.09) and 0.51(± 0.09) $\mu\text{mol m}^{-2} \text{s}^{-1}$ (2009) during July of each year. Spatially averaged soil temperature ranged from 6 to 12 °C and soil water content ranged from

13 to 27% during measuring of soil CO₂ emission. The patterns of soil CO₂ emission for study periods generally followed those of soil temperature.

ACKNOWLEDGEMENT

This study was supported by 'Integrated research on the COMposition of Polar Atmosphere and Climate Change (COMPAC)' of Korea Polar Research Institute.

References

- Marion, G.M., Bockheim, J.G., Brown, J., 1997. Arctic soils and the ITEX experiment. *Global Change Biology* 3, 33-43.
- Oechel, W.C., Vourlitis, G.L., Hastings, S.J., Bochkarev, S.A., 1995. Change in arctic CO₂ flux over two decades: effects of climate change at Barrow, Alaska. *Ecological Applications* 5, 846-855.

The Search for Life in Space: Terrestrial Habitat Characterisation of Extremophiles for Biological Space Research Topics

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Extremophiles are microorganisms, which are living in extreme habitats. The environmental conditions in these habitats are very harsh. They can be characterised by very low or high temperatures, high radiation fluxes, low water availability up to total dryness, high salinity and very low or very high pH-values. Extremophiles are specialists which colonise special niches in these extreme environments due to their adaptation capacities attained during the evolution of life. Some examples of extremophiles and their potential to deal with harsh conditions as well as the characterisation of their niches in the Victoria-Land-Region of the Transantarctic Mountains, the European Alps and the Spanish Mountains “Sierra de Gredos” will be presented. Based on observations in the habitats of the global transect from temperate

Alpine regions to Mediterranean mountains and Polar Mountain regions different strategies of colonisation of the mountain features as there are, the colonisation of rocks, fissures, cracks, polygon forming substrates, permafrost and glaciers can be distinguished. Data of UV B-, PAR- and IR-radiation measurements, humidity and temperature as well as the activity of microorganisms are accomplishing with more details the habitat characterisation and may give relevant information on probably niches for life on other planets as e.g. the planet Mars. These results will also form the basis of a series of new space experiments on satellites or on the International Space Station (ISS) and furthermore may lead to progress in probes- and rover-development for particular “hardly” accessible terrains.

Methanogenesis and Methanogens in an Arctic Peat: Temperature Dependencies of Rates and Populations.

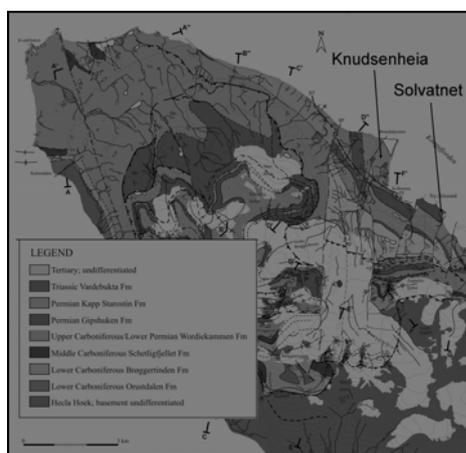
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1 INTRODUCTION

Methane is next to carbon dioxide the second most important greenhouse gas. Wetlands and Northern wetlands in particular, are among the most important sources of atmospheric methane. The expected temperature increase in the North will affect the extent of wetlands and stimulate the activity of microbes including methanogens. Here we studied the effect of temperature on rates and population structure. To get an insight in species-specific activity, we used the transcripts of *mcrA*, a key gene for methanogenesis, as a proxy.

2 MATERIALS AND METHODS



Peat was sampled at Knudsenheia (Brøggerpeninsula, Spitsbergen) below the water table and transferred to the lab where it was incubated for two months under strict temperature control in the dark. Headspace methane was measured regularly by GC-FID, and nucleic acids were extracted from peat at the end of the experiment.

3 RESULTS

Methane production ranged from 110 to 520 nmol·gDW⁻¹·d⁻¹ at 1 and 10°C, respectively. The methanogenetic community was analyzed based on the *mcrA*. Based on DNA-tRFLP, the community did not change during two months' incubation, and was essentially the same at 1, 4, and 10°C. The two primer sets used (ME and Luton) gave consistent results. Transcriptional analysis of *mcrA*-mRNA showed largely the same pattern.

4 CONCLUSIONS

Methanogenesis reacts very sensitive on minor temperature changes showing strong responses as found in other Arctic wetlands.

This response is due to the activity of the extant population being well adapted to the low temperature range under current environmental conditions, but able to cope with temperatures up to 20°C.

The Potential Use of Oblique Aerial Photography for Estimating Methane Ebullition from Interior Alaska Lakes

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Key words: lakes, methane, climate change, permafrost, aerial photography

Arctic lakes are significant emitters of methane (CH₄), a potent greenhouse gas, to the atmosphere; yet no rigorous quantification of the magnitude and variability of pan-Arctic lake emissions exists. If documented, they would have significant impact on CH₄ budgets and climate models in high latitudes. In this study, we analyze the potential for a new method using aerial photography to determine methane seep coverage in Interior Alaskan lakes and scale-up whole-lake methane measurements to regional scales.

Ebullition is the dominant mode of northern lakes emissions and needs to be quantified at regional scales. Many previous studies on CH₄ emissions from northern lakes reported only diffusive emissions, given the high spatial and temporal variability of ebullition dynamics.

Walter et al (2006) use a CH₄ quantification method that reduces uncertainty due to ebullition patchiness. As ice forms in autumn, bubbles released from lake sediments are trapped under the surface ice. These bubble clusters act like a map of methane seeps across lakes. Mapping the distribution of point sources across lake surfaces reveals spatial patterns of ebullition and allows quantification of whole-lake CH₄ emissions.

The outcomes of this ebullition quantification method are more accurate estimates of northern lakes methane emissions. For logistic reasons, however, this method can be applied only to a small percentage of lakes. Therefore we developed a new method to scale-up field measurements to regional scales.

We quantified the number of seeps distinguishable in each lake in aerial photographs and analyzed the year-to-year variability in seep numbers, sizes, and locations. Applying ebullition rates previously measured in the field, we determined how well ground surveys of seeps predict total seep coverage of lakes as determined through aerial photography. Based on this relationship, we scale-up field measurements to lake districts, thus complementing re-

mote sensing use to ultimately produce a regional estimate of CH₄ emissions from lakes.

References

- Walter, K. M., Zimov, S. A., Chanton, J. P., Verbyla, D., & F. S. Chapin III. 2006 Methane Bubbling from Siberian Thaw Lakes as a Positive Feedback to Climate Warming, *Nature* 443, 71-75.
- Walter, K. M., L. C. Smith, & F. S. Chapin III. 2007. Methane bubbling from northern lakes: present and future contributions to the global methane budget, *Philosophical Transactions of the Royal Society A*, vol. 365, 1657-1676

Methane Fluxes from Western Siberian Tundra Wetlands

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Wetlands are one of the most intensive natural methane sources. They cover 27% of the land surface in Western Siberia and 29% in the tundra zone (Romanova, 1985) but are grossly underrepresented in current literature on high-latitude methane fluxes. Here, we present recent methane flux measurements from the Western Siberian tundra zone.

Fluxes were measured during August 2009 at poor fens (41 measurements) and lakes (33 measurements). In December 2009 fluxes were measured in oligotrophic bogs (68 measurements). All sites are situated near the Tazovsky settlement (67°28'N, 78°45'E, Tumenskaya Oblast) and are underlain by continuous permafrost.

We used cubic plastic chambers of 40 cm size, which were placed onto stainless steel collars (in summer) or directly inserted 15 cm into the snow (in winter). For each observation four samples were collected during the 30-45 min closure of the chamber and methane concentrations were determined with a GC-FID. Fluxes were calculated by linear regression of concentration versus time. Environmental factors (pH, EC, O₂ concentration in water, and temperature profile) were measured at the mesotrophic bogs and lakes in summer. Snow temperature profiles were measured for oligotrophic bogs in winter.

Results of the flux measurements are given in table 1, where positive fluxes represent emissions into the atmosphere and negative fluxes represent methane uptake. Surprisingly, methane uptake was found in winter, when snow cover and low temperatures likely rule out any explanation by biological processes. Therefore, we assume that CH₄ is adsorbed by the snow. In this case, fluxes must depend on a temperature difference between air (T_{air}) and snow (T_{surface}): if, at the beginning of the measurement, T_{air} > T_{surface} in the chamber, then T_{surface} will increase and desorption will result in a positive methane flux.

Table 1. Summer and winter (*) methane fluxes near Tazovsk, Western Siberia. All fluxes are given in mg·m⁻²·h⁻¹.

	1 st quartile	median	3 rd quartile
Mesotrophic bog	4.58	5.79	6.79
Lakes	0.45	0.85	1.42
Oligotrophic bog*	-0.06	0.00	0.16

If T_{air} < T_{surface}, then T_{surface} will decrease leading to adsorption by the snow and negative methane flux. We averaged fluxes at each temperature difference and actually detected the weak trend explained above. However, since the median of winter fluxes from tundra oligotrophic bogs is near zero, they can be omitted when calculating annual CH₄ emissions.

To extract the main environmental factors controlling CH₄ emission from lakes we used "forward step-wise regression" (FSWR). During the first step of the FSWR the strongest correlation (R²=0.616) was found with lake water oxygen concentration at 20 cm depth ([O₂]₂₀, mg/L). The second step then provides $F = a_1 \cdot [O_2]_{20} + a_2 \cdot [O_2]_5$, where F is the CH₄ emission (mg·m⁻²·h⁻¹) and [O₂]₅ is the oxygen concentration at 5 cm depth. Since numerically $a_1 \approx -a_2$, we define a new variable $\Delta[O_2] = ([O_2]_{20} - [O_2]_5)$. The third step provides $F = a_3 \cdot \Delta[O_2] + a_4 \cdot \text{pH}_{\text{max}}$ (with $a_3 = 0.91 \pm 0.14$, $a_4 = 0.09 \pm 0.02$, R² = 0.654), where pH_{max} is the maximum pH in the water layer 0-50 cm. The fourth step of the FSWR does not reveal any significant variables.

The variable "pH_{max}" can characterize conditions of mineral nutrition, so a positive a_4 indicates the increase of methane emission in richer conditions. $\Delta[O_2]$ can be interpreted as oxygen gradient in the lake and can thus characterize the intensity of O₂ input into the lake. However, since aerobic conditions allow high methane oxidation activity, decreased methane fluxes should be expected.

The regional annual CH₄ flux from Western Siberian tundra was estimated to be 0.16 Mt CH₄, representing 5% of the flux from all Western Siberian wetlands.

References

Romanova E.A. Rastitelnost bolot [Wetland vegetation] // *Rastitelnii pokrov Zapadno-Sibirskoi ravnini [Plant cover of West Siberian plain]* / V.V. Vorobiev, A.V. Belov (eds.). – Novosibirsk: Nauka, 1985.– p.138–159. (In Russian)

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Methane Oxidizing Communities in High Arctic Wetlands, Svalbard

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1 OBJECTIVE

The objective of this study is to compare the genetic diversity of methane oxidizing communities at two different wetland sites at Brøgger peninsula, Svalbard.

2 INTRODUCTION

2.1 Methane Oxidation in Arctic Ecosystems

Methane oxidizing bacteria (methanotrophs) represents key organisms in the regulation of methane emission from wetlands, as the amount of methane released to the atmosphere is mitigated by their presence and activity. This process occurs in the oxic surface layer, while methanogenesis is the dominating terminal process of mineralization in anaerobic soil above permafrost. Methane is a greenhouse gas and the second largest radiative forcing after carbon dioxide. Hence, changes in the presence and activity of methanotrophs may eventually cause a climate feedback and even modest changes in methane emission to the atmosphere maybe of global importance.

2.2 Climate change, methane and the Arctic

About 20% of the Earth's surface is frozen, with a significant part consisting of permafrost. Northern permafrost zones contain approximately 1672 Gt of carbon, representing a major yet currently resilient part of the global carbon budget. Natural wetlands, including Arctic tundra, are one of the largest sources of atmospheric methane and high northern latitudes represent an important player in the global methane budget. Considering the predicted warming of the Arctic, a larger fraction of these carbon reservoirs will become available for mineralization.

3 SAMPLING SITES

3.1 Solvatnet, Brøgger-peninsula

The site Solvatnet (78° N) on Spitsbergen (Norway) is a typical High Arctic wetland on limestone bedrock. The methanogenic community was illustrated

by Høj and co-workers (2005 & 2006), while the diversity of methane oxidizing bacteria was revealed by Wartiainen and co-workers (2003). Two methanotrophic isolates originate from this site: *Methylocystis rosea* and *Methylobacter tundripaludum* (Wartiainen *et al.* 2006).

3.2 Knudsenheia, Brøgger-peninsula

The site Knudsenheia (78° N) is also a High Arctic wetland on limestone bedrock. Results describing the methanotroph communities at these wetland sites will be presented at the EUCOPIII meeting.

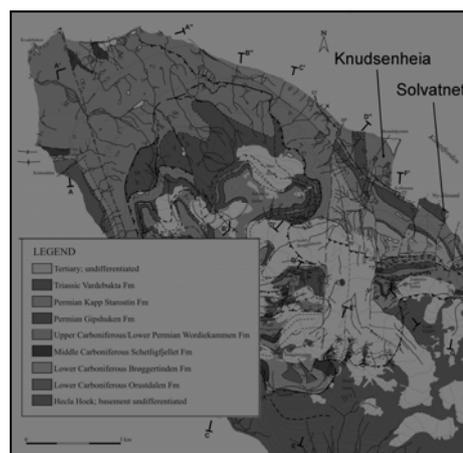


Figure 1. Brøgger-peninsula on Spitsbergen with the sampling sites Solvatnet and Knudsenheia.

4 COLLABORATIONS

This project is associated to a European collaboration within the ESF (European Science Foundation) EuroDiversity project METHECO. Furthermore, the project is connected to an ARCFAC (European Centre for Arctic Environmental Research in Ny-Ålesund) project (026129).

References

Wartiainen I, Hestnes AG, Svenning MM. 2003. Methanotrophic diversity in high arctic wetlands on the islands of Svalbard (Norway)-denaturing gradient gel electrophoresis analysis of soil DNA and enrichment cultures. *Can J Microbiol.* 49(10):602-12.

Microbial Driven Methane Dynamics in the Siberian Arctic During Glacial-Interglacial Climate Changes

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1 INTRODUCTION

Permafrost environments are supposed to be strongly affected by the currently observed global temperature rise. About one third of global soil carbon is stored in permafrost and an increase in temperature might increase the microbial turnover of recent as well as ancient carbon and cause the release of large amounts of greenhouse gases such as methane. To predict the risk for future climate and to estimate the global atmospheric carbon budget, it is important to understand the microbial driven methane dynamic and its response to climate changes in the past. Therefore, a combination of quantitative as well as qualitative analyses of bacterial and archaeal communities was accomplished to reveal variations in permafrost deposits of the Siberian Lena Delta.

2 RESULTS

A 23 m long permafrost core drilled in 2002 on Kurungnakh Island, Lena Delta, Siberia, was examined using biogeochemical as well as microbiological methods. As a general result it is shown that it was possible to recover lipid biomarkers and amplifiable DNA throughout the Kurungnakh permafrost sequence with an age of up to 42 ka. First analyses of glycerol dialkyl glycerol tetraethers (GDGTs) were conducted. GDGTs provide paleo-signals of archaeal and bacterial communities, since these lipids are already partly degraded but their core lipids are relatively stable outside intact cells. Highest amounts of ether lipids were found in the upper layer and at the bottom of the core. Generally, the results of GDGT analyses correlate to measured contents of total organic carbon (TOC) and concentrations of in-situ methane in the deposits. Furthermore vertical variations of archaeal biomarkers such as archaeol, caldarchaeol and crenarchaeol could be detected. These changes are probably caused by changing compositions of archaeal communities as a response to temperature changes.

Aerobic methanotrophic communities were analyzed using diploptene (Hop-22(29)ene) as a characteristic biomarker. It can be regarded as a paleo-signal for methane oxidizing bacteria being

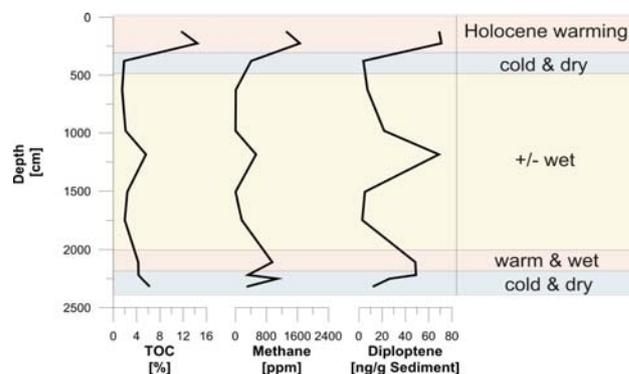


Figure 1. Vertical profile of TOC, methane concentration and diploptene biomarker concentrations. Paleoclimate reconstruction according to Schirrmeister et al., 2003.

present during time of sedimentation of the respective deposits (former upper "aerobic" active layer). The variability of the diploptene distribution correlates to measured rates of methane and content of TOC (Fig.1). The fact that sedimentary intervals with high amounts of trapped methane (presumably intervals with in-situ methane production) also contain high contents of diploptene suggests that these sediments released also high amounts of methane in the past being the host of considerable aerobic methanotrophic communities.

To complete our information on the qualitative composition of microbial communities, DNA-based analyses using DGGE and clone libraries were conducted using archaeal and methanotrophic specific primer combinations. Fingerprints of archaeal 16 S rRNA gene sequences of the different permafrost samples show variations within the vertical profile. Sequence analyses showed a distinct diversity of methanogens affiliated with *Methanobacteriaceae*, *Methanosarcinaceae* and *Methanomicrobiaceae*. Highest diversity of methanogens could be detected at depth of 1507 cm and 1745 cm, which were also characterized by high amounts of archaeol.

3 CONCLUSION

Both biogeochemical as well as microbiological methods revealed variation within the composition of past and present microbial communities and showed indications of response to climate changes.

Characterization of Soil Organic Matter in Permafrost Terrain – Landscape Scale Analyses from the European Russian Arctic

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1 INTRODUCTION

Soils of high latitude terrestrial ecosystems are considered key components in the global carbon cycle and hold large stores of Soil Organic Carbon (SOC). The absolute and relative sizes of labile and recalcitrant SOC pools in periglacial terrain are mostly unknown (Kuhry et al. *in prep.*). Such data has important policy relevance because of its impact on climate change.

We sampled soils representative of all major land cover and soil types in discontinuous permafrost terrain, European Russian Arctic. We analyzed the bulk soil characteristics including the soil humic fraction to assess the recalcitrance in organic matter quality in down-depth soil profiles.

2 METHODS

A comprehensive stratified random soil sampling program was carried out in the Seida area during late summer 2008. From these, we selected nine sites considered representative for the landscape. Active layer and permafrost free upland soils were sampled from dug soil pits with fixed volume corers. Peat plateaus were sampled near thermally eroding edges. Permafrost soils were cored using steel pipes hammered into the frozen peat. Permafrost free fens were sampled using fixed volume Russian corers. Radiocarbon dating was used to determine the SOC ages. The soils were analyzed for dry bulk density, elemental content, and stable isotope composition of organic C and N ($\delta^{13}\text{C}$, and $\delta^{15}\text{N}$). Further, humic acids were extracted, and the degree of humification of SOM assessed based on A_{600}/C and $\Delta \log K$ (Ikeya and Watanabe, 2003).

3 RESULTS

Figure 1 shows soil organic matter (SOM) characteristics in a peat sequence from one of the nine described sites, a raised bog peat plateau. The peatland first developed as a permafrost-free fen during the Holocene Hypsithermal. Permafrost only aggraded in the late Holocene. Anoxic conditions in

the fen and permafrost in peat plateau stages reduced decomposition rates and the degree of humification (A_{600}/C) is relatively constant throughout the peat deposit.

Botanical origin is a key factor in determining SOM quality, which is clearly reflected in the elemental ratio (C/N) and isotopic composition of C and N. There are sharp shifts in humification, C/N and isotopic composition at the peat/clay interface.

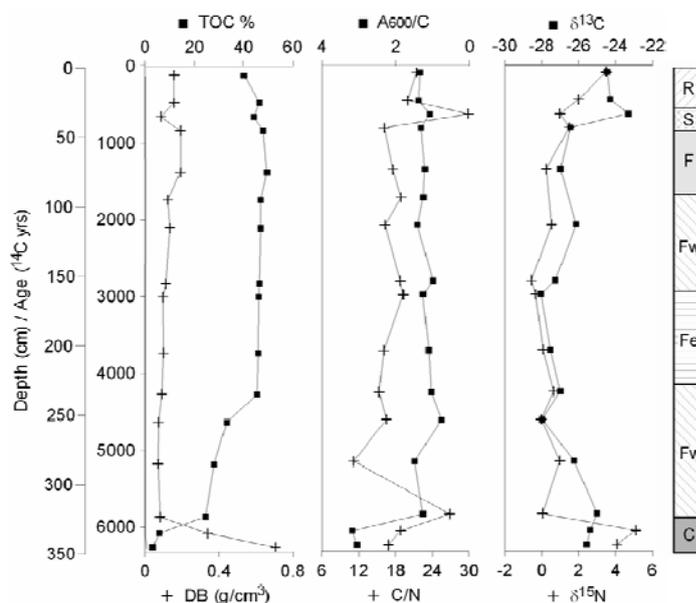


Figure 1. Soil organic matter characteristics in a raised permafrost peat plateau profile. X-axes show total organic C content (TOC %), bulk density (BD), degree of humification (A_{600}/C , increased humification to the left), C/N ratios and stable isotope composition of organic C and N ($\delta^{13}\text{C}$, and $\delta^{15}\text{N}$). Y-axes to the left show depth and ^{14}C age (calculated from 3 dates) and Y-axis to the right shows the general stratigraphy where: R= rootlet peat, S= Sphagnum dominated peat, F= fen peat, Fw= Fen peat with > 10% wood, Fe= Fen peat dominated by *Equisetum sp.* and C= clay.

References

- Ikeya, K. and Watanabe, A., 2003, Direct expression of an index for the degree of humification of humic acids using organic carbon concentration. *Soil Science and Plant Nutrition*, 49: 47-53.
- Kuhry, P., Dorrepaal, E., Hugelius G., Schuur, E.A.G. and Tarnocai C., Potential remobilization of permafrost carbon under future global warming. *Permafrost and Periglacial Processes*, Submitted.

Isolation of Cultivable Anaerobic Bacteria from Alaska Peatlands

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Total 58 strains of anaerobic bacteria were isolated from soil samples collected from peatlands in Fairbanks, Alaska. The soil samples were cultured anaerobically in EM1 medium at 15°C for one month. The supernatant was inoculated on TSA agar media, and colonies were purified by four times sub-culturing on the same media at 15°C for one week. Phylogenetic analysis of the 58 strains was performed using 16S rRNA gene sequences and EZ-taxon (Chun et al. 2007), and they were identified as 23 species (Table 1).

The 23 species belonged to only two groups: Firmicutes and Gammaproteobacteria. Among them, five species were Enterococcus species and one species was Klebsiella. They might be originated from animals lived around the sampling site. One isolate, KOPRI 90141 showed high similarity with *Exiguobacterium sibiricum* 255-15 isolated from the Siberian permafrost (Rodrigues et al. 2006).

References

- Chun J., Lee J.-H., Jung Y., Kim M., Kim S., Kim B.K. & Lim Y.W. 2007. EzTaxon: a web-based tool for the identification of prokaryotes based on 16S ribosomal RNA gene sequences. *Int J Syst Evol Microbiol* 57, 2259-61.
- Rodrigues D.F., Goris J., Vishnivetskaya T., Gilichinsky D., Thomashow M.F., Tiedje J.M. 2006. Characterization of *Exiguobacterium* isolates from the Siberian permafrost. Description of *Exiguobacterium sibiricum* sp. nov. *Extremophiles* 10, 285-94.

Table 1. Anaerobic bacteria isolated from Alaska peatland

Strain	The closest type species	Similarity	Taxa
KOPRI 90101	<i>Acinetobacter johnsonii</i> DSM 6963(T)	99.8	G
KOPRI 90102	<i>Aeromonas salmonicida</i> subsp. <i>masoucida</i> ACC 27013(T)	100.0	G
KOPRI 90103	<i>Bacillus muralis</i> LMG 20238(T)	98.2	F
KOPRI 90104	<i>Bacillus thuringiensis</i> ATCC 10792(T)	99.8	F
KOPRI 90105	<i>Budvicia aquatica</i> DSM 5075(T)	99.5	G
KOPRI 90106	<i>Carnobacterium maltaromaticum</i> BA	99.6	F
KOPRI 90117	<i>Citrobacter murlinae</i> CDC 2970-59(T)	98.5	G
KOPRI 90121	<i>Clostridium glycolicum</i> DSM 1288(T)	99.3	F
KOPRI 90122	<i>Enterococcus aquimarinus</i> LMG 16607(T)	99.6	F
KOPRI 90128	<i>Enterococcus faecalis</i> JCM 5803(T)	98.6	F
KOPRI 90137	<i>Enterococcus gallinarum</i> CECT970(T)	99.7	F
KOPRI 90138	<i>Enterococcus moraviensis</i> CCM 4856(T)	99.5	F
KOPRI 90140	<i>Enterococcus mundtii</i> CECT972(T)	99.9	F
KOPRI 90141	<i>Exiguobacterium sibiricum</i> 255-15(T)	99.8	F
KOPRI 90143	<i>Klebsiella oxytoca</i> JCM 1665(T)	99.5	G
KOPRI 90144	<i>Kurthia gibsonii</i> NCIMB 9758(T)	99.4	F
KOPRI 90146	<i>Lactococcus lactis</i> subsp. <i>lactis</i> NCDO 604(T)	99.8	F
KOPRI 90150	<i>Morganella morgani</i> subsp. <i>sibonii</i> DSM 14850(T)	99.0	G
KOPRI 90153	<i>Pseudomonas lundensis</i> ATCC 49968(T)	99.9	G
KOPRI 90154	<i>Pseudomonas taiwanensis</i> BCRC 17751(T)	98.9	G
KOPRI 90156	<i>Shigella flexneri</i> ATCC 29903(T)	99.8	G
KOPRI 90157	<i>Sodalis glossinidius</i> M1(T)	96.6	G
KOPRI 90158	<i>Yersinia intermedia</i> ATCC 29909(T)	99.7	G

* Taxa: F, Firmicutes; G, Gammaproteobacteria



Figure 1. Sampling site of peat land in Fairbanks, Alaska.

Seasonal Variation in CH₄ Fluxes from a Greenlandic High Arctic Fen

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1 INTRODUCTION

Global warming is not evenly distributed over the world and high northern latitudes are projected to larger increase in temperature, precipitation and growing season length than the rest of the world. CH₄ fluxes from permafrost regions are considered a major source of atmospheric methane. As a part of the international polar year 2007, the Zackenberg research station was operated during autumn and the early winter. During this period Mastepanov *et al.* (2008) found some unexpectedly high CH₄ fluxes as the active layer gradually froze. The main aim with the present study was as a follow-up to quantify CH₄ fluxes from a larger area of the same high arctic fen, during growing season and the potential high-peak seasons when the soil was freezing in 2008 and 2009.

2 MATERIALS AND METHODS

The study took place in a fen in the Zackenberg Research Area (74°28'N 20°34'W), located in the National park of North Eastern Greenland. We combined the eddy covariance technique with the gradient method to estimate CH₄ fluxes. CH₄ fluxes were monitored continuously and averaged half-hourly from 25 June -28 October 2008 and 16 May -24 October 2009. Soil temperatures, water table and active layer depths were monitored as well. Our long time series of both CH₄ fluxes and environmental conditions allowed us to investigate temporal variation of fluxes and their environmental controls.

3 RESULTS

No diurnal variation in CH₄ fluxes was observed during the measurement period. Small CH₄ bursts were observed during spring thawing, but these occurred during short time periods and do not have any significant effect on the annual budgets. Variation in growing season CH₄ fluxes was highly

correlated with increases in active layer depth and soil temperature whereas no inter-seasonal relationships were seen to water table depth. However, the growing season CH₄ fluxes were larger in 2008 than in 2009 (~5.5 mg CH₄ m⁻² h⁻¹ and ~3.5 mg CH₄ m⁻² h⁻¹, respectively), and the inter-annual variation could possibly be explained by higher water table depths and higher soil temperatures in 2008 than in 2009. No increases in CH₄ fluxes were seen as the soil froze in 2008 corresponding with limited automatic chamber measurements from the same site where the 2007 burst was observed; however, there was a high episodic CH₄ emission event at one occasion and it was well correlated with atmospheric turbulence. In 2009, an increase in CH₄ fluxes could be seen before the end of the measurement campaign, and it occurred simultaneously with the onset of active layer freezing.

