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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

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Report summary

The International Glaciological Society - Nordic Branch Meeting 2010 is held at the Geocenter Denmark from October 28 to 30. The meeting provides an informal venue for Nordic-based glaciologists and students in glaciology to present their latest results and projects. The conference was sponsored by the NordForsk Nordic Centre of Excellence Stability and Variations of Land Ice (SVALI), The International Glaciological Society and GEUS.

Approximately 120 people have registered to the meeting. 76 titles were submitted distributed as 47 talks and 29 posters. The presentations represent a variety of topics including: Calving, ice dynamics, ice cores, ice sheet modelling, surface properties, subglacial hydrology, mass balance, glacier mapping and more. Presentations on a special session on ‘The Link between the cryosphere and other parts of the Earth System’ are also included.

This Report is comprised of the abstracts for each presentation and a list of participants. Abstract are ordered alphabetically by first author.

Abstracts

Updating the ice sheet model SICOPOLIS with an improved treatment of ice flow

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We present preliminary results from an effort to improve the mathematical treatment relating internalstresses to deformation in the ice sheet model SICOPOLIS (http://sicopolis.greveweb.net/) . Untilre cently, all established large scale numerical ice sheet models were based on the Shallow Ice Approximation (SIA). Employing the SIA, complexity is essentially traded off in favor of computability: simulations for large modeling domains such as the ice sheets of Greenland and Antarctica can be run through entire glacial cycles and give sufficiently good results for the behavior of the bulk of the ice masses. However, today's ice sheets behave critically in zones where SIA based simulations are known to fail or lead to false results. Discrepancies between the modeled and real ice sheets are especially noticeable in regions of fast flow (in ice streams) and in the ice sheet/ice shelf transition region (at the grounding line). To get the ice dynamical behavior right, more complex models than the SIA have to be employed. Full Stokes models provide the best representation of ice flow physics, but are computationally expensive. Alternatively, higher order models such as the Second
Order SIA provide a middle ground: they capture the dynamics of ice streams and allow for a systematic coupling of ice sheet an ice shelf in the transition zone, and are computationally much cheaper than full Stokes models.

We are currently amending the SIA code SICOPOLIS (Simulation Code for Polythermal Ice Sheets) by adding Second Order functionality to it. This task involves derivation and implementation of the second order perturbation expansion equations for grounded ice sheets and is performed in a modular fashion. To limit the problem, the temperature is held constant, a no-slip condition is applied at the ice base, and we neglect isostasy. After a brief explanation of what perturbation expansion really means,
we illustrate the procedure using the equation of the shear stress in the x-z plane: we present its SIA and SOSIA version, comment on the requirements the second order equations have in their algorithmic treatment, and compare results obtained for both equations in simple test scenarios. We conclude with an outline of what remains to be done and what we hope to achieve.

PROMICE - Monitoring the mass loss of the Greenland Ice Sheet

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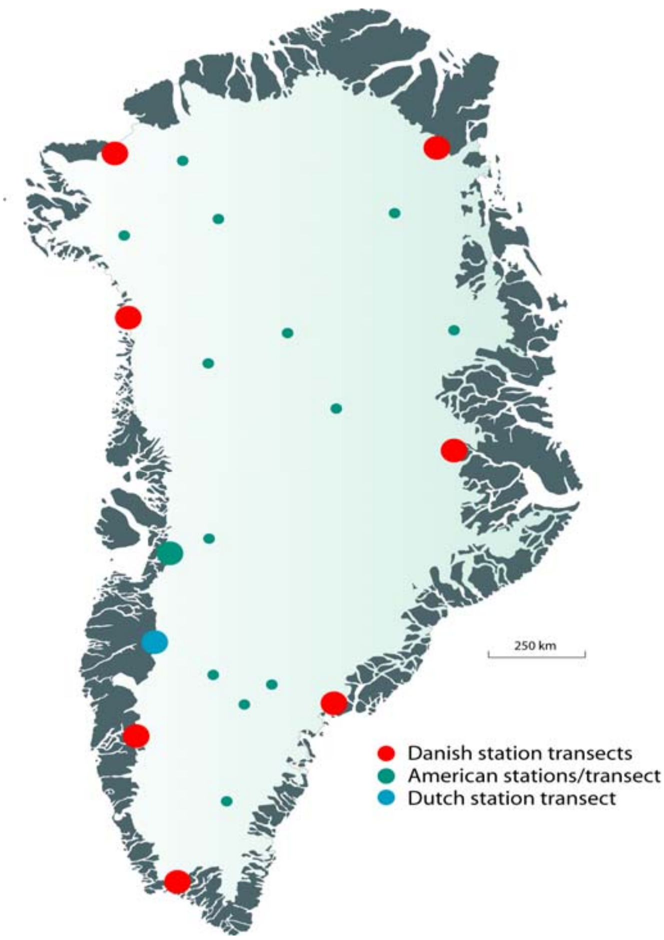
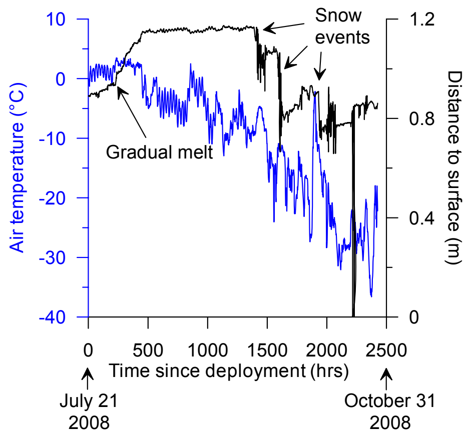
Summary:
PROMICE, the Danish governmental programme for monitoring the mass loss of the Greenland ice sheet, is presented. Results are presented from the automatic mass-balance station network, the airborne elevation and thickness surveys and the satellite-derived ice sheet velocity and glacier extent products.

Abstract:
The Greenland ice sheet has been losing mass at an increasing rate during recent years, raising political concern worldwide due to the possible impact on global sea level rise and long-term climate dynamics. The Arctic region as a whole is warming up considerably faster than the global mean; it is necessary to quantify these climatic changes in order to assess the potential consequences and to provide the decision-makers with a firm knowledge base. To cover this need, the Danish Ministry of Climate and Energy has launched the Programme for Monitoring of the Greenland Ice Sheet (PROMICE) in 2007, designed and operated by the Geological Survey of Denmark and Greenland (GEUS) in collaboration with the National Space Institute at the Technical University of Denmark and the Greenland Survey (ASIAQ). The aim of the programme is to quantify the annual mass loss of the Greenland ice sheet and track changes in the extent of the glaciers, ice caps and ice sheet margin in Greenland.

The two main mechanisms responsible for the mass loss from the Greenland ice sheet are surface melting and iceberg calving. To quantify mass loss by melting, a network of automatic mass-balance stations is being deployed in the low-lying, melting part of the ice sheet, covering every distinct regional climatic zone around Greenland. Each station measures the climate factors causing melt as well as the subsequent local mass loss. In the past four years fourteen stations have been deployed by PROMICE, filling the gaps between the more than 20 additional Danish, US and Dutch stations previously placed on the Greenland ice sheet and independent glaciers. The observations will feed into a melt model to calculate surface melt – and changes/trends on a year-to-year timescale – over the entire ice sheet. The measurements will also provide a direct way to check the performance of climate models over Greenland, potentially improving accuracy of future-climate scenarios. Currently, live observations are transmitted to serve as input for weather predictions, as well as to inform people of the Greenland climate worldwide.





The mass loss by iceberg calving is obtained from airborne surveys and satellite observations. A combination of the two allows us to determine the thickness and flow speed of the ice along the ice sheet margin, giving us the flux from the inland towards the ocean via Greenland's outlet glaciers. The first airborne survey was carried out in 2007 measuring ice sheet elevation by laser altimetry and thickness by ice-penetrating radar along the entire ice sheet margin. The next survey is scheduled for 2011. Repeating the effort every few years will show the dynamic response of the ice sheet to changing climate conditions.

In order to produce geocoded velocity measurements, a Synthetic Aperture Radar data processing software is currently under development at the National Space Institute. The processing chain implements coherence- and intensity-tracking of SAR images as well as differential SAR interferometry techniques. The core processing modules are provided by GAMMA Remote Sensing and Consulting AG, with additional functionalities developed at the National Space Institute, concerning error prediction, fusion of measurements from multiple satellite tracks and combination of offset-tracking and interferometric techniques. First results for Nioghalvfjerdsfjorden Glacier in Northeast Greenland is shown in Figure 3, utilizing ERS-1 and ERS-2 data from 1996.

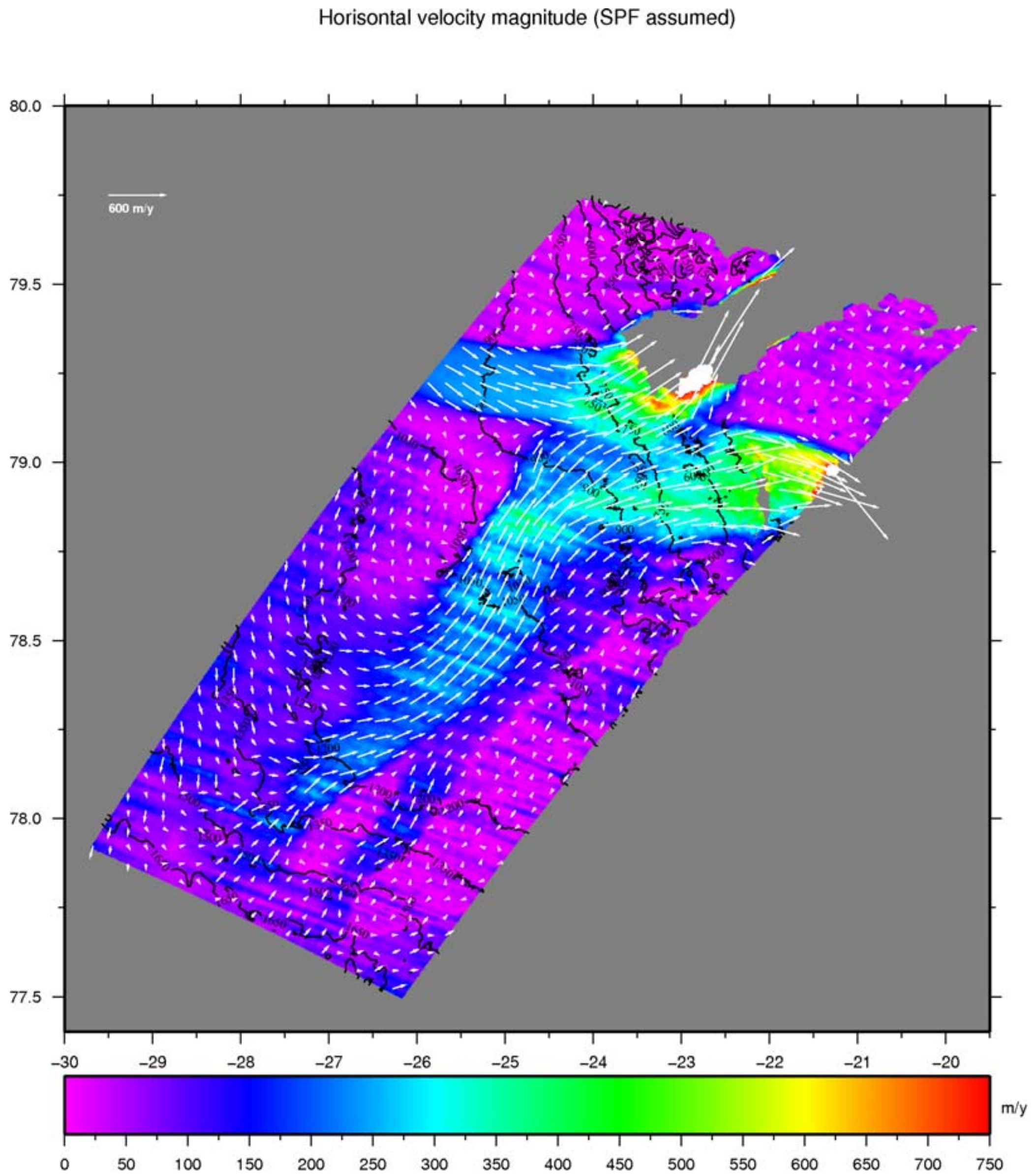


Figure 3. ENU (east-north-up) velocities computed from InSAR double-difference line-of-sight velocity and coherence-tracked azimuth velocity. Height contours derived from InSAR double-difference. Surface parallel flow assumption (and height gradients from InSAR double-difference) used to relate UP velocity component to horizontal ones.

The PROMICE data base

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The Greenland ice sheet has been losing mass during recent years, with possible impact on global sea level rise and climate dynamics. With this in view the Programme for Monitoring of the Greenland Ice Sheet (PROMICE) has been launched by the Danish Ministry of Climate and Energy. The aim of the programme is to quantify the annual mass loss of the Greenland ice sheet and track changes in the extent of the glaciers, ice caps and ice sheet margin. It is the intention that data and results from this programme should be available to the public.

One of the main activities within PROMICE is establishment and maintenance of a network of automatic mass-balance stations (AMS) on the margin of the Greenland ice sheet. The station network includes a total of 14 stations located in seven climatically different regions of the Greenland ice. At each location, one station is placed in the lower ablation zone, another in the higher ablation zone, near the equilibrium-line altitude.

