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Frost in Ground 2010

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Front page: View towards Adventdalen and Isdammen water supply with ancient coal transportation system in front. (Photo: Ivar Horvli)

Contents

Preface

The Frost in Ground Committee is affiliated to the Norwegian Geotechnical Society, and submission of the publication Frost in Ground is one of the main goals for the committee.

This issue of the publication Frost in Ground gives 13 articles developed from extended abstracts submitted at the Third European Permafrost Conference (EUCOP III) which was arranged in Longyearbyen, Svalbard in June 2010. This is a collection of articles written by Norwegian researchers and covers engineering as well as scientific topics. The first article (Christiansen and Etzelmüller) gives a brief resume from the whole conference which attracted 241 participants from 27 different countries. The focus at this conference was the polar areas and the output of the research projects under the Fourth International Polar Year (IPY) 2007-2008. The conference was hosted by the University in Svalbard (UNIS).

The Norwegian Committee Frost in Ground is pleased to submit this collection of articles from the conference, and we are grateful to the National Organizing Committee which gave us the opportunity to do this. We believe that this small collection of articles gives an insight into the scientific and engineering area covered by the conference. We hope that this might inspire to take contact with the professionals who contributed at EUCOP III and thus give an extended and strengthened network.

We would like to acknowledge the Norwegian Public Roads Administration for sponsoring this publication.

Ivar Horvli

(Chairman 2010)

Trondheim, January 10, 2011

Report from the International Permafrost Association: Third European Conference on Permafrost in Longyearbyen, Svalbard

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Introduction and key conference focus

For the very first time the European Conference on Permafrost was held on permafrost in the University Centre in Svalbard, UNIS, in Longyearbyen in Svalbard at 78°N. 241 scientists and engineers found their way to Svalbard for The European Conference on Permafrost from 13 to 17 June 2010. The conference had participants from 27 nations, with the largest amounts of participants from Germany (36), Norway (35), Switzerland (21), the United States (20), Russia (18), Canada and Sweden (17), France (16), Denmark and Portugal (7), Austria, Finland, Italy (6), Spain (5), Korea (4) and China (3). Of these 171 were from Europe, 77 were student participants. 31% of all participants were female and 69% male.

At the Second European Conference on Permafrost in 2005 it was decided to focus in the next conference on the polar areas and the output of the Fourth International Polar Year (IPY) 2007-2008. Thus The Third European Conference on Permafrost (EUCOP III) had a focus on the 'Thermal State of Frozen Ground in a Changing Climate During the IPY', to show the various outputs from the different permafrost research fields obtained during the IPY, including the first international overview of the thermal state of frozen ground.

The IPA Executive Committee approved in December 2008 our suggestion for making the Third European Conference on Permafrost a regional conference of the IPA. An International Organising Committee with 20 members from all over Europe, Russia, Canada, USA and Japan, and a Norwegian Organising Committee with 21 members from science and engineering were formed to be responsible for the development of the

Conference. The Norwegian Organising Committee met in June 2009 in Oslo, and both Committees met for a one day workshop in Oslo in March 2010 to design the scientific programme based on the received 284 abstracts.

Conference presentations

The conference started each day with two plenary oral keynote presentations. The keynotes focussed on results from the IPY in lectures on 'Thermal State of Permafrost [TSP] - An Overview and Status of the Activities in the polar northern Hemisphere' presented by Vladimir Romanovsky, on 'State of Periglacial Research at the End of the IPY' by Norikazu Matsuoka, on 'Remaining challenges in Permafrost Carbon Research – a Status at the End of the IPY' by Peter Kuhry and 'Where, How Fast and Why Arctic Permafrost Coasts Undergo Coastal Erosion' by Hugues Lantuit. Also two local keynotes on 'Permafrost Research in Norway and Svalbard' by Ole Humlum and 'The Development of Infrastructure on Permafrost in Svalbard' by Arne Instanes, were presented to introduce the local permafrost science and engineering research.

The main part of the conference programme consisted of four 2 hours blocks with three parallel sessions with 15 minute oral presentations, in total having 96 oral presentations, and two poster sessions with 188 posters. There were eleven different session themes covering a major part of permafrost science and engineering. Most presentation were in the Geophysical monitoring in Permafrost Regions session, with 8 oral presentations and 44 posters, second largest was the Periglacial Processes and Landforms session, with 16 oral presentations and 24 posters. This is clearly showing the large efforts carried out during the IPY to improve the permafrost observation network.

The EUCOP III participants in front of the University Centre in Svalbard, UNIS, 15 June 2010. Photo by Stephan Vogel.

An open public lecture 'The Unintended Research Legacy of John Munro Longyear' was given by Frederik Nelson, University of Delaware, USA, to all participants, residents and visitors to Longyearbyen in the evening of the first day of the conference. The Permafrost Young Researchers Network, PYRN, had a special PYRN Social event. The conference provided a very cheap registration fee and low cost accommodation for all students.

The scientific publication from the conference is the book of the 284 one page abstracts of all accepted presentations, reviewed by the two Committees, and published (Mertes, Christiansen & Etzelmuller, 2010). All delegates to the Conference received the book of abstracts on a specially designed memory stick together with all other written material for the conference. This way we avoided printing more than 65000 pages on paper, and saved the planes lifting the EUCOP participants out of Svalbard for many kilos of weight.

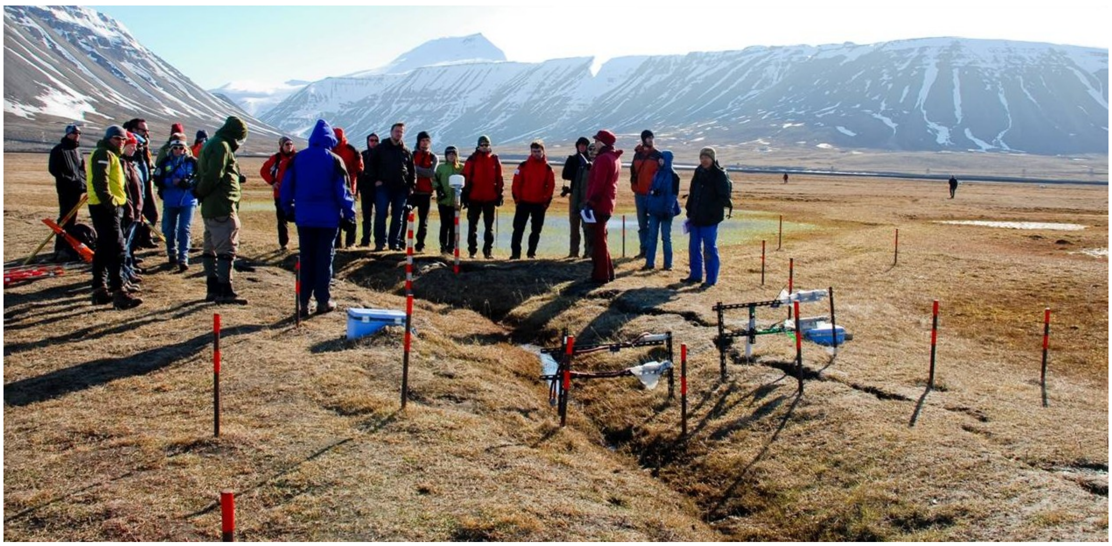
Field presentations

Hosting the conference in Svalbard enabled a dedicated field component of the conference. One half day of the conference was designed to present all participants to some of the science and engineering activities run by Norwegian and international colleagues around and in the Longyearbyen area. During this half-day field excursion several of the EUCOP papers were orally presented and they would then also be poster presentations in the indoor part of the conference.

The field sites visited ranged from 'Svalbard Airport and the seed vault' guided by Ivar Horvli, 'House infrastructure in Longyearbyen - UNIS on poles' guided by Arne Instanes, 'Solifluction in Endalen' guided by Antoni Lewkowicz, 'UNISCALM and TSP boreholes in Adventdalen' by Håvard Juliussen and Ketil Isaksen, 'Longyearbyen slope processes' guided by Ole Humlum and 'Ice-wedge process research in Adventdalen' by Hanne H. Christiansen, Norikazu Matsuoka and Tatsuya Watanabe. All participants were circulated between the six major field sites and escorted by two EUCOP guides, who were all UNIS or University of Oslo Ph.D. or master students participating in the conference, or UNIS student helpers to guide the participants around between the sites and to take care of their safety. The field excursion ended with a large Arctic outdoor barbeque at for all participants in nice sun shine in downtown Longyearbyen outside the SAS Radisson Blu Polar Hotel.

The conference ended with two days of seven different one-day excursions either for free or at a low cost. The excursion titles were: A walking tour of the Longyearbreen and Larsbreen glaciers guided by Håvard Juliussen and Jordan Mertes, a walking tour to Gruvefjellets TSP boreholes, avalanche sites and rock glaciers guided by Ole Humlum and Stephan Vogel, a walking tour of the Hjortfjellet rock glacier and the first settlement Advent City guided by Ketil Isaksen and Rune Ødegård, a walking tour of Todalen visiting periglacial slope landforms including active avalanche sites guided by Lena Rubensdotter and Markus Eckerstorfer, a visit to the Russian mining town Barentsburg guided by Nataly Marchenko, a visit to the mining settlement Svea by the local Coal mine company guided by Malte Jochmann and a field trip to visit remote sensing of the periglacial landscapes of Svalbard with UAV demonstration and visit to the Svalsat satellite receiving station guided by Tom Rune Lauknes and Ulrich Neumann.

The field excursions were a large success, so much so that we could not provide enough spaces on all the one-day excursions as requested, but all who wanted to participate were accommodated onto one of the field excursions. The first day 154 conference participants walked, sailed and visited 5 different sites, while on the second day 83 participants attended 5 excursions.



Conference participants visiting the ice-wedge research site in Adventdalen on the half-day field excursion, and being presented to results by Norikazu Matsuoka and Hanne H. Christiansen. Photo: Stephan Vogel.

Conference results

The conference produced results in many different ways; however, the scientific results are of course the most prominent. The Circumpolar permafrost thermal snapshot presented during the conference through the many local, regional or international presentations clearly showed that the warmest permafrost this far north in the Northern Hemisphere during the IPY 2007-2009 is found in Svalbard. The international coordination which has been significantly improved due to the IPY, lead to the organisation through the different international IPY permafrost project clusters, of a special issue entitled 'Permafrost in the Polar Regions during the International Polar Year' published in the journal Permafrost and Periglacial Processes, Vol. 21, Issue 2 (http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1099-1530/issues). This issue was launched the week before EUCOP III at the IPY Oslo Science Conference in Oslo, Norway, and free access is provided to all the six research articles, the editorial, the one short communication and the previous report of the IPA on the IPY permafrost legacy.

'There has never been such a proud time in the history of permafrost research' said Professor Hans Hubberten, President of the IPA, at the conference closing session. 'This conference is a result of taking the IPY momentum to bring together scientists, engineers, different research fields, young and old people – to go further in the future' he said.

During the conference several student prices were awarded. The winners of the Permafrost Young Researchers Network (PYRN) awards were: Britta Sannel (Stockholm University, Sweden) for the best international poster 'Warming-Induced Destabilization of Peat Plateau/Thermokarst Terrain' (A.B.K. Sannel and P. Kuhry) and Marc Oliva (University of Lisbon, Portugal & University of Barcelona, Spain) for the best international oral presentation 'Long-Term Solifluction Response to Increasingly Arid Conditions in Sierra Nevada, Southern Spain'. The awards were sponsored by the Cryosphere Journal. Also two national Norwegian prices were awarded for the best oral or poster contribution, sponsored by the Norwegian Journal of Geography and its publisher Taylor and Francis. These were given to Kjersti Gisnås (University of Oslo) for her poster presentation 'Regional Scale Mapping of Permafrost Distribution in Norway Using the TTOP Model' (K. Gisnås, H. Farbrot, B. Etzelmüller and T.V. Schuler) and to Håvard Juliussen (The University Centre in Svalbard) for his poster presentation 'Active Layer Freeze and Thaw Dynamics Revealed by Year-round Electrical Resistivity Tomography in Svalbard' (H. Juliussen, A. Oswald, T. Watanabe, H.H. Christiansen and N. Matsuoka).

Conference logistics

Despite the arctic location it was possible to keep the registration cost at a relative low level, with most of the food during the conference days included in the registration. The challenge of having the 241 conference participants come to Longyearbyen, a village of 2500 inhabitants worked out nicely. Only weeks before the conference, Svalbard was cut off from the rest of the world due to Icelandic ash clouds, but it worked out almost without problems to accommodate all visitors as they had requested in Longyearbyen. Hosting such a size conference at the University Centre in Svalbard, UNIS, had never been done before, but turned out to become a real pleasure, with nice facilities for the presentations, the ice-breaker and the conference dinner. Right before the conference a polar bear decided to visit Longyearbyen. We included the usual safety briefing of all participants on the specialities of life in the Arctic in the Opening session, and had luckily no polar bear encounters during the conference and its field excursions.

IPA Council and Executive Committee at EUCOP

The IPA Council and Executive Committee met at EUCOP and the results from these meetings will be the topic of the next report from the IPA in this journal.

Sponsors

The conference budget was in total around 50000 Euros. The Norwegian Research Council was the main sponsor of the conference with 25000 Euros. In addition, other institutions have been directly sponsoring the event, such as the Caixa Geral de Depósitos, Portugal; The Cryosphere Journal, Taylor and Francis and the Department of Geography, University of Technology and Natural Sciences, Trondheim, Norway. The journal 'Permafrost and Periglacial Processes' provided a student price and free access to the special IPY issue. Several institutions had staff work in the National Committee for the conference and as such sponsored the conference. These are: The Geological Survey of Norway, NGU; The Northern Research Institute, Norut; The Norwegian Meteorological Institute, met.no; The Norwegian Geotechnical Institute, NGI; Vianova Plan and Traffic AS and the high school in Gjøvik. However, two other main sponsors were of course our two institutions, the Department of Geosciences, University of Oslo and the Geology Department, The University Centre in Svalbard, UNIS, who together allowed us to host this conference.

Acknowledgements

As main organisers of this conference we have several persons and institutions to thanks for their contributions, which enabled us to develop and run the conference here in Svalbard. These include the University Centre in Svalbard, UNIS who hosted the conference in the best possible way, by not having any teaching going on during the conference, so that we could use all the facilities, including the student housing. The University of Oslo, Department of Geosciences, and all the field EUCOP excursion guides: Malte Jochman, Tom Rune Lauknes, Ulrich Neumann, Lena Rubensdotter, Markus Eckerstorfer, Ketil Isaksen, Rune Ødegård, Ole Humlum, Stephan Vogel, Håvard Juliussen, Jordan Mertes, Nataly Marchenko, Arne Instanes, Norikazu Matsuoka, Tatsuya Watanabe, Antoni Lewkowicz, Ivar Horvli, Hanne Christiansen, Stephanie Härtel and Kjersti Gisnås. Regula Frauenfelder who organised the poster sessions. Herman Farbrot and Stephan Vogel who were the conference photographers. Ivar Berthling the field guide editor. Ole Humlum the half-day field excursion responsible. Spitsbergen Travel, especially Anja Kristoffersen, who managed the registration process for us. Jordan Mertes, our EUCOP Conference Secretary, who has worked for us since the summer 2009 and until the end of EUCOP, at the same time as trying to work on his master thesis. We wish you good luck with the thesis work and your future in cryospheric sciences, now that you know all about the permafrost community. We had the pleasure of hiring 7 UNIS Geology students: Wesley from the US, Maximilian from Germany, Peter from Switzerland, Alexandra from Russia, Samuel from France, Scott from Canada and Alexis also from France, who did an excellent job with all the logistics around the conference. Our best thanks to all of you mentioned above, it was a very good experience to work with you!