References

Mastepanov, M., C. Sigsgaard, E.J. Dlugokencky, S. Houweling, L. Strom, M.P. Tamstorf & T.R. Christensen (2008) Large tundra methane burst during onset of soil freezing. *Nature*, 456(7222): 628-630

Methane Fluxes from Permafrost-Affected Soils of the Siberian Lena Delta: Who is Active under in Situ Conditions?

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1 INTRODUCTION

Wet tundra environments of the Siberian Arctic are natural sources of the climate relevant trace gas methane. Thawing of permafrost could release large quantities of greenhouse gases into the atmosphere, thus further increasing global warming and transforming the Arctic tundra ecosystems from a carbon sink to a carbon source. Trace gas fluxes from permafrost ecosystems are influenced by a number of biotic and abiotic parameters. The decomposition of soil organic matter and the generation of greenhouse gases result from microbial activity, which is affected by habitat characteristics (soil parameters) and by climate-related properties (forcing parameters). The structure and reaction of microbial populations to environmental changes is largely unknown, which means that also an important part of the process knowledge on greenhouse gas fluxes in permafrost ecosystems is far from completely understood. This also hampers prediction of the effects of climate warming on Arctic methane fluxes. Further research on the stability of the methane cycling communities is therefore highly important for understanding the effects of a warming Arctic on the global climate.

The aim of this study was to identify and characterize the methane producing microorganisms (methanogens) which are active under in situ conditions in permafrost-affected soils. Therefore, samples from a permafrost soil of Kurungnakh Island (Lena Delta, Siberia) were incubated with ^{13}C -labeled substrates (acetate, CO_2/H_2) – so-called stable isotope probing (SIP) – to distinguish the active from the passive part of the methanogenic community by incorporation of ^{13}C -carbon into the DNA. The ^{13}C -DNA was separated from the ^{12}C -DNA by density gradient centrifugation and subsequently analyzed by clone library investigations.

2 RESULTS

The methane production, which was measured during the SIP-incubation, revealed a vertical profile of methanogenesis with a maximum rate of about $0.8 \text{ nmol CH}_4 \text{ h}^{-1} \text{ g}^{-1}$ soil in the bottom of the active layer close to the permafrost table. The clone library analyses showed a distinct diversity within the group

of methanogens (Fig. 1). The sequences affiliated with *Methanosarcina*, *Methanosaeta*, *Methanobacterium* and species of the order *Methanomicrobiales*. Furthermore, members of *Halobacteriales*, *Thermoplasmatales* and *Crenarchaeota* could be identified. Most of the sequences were found in the ^{12}C -DNA fraction as well as in the ^{13}C -DNA fraction, which indicated active and inactive species within most of the genera.

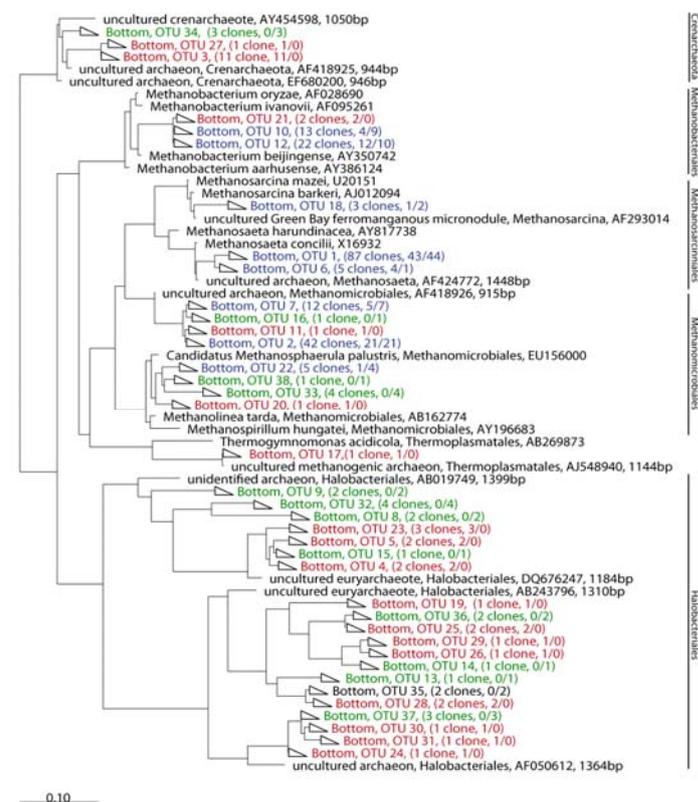


Figure 1. Phylogenetic tree showing the relation of 16S rRNA gene sequences of archaea from active layer samples of Kurungnakh Island to most closely branching 16S rRNA gene sequences of known archaeal isolates

3 CONCLUSION

The results of this study suggest that in permafrost-affected soils of the Lena Delta a diverse and well-adapted methanogenic community exist, that under in situ conditions is metabolically active and flexible enough to maintain under changing environmental conditions, their role in the anaerobic degradation of organic matter.

First Insights from Biomarker Composition & Compound-Specific ^{14}C Analysis of Permafrost Soils, Suspended Particulate Matter and Sediments

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1 INTRODUCTION

Extensive permafrost thawing increasing active layer depths results in enhanced river discharge and remobilization of fresh and previously frozen organic matter (OM) exported to the Arctic Ocean. Associated changes in source and molecular composition of the OM will considerably alter carbon budgets and biogeochemical carbon cycling in the Arctic Ocean and its shelf seas. Until now, it is rather unknown which compounds are remobilized and metabolized, transported and finally buried in the marine environment. To assess these processes influenced by environmental changes biomarker-specific isotope analyses can be used. Here, we present results on the biomarker composition and compound-specific radiocarbon ages of soils and sediments from Svalbard and the Lena Delta, NE Siberia. Both study areas differ significantly in permafrost characteristics, river catchment area size and their impact on carbon cycling in the Arctic Ocean.

2 STUDY SITES

During a summer field campaign in 2008, permafrost soil samples, fluvial and marine surface sediment samples were taken in the Bayelva drainage area near Ny-Ålesund, Svalbard. Further sampling was performed in August 2009 in the Lena Delta, NE Siberia. These samples include permafrost soils, suspended particulate matter (SPM) and surface sediments taken with a grab sampler along the major channels of the delta.

3 ORGANIC MATTER COMPOSITION AND RADIOCARBON AGES

Analyses of permafrost soil profiles near Ny-Ålesund showed relatively low total organic carbon (TOC) contents of 1.3 to 1.7wt% compared to other permafrost regions (e.g. ~2-20wt% in NE Siberia). TOC ^{14}C ages of the topsoil were unexpectedly high (5800±50 yrs BP) and increased with depth to maximum values of 26000±130 yrs BP. Radiocarbon ages of river sediments were comparable to val-

ues in the upper 60 cm and thus suggest that the upper active layer is predominantly eroded contributing particulate organic matter (POM) to the Bayelva drainage system. Long-chain aliphatic compounds used as biomarkers for higher plant input document contribution of higher plants to soil organic matter mainly in the upper 30 cm. Compound-specific radiocarbon ages were obtained for higher-plant derived long-chain fatty acids (figure 1), which imply slow turnover of these compounds within the active layer and export of significantly pre-aged material to the sediments in the adjacent fjord.

Additionally, soil samples, SPM and sediments from the Lena Delta are currently analyzed for their biomarker composition and radiocarbon content.

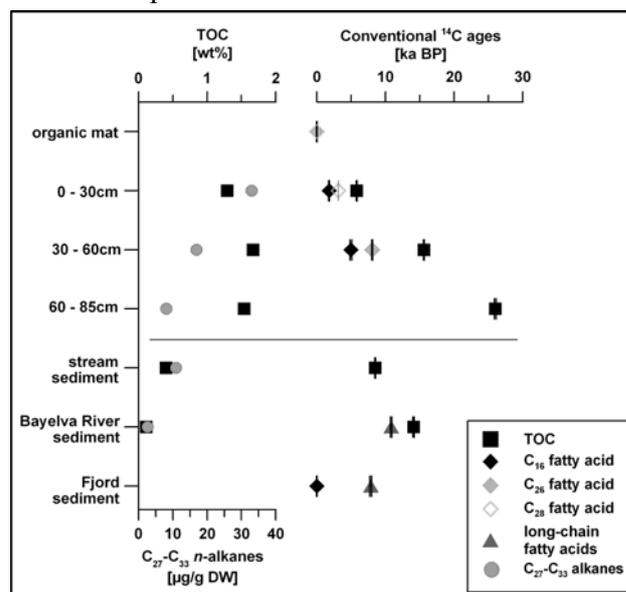


Figure 1: TOC contents, n-alkane concentrations based on dry weight (DW) and conventional ^{14}C ages from soil and sediment samples of the Bayelva drainage area, Svalbard.

4 CONCLUSIONS

Pre-aged terrigenous OC, primarily derived from the uppermost active layer, made up a large fraction of the OM in Bayelva River and fjord sediments (Svalbard) implying considerable export of fossil OC to the ocean from these soil depths. Ongoing work focuses on identifying predominantly exported organic compounds, study degradation processes, and determine timescales of transport.

Posters Wednesday, cont.

Palaeo-permafrost and Coastal Dynamics:

in Kapp Lee

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Flooding of the Fyrsjøen Catchment and its Effects upon Breeding Birds, Kapp Linné, Svalbard, Norway

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1 INTRODUCTION

Changes in Arctic sea-ice conditions have affected conditions ashore along the west coast of Svalbard. Effects upon the discharge characteristics of some drainage basins along the seashore are considerable. The area studied lies on the strandflat plain, south of Kapp Linne' (78°04'N, 13°38'E). The anomalous discharge pattern of the Fyrsjøen Lake catchment depend upon the fact that the outlet is blocked by ice-cemented storm ridges delaying the spring peak flow several weeks and thus raising the lake level dramatically. The water level in the Fyrsjøen Lake will, during summers with at blocking storm ridge, a rise to 1.25m above normal. At this level it starts to overflow or drains through a thermokarst break through and a flush flow that drain the excess water in a few days

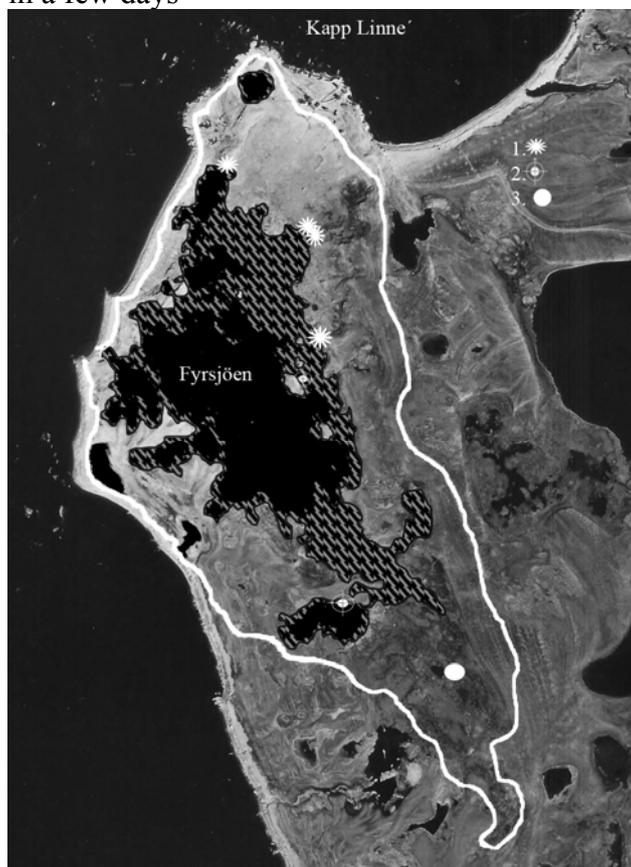


Figure 1. Hatched area is flooded area when water level is 1.2m above mean summer level in the Fyrsjøen lake. 1. *Somateria spectabilis*, 2. *Gavia stellata* 3 *Stecorarius paraciticus* indicate typical location for destroyed nesting sites

Large bog areas next to the lake which are important for the nesting wetland birds are in these cases flooded, affecting also snowmelt, the active layer, the vegetation and the breeding birds of the area (Fig.1).

2 BREEDING BIRDS

The breeding birds of the catchment area that has been monitored are shown in table 5 and we find that the Red throated diver (*G. stellata*) and the Arctic skua (*S. parasiticus*) are the species mostly affected in this case. But also the Grey phalarope (*P. fulicarius*), the less common King Eider (*S. spectabilis*) and the purple sandpiper (*C. maritima*) may here locally suffer a loss of 40 to 60% due to the flooding.

This is of course only a very marginal loss considering the total population of these species along the coasts of Svalbard. But considering that this scenario is a trend that become more and more frequent it might be of importance.

Table 1. Breeding failure, specifically caused by flooding during a flooding year (1994) for seven regularly breeding species within the Fyrsjøen catchment area.

SPECIES	Nests/failure	%
<i>Sterna paradisaea</i>	25/5	21
<i>Phalaropus fulicarius</i>	6/3	50
<i>Calidris maritima</i>	3/2	66
<i>Somateria molissima</i>	26/5	21
<i>Somateria spectabilis</i>	10/4	40
<i>Gavia stellata</i>	2/2	100
<i>Stecorarius paraciticus</i>	1/1	100

References

- Akerman, H. Jonas, 2008, Coastal Processes and their influence upon discharge characteristics of the Strokkdammane plain, West Spitsbergen, Svalbard. P:19-24 (eds. Kane & Hinkel). Proceedings NICOP. Fairbanks: Univ. of Alaska.
- Løvenskiold, H.L. 1964 Avifauna Svalbardiensis. Oslo: Norsk Polarititt

Isotopic Composition of Massive Ground Ice Exposure at the Kharasavey Coast, West Yamal

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1 SUBJECT OF INVESTIGATION

Massive ground ice and icy sediments have been studied near the Kharasavey settlement at the West Yamal coast of Kara Sea from the 1980es. Several points of view on its origin have been suggested, the main are intrasedimental origin of ice, redeposited and deformed by glacier marine sediments or buried fast ice. In order to clarify this question one massive ice exposure were described and sampled in 2008.

2 HOST SEDIMENTS

2.1 *Composition, stratigraphy and dates*

At the Kharasavey Cape area fine grained frozen sediments are exposed in coastal bluffs of 3-14 m height along 10 km coastal section. These sediments are presented mostly by saline clays and clayey sands, which often contain shells. Massive ground ice lies inside the sandy stratum that rises above the sea level at some parts of the coast. In some costal sections sands compose all the bluff. Massive ice tent to be confined at the contact of sandy and clayey strata. The oldest known radiocarbon dates of the sediments are 43600±700, 39700±1000 and 35404±340 (GIN-2649; 2650; Ri-284), than there is a gap up to 9560±130 (GIN-2651, peat in the upper part of the cliff) (*Vasil'chuk Yu.K.*).

2.2 *Position of the studied massive ice bed*

The studied outcrop was formed in a coastal bluff of 10 m height a.s.l.. Massive ice is exposed at 3 m depth from the surface and overlaid by sandy-clayey stratified sediments. On its sides massive ice is replaced by sands, so we can say the ice bed lies in the upper part of sandy strata in the place where the top of the sands rises above the sea level. The upper contact of massive ice is in general dome-shaped. Upper boundary can't be defined clearly – at 2-3 m down the surface ice lenses of 2-20 cm thick subparallel to the top of the ice arise; down the bluff they gradually turn to massive ice body. The lower boundary haven't been exposed. Massive ice bed apparent thickness is 1 m or 1.5-2 m together with

ice lenses and icy sediments, it forms thermocirque of 7 m diameter.

3 MASSIVE GROUND ICE

3.1 *Description of ice, chemical composition*

Massive ice body consists of separate ice lenses 5-35 cm thick which are divided by 1-10 cm ground layers. The predominant type of ice is transparent with inclusions of the sediments, bubbly ice is rare. Conductivity of ice is low (15-122 $\mu\text{S}/\text{cm}$), which disprove idea of buried fast ice, Cl and Na are predominant ions, chemical composition is in general of the same type with intrasedimental ice veins in adjacent coastal sections. In the center of ice bed the values are higher thanks to prevalence of Ca.

3.2 *Isotopic composition*

34 samples of massive ice and lenses above it and few samples of intrasedimental ice in clays were analyzed in Isotope Laboratory of AWI.

The values of $\delta^{18}\text{O}$ vary from -18.6 to -26.3‰ (average -21.9‰) in massive ice and from -15.3 to -20.9‰ in ice lenses above massive ice. In general isotopic composition is lighter in central part of ice bed and become heavier towards the upper ice lenses. Intrasedimental reticulate ice veins in clays in other coastal sections have, for example, -13.8 to -21.5‰ $\delta^{18}\text{O}$ values, which are close to one in massive ice and lenses above it. But d excess is higher in massive ice and ice lenses (average 8.4 and 6.0) than in intrasedimental ice veins (4.4).

4 CONCLUSIONS

Small dimensions of the ice bed, isotopic and chemical composition of ice close to those into intrasedimental ice veins and apparently saline overlying sediments points to intrasedimental origin of this massive ice bed.

References

Vasil'chuk Yu.K. at al. (ed.) 2006. *Cryosphere of Kharasavey gas condensate field*. St.-Petersburg: Nedra.

Surface Exposure Dating of a Rock Glacier in the Gaissane Mountains, Northern Norway: Shedding New Light on the Regions Glacial History?

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1 GLACIAL AND PERIGLACIAL SITUATION

The Gaissane Mountains are situated in the county of Finnmark, northern Norway. The mountains reach elevations ≥ 1000 m a.s.l. The winds are strong during winter, and above the timberline (250-300 m a.s.l.) extensive snow cover is restricted to depressions. At present, permafrost is common in the area above 350-450 m a.s.l. (Farbrot et al. 2008).

The area is situated well inside the glacial limits of the Younger Dryas (YD) ice extension, and an earlier study suggests that only the highest summits were ice-free nunataks at that time. Today, the area is devoid of glaciers.

Our field area contains a range of active and relict periglacial features. Facing east, some lobate-shaped, talus-derived rock glaciers (front at 450 m a.s.l.) are found below a steep escarpment that separates a high plateau from the broad glacially modified valley. The rock glaciers have crept over morainic ridges that have been assumed to be of Preboreal age. Previous investigations on one presumably active rock glacier indicate that the rock glacier contains permafrost at present, probably with a considerable amount of ground ice. Here we present exposure dating results of this rock glacier from boulders of its frontal ridge.

2 COSMOGENIC NUCLIDE DATING

The samples for exposure dating were obtained with hammer and chisel and prepared following the method of, among others, Ivy-Ochs (1996). The $^{10}\text{Be}/^9\text{Be}$ ratios were measured at the ETH/PSI Zurich Tandem Accelerator Mass Spectrometry (AMS) facility using ETH AMS standard S555 ($^{10}\text{Be}/^9\text{Be} = 95.5 \cdot 10^{-12}$ nominal) with a ^{10}Be half-life of 1.51 Ma. The surface exposure ages were calculated for sea level and used a high latitude production rate of 5.1 ± 0.3 ^{10}Be atoms/ SiO_2 gram/year and incorporated a 2.2 % production due to muon capture, a rock density of 2.65 g cm^{-2} and an effective radiation attenuation length of 155 g cm^{-2} . The production rate was scaled for latitude and altitude, corrected for sample thickness, topographical (skyline) shielding, and an erosion of 3 mm ka^{-1} . Snow cover was assumed to have a negligible effect on the age calculations. Results are given in Table 1.

Table 1. Cosmogenic nuclide concentrations and calculated exposure ages for the rock glacier in the Gaissane Mountains, Finnmark, northern Norway. QS = Quartzite sandstone.

Sample codes	L-A1	L-A2	L-A4
Latitude ($^{\circ}\text{N}$)	69.93	69.93	69.93
Longitude ($^{\circ}\text{E}$)	24.79	24.79	24.79
Elevation (m a.s.l.)	467	478	469
Sample material	QS	QS	QS
^{10}Be (atoms $\text{g}^{-1} \times 10^4$)	8.05	4.54	7.34
Surface dip angle ($^{\circ}$)	30	35	42
Dip direction	256	120	252
Measurement error (%)	11.2	14.4	11.8
Local production rate ¹⁾	7.808	7.888	7.823
Prod. rate ²⁾	7.093	7.472	6.961
Corr. factor for shielding	0.932	0.963	0.936
^{10}Be exposure age (yrs)	11380 ± 1270	6090 ± 880	10570 ± 1260
^{10}Be exposure age (yrs) ³⁾	11730 ± 1310	6180 ± 900	10870 ± 1290

¹⁾ Local production rate (atoms $\text{g}^{-1} \text{ yr}^{-1}$)

²⁾ Production rate corrected for shielding (atoms $\text{g}^{-1} \text{ yr}^{-1}$)

³⁾ ^{10}Be exposure age (yrs) corrected for erosion

3 IMPLICATIONS OF DATING RESULTS

Two samples from the rock glacier front (L-A1, L-A4) give ages in the order of 10870 ± 1290 yrs and 11730 ± 1310 yrs, while sample L-A2, located 10 m higher up and ca. 20 m from the other two, yields an age of 6180 ± 900 yrs. Due to general theories on rock glacier dynamics, the onset of the rock glaciers' formation can be considerably older than its frontal surface age, i.e. of at least YD age, but presumably older. If correct, this may imply ice free conditions during the YD not only on the mountain tops - as previously suggested - but also in parts of the valley floor, which then must have been shielded from the main ice stream. Alternatively, the rock glacier could have started to develop even earlier, and subsequently been covered by cold-based ice. Either way, the results indicate that the overridden terminal moraines are older than assumed. However, due to the small analysable sample size our results are just indicative and would need to be verified by more extensive dating in the area.

References

- Farbrot, H., Isaksen, K., Etzelmüller, B. 2008. Present and past distribution of mountain permafrost in the Gaissane Mountains, northern Norway. *9th International Conference on Permafrost, Proceedings*, Institute of Northern Engineering, University of Alaska Fairbanks: 427-432.
- Ivy-Ochs, S. 1996. The dating of rock surfaces using in situ produced ^{10}Be , ^{26}Al and ^{36}Cl , with examples from Antarctica and the Swiss Alps. Ph.D. Thesis, ETH Zürich, No. 11763 (<http://e-collection.ethbib.ethz.ch/view/eth:40688>).

Detecting Near-Shore Submarine Permafrost at Barrow, Alaska Using Electrical Resistivity

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1 INTRODUCTION

Non-consolidated sections of the arctic coastline are generally rich in ground ice and highly dynamic due to the combined effects of thermal abrasion and erosion. Subsidence following thaw may contribute to shaping shore-face profile and speed erosion, analogous to the removal of material in the near-shore zone. Ice dynamics in the near shore are thus important to coastal erosion rates. We test electrical resistivity tomography as a means of measuring the depth of ice-bearing permafrost within the sediment and to gain insights into how sediment ice content may control coastal dynamics. Coastline position change rate studies at Elson Lagoon at Barrow, USA, provide background information on long-term coastal evolution as far back as the end of the 19th century. We couple observations on change in coastal geomorphology with geophysical observations along a submarine sub-bottom profile obtained using electrical resistivity soundings and drilling.

2 SITE

Permafrost on the land-side of the coastline at Elson Lagoon (71° 18' N, 156° 32' W) is ice-rich near the ground surface. It is cold at Barrow (about -9 °C at 20 m, the depth of zero seasonal amplitude) and warmed by about 2°C during the last century. Despite sheltering by barrier islands, coastal retreat rates on the western and southern coasts of the lagoon have been high over the past few decades.

3 METHOD

Permafrost evolution after inundation following coastal retreat was examined using a combination of electrical resistivity surveys, sediment sampling and temperature measurements. Sub-bottom apparent electrical resistivity was collected in the summer of 2008 using an IRIS Syscal Pro(TM) system and an electrode cable with 5 m spacing. A GPS and echosounder measured position and bathymetry. In spring 2009, 4 boreholes were drilled along 2 transects at 1 and 2.25 m water depth. Borehole tem-

peratures, sediment pore water salinity and stable isotope composition were measured.

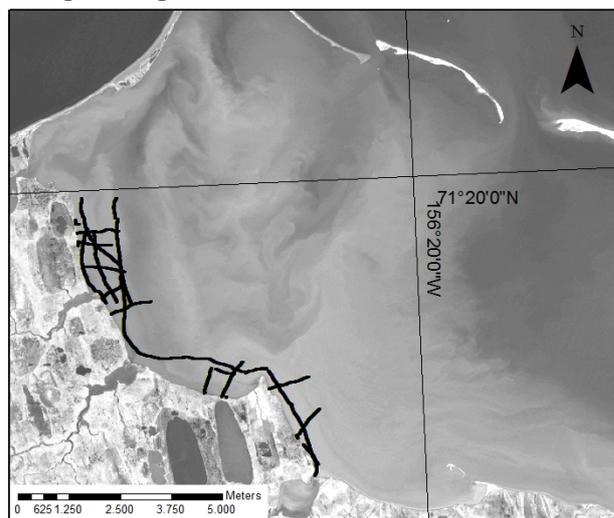


Figure 1. Electrical resistivity profiles measured in Elson Lagoon, overlaid on a July 24, 2007 ALOS PRISM image.

4 RESULTS & DISCUSSION

Over twenty offshore profiles were measured with a penetration depth of about 15 m. Resistivity profiles perpendicular to the coastline showed a sharp increase in resistivity at some depth. This depth increased with increasing distance from the shore. The underline high-resistivity layer disappeared beyond approximately the 2 m isobath (at least in the upper 14 m of sediments). Drilling and sediment temperature suggested that this layer coincided with the ice-bearing permafrost. Salinity of pore water within the sediment reached values over four times that of seawater.

We suggest that bottom-fast ice in water depths of less than 2 m works to preserve ice within the sediment. Beneath water columns deeper than the maximum annual ice thickness, penetration of highly saline bottom water into the sediment facilitates permafrost degradation.

Coastline retreat rates have been reported by numerous authors for this site and currently generally increase towards the southeastern portion of the study site. The distribution of the interpreted ice-bearing permafrost along the coast changes too little to be related to differences in coastal retreat rates.

Past and Present Permafrost Distribution in the Southern Hemisphere: Comparison of the GCM-Based Mapping with the Observations

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1 INTRODUCTIONS

Due to relatively small portion of the terrestrial areas, the distribution of frozen ground (permafrost and seasonally-frozen ground) in the Southern Hemisphere has not been intensively surveyed and/or mapped. Saito et al. (2009) demonstrated that the frozen ground distribution on the large scale can reasonably be reconstructed through the mapping from the near-surface thermal conditions (i.e. freeze and thaw index, as the cumulative degree-day values below and above the freezing point, respectively), despite simplifications of the determining factors of permafrost in the reality. We attempt to apply the methodology to deduce the preliminary distribution maps of Southern Hemisphere frozen ground under the present-day and glacial climate, and compare them with the evidences obtained by observations.

2 DATA

2.1 Observations and simulated near-surface climate in the Southern Hemisphere

Some of the critical evidences of the frozen ground distributions under the present and past (e.g. Last Glacial Maximum) are available through observations in Patagonia and the Andes regions as summarized in Trombotto (2002). Map of winter freeze in Patagonia is also available for comparison and validation. The near-surface atmospheric conditions in the Southern Hemisphere have been simulated by numbers of different global climate models (GCMs), both for the present-day (e.g. Inter-governmental Panel for Climate Change, the fourth Assessment Report simulations) and the glacial (e.g. Paleoclimate Model Intercomparison Project 2 for six-and twenty-one thousand years ago) climatic conditions. Near-surface air temperature at 2m is used as thermal index in the analysis.

3 MAPPING OF THE FROZEN GROUND DISTRIBUTION IN THE SOUTHERN HEMISPHERE

In Saito et al. (2009) the abovementioned mapping result was provided only for the Northern Hemisphere, but the methodology is easily extended to application to the Southern Hemisphere to produce

the large-scale distribution map of frozen ground in the austral continents. Firstly, observed freeze index in Patagonia is used for validation of the simulated thermal index distribution. Further, the resulting frozen ground maps are presented and compared with the observation-derived evidences for current and glacial climate.

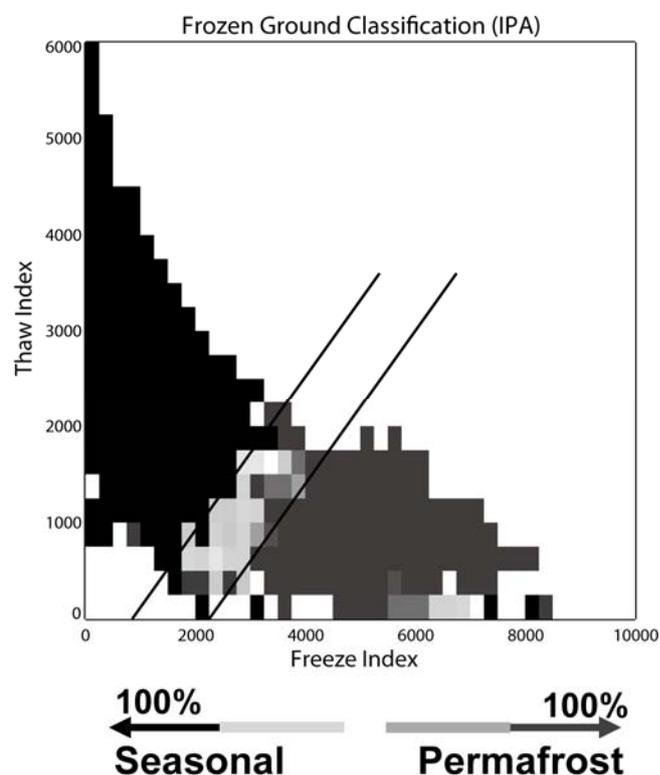


Figure 1. Mapping of the permafrost and seasonally frozen ground from a given combination of the Freeze and Thaw Index values, constructed by the present-day observations (produced from NSIDC-compiled freeze and thaw indices based on the monthly data, and the International Permafrost Association map of permafrost distribution).