The GEUS station setup includes measurement of air temperature, relative humidity, wind speed and direction, atmospheric pressure, incoming and outgoing short- and long wave radiation, ice temperature, surface velocity, snow depth and ice ablation.

Here we present the PROMICE data base. The data from the PROMICE stations is available for download at http://www.promice.dk.

Langfjordjøkelen, a rapid shrinking glacier in northern Norway

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Langfjordjøkelen (70º10'N, 21º45'E) is a small ice cap (7.7 km^2) in the northernmost part of mainland Norway. Mass balance measurements have been carried out on an east-facing part (3.2 km^2) and reveal a large annual mass turnover in the same order as at the maritime glaciers much farther south in Norway. Mean summer balance (−2.9 m w.e.) exceeds mean winter balance (2.1 m w.e.) resulting in an annual deficit of −0.87 m w.e. for the period 1989-2009 (estimated values for 1994 and 1995 included). The cumulative net balance for this period is thus −18 m w.e. Balance year 2008/2009 was the thirteenth successive year with significant negative net balance (_−0.35). The recent increased thinning is stronger than observed for any other glacier in mainland Norway. Geodetic mass balance has been obtained by comparing digital terrain models (DTM) from 1966 and 1994 (maps constructed from vertical aerial photographs) and 2008 (laser scanning) by subtracting the DTMs and adjusting for melt after the date of the photography. The results from traditional mass balance measurements and the geodetic method (maps) compare well for the period 1994-2008. Maps for the period 1966-1994-
2008 show a strong decrease (for the east facing outlet) in mean thickness (−35 ±2 m w.e.), area (−38 %) and length (−22 %). Ice thickness measurements reveal a present (2008) average thickness of ~70 m and a loss in volume of ~30% over 1966-2008. A mass balance model using upper-air meteorological data was used to reconstruct annual balances back to 1948; revealing a loss of 28 m w.e. for 1948-1998 total or ~0.6 m .e./a.

Simple Bayesian calibration of a quasi-equilibrated Greenland ice sheet model

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We match an ensemble of ice sheet model runs to the observed modern ice volume on Greenland to estimate model input parameter values and their associated uncertainties. Ice sheet models have many poorly known input parameters. This lack of knowledge likely reduces our ability to reproduce past changes or forecast future ones.

To address this problem, we ran a perturbed-parameter ensemble using the SICOPOLIS ice sheet model (Greve, 1997; http://sicopolis.greveweb.net/) and methods developed by E. J. Stone and colleagues (2010). The ensemble included 250 runs, each with a different parameter combination. Investigated parameters included the ice flow factor, the positive degree-day factors for snow and ice, the geothermal heat flux, and the basal sliding coefficient. The parameter values for each run were chosen by Latin hypercube sampling, guaranteeing that the runs cover the parameter space evenly. Each ensemble member started from the modern ice geometry and isothermal conditions, and then evolved for 50,000 years under the observed climatology.

We then compared the individual model runs to the observed ice sheet in a Bayesian sense. We assumed that our state of knowledge about the modern ice volume on Greenland is described by a Gaussian distribution with a mean corresponding to the best estimate and an arbitrarily chosen standard deviation. Using this likelihood function, we derived marginal probability density functions for each of the model input parameters.

This work is novel because it uses a quantitative objective function to calibrate several ice sheet model parameters simultaneously. We comment on the potential weaknesses of this method and point out ways to make further progress.

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Meltwater Generation and Routing at Paakitsoq, West Greenland: Insights from a Distributed, Physically Based Numerical Model

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Recent field-based geophysical studies show that surface meltwater reaches the bed of the Greenland Ice Sheet (GrIS) and modulates glacier sliding rates at the ice sheet margin. However, the detailed hydrological characteristics of the surface, englacial and subglacial **drainage** system remain uncertain. Furthermore, the extent to which the subglacial system is channelised or distributed, whether it operates at pressures at, below or above ice overburden pressures, and the degree to which these characteristics vary in space and time are all largely unknown and yet have profound implications for ice flow and how the ice sheet may react to future increases in meltwater production. As the **subglacial drainage** system of the GrIS is physically inaccessible and beyond the resolution of geophysical imaging techniques, numerical models will increasingly become important tools for investigating its behaviour. We present the latest results of a numerical model that we are using to investigate surface melt water production and surface, englacial and subglacial routing of water in the 1000km^2 **Paakitsoq** region of W. **Greenland**, north of Jakobshavn Isbrae. Subglacial drainage system structures (the location, alignment and interconnection of major drainage pathways) are defined from patterns of subglacial hydrological potential derived from surface and bed DEMs. Discharge and hydraulic head within subglacial pathways are modelled using a component of the US EPA Storm Water Management Model (SWMM), modified to allow for enlargement and closure of ice walled channels (Arnold et al., 1998, *Hydrological Processes*, 12).

The subglacial model is fed with diurnally varying melt inputs calculated from a full energy balance model, driven by meteorological data from the JAR 1 GCNET station and consisting of two coupled components. First, a surface model calculates the energy exchange between the ice surface and the atmosphere. Second, a subsurface model simulates changes in temperature, density and water content in the snow, firn and upper ice layers. The coupled model calculates the melt per hour for each 30m DEM grid cell. MODIS imagery showing the retreat of the snowline for a summer melt season is used to test this aspect of the model.

Modelled melt is then routed within saturated snow / firn, or across the ice surface, by a lumped surface routing model. The surface DEM, an existing map derived from air photos, and satellite imagery are used to identify the locations of major lakes and moulins. The surface routing algorithm enables the time delay between each grid cell and the moulin to which it drains to be calculated as a function of surface topography and snow / firn thickness. The discharge hydrographs entering each lake or moulin are thereby determined. This aspect of the model will eventually be tested using lake volumes calculated from satellite and ground based measurements, and moulin hydrographs measured in the field. Meltwater can pond in supraglacial lakes around moulins, but once in the moulin, meltwater is delivered instantaneously to the bed.

Finally, we simulate **drainage** beneath the ice sheet and compare the results with measured proglacial stream discharges.

Spatial and temporal variability of precipitation volume and snow chemistry on Vestfonna ice cap (Svalbard, Nordaustlandet)

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Calibrations of surface mass balance models of Vestfonna ice cap (Nordaustlandet, Svalbard) are lacking direct accumulation, ablation and temperature measurements from the most inaccessible part of the glacier (NW-SE ridge). Soluble ionic particles and oxygen isotopic concentrations measurements were made on snow-pits and firn-cores (10m and 15m deep) samples from the highest summits of the glacier (one being located on the NW-SE ridge). Despite some post-depositional attenuation of the sub-seasonal $\delta^{18}O$ and ionic records, annual cycles are preserved and allow establishing a depth/age scale for the 2 cores.

The derived annual accumulation rates could indirectly fill the geographical gap for mass balance measurements and thus provide information on spatial and temporal variability of precipitations over the glacier for the period spanned by the cores (1993-2009). Comparing snow and ice chemistry records at the two locations also reveals that the easternmost part of the ice cap receives fewer precipitations and is more subjected to dry deposition and sublimation than the western part.

Influence of carbon pollutions on radiation characteristic snow cover in Barentsburg of archipelago Spitsbergen.

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The process of gradual increase the average annual temperature of atmosphere bring to shortening square of polar arctic glaciers. One of example is arctic glaciers of Svalbard, which balance mass was negative for the last years. Besides natural process influencing on the thaw of snow cover and glacial ice, exists anthropogenic effects. Change of the component of the radiation balance of the system, accompanied by a continuous change of quality of surface for the reason of surface pollution, and the qualities of the atmosphere, due to decrease coefficient of transparency, in the result of the emission of carbon aerosols, mainly manifesting near of Barentsburg.

The snow cover is famous component of climate system, rendering essential influence on formation radiation balance of underlying surface, and also formation of freshwater balance of upper ocean stratums. Therefore this research has been presenting an actual today. Special interest offers research of influence the carbonaceous pollution of snow cover on changes of reflectivity ability and change quantity penetrating into snow cover the short-wave radiation.

Barentsburg is a coastal territory of Greenfjord at Spitsbergen. The research of radiation quality of underlying surface in this place has high applied and science meaning. Special scientific interest arises when considering the study area as a territory finding near vicinity from local CHP and plants enterprises engaging of mining, transportation and storage of coal.

For research of influence anthropogenic effect on radiation characteristic of snow cover was conducted observations using pyranometers LI-COR.

Measurement of albedo with pyranometers M-115 gives possibility to price the integral albedo in the visible and close infrared spectral region. In this case, the integral characteristic measures in the wavelength range 0.3 - 3.0 microns and there is not considering a significant change of reflecting ability of the investigation of selectivity properties of the snow surface. The maximum reflection is observed in the visible spectrum, while radiation with a wavelength bigger than 1 micron is almost completely absorbed on the snow surface. Therefore it is important to evaluate the radiative qualities of snow in the area of maximum meaning as the

spectrum of incoming radiation and the spectrum of reflection, as well as to estimate the size of attenuation penetrating into the snow cover of radiation.

Observations included the simultaneous measurements of flows of incoming reflected penetrating and outgoing radiation in the visible wavelength range (0.4 -0.7 mm) in stratums of different power (from 5 to 25 cm from the surface). The top stratum in 5 cm represented fresh snow and contained pollution accumulating during two days. In this case, wasn't take into account spatial changes in distribution of density in the upper stratum of snow cover, which was insignificant.

The degree of pollution of the snow stratum was evaluated by the selection and melting samples of snow cover fixing thickness with following by passage through a filter system to identify the number of falling substances on the filter paper.

Pollution of snow cover in Barentsburg mainly connects with production, transportation and storage of coal (coal dust) and also emissions products of burning coal on the local heating plant.

Another sources are emissions of engines snowmobile, which may be significant in the place of the parking snow mobiles.
The highest pollution was found by the coal storage of Barentsburg and was 1.93 g/l, minimum pollution - 0.1 g/l, with an average of 0.6 grams per liter.
The research of characteristics of penetrating radiation in the stratum of snow, the great importance was the evaluation of reflecting ability of the underlying surface, the snow cover. During the period of research was carried out 60 measurements of albedo (each measurement consisted of three series of observations on which we calculated the average mean). Characteristics of reflecting ability of surface snow were subsequently divided into 5 classes depending on the degree of surface pollution. The results are shown on fig. 1. and characterize the average meaning albedo in the range of 0.4-0.7 microns. The lowest albedo is typical for very polluting snow surface and an average of 0.41, but the minimum fixing meaning observing in the coal storage Barentsburg is 0.19. For very polluting surface the average albedo is 0.41, which almost 2 times less than for fresh snow (0.83).

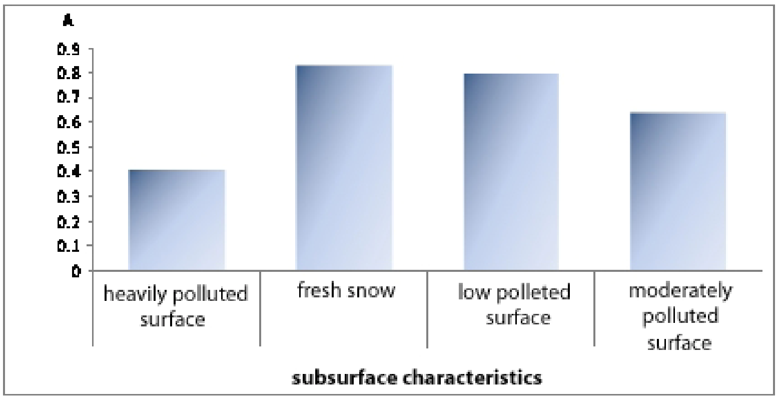

Fig. 1. – Albedo of different degree pollution of surface snow.

In order to reveal dependence between penetrating radiation and the degree of pollution stratum of snow was computed middle for the visible area of spectrum the percent of attenuation, which shows the attenuation of radiation intensity on the way.

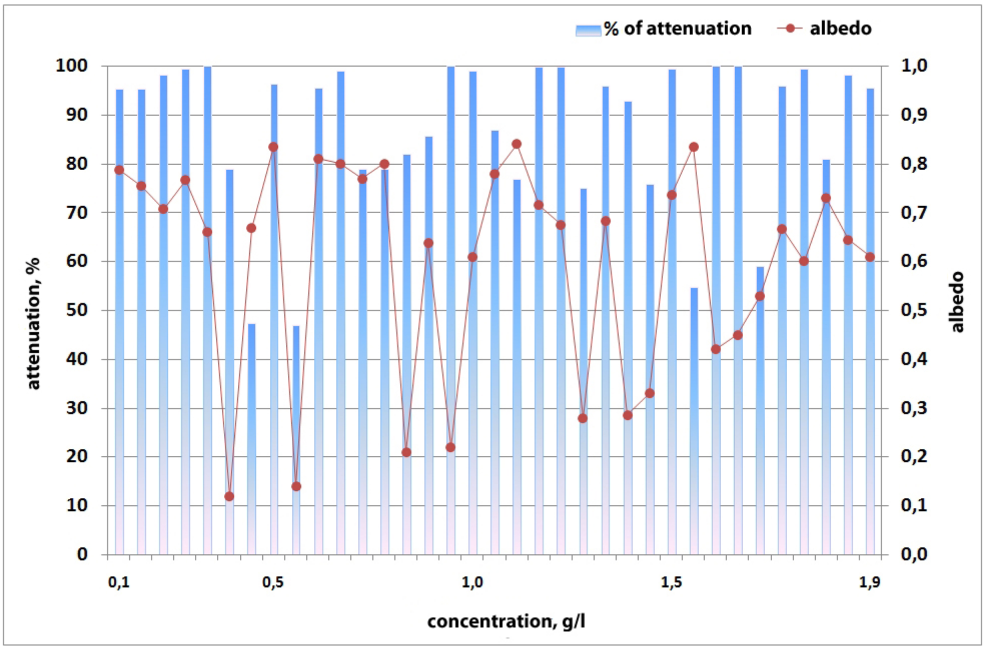

Fig.2. - Attenuation of solar radiation in the range of 0.4 - 0.7 m
in the top 5 cm stratum of snow, in depending on the magnitude of pollution.