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The development of infrastructure on permafrost in Svalbard

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1 Introduction

The development of infrastructure on permafrost in Svalbard has gone through several stages during the last hundred years. This article 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 acitivity 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-ies, 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, see Figure 1. 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, see Figure 2.

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 Foundation techniques

In Svalbard, before approximately 1980, foundation techniques were limited by available machinery and construction materials. In general foundations footings were placed just below the active layer (Instanes, B., 2000). In 1980, a new drill rig was developed, capable of drilling 350 mm diameter boreholes down to 12 meters depth below surface. This allowed installation of piles in predrilled holes and has been the most common foundation technique during the last 30 years (Instanes, A. and Instanes D., 1999; Instanes, B., 2000). From 1986 foundation design using a heat pump cooling system has also been used (Instanes, A. and Instanes, B., 2008; Instanes and Rongved, 2009). This method is used when ground conditions are not favourable for piles such as high ice content and ice inclusions in the ground, discontinuous permafrost or taliks and high salinity permafrost. The main advantages using this technique are that the structure can be placed directly on the ground and the air space between the floor and ground is avoided. In this way, the heat loss from building is reduced and easier access to the building is achieved. It is possible to have heated floor in the building. The main disadvantages are that the initial cost is higher than using pile foundations, the heat pump requires electricity and maintenance.

5 Changing climate

During the last two decades the mean annual air temperature has increased in Svalbard. Climate models indicate that the mean annual air temperature may increase from the present level of -6,7 °C to warmer than +5 °C , see Figure 3. 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 (Hayley and Horne, 2008; Instanes et al., 2005). 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.

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Figure 1 Buildings in Longyearbyen

Figure 2 Buildings in Pyramid

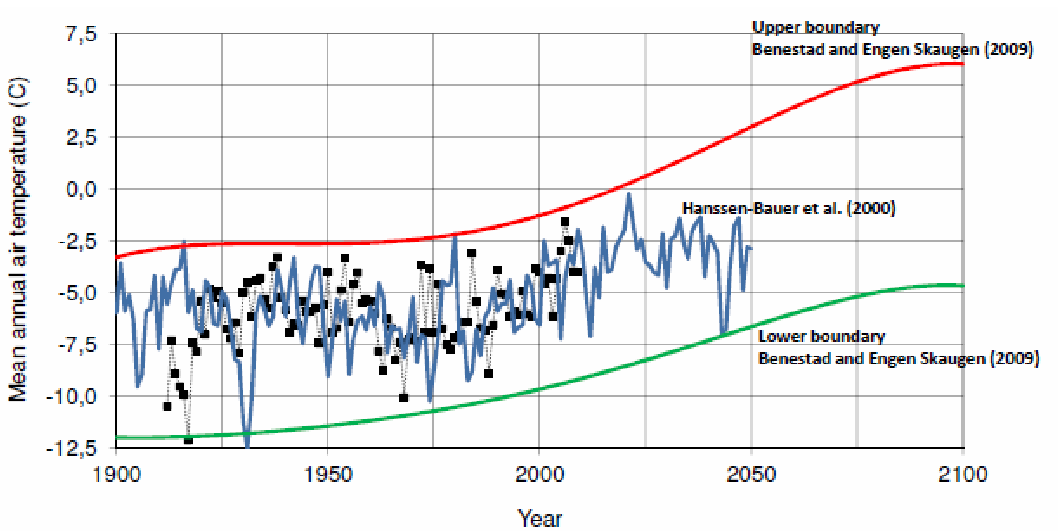

Figure 3 Mean annual air temperature Longyearbyen from downscaled GCMs. Dotted line = observations

Foundation reconstruction for the Governor's residence in Longyearbyen

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Sweco Norge AS, Bergen, Norway

1 Introduction

The city of Longyearbyen contains several buildings constructed at around 1950. Several of these buildings are now experiencing severe settlement damages. The settlements are often caused by foundation designs not suited for permafrost areas, by deviations from the original design criterions, or simply that the buildings have exceeded their original life expectancy.

All constructions from prior to 1949 are automatically protected by law. In addition there are some buildings that do not fall under automatic protection, but which are still sought to be preserved from a historical incentive. For these buildings visible alterations to the constructions are prohibited.

One such building, which is now experiencing severe settlement damage, is "Sysselmannsgården", the residence of the governor of Svalbard. Sysselmannsgården is managed by Statsbygg, who acts on behalf of the Norwegian government as property manager and advisor in construction and property affairs. Sweco Norge was in 2008 commissioned by Statsbygg to evaluate the cause of the settlements of Sysselmanns-gården and to propose remedial action to retain the structural integrity of the building.

2 Problem description

2.1 Sysselmannsgården

Sysselmannsgården is the housing and residence of representation for the governor of Svalbard. A photo of the building is shown in Figure 1. The construction consists of four connected buildings, whereof two, the main building and the tower, have problems with settlements. Both of these buildings have a heated lower storey beneath terrain level, and the foundation of these buildings consists of a 20 cm slab of plain concrete. It was also believed to be a layer of timber underneath the concrete slab. This was later confirmed during the actual reconstruction of the foundations.

Figure 1: Overview of Sysselmannsgården

Measurements of the buildings show that the tower has tilted, and is leaning against the main building. This has caused severe fissuring in the plain concrete walls of the building. The damage has also propagated upwards to the first and second storey of the building.

2.2 Site conditions and temperatures

Site investigations were performed by SINTEF in 2008.

Figure 2 shows measured temperatures from two thermistor strings installed near the basement, plotted with temperatures from a reference string installed some distance from the building.

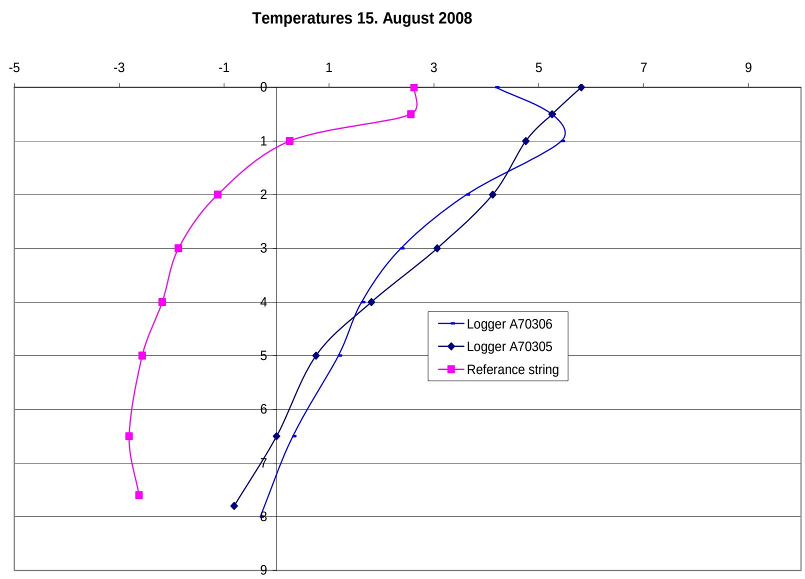

Figure 2: Temperatures

Collected soil samples shows that the ground around the structure consists mainly of sand and gravel over silt and clay. The investigations also showed a top layer of fill material, with bits of wood, bricks and coal. From the investigation report it is estimated that bedrock is at approximately 8 m below terrain level. The temperature data combined with the site investigations shows that the permafrost is thawed down to just above bedrock.

2.3 Foundation reconstruction

Based on the performed investigations it was concluded that the cause of the settlement damages was melting of the permafrost under the building due to the heated basement. Several methods for foundation reconstruction were considered. It was first considered to refreeze the ground beneath the building, to slow down further settlement. This would however have required much demolition in the basement of both the tower and the main building. The concrete floor and the underlying concrete slab and timber would have to be removed, cooling pipes would have to be installed, and a new floor added. The uncertainties related to the phase change from thawed to frozen ground were also considered, with the risk of frost heave and the resulting added stresses on an already damaged structure. Because of these uncertainties, it was finally decided to use a method of pile foundation more commonly used in non permafrost areas. The challenge with this method was how to install piles in the limited space available in the basement, and also how to install the outside 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 as the piles and the structure itself are not designed to withstand frost heave and frost jacking. To ensure that the ground around the piles remains thawed, insulation in the outer walls of the basement is minimized. Also the ground surface around the building will be insulated to approximately 1 m outside of the outer walls.

Figure 3 shows how the pile foundation for the outer walls will be performed and Figure 4 shows a photograph from the installation of the piles. The foundation rconstruction was started in early summer of 2010, and is scheduled to be completed during the autumn 2010.

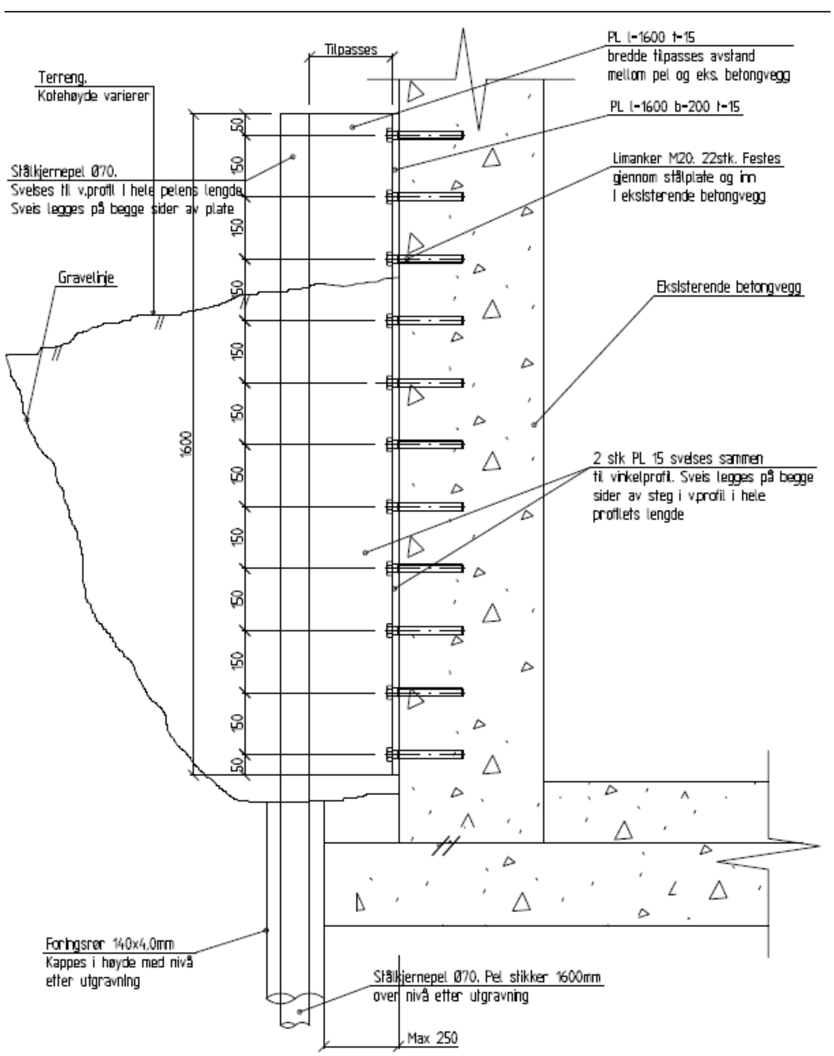

Figure 3: Detail of pile foundation along outer wall

The foundation reconstruction is performed as a turnkey contract on behalf of Statsbygg, and is executed by the Tromsø firm Byggmester Johnsen & Sønn AS.

Figure 4: Pile installation

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 is being performed on behalf of Statsbygg as a turnkey contract during summer and autumn of 2010.

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Experiences from geotechnical sampling and sounding in permafrost

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1 Introduction

SINTEF Building and Infrastructure has been present on Svalbard the last few years; among other things, to perform geotechnical research and surveys 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 article 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 and increase the number of geotechnical surveys connected to piling and new infrastructure. 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. In addition the tool-bit was changed to a diamond/carbide bit on the "NTNU sampler". SINTEF is planning to incorporate the following equipment in future Arctic research:

- New drill rig equipped for easy helicopter handling (2011)
- New sampling equipment (reduced diameter), both NTNU and Atlas Copco (2011/2012)
- Equipment for installation of environmental wells and pipes in permafrost (2011/2012)

Picture 1: Drill rig at Lunchefjell

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 Svalbard 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 of 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. When 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 is normally too high.

A modified method uses both constant load and rotation speed, with penetration rate as the only variable with hammering and flushing for all frozen soils using air as a flushing medium. Water is not present during wintertime and melting snow for this purpose is both costly and not sufficient due to possibility of melting the soil with a warm flushing medium. Non cooled air will also melt the soil, but tests shows that the amount of soil melting in front of the bit is very small, the main problem is melting of drill cuttings. For mainland sounding the standard requires ø 57 mm drill bit, type “button bit”, with ø 45 mm rod system. Drill bits with this diameter have been tested in frozen soils without any luck, due to challenges connected to flushing the cuttings in the small channel outside the rods. Clogging caused by cuttings freezing to the side of the hole is a normal problem. To avoid the clogging SINTEF has found that using an ø 76 mm drill bit is more sufficient.

Picture 2: Sounding for coal at Mine 7

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

Picture 3: NTNU Sampler

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. NTNU sampler is working well in finer material such as frozen sand, silt and clay. After testing out different material and geometry for the bits, SINTEF has found a method for taking a frozen sample with dimension (ø 70 mm x L 500 mm) using only approx 1-2 minutes.

For rock sampling there have been several tests with Atlas Copco sampler, T2-76, with modification for use by geotechnical drill rig with low rotation speed. So far the speed rate obtained is too low, but a new drill rig (2011) will be modified with sufficient rotation speed both for soil and rock sampling.

Picture 4: Coal sampling by use of Atlas Copco sampler

Sampling in soils with inclusions of stones and blocks is still a challenge and will be given focus the next years together with further development of both methods and equipment for sampling and sounding in permafrost.

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-evasive 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.