References

- Saito, K., Marchenko, S., Romanovsky, V., Bigelow, N., Yoshikawa, K., and Walsh, J. 2009. Thermally-Conditioned Paleo-permafrost Variations from Global Climate Modeling. *SOLA*, 5: 101-104.
- Trombotto, D. 2002. Inventory of fossil cryogenic forms and structures in Patagonia and the mountains of Argentina beyond the Andes. *South African Journal of Science*, 98: 171-180.

Relative-Age Dating of Rock Glacier Surfaces with Schmidt Hammer in Blenio Valley, Southern Swiss Alps

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1 INTRODUCTION AND STUDY AREA

Within the framework of scientific researches related to geomorphological and climatic evolution of the Alps during Lateglacial and Holocene, only few studies were carried out on periglacial sedimentary terrains. In order to reconstitute the palaeoenvironmental history of the alpine periglacial domain, this research had focused on the morphostratigraphy of relict, inactive and active rockglaciers. This relative surface dating was performed with the analysis of Schmidt hammer rebound values (*R*-values) (for the method, see Kellerer-Pirklbauer, 2008).

The studied area is the Cima di Gana Bianca massif, in the Eastern part of the Blenio Valley (Lepontine Alps of the Tessin, Southern Switzerland). The rockglaciers of this area have been described by Scapozza and Fontana (2009), who proposed a relative-age dating of the relict rockglaciers based on the correlation with Lateglacial glacier fluctuations. Schmidt hammer rebound values have been measured on six rockglaciers, on a talus slope and on glacial landforms (moraines, *roches moutonnées*, etc.). We present here the results obtained on the Stabbio di Largario and the Pièi active rockglaciers.

2 RESULTS AND DISCUSSION

The Schmidt hammer results of the two studied rockglaciers are summarised in Fig. 1. The 95% confidence limits are generally below ± 1.00 , except for the sites 10 and 11.

The Stabbio di Largario rockglacier is a large monomorphic rockglacier. Mean *R*-values range from 48 on a rock surface adjacent to the rockglacier (site 10 on Fig. 1) to 60 in the rooting zone of the rockglacier (site 1), occupied in the Little Ice Age (LIA) by a small glacier. A constant decrease in *R*-values is observed between the rooting zone and the front of the rockglacier (site 4), indicating an increasing in surface age from the top towards the front of the rockglacier.

The Pièi rockglacier is a large polymorphic rockglacier, composed by two superposed lobes. Mean *R*-values range from 44 on the *roches moutonnées* attributed by Scapozza and Fontana (2009) to the end of the Oldest Dryas (site 11) to 57 on the upper lobe of the rockglacier (sites 5 and 6). The *R*-values of 55 measured on the lower lobe of the rockglacier are

significantly lower than the ones measured on the upper lobe.

A tentative of calibration of the ages based on the *R*-values measured on three surfaces of known age (cf. Kellerer-Pirklbauer, 2008) is presented in Fig. 1. In a chronological point of view, the result shows that the minimum surface age of the investigated rockglaciers lies between 3 and 5 cal ka BP and that it is likely that these rockglaciers started to evolve during the early phases of the Holocene or, at the latest, after the early-to-mid Holocene temperature optimum (ending around 5 cal ka BP).

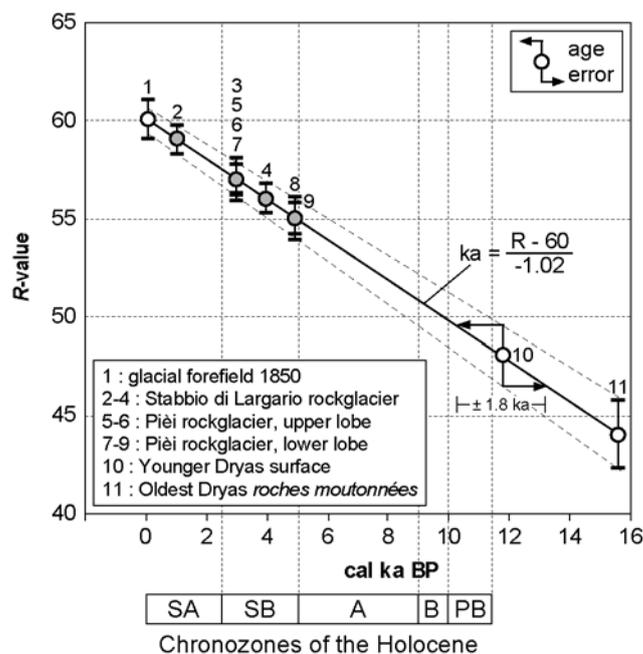


Figure 1. Tentative age-calibration curves based on three surfaces of known age (open circles) for the *R*-values measured on the Stabbio di Largario and Pièi rockglaciers. The calculation of age error is illustrated for the Younger Dryas surface. Grey circles indicate calculated ages based on this approach. Holocene chronozones: SA = Subatlantic; SB = Subboreal; A = Atlantic; B = Boreal; PB = Preboreal.

References

- Kellerer-Pirklbauer, A. 2008. The Schmidt-Hammer as a relative age dating tool for rock glacier surfaces: examples from Northern and Central Europe. *Proceedings of the 9th International Conference on Permafrost, Fairbanks, Alaska, July 2008*: 913-918.
- Scapozza, C., Fontana, G. (eds.) 2009. *Le Alpi Bleniesi: storia glaciale e periglaciale e patrimonio geomorfologico. Memorie della Società ticinese di Scienze naturali e del Museo cantonale di storia naturale, Lugano* 10: 1-111.

Oxygen and Hydrogen Isotopic Composition of Ice in Northern Transbaikalia, Russia

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Frost cracking is widely spread in Northern Transbaikalia. The isotopic composition of relic and modern ice wedges, natural waters and snow was studied within southern cryolithozone in Russia during 2006–2008 (tab.1, fig.1). The oxygen isotope composition was specified, the hydrogen is obtained for the first time in Northern Transbaikalia. To analyze isotopic composition of ice wedges is one of the best ways to recognize paleo or modern air temperature of winter. Isotope composition of all kinds of ice allows to definite their genesis and temperature of forming in some cases.

The isotopic composition of syngenetic ice wedges mainly reflects the paleoclimate of winter conditions. In southern cryolithozone, in Northern Transbaikalia, comparatively large ice wedges with the relatively warm isotopic signature of -22‰ for $\delta^{18}\text{O}$ and -175‰ for δD were growing in gravel sand deposits in depression. Syncryogenic ice wedges were forming during Holocene ($10\text{--}7.5\text{ }^{14}\text{C ka BP}$) practically continuously, they are found at the different depths.

Modern ice wedge formation is now developing in peat deposits and at the high altitudes on ridges only. Today ravines are developed in place where ice wedges are melting on river terrace.

The interpretations of the isotopic data support the assumption that ice wedges are basically fed by meteoric water, released during snow melt in spring and provide an isotopic signal of winter precipitation.

Isotope variations within sediment are difficult to interpret in paleotemperature terms, because of various processes involved such as seasonality of precipitation, amount of rain and snow feeding the active layer, fractionation during evaporation, melting and freezing; all of them may influence the isotopic composition.

The author is grateful to Professor Yu.K. Vasil'chuk, Dr. H. Meyer for isotope analyses and useful advice; to Dr. D.O. Sergeev, V.G. Podgorbunsky, V.V. Samsonova, J.A. Ukhova, E. Savel'ev and A.A. Sviridov for ice wedge investigating during field work; to N.Belova for working under samples.

Table 1. Mean isotopic composition (in ‰) of ground ice, snow, rain, river and lake waters.

Type of sample	$\delta^{18}\text{O}$	δD	d_{exc}
Snow, Oct.-Nov.2008	-39,29	-286,1	28,3
Rain, Nov.2009	-16,69	-	-
Belen'ky 1 (ice wedge)	-21,43	-175	-5
Belen'ky 2 (ice wedge)	-17,16	-138,5	-1,2
Belen'ky 3 (ice wedge)	-23,38	-183,4	3,1
Belen'ky 4 (ice wedge)	-22,79	-180,5	1,4
Segregated lenses from sandy loam	-15,77	-133	-6,9
Segregated lenses from peat	-15,27	-117,9	4,3
Massive ice	-15,54	-127,7	-3,4
Water of Chara river	-18,28	-139,5	6,7
Injected ice from hydrolaccolithes	-15,22	-124,1	-2,3
Udokan 1 (ice wedge)	-22,3	-169,9	8,5
Thermokarst puddle water (Udokan)	-13,27	-108,6	-2,4

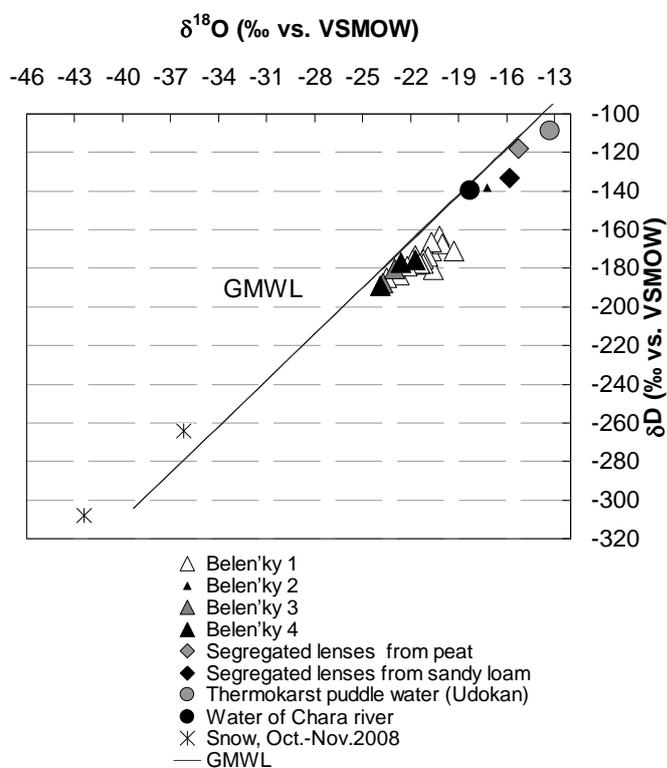


Figure 1. Mean isotopic composition of ground ice, snow, rain, river and lake waters.

Subsea Permafrost Degradation in the Western Laptev Sea (NE Siberia)

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1 INTRODUCTION

Subsea permafrost in Arctic shelf seas is largely understudied. In order to characterize its properties and to understand its dynamics during the Quaternary past, a joint Russian-German sea-ice-based drilling campaign (COAST I) was undertaken in spring April 2005 in the western Laptev Sea, Siberia. Permafrost outcrops had already been studied in summer 2003 and represent the upper terrestrial counterpart of the submarine sequences. Here, we present detailed hydrochemistry and stable water isotope data of ground ice and pore water samples from both the subsea and the terrestrial part as tracers for permafrost degradation under subsea conditions.

2 STUDY SITE

The study site was located on the coast of Cape Mamontov Klyk (73.61°N, 117.18°E), where a 12 km long coring transect of five cores was drilled including four offshore cores at different distances from the coast, and one terrestrial core (Fig.1).

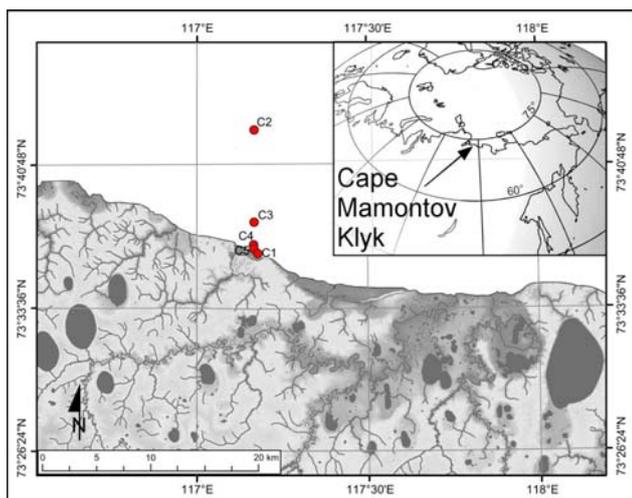


Figure 1: Position of the COAST I drilling transect

The sampled coastal cliff of about 25 m height above the sea level (m a.s.l.) is an additional data source for the sequences of the upper part of core C1. The coring reached a maximal depth below sea level (b.s.l.) of 77 m in the core C2 located furthest from the coast (~12km from the coast).

3 GROUND TEMPERATURES, HYDRO-CHEMISTRY AND STABLE ISOTOPE

Borehole temperature logging showed increasing ground temperatures seawards from about -12 °C in C1 on land up to -1 °C in the marine cores, pointing to thermal degradation of relict terrestrial permafrost under marine influence.

Hydrochemical and stable water isotope data from ground ice in ice-bonded deposits or from pore water in cryotic deposits reveal clear evidence for chemical degradation of relict terrestrial permafrost under subsea conditions. The marine influence acts downwards via conductive heat transfer, via pressure-gradient and via concentration-gradient diffusion of warm, saline and isotopically heavy sea water into the ground. Accordingly, relict terrestrial permafrost shows low ionic contents (measured as electrical conductivity, EC) that increase under marine influence to values much more than 10 mS cm⁻¹. The respective stable water isotopes ($\delta^{18}\text{O}$, δD) of relict terrestrial permafrost are generally lighter than -15‰ for $\delta^{18}\text{O}$ and -15‰ for δD . In all four marine cores, the infiltration of marine waters into underlying former terrestrial permafrost following the Holocene sea transgression is mirrored by abrupt shifts in hydrochemical and stable isotope parameters in transition zones between degrading and non-degraded permafrost. However, the cryolithologically observed borders between cryotic, but not ice-bonded versus ice-bonded sediments do not correspond to the shifts evident in hydrochemical and stable water isotope data.

4 CONCLUSIONS

Based on current coastal erosion rates of 4.5 to 5m year⁻¹ at Cape Mamontov Klyk, the furthest offshore located coring site (C2) was likely flooded at about 2500 years ago showing an increase in borehole temperature of more than 10°C during that time. Taking into account the reconstructed timing of inundation on the Western Laptev Shelf and the depth of non-degraded terrestrial subsea permafrost, a maximum infiltration (or permafrost degradation) rate of 0.7 to 1.3 cm year⁻¹ seems to be reliable.

Data on Chemical and Isotopic Composition of Massive Ground Ice at Yeniseyskiy Bay Coast

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This paper is based on the field investigations at Western Taimyr coast in July-August 2007-2008. Field works were carried out as part of International Polar Year programme as “The field courses on geocryology for the young researchers”. Area of study was Yeniseyskiy bay coast: from polar station Sopochnaya Karga (71°88'N/82°68'E) to Dikson town (73°31'N/80°34'E).

Isotopic and chemical composition of massive ground ice has been investigated and analyzed. One of the results of the work is a sketch map of ground ice distribution in the Yeniseyskiy Bay region (northward of 71°N), based on analysis of the literature and personal investigations of the region.

The complex of such methods as geological, geomorphological and cryolithological was applied.

Chemical composition of massive ground ice is very different from compositions of present-day snow and Holocene ice wedges. Mineralization of massive ice several times exceeds mineralization of ice wedges. In general, it increases from 266 mg/l to 722 mg/l in vertical profile of massive ice body. In all samples hydrocarbonates (HCO_3^-) are highly predominating among anions. Sodium (Na^+) is predominating among cations, its amount increases with depth up to 92 %. Amount of oxygen isotopes ($\delta^{18}\text{O}$) is not changes through the ice profile and in average mean it is equal to -23‰, what is close to the isotopic composition of present-day snow. Values of *d* excess are different from snow and equal to -4,5 – -5,8‰. Values of this parameter (*d* excess) if less than 10‰ are indicative for ice, formed during ground water freezing or for surface water, which have been fall under evaporative fractionating.

During the expedition Pleistocene-Holocene deposits in coastal exposal of the right bank of Yenisey river and Yeniseyskiy Bay have been studied. Obtained data allows to estimate the present-day situation in Western Taimyr permafrost zone and reconstruct conditions of permafrost evolution and formation in the past.

Posters Wednesday, cont.

Engineering in Permafrost Environments:

in Kapp Schultz

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Investigation of Newly Exposed Very Sensitive Fine-Grained Marine Deposit at Kangerlussuaq, Western Greenland

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1 BACKGROUND

In 2007, a previously unknown fine-grained marine deposit was exposed in a river bank at Kangerlussuaq, Western Greenland, subsequent to a jökulhlaup originating from the sudden drainage of an ice-dammed lake. Preliminary studies revealed a material with very high sensitivity; properties that have not previously been reported from near-surface deposits in Greenland, although deeper seated (less) sensitive deposits have been observed by Foged (Foged, 1979) in Sisimiut and Narsaq.

The formation in Kangerlussuaq is stabilized by permafrost, but with climate amelioration, this deposit may lose bearing capacity and become prone to sliding and solifluction posing a threat to future infrastructural development and construction projects.

2 RESULTS OF PILOT TESTS

Two drill cores were retrieved from the formation during a 2009 field campaign. These will be subjected to geotechnical classification supplemented by geochemical analyses and investigation of thermal properties and unfrozen water content. Results from the pilot sample is presented in table 1.

Excess ice content is calculated based on the amount of water draining from the sample upon thawing in a closed humid environment. Gravimetric

water content is determined by measuring the loss of mass upon drying of the remaining material.

To determine the thermal properties and the unfrozen water content, an undisturbed sample was fitted with an Isomet surface probe (λ and c_p), a Stevens Hydra Probe (ϵ_r) and a thermistor. During a full thaw-freeze-thaw cycle measurements were recorded and the permittivity measurements (ϵ_r) transformed to unfrozen water content based on calibrations provided by Stevens (Bellingham, 2007).

3 CONCLUSIONS

The exposed deposit displays quick properties in terms of high sensitivity and a gravimetric water content above the liquid limit. The material has a residual chloride content of about 0.2 g/L which is around the upper limit normally expected for the development of very sensitive materials.

The existence of a deposit with quick properties in the central part of West Greenland indicates a risk of encountering similar deposits in other current and future infrastructural development areas. Where the challenges of handling such deposits are well known in other parts of the world, there has been no previous experience in Greenland. With the new discovery, it has become a priority to inform and educate the local stake holders on the risks involved.

ACKNOWLEDGEMENTS

This research is funded by the Polar Earth Science Program, National Science Foundation (ARC-0612533), and by the Danish Commission on Scientific Investigations in Greenland (2138-09-0011).

References

- Foged, N. 1979. Ingeniørgeologiske undersøgelser af kvartære marine aflejringer på Vestgrønland. PhD-thesis at Department of Technical Geology, Technical University of Denmark.
- Bellingham, K. 2007. The Stevens Hydra Probe Inorganic Soil Calibrations. *Stevens Water Monitoring Systems Inc.* Portland, Oregon.

Table 1. Classification properties of the Kangerlussuaq deposit. Borehole Grav1A, UTM cords.: N7433761m, E517561m, elev. 31.9 m asl. (WGS84), sample depth 3.18 mbs.

Property	Value	Unit
Bulk density	1710	kg/m ³
Grainsize, d_{50}	9.8	μm
U (d_{60}/d_{10})	13.4	-
Gravimetric water content	30.4	%
Excess ice content	9.9	% Vol.
Liquid limit, w_L	25.1	%
Plastic limit, w_p	18.0	%
Shear strength, $C_v/C_{v,r}$	49/0.5	kPa
Sensitivity	98.0	-
Chloride content	177	ppm
Organic content	0.64	%
Heat capacity, c_p	2.06	MJ/(m ³ K) @ 10°C
Thermal conductivity, λ	1.06	W/(m K) @ 10°C
Unfrozen water content	5.3	% Vol. @ -5°C

Monitoring of Active Layer and Permafrost Disturbances Caused by “Low Frequency Traffic” at Kapp Linné,– Svalbard, Norway

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The active layer, has been monitored in the vicinity of Kapp Linne', (78°03'42''N 13 °37'07''E) Svalbard since 1972. These measurements are in the Circum Polar Active Layer Permafrost Monitoring (CALM) program. In addition to the long term monitoring program special case studies have been performed. Tractor traffic over an ice wedge polygon system have triggered and enhanced thermokarst processes. The mean active layer in the polygon area varies between 1,92m and 0,38m with the deepest in the exposed, well drained raised beach ridges and the shallow sites in the bogs.

The summer mean air temperature 1972-2006 is +3,7°C. The average DDT is 399.6 °C. There is no clear over-all trend in the summer climate during the monitoring period but a clear division between the period from 1972 to 1983, which had a decreasing summer temperature, and 1984 to 2004, which show an increase in the air temperature.



Figure 1. Subsidence in a ice wedge polygonal pattern east of Kapp Linné caused by anthropogenic surface disturbances. Photo J. Åkerman 1993

The observed changes in the depth of the active layer during the period 1984 -2000 have resulted in an increased amount of soil water in the active layer – as ice rich layers are thawed. The well drained raised beach ridges with ice wedges are generally not affected very much as seen on the surface. One exception is where tractor traffic over the studied ice wedge polygon system have triggered and enhanced thermokarst processes and disturbances in the vegetation cover (Fig.1).

Generally the active layer variations during the investigation period have not yet reached a depth at which the ice wedges proper are influenced. The marginal is however in some cases only a few centimeters. The average depth to the upper part of the ice wedges in coarse beach gravel sites is 175 cm, on vegetated surfaces the figure is more variable (average 120cm). At the site where the tractor tracks are passing the ice wedge system the surface disturbances have caused an increased active layer depth (from 90 to 120cm), thawing of the ice rich layers, including the top of the wedge ice, causing surface subsidence and an accelerated thermokarst process.

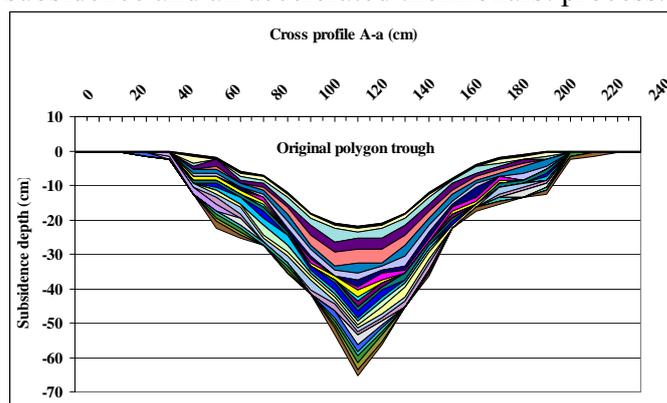


Figure 2. Annual progression (1972-2000) of subsidence across the ice wedge polygon furrow in Fig 1

The process was initiated during the increased “traffic” during installations works of a power line in 1974 (Fig.2). The surface subsidence across the ice wedge polygon troughs is considerable - up to 4 cm/year in the water filled central part during the first 5-6 years.

After an initial period the thermokarst process has continued but at a slower rate. The polygon through is both widening and getting deeper and the accumulated water is also filling the trough during a so long part of the vegetation period that vegetation is killed.

References

- Råheim E, (ed.) 1992. Registration of vehicular tracks on the Svalbard archipelago.: Norsk Polarinstittutt, Oslo 1992
- Richard, W.E. & Brown, J. 1974. Effect of Vehicles on Arctic tundra. *Environmental Conservation* nr. 1, vo.1 1 55-62. Lausanne.

Findings of Relict Permafrost in the Kiruna Area – Sweden

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1 INTRODUCTION

The Kiruna iron ore mine close to the city of Kiruna (67°51'N 20°13'E, 500 m.a.s.l) is expanding in the direction of the city proper. Both the mine and the infrastructure like railroads and roads must be expanded north. As a consequence the entire city centre and its buildings have to be moved to allow for expansion. This gigantic and expensive project has actually begun. One of the first major physical components is to drain Lake Loussavara. During constructions of a concrete drainage channel/tunnel problems with instability and rapid settlements occurred already after a few month of work. Permafrost has up till now only been found at higher elevations and in palsa bogs west of Kiruna. Permafrost hence was not taken into account by the contractor during planning of the construction. Thawing permafrost now turned up as a possible explanation.

2 METHODS

During late 2009 a number of drillings were done with a band propelled drilling rig using 90mm screw and 70mm coring bits. The drillings were made in the direct vicinity of the concrete construction, close to the lake and also in the undisturbed terrain with scrub covered bogs. Soil samples were taken at every 50 cm, temperature was measured at every 10 or 50 cm and turf samples for C¹⁴ dating were taken at the bottom of the turf layer.

3 OBSERVATIONS

The drillings showed a rather simple stratigraphy similar to all the holes. At the top spongy *sphagnum* turf between 2 and 3 m thick. The variations in the turf layer showed only minor connections with the surface topography. No palsas or other signs of permafrost or ground ice could be seen. No permafrost or remaining annual frost was found in the turf layers which on the contrary were “warm” and very wet. The age of the bottom layer of the turf was 6550 ±55 & 7795 ±55 BP under the 2 m and 3 m layer respectively. This corresponds to the age of bottom turf from bogs of the regions – the post glacial warm period. Below the turf is a uniform moraine, silt (45%) sand (43%) and 12% gravel. Bed-

rock was reached in all the holes at between 7m and 9m depth

At levels between -3.5 and 3.75m a majority of the holes revealed sub zero temperatures. The frozen layer had temperatures between -1.5°C and -0.1 °C. The frozen layer was between 1 and 3.5 m thick in the different holes. The deepest level with negative temperatures was -7.2m (figure 1.). The layers showed very low amounts of ground ice, and no segregation ice layers were observed.

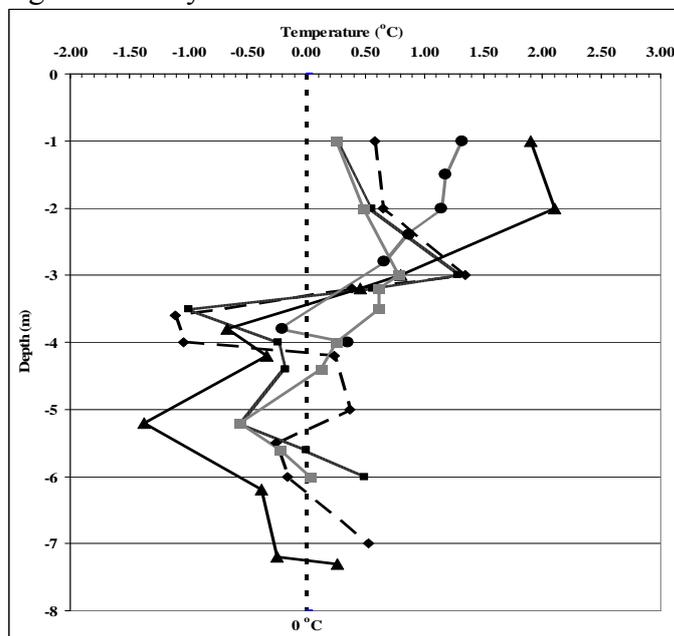


Figure 1. Vertical temperature profiles near the Lake N. Loussavara discharge culvert. The recordings of negative temperatures lie in the -3.5m to -7.2m depth interval

4 CONCLUSIONS

- The observed frozen layers are permafrost.
- As such it is unique to the area at this elevation, as permafrost in the region only has been found in palsa bogs.
- The of the frozen layers under a 2-3 m turf layer clearly indicate that the permafrost here do not have a direct connection the present climatic and soil temperature conditions.
- It is therefore **relict permafrost**.
- More detail investigations are necessary both for the contractors planning to move a city to grounds in this area and from a scientific point of view.

Increase Frozen Soils and Ice Strength with Water-Soluble Polymers

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The methods of increase soil strength are designed for the unfrozen soils. They can't be used in soils in severe conditions where changes of phase occur. We propose energetic and structural interactions between soils and chemical additives are the reason of phase changes. It leads to the growth of polymer chains and their linking with soil components. We can deliberately manage structural varieties by selecting the ameliorant composition and maintaining special thermal conditions. Physical models have been proposed. The modeling was carried out on different types of the soils widespread within the region of the Arctic coast where the method is supposed to be used. While modeling we use polymers with various molecular weights. A structured analysis has been carried out and the main physicochemical characteristics of the received material have been determined. A method of physicochemical effect on soils to improve their strength while using as building foundations has been presented. The method allows use of soils and ice as construction materials and also as protection of constructions against permafrost processes.