The graph shows, in the top stratum of 5 cm there absorbs from 50 to 100% of solar radiation in the visible range of spectrum. However, as can be seen, the expected increase of attenuation the solar radiation with increasing pollution in the upper stratum of snow is not observed. Such a result suggests that a relatively small amount of pollution (in the range 0.12 - 0.73 g/l) doesn't render an essential effect on the absorbed by stratum snow the shortwave radiation and doesn't contribute to a possible increase of melting snow. On the other hand, require to clarify the methodology of the study. A small number of observations don't allow conducting of preliminary assessment of the character of pollution, with following by separation into two groups: the pollution is distributed throughout the stratum, or it is concentrated on the surface. Separation into groups on these indications could be making on the size of albedo on the surface snow. The small size of albedo with the same content of polluting substances in the selecting sample will indicate about predominantly superficial pollution of the snow cover.

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Calving Laws for Ice Sheet Models: Where Next?

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Calving accounts for most ice losses from the Antarctic Ice Sheet, around half of the losses from the Greenland Ice Sheet, and a substantial amount of the ablation from many high-latitude glaciers and ice caps. Despite this, calving processes are still poorly represented in prognostic ice sheet models, limiting our ability to predict ice-sheet response to climate change. A new approach to quantifying calving losses has been developed, based on the depth of penetration of surface crevasses, which in turn is a function of the velocity field near the glacier margin. The potential of this new approach has been demonstrated in two recent papers, which incorporate crevasse-depth calving laws (CDCLs) in glacier models. First, Otero et al. (2009) used a static, three-dimensional, higher-order model to successfully predict the calving front position of a small Antarctic glacier. Second, Nick et al. (2010) conducted a series of experiments with a higher-order flow-line model, and showed that CDCLs allow a much broader range of glacier behaviour than other ‘calving laws’. While the success of these implementations is very encouraging, the incorporation of CDCLs in a time-evolving, three-dimensional higher-order model remains an important goal for the future.

Future development of calving models requires both systematic observations of calving margins and improved modeling routines. Empirical data are urgently needed to determine how well models represent real calving processes and ice-front behaviour, and to identify key areas where improvements are needed. Many issues remain with modeling calving glaciers, but perhaps the most fundamental challenge is to find robust methods of incorporating basal motion (sliding) in higher-order models. It is clear that there are intimate links between calving and glacier dynamics, but realistic, workable ‘sliding laws’ remain elusive. This problem is closely linked with another of glaciology’s ‘last great problems’ – the calculation of evolving subglacial water-pressure fields. By bringing together field scientists, remote sensing experts and modellers, the SVALI initiative provides a unique opportunity to make significant advances on these issues.

Surface and snow pit ^{10}Be from the NEEM drill site, Greenland

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During the field season of 2009, a total of 48 snow samples were collected at the NEEM deep ice core drilling site in Greenland (77.45°N, 51.06°W. 2484 m a.s.l.) in order to study lateral and vertical variability of ^{10}Be. Sampling of freshly fallen snow of May 28 and June 1-2 took place at three sites in the immediate camp vicinity. A few samples of drifted and wind-packed snow were also collected. Additionally, three samples of tap water were collected on three occasions during the first half of June. The tap water is produced from snow collected in a designated area of the camp, and was used for rinsing the equipment between samples. Two snow pits situated 0.5 km and 4.8 km away from camp were sampled at 10 cm intervals from the surface to depths of 160 and 120 cm. All samples were melted in the field after addition of ^{9}Be carrier, and passed through ion exchange columns. Subsequently, ^{10}Be was extracted from the columns at Uppsala University, and ^{10}Be measured at the Uppsala Tandem Laboratory. Measuring errors range from 3% to 9%.

Five surface samples taken at one location have concentrations of 0.4-1.1×10^4 atoms g^{-1}. At the second sampling site of freshly fallen snow, values vary within the range 0.3-0.7×10^4 atoms g^{-1}. Finally, three surface samples collected at a third site all have a concentration of 1.0×10^4 atoms g^{-1}. The tap water, snow drift and surface crust all have similar ^{10}Be concentrations of 0.8-0.9×10^4 atoms g^{-1}. These concentrations are relatively low compared to annual averages we have previously measured in Greenland ice, which is likely an expression of intra-annual variability of ^{10}Be deposition. The differences in concentration observed in adjacent surface samples indicate lateral variability of ^{10}Be deposition on a snow fall event scale.

Snow pit ^{10}Be concentrations are 0.5-3.7×10^4 atoms g^{-1} and 0.6-1.9×10^4 atoms g^{-1}, with averages of 1.1×10^4 atoms g^{-1} and 1.0×10^4 atoms g^{-1} for the two pits respectively. (If only samples covering the common depth of 0-120 cm are considered, the average of pit 1 is slightly higher at 1.2×10^4 atoms g^{-1}.) At both sites the highest ^{10}Be concentration occurs at 90-100 cm depth. Concentrations in pit 1 vary more between samples compared to those in pit 2, where variations are less dramatic. The partial difference in vertical distribution could again be an effect of surface deposition variability, or it could imply that some post-depositional redistribution has taken place.

The possible existence of lateral variability or redistribution could have implications for the interpretation of ice core ^{10}Be records, if the effect of such mechanisms is large enough to influence annual or longer-term values. Further sampling is underway in order to unveil the causes or mechanisms behind the observed uneven spatial distribution of ^{10}Be.

Modeling *in situ* cosmogenic production of radiocarbon in Taylor Glacier, Antarctica

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The ^{14}C signature of gases trapped in glacial ice contains a wealth of information. Potentially it could be used for determining the age of the gas through radiocarbon dating. Secondly, it bears the imprint of the fossil contribution to paleo-atmospheric budgets of carbon containing gas species. In particular, the ^{14}C variations in methane (CH_4) over the last glacial termination can teach us how much destabilization of (^{14}C depleted) methane clathrates contributed to the CH_4 budget [1].
Taylor Glacier is an outlet glacier of the East Antarctic Ice Sheet that originates at Taylor Dome, and terminates in the McMurdo dry valleys. In the ablation zone ice with estimated ages between 11.5 and 65 kyr is being exposed [2]. The ice stratigraphy along the centre flow line can be dated by comparison of trace gas mixing ratios and gas stable isotope measurements to ice core records, and comparison of water stable isotopes to the Taylor Dome record [3]. The large ice samples (>500 kg) required for high precision ^{14}C measurements of trace gas species such as CH_4 and carbon monoxide (CO) can easily be mined from near the glacier surface.
Efforts to interpret ^{14}C data are complicated by *in situ* production of ^{14}C in ice by cosmogenic radiation. We consider three mechanisms of radionuclide production; neutron spallation of ^{16}O atoms, negative muon capture and production by fast muons. Production rates fall exponentially with depth, with the fast muon mechanism producing measurable amounts of ^{14}C down to a depth of ~200m. Consequently the amount of ^{14}C in surfacing ice parcels is a function of their flow path in the glacier.
Using surface velocity, strain rate and ablation rate measurements [4] we model flow lines of ablating Taylor Glacier ice. We estimate production rates with a recent model [5] that includes altitude and latitudinal scaling, as well as solar modulation of the cosmic ray flux. On integrating the production rates along the path we obtain a theoretical estimate of the total ^{14}C production.
The change in strain rates with depth is a source of uncertainty. We present several parameterizations, including two extreme end-member scenarios that produce an envelope to the true flow paths, resulting in either maximum or minimum ^{14}C production. Our sensitivity study shows that uncertainties in the strain rate parameterization, ablation rates and muogenic production rates introduce errors of the same magnitude. Measurements planned for the 2010-2011 Austral summer field campaign will

focus on understanding in-situ ^{14}C production and should significantly reduce the uncertainties in muogenic production rates reported in literature.

The modeling results presented here will aid us in determining a successful field sampling strategy, and can be used for interpretation of measurements obtained in the field. Most importantly, it will serve as a framework for correcting future $^{14}CH_4$ measurements for the effects of *in situ* production, which will allow determination of the true atmospheric signal.

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Quantifying the glacier ice albedo from black carbon and other aerosols

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On wet glacier ice surfaces the melt rates are highly sensitive to changes in the surface reflectivity. In fact, the natural variability in ice surface albedo can produce more melt than the increased warming will produce. This calls for robust parameterizations of the glacier ice albedo during melt.
Due to the high spatial albedo variability new and effective sampling and analysis methods had to be developed first. The outcome is now a large and representative dataset which has been used for first the three dimensional shape of granules of surface cryoconite. Next the dataset has been used for quantifying the relation between the albedo and the deposited aerosol dry-mass. Based on a controlled experiment the effect of soot within cryoconite has been quantified. And, analysis of the impact of micro-organisms on cryoconite albedo has also been documented by controlled experiments.
Based on results obtained we propose a model for predicting the temporal surface albedo evolution on a melting glacier ice surface.

Precipitation patterns and variations over Nordaustlandet dynamically downscaled from re-analysis data

Björn Carlsson, *Veijo Pohjola*

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Single meteorological observations are seldom representative for larger areas and established re-analysis data sets of meteorological fields are too coarse to catch the influences from the details of the Svalbard topography. Therefore, in the Kinnvika project, ERA-Interim re-analysis data (0.75°x0.75°) have been dynamically downscaled with the meso-scale atmospheric WRF model onto a 8 km grid over Svalbard for the period 1990-2008. The talk will focus on the analysis of the small scale patterns and variations of precipitation and wind over Nordaustlandet not caught by ERA-Interim. The analysis is also put into the context of the ice surface build-up over Vestfonna during 2003-2008, seen by ICE Sat altimetry and presented by Veijo Pohjola.

What terrestrial ecosystems do to atmosphere gases at elevated temperature. Regulation of CO_2, CH_4, and N_2O differ.

Søren Christensen, University of Copenhagen

The gases CO_2, CH_4, and N_2O are substrates and products of living organisms. For upland soils spatial patterns of activity differ from regular for CH_4 consumption over random for CO_2 emission to aggregated for N_2O emission. Similarly the effect of a temperature increase on exchange rates goes from non-significant for CH_4 consumption over moderate for CO_2 emission to potentially dramatic for N_2O emission. I will discuss the background for these differences and the implication for the importance of the three gases in a future climate including their eventual role in future melting of polar ice.

Implementing Calving into a Full Stress Model

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Calving and the mechanisms tightly connected to it (i.e., crevasse dynamics and sliding) are one of the most actual topics in numerical Glaciology. Based on the open source Finite Element model Elmer (http://www.csc.fi/elmer), some principle issues of including such spatially and also in time discontinuous processes into a continuum model are discussed and first approaches to dealing with this numerically are presented. In the connection to this, preliminary results obtained on a flow line model of the Columbia glacier, Alaska, U.S.A., are presented.

The role of the atmosphere during abrupt climate shifts.

Ivana Cvijanovic, Peter Langen and Eigil Kaas, Niels Bohr Institute, Center for Ice and Climate.

Abstract
Ice-core, terrestrial and oceanic paleo-data seems to agree that high latitude temperature variations were considerably larger during the last ice ages than during the Holocene. There is almost consensus in the scientific community that the abrupt climate events (such as Dansgård-Oeschger events) seen under the ice ages have a global signature, e.g. in terms of the so-called bi-polar seesaw and changes in tropical precipitation patterns. It is believed that the oceans and/or sea-ice played a major role in triggering abrupt events.

A question of major importance is why the abrupt events seem to have been much weaker in warm climates. An obvious answer is that the local high latitude positive feedbacks in terms of ice/snow albedo feedbacks have been weaker.

Another supplementary possibility, to be presented here, is that the negative, (damping) feedback of meridional heat transports in mainly the atmosphere could depend on the background temperature (cold or warm climate) and on the background meridional temperature gradient.

In a set of atmospheric climate model simulations we have found that the atmospheric ability to neutralize high latitude warmings or coolings is considerably higher at present days than at LGM. An implication is that such events can grow faster and to higher amplitudes in cold climates with large meridional temperature gradients.

This may be because of the simple Clausius-Clapeyront relationship and/or because the atmospheric dry dynamics are working close to their maximum “speed” in the cold climate with large temperature gradients.