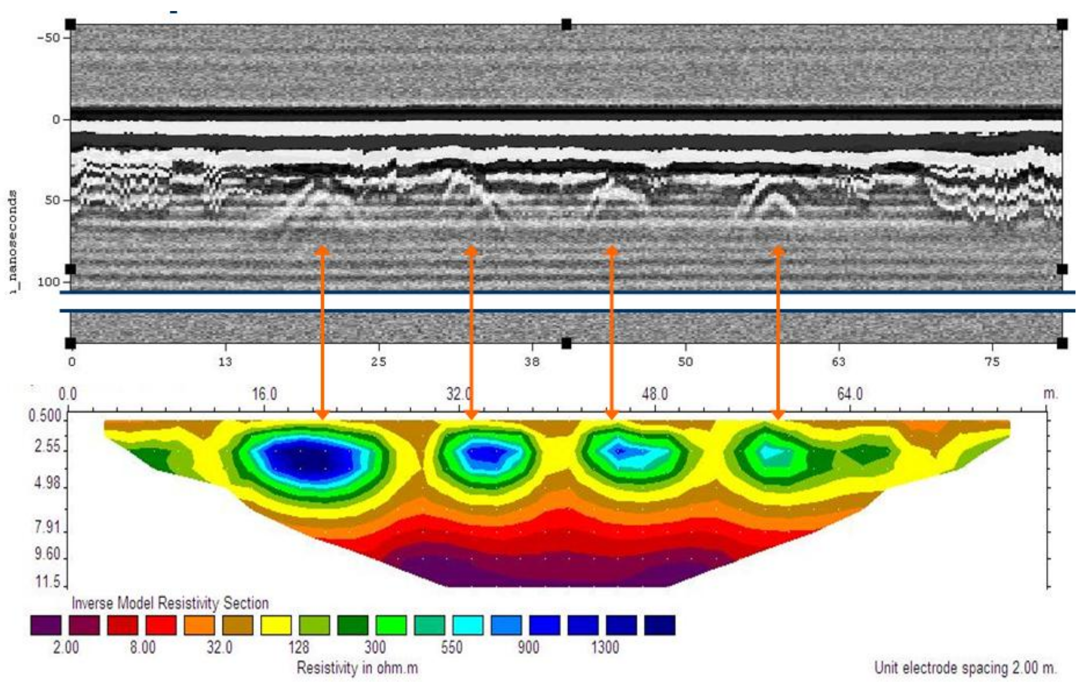

Fig 1. Comparison of radar and resistivity results

Fig 2. The SINTEF drill rig placed in Longyearbyen

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 several locations where ice might be present along the investigated corridor.

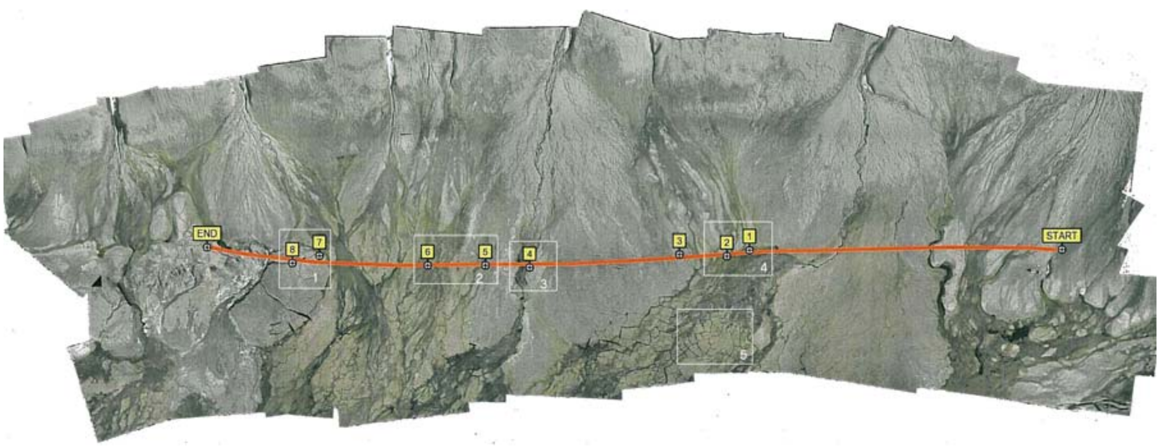

Fig 3. The aerial photo with the radar profile and boreholes marked

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.

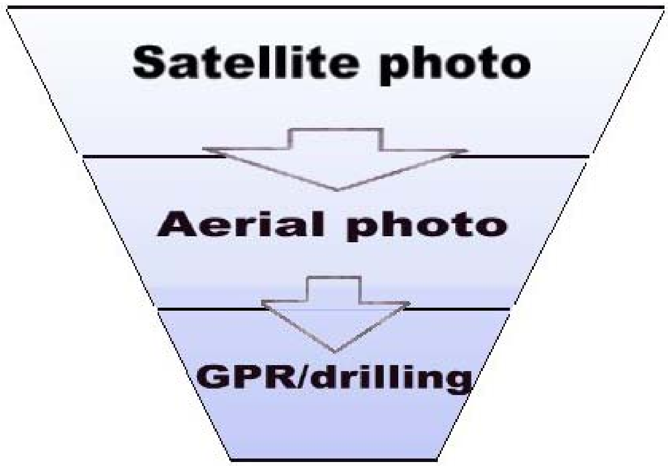

Fig 4. Suggested progress of permafrost investigation in areas with high ground ice content

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Effective thawing of frozen ground – performance testing of a new thawing method based on hydronic heat

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1 Background

1.1 Applicability in cold regions

In regions with seasonally frozen ground conditions it is challenging to establish infrastructure and perform maintenance work during the coldest months of the year. Placing foundations or gaining access to buried pipe-lines for maintenance work inevitably calls for effective methods for thawing of the frozen top layer.

Access to improved 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 work-force 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 (Esch, 2004) published by the American Society of Civil Engineers (ASCE), 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 mentioned.

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.

Figure 1. Hydronic-based defrosting system mounted on a trailer for in-situ thawing operations. After initial programming and start-up, the system is left on the site until the desired thaw depth is reached.

3 Performance testing

3.1 Introduction

The hydronic method was introduced in USA and Canada back in 1996 (Construction Equipment, 1996), and has since then gradually taken over as the preferred method for thawing of frozen ground also in Northern Europe. In spite of this, there seems to have been made small or no efforts to investigate the method in the same thorough manner as the traditional thawing techniques.

As a response to this the Cold Climate Technology Research Centre (CCTRC) in Narvik has established a Frost in Ground laboratory (FiG-lab) for full scale performance testing and documentation of the hydronic method.

The FiG-lab is the base for the empirical part of an ongoing PhD project at NUC regarding artificial thawing of seasonally frozen ground.

The Fig-lab consists of six square bins filled with different types of homogenous soil to a depth of 2.55 m. In addition there is a measurement central for data collection. The thermal response at different depths during thawing is detected by a vertical temperature string mounted at the centre of each bin down to 2.55 m depth.

3.2 Experimental set-up

The first performance tests at FiG-lab were made in March 2007, using the defrosting system developed by Norwegian based Heatwork AS.

Two similar tests were made, simultaneously thawing three different types of homogenous soil (bins) each time. The three types of soil were (a) silty sand, (b) well graded sand and (c) clean gravel, grain size distribution curves (GSD's) ranging from predominantly fine to coarse soil.

The thermal response was detected by measuring ground temperatures at the centre of each bin, 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 (18 thermocouples in total per bin). Air temperature, relative humidity and wind speed prior to and during the tests were monitored by a weather station at the site.

4 Preliminary results

4.1 Initial set-up

The first test was conducted by the aid of the standard Heatwork defrosting system, with the hoses laid out with 10 cm horizontal distance, covering a ground surface area of 4.5 x 4.5 m of each bin. The ground surface was free of excess snow and ice cover at the beginning of the test.

4.2 Thaw rates

Figure 2 shows the thaw depth vs. time down to 100 cm for the various types of soil. Thaw depths after the first 24 hours of artificial thawing are approximately 38 cm for gravel, 33 cm for well graded sand and 25 cm for silty sand.

The graphs are logarithmic in the beginning, gradually becoming linear as the thawing process continues.

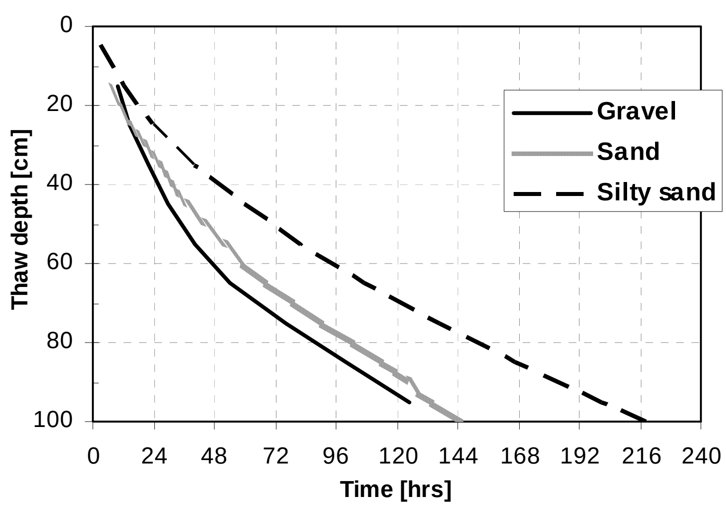

Figure 2. Thaw depth (in cm) as a function of time.

The shape of the curves suggests a higher thaw rate close to the surface (heat source), as shown in Figure 3.

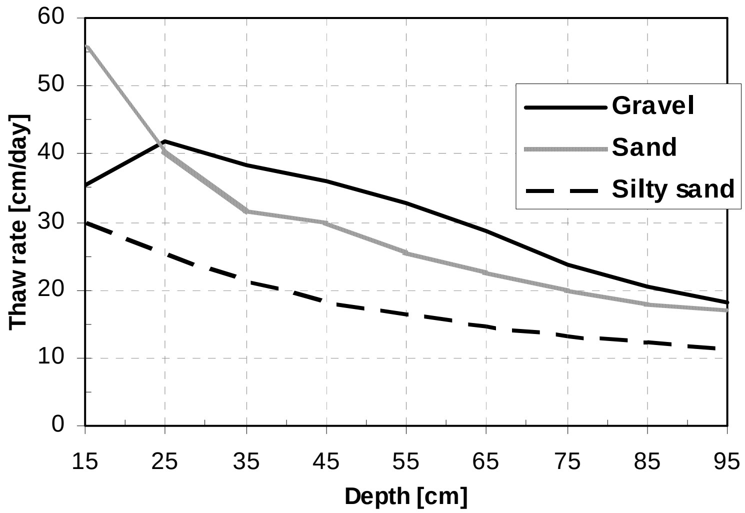

Figure 3. Thaw rate (in cm/day) as a function of thaw depth.

Figure 3 shows that in general the thaw efficiencies are decreasing with depth. The exception is early in the thawing process (at shallow depths) for uniform gravel, which has a high void ratio and low initial ice content.

5 Conclusions and further work

The initial performance tests from 2007 have provided some general impressions regarding the efficiency of the hydronic thawing method utilized on various types of homogenous soil. They also were very useful for testing the functionality of the FiG-lab, the measurement systems and sensors used, as well as the applied method for gathering experimental data.

However, all assessments are based solely on one parameter, i.e. ground temperature, and a very limited amount of experiments. There is also a need to know more of the hydrodynamics taking place during artificial thawing, such as variations in frozen/unfrozen water content and phase changes. Furthermore, more emphasis on air-/ground temperature records, precipitation etc prior to testing is needed.

A part of the ongoing PhD work is therefore allocated to re-establishing the FiG-lab at a new location during autumn 2010, at the same time implementing new functionality in order to ensure more versatile scientific experiments on frozen ground in the near future.

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Permafrost research in Norway and Svalbard, a brief outline

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1 Permafrost research

1.1 Svalbard

Permafrost in Svalbard has recognized since the first International Polar Year in 1882 and the first coal mining operations in 1898. Ekholm (1890) measured ground temperatures at Kap Thordsen in 1883, and demonstrated temperature variations to a depth of 2 m. Holmsen (1913) studied ground ice in Colesdalen, central Spitsbergen. From this a late Holocene age of low-altitude permafrost in Svalbard was suggested by observations on ground ice below the upper marine limit.

Nansen (1920) resented some of the first published information about permafrost i Svalbard, based on observations made during a scientific expedition in 1912. The term permafrost was, however, not used by Nansen in this early description. The background was the new coal mining activity, which opened near the present settlement Longyearbyen a few years before. Nansen (1920) makes the observation, that high temperatures in deep mines often represent a difficulty for efficient mining activities. This is, however, not a problem in Spitsbergen, as the ground temperature remains below freezing to great depths. Nansen assumes that the ground temperature increases about 1^{o}C per 30 m depth, and using a surface temperature of about -9.8^{o}C (Green Harbor), he calculates the 0^{o}C isotherm to be located at about 400 m depth. Nansen (1920) also states that problems with leakage of water are not to be expected in the Spitsbergen coal mines. In the zone with freezing temperatures this is unlikely, as water will remain frozen. At greater depths, where the temperature is above freezing, the uppermost frozen layer acts as a watertight membrane. Only below sea level, the influence of the oceans was expected to elevate ground temperatures to above freezing conditions, and problems with water encountered.

In 1922 the first review of frozen ground phenomena in Spitsbergen was 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.

Liestøl (1976) was the first to systematically consider the thickness and thermal conditions of Svalbard permafrost. This classic paper describes the distribution of pingos, springs and permafrost in Spitsbergen. From observations made during mining operations, he was able to estimate the magnitude of the geothermal gradient, being about 2-2.5°C/100 m in central Spitsbergen. Péwé (1979) and Péwé et al. (1981) also discussed Svalbard permafrost in relation to climate and ongoing mining operations.

In the following years, most studies relating to permafrost in Svalbard had a geomorphological focus. Among other themes, the glacier-permafrost relation and its consequences for glacial sedimentology, hydrology and geomorphic activity, has been investigated by a number of different authors, e.g. Ødegård et al. (1992) and Etzelmüller et al. (1996).

However, a major change in permafrost related research in Svalbard was introduced by the recognition of the vertical temperature profile of thick permafrost representing an important means of obtaining information on past surface temperatures. This became the object of a joint European research initiative, PACE, that established a number of permafrost monitoring sites in a north-south European transect (Sollid et al. 2000). The northernmost site is located on Janssonhaugen in upper Adventdalen, central Spitsbergen. The temperature profile from the more than 100 m deep borehole clearly demonstrates the effect of the 20th century warming on permafrost temperatures (Isaksen et al. 2001).

The latest important development in permafrost research in Svalbard was the launch of the IPY TSP-Norway project 2007-2009. The main objective of was to measure and model the permafrost distribution in Svalbard (and northern Norway), including its thermal state, thickness and influence on periglacial landscape-forming processes. Several new permafrost boreholes to 20-30 m depth were established in Svalbard by the project, and the main findings on modern permafrost thermal conditions in Svalbard an Norway have recently been described by Christiansen et al. (2010).

1.2 Norway

In mainland Norway permafrost research began relatively late, even though the Scandinavian mountains represent one of Europe's largest highland areas, extending beyond the polar circle. 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 1986, where King (1986) demonstrated the wider potential of geophysical methods in a Norwegian permafrost-periglacial context. The successful introduction of this 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. In addition, a first overview of permafrost distribution in Norway was presented by Etzelmüller et al. (2003). Latest, several new shallow permafrost boreholes were established during the 2007-09 IPY period, by the TSP-Norway and the CRYOLINK research projects.