Hydrate Formation Processes at Sequestration of Industrial CO₂ in the Permafrost Area

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It is well known that we experience nowadays a steady increase in the emission of greenhouse gases by plant facilities, especially of CO₂. It can have an impact on the global climate change. That is why many researchers are working on elaborating different technologies of CO₂ sequestration. In our view one of the promising places for CO₂ storage can be gas-permeable collectors in under-permafrost horizons. The advantages of preserving CO₂ in these places are as follows: low permeability of overlying frozen sediments, low temperatures, the existence of a CO₂ hydrate stability zone, and the possibility of sequestration at shallow depths (less than 800-1000 meters).

When CO₂ (in liquid or gas phase) is pumped into the under-permafrost collectors it is possible that some CO₂ migrates towards the hydrate stability zone and hydrate-saturated horizons can be formed. This can result on the one hand in the increase of effective capacity of the collector, and on the other hand, in the increase of isolating properties of cap rock. Therefore, CO₂ injection sometimes can be performed without a good cap rock.

Conditions for CO₂ sequestration can be different depending on the permafrost thickness and temperature conditions of sediments (figure 1).

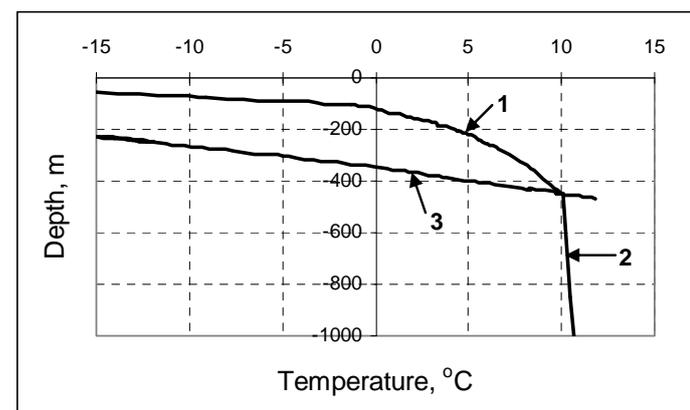


Figure 1. Conditions of CO₂ hydrate existence in the permafrost area.

1- equilibrium between CO₂(gas), water(or ice) and CO₂ hydrate; 2 - equilibrium between CO₂(liquid), water and CO₂ hydrate; 3 - equilibrium between liquid and gaseous CO₂.

Optimal conditions exist at permafrost thickness more than 350 meters. In this case CO₂ hydrate stability zone can be 700-900 meters, depending on geothermal gradient. Hydrate formation can occur from pore water (or ice) and CO₂ (in liquid or gas phase) according to depth.

If permafrost thickness is from 350 to 120 meters then the thickness of CO₂ hydrate stability zone is 350-750 meters, depending on geothermal gradient. In distinction from preceding case, hydrate formation will not take place from liquid CO₂ and pore ice.

If permafrost thickness is less than 120 meters, then the thickness of CO₂ hydrate stability zone is 0-500 meters, depending on geothermal gradient. In this case, if hydrate formation is possible, it can take place only from liquid water and CO₂ in liquid or gas phase.

Thus, there are two possible schemes of hydrate formation in pore medium of sediments: from liquid CO₂ or the gas. The pore water in the sediment may be either in frozen or liquid states.

To study the peculiarities of hydrate formation in the sediments of permafrost area at CO₂ deposition a complex of experiments has been performed. It included the research of mechanisms and kinetics of hydrate accumulation in porous media from liquid and gaseous CO₂ under positive and negative temperatures [1], and also the influence of CO₂ gas pressure on freezing temperature of pore water. The researches have been made on special gas hydrate cells using the PVT method and NMR imaging.

The performed experimental researches allowed to reveal the influence of temperature, pressure, water saturation, mineral skeleton, phase composition of CO₂ on the peculiarities of hydrate accumulation in porous media.

References

- [1] Chuvilin E.M., Guryeva O.M. 2008. Carbon dioxide gas hydrates accumulation in freezing and frozen sediments. *Proc. of the 6th Intern. Conf. on Gas Hydrates, Vancouver, #5469.*

Experiences from Geotechnical Sampling and Sounding in Permafrost EUCOP2010 – Svalbard, Norway

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SINTEF Building and Infrastructure, Trondheim, Norway

1 INTRODUCTION

SINTEF Building and Infrastructure has been present on Svalbard the last few years; among other things, to perform geotechnical research on permafrost. One of the activities has been geotechnical sampling and sounding at different sites on the island, both for research, educational and consultancy purposes. These projects have given SINTEF the opportunity to test and develop both procedures and equipment for geotechnical field work. This abstract will deal with improvement of test procedures, and innovative use of known technology, for different geotechnical field equipment. Mainly sampling, but also sounding procedures have been improved through research carried out on Svalbard.

2 BACKGROUND

In 2007 SINTEF brought a geotechnical drill rig to Longyearbyen with the purpose to improve the infrastructure for arctic geotechnical research. The rig was equipped with the following equipment:

- Core sampler for soils (“NTNU-sampler”)
- Total sounding
- Rotation pressure sounding
- Data logger

In 2010 the sampling equipment has been supplemented with an Atlas Copco T2-76 sampler with inner tube and interchangeable drill bits for both soil and rock sampling. Another improvement is changing of bit material from tool-bit to diamond/carbide bit on the “NTNU sampler”.

3 SVALBARD SOILS, AND BEDROCK QUALITY

In Svalbard there are a number of variations in both soil type and soil properties, both mechanical and thermo physical. This can be quite a challenge when it comes to selecting methods and equipment for sampling and sounding. There is always a possibility to run into stones and blocks mixed with the soil. It is difficult to confirm the exact depth to bedrock due to a thick zone of cracked rock and rock with disintegrated quality, showing the same sounding results as e.g. coarse sand.

4 SOUNDING

For geotechnical sounding in these soils and rock materials studies have shown the necessity to improve or develop already existing methods for this purpose. Total sounding is a standardized method for geotechnical sounding on unfrozen soils, primarily used to detect the layering of the soil. This method is based on constant rotation speed and constant penetration rate. The only measured variable is the load. Entering more dense layers or rock/blocks, it can be necessary to increase the rotational speed and introduce hammering/flushing. Through tests carried out on Svalbard this procedure is not found suitable for all kinds of frozen soils. The drilling resistance are too high. A modified method uses both constant load and rotation speed, with penetration rate as the only variable. Hammering and flushing are required for all soils.

5 SAMPLING

Sampling in permafrost can be quite a challenge. The experience obtained from several years of geotechnical field work shows the subsoil in the permafrost on Svalbard can be divided in five main groups:

Frozen soil up to grain size of coarse sand

Frozen soil with inclusion of stones or blocks

Unfrozen soil up to grain size of coarse sand

Unfrozen soil with inclusion of stones or blocks

Rock

The different types of permafrost require different sampling equipment, e.g. it is impossible to use the same sampling tool, or bit geometry, for unfrozen marine clay and for frozen soil with inclusion of stones or blocks. By having an interchangeable sampler and a rig customized for quick change of equipment it is possible to perform effective sampling, while at the same time giving an opportunity to obtain samples of good scientific and engineering quality.

Permafrost and Gas Hydrate Related Methane Release in the Arctic and Its Impact on Climate Change - European Cooperation for Long-Term Monitoring: COST Action PERGAMON

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The Arctic is a key area in our warming world as massive releases of terrestrial and oceanic methane could increase atmospheric methane concentrations much faster than expected. The vast Arctic shelf might become a major emitter of methane in the future. Only a few projects are engaged in research on methane seepage in this area. The exchange of information about ongoing and planned activities in the Arctic with respect to gas hydrate destabilization and permafrost thawing is low within the EU and almost non-existent at an international level. The aim of the COST Action PERGAMON is to promote networking internationally within the EU and beyond: data integration of terrestrial studies from wetlands and permafrost regions marine research on gas release from seeps due to decomposing gas hydrate and/or permafrost melting and atmospheric investigations carried out by monitoring stations and via satellite is urgently needed to achieve a better understanding of methane emission processes in high latitude areas.

The “official” main objective of PERGAMON is to quantify the methane input from marine and terrestrial sources into the atmosphere in the Arctic region, and ultimately to evaluate the impact of Arctic methane seepage on the global climate. This will be achieved by studying the origin and type of occurrence (dissolved/free gas, gas hydrate) of different methane sources (both on land and in the sub-seabed) as well as methane migration mechanisms, biogeochemical turnover, release mechanisms, and finally by quantifying the flux into the atmosphere.

Biannual meetings and open workshops/conferences that will be announced throughout the scientific community serve as a platform to exchange and proliferate knowledge on methane in the Arctic. At present, fourteen European countries are partners in PERGAMON, several non-COST country institutions are currently applying to participate (e.g. the US and Russia). PERGAMON aims to be open for new members, suggestions and input at any time of

the Action. PERGAMON officially runs until November 2013 with a final meeting early in 2014.

Community Planning on Permafrost in Nunavik – The case Study of Salluit

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1 PREMISE

Salluit is a village that lies in the continuous permafrost zone in Nunavik (Northern Québec). It is located in the bottom of a narrow valley with limited space for expansion and built in large part on ice rich silty permafrost. With recent climate warming, geotechnical problems have been encountered, such as some instabilities of several building foundations as well as increased risks of active layer slides on slopes. These geomorphic processes are expected to intensify with future climate changes, creating an additional challenge for the land-use management of this expanding community. To support the development of the community an interdisciplinary study, which combines elements from physical geography, human geography, civil engineering, economics and politics has been produced.

2 METHODOLOGY

In order to best identify local vulnerability and capacities for adaptation, geoscientific and climatic data are integrated with policy analysis and community perspectives. Public community hearings organized by Quebec's Ministry of Municipal Affairs and regular meetings with the decision makers were held in order to identify specific needs that have to be addressed. Maps integrating the collected data and the forecasted permafrost conditions have been produced. The identification of adequate adaptive measures asks also for a better understanding of the interaction between permafrost and the different types of foundations for buildings and municipal infrastructures.

A specific experiment was established in town to measure settlement and effectiveness of embankments for permafrost recovery. Thermistors and settlement plates are installed in an experimental pad and down into the underlying permafrost. The intent is to assess the best design parameters to provoke the recovery of permafrost in the newly installed pad to support the new house for a long period. An economic analysis of the possible choices of adaptation solutions will complete this study and cost-benefit analysis will be used to draw recommendations for local and regional land-use planners.

3 RESULTS

Information gathered from the policy makers and the local Inuit population show community based preferences and dislikes on the possible sites of expansion, as well as technical and geophysical constraints. These important results lay the basis for future master plans.

As for the experimental pad, the data clearly show that the ground has cooled in 2009 compared to 2008. Where there used to be a thermokarst pond, the cooling was much faster than in the surrounding less perturbed area, and after only one year of cooling the two areas have almost an identical thermal profile. This means that not only the cooling is making up for the extra thermal perturbation, but there is also a tendency of temperatures to come back towards the original unperturbed thermal profiles. Given the present data, we can expect to see the cooling trend to pursue itself during the coming years, maybe even reestablishing the natural thermal profile of the lot. This positive outcome of the experiment indicates that some disturbed terrain affected by past human activity and the presence of obsolete buildings can be restored in order to optimize the use of space within the community.

4 DISCUSSION

This leads us to the suggestions that the foundation technique of padding will not only help to restore already thermally disturbed grounds, but will also serve as a buffer zone to absorb increased air temperatures and hence help to protect, to some extent, the permafrost from global warming. This knowledge, combined with the local inuit preferences, will allow to optimize pad geometry for reclaiming degraded permafrost in the community.

In a further step this conclusion will be compared to other foundation methods, like piles, and a cost-benefit analysis will determine which method suits best not only in terms of permafrost recovery, but respects also local inuit cultural needs for future community planning.

Norwegian Committee Frost in Ground – Mandate and Work

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1 INTRODUCTION

In 2005 the Norwegian committee Frost in Ground, a subcommittee under the Norwegian Geotechnical Society was constituted. The mandate for the committee is to increase our knowledge on frozen ground and its effect on geomorphology and human activities. Furthermore to contribute to satisfactory solutions, technically and environmentally, for infrastructure and social development in cold regions.

The intention of the committee was in fact a kind of a follow-up of two previous committees: Frost Action in Soils (1970-1976) and The Committee on Permafrost (1976-87). The first one was the steering committee for a substantial Norwegian research project. The outcome from this was a series of publications in addition to a textbook with the main findings from the project. This was the publication no 17: Frost Protection / “Sikring mot teleskader”

2 TOPICS AND PRODUCTS

2.1 Topics

The main topic included in the committee’s work is science and technology in cold regions which includes:

Climate

Geomorphology

Seasonal frost

- Freezing index and frost depths
- Frost heave and heaving forces
- Infrastructure
 - Buildings
 - Structures
 - Pipelines
 - Water and sewage
 - Roads
 - Railways
 - Traffic tunnels
 - Airfields

Permafrost

- Types and distribution
- Terrain stability
- Infrastructure
- Soil contamination
- Waste handling

Ground freezing

Properties of materials

- Thermal properties
- Strength and deformation
- Permeability
- Frost susceptibility

2.2 Products

The outcome of the Committee work is:

- Publication on Frost in Ground
- Lectures and short courses
- International contacts

The committee also acts as the official Norwegian adhering body for IPA.

3 RELEVANT PROJECTS

3.1 Some relevant projects

One main task of the committee is to inform of new findings and relevant projects within the topics defined in the mandate. This may be done by dissemination of our publication or on meetings / short courses to be arranged. Some relevant projects are listed in the table below.

Table 1. Examples of some relevant projects

Project Title	Year	Country
Pile Load Test in Saline Permafrost, Longyearbyen	2003-06	Norway
Field studies on frost protection materials in road constructions	2005-08	Norway
ROADDEX I-II, subproject A: Road Condition Management in the Northern Periphery	1998-2005	Scandinavia and Scotland
Permafrost response to Environmental Impacts	1999-03	Norway
PACE-Permafrost and Climate in Europe	1997-2001	Several European countries
Frost Action in Soils	1970-76	Norway

References

- Myhre, Ø. (ed.) 2005. *Frost in Ground 2005* Norwegian Public Roads Administration, Publication no 108. Norway.
- Myhre, Ø. (ed.) 2007. *Frost in Ground 2007*, Norwegian Public Roads Administration, Publication no 109. Norway.

Geotechnical Implications of a Warming Climate in Greenland Evaluated on the Basis of Permafrost Temperature Reanalysis and Model Projections

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1 INTRODUCTION

Permafrost occurring in the inhabited parts of West Greenland is relatively warm, with temperatures in the range from 0 to -5°C . It is therefore expected that Greenlandic permafrost will be severely affected by climate amelioration over the coming centuries.

We present here an integrated study aimed at providing a proper basis of decision for town planners and politicians in West Greenland. The study consists of a comprehensive geotechnical study, combined with permafrost temperature reanalysis and projections of future permafrost dynamics.

2 METHODOLOGY AND RESULTS

The geotechnical study has focused on mapping the geology of the sedimentary basins and the current permafrost distribution using a combination of geophysical measurements and information from geotechnical boreholes. The properties studied include unfrozen water content and ice saturation, pore water salinity, and stability during controlled thawing.

We have studied recent permafrost dynamics through a reanalysis approach calibrating a sophisticated numerical model (GIPL, developed at the University of Alaska Fairbanks) against observed ground temperatures over a period of several years. This calibrated site specific model is then applied to the entire period of observed meteorological data from the nearest climate station, in order to model active layer thickness variations and ground temperature dynamics over the past decades. The modeled temperature field fits well with available ground temperature data from the period 1968-1982 as well as data from newly established ground temperature measurement stations (2007-2009), and the modeled vertical variation in unfrozen water content is backed by results from the geophysical survey.

By using the output of the high resolution regional climate model HIRHAM (provided through the Greenland Climate Change data archive, see <http://klimagroenland.dmi.dk>) as climatic forcing to the calibrated permafrost model, we have produced a projection for the permafrost temperature dynamics and active layer thickness variations of the Ilulissat

area until 2080. The projection shows that at the site used as basis for the calibration, permafrost in the sedimentary basin will have thawed completely by 2080.

It should be pointed out that geological conditions at Ilulissat are quite special, as the fine grained glaciomarine sediments at this location have a high residual salinity, causing a freezing point depression of up to 3°C in the deeper part of the sedimentary basins. This effect accounts for the sudden and very rapid increase of active layer thickness observed in the projected data.

In many other towns in west Greenland, the marine sediments have been completely leached, and high ice contents in pores and free ice in the fine-grained sediments are expected to delay permafrost degradation due to latent heat buffering.

In accordance with the scientific definition of permafrost, we have used the 0°C isotherm for establishing active layer thicknesses. However, in a technical sense, unfrozen water content is much more important, as it controls the dynamics of settlements, and thus the effects on man-made structures.

3 CONCLUSIONS

Our results from the Ilulissat field site predict severe settlement and stability problems over the coming 30-50 years culminating with complete thaw in some areas of town before the end of the 21st century. It is thus of utmost importance that mitigation strategies are adopted in the present construction practice in Ilulissat, especially in connection with road construction and major maintenance as well as other larger infrastructure projects.

ACKNOWLEDGEMENTS

This research is funded by the Polar Earth Science Program, National Science Foundation (ARC-0612533). We wish to acknowledge the cooperation with our project partners at University of Alaska Fairbanks, Asiaq Greenland Survey, and the Danish Meteorological Institute.

Freezing and Thawing Indices to be Used in Design of Foundations in Seasonal Frost and Permafrost.

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1 INTRODUCTION

Freezing and thawing indices are commonly used in engineering design of foundations in the seasonal frost zone and permafrost areas.

This presentation gives an updated evaluation of the thawing and freezing indices to be used in the design of foundations in seasonal frost on the mainland Norway and in permafrost in Svalbard.

2 THAWING AND FREEZING INDICES FOR CALCULATION OF ACTIVE LAYER THICKNESS AND FROST DEPTH

The surface thawing index (STI) is a useful parameter to determine the “magnitude” of the thawing season in permafrost regions, and will in the following be defined as an environmental load. STI is defined as the integral of the sinusoidal ground surface temperature variation during one year for $T > 0^{\circ}\text{C}$. If it is assumed that the heat flow in the ground is by conduction only, thaw depths (active layer thickness) can be estimated by a solution of the Stefan equation:

$$X = \alpha t^{0.5} \quad (1)$$

where X = thaw depth [m],

α = parameter containing soil thermal properties and surface temperature $T > 0^{\circ}\text{C}$ [$\text{m/s}^{0.5}$],

t = time [s],

Surface temperature $T > 0^{\circ}\text{C}$ multiplied by time is in essence the thawing index. Equation (1) can then be expressed as:

$$X = \beta_T STI^{0.5} \quad (2)$$

where X = thaw depth [m],

β_T = parameter containing soil thermal properties during thawing [$\text{m}/(^{\circ}\text{C s})^{0.5}$],

STI = surface thawing index [$^{\circ}\text{C s}$],

In a similar manner the frost depth in areas of seasonal frost can be expressed with the surface freez-

ing index, SFI. SFI gives an indication of the “magnitude” of the winter in a seasonal frost zone. SFI is defined as the integral of the sinusoidal ground surface temperature variation during one year for $T > 0^{\circ}\text{C}$. Equation (2) can then be expressed as:

$$X = \beta_F STI^{0.5} \quad (3)$$

where X = frost depth [m],

β_F = parameter containing soil thermal properties during thawing [$\text{m}/(^{\circ}\text{C s})^{0.5}$],

SFI = surface thawing index [$^{\circ}\text{C s}$],

3 DESIGN THAWING AND FREEZING INDICES AND CHANGING CLIMATE

For frost protection purposes, engineering practice in Norway is to use design air freezing indices with varying probability of occurrence. These values are based on statistical analysis of historical meteorological data (NTNF & PRA, 1976). A similar approach can be used for air thawing indices in permafrost areas (Instanes, A., 2003).

The alternative approach presented in this presentation is to use the output from general circulation models (GCMs) to construct artificial air temperature time series for given locations from 2010-2100. This data can be used to investigate how the probability of occurrence of air thawing or freezing index changes with time and climate scenario.

References

Instanes, A. 2003. *Climate change and possible impact Arctic infrastructure*. Proceedings of the 8th International Conference on Permafrost (ICOP), Zürich, Switzerland, July 21-26, 2003, pp. 461-466. Balkema publishers, the Netherlands.

NTNF & PRA. (Royal Norwegian Council for Scientific and Industrial Research and the Public Roads Administration) 1976. *Frost actions in soils (in Norwegian)*. Publication No. 17, November 1976, Frost i Jord, Oslo, Norway.

Complex Approach to the Drilling of Fine Grained Frozen Sediments for Scientific Purposes.

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1 INTRODUCTION

Drilling is the universal method of multidisciplinary permafrost research. There are several techniques of drilling. Most common are rotary auger and column drilling. The latter is preferably, because allow obtain the core for description and sampling. Usually we use portable drilling equipment UKB-12/25, which allow use both auger and column drilling techniques. It allows drill boreholes up to 50 m depth in fine grained frozen deposits. Drilling accompanied by the core description and sampling. Usually we take samples for lithological, biogeochemical, isotopic and microbiological analyses. Then borehole can be used for different types of logging (thermometry and radiation logging).

The presentation based on the almost 30 year's experience of multidisciplinary investigations carried out by the research team from Institute of Physical-Chemical and Biological Problems of Soil Science in the North-Eastern part of Russia, Kamchatka Peninsula and Antarctic.

2 METHODS AND APPROACH

2.1 Used equipment

Despite of drilling is not best way to investigate quaternary research in comparison to outcrops description it has some advantages. It allows to do sterile sampling for microbiological and some biogeochemical analyses and different types of logging in a borehole.

The UKB-12/25 drilling machine was used as main drilling equipment. The main parameters of the aggregate are shown in the table. It allows to drill up to 50 m deep boreholes without blowing or washing out crashed material, what is very important for samples sterility. It is possible to use both corer and auger drill rig.

We use drilling with diameter 105 mm for drilling of top 1 m and decrease it downward up to 45 mm.

Case string installed only in the top 1 m of borehole to prevent water infiltration from the active layer.

The aggregate designed for drilling of fine grained sediments, but also can be used to drill shallow boreholes in slightly weathered solid rocks.

Table 1. UKB-12/25 Technical Specifications

Parameter	
Dimensions:	
High	2m
Length	1.35m
Width	1.06m
Weight	135 kg
Rotation frequency	100/270 rt/min
Type of engine	Ural 2T gasoline (2 strokes)
Engine capacity	4.5 horse power

2.2 Core description and sampling

Drilling accompanied by the cryolithological core description in order to determine genetic peculiarities of investigated deposits. It includes description of color, grain size and texture of soil, any accessories and cryogenic structures (i.e. form of ice segregation).

Sampling: Samples are taken with regular interval 0.5 m or more detail. Each lithological or cryogenic layer should be sampled.

Water content and soil density are determined immediately after sampling.

Samples for lithological analyses volume 200 – 300 should be air dried.

Gas samples were collected by degassing 50 g of frozen cores in a 150-mL syringe under nitrogen atmosphere. Total methane and carbon dioxide concentrations was measured by a modification of the headspace equilibration technique

For microbiological samples strict protocols for drilling and the subsequent handling of cores to ensure uncontaminated material was designed and tested.

2.3 Logging

After drilling, description and sampling borehole is available for logging. We use 2 (occasional and continuous measurements) strategy for temperature observations.

Another type of logging we do is radiometry.

Anti-Frost Heaving Tower Supports

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The provision and effective utilization of basic facilities of railways in areas of a permafrost and deep seasonal soil freezing is associated with significant difficulties. As an example, on the Transbaikalian Railroad during the 1997-2006 years 17,192 power line tower supports required corrective repairs and 3,294 were replaced. In most cases deformation of support structures were caused by frost jacking within wet friable sediments of seasonally thawed (STL) or seasonally frozen (SFL) layers.

In responding to this problem, a patented solution for an anti-frost heaving measure was developed for the purpose of decreasing the influence of frost heaving forces. This is accomplished by the simultaneous increase in lateral forces on the tower support in STL by freezing and by cooling within long term frozen soils by means of: a) thermosyphon support in STL, inserted into a hollow reinforced concrete support or metal base, b) wrapping of an anti-frost heaving sleeve made of nonfreezing grease and a protective casing made of frost-resistant material, c) placement of heat and hydroinsulation at the soil surface around the support, and d) inclusion of a sun-precipitation protective shed around the support and anti-frost heaving sleeve (Kondratiev, 2005).

The anti-frost heaving device design for a metal tower support having a screw base (Figure 1) consists of three basic elements: the thermosyphon, the thermal insulation and the anti-frost heave sleeve.

In October, 2003, anti-frost heaving devices consisting of the thermosyphon structure and a 1.25 m long anti-frost heaving sleeve were installed on five tower support pile bases along the Erofey-Pavlovich-Sgibievo segment of the Transbaikalian Railroad.

Work on placing the insulation layer around the support bases and protective soil cover was performed in April, 2004 after allowing maximum winter freezeback of the soil around the metal support bases. The elevated portion of the supports were then painted with a white cover.

Analysis of the data recovered since November, 2004 shows, owing to the cooling influence of the thermosyphons, that soil freezing near the base (at 0.1 to 0.2 m from the surface) occurred more quickly than at 0.55 to 0.65 m. Around one support, the frozen soil mass that normally by late autumn thaws to a depth of 2.5 to 4 m, was found to preserve the soil

in a constantly frozen state around the lower portion of the support at a depth of 1.5 to 3 m.

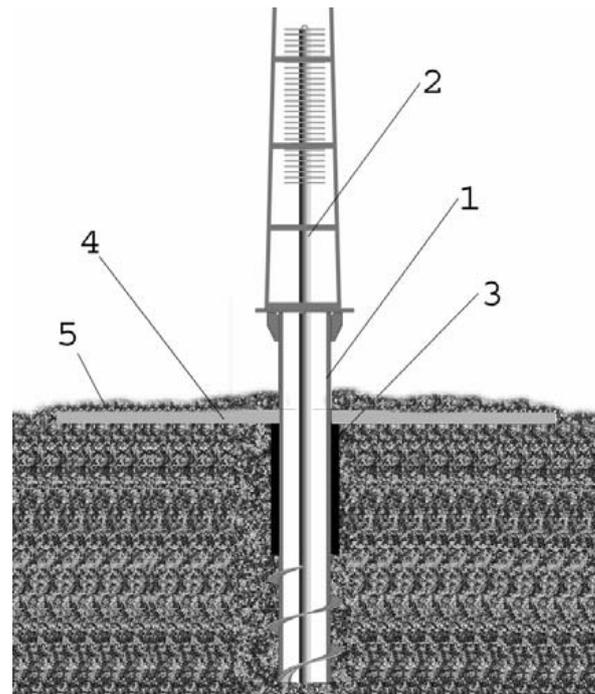


Figure 1. Metal support with screw base (1) with thermosyphon inset (2), anti-frost heaving sleeve (3), thermal insulation (4), and, a covering soil layer (5)

Periodic level surveys were conducted on the top part of the tower supports and have shown that the tower bases having anti-frost heaving devices have remained stable under the varying conditions of soil freezing and thawing cycles. Measurements indicate the vertical movement does not exceed 10 mm. Whereas, 20 to 30% of the tower bases not having anti-frost heaving devices have begun to heave after 2 to 3 years following installation. Their vertical moving for five annual cycles of freezing-thawing have ranged from 10 to 280 mm.

References

Kondratiev, V.G. 2005. Stabilization of roadbed and contact-line and air line supports on permafrost. Chita: Chitgu, 241 p. (in Russian).

The Ion Fractional Yield Sequence during Solution Filtration through the Dispersed Ice

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1 INTRODUCTION

In the permafrost affected soils, the element runoff by supraperafrost flow is characterized with complicated seasonal dynamics under a control of the interaction between migrating solution and ice. We study an influence of ice on the ion transfer during the solution filtration in soils. In this paper, we present the experimental data about the ion yield sequence during solution filtration through the dispersed ice.

2 METHODS

An artificial dispersed ice was prepared for experiments using the diluted sodium sulfate solution. A sample of dispersed ice (about 400 g mass) was thawed in the heat-insulated plastic box with the perforated lower and upper wall. The temperature-controlled pumpable air was filtrated trough the column to thaw the ice in volume slowly also to support the water filtration. The thawed water fractions were isolated from the lower funnel at the column output. In the isolated fractions, the sodium concentrations were measured using the emission spectroscopy. Also the sulfate concentrations were measured using the turbidimetric titration. The sand sample was used for the check experiments. The solution filtration was carried out through sand sample under the temperature $+18^{\circ}\text{C}$ in the some column. The normalized concentrations were calculated to describe the sequence of ion output from the column. Also a half ion output time was calculated to compare the output dynamics of anions and cations.