The geodetic glacier mass balance of Jan Mayen for the period 1949 to 2008

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3 Arctic Centre, University of Lapland, Finland

Abstract

The volcanic island Jan Mayen covers an area of 377 km2 and it is located at N 71°02’, W 8°12’. Twenty glaciers covering an area of ~111 km2 are protruding the 2277 m high Beerenberg crater. Ground penetrating radar survey on two of the glaciers imply that the glaciers are thin (<100 m). They consist mainly of cold ice except in the lowest parts of the glaciers where only a thin cold layer covers temperate ice. The glacier mass balance has not been monitored before, except for Sørbreen glacier (area: ~15 km2), where the direct glaciological mass balance was measured in 1972 to 1974, and 1976 to 1977. The island Jan Mayen was mapped by the Norwegian Polar Institute using photogrammetry on oblique aerial photographs recorded in 1949. This dataset is now combined with a digital terrain model derived from the 2008 SPOT 5 stereoscopic survey of Polar Ice: reference images and topographies (SPIRIT) by CNES. Preliminary results show that the geodetic mass balance for 1949 to 2008 is 6.3±11 m w.e. The uncertainty in the elevation difference for the two data sets is estimated for the surrounding rocks, and this value is assumed to be representative for the glacier surface. The uncertainty is determined as follows; the elevation grids for the surrounding rocks are subtracted and the scales of spatial correlation are determined for this differential data set. Finally the standard deviation for the spatially averaged elevation differences is calculated. The results show that no statistically significant glacier ice volume change in respect to the determined uncertainty for this data set has occurred in this 59 year period.

Thousand yearlong reconstruction of winter air temperature variations in Longyerbyen, Svalbard Archipelago and Vardø, northern Norway, based on Svalbard ice core oxygen isotope data.

Dmitry Divine[1,2], Elisabeth Isaksson[2], Tonu Martma[3], Vejio Pohjola[4], Harro Meijer[5], Roderik S.W. van de Wal[6] , John Moore[7], Fred Godtliebsen[1].

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Two isotopic ($\delta^{18}O$) ice core records from western Svalbard are examined for a potential to be used as proxies for past surface air temperatures (SAT). The core sites are located at Lomonosovfonna at 1250 m asl and Holtedahlfonna at 1150 m asl. Both cores were dated by a combination of annual cycle counting in $\delta^{18}O$ series and reference horizons left by tritium 1963 bomb peak, Grimsvotn 1903 (Lomonosovfonna only) and Laki 1783 eruptions. The analyzed isotopic time-series are estimated to cover the periods of AD 1020-1997 and AD 1700-2005, respectively. The most recent estimates however suggest that the ice in the bottom section of the Lomonosovfonna ice core can be potentially some 200 years older. The isotope concentrations in the snow pack are considered to be a proxy for condensation temperatures at the time of precipitation at the core site and can subsequently be associated with past local SAT variations. The analysis of $\delta^{18}O$ series against the instrumental temperature record from Longyearbyen on Svalbard (regular data available since 1912) and longer but more remote Vardø series from northern Norway (since 1840) suggests that $\delta^{18}O$ can successfully be used as a proxy for winter SAT on Svalbard. The isotopic series were calibrated to reconstruct approximately 1000 years of past winter (DJF) surface air temperature variations in Longyearbyen, Svalbard and Vardø, northern Norway. Analysis of the derived reconstructions suggests that the climate evolution of the last millennium in these study areas comprises three major sub-periods. The cooling stage in Svalbard (ca. 1020-1800) is characterized by a progressive winter cooling of approximately 1 ˚C century^{-1} (0.4 ˚C century^{-1} for Vardø) and a lack of distinct signs of abrupt climate transitions. This makes it difficult to associate the onset of the Little Ice Age (LIA) in Svalbard with any particular time period. During the 1800s, which according to our results was the coldest century in Svalbard, the Little Ice Age –associated winter cooling was of the order of 4˚C (1.3˚C for Vardø) compared to the 1900s. The rapid warming that commenced at the beginning of the 20th century was accompanied by a parallel decline in sea ice extent in the study area. However, both the reconstructed winter temperatures as well as indirect indicators of summer temperatures suggest the medieval period before the 1200s was at least as warm as at the end of the 1990s in Svalbard. The inferred cli

mate evolution of Svalbard shows a good agreement with other multiproxy reconstructions indicating long term SAT decline in the Arctic, cooling of the Norwegian Atlantic Current and shift in the state of the NAO throughout the last millennium, which has been interrupted only by a recent rapid warming.

High N_2O production from thawing permafrost

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Mineralization of organic matter and release of previously frozen carbon as carbon dioxide and methane from thawing permafrost caused by a warmer climate constitute a potential feedback from terrestrial ecosystems to the atmosphere. The few studies investigating nitrogen cycling in thawing permafrost soils have focussed on the active layer and have concluded that nitrous oxide production is negligible. Although this is in line with findings in the nutrient-deficient soils typical of the tundra ecosystem, a hotspot of near-surface nitrous oxide production was recently reported from cryoturbated peat soil. This study shows that the level of production and net release of N_2O from permafrost cores extracted from wetlands in ice-rich sedimentary Greenlandic lowlands is high, but consistent with the high levels of dissolved nitrogen and carbon measured in the permafrost. Variations in water level, redox and the supply of dissolved nitrogen and carbon to wetland areas were simulated in laboratory incubations and showed that fluctuating redox conditions increased N_2O production by more than a factor 20 and resulted in higher emissions (>30 mg N_2O $m^{-2}d^{-1}$) than previously reported from the Arctic. Measurements of ammonium concentrations and nitrous oxide production in thawing permafrost layers from five additional high Arctic sites suggest that the observations from the Greenland site are in the low range and that the importance of thawing permafrost for accelerating nitrogen cycling has so far been underestimated.

Revision of long term mass balance records, a case study of Engabreen, Norway.

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In mass balance studies point measurements are aggregated to area values. In long term studies, the effects of systematic bias (e.g. overestimating snow accumulation by measuring in safer, flatter areas, or underestimating summer melt by excluding dangerous, crevassed areas) are more important than arbitrary errors. Several of the Norwegian mass balance glaciers are outlets from plateau glaciers where the actual glacier basin boundary may not be obvious.

Engabreen is one example and here the mass balance record (from 1970 onwards) has shown a remarkable mass accumulation, concentrated in the periods 1971-77 and 1989-97. The cumulative mass balance 1970-1997 was +22.5 m w.e. This mass accumulation was reflected in glacier advances in the 1970s and 1990s. However, in between and after the glacier advances the glacier retreated similar distances, indicating a mass balance deficit yet the mass balance record shows small mass surpluses. LIDAR mappings of Engabreen in 2001 and 2008 were used to calculate a volume change corresponding to -0.05 m w.e.a^{-1} whereas direct mass balance calculations give +0.46 m w.e.a^{-1}. Volumetric mass balance between 1968 and 2001 indicates similar discrepancies. The direct mass balance record will be adjusted to correspond with the geometric mass balance. Similar revisions will be performed for other long term records.

Can meteorological data from SeNorge be used as input for mass balance modelling on Norwegian glaciers?

Markus Engelhardt, University of Oslo

Abstract:

For glacier surface mass balance modelling it is crucial to use appropriate meteorological input data (above all temperature and precipitation). As meteorological stations are often situated in populated areas, and therefore in particular in valleys, upscaling of data is necessary. Moreover, due to local meteorological effects, the stations may not be representative for the location of the glacier. For that reason an improvement could be achieved by the use of gridded data sets provided by SeNorge.

SeNorge is a Norwegian collaborating project between the Norwegian Meteorological Institute, the Norwegian Water Resources and Energy Directorate (NVE) and Statens kartverk (the Norwegian Mapping Authority). It provides daily meteorological data recalculated from measurements since 1960 for whole Norway on a 1 km x 1 km grid.

First results from using temperature and precipitation data from SeNorge show a good correlation with the stake measurements obtained on Nigardsbreen (an outlet glacier of Jostedalsbreen, Western Norway) on a range of 600 m to 2000 m asl.

A simple model for the response of mountain glaciers to climate scenarios

Aslak Grinsted, University of Copenhagen

Abstract:
In order to project regional sea level rise it is necessary to model the response of glaciers and ice caps to climate scenarios. We propose a simple model for the aggregate volume response of all mountain glaciers and ice caps. The model formulation is tested against the modelled response of thousands of glaciers in the World Glacier Inventory.

Balkan glacier features as witnesses of local-regional climate-ecological changes

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Because of the low altitude and southern location most Balkan Mountains are not recently glaciated terrains. Whether or not there are adequate features to observe and reconstruct, climatic and environmental changes are little known in the Balkans, since they have only rarely been investigated. Only 100 years ago, glaciers were much more extensive than at present in high mountain areas of the Balkans and in many of these areas, the glaciers have since disappeared.

To understand the response of Balkan glaciers to recent climate change we have studied the Snezhnika Glacieret in Bulgaria during the past few years. Snezhnika is the remains of the Vihren Glacier in the Pirin Mountains. This glacier-patch covers an area of nearly 0.01 km^2 and is currently Europe's southernmost glacieret (41° 46' N). The Snezhnika Glacieret is exceptional, persisting despite a relatively high (and recently increasing) annual mean temperature and low precipitation. To examine the special conditions pertaining to this glacier-feature in south-eastern Europe we carried out an ice core drilling project on the glacieret. We also consider past climatic and environmental conditions from other geo-archives (e.g. dendrochronology). Last but not least we analysed a lot of inorganic and organic components of snow, firn and ice. The accumulation of the xenobiotics in this high mountain region is recognised to be low. Nevertheless, traces of pesticides and chelating agents like EDTA and NTA in ice (firn) and soils were found. The surrogate AOX should be a parameter, suitable for routine environmental screenings of such areas.

The glacier fluctuation of the cirque Golemya Kazan in the Pirin Mountains was estimated for different time scales (Holocene, LIA: Little Ice Age, recent warm period). It is certain that all smaller southern glaciers melted at the climate optimum of the Atlantic Period. The reconstruction of the alpine timber line implies that the snow line during the Holocene did not change significantly. During the LIA (beginning 1300-1550 AD, end 1850-1860 AD) the Balkan glaciers reformed or advanced and this interval was a significant climatic event for geomorphology and culture in this region. Young, loosely bedded moraines are the definite result of glacier advances and the current glaciers of southern Europe are relics of this cold Holocene era.

The smaller southern glaciers respond quickly and in whole to extreme weather phases. Measurements at the Snezhnika Glacieret give examples of the accumulation and melt behaviour. If warm summers follow winters with few snow falls over several years, the glaciers and glacierets shrink until they reach a new equilibrium mass balance or melt completely. This was established for the Balkans Peninsula (also High Tatra) e.g. in 1994. Glaciers survived single heat summers such as, 2003 and 2007 although they experienced significant retreat. Phases with above-average winter precipitation and cooler summers are often sufficient to stabilise small glaciers or even produce re-advance. Overall, it is typical that during the recent final step of a glacial degradation process in the study area, the relative influence of climatic factors decreases as the influence of topographic and other geo-factors increases.

Tephra, mass- and energy balance: the influence of the Eyjafjalla-jökull eruption 2010 on Icelandic ice caps

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During the eruption in the subglacial Eyjafjallajökull volcano in March to April 2010, tephra was spread over all the main ice caps in Iceland. After the eruption, a thick insulating ash layer covered most of the Eyjafjallajökull and Mýrdalsjökull. In contrast, most of the surfaces of Vatnajökull, Hofsjökull and Langjökull were covered with thin thephra which increased glacier melting (Fig. 1).

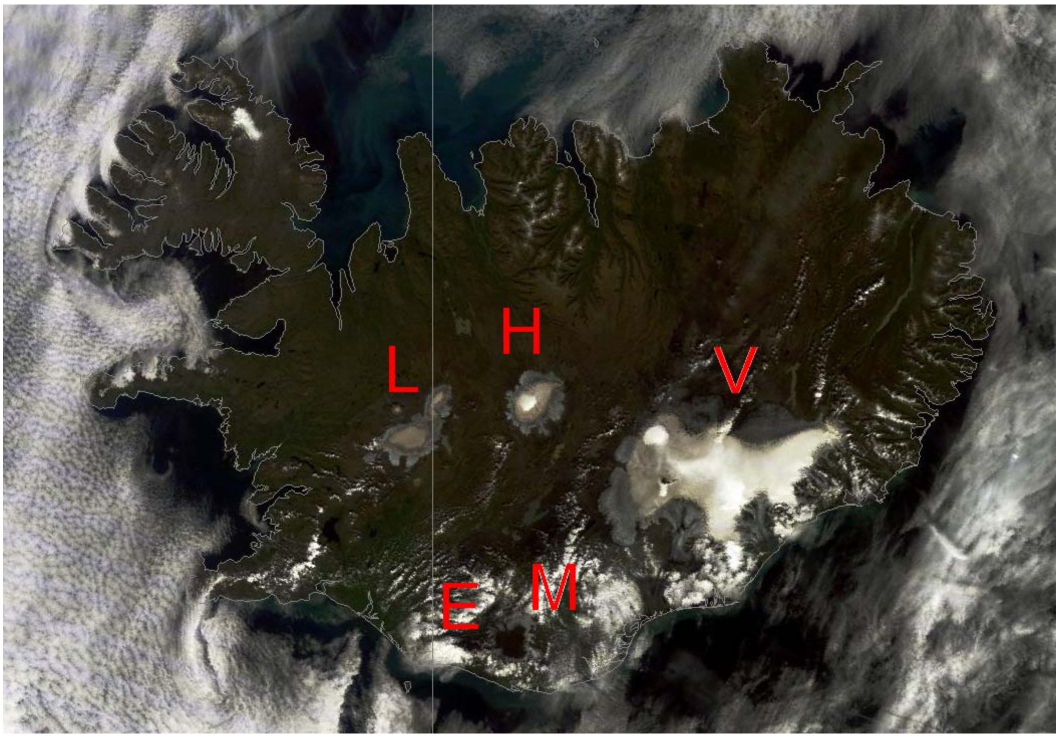

Figure 1. MODIS satellite image of Iceland, 9 August 2010. The image shows the thick insolating ash layer on Mýrdalsjökull (M) and Eyjafjallajökull (E) ice caps as well as the thin tephra layers on Langjökull (L), Hofsjökull (H) and Vatnajökull (V) ice caps.