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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

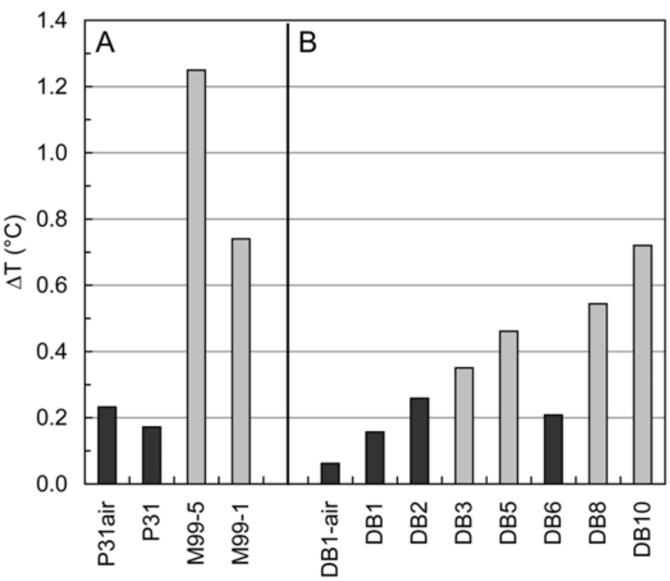
Long-term ground thermal data are derived from a 129 m deep borehole in Jotunheimen (61°40'N, 8°25'E), established within the PACE-project (Permafrost and Climate in Europe) and 11 shallow (9 m deep) boreholes on Dovrefjell (62°20'N, 9°20'E), along a transect from deep seasonal frost to discontinuous 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 and model calibration.

Time-lapse inversion of repeated electrical resistivity tomography (ERT) between summer 1999 and 2009-2010 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.

3 Results

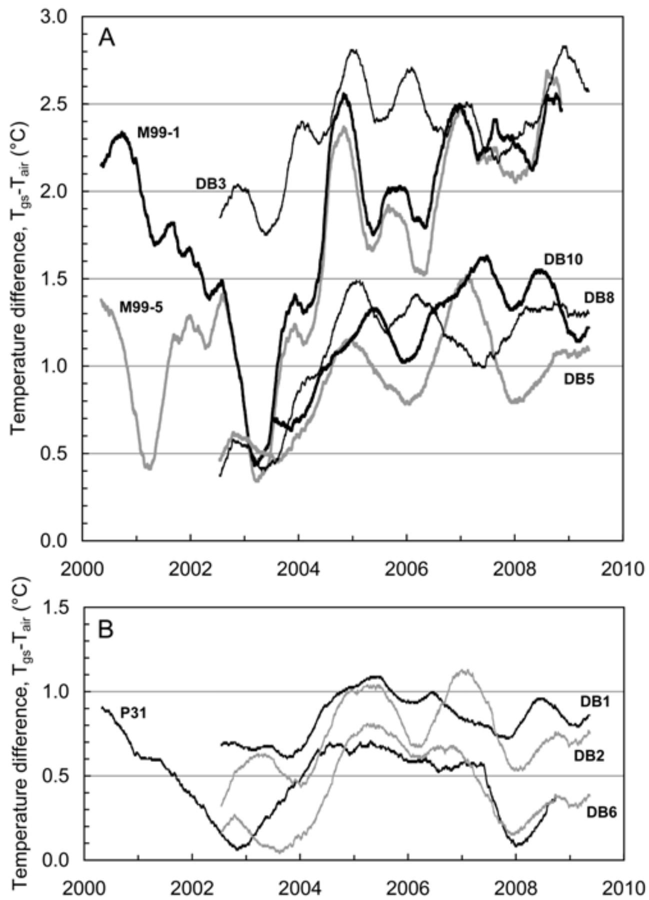
Data from the PACE-borehole show a significant warm-side deviation in the ground thermal profile to 70 m depth, associated with surface warming of ~1.0 ºC during 1970-2000. Observations since 1999 indicate that present decadal warming rates at the permafrost surface are 0.04-0.05 ºC/yr (Isaksen et al.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



Temperature differences of MGST between the 4-year periods 2009-2006 and 2003-2000 for three sites in Jotunheimen (A) and between 2009-2006 and 2004-2001 for the Dovrefjell sites (B). Dark bars indicate sites having thin or absent snow cover during winter - grey bars indicate sites having more developed snow cover

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.



Temperature differences between annual MGST and MAT during the observation period for sites with a late winter snow cover thicker than 0.2-0.8 m (A) and sites having a thin or absent snow cover during winter (B), cf. Figure 6. Note the differences between M99-1 and M99-5 in 2000-2001 (cf. Figure 11).

4 Conclusions

The presented results document warming between 1999 and 2009 in different types of settings in two mountain massifs in southern Norway; at sites having cold- and marginal permafrost and deep seasonal frost (Isaksen et al. 2011). The combined findings from direct temperature measurements and repeated electrical resistivity tomography (ERT) presented here suggest clear signs of permafrost degradation. The main findings are:

For most of the sites there is a clear increase in mean ground temperature (MGT) at 6-9 m depth, ranging from ~0.015 to ~0.095 °C a^{-1}. The greatest increases in MGT are found at sites with ground temperatures slightly above 0 °C where permafrost seems to recently have degraded. The lowest MGT increase is found at sites in marginal permafrost, where MGT are within a few tenths of a degree of 0 °C and are strongly modulated by latent heat exchange.

Analyses of observed changes (ΔT) in mean ground surface temperature (MGST) suggest the highest ΔT for the lower lying sites located in marginal permafrost and deep seasonal frost with a snow cover of 0.2-0.8 m in late winter. Here, increased snow depths seem to be the most important factor for the observed ΔT, followed by an increase in winter air temperatures. For the higher elevations exposed to strong winds, where permafrost is widespread, increase in winter air temperature is the most important controlling factor.

The repeated ERT profiles show substantial increase in the resistivity of the upper surface layers, and a decrease below 5-10 m depth, indicating a degraded permafrost layer which was still present in 1999. The overall resistivity increase in the near-surface layer is interpreted to indicate drier conditions due to the fast drainage of infiltrating water through the hydraulically conductive morainic material, compared to moister conditions during ongoing permafrost degradation in 1999. No resistivity changes are observed at greater depth in the uppermost high resistive part of the profile, which points to unchanged conditions during the past 10 years and may indicate that permafrost is still present there.

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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 (cf. Hipp et al. 2010).

Here we present the first two years of air and ground temperatures from the sites. A more detailed discussion of the the influence of air temperature and ground surface characteristics (snow conditions, sediments/bedrock, vegetation) on ground temperatures in the field areas can be found elsewhere (Farbrot et al. Submitted).

2 Setting

The borehole areas (Juvvass, Jetta and Tron) are situated along a west-east transect (Fig. 1) 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 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 new borehole at Juvvass (Juv-BH1, 1861 m a.s.l.) is situated close to the Juvvasshøe PACE borehole (1894 m a.s.l.) where air and ground temperature measurements exist since 1999 (Isaksen et al. 2001).

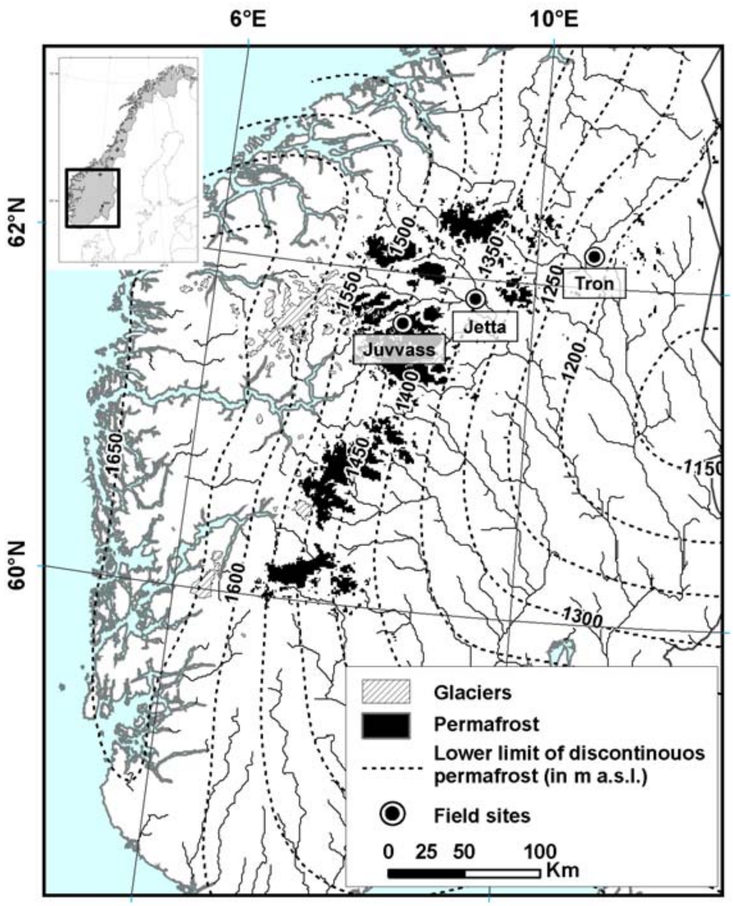

Figure 1. Overview map of borehole areas in Southern Norway (dots) with distribution and regional lower limits of mountain permafrost (cf. Etzelmüller et al. 2003) based on the assumed -3°C isotherm.

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; TSF: Thickness of Seasonal Frost; 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	12.4	~2.2
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	-	> 8*
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

* Observed October/November 2009

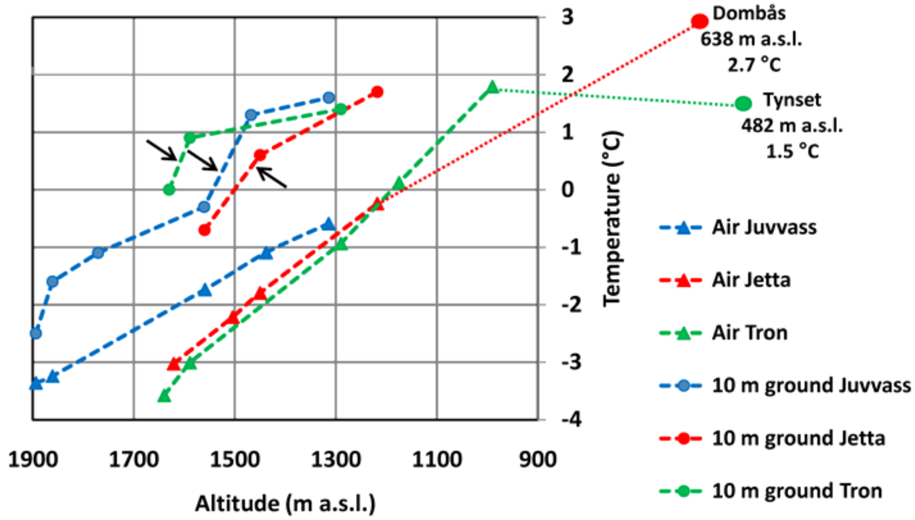

Figure 2. Altitudinal lapse rate of mean air and ground temperatures at 10 m depth (MAT and MGT, respectively) for the different areas (01.09.2008-31.08.2009). The MGT gradients show a marked jump when passing 0 °C (see arrows). This pattern may reflect degradation of mountain permafrost and a non-linear response to changes of the boundary conditions (see Farbrot et al. Submitted)

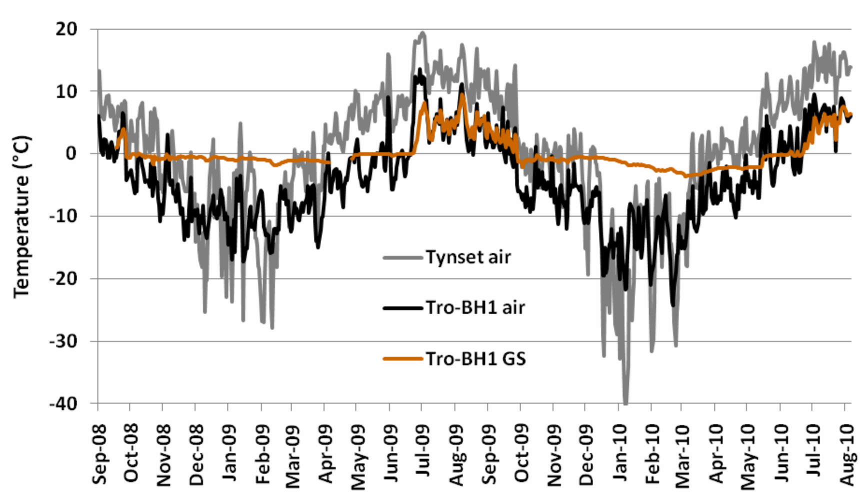

Figure 3. Daily air and ground surface temperatures at Tron BH1 (1640 m a.s.l.) for the period 2008-2010 compared to air temperatures from the low elevation weather station at Tynset – Hansmoen (482 m a.s.l.), 10 km to the north. Note the long periods of air temperature inversions during winter. The ground surface temperatures at Tron BH1 are decoupled from the air temperatures during winter due to the insulating effect of the snow cover.

3 Results

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, Fig. 2). This pattern is mainly governed by climatic conditions and differences in local 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. At most borehole sites the frost penetration of the winter 2009-2010 was greater than the previous one due to lower air temperatures and less snow.

Especially at the easternmost site, Tron, there are heavy air temperature inversions during winter (Fig. 3). Above the tree line, however, the mean altitudinal lapse rate of air temperature (ALRT) is fairly stable with altitude, but differs from –0.005 °Cm^{-1} at Juvvass to –0.008 °Cm^{-1} at Tron (Fig. 2).

4 Discussion and conclusion

The increase in ALRT with continentality for high mountain areas in southern Norway has also been reported elsewhere. This pattern presumably reflects the drier air in the east (dry adiabatic lapse rate ~–0.01 °Cm^{-1}, whereas moist adiabatic lapse rate is around –0.005 °Cm^{-1}). Hence, the ALRT pattern observed is considered fairly representative for its elevation span although only two years of data is available. Our measurements indicate that MATs at a certain elevation range (1200-1400 m a.s.l.) are fairly equal in southern Norway. This challenge the existing assumption that the decrease in lower limit of mountain permafrost regionally going eastwards is due to the lowering mean annual air temperatures (MAAT) for a given altitide. The MAAT maps these studies are based upon, however, are mainly generated from lower situated weather stations, thereby increasing the uncertainty of the ALRT used. Although a lower limit of mountain permafrost has been indicated in eastern (transition zone at 900-1100 m a.s.l.) than in western parts of southern Norway (transition zone at 1300-1550 m a.s.l.) other effects such as surface material and snow cover evolution may have a greater importance.

The lower limit of block fields, which are known to represent a pronounced negative thermal anomaly, decreases from 1600 m a.s.l. in Jotunheimen to ~1000 m a.s.l. towards the Swedish border in the east. Further, the snow distribution within the transition zone of mountain permafrost is a primary controlling factor for permafrost occurrence in Norway. Regionally, however, the snow thicknesses decrease with continentality. Hence, we suggest that the decrease in the regional lower limit of mountain permafrost towards east in southern Norway mainly is driven by snow conditions and ground surface material, rather than by MAAT, solely.