3 RESULTS

The figure shows the output curves (Figure 1) of ions during the filtration of sodium sulfate solution through the column filled with dispersed ice. The maximal concentration of sulfate anions in fractions is observed in the 16 minute after start of filtration. The time of maximal concentration is 3 minutes only for sodium cations. The half mass output time was about 43 minutes for sulfate-ion and 22 minutes for sodium. These data shows that cations have higher mobility than anions during the solution filtration through the dispersed ice. In the check experiments (solution filtration through the column filled with sand under $+18^{\circ}\text{C}$), the anion output was leaded relatively the cation output.

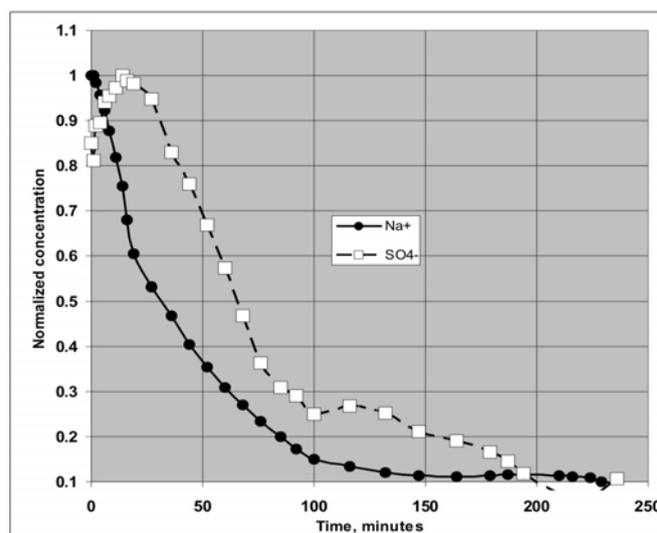


Figure 1. The output curves of sodium and sulfate during the solution filtration through the column filled by dispersed ice.

4 DISCUSSION

The solution filtration through the mineral dispersed matrixes is studied in detail as a chromatographic process. The separation of solution compounds takes place as a result of the ion adsorption by the active surface of mineral particles. Such cation adsorption depresses the migration of cations during the filtration through the sand. In a case with ice, we meet an opposite situation. The cations lead in the flow relatively anions during the filtration through the disperse ice. This peculiarity of the ion sequence under the interaction of solution with ice is explained by the adsorptive depressing of anions. The surface of ice particles has a positive electric charge under an impact of the positive charged defects of the crystal structure of ice.

5 CONCLUSIONS

A chromatographic separation of the ions takes place during the filtration of diluted solution through the dispersed ice. An output sequence of anions and cations is controlled by surface charge of ice particles. Data about the sequence of ion output can be used for estimation of the charge of ice particle surface. It will be useful to take in attention the ion adsorption by ice for interpretation of the observation data about the ion runoff in frost affected soils.

This work is supported by RFBR, project 08-05-00175

The Assessment of Permafrost Landscapes Sustainability under the Human Impact

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Nowadays the active development of the northern territories goes associating mainly with the extraction and transportation of minerals. Therefore the problem of change and disturbance of the natural environment due to anthropogenic interference is urgent. Human activity causes reducing of the landscapes stability and environmental degradation. There is a need in identifying of patterns of permafrost landscapes development and formation under natural conditions to assess their resistance to technogenic loads.

Based on the results of 2 expeditions of JSC "Fundamentproject" (in 2007 and 2008) along the of gas pipeline Bovanenkovo-Ukhta rout in the north-east Bolshezemelskaya tundra an analysis of possible changes in landscapes under stress has been done. Key areas are located at 370 - 380 km and 317-318 km of pipeline route, in the typical tundra subzone. The territory is characterized by complicated permafrost and thermal conditions. According to the engineering geocryological map of the pipeline route area compiled by JSC "Fundamentproject" (2006) region is located in a zone of massive-island permafrost distribution with a range of changes in permafrost temperature 0 - minus 2,5 ° C.

Within the two key sites were identified different landscape types: peat bogs, swamps, runoff lines, etc. At both sites the engineering of constructions, buildings and linear structures is expected. This implies even at the initial stages a sufficiently intensity of anthropogenic pressing. In connection with the coming up development of these territories it's needed to evaluate the permafrost landscape conditions in terms of their response under stress - that is, evaluate the stability and their ecological state.

The assessment methodology is the analysis of permafrost-landscape map and selecting the basic characteristics of the conditions that determine the sustainability and ecological situation under human impact. 10 key features were selected: non permafrost related (micro relief, vegetation, drainage, soil composition) and permafrost related (ice content, distribution and temperature of the permafrost, the depth of freezing, cryogenic processes and the degree of their spreading within landscapes). The result of component analyses is a landscape dividing into three categories of sustainability and into types

of the ecological situation. Types of ecological situations: taut (relatively small alteration of landscape structure, after impact removing cryogenic processes fade away, biota regenerates itself, but there are consequences), critical (self-healing after the removal of the load takes a long time, and the changes can be not full) and crisis (profound, sometimes irreversible changes and loss of natural resources, the sharp intensification of cryogenic processes, failure of engineering structures, simplifying the structure of the landscape). Types of landscape sustainability: relatively stable (landscapes tops of hills, their gentle slopes and foothills, on drained runoff) - intense freezing-ecological situation; relatively unstable (small and medium-size ravine forms, small streams, with peaty surface and thin) - critical and crisis freezing-ecological situation; unstable (thick peat bogs, marshes and mesorelief forms, such as sinks, large gullies, mounds swelling) - crisis and the disastrous freezing-ecological situation.

Based on the permafrost landscape maps and selected parameters the map of stability have been made (Figure 1).

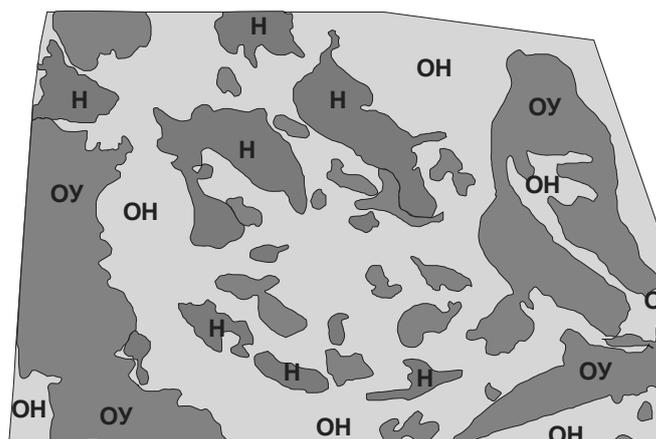


Figure 1. Caption of a typical figure. Photographs should have at least 200 dpi.

Foundation Reconstruction for the Governor's Residence in Longyearbyen

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1 INTRODUCTION

The city of Longyearbyen contains several buildings constructed at around 1950. Although these buildings are too young to be automatically protected as a cultural monument, some are still sought to be preserved from a historical incentive. One such building, which is now experiencing severe settlement damage, is "Sysselmannsgården", the residence of the governor of Svalbard. Sweco Norge has been commissioned by Statsbygg to propose remedial action to retain the structural integrity of this building.

2 PROBLEM DESCRIPTION

2.1 Sysselmannsgården

Sysselmannsgården is the housing and residence of representation for the governor of Svalbard. The construction consists of four connected buildings, whereof two, the main building and the tower, has problems with settlements. Both of these buildings have a heated lower storey beneath terrain level, and have a slab foundation directly on permafrost. Settlements have caused the tower to tilt, and lean against the main building, causing severe fissuring in the plain concrete walls of the building.

Site investigations were performed by SINTEF in 2008. **Figure 1** shows measured temperatures from two thermistor strings installed near the basement, plotted with temperatures from a reference string installed some distance from the building.

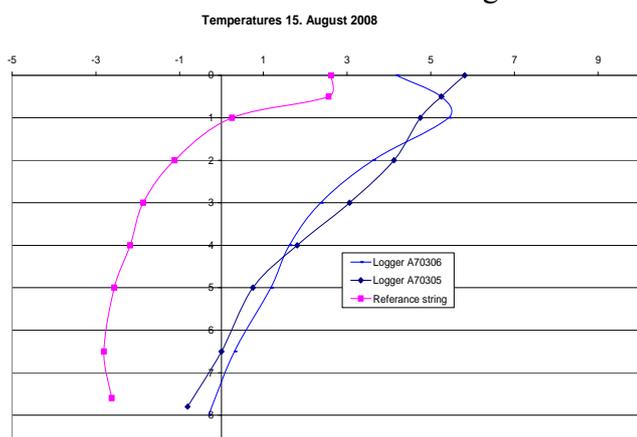


Figure 1. Measured temperatures at Sysselmannsgården

The temperature data shows that the permafrost is thawed nearly down to bedrock at approximately 8-10 m below terrain level.

Collected soil samples shows that the ground around the structure consists mainly of sand and gravel over silt and clay.

2.2 Foundation reconstruction

It was concluded that the cause of the settlement damages was melting of the permafrost under the building due to the heated basement. It was considered to refreeze the ground beneath the building to slow down further settlement. However, due to uncertainties related to the phase change from thawed to frozen ground, with the risk of frost heave and the resulting added stresses on an already damaged structure, it was decided to use a method of pile foundation more commonly used in non permafrost areas. The challenge with this method was how to install the piles with minimum visible disturbance to the structure, while at the same time ensuring a solid foundation for all load bearing walls and structures. The precondition for this chosen method of piled foundation is that the ground beneath and around the structure has to remain thawed.

3 CONCLUSION

To stop the ongoing settlements of Sysselmannsgården, it was advised to keep the ground thawed around and beneath the building, and reconstruct the building's foundation as a pile foundation. A method for installing the piles with a minimum visible disturbance was proposed, and will be performed on behalf of Statsbygg as a turnkey contract during spring and summer of 2010.

References

SINTEF, 2008-04-24, Notat vedrørende geotekniske boringer i forbindelse med nedsetting av thermistorstrenger, samt laboratorieprøver, ved Sysselmannsgården

Problems of Coastal Permafrost Zone Development in Northwest Yamal Peninsula

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Long-term comprehensive studies of the coastal permafrost zone in the north-western part of the Yamal Peninsula resulted in discovering specific engineering permafrost conditions complicating the development of oil and gas fields, such as:

1. Complex and heterogeneous structure of cryogenic strata present in modern and relict (Pleistocene) frozen and chilled soils.
2. High dynamics of the environment caused by new formation of frozen sediments on laida and shallow waters, and by active thermal abrasive destruction of the coast. In the coastal zone of the shelf a hetero-directed development of frozen strata, a degradation under the sea bottom and abrasion areas and aggradation in the shallow zone in areas of intensive contemporary sedimentation.
3. Presence of ice-rich layers and mono-mineral deposits of ground ice in frozen ground under engineering structures.
4. Widespread salted frozen ground containing cryopeg lenses in coastal saline permafrost.
5. Unsteadiness of physical and mechanical properties of soils conditioned by a diversity of composition, ice content, temperature and salinity of ground, reduced strength properties of plastically frozen and freezing ground.
6. Active manifestation of dangerous cryogenic processes (thermal erosion, thermokarst, thermal abrasion, landslides and creep), causing deformation of engineering structures, as well as irreversible changes of natural ecosystems.
7. Due to extreme complexity of permafrost conditions of coastal permafrost zone any construction development shall require:
 - a) an evaluation of the geological environment resistance to man-caused impact as well as a definition of admissible technical and engineering loads under various types of construction;
 - b) elaboration and implementation effective methods of engineering protection of the developing

areas as well as buildings from hazardous processes;

c) monitoring of the state permafrost environment and sustainability of the construction projects.

An assessment of permafrost environment resistance to man-caused impact has been carried out on the basis of the territory's engineering and permafrost situation analysis along with prognostic assessments of their man-caused alterations. The possible development and character of permafrost processes emergencies allowed to class the natural complex phenomena into two categories.

Relatively stable, where man-caused alterations do not raise any considerable activation of permafrost processes, whose emergence is of minor probability, the land surface does not suffer any deformation, the geological environment changes either negligible or its changes are recoverable.

Unstable, where man-caused alterations bring about a progressing development of dangerous permafrost processes, the land surface is being deformed with likely irreversible changes of the geological environment. These areas are most ecologically vulnerable. The permafrost processes operation is of no effect:

The major recommendations to the environment preservation and engineering constructions stabilization are as follows.

1. Sand ground fills arrangement during the terrain engineering development.
2. Preservation of the vegetation and soil strata.
3. Drainage of surface waters to prevent thermokarst upon flat surfaces and thermal erosion along slopes.
4. Preventing from huge snow piles accumulation at construction sites above critical thickness.
5. Special engineering measures to maintain low temperatures of permafrost and small depth of thawing at unstable areas that undergo destruction under slope processes.

Effective Thawing of Frozen Ground – Performance Testing of a New Thawing Method Based on Hydronic Heat (conduction)

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1 BACKGROUND

1.1 Applicability in cold regions

Establishing infrastructure during the coldest months of the year can be challenging because of frozen ground conditions.

Access to effective methods for accelerated or artificial thawing of frozen ground is therefore important to commercial and industrial construction companies, residential contractors, utilities and municipalities operating in cold regions. Successful employment of such methods allows for excavations, ditching and other ground work to take place during winter. Extending the season for such activities is especially beneficial with regard to workforce deployment throughout the year and helps reduce seasonal lay-offs.

1.2 Traditional methods

Over the years several methods to facilitate construction work also during winter have been tried, both in regions with seasonal frost as well as in areas with perennially frozen ground (permafrost).

A monograph sponsored by The Technical Council on Cold Regions Engineering (Esch, 2004), gives both a historical overview of the techniques applied by miners during the gold rush to Alaska and northern Canada in the late 1800s, as well as different approaches with the mechanization of mine workings in the early 1900s. Open fire and solar thawing were the first methods used, replaced by cold-water and steam thawing as the development progressed. Also electric thawing is listed.

A more recent method is based on convection, i.e. heated air confined in a suitable contraption placed onto the frozen ground surface. This technique is still in use although the method based on hydronic heat seems more effective and versatile.

2 HYDRONIC HEAT

2.1 Innovative approach for thawing frozen ground

The hydronic method is based on known principles and technology – assembled in a way that enables the complete system to deliver the necessary heat for the process. A boiler is used for heating a mixture of water and glycol. Flexible rubber pipes or hoses are connected to the boiler in a closed loop. The hoses

are laid out in a serpentine pattern onto the surface to thaw the underlying ground. A pump ensures circulation of the hot liquid.

2.2 Experimental set-up

The first full scale performance tests were made in March 2007 at the Frost in Ground laboratory (FiG-lab) in Narvik, using the defrosting system developed by the Norwegian company Heatwork. Three bins (4 x 4 m, 2.5 m depth), each containing various types of homogenous soil, were thawed simultaneously; (a) sandy silt, (b) well graded sand and (c) clean gravel.

A vertical thermocouple string was mounted at the center of each bin, measuring ground temperatures in 10 cm intervals from 5 cm to 155 cm depths, including one at depth 2.05 m and another at depth 2.55 m. Air temperatures, relative humidity and wind speeds were monitored by a weather station at the site.

3 PRELIMINARY RESULTS

3.1 Thaw rates

Table 1 shows the thaw rates as a function of thaw depth for the various types of soil down to 100 cm depth. The results show that the thaw rate is higher for coarse grained soils compared to fine grained soils. The thaw efficiency is higher the nearer the surface (heat source), gradually declining with increasing depth.

Table 1. Thaw rates as a function of thaw depth.

Thaw depth	Thaw rate		
	Sandy silt cm/day	Well graded sand cm/day	Clean gravel cm/day
10 cm	21	34	30*
30 cm	18	26	30
50 cm	14	22	26
70 cm	11	19	22
90 cm	10	16	17
100 cm	9	15	16

* Reduced thaw efficiency at low depths for clean gravel.

References

Esch, D.C. (ed.) 2004. *Thermal Analysis, Construction, and Monitoring methods for Frozen Ground*. Reston, Virginia: American Society of Civil Engineers.

ESIMP Efficient Soil Investigative Methods in Permafrost

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1 INTRODUCTION

The Efficient Soil Investigative Methods in Permafrost (ESIMP) study is a project initiated by Statoil and carried out by SINTEF together with students from the University Centre in Svalbard (UNIS). The ESIMP-project evolved as a natural reaction to the increased focus on possible oil and gas exploration in the arctic regions. Large ice structures in the ground can cause severe damage both to infrastructure, such as roads and pipelines, and structures, such as buildings and other installations. It is deemed important to avoid building in such areas which can prove to introduce significant challenges, especially related to melting of permafrost.

Current soil investigative techniques are mostly invasive and will often only reveal the soil conditions in a certain point. Therefore the objective of the ESIMP-project is to test easy, non-invasive and efficient methods for disclosing pure ice structures in permafrost, so that the development in arctic regions can be done more efficient.

2 METHOD

From a literature study it was concluded that ground penetrating radar and resistivity most likely would yield the best results in the field. Both these methods are well known and have proven efficient for ground investigations on Svalbard. A close cooperation with scientists and the logistic department at UNIS gave a solid base for the field investigations in the upcoming phases of the project.

3 FIELD WORK 2007/2008

The first field investigations were carried out during autumn 2007 and spring 2008. These investigations gave the foundation for the first of two Master theses produced during the project. The area investigated was a site close to the old aurora station in Adventdalen which is well known and documented by the geology department at UNIS. The GPR and resistivity methods gave good indications for the locations of the ice wedges. A geotechnical drill rig owned by

SINTEF and permanently based on Svalbard (Finseth & Wold, 2010) was used to confirm the results from this investigation.

3.1 Evaluation of methods

After evaluating the methods it was decided that the resistivity method was not very effective for this type of investigation. In addition it was difficult to obtain satisfactory results when the active layer was frozen. For the next field period during spring 2009 only the GPR was used. This fieldwork was the base for the second Master thesis produced in the project.

4 FIELD WORK 2009

In addition to the radar investigation during the spring of 2009, an aerial photo was acquired of the same area to see if it was possible to relate structures on the ground surface to ice structures found by the radar. The area investigated in 2009 was located on the south side of Adventdalen in an area where it was expected to find more coarse ground conditions. This was done to check the radars capacity to differ between rock, boulders and pure ice. Only one of the locations where the radar showed possible ice existence was confirmed with the drill rig. The aerial photo however revealed that several locations where ice might be present along the investigated corridor.

5 CONCLUSION

Satellite and aerial photos can be used in a preliminary survey to detect ice structures within the permafrost. Thereafter the radar, in combination with a geotechnical drilling rig, can be used to find the exact location of these structures when it comes to detailed planning of installations.

References

Finseth, J & Wold, M. 2010. Experiences from geotechnical sampling and sounding in permafrost. EUCOP2010 - Svalbard, Norway

Triaxial Laboratory Tests on Artificial Frozen Samples

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1 INTRODUCTION

Alpine permafrost is sensitive to climate change, and the knowledge of mechanical behaviour of permafrost soil, especially in its response to a gradual warming cycle, is necessary to estimate the stability of rock glaciers and infrastructure in cold regions. Moreover, extension features in rock glaciers are becoming apparent in the field. The existence of cracks and crevasses (Roer et al., 2008) in some rock glaciers indicate that tension features will play a role in possible future failure mechanisms.

Preliminary triaxial compression and extension tests on artificial frozen soil samples are underway in a cold room at different temperatures very close to 0°C. Artificial samples were developed in order to achieve controlled and repeatable sample states.

2 SAMPLE PREPARATION

Cylindrical laboratory samples were prepared. Solid soil grains were taken from a rock glacier at Murtèl-Corvatsch and sieved. The grain size distribution corresponds to a typical Fuller-distribution (Figure 1). A pre-weighed soil fraction following the power curve, and with a maximum grain size of 4 mm (Figure 1), was mixed with crushed ice, according to planned relative ice-solids fractions. The ice-solid mixture was placed in an insulated mould and

saturated slowly with 0 °C de-aired water from the bottom to fill the air voids, with the help of a vacuum of 25 torr, applied at the top. The sample was then frozen one-dimensionally from the top in a freezer at a temperature of -18 °C, while drainage was permitted from the bottom.

The samples had a diameter of 50 mm and an initial length of 130 mm. Both ends of the sample were trimmed to a length of 100 mm with a circular diamond saw to form smooth parallel surfaces, before being mounted in a triaxial test apparatus (Arenson & Springman, 2005).

3 TRIAXIAL TESTS

Axial compression and extension tests were carried out in a triaxial test apparatus at different temperatures in order to determine the strength of frozen soil as a function of temperature and soil-ice volume fraction in frozen soil specimens. Axial extension stress paths could be thought to represent the unloading behaviour around the base of crevasses in the field. The strength in axial extension is lower than that obtained from axial compression.

All the tests were conducted under undrained conditions. Effective stresses were not calculated since pore water pressures in air and unfrozen water could not be measured in a frozen specimen. The confining pressures were selected to represent in situ frozen soil conditions. The influence of volumetric ice content on the strength was also investigated. The strain rates were chosen in order to achieve a ductile response instead of brittle behaviour.

References

- Arenson, L.U., Springman, S.M. 2005. Triaxial constant stress and constant strain rate tests on ice-rich permafrost samples. *Canadian Geotechnical Journal* 42(2): 412-430.
- Roer, I., Haerberli, W., Avian, M., Kaufmann, V., Delaloye, R., Lambiel, C. and Käab, A. 2008. Observations and Considerations on Destabilizing Active Rock Glaciers in the European Alps. In: D. L. Kane, K.M. Hinkel (Editors). *In Proceedings of the Ninth International Conference on Permafrost*, Fairbanks:1505-1510.

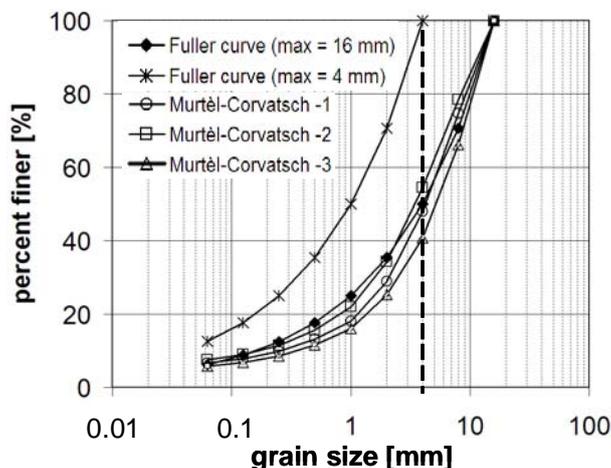


Figure 1. Grain size distribution of the soil borrowed from the surface and front of the Murtèl-Corvatsch rock glacier.

Geophysical Monitoring in Permafrost Regions 2:

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South Shetland Islands - the Northern Permafrost Boundary in Antarctica.

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1 ABSTRACT

According to climatic data the permafrost boundary in South circumpolar area near sea level lies at 55-60°. The main part of this area is ocean, and terrestrial segments are represented by small archipelagos. The formation of permafrost here was possible since the deglaciation (6-9 kyr BP). The MAAT on King George and Deception Islands (15 m a.s.l.) is between -2.5...-1.5°C, and is -4 °C on Livingston Island (Mt.Sofia, 275 m a.s.l.). The new data obtained by drilling and ground temperature measurements by loggers in the boreholes on King George, Livingston and Deception Islands at 62°S are presented. The studies were carrying out in the frame of IPY projects: ANTPAGE, ANTPAS, TSP.

1.1 Sites and Cores

First borehole on King George Island (Bellingshausen station) was drilled in 1968 by Zamoruev. In 2008-2009 two 10-m boreholes were drilled in the same place at a marine terrace (S62°11'48'', W58°57'56'', 13 m a.s.l.). The upper 3 m are thawed pebbles underlain by coarse grained ice cemented sands (ice content of 10-30%) and below a fine dispersed clay aquiferous horizon was reached. The boreholes at 25 m a.s.l. revealed several meters of frozen debris over bedrock. The deepest borehole (25 m) was drilled in the bedrock on Livingston Island (S62.67028, W060.38222270). Three 6-m boreholes were drilled on the Deception Island at a plateau near Crater Lake (S62°59'7", W60°40'43", 90 m a.s.l., active layer ~0.5 m) covered by 4-6 m thick scoria (ice content ~25%) underlain by non frozen basalt lava from 19 century. All these sites have no vegetation cover and are well drained. Snow cover vary from 10 to 100 cm. The boreholes (5-10 cm in diameter) are cased by plastic pipe. Temperature measurements then were made using U12 Hobo (Onset) and iButton loggers (4 times per day, 2008-2010). One of the sensors was installed on the surface and the others at various depths inside the borehole.

1.2 Results and discussion

The MAGT on Bellingshausen station is -0.3°C at 9 m depth. The active layer at the marine terrace is 2-3 m, and about 1 m at upper levels. The MAGT at Livingston Island is -1.8°C. The MAGT at 5 m on

Deception Island is close to -1...0°C and active layer is about 0.4 m. The above mentioned data indicate permafrost existence in all drilled sites, but the thickness of permafrost is different: thin horizon 5 to 10 m on King George and Deception Islands, and ~130 m thick on at Livingston Island. These data characterize the northern border of permafrost distribution in Antarctica as following: sporadic permafrost can be found here from the seashore. At seashore, and up to 30-90 m a.s.l. it have thickness about 5-15 m, have sporadic distribution and MAGT slightly lower than 0°C. Such permafrost distribution is sensitive to even small climatic changes, especially of the air temperature and the thickness of snow cover. At elevations about several hundreds meters it is about 100 m thick with MAGT about -2°C. On Signy Island permafrost is bit colder, with values close to -2.5 °C at 90 m a.s.l. (Guglielmin et al. 2008). It was known before, that the northern border of permafrost in Antarctica is somewhere at sub-arctic islands. Such estimations are based on geomorphological mapping and MAAT analysis (Serrano et al., 2008). Our investigations on South Shetland Islands allowed identifying this boundary by drilling and temperature measurements. The observations in boreholes monitoring network will give us the possibility to follow the changes in such sensitive permafrost area, as well as the possibility to estimate the permafrost reply on climatic changes.

ACKNOWLEDGMENTS

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References

Serrano E et al. 2008. Permafrost in the South Shetland islands (maritime Antarctica): spatial distribution pattern, Proceedings of NICOP, Fairbanks: 1621-1625.

Guglielmin M et al. 2008. Periglacial and Permafrost Map of Signy Island, South Orkneys Islands, Maritime Antarctica. Proceedings of NICOP, Fairbanks: 569-574.

Modelling of Future Hydrology and near-Surface Hydrogeology at Forsmark under Periglacial Climate Conditions – Applied Numerical Modelling with MIKE SHE

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1 ABSTRACT

Spent nuclear fuel from nuclear power plants in Sweden is managed by the Swedish Nuclear Fuel and Waste Management Co, SKB. SKB has performed site investigations at two different locations in Sweden, referred to as the Forsmark and Laxemar areas, with the objective of siting a final repository for spent nuclear fuel. In 2009 a decision was made to focus on the Forsmark site, and SKB plans to submit an application for building a deep geological repository there. The repository will be built at a depth of approximately 500 m in the granitic bedrock.

In the hypothetical case of a release from the repository the radionuclides would be transported by the groundwater towards the surface and eventually reach streams, lakes and wetlands. The assessment of long-term repository safety is an important part of the application and the analysis of the water flow paths in the bedrock and the overlying Quaternary deposits is of utmost importance for this assessment. Within the safety assessment, several possible future climate scenarios are considered. As a part of the Forsmark assessment, the hydrological and near-surface hydrogeological conditions under a periglacial climate with continuous permafrost interrupted by through taliks have been studied. This presentation aims to describe the methodology for simulating the hydrology in a permafrost landscape and the results of the study.

By using MIKE SHE, a spatially distributed and physically based integrated groundwater and surface water modelling tool, the hydrology and near surface hydrogeology at the Forsmark site under present and possible future conditions have been analysed. Data from the site investigations have been used when calibrating the model describing present conditions. With the model describing present conditions as a starting point, the periglacial hydrology has been simulated. Different permafrost depths and associated different numbers and locations of through taliks have been implemented to the model. Both

flow and particle transport simulations have been performed.

In addition to the climate input data, the hydraulic properties, both of the unsaturated and saturated zones and those of the surface water system, have been changed in order to describe a permafrost landscape. The uppermost part of the model is an active layer where the ground surface is affected by meteorological processes and the layer has a frozen, a thawing, an active and a freezing period each year. The hydraulic properties in the active layer are transient throughout the year. Within the permafrost layer the ground is continuously frozen and the hydraulic conductivities are low to imitate a frozen ground with a high flow resistance. A number of through taliks have been defined within the model area. The presence of taliks depends on the prevailing temperature, the presence of lakes and streams as well as on other surface conditions (e.g. vegetation and snow cover).

As expected, the results show that the permafrost, the occurrence of through taliks and the applied periglacial climate have a large impact on the overall water balance of the area, on the pattern of recharge and discharge areas and on magnitude of groundwater flow.