The mass balance has been observed at 40-50 stakes at Vatnajökull since 1992 and at 22-23 stakes at Langjökull since 1996. The mass balance observations have been supplemented with automatic weather stations (AWSs) at 2-10 locations on Vatnajökull since 1994 and 2-3 stations on Langjökull since 2001, observing at 10 minutes interval all the weather parameters needed to calculate the surface energy balance. Here we present the mass- and energy balance observations on Langjökull and Vatnajökull during the exceptional circumstances 2010. The results are compared to the mass- and energy balance of the more climatically driven years from 1992-2009. The results show that the tephra lowered the albedo and significantly lowered the summer balance and increased the melting within the accumulation area (by >2 fold).

Evaluation of different automatic image matching methods for deriving glacier displacements

Torborg Heid, University pf Oslo

Abstract:
Although many studies use automatic image matching of images from two different times to derive glacier velocity, there has been little comparison of different matching methods. This study compares six different matching methods: normalized cross-correlation (NCC), the phase correlation algorithm used in COSI-Corr, and four other Fourier methods with different normalizations. This is done for five regions of the world with different glacier characteristics: Karakoram, the Alps, Alaska, Pine Island and southwest Greenland. The study is performed on Landsat images because they expand back to 1972, they cover large areas, and at the same time the spatial resolution is as good as 15 m. Preliminary results show that NCC experiences problems in areas with poor contrast, but performs well in areas with good contrast. Thin clouds and changing snow cover, however, can easily make the method fail. The matching method from COSI-Corr and the best performing method of the four other Fourier methods, cross-correlation on orientation images, perform well both in areas with high and low contrast. The problem for these two matching methods, however, is small glaciers that need small window sizes to be correctly matched. In those cases, NCC seems to be a better choice.

Antarctic Snow Grain Size variability at regional, local and sample scale and its relation to satellite retrieved Snow Grain Size information

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Surveying snow grain size and its spatial and temporal variability is of great importance since it influences the albedo of snow covered areas and is also an important parameter in remote sensing of the cryosphere. It is therefore important to narrow the gap between modeled and algorithm-retrieved snow properties, and the field data retrieved to validate the remote sensing data. The aim of our work was to develop an efficient field method for rapid snow grain-size sampling that would provide a quantitative measure of snow grain size variability. We furthermore intended to connect extensive field measurements to satellite imagery to improve the understanding of satellite-imagery-derived information. Methods based on visual determination of snow grain sizes are subjective and typically only provide mean grain size for each sample and do not produce full size distributions for each sample. Several different methods are currently used to identify snow grain size; some are both demanding in terms of time and resource and some have limited spatial distribution. The use of several different methods also complicates intercomparison between different data sets. We have developed a cost and time efficient so-called *Digital Snow Grain Properties* (DSGP) method and applied it to datasets from Antarctica and northern Sweden. The DSGP-method is based on in-field photography of snow samples and pixel-based object oriented image analysis. The DSGP-method enables an effective, objective and reproducible method generating snow grain shape and size variability by retrieving grain properties in multiple parameters. Each image references a calibration plate used for pixel size determination: the calibration plate consists of 0.1 mm dots placed with an accuracy of 0.001 mm. The results from Antarctica show decreasing snow grain size towards the center of Antarctica and larger grains in the coastal areas. The data, furthermore, demonstrate variability at regional, local and sample scale between 0.19 mm and 1.38 mm. By using data retrieved by the DSGP method for validation of remote sensing products such as MODIS and MERIS, the gap between space and the snow surfaces is narrowed.

Simultaneous measurements of surface motion, basal pressure and seismicity at Engabreen glacier, northern Norway

Authors

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Continuous measurements of glacier surface motion, subglacial pressure and seismic activity at Engabreen glacier in northern Norway were made over an eight-day period in the spring of 2008.

Surface motion was measured using both dGPS receivers and ground based interferometric radar using a frequency of 5.7 GHz and recording distance to reflectors twice a second. GPS receivers and reflectors were placed at three different points on the lower part of the glacier at elevations of 320, 340 and 398 m a.s.l. Motion was smooth over the whole period, but showed variations at shorter time scales.

Simultaneous measurements were made of subglacial pressure by earth pressure sensors that are installed at the Svartisen Subglacial Laboratoy under 200 m of ice. These sensors are approximately 1.7 km upstream of the highest of the surface stations. Six sensors recorded data at 90-second intervals, although only four sensors have unbroken records for the whole period. Changes in subglacial pressure recorded at the sensors are due to several factors including large clasts embedded in the ice being dragged over a sensor (which is then recorded at only one sensor) and changes in the water pressure at the bed (which is then registered at several sensors). Records show that major changes (of up to 30%) in the subglacial pressure occurred during the study period, but generally did not show a corresponding change in surface motion. Also, major changes in surface motion did not necessarily have a corresponding signal in the subglacial record.

3-component geophones were also installed on the surface of the glacier at the surface motion stations, as well as underneath the glacier in a bedrock tunnel within a few metres of the glacier-rock interface. The subglacial geophone recorded between ~50 and several hundred low amplitude (~10 μm/s) seismic events per day that are not well correlated with events recorded on the surface. Hourly event time series show fluctuations from 0 to over 100 events per hour, which indicates a highly dynamic system. Events are identified using a standard short-term average/long-term average P-wave first arrival detection algorithm and are classified by their frequency characteristics using artificial neural networks. The basal event time series correlates well with changes in surface meteorological conditions and individual quasi-periodic events show source-time functions consistent with stick-slip sliding behavior at the ice/rock interface.

SESONAL FLUCTUATIONS OF VELOCITIES ON HANS GLACIER ICE-CLIFF (SPITSBERGEN, SVALBARD)

Jacek A. Jania[1], Dariusz Ignatiuk[1], Sebastian Sikora[2]

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Since measurements of movement of the calving glaciers in polar night is very difficult, new techniques has been used to observe velocities at cliff terminus. The research was carried out on Hans Glacier, which is a medium size (area of c. 56 sq. km, up to 400 m thick) polythermal tidewater glacier located in South Spitsbergen. The glacier extends from more than 500 m a.s.l. down to calving cliff in Hornsund Fjord. Measurements were carried out by the Riegl FG21-LR laser distance ranger every 10 minutes. Data from middle December 2009 to May 2010 has been analyzed. Additionally oblique time lapse photos by use of the Canon A530 camera has been taken from the eastern slopes of the glacier valley during polar night 2009/2010. Preliminary results of are presented in the paper. Observed displacement of the ice-cliff amount 112,8 m for 149 days with gives mean velocity 0,76 m per day. Cliff velocities varies between 0,5 to 1,5 m/day (91% of values). It has been observed that in analyzed period velocity at the ice-cliff was more than 2 times higher than on stake 4 located c. 3,5 km upstream from the glacier terminus and surveyed by time lapse static GPS survey. In some periods of time, velocity of cliff had repeatable pattern of fast and slow velocity. It is connect with released and accumulate of stress. After time of slow down of cliff, faster displacement had been observed (10 m/day). Data from distance meter has been compared with meteorological data from the Polish Polar Station. Any significant simple correlation has been found. However influence of liquid precipitation and positive temperatures are observed. Preliminary results show relatively high velocity of glacier flow near terminus during dark winter and significant speed up events associated to warming spells with rainfalls. Calving was not noted during winter until the last week of May, except 2-3 small cases. Dynamics of tidewater glacier terminus during dark winter is more vigorous than previously thought.

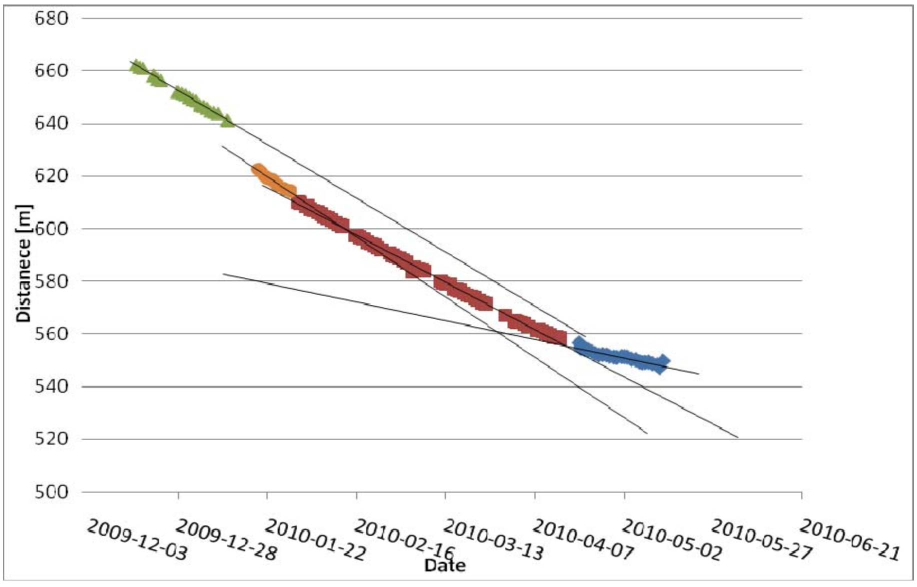

Fig.1. Distance between laser distance ranger (Riegl FG21-LR) and Hans Glacier ice-cliff from 16th December 2009 to 13th May 2010. Note slowing down at the end of spring.

Greenland ice cores tell tales on the extent of the Greenland Ice Sheet during the warm climate Eemian period 120.000 years BP

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A new Greenland ice core has been drilled. The first results from the NEEM ice core are presented and then combined with the results from the other deep ice cores from the Greenland Ice Sheet.

All the ice cores drilled though the Greenland ice sheets have been analyzed and the results show that all the ice cores contain ice from the previous warm Eemian period near the base. Is it thus clear that the Greenland Ice Sheet did exist for 120.000 years ago in the previous warm period where it was 5 deg C warmer over Greenland.

The difference between the Eemian and the Holocene stable oxygen isotope values have been combined with an ice sheet flow model constrained by the ice core results and internal radio echo sounding layers to estimate the volume of the Greenland Ice Sheet 120.000 years ago.

The results show that South Greenland has not been ice free during the Eemian period and that the sea level contribution from the Greenland Ice Sheet has been 1-2 m.

Mapping the Surface and Surface Changes of Icelandic Ice Caps with LIDAR

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Icelandic glaciers have an area of ~11000 km² and store a total of ~3600 km³ of ice, corresponding to ~1 cm rise in global sea level. As a part of and following the International Polar Year (IPY), an accurate DTM of Icelandic ice caps is being produced with airborne LIDAR technology. It is important that the glaciers are accurately mapped now when rapid changes have started in response to warming climate. The mapping is organised by the Icelandic Meteorological Office and the Institute of Earth Sciences of University of Iceland and carried out by the German company TopScan. Financial support has been provided by the Icelandic Research Fund, Landsvirkjun (the National Power Company of Iceland), The Icelandic Public Road Administration, Reykjavík Energy Environmental and Energy Research Fund and the National Land Survey of Iceland. As of now more than 4500 km² have been surveyed in this effort including Hofsjökull, Mýrdalsjökull, Eyjafjallajökull, Snæfellsjökull, Eiríksjökull and the southeastern ice flow basins of the Vatnajökull ice cap. In addition, most of Langjökull (~900 km²) was mapped by LIDAR in 2007 by the Scott Polar Research Institute. Preliminary comparison of the LIDAR DTMs with older maps confirm the rapid ongoing volume changes of the Icelandic ice caps which have been shown by mass-balance measurements since 1995/1996. In addition to the LIDAR surveys, a reanalysis of available digital photogrammetric maps of the ablation areas of the glaciers from the 1990s will be carried out using the new LIDAR DTMs in the proglacial areas and on nunataks as a reference to reduce systematic bias in the earlier maps. This will make it possible to obtain an accurate estimate of ice volume changes of Icelandic ice caps during the last 10–20 years.

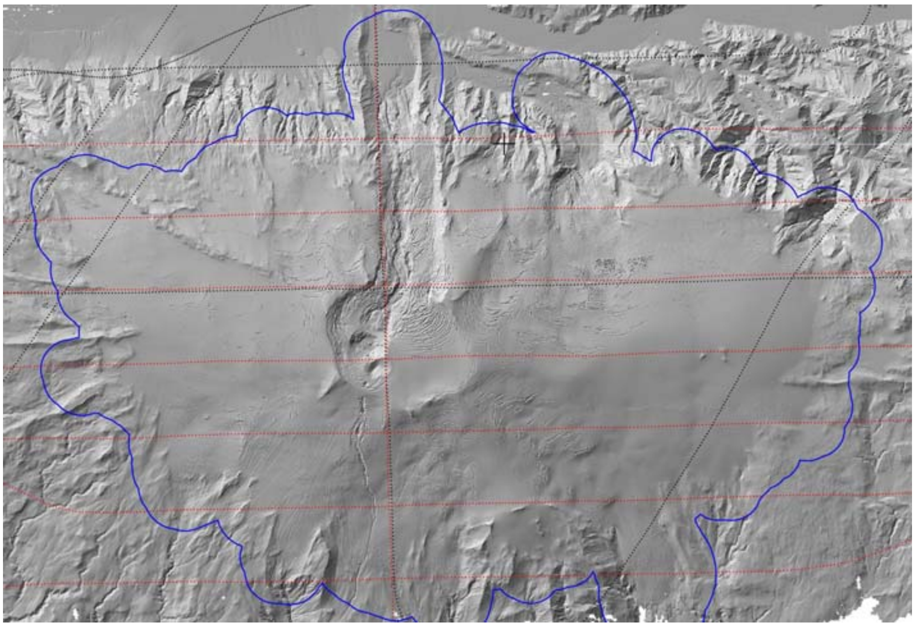

Figure: A shading of a preliminary version of a LIDAR DTM of the Eyjafjallajökull volcano (70 km²) surveyed on 10 and 11 August 2010. Craters that erupted in April 2010 are clearly visible within the top caldera. A lava stream that flowed to the north from the crater and paths carved by outburst floods caused by the eruption down the flanks of the mountain both towards north and south can also be seen. Further data processing will eliminate the scars in the DTM that can be seen at some locations in the image.