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Modeling the thermal regime of mountain permafrost in Southern Norway with respect to a changing climate

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1 Introduction and study sites

In this study a one-dimensional transient heat flow model was applied to model the thermal regime of mountain permafrost in Southern Norway. Besides a model validation, first results on the modeled permafrost evolution in this area from 1860 until today and further until 2100 using climate change scenarios are presented.

In the framework of the CRYOLINK project a monitoring network consisting of 13 boreholes, miniature temperature loggers (MTD), air temperature loggers and snow height stations has been installed in 2008 to monitor permafrost and seasonal freezing. This allows the detailed analysis of the heat transfer between atmosphere and ground at different climatological, altitudinal and geomorphological settings.

The boreholes at Juvvass range from 1771 m a.s.l. to 1200 m, where 5 of the 7 boreholes are showing permafrost. At Tronfjell 3 boreholes range from 1640 m a.s.l. to 1300 m a.s.l., where only the uppermost shows permafrost (Figure 1).

2 Method

2.1 1-D Model

A one-dimensional finite differences transient heat flow model solving the heat flux equation was used to simulate ground temperatures in this study.

The ground stratigraphy is implemented in the model by specifying the most important ground thermal parameters being specific heat capacity *C*, thermal conductivity *k*, density and volumetric water content (*VWC*). The mean daily air temperature (MDAT) was used as upper boundary condition and thus is the driving parameter of the model. N_f- and N_t-factors, derived from measured ground surface temperature (GST) and air temperature (T_{air}) were used to parameterize the effect of snow cover and vegetation. The geothermal heat flux as lower boundary condition at a depth of 150 m allows to model the effect a changing climate on ground temperatures (GT) at lower depths.

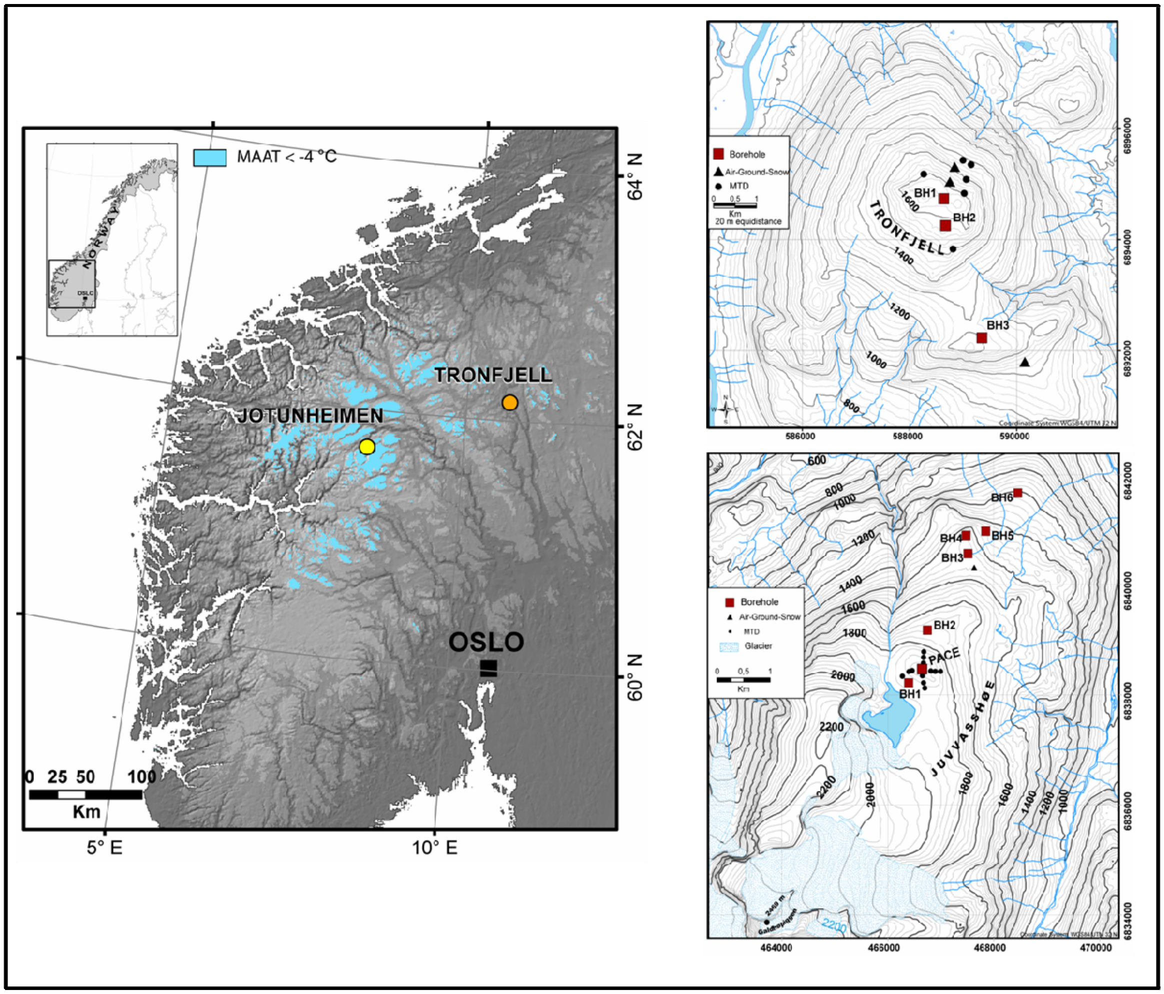

Figure 1. Study sites and boreholes of the CRYOLINK project

2.2 Input Data

For calibration and validation measured GTs, T_{air}, GST and snow height (SH) was available from the period September 2008 – August 2009.

Applying a method proposed by the Norwegian Meteorological Institute (Hanssen-Bauer, 2005) a long time series of mean monthly air temperatures from 1860 until 2010 could be created for each individual borehole location (Figure 2).This data set was used to model former permafrost conditions from 1860 until today.

For the climate change modeling studies an ensemble of 20 different climate change models was available, all assuming the moderate A1B climate change scenario. The models were statistically downscaled to the close by Fokstugu Weather Station and correlated to each borehole individually ($r^2 > 0.9$).

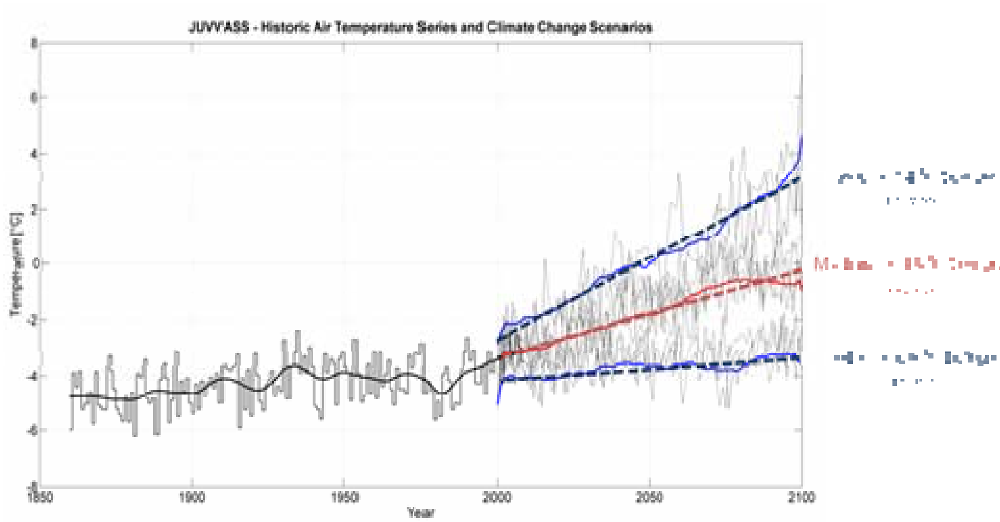

Figure 2. Historical air temperature time series and climate change scenarios at the uppermost borehole (BH1) at JuvvassBH1

2.3 Initial conditions

Steady-state conditions were generated by running the model with the mean air temperature of the 1860s (MAT_{1860}) for about 800 model years. A characteristic seasonal cycle of T_{AIR} was generated by fitting a 2nd degree Fourier fit on the measured MDAT values. Forcing the model with the parameterized temperature curve with MAT_{1860} created the initial thermal conditions including a typical seasonal cycle and active layer development.

3 Calibration And Validation

After calibration, the model accuracy was assessed by comparing measured and modeled GTs from the period Sept. 2009 – August 2010 (Figure 3). Measured and modeled GT values show a good correlation of $r^2 > 0.83$ at Juvvass and $r^2 > 0.77$ at Tron. The root mean squared error (RMSE) was calculated for each ground depth individually, ranging from ~1.5 °C at the ground surface to less than 0.1 °C at a depth of 10 m. The mean RMSE for the whole soil column throughout the validation period shows values < 1 °C (Table 1).

Table 1 Validation of modeled ground temperatures

SITE/BH	r^2	RMSE	ALT	
			Measured	Modeled
Juvvass				
BH1	0.83	0.54	1.41	1.39
BH3	0.91	0.52	8.3	7.05
BH5	0.92	0.27	--	--
BH6	0.91	0.52	--	--
Tron				
BH1	0.77	0.23	10.7	11.8
BH2	0.92	0.48	--	--
BH3	0.92	0.37	--	--

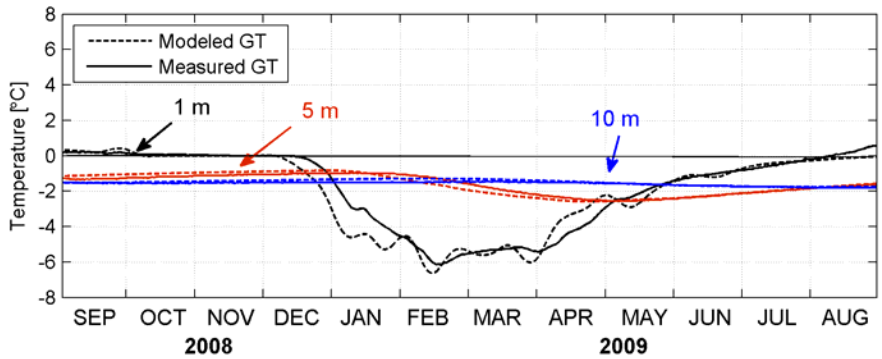

Figure 3. Modeled (solid line) and measured (dashed line) GTs at 1 m, 5 m and 10 m depth

4 Results

4.1 Past Permafrost Development

A warming of 1.2 and 1.5 °C in T_{air} occurred from 1860 until 2009 at Juvvass and Tron respectively (Figure 2). At all depth a significant warming was modeled with a strong increase during the last decade. At Juvvass the uppermost borehole (BH1) shows a warming of +1.1 °C and +0.5 °C at depths of 30 m and 100 m respectively. A much stronger warming rate shows the borehole BH4 in bedrock with +1.6 °C and +1.0 °C at the same depths.

This warming seems to have different impacts on the active layer of the boreholes on Juvvass depending on stratigraphy and altitude. While BH6 at low altitude shows a very rapid ALT increase and permafrost degradation by the end of the 19^{th} century, the upper boreholes show a steady increase of ALT at different rates. BH1 and BH3 increased their ALT by about +0.7 and +0.6 m respectively, while the strongest ALT changes seem to happen during the last decade only. Although being on the same altitude as BH3, BH4 shows an increase of +1.3 m.

4.2 Future Permafrost Development

The median of the climate change model ensemble predicts a further warming of +3.5 °C until the end of this century (Q90: +7.4 °C; Q10: +0.9 °C) (Figure 2).

GTs show a stronger warming trend than in the historical analysis. Until 2100 temperatures at BH1 increase by +1.9 °C and +1.1 °C at 30 m and 100 m depth respectively. At the same depths, BH4 shows the same warming rate at 100m depth, however, a much more pronounced increase in GT at 30m with +2.6 °C.

Although the model is forced by a purely linear warming trend a variable and non-linear response in ALT and GTs was modeled. The ALT of BH1 increases linearly by about +0.8 m until 2080, thereafter, however, a rapid degradation of permafrost takes place until the end of this century. A similar warming pattern can be seen at BH3, however with higher ALT deepening rates and an earlier degradation of permafrost (Figure 4).

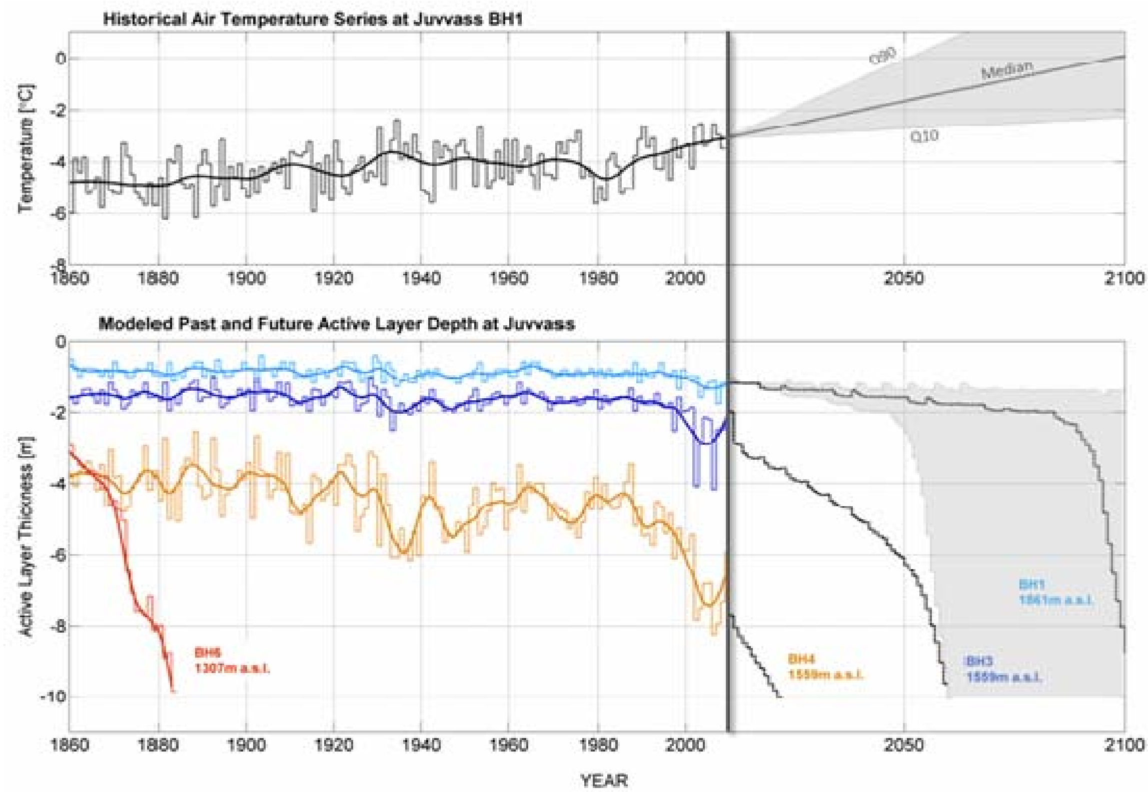

Figure 4. Modeled ALT for different boreholes at Juvvass from 1860 until 2100

5 Discussion

Not only the effect of altitude, but also the effect of different surface cover and borehole stratigraphy can be observed in the model results on the ALT development. BH4, which is drilled in bedrock, shows a direct and undampened response of the ALT to TAIR resulting in a stronger interannual variability. This explains its faster and earlier warming than e.g. BH3 at same elevation, where warming mainly starts during the last century.