During the present temperate period, the local topography has a strong influence on the location of recharge and discharge areas, whereas the recharge and discharge areas are concentrated to the through taliks under permafrost conditions. Thus, the periglacial flow paths from the repository towards the surface will deviate from the flow paths developed under present climate conditions. Many of the areas defined as taliks are recharge areas also under present conditions. However, the radionuclide concentrations might be higher in the talik areas during a period of continuous permafrost, which could affect doses calculated for this and subsequent time periods.

Improving Permafrost Simulation in the Austrian Alps – Preliminary Modelling Results and New Field Data

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1 INTRODUCTION

Alpine permafrost responds very sensitive to climate change. Thus, detailed knowledge about permafrost characteristics is a very important prerequisite concerning alpine hazard and risk assessments.

In the year 2008 a pilot study was performed to give an overview of possible and probable permafrost distribution in the Austrian Alps. Improving the preliminary approach it should be tested, if a statistical empirical model on a larger scale with a higher resolution will deliver appropriate results.

2 PILOT STUDY

First modelling outcomes show that in Austria approx. 2 % (1600 km²) of the federal territory can be assigned to mountain permafrost (Ebohon & Schrott, 2008). Based on an adapted topo-climatic-key, that results from the relation between slope, altitude and aspect, the possible and probable distribution of permafrost was calculated with the empirical statistical models PERMAKART (Keller, 1992) and PERM. Although a small scale regional map (50 m resolution) has a limited accuracy, it allows approximations of the permafrost distribution but there are still some unsolved problems.

3 APPROACH AND METHODS

3.1 New tasks

For the area of the “Hohe Tauern” range (Fig. 1) more precise adjusted lower limits of permafrost will be developed. With newly gathered field data statistical analyses will be carried out and interrelated with the topo-climatic-key. In addition relevant parameters like the short wave solar radiation as well as surface conditions will be included in the model. Based on the adapted topo-climatic-key, the new simulation will show an index of permafrost occurrence between 0 and 100, which replaces “hard” lower borderlines of the subdivision “probable”, “possible” and “no permafrost”. All queries will be applied on a DEM with a resolution of 10 m to enhance the accuracy of the simulation.

3.2 Research area and data gathering

In three test sites (Glorer Huette, Obersulzbachtal, Kitzsteinhorn) UTL data logger were installed at different heights and aspects to measure the ground surface temperature during sub-snow-conditions. Furthermore, geophysical- (DC-resistivity and ground penetrating radar) and BTS measurements were performed in 2009 at various altitudes, settings and aspects.

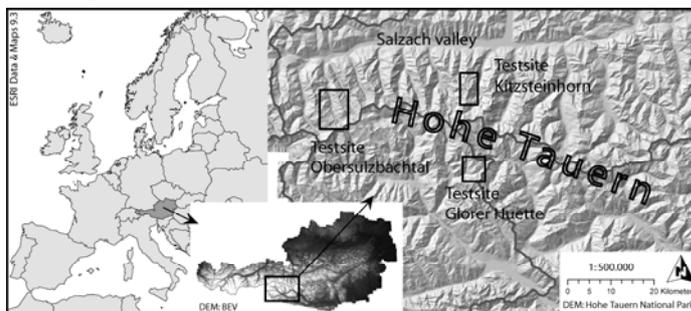


Figure 1. Research area and local test sites

4 CONCLUSIONS

BTS- and geophysical measurements contribute to a better ground truth and allow an enhancement of the topo-climatic-key. Additionally, detailed geomorphological mapping of permafrost related landforms will be used to validate the model. The resulting map will be implemented in a web GIS making data accessible to the general public and providing an important tool for decision makers concerning infrastructure in high mountain areas. A project description, news and results of the pilot study can be seen via www.permalp.at.

References

- Ebohon, B. & L. Schrott (Kane, D. & K. Hinkel eds.) 2008. Modeling Mountain Permafrost Distribution. A New Permafrost Map of Austria. *Proceedings of the Ninth International Conference on Permafrost*. Fairbanks – Alaska. 397-402.
- Keller, F. 1992. Automated mapping of mountain permafrost using the program PERMAKART within the geographical information system ARC/INFO. *Permafrost and Periglacial Processes*, Vol. 3 (2): 133-138

Past, Present and Future Thermal Conditions in Mountain Permafrost in Northern Norway and Svalbard

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1 BACKGROUND AND OBJECTIVES

The Norwegian funded IPY project 'Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost in Norway and Svalbard' (TSP NORWAY) is a part of the international IPY full project 'Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost (TSP)'. TSP will obtain a "snapshot" of the permafrost environments as a benchmark against which to assess past and future changes by making standardized temperature measurements in existing and new boreholes throughout the World's permafrost regions.

This presentation aims to quantify former and future ground thermal regime and permafrost development at selected sites in northern Norway and Svalbard.

2 BOREHOLES

During the TSP-NORWAY project, boreholes were drilled in several location, along the altitudinal lower limit of mountain permafrost in northern Norway and in several topographic and landform settings in Svalbard. Most boreholes in northern Norway are drilled in bedrock besides one at Iskoras in Finnmark. In Svalbard the boreholes are drilled both in bedrock and in sediment cover. All boreholes are equipped by automatic logger devices of different kind, and a measurement accuracy of better than $\pm 0.2^\circ\text{C}$.

3 MODEL AND RESULTS

The obtained ground temperature data series (at present one to three years) were used to calibrate a transient heat flow model, solving the heat conduction equation including phase changes. The model is implemented in MATLAB, and free parameters are water content, thermal conductivity, heat capacity

and material density. For the boreholes in northern Norway and partly for Svalbard, values for rock density and thermal conductivity were obtained in the laboratory.

The calibrated model was then forced with historical temperature data records from the end of the little ice age, obtained by linear regression from nearby climate stations. This analysis clearly demonstrated that the present ground temperature profiles witness of a recent permafrost degradation.

Subsequently, the model was forced with the results of empirical statistical downscaled GCM ensemble covering the 21st Century. The latter is based on the multi-model World Climate Research Programme (WCRP) Coupled Model Intercomparison Project (CMIP3) of the most recent Special Report Emission Scenario (SRES) A1b (in which atmospheric CO₂ reaches 720 parts per million by 2100) produced for the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 4 (AR4).

The presentation demonstrate the possible impact of projected higher air temperatures in northern Norway and the high Arctic on the ground thermal regime.

Towards a Distributed Ground Heat Flow Model for Norway – “CRYOgrid”

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Within the IPY project ‘Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost in Norway and Svalbard’ (TSP NORWAY) and the nationally-funded CRYOLINK (“Permafrost and seasonal frost in southern Norway”) we develop a framework for transient and distributed modelling the ground thermal regime. The model is driven by operationally gridded data of daily air temperature and precipitation. These datasets are available for the period 1961 to date having a spatial resolution of 1 km².

In CRYOgrid, the subsurface heat flow is driven by conduction using the ground surface temperature as upper boundary condition. As an important step in model development, we have established simplified schemes for converting air temperature to ground surface temperature, parameterization the effects of snow cover. This parameterization scheme is tested using an extensive observational dataset comprising air temperature, ground surface temperature and snow thickness from various regions across entire Norway.

The spatio-temporal distribution of subsurface temperatures is calculated using a 1-dimensional heat flux scheme at each grid cell of a 1 km digital terrain model of Norway, or a subset of the latter. In doing so, we implicitly neglect horizontal heat transport. Spatial distributions of the ground thermal properties (e.g. heat conductivity), surface cover (e.g. vegetation, block fields) were derived from geological maps, borehole measurements and remotely-sensed data. For snow cover, we use the operational products available at <http://senorge.no>.

We present preliminary results from the first model runs to demonstrate the capacity of the approach to simulate permafrost distribution, penetration depth (Fig. 1) and duration of seasonal frost and discuss a variety of future calibration and validation activities.

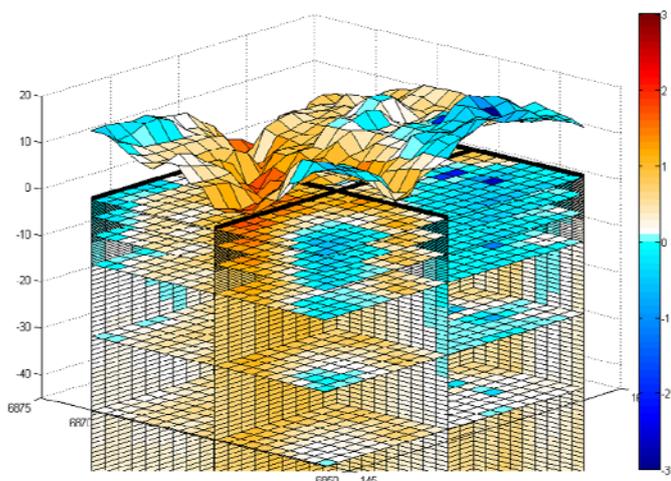


Fig. 1: First results of a CRYOgrid equilibrium run over a 20*20 km grid from the Jotunheimen area. Grid cells in horizontal space are 1 km², the discretisation increases with depth.

Assessing the Sensitivity of Permafrost Systems in Norway and the European Alps - a Project Cooperation of SPCC & CRYOLINK

The SPCC team

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Within the cryosphere community permafrost is of increasing interest, since it is a valuable indicator for past and recent changes in the climate system – in lowland as well as in mountain geosystems. The thermal state of mountain environments is influenced by complex topography and related microclimate conditions and is characterized by a strong spatial and temporal heterogeneity. Therefore, recent investigations focus on the coupled analysis of atmospheric conditions, surface and subsurface material properties as well as geomorphic process activities. The scientific motivation is to identify controlling factors for permafrost degradation and aggradation and to describe pathways from an atmospheric forcing to a thermal response of the permafrost body as well as to rheological/instability reactions. The overall aim is to describe the sensitivity of mountain permafrost to climate change.

The SPCC (Sensitivity of mountain Permafrost to Climate Change)-project (funded by the German Research Foundation (DFG)) includes five closely interlaced projects, initiated to bridge the gap between climate simulations, spatio-temporal surface and subsurface characteristics and the response of whole landforms to these changes and, hence, increase the understanding of the mountain permafrost system in the European Alps. The CRYOLINK-project (funded by the Research Council of Norway (RCN)) on the other hand aims at improving knowledge on past and present ground temperatures, seasonal frost, permafrost distribution and related periglacial processes in Southern Norway and adjoining regions of the North Atlantic region, by addressing the fundamental problem of heat transfer between the atmosphere and the ground surface. Thus, there is a strong linkage regarding the scientific motivation and goals of SPCC and CRYOLINK.

In the project cooperation, methodological know-how as well as modeling approaches are shared and combined. By comparing data from different sites, morphologies and substrates in Norway and the European Alps and by analyzing regional differences in driving forces and reactions to atmospheric changes, it is expected to better understand the sensitivity of permafrost systems in mountain environments. This presentation focus about the sensitivity of permafrost to climate change, and strategies of how to assess this problem within the projects.

Table 1. Summary of SPCC and CRYOLINK activities and sites

	SPCC	CRYOLINK
Sites	Grisons, Valais, Bernese Alps (CH), Zugspitze (D)	Southern Norway, Iceland, Northern Norway
Elevation	2500-3400 m a.s.l.	S. Norway: 1200-1900 m a.s.l., N. Norway: 500-1000 m a.s.l., Iceland: 900-950 m a.s.l.
Methods	<ul style="list-style-type: none"> - temperature logging (MTDs, snow poles and boreholes) - geophysical sounding and monitoring (electrical resistivity tomography, refraction seismic tomography, ground penetrating radar) - laboratory experiments - kinematic surveys (photogrammetry, tachymetry, laser scanning, DGPS) - ground-snow-atmosphere modeling - Regional Climate Model scenarios 	<ul style="list-style-type: none"> - temperature logging (MTDs, snow poles and boreholes) - geophysical sounding and monitoring (electrical resistivity tomography, refraction seismic tomography, soil moisture content) - BTS - ground-snow-atmosphere modeling, 1D and 2D (profile) and 3D (area) - snow cover modeling - RCM and down-scaled GCM scenarios - Past instrumental data and Holocene (ice-cores and proxies)
Ground conditions/Landforms	rock glaciers, glacier forefields, rock faces, talus slopes, bedrock	bedrock, ground moraine, block fields, rock glacier / ice-cored moraines

The Investigation of Ground Temperatures in High Mountain Areas Using IButton

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Mountain areas are characterized by extreme variability in elevation, exposure to solar radiation and ground material. Many physical processes, that control ground temperatures and thereby permafrost, are highly affected by this variability. An improved understanding of permafrost and related processes in mountain areas therefore requires investigation at high spatial resolutions.

The aim of this project is to investigate ground surface temperatures in high mountain areas. We focus on the effects of topography and local ground properties on surface temperatures at high spatial and temporal resolutions. We distributed 390 mini temperature logger *IButtons* (www.maxim-ic.com) at Corvatsch in the Upper Engadin (Switzerland) logging surface temperatures at a 3 hour time step. This distributed network of temperature loggers is planned to operate for 3 years.

The programming, distribution and recovery of many *IButton* devices in high mountain areas is very time-consuming. It requires a systematic recording and storage of relevant metadata such as the geographic coordinates of each *IButton* as well as other topographic characteristics. To easily handle these requirements and to stream-line field work, we developed an effective working procedure and supporting software to program and read-out *IButtons* (precision, time resolution, etc.) and to store the temperature measurements in a database together with the relevant metadata. The possibility to connect a GPS device and digital camera to this system makes the recording of meta-data and the reclamation of loggers very efficient.

We present the project together with the main tools of the developed software.

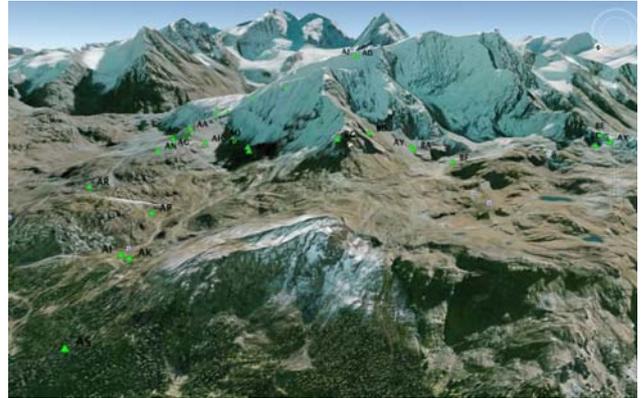


Figure 1: Position of ibutton footprints at Corvatsch (view SE), Engadin, Switzerland

Introducing a Soil-Freezing Scheme Within the IPSL Land Surface Model ORCHIDEE

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1 INTRODUCTION

1.1 Context

Underlying 25% of northern hemisphere soils with notable extents in northern Eurasia, permafrost is a major feature of arctic climate, with high implications on the hydrological, energy and carbon cycles of those regions.

In a context of global warming, the possibly abundant CO₂ and CH₄ release by thawing permafrost – a positive feedback on climate [Friedlingstein et al., 2006] – enhances the challenges of proper frozen ground processes modeling in global climate models and therefore land surface schemes.

1.2 Objectives

We plan to introduce a physically-based parameterization of frozen soils in the land surface scheme ORCHIDEE [Krinner et al., 2005], which is part of the IPSL-CM4 coupled climate model.

2 MODEL DEVELOPMENT

2.1 Soil freezing scheme

Frozen/unfrozen water partition within the soil is accounted for using soil-type dependant freezing characteristic curves. This partition is then used to compute thermal and hydrological soil properties and effects of freeze-thaw cycles on discretized temperature and water diffusion schemes.

2.2 Further development prospects

Thermal insulation and water storage by a surface organic layer – a frequent feature of boreal regions – is also to be introduced as it significantly alters ground thermal and moisture regime.

The observed considerable spatial variability in snow cover and frozen soil distribution at the model's grid-cell scale will be accounted for using a subgrid variability approach.

2.3 Calibration and validation

A collaboration with the German Alfred Wegener Institut will provide local-scale observational data (Samoilov Island, Siberia ; Koldewey station, Svalbard) for model calibration and validation, while global and spatially integrated data (R-ArcticNet, CALM) will also be used.

3 PERSPECTIVES

Those developments are expected to improve the model's performances in arctic regions. They should later lead to a quantification of permafrost-related feedbacks on boreal and global climate through the coupling with a carbon cycle model.

References

- Friedlingstein, P. et al. 2006. Climate-carbon cycle feedback analysis: Results from the C4MIP model intercomparison. *Journal of Climate* 19(14): 3337–3353.
- Krinner, G. et al. 2005. A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system. *Global Biogeochemical Cycles* 19(1), GB1015.

Simulation of the Sensitivity of the Active Layer Depth of Mountain Permafrost to Different Idealised Forcing Scenarios

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1 INTRODUCTION

To evaluate the sensitivity of mountain permafrost to atmospheric forcing the dominant meteorological variables such as temperature, precipitation and timing and duration of snow cover have to be considered. To predict possible changes in the mountain permafrost distribution, the link between small scale subsurface characteristics and predictions from climate models has to be established. The assessment of climate impacts on mountain permafrost is, however, challenging. Whereas there is a steadily increasing number of studies using Global and Regional Climate Model (GCM, RCM) simulations to assess permafrost evolution and its impact in arctic regions, similar efforts for mountainous terrain have only started very recently due to the small-scale variability, especially concerning topography, snow cover and (sub-)surface conditions.

In this contribution simulations with the one-dimensional coupled heat and mass transfer model COUP were used to investigate the interactions between the atmosphere and the ground along a 1-dimensional vertical section. Hereby, the study focused on ground temperature evolution and the temporal variability of the active layer depth.

2 STUDY SITES, DATA & METHODS

Based on energy balance and ground temperature data sets from the PERMOS site Schilthorn (2970 m asl, Berner Oberland, Swiss Alps), subsurface model studies using the COUP model were conducted to simulate freeze and thaw processes on different temporal scales. The observed 10-year ground temperature data set within a borehole was used for model verification.

After validating the performance of the model, idealised and observed atmospheric forcing data sets were used to determine the meteorological conditions, which show the largest impact on the permafrost regime. To analyse the seasonally variable importance of the dominant forcing variables and their respective impact on ground temperatures and active layer depth, we performed a sensitivity study using

reduced/increased precipitation and air temperature values, respectively.

But due to the strong dependence of ground temperatures on the timing and duration of the snow cover, the response of the active layer thickness will depend not only on the changes of mean parameters (such as MAAT or annual precipitation), but especially on seasonal or even monthly temperature and precipitation anomalies. For this, additional simulations with monthly instead of annual temperature and precipitation anomalies were performed.

In a further step, forcing data sets from Regional Climate Models are used to determine the range of possible reactions of mountain permafrost to different RCM ensemble projections.

3 RESULTS

The model simulations for Schilthorn revealed the influence of the coupled temperature and precipitation effect on the active layer thickness on a monthly to seasonal basis. In summer, temperature changes have the largest impact on the ground thermal regime, as the absence of the snow cover directly couples the atmospheric evolution to the ground. On the contrary, the simulations showed that summer precipitation has a minor impact on the active layer evolution. Winter precipitation has a direct effect on the total height of the snow cover in spring and therefore on the timing of the snow melt in early summer. An important nonlinear effect can be observed for temperature and precipitation in autumn as air temperatures can be positive or negative, by this determining whether autumn precipitation falls as rain or snow. Sensitivity analyses with increased and decreased precipitation amounts lead to both, increase and decrease of the active layer thickness. However, for the idealised settings of our model study, a tendency for an active layer thickness decrease due to changing October forcing could be observed.

Annual Changes in Volumetric Ice and Water Contents of Two Mountain Permafrost Sites in Switzerland Quantified by Geophysical Measurements

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1 INTRODUCTION

During recent years geophysical monitoring approaches have evolved quickly regarding the observation of changes in the ice and unfrozen water content of the subsurface over short and long time spans. Relative changes in electrical resistivities or seismic velocities provide rough approximations on different amounts of spatio-temporal changes in the subsurface. Compared to temperature monitoring in 1-D boreholes, electrical resistivity tomography (ERT) monitoring and refraction seismic tomography (RST) monitoring provide additional information on the distribution of higher and lower ice contents within 2-D subsurface sections and concerning spatial variability in temporal changes. However, as straightforward relations between observed resistivity or velocity and ice content do not exist, absolute quantification of long-term ground ice degradation is still impossible from the consideration of relative resistivity/velocity changes alone.

A novel approach to estimate volumetric fractions of ice, water, and air within the pore volume of a rock matrix by jointly using complementary data sets from geophysical surveys was introduced by Hauck et al. (2008). The so-called four-phase model (4PM) uses coincident ERT and RST data sets to relate the physical properties of the subsurface to the measured electrical resistivities and seismic velocities. Due to inherent ambiguities in the model the approach is still limited to specific cases and often allows only a rough estimation of the quantities of the solid (ice), liquid (water), and gaseous (air) constituents of the available pore volume.

2 APPROACH

As a step towards reducing the uncertainties and to gain higher confidence in the calculated values, the 4PM was applied to time-lapse ERT and RST data sets in order to quantify the *changes* in volumetric phase fractions. Provided that the porosity of a subsurface section will not change over the observation period, the calculation of *changes* in ice, water and air contents over time may give a more reliable indication on the subsurface characteristics than the es-

timination of *total* fractions. This new approach comprises the estimation of *temporal changes in volumetric ice content* for a prescribed porosity model (which is constant over time) for subsequent data sets as opposed to the estimation of *volumetric ground ice contents* (relative to porosity).

From a monitoring point of view, the uncertainty in the determination of an adequate porosity model is less critical when *temporal changes* in the fractions of ice, water and air are considered *relative to porosity*. In theory, temporal changes in the respective fractions should be unaffected from differences due to uncertainties in the model parameters, as the latter are kept constant for both time instances.

3 RESULTS

In this contribution, annual changes in ice, water and air content per porosity were calculated for two permafrost sites in the Swiss Alps from August 2008 to August 2009. The sensitivity of these changes to variations in model parameters was analysed compared to the sensitivity of the total fractions.

The test sites comprise a rock slope (Schilthorn, Bernese Alps) and a talus slope (Lapieres, Valais) characterised by pronounced differences in subsurface material and ice content. The performance of the time-lapse 4PM is similarly good for both sites. Results show that the selection of an appropriate porosity model is still crucial, but observed changes in ice content are significantly higher than the estimated uncertainty of about $\pm 5-10\%$.

The time-lapse approach of the 4PM allows for a partial compensation of current deficiencies of the 4PM, as inaccuracies in the prescribed model parameters will not affect the relative temporal change of the ice, water, and air content within the available pore space.

References

Hauck, C., Bach, M. & Hilbich, C. 2008. A 4-phase model to quantify subsurface ice and water content in permafrost regions based on geophysical data sets. *Proceedings of the 9th International Conference on Permafrost*, Fairbanks, Alaska 1: 675-680.

Active Layer Processes on Rock Glacier Murtèl-Corvatsch

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1 BACKGROUND

Coarse debris is a characteristic ground material in high alpine environments. The special thermal properties of this ground material favor the existence of permafrost at sites, where it would not occur otherwise. However, the processes explaining the thermal anomaly found within these materials are still not fully understood. The most common explanation is that the heat transfer between atmosphere and ground driven by heat convection in autumn and winter and stable stratification of the interstitial air in summer. Such processes have been detected through measurements at many different sites by several studies. In modeling studies these processes are often parameterized by using very low thermal conductivities. With such approaches, the observed measurements can be modeled quite accurately, independent of the convective processes.

However, adjusting models to fit measurements by taking a low thermal conductivity as tuning parameter could be misleading, especially when future conditions are modeled, where changes of climatic and site-specific variables will probably lead to different process behavior. Therefore, attempts to gain a better understanding of the convective and advective processes involved within an active layer of coarse material should be intensified.

At the investigation site Murtèl-Corvatsch, Upper Engadin, Switzerland several studies with extensive measurements (energy balance, active layer measurements such as ground temperatures, wind speed, humidity, etc) have been performed for many years to get more insight in these processes. Energy balance studies showed an annual deviation between a zero energy-balance and the calculated sum of the energy-balance components of 19 Wm^{-2} for 1997, 17 Wm^{-2} for 1998 and 19 Wm^{-2} for 1999. Thus, a more or less constant surplus of energy is obtained from year to year.

Possible reasons for the surplus (summer months) or lack (winter months) of energy at Murtèl-Corvatsch include measurement errors, inadequate calculation of heat fluxes (methodological errors) and unmeasured energy fluxes from advective/convective processes within the active layer. The most probable reason for the surplus/lack of energy besides inaccurate determination of the turbulent energy fluxes in the atmosphere can be found within the coarse blocks at

the surface of the rock glacier, which allow air to circulate within the active layer.

2 RESULTS AND DISCUSSION

Bircher (2007) revealed that especially the thermal conductivity, heat capacity, porosity and permeability show a large uncertainty range with respect to proper input values for heat-flux model simulations in coarse blocky materials.

Furthermore it shows a large influence of the thermal conductivity on model results. When using high values of thermal conductivity, temperature differences of more than 7 and almost 4°C are required for the initiation of convection within a layer thickness of 3 and 6 m, respectively. Maximum temperature differences between the permafrost table and the ground surface at the location of the Murtèl borehole since 1987 amount to 10.6 °C and 4.6 °C, respectively. Though, for the borehole Murtèl, the monthly average of this difference lies in the range of between slightly negative temperature differences to about 6°C. These model results are supported by a study of Panz (2008), where measurements within the active layer revealed that the potential for free convection in the cavities of the upper blocky layer is high as soon as the stable thermal stratification during the summer month becomes instable due to a cooling of the surface. Especially in autumn and early winter a strong ground cooling can be observed caused by low air temperatures and the related vertical convective heat exchange. These processes are limited by the formation of a continuous snowpack. Within the blocky layer, however, the potential for convection remains high. During snowmelt in spring, the latent heat transfer is the dominant process. During the snow-free summer month, air circulation in the blocky layer is mainly caused by forced convection. However, this effect decreases with increasing depth of the blocky layer.

References

- Bircher, S., 2007 (unpubl.). First steps towards active-layer heat-transfer modeling within coarse blocky layers in Alpine permafrost. MSc Thesis, Universität Zürich, Zürich, 113 pp.
- Panz, M., 2008 (unpubl.). Analyse von Austauschprozessen in der Auftauschicht des Blockgletschers, Murtèl, Corvatsch, Oberengadin. MSc Thesis, Ruhr-Universität, Bochum, 111 pp.

Estimation of Potential Distribution of Present and Future Permafrost in Norway Based on Climatology

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1 BACKGROUND

Extensive studies in Norway show that the lower regional altitudinal limit of mountain permafrost is strongly correlated to the mean annual air temperature (MAAT) and decreases eastwards with increasing continentality (e.g., Etzelmüller et al. 2003) in a regional scale. Often used MAAT thresholds for potential permafrost is $MAAT < -4\text{ }^{\circ}\text{C}$ and no permafrost when MAAT is above $-2\text{ }^{\circ}\text{C}$. Factors such as winter snow cover and forest coverage decrease the probability of permafrost in the region.

2 GRIDDED CLIMATOLOGY

Norway has a network of approximately 250 weather stations. To increase the knowledge of the local temperature techniques to interpolate daily temperature records to a grid of 1 km^2 resolution has been developed. All Norwegian observations since 1957 are available electronically at eKlima.met.no, and have been used to generate daily grids.

Dynamical downscaling of Global Climate Models provides climate projections in time and space. The spatial resolution of the Regional Climate Models (RCM) are typically $\sim 25 \times 25\text{ km}^2$ with daily or 6 hourly time steps. For some analyses the spatial resolution of RCMs are still too coarse. Daily temperature and precipitation projections from selected HIRHAM runs have been interpolated to $1 \times 1\text{ km}$ covering the Norwegian mainland. The interpolated model runs have further been adjusted to be representative locally. The climate change signal obtained with HIRHAM is maintained, and high spatial resolution projections of temperature and precipitation are now available for the Norwegian mainland (e.g. Engen-Skaugen et al. 2007).

3 PRESENT AND FUTURE PERMAFROST DISTRIBUTION IN NORWAY

Combining the results from the thresholds found in previous studies and the gridded climatology opens the opportunity of regional maps of the potential permafrost distribution in Norway. The availability of both historic records and projections give the op-

portunity to study the projected decline of near-surface permafrost in detail.