Passive Seismic monitoring of in-situ lake drainage on the Greenland Ice Sheet

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A catastrophic lake drainage event was monitroed continuously using an array of
4.5 Hz 3 component geophones in the Russell Glacier catchment, Western Greenland.
Satellite imagery and helicopter reconnaissance identified a healed crevasse over a 1 km in length within the lake. The seismic array was subsequently deployed with this crevasse as the focus. However, extreme ablation results in dramatic changes in the terrain during the summer months making deployment of such instruments both hazardous and difficult. Many thousands of events were recorded often with events happening simultaneously but at different locations. In addition, different styles of seismic events have been visually identified. The presence of such a large and diverse dataset provides insight into the complex system of catastrophic lake drainage. During such drainage event large crevasses open allowing the contents of the lake to drain within the matter of hours with hydraulic fracture
believed to be the predominant mechanism. The propagation of surface-meltwater and the path that it takes has significant consequences for glacial and ice sheet dynamics. Future processing of the data will allow for the greater understanding of the extent of deformation, mechanism and influence such a drainage event has on ice sheet dynamics.

FINNARP 2009 Antarctica expedition: Solar radiation transfermeasurements in snowpack

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Snow and ice covers 98% of all surfaces in Antarctica and it is one of the principal components of our global climate system. Therefore understanding the evolution and spatial variations of the optical properties of Antarctic snow cover is crucial. Antarctica also provides a unique environment to study the geophysics of the snow cover. We present here results from FINNARP 2009 expedition which took place during austral summer 2009-10 with comparison to data collected during FINNARP 2004 expedition. Most of the measurement sites were within radius of 50 km from the Finnish research station Aboa (73o 02.5'S, 13o 24.4'W) with one longer transect from Aboa to Swedish station Svea. Transect was approximately 180 km in length. The radiation transfer measurements were conducted using time series recording Photosynthetically Active Radiation (PAR) -sensors and manual spectral measurements with a spectroradiometer. From these measurements transmittance and extinction coefficient were calculated. Also physical characterization of snow stratigraphy was done, including thickness, density, hardness (hand test), and grain size and shape (photographs from crystals). Snow Fork designed and manufactured by Toikka Oy was used to measure the liquid water content (wetness). Also measurements scheduled to conduct during FINNARP 2010 expedition are presented.

The quest for the lost picture and surface detection change of the Greenland Ice Sheet

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Past analogues to future change require long term records for ice marginal behavior around the entire Greenland Ice Sheet. Repeated surveys by satellite and airborne radar and laser altimetry have since the 1980s together with gravitational satellite estimates over the last decade shown a significant thinning at lower altitudes of the Greenland Ice Sheet, while the interior is in balance or thickening. The loss of ice is estimated to between 47 and 227 Gt per year, equivalent to 0.1-0.6 mm global sea level rise. The loss is concentrated in the southern dome of the ice sheet and can hardly be explained by increased ablation or decrease in snow accumulation. Instead, glacial dynamic processes are thought to have accelerated ice flow towards the coastal areas with increased release of ice and meltwater into the ocean. This implies a complex relationship between the interior of the ice sheet, where most of the ice is located, and the marginal zone where local climatic and topographical conditions control the discharge of ice – and therefore the intensity of response to climatic change.

The data collection involves a compilation and digitalization of data from more than a century of geological field work, unpublished historical material, and finally mapping of selected areas by combining remote sensing tools with field-based glacial-geomorphological interpretation of the landscape. We also seek to quantify the net thinning pattern at the ice margin and sub-marginal areas using trimline altitudes on valley sides, and, not least, nunataks situated far from the ice margin to quantify volumetric changes and estimate the sensitivity of the margin to temperature change (ΔVolume loss per °C). Upstream nunataks show the amplitude of former ice thickness and serve as a master signal for a certain sector of the ice sheet. The data source is based on multi-temporal aerial photographs and satellite imagery processed through digital photogrammetry and field sampling in selected areas. Here, we present the quest for some of these images in long lost achieves and their application in a climate change context.

Inferring histories of accumulation rate, ice thickness, and ice flow from ice-sheet internal layers

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The spatial and temporal histories of accumulation and ice-sheet flow are necessary to recreate ice-volume and sea-level histories, and are important to correctly interpret ice-core chemistry. Internal layers preserve information about how the ice sheet responded to past spatial and temporal changes in accumulation rate and ice flow, and present-day internal-layer shapes observed by radar are an accessible remaining record of this information. We solve an inverse problem on a spatially limited flowband domain to infer transients in accumulation rate, ice-sheet thickness, and ice flow from the shapes of deep internal layers and other available ice-sheet data.

The solution to this inverse problem depends on the data available, on the ability of the ice-flow model to generate realistic realizations of the data, and on the constraints used in the inverse algorithm in order to stably find a unique solution. To assess the capability of our new algorithm to infer histories of accumulation rate and ice flow, we first solve the inverse problem using synthetic data. Comparing the inferred parameter values to the known parameter values allows us to assess how well we can recover each parameter value for a given test. We solve inverse problems to infer spatial and temporal variations in accumulation rate at different temporal resolutions over the past tens of thousands of years. While variations in the spatial pattern of accumulation can drive divide migration, we expect that externally forced changes in ice flux at the boundaries of our limited domain (e.g. from changes in sea level or in ice-stream activity) will be the primary control on longer-term variations in ice-divide position. This general approach is well-suited to data in the vicinity of ice divides. We will discuss preliminary results using data near the West Antarctic Ice Sheet-Divide ice-core site.

Brine channel formation in sea ice - Turing structures or phase field pattern?

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The web of brine channels in sea ice is the natural habitat for many psychrophilic microorganisms. This brine channel texture moreover influences the heat exchange between the ocean and the atmosphere as a consequence of the permeability. The mechanismsof brine channel formation in sea ice are sophisticated. Especially the sea ice texture depends on the salinity and the temperature. The brine channel system in sea ice avoids the thermodynamical equilibrium driven by salinity exchange between both phases, ice and water. We have developed a phenomenological model for the formation of brine channels due to the Ginzburg-Landau theory of phase transitions considering the morphogenesis according to Turing[1]. In order to enforce conservation laws we incorporate presently phase-field methods in the model. The differential equations connecting the hydrodynamic equations with the statistical thermodynamics are solved numerically in two dimensions. In contrast to the Turing structures the phase field method considers the salinity as a conserved quantity. This leads to more realistic structures.

References:
[1] B. Kutschan, K. Morawetz, and S. Gemming. Phys. Rev. E 81, 036106 (2010).

DMI meteorological data available for glaciology –and vice versa!

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Abstract:
The Danish Meteorological Institute (DMI) has performed weather observation at Greenlandic coastal stations since 1873. Many climatological daily and monthly time series are available for directly download through publication in the DMI Technical Report series at www.dmi.dk . A new DMI initiative (fall 2009), has now also made many observations available for education and research free of charge for delivery etc. and the 2010 update of this is published as 'DMI Technical report No. 10-08. Lone Seir Carstensen and Bent Vraae Jørgensen. Weather and Climate Data from Greenland 1958-2009 Dataset available for research and educational purposes. Descriptions and Documentation of Observations of Temperature, Precipitation, Wind, Cloud Cover, Air Pressure, Humidity and Depth of Snow. Copenhagen 2010', the report being available for download as http://www.dmi.dk/dmi/tr10-08.pdf .

Because of the growing use of real-time satellite transmission of meteorological data from glaciology research stations, DMI since 2007 has followed the WMO (World Meteorological Organization) recommendation of developing strategies to facilitate closer cooperation between Meteorological Services (e.g. DMI) and research programmes (e.g. GC-Net and PROMICE) so that the available meteorological observations can be of use to operational meteorology and the meteorology research community. The first tryouts of operational use in numerical weather prediction of station level pressure and temperature from the GC-Net data were successfully performed by DMI summer 2010. Accordingly a Memorandum of Understanding regarding the dissemination of relevant GC-Net meteorological observations into the GTS (the WMO Global Telecommunication Network) for global exchange within WMO to improve numerical weather prediction for Greenland territory for the benefit of the protection of life and property and other public interests and to support atmospheric science and education was signed at DMI on October 8th 2010 by DMI director-general Peter Aakjær and GC-Net principal investigator director professor Dr. Konrad Steffen.

Characterising subglacial conditions and processes for land terminating section of the Greenland Ice Sheet using geophysical methods

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The purpose of the presentation is to inform about the aims for the recently started PhD project.

Although our general knowledge on glacier hydrological processes and conditions is advanced, it is based on research performed on a hand-full of mainly small (<10 Km^2) glaciers, no studies have been made on ice sheets. Much of the processes found on small glaciers can likely be scaled up to serve as models for ice sheet hydrology. However, ice sheets because of their size, involve different problems that need to be resolved before a useful model of ice sheet hydrology can be applied. In general, there is also a need to couple ice dynamics to the basal hydrology in order to significantly improve predictive numerical ice flow models; this requires much improved understanding of the processes on the ice sheet scale.

The main objective of the study is to contribute to answering the following questions:

- How does the regional scale connections between subglacial hydrology, ice flow and melt-water production look like?
- What are the controls on surface to bed melt water routing?
- How does the basal hydrological system respond to variable inputs of melt water?

The main task for the project will be to study spatial variability of subglacial hydrology/thermal zonation using radio echo soundings. These properties will be correlated with ice flow and melt-water production at the surface to get a better understanding of the influence of basal hydrology on ice sheet dynamics on both a regional and local scale.

The aims of the study can be summarized in:

1. Establishing a digital elevation model and reflectivity maps over the investigated area. Comparison with surface and satellite derived ice velocities for basal condition constraints on ice dynamics in the investigated area.
2. Comparison between bed reflectivity and surface water input points to determine sub- and englacial spatial variability to surface.
3. Detailed study of reflectivity around moulin/lake to delineate patterns in basal reflectivity and conditions to increase understanding of surface to bed routing of water.
4. Comparison of reflectivity data, hydraulic potential calculations and direct basal water pressure measurements in order to understand spatial variability of hydrological conditions better.

Changes in the aims may be necessary depending on outcome of fieldworks and the interpretation of the results.

Mapping snow and ice cover across mid Greenland - a CART approach

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The free and easily available satellite imagery, from the Moderate Resolution Imaging Spectrometer (MODIS) and the Landsat program are widely used to assess change in snow and ice cover over land. This thesis attempts to combine the high-temporal resolution imagery of MODIS with the high-spatial resolution of Landsat, to map the yearly change in snow/ice cover across mid Greenland, by using a supervised regression and classification tree (CART) approach to produce a percentage snow/ice for each pixel in a MODIS scene, derived by Landsat classifications. From independent validation data the overall mean absolute deviation of the resulting maps was estimated at 12.69% and a mean error of prediction (overfitting) at 6.4%. The quality of the classifications compared to Landsat based classifications showed a precision of 94.3% to 97.7%. Furthermore the classifications were tested against MODIS MOD10A2 snow cover product and showed an agreeance of 95.9%. In general the results produced by the CART model show good potential in remote sensing classifications of seasonal snow/ice cover in the Low-Arctic.

Spatial distribution of snow depth at Hardangervidda Mountain, Norway, measured by airborne laser scanning

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It is difficult to obtain measurements of snow depth distribution over a large area at a resolution that approximates the scale of its true variability. Such measurements are needed in order to validate spatially distributed snow simulations or observations from satellites. Manual data collection using snow stakes or probes, is labour intensive, expensive, and potentially dangerous in steep mountain environments. These issues call for new technology such as airborne laser scanning, which is a powerful tool for surveying large area within a short period. This study presents laser scanner mapping of snow depth in the mountain plateau Hardangervidda, Norway, in two different years (2009 with less snow than normal and 2008 with more snow than normal) at the peak time of snow accumulation during the winter. The extent of the survey area is more than 240 square kilometres.

We present the distribution of snow depth as derived from the laser scanning data and the results of a comparison of the measured snow depth and snow water equivalent (based on additional snow density measurements) derived from the laser scanning data with simulations using a snow model used for producing the Snow Maps for Norway available at http://senorge.no, which is run on a 1 km and 1 day resolution. The analysis showed that (1) the large scale spatial pattern of snow distribution of is well captured by the seNorge model and (2) that relatively large differences in amount (volume and depth) of snow between the measured and modelled snow were present.