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A regional inventory of glacial and periglacial landforms indicating alpine permafrost in Norway

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1 Introduction

1.1 Scope

An inventory of permafrost-related landforms in Norway have been compiled using pre-existing maps, aerial photos and field observations. Such a systematic inventory did not previously exist for Norway, and is needed as an independent validation of numerical permafrost distribution models. In addition, the inventory provides necessary input for understanding Holocene landscape development. As a first approach, the inventory has been used to examine possible relationships between landforms, climate and topography.

1.2 Methods

The mapped 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 by shape (lobate or tongue-shaped) and landform origin. For the origin of the permafrost landforms, *ice-cored moraines*, *talus rock glaciers*, and *transitional landforms* were identified, where the latter denotes landforms that have a glacial origin, following the terms 'glacier-derived rock glaciers' by Humlum (1982) or 'debris rock glaciers' by Barsch (1996). Statistical *t*-tests were applied to examine for any class-dependent trends in parameters such as surface area, mean annual air temperature (MAAT), elevation and aspect. MAAT over the landform surface was calculated by downscaling gridded MAAT values (© met.no, 1 km resolution) using a digital elevation model (DEM) (© Norwegian Mapping Authority, 25 m resolution).

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, and are mainly fossil features.

All together, there are only a few active talus rock glaciers in Norway today, while the transitional landforms show a higher degree of activity. Also, nearly all the landforms in southern Norway are situated inside the traditional interpretation of the Younger Dryas

(YD) glaciation limit, while the landforms in northern Norway are mainly situated outside the YD limit, but inside the limit of the assumed Weichselian maximum. This difference could reflect two different formation periods for the permafrost landforms in southern and northern Norway, with an earlier onset in the north. Also, in northern Norway the fossil permafrost landforms are situated all the way down to sea level, opposed to the situation in south where the lowest mapped landform are situated at 1000 m a.s.l. This situation probably reflects the earlier deglaciation of northern Norway.

The concentration of fossil talus landforms in northern Norway, mainly situated at low elevations, can be interpreted to reflect a former dry, periglacial climate that favored their formation, while few areas today are favorable for the development of these landforms. The transitional landforms and ice-cored moraines then reflect a more modern climate where glaciers and permafrost co-exist, and the lower permafrost limit has shifted to higher elevations. At some point during the Holocene, the dominating process creating permafrost landforms have changed. An alternative interpretation of this situation would be that the sediment supply immediately following the deglaciation were higher than in any other time period during the Holocene, favouring the early growth of talus landforms and the later stagnation.

2.2 Aspects, temperatures and permafrost limits

The active landforms in southern Norway are to a much higher degree dependent on aspect 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 average MAAT of the active landforms for southern and northern Norway are -4.4 and -1.3 °C, respectively, and the fossil -1.3 and 1.5 °C, respectively.

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, and corresponding values for northern Norway are 650 and 350 m a.s.l., respectively. These results correspond well to previous studies. Active landforms do, however, exist below the assumed regional permafrost limit (figure 1), reflecting the importance of local topography, debris supply and insolation for permafrost landform development.

3 Conclusions

Permafrost-related landforms in southern Norway are mainly ice-cored moraines and transitional, 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.

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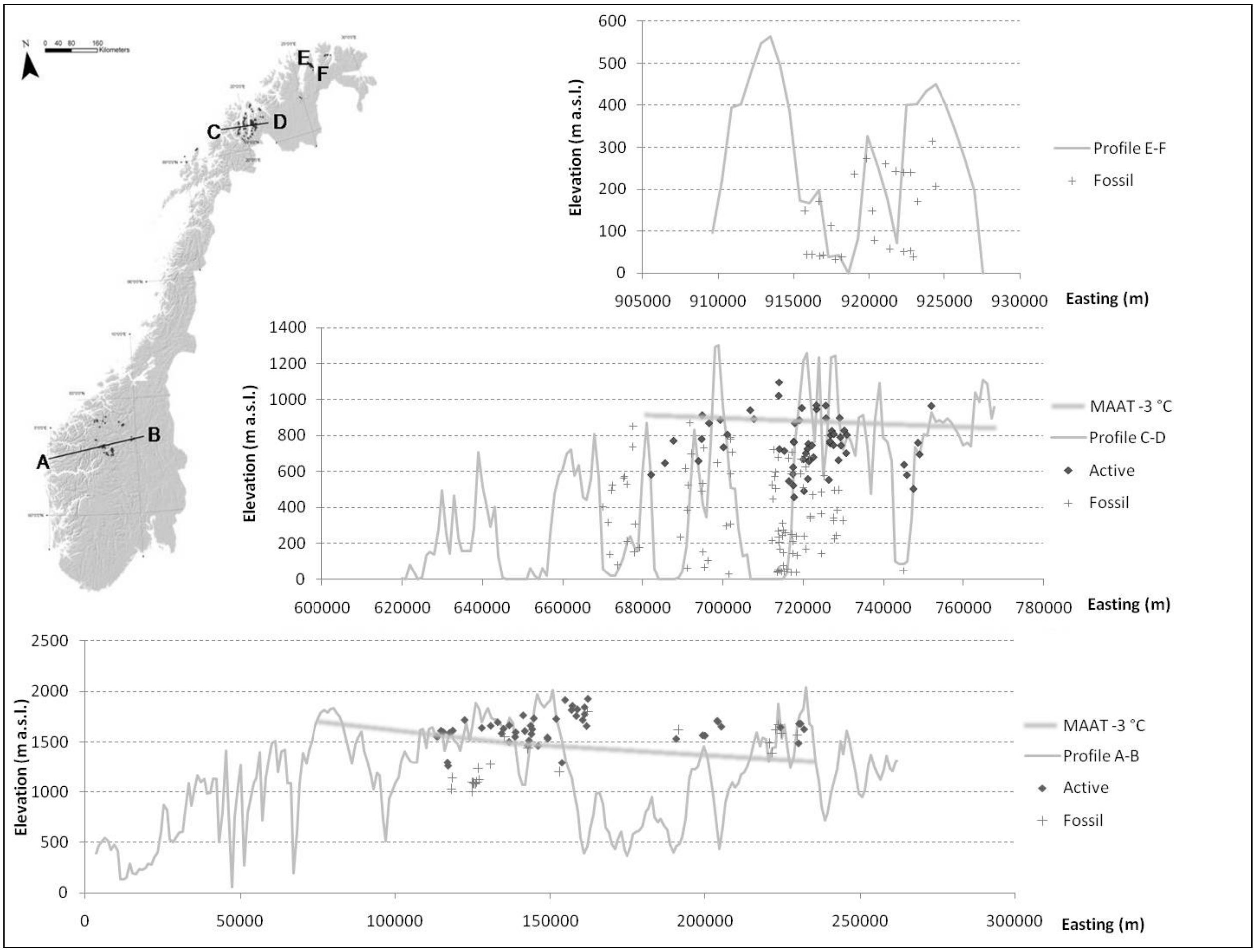

Figure 1. Three profiles through areas where permafrost landforms are present. Modelled MAAT limit of -3 °C are drawn. Note that active landforms exist well below this approximate regional permafrost limit, especially in profile C-D.

Permafrost influence on the active Nordnes rockslide

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Introduction

The Nordnes rockslide complex in northern Norway is located in arctic and periglacial conditions, and may pose serious consequences to inhabited areas due to its potential of generating disastrous tsunamis (Blikra et al., 2009). A monitoring program was initiated in 2007.

The 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 (Figure 1). Displacement measurements indicate that a volume of 8 to 22 million m^3 of rock are moving up to 5 cm/year (Figure 2). 2D resistivity measurements and seismic refraction data indicate that the depth of the instability can be more than 100 m (Rønning et al., 2008). 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 displacement data from the monitoring program and the instrumentation for studying the thermal regime allows evaluation of the relationships between deformation in the slopes and possible meteorological controlling factors.

Figure 1. One of the major fractures at the Nordnes rockslide, experiencing active movements.

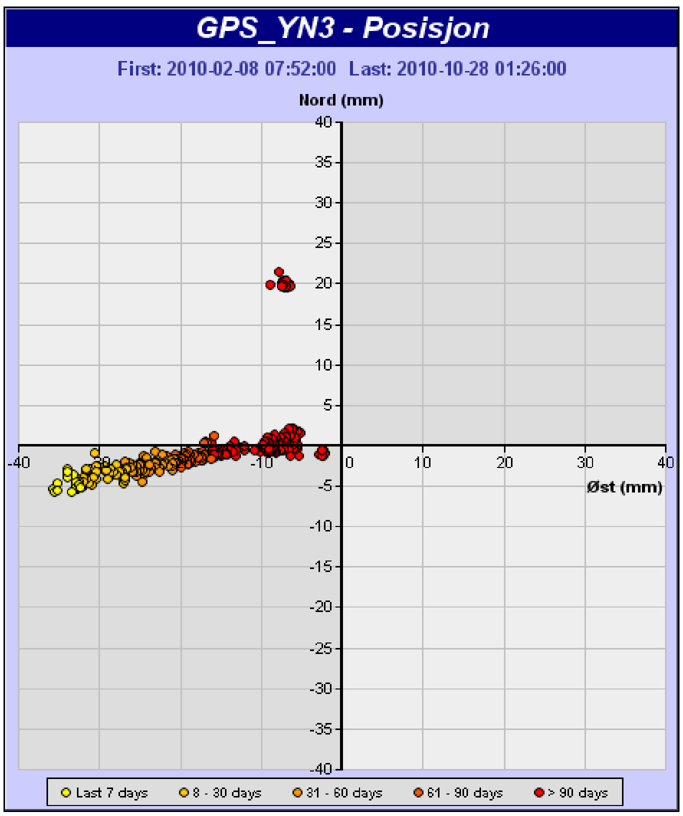

Figure 2. Horizontal movement of one GPS station. From 8th of February (red dots) to 28th of October 2010 (yellow dots).

1 Instrumentation

The present intermunicipality monitoring program includes a comprehensive sensor network in order to follow the displacements in different sectors of the rockslide. A differential GPS network of total 11 antennas is located in the entire unstable area. The monitoring system includes additional 3 lasers, 11 crackmeters, 3 large extensometers, 11 tiltmeters and a meteorological station in the upper part.

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 (Christiansen et al., 2010).

2 Temperature regime

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 deep into the fractures stress this interpretation.

3 Displacement pattern

The displacement data from continuous lasers and crackmeters from 2007-2010 show the following characteristic temporal pattern (Figure 3), see also Nordvik et al., 2010):

1. Displacement from late summer (August- September) until early winter (January-March.
2. Stable conditions from early winter until late summer.

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.

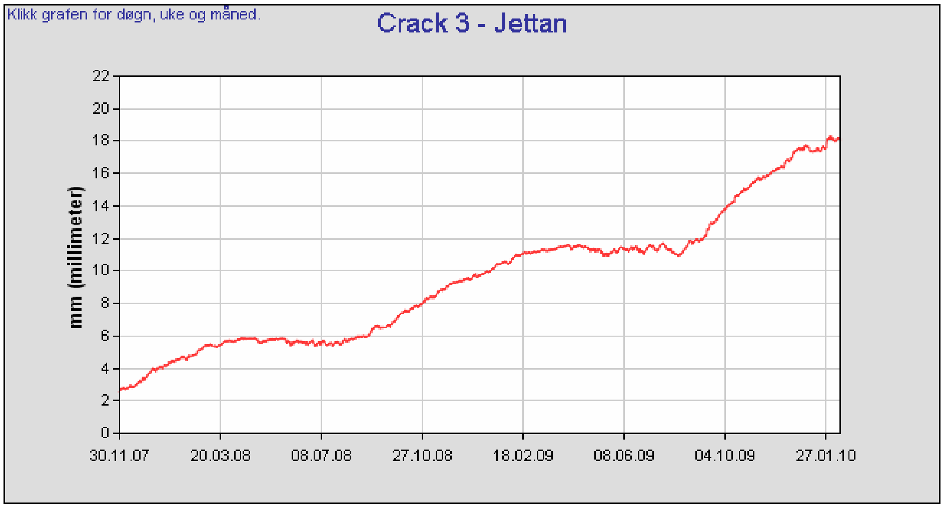

Figure 3. Displacement measured by a crackmeter across one of the main fractures at Nordnes

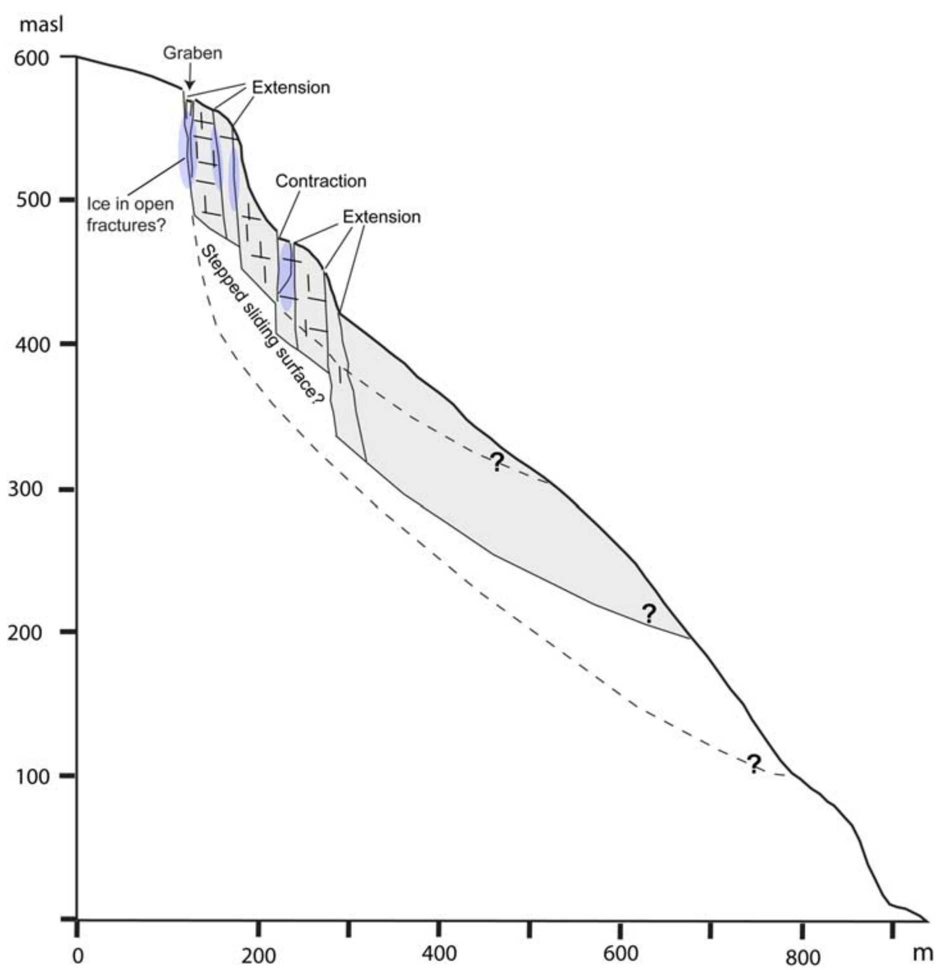

Figure. 4. A schematic profile of the Nordnes rockslide, showing the possible geometry and occurrence of ice in fractures (from Nordvik et al., 2010).