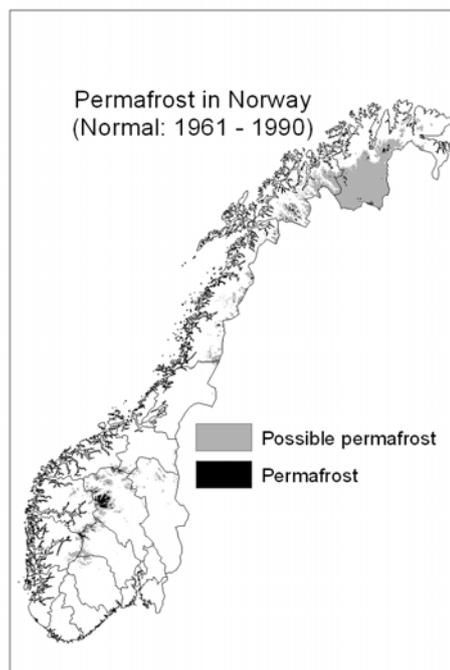


Figure 1: Map of permafrost distribution for the normal period (1961 – 1990) according to the thresholds of MAAT $-2\text{ }^{\circ}\text{C}$ and $-4\text{ }^{\circ}\text{C}$

4 FUTURE WORK

This small study is part of the CRYOLINK project (“Permafrost and seasonal frost in southern Norway”), where we will combine gridded meteorological information, a distributed snow model, surface and subsurface characteristics within both an equilibrium-based and a numerical transient heat-flux model for Norway.

References

- Etzelmüller, B., Berthling, I. & Sollid, J.L. 2003. Aspects and Concepts on the Geomorphological Significance of Holocene Permafrost in Southern Norway. *Geomorphology* 52: 87-104.
- Engen-Skaugen, T., Haugen, J.E., Tveito, O.E., 2007, "Temperature scenarios for Norway: from regional to local scale" *Clim.Dyn* 29:441-453 DOI 10.1007/s00382-007-0241-1

Improved Numerical Modeling of Permafrost Dynamics in Alaska Using a High Spatial Resolution Dataset

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1 INTRODUCTION

Climate projections for the 21st century indicate that there could be a pronounced warming and degradation of permafrost in the Arctic and sub-Arctic regions. Climate warming is likely to cause permafrost thawing with subsequent effects on surface albedo, soil organic matter degradation, hydrology and greenhouse gas emissions.

twelve decades from 1980 to 2100. The results of simulations show that by the end of the current century, the widespread permafrost degradation in Alaska could begin within the vast area southward from the Brooks Range except for the high altitudes of the Alaska Range and Wrangell Mountains.

2 METHODS

In order to assess possible changes in the permafrost thermal state and the active layer thickness, the GIPL2-MPI parallel transient model was implemented for the entire Alaskan permafrost domain. For this study we used an input data set with grid boxes size 2 km by 2 km. Input parameters to the model are spatial datasets of mean monthly air temperature and precipitation, prescribed vegetation and thermal properties of the multilayered soil column, and water content, which are specific for each vegetation and soil classes and geographical location. We used the Scenarios Network for Alaska Planning (SNAP) data set (<http://www.snap.uaf.edu/>) as a climate forcing. The five IPCC Global Circulation Models that performed the best in Alaska: ECHAM5, GFDL21, MIROC, HAD and CCCMA were assessed according to how closely model outputs for the recent past matched climate station data for temperature, precipitation, and sea level pressure.

3 RESULTS

All derived values are representing a single month within a given year for the five models composite. A1B emission scenario was used to obtain the climate forcing.

We performed more detailed analysis by calibrating model using shallow borehole measurements for available time periods and corrected in accordance with these measurements initial temperature distribution profiles. We analyzed ground temperature dynamics at the depths of 2 m, 5 m, and 20 m for

Active Layer Subsidence: an Indicator of Change

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1 INTRODUCTION

The active layer is the most dynamic and sensitive subsurface component of the permafrost environment; it also plays a very important role in many physical, biological and chemical processes and cycles. The thickness of the active layer is expected to increase in a warmer climate. It has been widely documented that both the annual air temperature and permafrost temperatures are increasing. However, in many cases it does not appear to be true that the thickness of the active layer has increased substantially over the past decade.

2 DISCUSSION

Part of our dilemma of not observing increased active layer thickness can be explained by the short observational records and natural variability that exist for active layer processes. Recorded air temperature observations exist for over 100 years, while active-layer thickness observations have only been recorded continuously over the past 15-20 years. After a few years of observations it was realized that another process was possibly masking the process of deeper active layer thaw. A new protocol strategy for measuring active-layer thickness was initiated by several research groups in northern Alaska. It quickly became clear that there was subsidence (thaw settlement) in the active layer and that this occurs in response to thawing of ice-rich soils at the base of the active layer or uppermost permafrost. The relevant questions of interest are: what is the typical annual amount of subsidence that can be expected, how long can this process of subsidence be sustained and what is the significance of this process? Increased active-layer thickness has hydrologic implications, as it increases subsurface storage and will both prolong drainage and freezing in the fall. If subsidence occurs during the thawing process, excess water is released and partitioned into either runoff and/or evapotranspiration. Long-term effects could involve significant changes in soil moisture, vegetation, and geomorphic processes. In low-lying coastal areas, the rate of subsidence could hypothetically eclipse sea level rise; and these areas could be-

come inundated sooner than expected and become more susceptible to storm surges. All of this depends upon the distribution, horizontally and vertically, of the ice-rich layer at the base of the active layer or at the permafrost table. Presently, we have only a qualitative understanding of the distribution of this ice-rich layer and a handful of studies that report on the magnitude of subsidence at some specific locations. For this reason, the Circumpolar Active Layer Monitoring (CALM) program, beginning in 2004, has made subsidence measurements a priority.

3 CONCLUSIONS

At the transition from the Brooks Range to the northern foothills in Alaska, Overduin and Kane (2006) monitored subsidence in the area of some frost boils that varied between 2 and 5 cm/yr over a three year study period. The CALM program's pilot subsidence studies were also made in northern Alaska. Initial results, reported by Streletskiy et al. (2008), showed that subsidence averaging 12 and 13 cm occurred in 1 ha areas of the coastal plain and Brooks Range foothills, respectively, over a five year period between 2001 and 2006. These average annual values are quite similar to those of Overduin and Kane (2006). If this magnitude of subsidence is sustained (given an appropriate climatic trend and ice-rich ground) over a few decades, it will significantly impact how the region looks and behaves in the future.

References

- Overduin, P.P. and D.L. Kane. 2006. Frost Boils and Soil Ice Content: Field Observations. *Permafrost and Periglacial Processes*, 17:291-307.
- Streletskiy, D.A., N.I. Shiklomanov, F.E.Nelson and A.E. Klene. 2008. Thirteen Years of Observations at Alaskan CALM Sites: Long-Term Active Layer and Ground surface Temperature Trends. *Proceedings: Ninth International Conference on Permafrost*, D.L. Kane and K.M. Hinkel (eds), Institute of Northern Engineering, University of Alaska Fairbanks, pp 1727-1732.

Circumpolar Greening May Amplify the Arctic Warming in Summer

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1 ABSTRACT

Climate model simulations coupled with vegetation dynamics suggested that greening in circumpolar region may amplify the Arctic warming through changes in heat budget over Arctic and high-latitude continents, and be further reinforced by atmospheric circulation change. A series of climate model simulation with present and doubling carbon dioxide (CO₂) concentration with/without active vegetation feedback were performed to investigate the vegetation feedback effect on Arctic climate under anthropogenic warming. Model predicts that anthropogenic warming promotes circumpolar greening, the northward expansion and enhanced greenness of the Arctic tundra and boreal forest, which lead to additional surface warming primarily through more absorption of incoming solar radiation. Furthermore, the induced circumpolar warming tends to weaken prevailing tropospheric westerlies in the sub-Arctic latitudes, which resembles the anomalous circulation during the negative phase of Arctic Oscillation. It is suggested that this circulation changes may amplify the Arctic warming while contribute to cooling in the mid-latitudes.

References

- Bonan, G. B. 1992 Effects of boreal forest vegetation on global climate. *Nature* 359:716-718
- Folley, J. A. 2005 Tipping points in the Tundra. *Science* 310:627-628

Mapping Active-Layer Thickness in an Urban Area Using the Modified Berggren Solution – Barrow, Alaska

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1 INTRODUCTION

Active-layer thickness (ALT) is typically mapped at coarse scales. For engineering projects, individual structures are often assumed to be situated in relatively homogeneous environments. As urbanization increases, however, it becomes increasingly important to understand complex interactions between the built and natural components of the local environment.

In this study, the modified Berggren solution was used to map ALT at a resolution of 30×30 m over the 150 km² area studied in the Barrow Urban Heat Island Study. Special attention was placed on analyzing the differences in accuracy obtained in urbanized and relatively undisturbed tundra, and between those produced by the Berggren and Stefan solutions.

2 BACKGROUND AND METHODS

2.1 Study area

Barrow, Alaska, (71.3°N, 156.5°W) is the northernmost community in the USA, and the largest native settlement in the circum-Arctic region (~4600 residents in 2000). It has a long history of scientific research and is the location of the Barrow Environmental Observatory.

Barrow is situated on the coast of the Barrow Peninsula, which separates the Chukchi and Beaufort Seas. Lakes comprise almost 25% of the land surface, vegetation is a complex of sedge-moss wetlands, soil are gelisols, and permafrost underlies the ground to a depth of almost 400 m. Maximum summer thaw depths are >50 cm in undisturbed tundra.

Modern buildings are elevated 1-2 m on piles and the road network is comprised almost exclusively of 2 m thick, graded sand and gravel pads.

2.2 Modified Berggren solution

The modified Berggren solution is based on the Stefan solution, which is known to overestimate the depth of frost and thaw. For the thawing case, Berggren uses thermal conductivity of thawed soil, summer n-factors, seasonal air temperatures, soil

density, soil water content, and the latent heat of fusion, as used in the Stefan solution. The Berggren solution introduces a dimensionless coefficient that accounts for heat required to raise the temperature of the soil, thereby improving the accuracy of predicted frost/thaw depths. Calculation of the Berggren coefficient requires information about mean seasonal and annual soil-surface temperature, thermal conductivity of the frozen soil, and frozen and thawed volumetric heat capacity of the soil (Zarling et al., 1989).

2.3 Data

As part of the larger Barrow Urban Heat Island Study, 34 miniature data loggers were used to obtain records of air and soil temperature in the area during 2001 and 2002 (complete documentation is given in Klene, 2005). These data facilitated calculation of air and surface temperature fields, as well as summer n-factors based upon nine urban and rural land-cover classes. Recent regional soils and land-cover maps were used to obtain additional input data. Soil and vegetation properties were assumed, based on classifications used on the maps and reference properties for soil classes.

3 RESULTS

Validation was performed by comparing ALT probe measurements at the study sites with predicted pixel values. The Berggren provided considerable improvement in estimated ALT in comparison to the Stefan solution. It performed well for estimating mean values for land-cover classes in the rural and urban areas and shows promise as a tool for mapping ALT in other applications.

References

- Klene, A.E., *Urbanization, climate, and frozen ground in Barrow, Alaska*. 2005. Doctoral Dissertation, University of Delaware, Newark, DE, USA.
- Zarling, J.P., Braley, W.A. and Pelz, C., 1989. The modified Berggren method: A review. In Michalowski, R.L., (ed), *Cold Regions Engineering: Proceedings of the 5th International Conference*. New York: American Society of Civil Engineering, pp. 262-273.

Geophysical Monitoring in Permafrost Regions 2:
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Temperature-Calibrated Electrical Resistivity Tomography in Steep Instable Permafrost Rocks?

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1 INTRODUCTION

Temperature is a key control of rock- and ice mechanical properties of instable permafrost rocks. As boreholes cannot be installed in instable rocks and thermal modelling is difficult to perform in highly dissected bedrock, temperature-referenced geophysics could (in future) become a key method for the assessment and monitoring of hazardous permafrost rocks. Here we show the first approach to perform quantitative pseudo-3D electrical resistivity tomography (ERT) in permafrost rocks.

2 METHODS, LABORATORY CALIBRATION AND ERROR MODEL

In 2006, a 3D ERT array was installed across a NE-SW exposed crestline at 3150 m a.s.l. in the Steintaeli, Valley of Zermatt, Switzerland. The 3D array consists of five parallel 41-electrode arrays with midpoints on the crestline. An in-line electrode spacing of 2 m was applied and the offset between the five arrays was 4 m. Electrode positions were aligned with a laser tachymeter to create a decimetre-resolution DEM. Topographic information was accommodated in finite-element grids underlying the ERT modelling with adjusted boundary conditions. The 3D array was measured repeatedly in 2006, 2007 and 2008. Three temperature loggers recorded rock temperatures in 10 cm depth in the field. The temperature-resistivity behaviour of two rock samples was measured in the laboratory. To obtain quantitatively reliable ERT values, we used an ERT data error model, derived from the analysis of normal-reciprocal measurement discrepancies, in the smoothness-constrained inversion code CRTomo (Krautblatter et al., in press).

3 RESULTS

The error analysis yielded a relative resistance error of 8-9 % for high resistances in all transects. Water-saturated paragneiss samples from the study site in-

dicate an equilibrium freezing point at -0.1 °C with resistivity values of 11-14 k Ω m in the laboratory. Resistivity at -2 °C approaches 24-32 k Ω m. ERT images consistently show decametre large frozen rock bodies between 16 k Ω m and 32 k Ω m, which refers to laboratory values between -0.1 °C and -2 °C, and is surrounded by a large zone in the range of 10-16 k Ω m indicating freezing or melting around -0.1 °C.

The presence of ice-filled crevices on the crestline and the NE face appears to have a crucial influence on spatial and temporal permafrost development. Next to 3-4 m deep melting from the surface, elongated recesses of unfrozen rock indicate melting by cleft water up to 10 m depth. ERT images of 2007 and 2008 indicate gradual widespread permafrost degradation.

4 CONCLUSION

Repeated Pseudo-3D ERT was performed in a steep instable permafrost rock wall. Temperature-resistivity of two samples was calibrated in the laboratory. We applied a smoothness-constrained inversion code with a normal-reciprocal data error model. Temperature-calibrated ERT in instable permafrost rock walls delivers sensible spatial and temporal temperature distributions and patterns. However, anisotropy along water-filled and ice-filled rock discontinuities still poses a great challenge for inversion and interpretation.

References

Krautblatter, M., Verleysdonk, S., Flores-Orozco, A. and Kemna, A. (in press) Temperature-calibrated imaging of seasonal changes in permafrost rock walls by quantitative electrical resistivity tomography (Zugspitze, German/Austrian Alps). *Journal of Geophysical Research - Earth Surface*.

Sensitivity Study of an Active Layer Monitoring Scheme Based on MODIS-LST Data at a Polygonal Tundra Site - Siberia

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1 INTRODUCTION

A significant warming of the arctic has been reported, which is expected to continue within different scenarios of climate change. Permafrost is directly affected by this warming trend which emphasizes the importance of a global permafrost monitoring scheme. Such monitoring projects can be realized by using remote sensing products, which provide continuous measurements on a pan-arctic scale. Since permafrost is a ground temperature phenomenon, it is not directly accessible to remote sensing applications. Therefore, remote sensing products must be combined with models, facilitating access to the temperature dynamics of the deeper ground. A possible scheme makes use of land surface temperature (LST) products to drive permafrost models. In this study the sensitivity of a simplified active layer monitoring scheme based on MODIS-LST measurements is evaluated at a wet polygonal tundra site in the Lena-River Delta. Previous studies show that temporal averages of medium scale satellite products, such as MODIS-LST (L2), can provide adequate surface temperature information for this purpose. (Langer et al. 2009).

2 STUDY SITE

The presented study was performed on Samoylov Island (72° 22' N; 126° 30' E), which represents a typical Siberian wet tundra landscape in the zone of continuous permafrost. The region is characterized by an arctic continental climate. The mean annual air temperature (MAAT) at Samoylov Island is -14.7 °C. The regional permafrost in the region reaches depths of 500-600 m and is characterized by a very low temperature of -9.2 °C at the depth of zero annual amplitude approximately 10 m beneath the surface. The site is characterized by wet tundra showing the typical polygonal micro-relief, which features elevation differences of 0.2 to 1.0 m. The size of the polygons typically ranges from 5 to 10 m. The depressed polygonal centers consist of water saturated peat soils or they constitute shallow ponds.

3 METHODS

In this study we investigate the performance of an active layer monitoring scheme based on a MODIS-LST product. The surface temperatures are projected into the ground, using a numerical solution of the heat transfer equation. The applied soil model features a freeze thaw algorithm and a three phase heat conductivity / capacity model. The results are compared to measurements of the active layer thickness and the effect of varying soil moisture contents is demonstrated. Additional model runs are based on ground-based infrared and direct surface temperature measurements, which show the impact on the model results caused by a different temperature forcing.

4 RESULTS

The first results show that the MODIS data are in good agreement with the ground-based thermal infrared measurements. However, a distinct offset can be observed between the both datasets for weekly averaged values, even if outliers are excluded. The positive bias of up to 4 K in the satellite data results from systematic measurement gaps during overcast conditions. Hence, active layer calculations based on the satellite data overestimate thaw depths by about 10 cm. This deviation of thaw depth is slightly larger than the deviation caused by a ten percent uncertainty of soil water content in the model calculations. Our results highlight the potential of satellite LST products in active layer monitoring schemes, but also demonstrate the significant uncertainties. Gap filling procedures might cope with the biased LST average values, but the uncertainties due to unknown soil properties will remain.

References

Langer M., Westermann S. & J. Boike, 2009. Spatial and temporal variations of summer surface temperatures of wet polygonal tundra in Siberia - implications for MODIS LST based permafrost monitoring. *Submitted to Remote Sensing of Environment*

Toward Regional Holocene Mean Annual Air Temperature (MAAT) Curves for Norway as Drivers for Numerical Permafrost Models

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1 INTRODUCTION

Numerical permafrost or ground heat flow models are developed for Scandinavian permafrost during several research projects (TSP-NORWAY, CRYOLINK). The understanding of ground thermal regime development during Holocene is crucial for addressing Holocene landscape dynamics and the formation and distribution of permafrost-related landforms. The Holocene glacier history is well established, however, the development of permafrost through the Holocene is poorly understood. Especially the Holocene climate optimum during the Atlanticum and the Little Ice Age (LIA) are of major interest within this respect.

Numerous previous studies have focused on the reconstruction of Holocene temperature curves for Norway and adjacent areas as in northern Sweden and Finland. Many are established by dating pollen, plant macrofossils and/or chironomids in lake sediment cores, by mapping tree line changes, and deposition rate of speleothems. The resulting temperature curves varies considerably between different sites and also between results from the same place using different methods. Also, for pollen and chironomid proxies, only mean July or summer season temperatures are available.

In this study we try to combine these data with reconstructed surface temperatures at the Greenland Ice Core Project (GRIP) site, as an input driver for numerical and empirical ground temperature models.

2 METHODS

At this stage we have tested several approaches:

a) The existing ‘spot’ temperature curves were collected and sorted for sites in southern and northern Norway, respectively. Mean July temperatures were then collected from modern meteorological stations, and correlated to the corresponding MAATs.

b) Holocene mean July temperature curves were compared with the GRIP temperatures.

c) Modern thawing and freezing degree-days (DDT and DDF) were compared with the modern MAAT, and to the mean July temperature, in the search for a possible relationship.

d) Different variants of established temperature curves were used to force a 1D heat flow model, calibrated to modern site conditions in Norway.

3 FIRST RESULTS

Poor correlations between modern mean July temperatures and MAAT were obtained. The correlations naturally improved when averaged over a 10-years running mean. Comparison of the GRIP temperatures and the Holocene mean July temperatures show that 100-years scale variations are lost in the Holocene mean July curves. The MAATs are normally better correlated to winter temperatures. For DDTs and DDFs compared to MAATs, the correlation is generally better than for monthly mean values. However, the relationship between modern DDTs and mean July temperatures are non-existing.

Running the heat flow model with 10.000 years of MAAT based on the GRIP data is useful to address permafrost depths and the calibrated site. For answering the question of survival of permafrost during the Holocene climate optimum, annual variations have to be taken into account due to the differences of thermal conductivity of material in frozen vs. thawed stage.

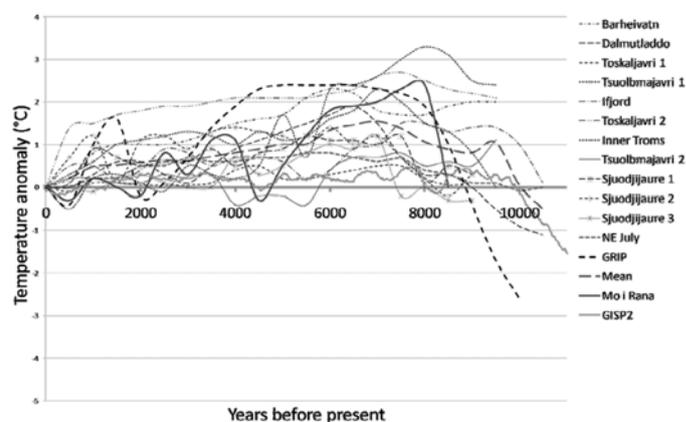


Figure 1. Compiled mean July temperatures from northern Norway with average value indicated, compared to GRIP temperatures (MAAT).

Surface Temperatures Distribution and Permafrost Depth in Gusev Crater (Mars)

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1 INTRODUCTION

1.1 Permafrost on other planets: Mars

The study of permafrost on other planets is a very interesting way to know how was the Earth and how may it would be in the future. The available data to develop these studies were acquired by different missions and they have high quality and mean spatial coverage, although they have low temporal continuity. For that reason, it is necessary to establish some new procedures by the use of all the available data, and try to obtain new results from them about the martian permafrost.

1.2 Sensors and records

THEMIS sensor (THERmal EMISSION Imaging System) is acquiring visible and infrared multispectral images from all over the planet Mars, with a mean resolution of 18 and 100 m/pixel, respectively. Here, we use Brightness Temperature Records (BTR) product derived from THEMIS-IR data.

On previous work (Molina et al., 2010), we analyzed the BTR from THEMIS images available of the area of Spirit's track and Mini-TES BTR information from concordant date, local time and coordinates. There, we showed that the values of surface temperature, coming from orbital and landing sensors could be comparables, with a mean difference about 10 K. The image used on this analysis (I15397002) has a difference of about 4 K.

2 METHODS

We used BTR products released by Arizona State University (themis.asu.edu) and the HRSC altimetry data from the Free University of Berlin (hrscview.fu-berlin.de). We calculate the isotherms applying a Geographic Information System (GIS).

We applied the lineal classical equation [$T_z = T_s + g_g \cdot z$], where T_z is the underground temperature, in our case 273 K (0° C), T_s is surficial temperature, g_g is geothermal gradient and z is the deep for T_z temperature. We assumed a intermediate value of geothermal gradient in this Martian region is about 15 K/km (Clifford, 1993).

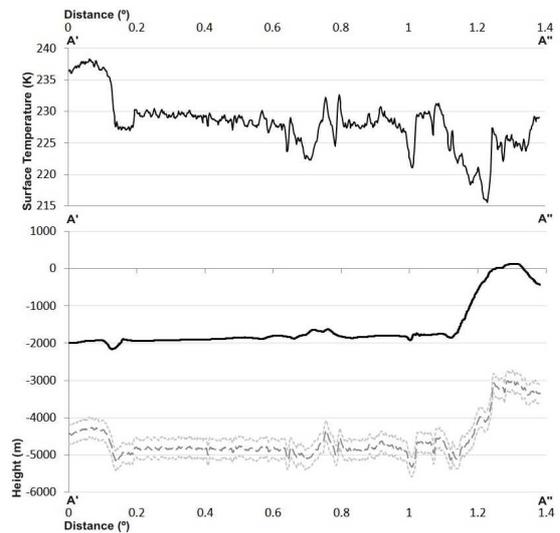


Figure 1. Surface temperature, topographical height and calculated deep of the 0°C isotherm values, though a profile A'-A''. It is located on Gusev Crater rim (14.6°S; 175.3°E), next to the Spirit landing site.

3 RESULTS AND DISCUSSION

As it is showed on the Figure 1, the 0°C isotherm on the area is more or less 3000 m deep. Different terrain orientations and materials composition generate differences on the surface temperature, what influence on depth. Even considering the decrease of surface temperature produced by the tiny Mars' atmosphere on the data acquired by orbital sensors, this layer is considerably deeper than we can find on the Earth. We will apply this tested procedure to other Martian areas in order to determine the regional distribution of permafrost.

References

- A. Molina, M.A. de Pablo, M. Ramos (In press). Studying Mars' permafrost from surface temperature data of Mini-TES, Spirit. *Proceedings of the II Congreso Ibérico de la IPA*.
- S.M. Clifford 1993. The role of the geothermal gradient in the emplacement and replenishment of ground ice on Mars. *LSPS XXIV*: 313-314.

The Permafrost Tunnel Near Fox, Alaska Expansion Project

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1 INTRODUCTION

1.1 Purpose

The Fox Permafrost Tunnel, now almost 50 years old, will be expanded in the next few years to stimulate research in key permafrost areas.

1.2 History

The tunnel, 10 miles north of Fairbanks, Alaska, was excavated in the 1960s by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and U.S. Bureau of Mines. It was not excavated to become a natural laboratory, but rather to research excavation methods in permafrost. In spite of the limitations, more than 70 technical papers have been written about the tunnel, including topics on mining and geotechnical engineering, surface geophysics, geocryology, geology, biology, paleontology, paleoclimatology, and Mars permafrost studies. Beyond the research, thousands of people, both leaders and students, have toured the tunnel and learned about permafrost firsthand there.

2 EXPANSION

2.1 Purpose

The permafrost tunnel expansion is in response to climate warming as well as long standing issues related to building on permafrost. The main research focus is expected to be on four critical areas: 1) improving standoff detection technology and surface geophysical methods for monitoring permafrost; 2) understanding how permafrost will respond to warming; 3) improving estimates of carbon stocks and release rates; and 4) developing models of permafrost heterogeneity for engineering.

2.2 Details

The expanded tunnel will more than double the current tunnel's length, and is designed to directly incorporate research needs. Some design ideas include: a) a detailed 3D map of complex permafrost features between the two tunnels; b) extensive baseline mapping and sampling; c) side rooms to allow

for permafrost warming experiments; and d) boardwalks and gantry above tunnel for test geophysics and remote sensing. In addition to the expanded tunnel, new facilities will be built on site, including laboratories, offices, cold rooms, and a learning center. Combined, these will form the Alaska Permafrost Research Center (APRC).

2.3 Website

The Permafrost Tunnel website contains a brief history and description of the tunnel.

<http://permafrosttunnel.crrel.usace.army.mil/>

3 CONCEPTUAL SITE PLAN

The current tunnel (H&I) is on the left side shown in light gray. The new tunnel and connecting side tunnels (A-E) is on right side shown in black. A surface trench (F), on the far right side, will be used to study the recent geology of the site. Boardwalks and stairways (9-11), shown in a checkerboard pattern, will be constructed on the surface to protect vegetation. The new buildings, mentioned above, are 1-4, with the refrigeration (6&13) and portal (7&12) at each tunnel entrance.

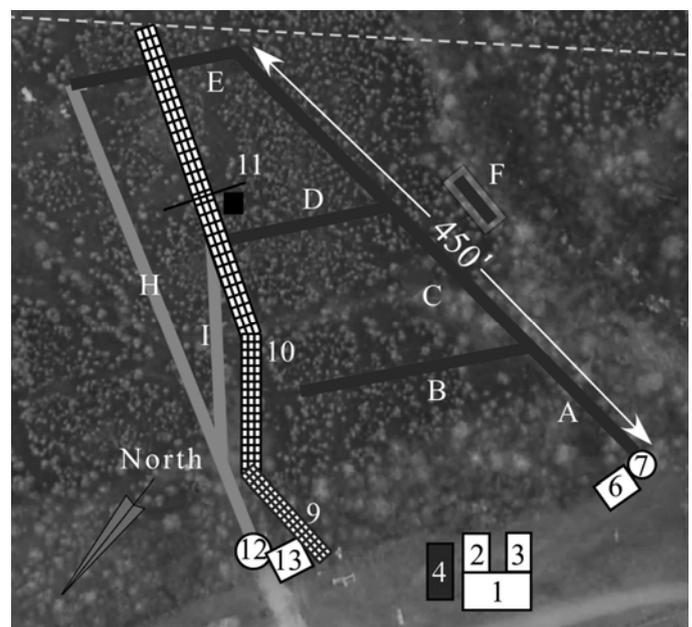


Figure 1. Conceptual Site Plan

An Idealized Experiment to Infer the Net Effect of Snow Cover on Mean Annual Ground Temperatures in Steep Slopes

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1 INTRODUCTION

Snow cover affects ground temperatures by increasing albedo, consuming melt energy and insulating the ground surface from cold atmospheric conditions. However such insulating effect is a non-linear function of snow thickness. Several studies show that thin snow covers promote cooling effect until a critical thickness above which a warming effect occur. In high-mountain regions, snow cover distribution and thickness are strongly variable within few tens of meters. While low slope angles promote thick snow cover, the snow thickness in steep bedrock is usually shallower but also spatially more variable and intermittent. Consequently, it is hypothesized that the cooling effect is largest in medium-steep terrain and it diminishes towards both vertical rock walls, because of the absence of snow cover and more gentle terrain, which promotes thick snow cover (Gruber&Haeberli 2007).