The historical global sea level budget

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Abstract
We analyze the global sea level budget since 1850. Good estimates of sea level contributions form glaciers and small ice caps, the Greenland ice sheet and thermosteric sea level are available over this period, though considerable scope for controversy remains in all. Attempting to close the sea level budget by adding the components results in a residual displaying a likely significant trend of about 0.37 mm/yr from 1955-2005, which can however be reasonably closed using estimated melting from unsurveyed high latitude small glaciers and ice caps. The sea level budget from 1850 is estimated using modeled thermosteric and inferences from a small number of mountain glaciers. This longer term budget has a residual component that displays a rising trend likely associated with the end of the Little Ice Age, with much decadal scale variability that is probably associated with variability in the global water cycle, ENSO and long-term volcanic impacts

The Surface Mass Budget of the Greenland Ice Sheet 1989 – 2009

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The surface mass budget of the Greenland Ice Sheet is a key term in initialising and running ice sheet models. Mass budgets from ice sheets are also important in earth system models in terms of both freshwater flux to the oceans and to atmospheric processes related to surface topography and albedo. However, the lack of observational data over large parts of the ice sheet complicates the calculation of present day surface mass budget and climate models thus provide a valuable means to determine both the present and projected future surface mass balance of the ice sheet, which can in turn be used in other glaciological applications.
The HIRHAM5 regional climate model has recently been upgraded to better represent surface and near surface processes over glaciers, ice sheets and snow covered ground. The model also explicitly calculates the surface mass budget and includes the effects of meltwater retention and refreezing within the snow pack as a source of accumulation. Here, we present results from a climate simulation over the period 1989 – 2009, driven by the ERA-Interim reanalysis dataset at the boundaries, at a resolution of ~25 km. The surface mass budget has been calculated through the period and we compare our results with those of other analyses including Ettema *et al*. (2009) and Box *et al*. (2009). Validation of key climatic variables against observations made at GC-Net weather stations indicates that important boundary layer processes are being well captured and give us further confidence in the calculated mass budgets. Future work will produce projections of mass budget over a 200 year period and these initial results are thus an important initial validation step in the process of projecting future change in Greenland.

Impact of large-scale circulation modes, regional temperature and precipitation on the mass balance of South Norwegian glaciers

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Maritime mountain glaciers are highly sensitive indicators of climate variability and a vital source of sustainable energy in Norway. The current research project DYNAMO-KG (Dynamic Statistical Modelling of Climate Related Glacier Mass Balance Changes in the Middle Latitudes) aims to develop a statistical model linking large-scale climate phenomena in the Northern Hemisphere to mass balance changes of selected glaciers in South Norway. It applies deduced statistical transfer functions for observed present-day conditions to global climate model simulations of the fourth IPCC assessment report to give a probabilistic estimate of future glacial mass change for a wider region. Localised disparities are, however, carefully considered.

Sea level pressure, temperature and precipitation data from National Centers for Environmental Prediction (NCEP) re-analyses (1948 - present day) and mass balance data from the Norwegian Water Resources and Energy Directorate (NVE) form the data basis for the statistical model. The first and last year of available mass balance records vary between the glaciers, but are all within the 1948 to present day window. The seven glaciers that proved suitable for this research project cover coastal and inland regions and, therefore, represent both the maritime and the continental glacier regimes in Norway.

The statistical model consists of a cross-validated stepwise multiple regression analysis between large-scale climatic phenomena (predictors), such as the North Atlantic Oscillation (NAO) and the East Atlantic pattern (EA), and glacier mass balance data (predictands). The data from NCEP re-analyses are used to construct predictor time series for each season. Summer and winter mass balances of each glacier are treated as seperate predictands. In order to take into consideration the phase of advance and possible change in glacier regime of some Norwegian glaciers, the analysis is carried out for predictor-predictand temporal overlaps in time periods 1949-1988 (pre-advance phase), 1989-2008 (includes advance phase) and 1949-2008 (total time span). This gives insight into the relative influence of the variability of the climatic predictors on the variability of each of the glaciers mass balances and shows how this varies with seasons and changes in glacier regime.
We find that large-scale climate phenomena account for more variance in mass balance of maritime glaciers than for the variance in mass balance of glaciers underlying a more continental regime. Furthermore, results indicate that the constructed predictors have most influence during the time period of 1989-2008.

Seasonal evolution of subglacial drainage and ice motion at the margin of the Greenland Ice Sheet

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The Greenland Ice Sheet (GrIS) contains 7m of potential eustatic sea level rise yet its present mass balance and future contribution to sea level is poorly constrained (IPCC, 2007). Recent observations indicate that mass loss near the margin is accelerating, in part the result of increases in ice motion. Surface meltwaters are known to access the ice sheet base and affect ice motion through the lubrication of basal flow. However, the ice-motion response to seasonal variations in meltwater inputs remains poorly constrained both spatially and temporally. Here, we present ice motion data from GPS sensors located along a 100 km transect at the western margin of the GrIS in the 'Russell Glacier' catchment. Our sensors reveal substantial increases in summer motion, of up to 250%, compared with winter background. These motion variations display an upglacier evolution over the course of the summer, with initial velocity enhancement occurring earlier at sites close to the ice margin. The pattern of ice motion and hydrological characteristics of the proglacial runoff (discharge, e.c. and turbidity) suggests a seasonal evolution in the subglacial drainage system similar to hydraulic-ice dynamic forcing mechanisms observed at smaller valley glaciers. Our findings show that the relationship between melt and ice motion varies both at-a-site and between sites during the melt season. This variability must be incorporated into ice-sheet models to improve future predictions of ice-mass change.

Historical glacier fluctuations of Jostedalsbreen and Folgefonna, southern Norway, reassessed by new documentary evidence, and their connection to climate

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Glaciers are sensitive indicators of past climate and thus valuable sources of climate history. To reconstruct glacier variability for the time before the onset of direct measurements, historical and geomorphological evidence has to be used. Here we present new glacier length reconstructions for selected outlet glaciers of Jostedalsbreen and Folgefonna in southern Norway. A wealth of different historical sources (drawings, paintings, prints, photographs, maps, written accounts; about 400 documents) allows reconstruction of glacier length variations for the last 300 (Jostedalsbreen), and 200 years (Folgefonna), respectively. We present historical material newly collected for Briksdalsbreen, Bøyabreen, Store Supphellebreen, Bergsetbreen, Nigardsbreen, Lodalsbreen (all Jostedalsbreen), and Bondhusbrea, Buerbreen (both southern Folgefonna).

At Jostedalsbreen, glaciers reached their Little Ice Age (LIA) maximum extent around AD 1750. Nigardsbreen is best documented, where also the advance in the mid-18th century can be quantified. However, the nearby Bergsetbreen shows more distinct glacier advances and retreats since the LIA maximum extent. A minor peak is documented in the 1870s for all outlet glaciers of Jostedalsbreen studied. At southern Folgefonna, the LIA maximum was attained in the late 1870s (second peak around 1890). So far, there is no direct historical evidence for the time before AD 1800.

In a second step, a non-linear back-propagation neural network has been trained with high-resolution multi-proxy reconstructions of temperature and precipitation (input data) and reconstructed glacier length variations (output data). By processing the used climate parameters with a sensitivity analysis based on the neural network we investigate the relative importance of different climate configurations during selected glacier advance and retreat periods. The results confirm the strong influence of (winter) precipitation on glaciers in western Norway. Finally, there is a striking asynchrony between Alpine and Scandinavian glaciers during the LIA and in the 20th century. LIA maximum peaks occurred around 1600/1640 and 1820/1850 in the Alps, and around 1750 (1870–1890) in southern Norway.

Mass change of Vestfonna, Svalbard Archipelago

By Veijo Pohjola, Rickard Pettersson, Björn Carlsson, Geir Moholdt, Chris Nuth, Mariusz Grabiec , Leszek Kolondra and John C. Moore

During IPY4 (2007-2009) DGPS ground elevation profiles where accomplished by snow-mobile traverses across the 2,500 km^2 sized Ice Cap Vestfonna situated in the northeast of the Svalbard Archipelago (80° N, 19° W). The repeated campaigns show local spatial and temporal changes of the ice cap elevation, most likely caused by changes in the wind patterns over the ice cap. Our ground profiles was aimed to follow ICESat profiles (2003-2008) and airborne NASA altimetry (1996, 2002) that criss-crosses the ice cap. Comparisons between ground DGPS altimetry and ICESat altimetry during near-in-time campaigns for both platforms in 2008 show good agreement between both series. Analyzing all the available elevation time series suggest only local changes, but brings no coherent trend in elevation change for the whole ice cap for this specific time period. On the other hand, dynamic measurements of ice flow suggest the ice cap has been in an unstable and negative mode for a century scale time period, with a kinematic ELA 150 m above but the average ELA measured during IPY4. We propose the recent decade has introduced an increase in accumulation rates, serving the ice cap to lower its ELA.

Longitudinal coupling in ice dynamics during the spring and summer regime on Storglaciären, Kebnekasie, Sweden

Helena Psaros, University of Uppsala

The aim of this study was to look at the short term variations during spring event on Storglaciären, Kebnekasie, Sweden. Two DGPS station was set up on Storglaciären in the upper (station 14) and lower part (station 7) of the ablation area. The study period lasted from April to July 2009 and the DGPS logged data every second.

There were four acceleration events during the study period but these cannot be interpreted as spring events. Spring events should lead to an increase in the overall trend of velocity. After the accelerations the velocity went back to a normal low state. The total movement of the DGPS station was ~26 m. The velocity was well correlated to the external changes in temperature and precipitation. It appears to be eleven days lag in response time from April to middle of May. The rest of the study period Storglaciären responded directly to temperature changes and precipitation events. The delay most likely depended on the hydrological system was not entirely evolved. There was a clear lag between the two stations which indicates longitudinal coupling between the upper and the lower part of the ablation area. Station 14 pushed from up-glacier until the acceleration event and after station 7 pulled from down-glacier.

A new glacier inventory for South-Eastern Greenland from LANDSAT and ASTER GDEM data: Applied methods and challenges

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The melting of glaciers and ice caps, possible long term imbalances of the mass budget of the Greenland and Antarctic ice sheets, as well as the thermal expansion of ocean water and changes in the terrestrial storage of water have been listed in the IPCC reports as the most important processes contributing to the observed global sea-level rise. The exact knowledge of glacier distribution and their topographic parameters is therefore mandatory to obtain more reliable projections of sea-level rise.

In work package 3 of the EU funded FP7 project ice2sea the University of Zurich is currently taking care for creating the related inventory data of all local glaciers and ice caps on Greenland using LANDSAT imagery acquired around the year 2000 and the ASTER GDEM for derivation of topographic parameters. Glacier mapping is based on an automated multispectral classification (thresholded band ratio), in combination with visual inspection and manual correction of the generated glacier outlines. Adverse snow conditions, debris cover, shadows, clouds and uncertain drainage divides make glacier mapping challenging in some regions of the study site. The quality of the GDEM proofed to be sufficient to obtain topographic parameters and ice divides in most cases, nevertheless some local artifacts require correction before the DEM is applied.

Of particular interest for the assessment of sea level rise is the separation of the ice sheet from the local glaciers and ice caps to avoid double counting and to be able to consider their differing characteristics and sensitivities. Examples will be shown that illustrate these aspects (Fig.1).

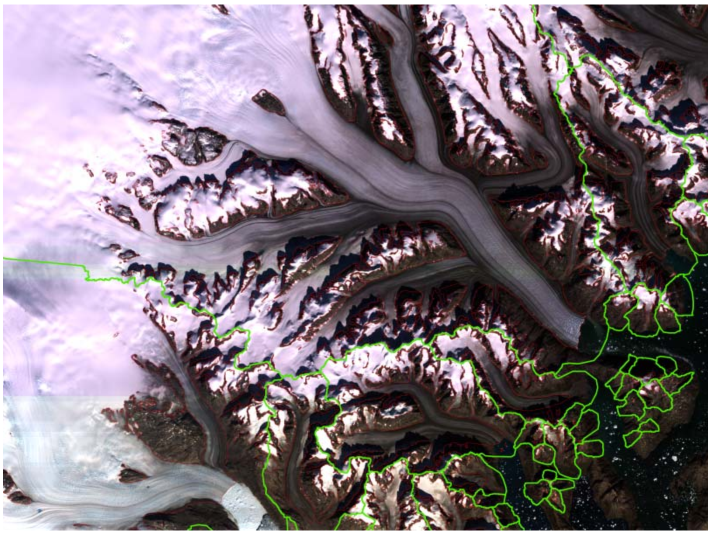

Fig. 1. Crucial step: Separation of the ice sheet from local glaciers and ice caps.

Ocean carbon uptake under different climate regimes

Katherine Richardson (University of Copenhagen) & Jørgen Bendtsen (Vituslab, Denmark)

This talk examines processes influencing ocean carbon uptake from the atmosphere during different climate regimes, including processes relating to ocean circulation and sea- ice extent. We focus, however, on biological processes as these are becoming increasingly recognized as being important mediators of change in the capacity of the ocean to function as a global carbon sink.

Specifically, we examine temperature effects on

a) the structure of planktonic ecosystems and resulting impacts on carbon turnover and transport and

b) bacterial metabolic rate and the resulting influence on carbon export to the inner reaches of the ocean under warm and cold climate conditions.