4 Permafrost occurrence and implications

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 (Figure 4). The deformation of the Nordnes rockslide 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.

The new understanding of the existence of permafrost and the influence of deformation and movement of unstable rockslopes has implications for the general handling and evaluation of other unstable areas in regions of permafrost. Permafrost and its related deformation effect may lead to displacement of large portions of rock in areas were the probability of catastrophic failure is low. Hazard evaluation focused to a large degree on displacement characteristics should thus be used with care in these regions.

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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.

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 'Norgeibilder' internet sites (www.norgei3d.no and www.norgeibilder.no). This 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. Both lengths and heights are picked from the orthophotos.

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. Areas are selected according to picture quality and parameters such as geology, slope direction, altitude and surficial deposits.

3 Solifluction form and process

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≥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 disproportionally 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.

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.

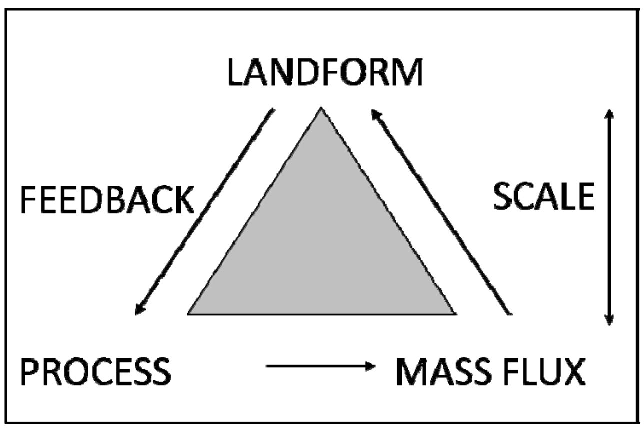

Figure 1 A generalized link between solifluction process and landform. The landform is shaped by the mass fluxes set up by the process. Feedback processes may be involved, since the landform will influence snow distribution, soil moisture, energy balance etc.

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

4 Preliminary results

We have chosen a test site at Tverrfjellet in Skjåk, Southern Norway. This site extends across the border between a surface cover of till and block fields, which also roughly coincides with the permafrost limit at about 1550-1600 m a.s.l. Here, a population of n=1000 solifluction lobes were measured for morphometric characteristics, using the measurement protocol of Fig. 2.

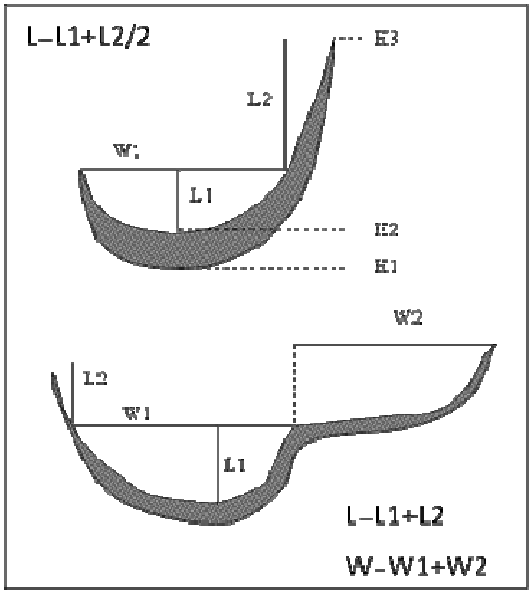

Figure 2 Protocol for morphometric measurements of solifluction landforms. Riser height is calculated from H2-H1, and slope is calculated based on (H3-H2) and (L1+L2). Area is measured directly from Norgeibilder. The protocol of Hugenholtz and Lewkowicz (2002) use L=L1 and W=W1, and calculate area as A=L·W/4

Not surprisingly, the new protocol reveals a larger distribution of solifluction morphometry than the one of Hugenholtz and Lewkowicz (2002). Turf-banked lobes are somewhat different from stone-banked lobes. The stone-banked ones are found at higher altitudes, and tend to have higher risers than turf-banked lobes. There is also a tendency for stone-banked lobes to be flatter compared to the parent slope, implying a tendency for rapid downslope accumulation and less mobile fronts.

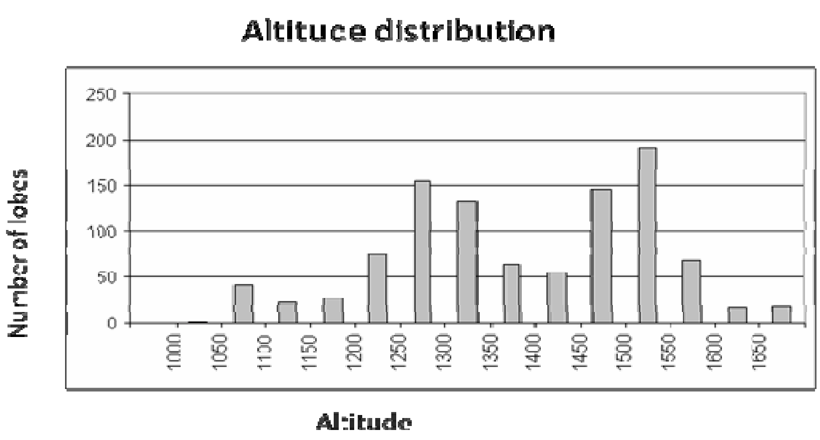

Figure 3 The altitude distribution of solifluction lobes on Tverrfjellet displays a bimodal distribution. This is caused by two populations of lobes: stone banked lobes at higher altitudes and turf-banked lobes in the lower areas.

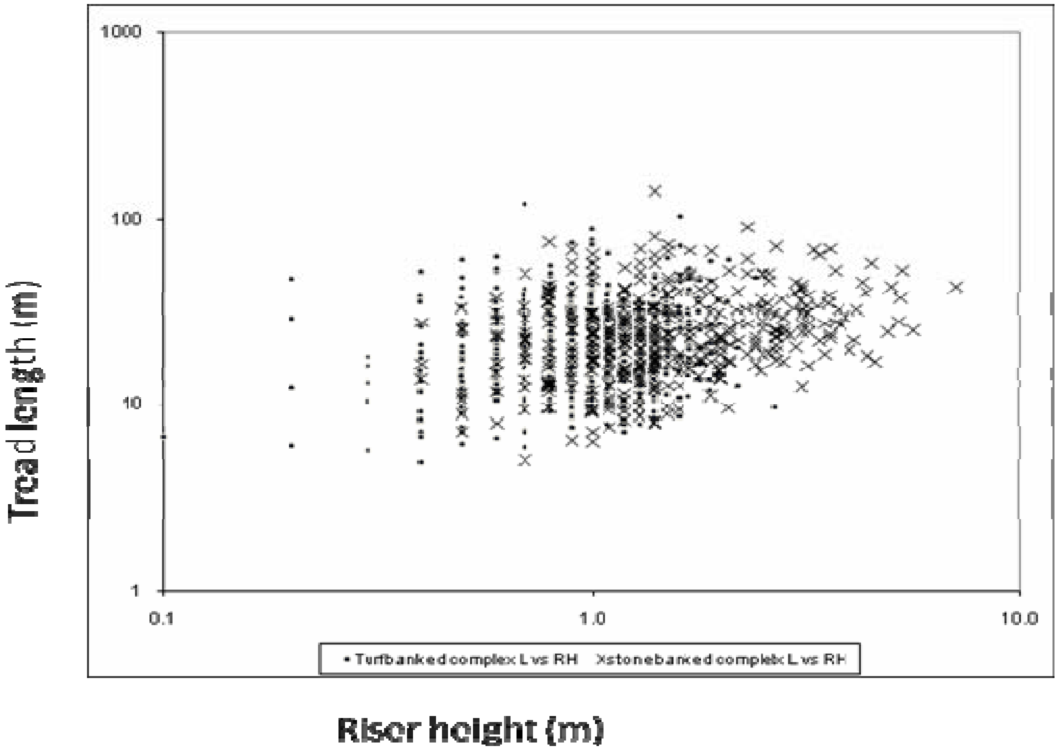

Figure 4 Riser height plotted against tread length (L). Stone banked lobes (crosses) tend to have higher risers than turf-banked lobes.

5 Further work

Morphometric measurements from several areas are currently being collected as part of a Master thesis (Høgaas in prep). The measurements will include the volume of solifluction landforms, with the aim of quantifying the average transport involved in the solifluction process through postglacial times.

6 References

Kielland, P. G. 2010. Kvartær landskapsutvikling i Tverrfjellet Nordøstlige Breheimen. Masteroppgave, Geografisk institutt, NTNU, 99 s.

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.

Appendices

(p. 67-76)

Vedlegg 1

Komité for Frost i Jord

Tilknyttet Norsk Geoteknisk Forening

Komitémedlemmer

Anne-Lise Berggren, Geofrost AS
Geir Berntsen, NCC Roads AS
Lars Grande, Norges teknisk-naturvitenskapelige universitet (NTNU)
Ivar Horvli, ViaNova Plan og Trafikk AS (leder av komitéen)
Gisle Håland, Statoil ASA
Arne Instanes, Instanes Polar AS
Ketil Isaksen, Meteorologisk Institutt
Øystein Myhre, Statens vegvesen Vegdirektoratet
Truls Mølmann, Barlindhaug AS
Anne Gunn Rike, Norges Geotekniske Institutt (NGI)
Even Øiseth, Rambøll Norge AS
Rune Ødegård, Høgskolen i Gjøvik (HiG)

Mandat

Søke å øke vår kunnskap om frostens art og utbredelse og dens effekt på geomorfologi og menneskelige aktiviteter. Bidra til miljømessig og teknisk gode løsninger for samfunnet og nødvendig infrastruktur i kalde strøk.

Tema: Vitenskap og teknologi i kalde strøk.
Klima
Geomorfologi
Sesongmessig frost

- Frostmengde og teledybder
- Telehiv og telekrefter
- Infrastruktur
  - Bygg
  - Konstruksjoner
  - Rørledninger
  - Vann og avløp
  - Veger
  - Jernbane
  - Trafikktunneler
  - Flyplasser

Permafrost

- Art og omfang
- Terrengstabilitet
- Infrastruktur
- Forurensing
- Avfallsbehandling

Grunnfrysing
Materialer

- Termiske egenskaper
- Styrke og deformasjon
- Permeabilitet
- Telefarlighet

Produkter

- Publikasjon om Frost i jord
- Foredrag og kurs
- Internasjonal kontakt

Forholdet til IPA

Komitéen vil fungere som "the Norwegian Adhering Body" i International Permafrost Association (IPA).

Appendix 1

Committee on Frost in Ground

Affiliated Norwegian Geotechnical Society

Committee members

Anne-Lise Berggren, Geofrost AS
Geir Berntsen, NCC Roads AS
Lars Grande, Norwegian University of Science and Technology (NTNU)
Ivar Horvli, ViaNova Plan og Trafikk AS (chair)
Gisle Håland, Statoil ASA
Arne Instanes, Instanes Polar AS
Ketil Isaksen, Norwegian Meteorological Institute
Øystein Myhre, Norwegian Public Roads Administration (NPRA)
Truls Mølmann, Barlindhaug AS
Anne Gunn Rike, Norwegian Geotechnical Institute (NGI)
Even Øiseth, Rambøll Norway AS
Rune Ødegård, Gjøvik College

Mandate

Increase our knowledge about frozen ground and its effect on geomorphology and human activities. Contribute to satisfactory solutions, technically and environmentally, for infrastructure and social development in cold regions.

Topics: Science and technology in cold regions.
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

Products

- Publication on Frost in Ground
- Lectures and short courses
- International contacts

International contact

The committee will act as "the Norwegian Adhering Body" of the International Permafrost Association (IPA).

Vedlegg 2 / *Appendix 2*

Publikasjoner fra Frost i Jord

Publications from Frost in Ground

Alle publikasjonene i serien er utsolgt, men kopier kan fremskaffes ved henvendelse til Statens vegvesen, Vegdirektoratet, Arkivet, Postboks 8142 Dep., 0033 Oslo. Alle artiklene har engelsk resymé.

All the publications in the series are out of print, but copies can be produced on demand. Please contact Norwegian Public Roads Administration, Directorate of Public Roads, P.O.Box 8142 Dep., NO-0033 Oslo, Norway. All papers are provided with English summary.

Nr. 1. – *Sv. Skaven-Haug:* Teleteknisk forskning – Historikk (Frost Research in Soils. Historical Review). *R. Sætersdal:* Utvalg for frost i jord. Virksomheten i årene 1968-70 (Committee on Frost Action in Soils. Activities in the Period 1968-70). *Ø. Johansen:* Varmeledningsevne av forskjellige vegbyggingsmaterialer. Del I. Varmeledningsevnens betydning i frostsammenheng (Thermal Conductivity of some Highway Construction Materials. Part I. The Role of the Thermal Conductivity in the Frost Problem).
Nov. 1970, 24 s.

Nr. 2. – Symposium: Frost I jord. Del I. Hurdal 23.-24. november 1970. Beregningsmetoder for frostens nedtrengning i jord – Meteorologi – Telemekanismen – Metoder for reduksjon av frostdybder – Måling av varmeparametre (Symposium: Frost Actions in Soils. Part I. Norway 23.-24. Nov. 1970 Meteorology – The Mechanism of Frost Heaving – Methods for Reduction of the Frost Depth andFrost Heaving – Me asuring of Heat Parameters).
Feb. 1971, 84 s.

Nr. 3. – Symposium: Frost i jord. Del 2. Hurdal 23.-24. november 1970. (Symposium: Frost Action in Soils. Part 2. Norway 23.-24. Nov. 1970). *Sv. Skaven-Haug:* Dimensjonering av frostfundamenter. Frysevarme og jordvarme (Design of Frost-Foundations). *R. Sætersdal:* Varmeisolasjonsmaterialer i vegoverbygningen (Insulation Materials in Road Construction). *Å. Knutson:* Frostsikre veger med bark. Orientering om pågående undersøkelser (Frost Protection of Highways by a Subbase of Bark).
Juli 1971, 48 s.

Nr. 4. – *H. Ruistuen:* Kostnader ved frostsikring av veger (Cost with Frost Protection of Roads). *Ø. Johansen:* Varmeledningsevne av forkjellige vegbyggingsmaterialer. Del II. Varmeledningsevne av grovkornige jordarter (Thermal Conductivity of some Highway Construction Materials. Part II. Thermal Conductivity of Sandy Soils). *T. Werner-Johannesen:* Varmebalansen i jordoverflaten og frostens nedtrengning i jorden (The Heat Balance of the Earth's Surface and the Penetration of Frost into the Soils).
Nov. 1971, 40 s.

Nr. 5. – *R. Gandahl:* Några svenska erfarenheter från användning av bark i väg (Bark as Road Building Material in Sweden). *Å. Knutson:* Termisk dimensjonering av barklag i veg (Thickness of Bark Layer in Frost Proof Roads). *G.S. Klem:* Bark i Norge. Tilgang på bark til vegbygging (Bark in Norway). *K. Solbraa:* Barkens bestandighet i veifundamenter. Feltobservasjoner (The Durability of Bark in Road Constructions. Field Observations).
Des. 1971, 36 s.