2 EXPERIMENTAL DESIGN

The main objective of the experiment is to evaluate the cooling effect of snow in rock faces. A 1D version of the model *GEOtop* (Rigon et al 2006) is used to estimate the mean annual snow thickness and MAGST over an idealized topography covering diverse aspects (0-360°N) and all slope angles (0-90°) over an altitudinal range between 2000 and 4000 m a.s.l. A large number of model runs are performed and the temperature difference between the mean annual air temperature (MAAT) and the modeled mean annual ground surface temperature (MAGST) with snow is evaluated as a function of the morphological variable (Fig 1). Following a review of possible mechanisms of sub-grid thermal interaction between snow cover and ground and of snow cover reduction in steep slopes, differing model runs are performed to estimate of the range of variability of the results.

3 MODEL VALIDATION

GEOtop is a distributed hydrological model with coupled water and energy budgets, a multilayer

snow pack and treatment of ground freezing processes. It has been validated in steep terrain using observed rock surface temperature and incoming solar radiation. Snow accumulation has been validated on gentle slopes comparing data of snow thickness over several years and at differing sites. The timing of snowfall as well as melting and accumulation processes are reproduced well.

4 EXPECTED RESULTS

The net effect of slope morphology on the MAGST via altered snow cover thickness in complex morphology will be explored for various ranges of slope, aspect and elevation.

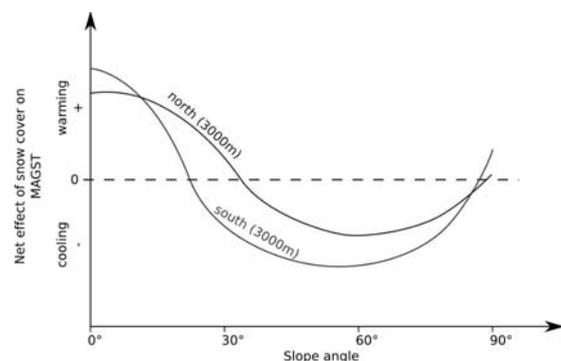


Figure 1. Conceptual scheme of the expected results

References

- Gruber, S. and Haeberli, W. 2007. Permafrost in steep bedrock slopes and its temperature-related destabilization following climate change. *J. Geophys. Res.*, 112, F02S18, doi:10.1029/2006JF000547.
- Rigon, R., G. Bertoldi, and T. M. Over (2006), *GEOtop*: a distributed hydrological model with coupled water and energy budgets, *J. Hydromet.*, 7, 371–388.

Rockfalls in the Mont-Blanc Massif in 2003, 2007, 2008, and 2009

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1 INTRODUCTION

Due to a lack of systematic observations, the magnitude and frequency of rockfalls and rock avalanches in high mountain areas are still poorly known. Those processes could have nevertheless burly consequences. During the heat wave of the Summer 2003 in Europe, a large number of rockfalls affected high-alpine steep rockwalls in the whole Alps. Data on those rockfalls are necessary to improve our understanding of this process and its probable relation with the permafrost degradation.

Using a SPOT-5 image, we surveyed the deposits of the Summer 2003 rockfalls at the surface of the glaciers in the Mont-Blanc massif. Furthermore, thanks to a network of observers set up in the Mont-Blanc massif since 2007, we document rockfalls that occurred during the three last years in the massif (except its Swiss and SW sides).

2 THE MONT BLANC MASSIF

The Mont-Blanc massif, with a surface area of c. 350 km², is characterized by an extraordinary combination of peaks and ridges, with glaciers covering about 40 % of the area. Many of its granitic, fractured rockwalls and summits stand well above 3000 m a.s.l.. The Mont-Blanc is mainly a granitic batholith, formed by intrusion in the gneissic basement. Multiple tectonic phases have fractured the rock with multiple direction planes that may overlap. The combination of past and present glacierizations, steep and fractured rockwalls, and strong relative relief, results in a high-magnitude morphodynamics on the rockwalls.

3 DATA ORIGINES

The SPOT-5 satellite acquires images at a 2.5 m resolution in panchromatic super-mode, well suited to the recognition of rockfall deposits on the glaciers of the Mont Blanc massif. For 2003, we used the image 051/257 of August, 23.

Parameters of each recognized deposit have been extracted using several methods. Elevation of the scars, slope and micro-topographic aspects of affected rock wall were calculated in Arc GIS 9.2 from a 10 to 50 m DTM. The surface area of the deposits was extracted from Bayo-IGN PhotoExplorer; with the estimation of the deposit thickness, volumes were computed. Finally, the probability of the permafrost

was determined from a model of distribution of the mean annual ground surface temperature (MAGST). Regarding the rockfalls in the recent years, a network of observers was set up (guides, hut keepers, mountaineers). A form is filled for each observed rockfall or deposit, with its characteristics. Data have been checked and completed on the field each autumn. Parameters of rockfalls are then extracted in the same way as for 2003.

4 RESULTS AND DISCUSSION

45 rockfalls have been reported in 2007, 21 in 2008 and 72 in 2009. In the area of the massif covered by the network of observers, 152 rockfalls occurred in 2003 (among a total of 182 for the whole massif). These rockfalls are ranging in volume from 100 to 50,000 m³. Analysis of the 2003 ones suggests that: (i) morphodynamics of the high-elevated rockwalls during the Summer was unprecedented in the recent period; (ii) most of the collapses of 2003 were probably related to permafrost degradation, by the deepening of its active layer; (iii) water from the interstitial ice melting or rain storm has probably contributed to this permafrost degradation (heat supply by advection) and triggered some of the rockfalls (pore pressure increasing); (iv) regression of the ice/snow cover on many slopes was probably the source of small events (mechanical detachment, formation of an active layer).

The analysis of the rockfalls of 2007, 2008, and 2009 complete the 2003 one. Most of their starting zones are located in warm permafrost areas, which is the most sensitive to warming. Massive ice has been observed in several detachment zones; this supports the relevance of the thaw of the ice which fills fractures in the rockwalls.

Finally, permafrost conditions seem today more and more important to explain how warming of the climate is driving rockwall stability, and consequently natural hazard in mountain areas, often densely inhabited.

References

- Ravanel L., Allignol F., Deline P., Gruber S., Ravello M. (in press). Rockfalls in the Mont-Blanc massif in 2007 and 2008. *Landslides*.
- Ravanel L., Allignol F., Deline P., Bruno G. (submitted). Les écroulements rocheux dans le massif du Mont-Blanc pendant l'été caniculaire de 2003. Lausanne: IGUL Press.

Climate Influence on Rockfalls in High-Alpine Rockwalls: Two Study Cases in the Mont Blanc Massif since the End of the Little Ice Age

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1 INTRODUCTION

Relationship between climate evolution and morphodynamics of high mountain rockwalls is not easy to establish, mainly because of a lack of data about rockfalls frequency and magnitude. Analysis of such datasets is nevertheless fundamental to study the probable impact of the degradation of rock wall permafrost on rockfalls in the context of global warming.

Based on a rich iconographic corpus, we have completed two studies about the rockwall instability since the end of the Little Ice Age (LIA) in the Mont Blanc massif, at the West face of Les Drus (Ravanel and Deline, 2008) and in the North side of the Aiguilles de Chamonix (Ravanel and Deline, submitted).

2 STUDY SITES

The West face of Les Drus (3754 m a.s.l.) is a 1000-m-high steep rockwall. It bears a 70-m-wide and c. 600-m-high grey scar that results from the June 2005 collapse of the Bonatti Pillar.

The North side of the Aiguilles de Chamonix is a 5-km-long part of the NW side of the Mont Blanc massif. Overlooking Chamonix, the eponymous fifteen needles form a sequence of 1000-m-high shear peaks, regularly exceeding 3500 m a.s.l.

3 METHOD

Reconstructing the evolution of mountain rockwalls since the mid-19th Century consists in several stages. For Les Drus: (i) identification of the scar extent on referenced photographs for each decade; (ii) detailed study of these documents, in order to identify periods of new rockfalls (morphological and colour changes); (iii) dating of rockfalls by completing the series of reference photographs by photo comparison of intermediate pictures and with historical sources; and finally, (iv) estimation of the collapsed volumes based on a ground-based LiDAR survey.

For the Aiguilles de Chamonix, stages were: (i) identification and delineation of the present rockfall scars, missing on the oldest photos; (ii) detailed study of dated photographic series for each face (determination of periods of occurrence of rockfalls); (iii) assessment of rockfall volumes by

studying photos and using laser ranging data and a 50-m-DEM (enhanced at 10 m).

4 EVOLUTION SINCE THE END OF THE LIA

The West face of Les Drus was stable up to the beginning of the 20th Century. The first rockfall was triggered by a 1905 earthquake (9000 m³). No other collapse is observed until the mid-1930s (5500 m³). The first large collapse took place in 1950 (20,000 m³). Pictures taken during the 1970s and 1980s show two small new scars (1750 and 350 m³). In 1997, a rockfall (27,500 m³) removed the 1950 overhang. During the summer of 2003, 6500 m³ of rock detached. Finally, the whole Bonatti Pillar collapsed in 2005 in four events (265,000 m³). Only one earthquake directly triggered a rockfall (1905), while no paraglacial control has affected this face which is well above the Last Glacial Maximum trimline. A strong correlation between rockfall occurrences and the warmest periods over the last 100 years points out the probable degradation of ice joints due to permafrost change.

On the North side of the Aiguilles de Chamonix, 42 rockfalls from 500 to 65,000 m³ (total volume: 390,000 m³) occurred since 1947, date of the first one. Ranging in elevation from 2615 m to 3500 m a.s.l, all rockwalls affected by rockfalls are likely in the permafrost zone. The study of the coupling between climate and rockfalls shows: (i) a very good correlation between rockfalls and the hottest periods (70 % of the rockfalls took place during the last two decades, characterized by a warming acceleration); (ii) a maximal frequency of collapses during the heatwave of Summer 2003; (iii) an average elevation of scars (3130 m a.s.l.) close to the lower permafrost limit, where degradation is potentially more active. Therefore, triggering of most of the recognized rockfalls in the Aiguilles de Chamonix since the end of the LIA is probably controlled by the current degradation of permafrost.

References

- Ravanel L., Deline P. (2008). La face ouest des Drus: évolution de l'instabilité d'une paroi rocheuse de haute montagne alpine depuis la fin du PAG. *Géomorphologie* 4 : 261-272.
- Ravanel L., Deline P. (submitted). Climate influence on rockfalls in high-Alpine steep rockwalls: the North side of the Aiguilles de Chamonix since the end of the LIA. The Holocene.

A Coupled Thermo-Hydro Model to Study Permafrost

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1 CONTEXT & GLOBAL OBJECTIVES

In the framework of nuclear waste storage in deep geological formations, one of the missions of the French Nuclear Waste Agency (ANDRA) consists in assessing future evolution of radionuclides in the geological host formation of the Underground Research Laboratory site (Meuse / Haute-Marne site, North Est, France).

Partners of Andra, LSCE-CEA aims to understand and model impacts of climatic cycles on groundwater flows.

Long-term evolution of climatic cycles is characterized by series of warm and cold periods, leading to occurrence (or disappearance) of permafrost. Consequently, deep hydrogeology and sub-surface hydrology are impacted.

To study these impacts, we developed a numerical code coupling thermal and hydraulic processes.

2 THE COUPLED "T-H" MODEL

We first present the development of a 2D-3D simulation approach in Cast3M code. Our numerical procedure couples heat transfer (conduction, advection and phase change process) with Darcy equations (temperature-dependant permeability).

Numerically, we solve equations with a Picard iterative algorithm and use under-relaxation factors to stabilize possible oscillations due to non-linearity of the phenomenon.

Then, we validate the code against 1D analytical solutions (Stefan problem), and 2D cases issued from literature (see e.g. McKenzie et al, 2007; Bense et al, 2009).

3 IMPACT OF PERMAFROST ON HYDROLOGICAL SYSTEMS

Before considering the large scale system for ANDRA (in Parisian Sedimentary Basin), we focused on some academic small scale systems characteristic of what is found around the ANDRA site.

Indeed, these landscape units, like a river-valley system, play a strong potential role in the local dynamic of permafrost and hydrological evolution. Depending on their thermal states (e.g. presence of open taliks), they can impact groundwater flows, preserving or not recharge/discharge zones of deep aquifers.

By means of numerical simulations on an idealized river valley configuration, we study the installation of permafrost and talik through a cold period of time and its later evolution considering climate change. The associated extensions (e.g. depth, shape) and the intensity in the temperature signal are investigated. The influence of each parameter of the system (e.g. permeability, flow rates) on the extension of the talik and permafrost is also observed. The associated controlling parameters and timescales are discussed.

Conclusions in terms of representation of rivers in the final global model for the ANDRA site are drawn.

References

- McKenzie J.M et al, 2007. Groundwater flow with energy transport and water-ice phase change: Numerical simulations, benchmarks, and application to freezing peat bogs. *Advances in Water Resources*. Volume 30, Issue 4 : pages 966-983.
- Bense V.F et al, 2009. Evolution of shallow groundwater flow systems in areas of degrading permafrost. *Geophysical Research Letters*, Volume 36.

Climate and Permafrost Relations Across Widely Separated Sites in Northern Canada.

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1 INTRODUCTION

Permafrost zones extend across 50% of Canada's land area, with conditions varying from continuous through to isolated patches, along latitudinal and elevational gradients (Heginbottom et al., 1995). The purpose of this study is to determine the spatially variable influence of climate on permafrost temperatures at nine widely separated thermal monitoring sites in northern Canada (Figure 1).

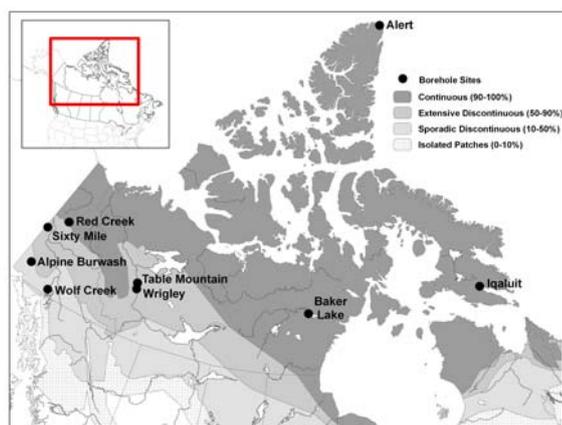


Figure 1. Location map of the thermal monitoring sites in relation to permafrost zones in Canada (Heginbottom et al., 1995).

2 STUDY SITES AND METHODS

The study sites encompass various environmental and climatic conditions, and range from ice-rich sediment with mean annual temperatures just below 0°C in the sporadic discontinuous permafrost zone, to bedrock at temperatures close to -15°C in the continuous permafrost zone. There are between one and five boreholes at each site ranging in depth from 3 to 60 m.

A comparative analysis was conducted to assess the variability in climate-permafrost relationships across space. The local characteristics at each borehole were assessed using the mean annual air and ground temperatures (MAAT and MAGT, respectively), freezing n_f -factor (n_f), apparent thermal diffusivity (ATD), snow characteristics, and substrate.

3 RESULTS AND DISCUSSION

A strong relationship exists between MAAT and MAGT across all of the sites. The differences be-

tween these two variables increase as MAAT increases. The strongest relationships were observed at Alert and Iqaluit, where the least amount of snow accumulates.

The sites with MAGTs close to 0°C are considered warm permafrost, and the sites below -2°C are considered cold permafrost. The ATD was at least an order of magnitude lower at the warm permafrost sites than the cold ones, and generally increased with increasing depth across all of the sites.

The warm permafrost sites at Wrigley, Table Mountain, and Wolf Creek had the lowest values of n_f , ranging between 0.21 and 0.44. Values of n_f were highest at very cold or bedrock sites, Alert, Iqaluit, Sixty Mile, and Alpine Burwash, even though some of these sites had significant amounts of snow. Although snow has a great influence on air-ground surface temperature relationships during the winter, the relationship is modulated by air temperatures, active layer thickness, and subsurface moisture.

The influence of vegetation and snow characteristics, substrate, and frozen and unfrozen moisture on the thermal link between air and permafrost temperatures is evident through the variations in annual temperature amplitude propagation.

4 CONCLUSION

MAAT is the primary determinant of permafrost temperatures across these study sites in northern Canada. Cold bedrock sites are more sensitive to changes in climate than the warm ice-rich permafrost sites. The relationship between snow and n_f depends not only on MAAT and active layer thickness, but also on the substrate material and moisture content, both frozen and unfrozen, at the site.

References

Heginbottom, J.A., M.A. Dubreuil and P.A. Harker 1995. Canada – Permafrost, in *National Atlas of Canada, 5th Edition*, National Atlas Information Service. Natural Resources Canada, Ottawa, MCR 4177.

Time	Thursday, June 17
8:00-10:00	Registration Desk Open <i>in UNIS Entrance Hall</i>
9:00-16:00	FIELD EXCURSIONS <i>Hjortfjellet: 2 Groups – Departs from UNIS</i> <i>Gruvefjellet: 2 Groups – Departs from UNIS</i> <i>Todalen: 1 Group – Departs from UNIS</i> <i>Longyear/Larsbreen Glaciers: 2 Groups – Departs from Nybyen</i> <i>Pyramiden: 3 Groups – Departs from UNIS</i>
Time	Friday, June 18
8:00-10:00	Registration Desk Open <i>in UNIS Entrance Hall</i>
9:00-16:00	FIELD EXCURSIONS <i>Hjortfjellet: 2 Groups – Departs from UNIS</i> <i>Gruvefjellet: 2 Groups – Departs from UNIS</i> <i>Todalen: 1 Group – Departs from UNIS</i> <i>Longyear/Larsbreen Glaciers: 2 Groups – Departs from Nybyen</i> <i>Remote Sensing: 1 Group – Departs from UNIS</i> <i>Svalbard Coal Mining Tour: 1 Group – Departs from UNIS</i>
Time	Saturday, June 19
9:00-10:00	Lunch Bags available at UNIS for pickup

Geomorphological mapping and characteristics of some periglacial landforms from Southern Carpathians, Romania

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1. INTRODUCTION

For the alpine landscape of the highest mountain area of Romania, a large varieties of periglacial landforms are characteristic (rockglaciers, talus cones and scree slopes, block fields, rock streams, cryoplanation terraces, patterned ground, solifluction forms, earth hummocks etc. To give a realistic appraisal of the nature of periglacial environments of Romanian Carpathians the mapping of the periglacial landforms and the evaluation of the present-day periglacial processes are two important targets (Urdea et al. 2004). To touch the second target, our team have applied new techniques based on GIS and geophysical instruments, and started a monitoring program for solifluction, frost heave, freezing depth, creep and the evolution of rockglaciers, talus cones, scree, rocks and soil temperatures. Some of the obtained results are presented in our paper.

2. STUDY AREA & METHODOLOGY

The Southern Carpathians, or Transylvanian Alps, are the most massive and highest part of the Romanian Carpathians, having 11 peaks above 2500 m and a maximum elevation of 2544 m in Moldoveanu Peak (Făgăraș Mountains). For this paper our investigations was focused on solifluction lobes (Paltinu, 2372 m), solifluction terracettes (Laita, 2305 m), situated in Făgăraș Mountains and earth hummocks (Muntele Mic, 1775 m), situated in Țarcu Mountains.

Based on the field mapping, the identified periglacial landforms was inserted on the 3D model, like cartographic support. The DC resistivity investigations was made using PASI 16GS24N system. Due to the special morphological characteristics, in the case of solifluction lobe and earth hummock the electrodes were arranged on equal distance of 0.2 m, for solifluction terraces on 1 m, and dipole-dipole arrays was used. 2D model interpretation was undertaken using the software package RES2DINV (Loke 1999).

3. RESULTS

In all cases, the results of the Electrical Resistivity Tomography (ERT) profiles show varying resistivity patterns. Analysing the profiles we can see, first, that all the resistivity profiles show, generally, a gradual increase in resistivity with depth and, also, each of profiles show varying strength patterns. On the other hand, the mottled aspect of all apparent resistivity profiles is an expression of heterogeneous deposits. Starting of this aspects we can know and interpret the structure of solifluction lobes and terracettes and earth hummock deposits and, very important thing, the depth and configuration of the surface contact with bedrock.

Especially by the inversion model profiles, we can inferred a low layered and corrugated stratification tendencies in the case of solifluction lobe, and an different design of solifluction terracettes and earth hummock internal structure. In the case of solifluction terracettes the inversion resistivity model show a clear differences between the upper part and the bottom part, with an expressive layering and a clear contact with the bedrock. On the upper part the internal design is characterized by the presence of the alternation of rounded pockets of low resistivities - in the area of the steep herbaceous and more humid risers -, and high resistivities bands, in the area of the flat surfaces, upholstered with frost-sorted clasts. For the earth hummocks, DC tomography reveal a gonflant structures, with asymmetric ellipsoidal bodies of high resistivities (Fig. 1). The ERT investigation at the end of cold season reveal the effect of the frost in the earth hummocks, and the configuration and dimensions of the frozen core.

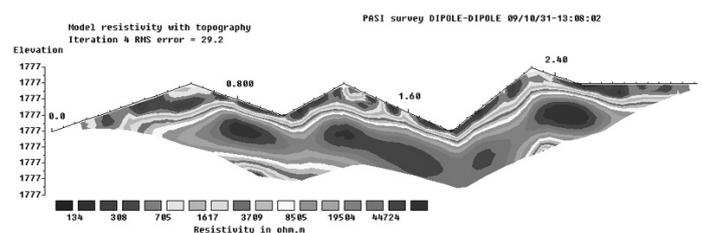
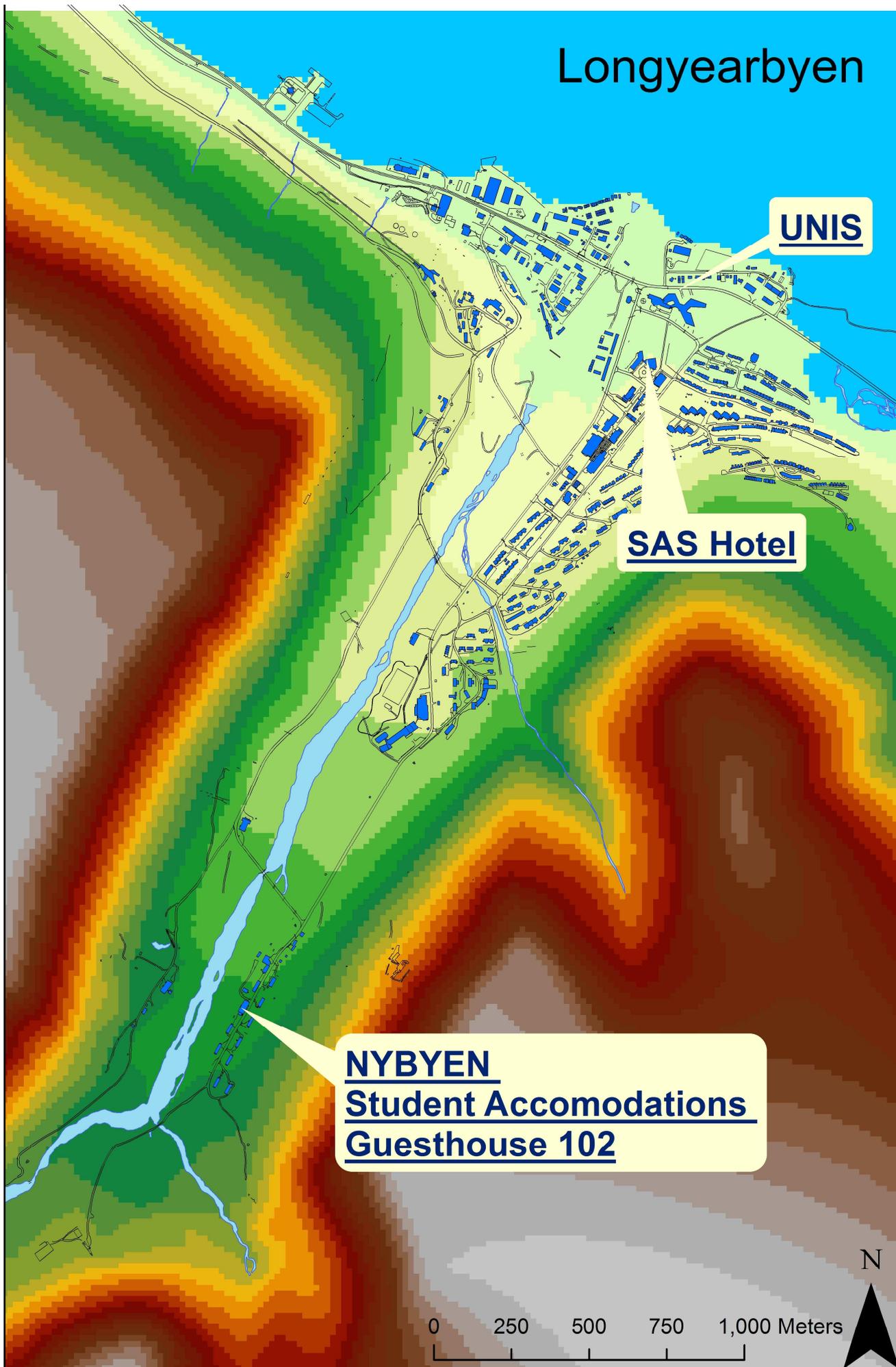


Fig. 1. Electrical resistivity tomography profile (inversion model) on the earth hummocks Muntele Mic.



Longyearbyen

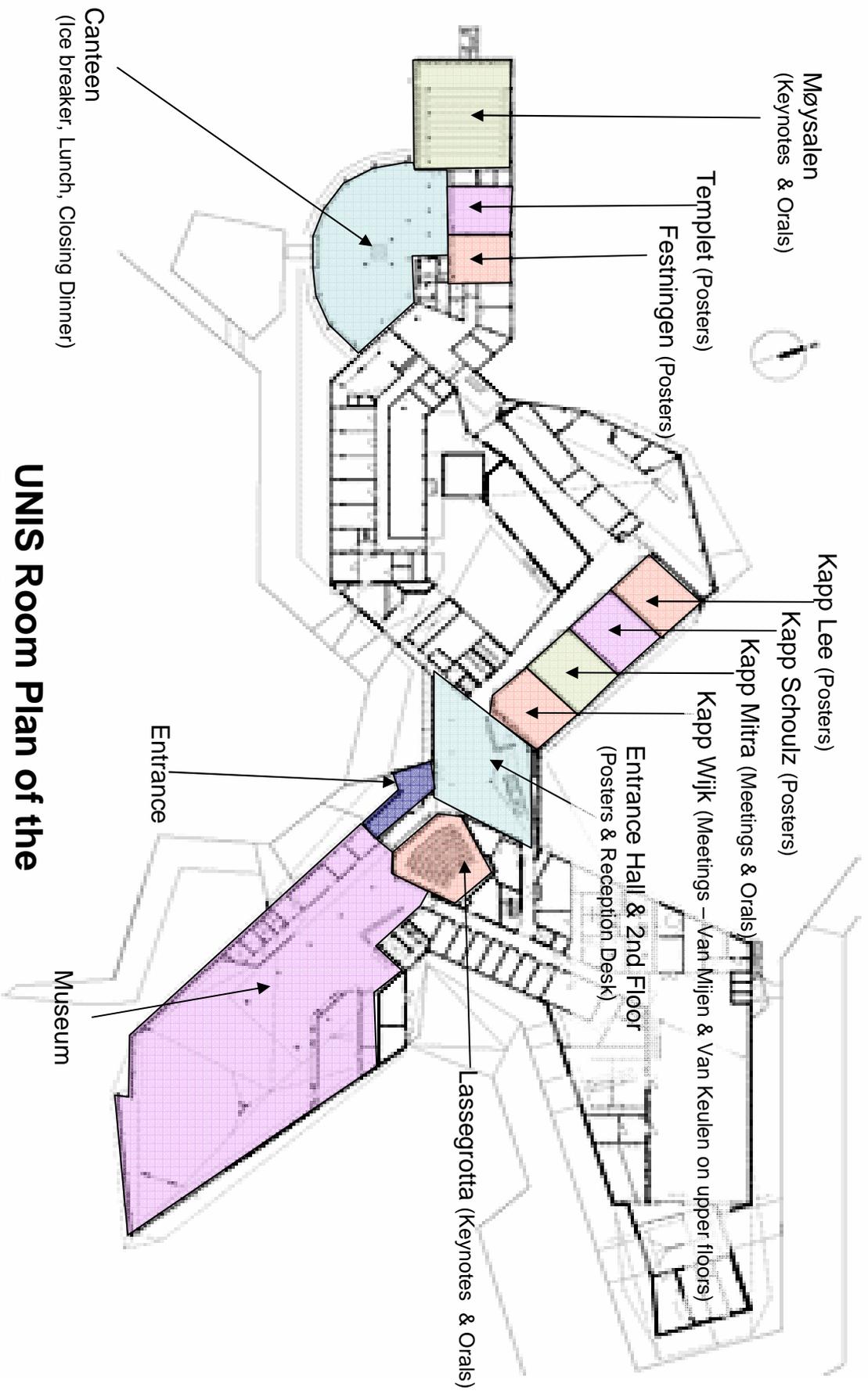
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