Quantifying the predictive uncertainty of numerical mass balance models

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Spatially distributed, physically based mass balance models are valuable tools forexploring the detailed spatial and temporal responses of mountain glaciers to climate forcing. Indeed, the last two decades have seen their application become increasingly widespread, partly due to the increased availability of computational resources, and partly because scientists have a natural tendency to adopt realistic descriptions of real-world processes. However, while considerable progress has been made in the development of sophisticated numerical models, very little attention has been given to their predictive uncertainty. In particular, glacier models have traditionally been calibrated (or "tuned") in order to identify a single set of model parameters (e.g. snow density, surface albedo, temperature lapse rate) such that the model's behaviour closely matches that of the real system it represents. But, as will be demonstrated for a valley glacier in Svalbard, it is often difficult (if not impossible) to find a single "best" set of parameter values that reproduce all the characteristics of real-world observations. Instead, multiple equally plausible parameter sets will usually exist, which undoubtedly introduces a degree of uncertainty into model forecasts. Despite knowledge of this problem within the environmental science community, there has yet to be a rigorous attempt to quantify the predictive uncertainty of glacier mass balance models. Hence, it is argued that a new calibration paradigm is urgently required to provide more useful information on the uncertainty associated with ongoing and future projections of ice volume and sea level rise.

Dating and multivariate analysis of Svalbard ice core data: a nitrogen perspective in 20th century

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Despite its remoteness from major anthropogenic polluting sources as compared to most Arctic glaciated areas, Svalbard has shown increasing interest those last decades by environmental scientists. One of the main reasons for this is that Svalbard is located at the crossroads of major oceanic and atmospheric currents from the Arctic, and is thereby affected by long-range transport of contaminants from industrial areas, including Eastern and Western Europe and Canada. Another reason, of particular interest to glaciologists, is that Svalbard ice caps are affected by seasonal melt, which has long been thought to irreversibly disturb the enclosed climate proxies. Ice core data from various sites in Svalbard have been reanalyzed here from a statistical point of view in order to investigate the potential for differential trends in environmental proxies and solute relocation. Dating models were also built, using both sulphate peak recognition and wavelet analysis techniques. Multivariate analysis allowed us to identify interesting concordant trends between nitrates, sea salt and sulphate during 20th century, which can be considered for further ice core/snow pit studies. Various hypotheses are discussed to explain these trends, keeping emphasis on nitrate dynamics (which are still poorly known but paramount for the study of the oxidation chain of atmospheric reactive nitrogen).
This work is part of the interdisciplinary NSINK Marie Curie program, the scope of which is to unravel the enrichment of Arctic terrestrial and aquatic ecosystems by reactive atmospheric nitrogen from low latitude emission centres.

Modeling the flow of the Antarctic Ice Sheet and ice shelves with the model SICOPOLIS and the SeaRISE set-up

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Abstract:
The dynamics of ice sheet and ice shelves is different; shear stress is the dominant in ice sheet but lateral stress is dominant in ice shelves. SICOPOLIS is dynamic/thermodynamic ice sheet model which had applied to various ice sheets but ice shelves had not implemented. An ice shelf model is established and coupled to a ice sheet model SICOPOLIS. Shallow Shelf Approximation is applied to ice shelf regions. Calving front strees conditions and thermodynamics of the ice shelves are also implemented. The Antarctic Ice Sheet is simulated by using the model with the SeaRISE set-up. Two conditions are set for simulations; One is ice sheet/ice shelves coupled analysis, the another is no ice shelves condition. Then flux through the grounding line is compared. Shelfy flow treatments are also considered and it is applied to the ice sheet.

Basal drag pattern inferred from surface velocities for Vestfonna ice-cap (Svalbard) with a Full-Stokes model

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Svalbard is an archipelago in the Arctic Ocean. Nordaustlandet is the second largest island in the archipelago. The island has two major
ice-caps: Austfonna and Vestfonna. These ice-caps on Nordaustlandet represent one of the largest ice-covered areas in the Eurasian Arctic.

In the current project we focus on a present-day simulation of the Vestfonna ice-cap. In this case the Vestfonna and Austfonna ice-caps can easily be modelled separately since the two ice-caps are currently not connected.

To conduct this present day simulation it is crucial to gain a better understanding of the occurrence of basal sliding and possible surge areas. Even though low temperatures and low balance gradients generally result in low flow rates on the glaciers of Svalbard, the Vestfonna ice-cap is characterized by fast-flow regions (velocities over 200m/yr and periodically even more). We use the full-Stokes finite element code Elmer/Ice (CSC-Finland) to model the flow of ice on the Vestfonna ice-cap. The spatial pattern of basal drag is inferred from the measured surface velocities using a Robin inverse method.
The obtained results will be discussed with respect to existing fast flow-regions and occurring surging events.

In a latter step prognostic future simulations are planned.

Data access was made possible by the Kinnvika IPY project consortium.

Mass balance of the Greenland Ice Sheet – From volume to mass change.

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Measured from ICESat the Greenland Ice Sheet (GrIS) has lost volume with a rate of 237 km^3 per year in the period from 2003 to 2008. A volume change of the ice sheet cannot directly be converted into mass change.

In order to convert the volume change of the GrIS into mass loss numerous corrections have to be applied to the elevation change observed from ICESat. The most prominent of the corrections is the change in firn compaction during the period of observation as a result of changes in accumulation and surface temperature. Here we show the model formulation of the firn compaction, which is needed in order to correct the observed elevation change. This correction is applied to the observations before the conversion of volume change to mass change of the GrIS from a temperature dependent model of surface density.

The observed volume change of the GrIS is equivalent to a mass loss of 210 Gt per year. This estimate is in consensus with GRACE observations covering the same period of time. However, our mass loss estimate is showing greater spatial resolution than GRACE and might be used to interpret local changes in the ice sheet dynamics.

Ice thickness and bottom topography of Fimbul ice shelf revealed by a ground based FMCW radar

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We show the first results of the continuous radar profiles measured in the 2009-2010 summer season on Fimbulisen, the largest ice shelf in Dronning Maud Land (DML), Antarctica. The ice shelf is fed by Jutulstraumen, the largest outlet glacier from DML, and it plays an important role in processes in the Weddell Sea area. We used a ground-based FMCW radar with a center frequency of 350 MHz to assess the basal topography and the ice thickness of Fimbulisen. Our results reveal that the bottom topography of the ice shelf is highly variable. The long profile along the main flow line shows several sharp of up to 100 m thickness variations over distances less than 5 km. Local thinning of the ice often aligns with locally higher accumulation. These sites are also visible in the TerraSAR-X mosaic. Strength of the bottom reflection varies strongly, and is often lost at sites of local thinning. No bottom reflection is received in the areas closer to the shear zones at the eastern and western margins of the icestream.

Using atmospheric circulation patterns to assess precipitation over Greenland in the EC-Earth model

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In this study we seek to validate and correct simulated precipitation over Greenland from the climate model EC-EARTH. The goal is to use the model output as forcing of an ice flow model. Annual and monthly mean precipitation rate output from an EC-EARTH AMIP type experiment spanning the period 1979-2008 is compared with accumulation maps based on observations as well as the monthly means from the DMI weather stations and ERA-40/ERA-Interim data for the same time period. In general, the model captures the large scale patterns as well as the seasonal variability well, but it simulates higher precipitation rates in coastal areas especially in southeastern Greenland and too dry conditions in the interior compared to accumulation maps. We indentify relationships between Greenland precipitation patterns and the large scale atmospheric circulation patterns using ERA-40/ERA-Interim data by application of principal component analysis. EC-EARTH simulates the large scale atmospheric circulation patterns well in comparison with that of the ERA-40/ERA-Interim. Therefore the identified relationships may be used to guide the correction and downscaling of the global climate model output before it is applied as forcing of ice flow models.

Terrestrial photogrammetry for velocity measurement of Kronebreen calving front

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Abstract

Crevasse tracking in optical satellite images has successfully been used for mapping glacier velocities. Temporal resolution is restricted to the repeat orbit periods, and the spatial resolution according to recording geometry. Terrestrial photogrammetry offers an advantage in both temporal and spatial resolution, but introduces other challenges. We have applied terrestrial photogrammetry close to the calving front of Kronebreen, in order to map velocities close to the terminus.

Two cameras are placed near the front: One is 2 km south west and one is 1 km north east of the measured points. They records photographs every hour and every sixth hour. In this project we aim to analyses images from June to August 2007, May to October 2009 and April to August 2010.

We have estimated the possible accuracy of the results, and as an initial test we use recordings every second days for velocity measurements. We now focus our work on this accuracy estimate, to determine which temporal resolution can be used. The most important contributions to the uncertainty are co-registration of images, matching technique, georeferencing and accuracy of elevation model, and image quality which depends mainly on weather conditions. The accuracy of velocity measurements also depends on the glacier speed. We present velocity results and error assessment for 2007 and 2009. Results from 2007 are compared to Formosat satellite images velocities. Preliminary results show an average velocity of 2.2 m/day for summer 2007, and the standard deviation to velocities measured in Formosat images ranges from 0.16 to 0.25 meters per day.

High-Resolution Continuous Flow Analysis of chemical signals in Greenland ice and snow

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Ice cores from Greenland and Antarctica have demonstrated the great value of the polar ice caps as sensitive archives of atmospheric composition and climatic variability. Soluble and insoluble particulates deposited in the ice can be measured and used to interpret climate variations, as well as studying glacial stratigraphy and developing ice core chronologies. Spatial (depth) resolution of chemical analyses is critical to obtaining the oldest and most reliable possible ice core chronology. At the Centre for Ice and Climate, we have developed a Continuous Flow Analysis (CFA) system in which 55 cm long sticks of firn or ice can be melted and analyzed at high spatial resolution, with the ability to resolve annual layer thicknesses of 3 to 4 mm for some components. The current setup includes measurements of electrolytic conductivity, particle concentration, Ammonium (NH_4^+) and Sodium (Na). The system can also be coupled to Cavity Ringdown Spectrometers for online continuous measurements of stable water isotopes and methane gas concentrations. Results from analyses of deep sections of the NorthGRIP ice core will be presented and application of the system to determining Eemian ice layers will be considered.

In situ melting experiments: evaluating nitrate relocation after percolation events by means of stable nitrate isotopes

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ABSTRACT

The increasing input of reactive nitrogen (Nr) as consequence of anthropogenic activity has resulted in an increase of atmospheric Nr load in the Arctic with an increment of about twofold in nitrogen deposition in Greenland during the last 100 years and since the mid-20th century in Svalbard. Nr can alter nitrogen-limited ecosystems in a way that some authors have described as a “nitrogen cascade”. To evaluate temporal trends of atmospheric nitrogen proxy data can be obtained from ice cores. Nitrate (NO_{3-}) concentrations quantified in the ice are difficult to interpret because NO_{3-} has several sources and experiences post-depositional processes such as photolysis, relocation and diffusion. To use ice core data as a proxy for past atmospheric nitrogen it is necessary to improve the knowledge about nitrate relocation in the snow after percolation events. *In situ* snow melting experiments using infrared lamps were done to estimate the effects of meltwater percolation and refreeze on nitrate concentrations at different sites in Svalbard. Snow temperatures were measured during the experiments and the snow profile was sampled for chemical analyses. Major ions and nitrate stable isotopes ratios ($\delta_{15}N(NO_{3-})$ and $\delta_{18}O(NO_{3-})$) measured in snow and ice will be employed to evaluate the relocation of nitrate. The results of these experiments are expected to improve the interpretation of nitrate concentrations in Svalbard ice cores.

Structure, morphology and water flux of a subglacial drainage system, Midtdalsbreen, Norway

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Abstract

Digital Elevation Models of the surface and bed of Midtdalsbreen, Norway are used to construct maps of subglacial hydraulic potential and drainage system structure for a series of subglacial water-pressure assumptions ranging from atmospheric to ice-overburden. A distributed degree-day model is used to calculate the spatial distribution of melt on the glacier surface throughout a typical summer, which is accumulated along the various drainage system structures to calculate water fluxes beneath the glacier and exiting the portals for the different water pressure assumptions. In addition, 78 dye-tracing tests were performed from 33 injection sites and numerous measurements of water discharge were made on the main proglacial streams over several summer melt seasons. Comparison of the calculated drainage system structures and water fluxes with dye tracing and proglacial stream evidence suggests that the temporally- and spatially-averaged steady state water pressures beneath the glacier are ~ 70% of ice overburden. Detailed analysis of the dye return curves, together with the calculated subglacial water fluxes shows that a channelised drainage system dominates the eastern half of the glacier, with smooth walled, approximately semi-circular channels in which throughflow velocities are high and dispersivities are low. Conversely, a distributed system with broad, low, rough channels characterised by low transit velocities and high dispersivities, dominates the western glacier.

Assessing glacier area change in Finnmark, northern Norway, using maps and Landsat imagery

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In the Øksfjord and Seiland region in West-Finnmark, northern Norway the five largest ice caps - Normannsjøkelen, Seilandsjøkelen, Øksfjordjøkelen, Svartfjelljøkelen and Langfjordjøkelen, have decreased in size during the last century. Mass balance and glacier length change measurements for a part of Langfjordjøkelen show a large mass deficit and area reduction over the last few decades. A detailed survey of the total glacier area changes in this region has not been performed since the compilation of a glacier inventory in the early 1970s. A semi-automatic method was used for deriving glacier outlines from a Landsat (TM) image from 2006 using different thresholds of TM3/TM5. This method uses the spectral differences between the visible (high reflection of glacier ice) and the mid-infrared (high absorption of glacier ice) spectrum. Analyses of the sensitivity of the different thresholds values used in the glacier area detection will be presented. Glacier area and length changes were extracted by comparing the new Landsat derived outlines (year 2006) with topographical maps (year 1966 and ~1900) and aerial photographs. In the period ~1900 to 2006 the estimated glacier area reduction was 54%, an area loss of 80km2. This study also discusses the uncertainties and challenges in assessing area changes when comparing different sources (imagery, maps, and inventories).

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