Nr. 6. – *R. Orama:* Värmeisolering på finska vägar och flygfält (Thermal Insulation in the Finnish Highways and Airports). *R.L. Berg:* The Use of Thermal Insulating Materials in Highway Construction in the United States. *K. Solbraa:* Barkens bestandighet i veifundamenter. Laboratorieforsøk (The Durability of Bark in Road Constructions. Laboratory Experiments).
April 1972, 32 s.

Nr. 7. – *Å. Knutson:* Dimensjonering av vegar med frostakkumulerende barklag (Design of Roads with a Frostaccumulating Bark Layer). *Ø. Johansen:* Beregningsmetode for varmeledningsevnen av mineralske jordarter. Del I. Teoretisk grunnlag (A Method of Calculation of Thermal Conductivity of Soils. Part I. General Theory). *P. Gundersen:* Frostsikring av vannledninger ved hjelp av elektriske varmekabler (Frost Protection of Water Pipes by Means of Electric Heating Cables). *O.M. Benestad:* Teledybdemåling (Frozen Earth Indication).
Okt. 1972, 40 s.

Nr. 8. – *S.D. Svendsen:* Moderne småhusfundamentering (New Ways of Small House Foundation). *L. Nordgård:* Teleproblemer ved småhuskjeller (Frost Problems in Basement Constructions). *B. Adamson:* Frostnedträngning och bjälklagsisolering vis kryprumsgrundläggning (Foundation with Crawl Spaces. Frost Penetration and Equivalent U-value of Floor Slab). *K. Kløve og J.V. Thue:* Plate på mark (Slab-on-Ground Foundation). *F. Færøyvik:* Gulv på grunnen – fra en praktisk synsvinkel (Slab Directly on Ground – From a Practical Point of View). *J.R. Herje:* Pilarer og peler i jord. Frostproblemer (Pilares and Piles in the Ground. Frost Problems). *P. Gundersen:* Frostisolering av rørgrøfter (Frost Insulation of Pipe Trenches). *J.V. Thue:* Vinterbygging (Winter-Construction).
Des. 1972, 68 s.

Nr. 9. – *P. Borg-Hansen:* Frostbeskyttelse av eksisterende veger med toppisoleringsmetoden (Frost Protection of Existing Roads by a Top Insulating Layer). *Per-Erling Frivik:* Termisk analyse av frost i jord. Elementer og prinsipper. Del 1 (Thermal Analysis of Frost in Soils. Elements and Principles. Part 1). *G. Refsdal:* The Use of Thermal Insulating Materials in Highway Engineering (Results from Norwegian Test Roads).
Mars 1973, 40 s.

Nr. 10. – *R. Gandahl:* Styrencellplast i väg (Road Construction with a Layer of Polystyrene Foam). *Ø. Johansen:* Beregningsmetode for varmeledningsevnen av fuktige og frosne jordmaterialer. Del II (A Method for Calculation of Thermal Conductivity of Soils. Part II). *Å. Knutson:* Praktisk bruk av bark i vegbygging (Specifications for Use of Bark in Highway Engineering). *M.R. Thompson:* Lime Stabilization of Frost-Susccseptible Soils.
Juli 1973, 54 s. + figurbilag.

Nr. 11. – *G.M. Shakhunjants:* Soviet Experience in Handling Harmful Frost-Heaving Effects on Railways. *V.S. Lukjanov:* Application of Hydraulic Analogue Method to Investigation of Physical Processes in Soils. *Akin Önalp:* A Study of the Mechanism of Frost Heave and Stabilization by the Use of Deflocculation Agents. *Bjarne Korbøl og Per Jørgensen:* Faktorer som er bestemmende for kvartære sedimenters innhold av kvarts (Factors which Determine the Quartz Content in Norwegian Pleistocene Sediments). *Seiiti Kinosita:* Water Migration in the Soil During the Frost Heaving.
September 1973, 40 s.

Nr. 12. – *W. Schmidt:* Results of Insulating a Highway Test Section with Rigid Polyurethane Foams. *W. Schmidt:* Opportunities for the Use of Rigid Polyurethane Foams in Roadbuilding to effect Savings in Frost Blanket Gravel. *M.B. Korsunsky, V.N. Gaivoronsky and P.D. Rossovsky:* Moisture Content and Frost Heaving of Highway Subgrade Soils. *Y.M. Vasilyev:* Factors affecting the Heaving of Subgrade Soils at Freezing. *Tore Østeraas:* Kvartærgeologisk kart – En presentasjon med vurdering av nøyaktighetsgrad og begrensninger (Quarternary Maps – A presentation and Evaluation of Exactness and Restrictions). *C. Apostolopoulos, H. Kuhle und W. Schneider:* Theoretishe Untersuchung möglicher frostbeständiger Strassenkonstruktionen hinsichtlich ihrer thermo-dynamischen Eigenschaften (Theoretical Investigation of some Possible Frostresistant Pavement Constructions in Relation of their Thermal Properties).
Des. 1973, 44 s.

Nr. 13. – *Jan V. Thue:* Om utforming av grunne fundamenter (Thermal Design of Shallow Foundations). *Eli I. Robinsky and Keith E. Bespflug:* Design of Insulated Foundation. *Per Gundersen:* Frostisolering av rørgrøfter (Frost Insultation of Pipe Trenches). *M.B. Korsunsky, V.N. Gaivoronsky and P.D. Rossovsky:* Determination of Temperature and Depth of Frost Penetration in Pavements and Subgrades. *Reidar Sætersdal:* Utvalg for frost i jord. Årsberetning for 1973 (Committee on Frost Action in Soils. Annual Report of 1973).
Mai 1974, 58 s.

Nr. 14. – *Kenneth A. Linell and G.H. Johnston:* Teknisk planlegging og bygging i permafrostområder (Engineering Design and Construction in Permafrost Regions: A Review). *J. Aguirre-Puente, A. Dupas and A. Philippe:* Frost Heaving and the Classification of Soils in accordance with their Frost Susceptibility. *Frode Færøyvik:* Frostsikre gulv på grunnen (Frost Protected Shallow Foundations). *Lars-Erik Janson:* Undersökning av frysrisken för vattenledningar ovanför tjälgränsen (The Freezing Risk for Water Mains in Frozen Ground).
Oktober 1974, 68 s.

Nr. 15. – *Roy Scott Heiersted:* Ingeniørens rolle i klimaforskningen (A Brief View on Engineering Climate Research). *Roy Scott Heiersted:* Måling av termisk klimabelastning på mark (Field Stations for Recording of Climatic Regime on Ground. *Inge Berg:* Flyplassprosjektet på Svalbard – Anleggstekniske arbeider (The Airfield at Svalbard). *Bjarne Instanes:* Svalbard lufthavn – hangar og kontrolltårn (Svalbard Airport – Hangar and Control Tower). *M.B. Korsunsky, V.N. Gaivoronsky and P.D. Rossovsky:* Thermal Insulation of Motorway Subgrades using Foam Plastic. *Y.M. Vasilyev and M.G. Malnikova:* Frost-Protective Layers made of Stabilized Soils. *Svein L. Alfheim:* Skumplast i vegbygging, - ikke bare til isolering (Plastic Foams in Road Construction – not only for Insulation). *Reidar Sætersdal:* Utvalg for frost i jord. Årsberetning for 1974 (Committee on Frost Action in Soils. Annual Report 1974).
Mai 1975, 60 s.

Nr. 16. – *Roy Scott Heiersted:* Thermal Climate Regime on Road and Ground Surface. *Øistein Johansen:* Thermal Conductivity of Soils and Rock. *Sofus Linge Lystad:* Meteorologiske data. Det norske meteorologiske institutt sett i sammenheng med ulike brukergrupper (Meteorological data and The Norwegian Meteorological Institute). *Vigleif Næss, Øystein Salthaug:* Grunne ledninger og forenklede kumløsninger i utbygging av vannforsynings- og avløpsnett (Possibilities with Shallow Trenches and simplifies Manhole Constructions in Water Supply and Sewage Systems). *Arild Aa. Andresen:* Pilar i telefarlig grunn bør forankres (Pillars in Frost Susceptible Soil ought to be Anchored). *N.A. Peretruhin:* Frost Heaving Forces in Soils.
Oktober 1975, 60 s.

Nr. 17. – Frost i Jord-prosjektets sluttrapport: *Sikring mot teleskader*. *Reidar Sætersdal:* Problemer ved frysing av jord. Forsikringsaktivitet. *Øistein Johansen:* Grunnlag for termisk dimensjonering. *Roy Scott Heiersted:* Klimadata til frostsikring. *Øistein Johansen m.fl.:* Varmetekniske egenskaper av jord og bygningsmaterialer. *Reidar Sætersdal:* Jordarters telefarlighet. *Geir Refsdal m.fl.:* Frostsikring av veg. *Håkon Hartmark:* Frostsikring av jernbane. *Knut Borge Pedersen m.fl.:* Frostsikring av kulvert, undergang, støttemur og brufundamenter. *Per Gundersen:* Frostsikring av ledninger. *Svein Erik Torgersen:* Frostsikring av gulv på grunnen. *Erik Algaard:* Frostsikring av kalde konstruksjoner. Frostsikring av gulv, fundamenter og grunn i byggeperioden. *Erik Algaard:* Kryperom. *Svein Erik Torgersen:* Frostsikring ved åpen fundamentering.
Nov. 1976, 400 s.

Nr. 18. – *E.E. Ziegler:* The Trans-Alaska oil pipeline. *H.R. Peyton and E.E. Ziegler:* Permafrost. *Sofus Linge Lystad:* Noen betraktninger over snødekke, snødyp og deres sammenheng med meteorologiske parametre (Some remarks on snowcover and snowdepth in relation to other meteorological elements). *Erik Sandegren:* Cellplast användning för lösande av ingenjörgeologiska problem

inom Statens Järnvägar (The use of cellular plastics in the Swedich State Railways to isolate against frost). *Olle Andersson and Sven Freden:* The influence of a plastic fabric upon the pavement at frost break.
Juli 1977, 52 s.

Nr. 19. – *Tory L. Péwé:* Permafrost research. A workshop survey of some recent activities. *Reidar Sætersdal:* Overslagsberegning av tykkelse på aktivt lag (tinedybde) på Vest-Spitsbergen (An approximate method to calculate the thaw depth on Vest-Spitsbergen). *Knut Borge Pedersen:* Litt om frostsikring av norske vegtunneler (Frost protection of Norwegian road tunnels). *R.S. Heiersted:* Statistisk bestemmelse av klimapåkjenninger. Eksempler med frostmengde og tinemengde (Statistical treatment of climatic loads on constructions).
Desember 1977, 38 s.

Nr. 20. – *O. Gregersen:* NTNFs Utvalg for permafrost. Virksomhet i årene 1976-78 (The Norwegian Committee on Permafrost. Activities in the Years 1976-78). *Tore I. Moen:* En generell omtale av vann- og avløpssystemer i permafrostområder (Utilities Delivery in Permafrost Regions. A general discussion). *J.P.G. Loch:* Influence on the Heat Extraction Rate on the Ice Segregation Rate of Soils). *J.P.G. Loch:* Suggestion for an Improved Standard Laboratory Test for Frost Heave Susceptibility of Soils. *R.S. Heiersted:* Risiko for lastoverskridelse i bygningers funksjonstid (Calculated Risk for Exceeding Design Load during Service Life of structures). *S. Outcalt:* The Influence of the Addition of Water Vapour Diffusion on the Numarical Simulation of the Process of Ice Segregation.
Juni 1980, 60 s.

Nr. 21. – *O. Gregersen:* Permafrost engineering research on Spitsbergen. (Projects initiated by the Norwegian Committee on Permafrost.) *P. Gundersen:* Frostsikring av ledninger i praksis (Practical frost protection of buried pipes). *O. Liestøl:* Permafrost conditions in Spitsbergen. *M. Fukuda and J.N. Luthin:* Pore-water pressure profile of a freezing soil. *O.Th. Mellerud:* Permafrost og byggearbeider på Svalbard (Permafrost and construction work on Svalbard). *T. Førland and S. Kjeldstrup Ratkje:* On the theory of frost heave.
Juni 1980, 48 s.

Nr. 22. – *P. Gaskin:* Review of frost susceptibility classification. *T. Hailikari:* The frost susceptibility test for public roads in Finland. *J. Livet:* Experimental method for the classification of soils according to their frost susceptibility, France. *J. Livet:* Technical and regulatory aspects of traffic restrictions during thawing period for public roads in France. *H. Behr:* Criteria for the determination of the frost-susceptibility of soils in the Federal Republic of Germany. *R. Sætersdal:* Prediction of the frost susceptibility of soils for public roads in Norway. *H. Thorén:* Prediction of the frost susceptibility of soils for public roads in Sweden. *Linus B. Fetz:* Short-cut frost heaving test for soils. *P.T. Sherwood:* British experience with the frost-susceptibility of roadmaking materials. *Edwin J. Chamberlain and David L. Carbee:* The CRREL-frost heave test, USA.
November 1981, 63 s.

Nr. 23. – *T.L. Pewe, D.E. Rowan and R.H. Pewe:* Engineering Geology of the Svea Lowland, Spitsbergen, Svalbard.
December 1981, 16 s., Description of Geologic Units.

Nr. 24. – *S. Bakkehøi:* Datainnsamlinga på permafrost-stasjonen i Svea, Svalbard (Collection of data at the permafrost station in Svea, Spitsbergen). *S. Reimers:* Drilling and sampling in frozen ground. *M. Dysli and R. Pfister:* Test of bearing capacity during thaw. *S. Kjelstrup Ratkje, H. Yamamoto, T. Takashi, T. Ohrai and J. Okamoto:* The hydraulic conductivity of soils during frost heave. *Ø. Johansen:* Termisk dimensjonering av jernbanefundamenter. Frostsikring med isolasjon (Thermal design of railway structures. Frost protection by insulation).
Juni 1982, 40 s.

Nr. 25. – *Per Gundersen:* Rasjonelle grunnarbeider for småhusfelt (Provision of utilities and services for single-family housing areas). *Svein Erik Torgersen:* Småhus-fundamentering (Foundations for single-family houses).
April 1984, 49 s.

Nr. 26. – *G. Refsdal:* Frost protection of road pavements with insulating boards. Norwegian practice and experience. *Kaare Flaate:* Permafrost in the Northern Hemisphere. *Hans Christian Langager:* Permafrost and hydropower development in Greenland. *Ivar Torblaa:* Dam Rieppejavri, Troms – Dam foundation with perma-frost. *Steinar Bakkehøi and Christina Bandis:* A preliminary analysis of climatic data from the permafrost station at Svea, Spitsbergen. *Odd Gregersen:* Foundation design on permafrost. *Lasse Sondbø and Alv Orheim:* Experiences from tunnelling in Svalbard.
Desember 1987, 43 s.

Vedlegg 3 / *Appendix 3*

Publikasjoner fra Teknologiavdelingen

Publications from the NPRA, Technology division (most are out of print)

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