DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2013/3

The Dynamics and Mass Budget of Arctic Glaciers

Abstracts, IASC Network of Arctic Glaciology, 9 - 12 January 2012, Zieleniec (Poland)

A. P. Ahlstrøm, C. Tijm-Reijmer & M. Sharp (eds)

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

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Indhold

Preface

The 2012 annual meeting of the IASC Network on Arctic Glaciology (NAG) took place in Zieleniec, Poland from January 9-12, 2012. It was expertly organised by Krzystof Migala, and attracted 65 participants drawn from 18 countries. Eight young scientists from six countries received support from IASC to cover part of their costs in attending the meeting.

In all, 25 talks and 22 posters were presented and an afternoon was devoted to a discussion of tidewater glacier research in the Arctic – part of an effort being started by the NAG and the IASC Working Group on the Cryosphere to try to develop an ongoing research and training program in this area of science. The follow-up to this discussion was a training workshop for young scientists on board the Polish Research Vessel MV Horyzont II in Svalbard in September 2012, led by Jacek Jania.

At this meeting, Carleen Tijm-Reijmer took over as Chair of the NAG in place of Andreas Ahlstrøm, who we thank for his work on behalf of the network during his term as Chair. It was decided that the next meeting of the NAG will be held in Obergurgl, Austria, in February 2013, and that Carleen would be in charge of the organization.

Martin Sharp
November 2012

Programme

Monday 9 January 2012

Arrival
20.00-22.00 – Icebreaker "Aurora borealis"

Tuesday 10 January

9.00-10.45: Morning session I

Chair: Michael Kuhn

1. **Dieter Scherer, Roman Finkelnburg, Fabien Maussion:** A regional atmospheric reanalysis for studying weather and climate in Svalbard.
2. **Waldemar Walczowski:** Influence of the Atlantic Water variability on the Spitsbergen climate and ice conditions.
3. **Agnieszka Promińska:** Hydrological regime of Hornsund Fjord based on 10 years of observations.
4. **Alba Martín, Francisco Navarro, Malgorzata Błaszczyk, Javier Lapazaran, Mariusz Grabiec:** Progress in the development of techniques for estimation of the ice volume of Svalbard glaciers from GPR data.

10.45-11.15: Coffee break

11.15-13.00: Morning session II

Chair: Volker Rachold

1. **Jon Ove Hagen:** The mass balance of Austfonna Ice Cap, Svalbard.
2. **Thorben Dunse:** Seasonal and interannual velocity variations of two outlet glaciers of Austfonna, Svalbard, inferred by continuous GPS measurements.
3. **Martina Schäfer, Thomas Zwinger, Veijo Pohjola, Rickard Pettersson, Fabien Gillet-Chaulet, Tazio Strozzi, Marco Möller,John Moore:** Basal drag pattern inferred from surface velocities for Vestfonna ice-cap (Svalbard) with a Full-Stokes model in 1995 and 2008.
4. **Carleen H. Reijmer:** 5 years of mass balance and velocity observations on Nordenskiöldbreen, Svalbard.
5. **Francisco Navarro, J. Otero, J.J. Lapazaran, M. Grabiec, D. Puczko, A. Vieli:** 2D modelling of the variations of the calving front position of Hansbreen, Svalbard.

13.00-15.00: Lunch break

15.00-17.00: Presentation of posters and poster session

Chair: Martin Lüthi

- **Małgorzata Błaszczyk, Jacek Jania, Leszek Kolondra:** Seasonal and multi-year fluctuations of tidewater glaciers cliffs on Southern Spitsbergen.
- **Michał Ciepły:** Estimation of icebergs flux to the Hansbukta (Southern Spitsbergen) based on time-laps photos.
- **Dariusz Ignatiuk, Agnieszka Piechota:** Map of supraglacjal drainage system on Werenskiooldbreen (Southern Spitsbergen).
- **Keiko Konya, Tetsuo Ohata Hironori Yabuki and Tsutomu Kadota:** Glacial environment of De Long Archipelago in the Siberian Arctic.
- **Krystyna Kozioł:** Do glaciers accumulate organic matter?
- **Michał Laska:** Influence of ablation upon temperature changes in vertical and longitudinal profile of snow cover on the Hans Glacier (S Spitsbergen).
- **Bartłomiej Luks:** Uncertainty analysis of UEB snow energy mass balance model.
- **Elżbieta Majchrowska:** The dynamics of suspended sediment transport in a glaciated catchment at the beginning of the ablation season 2011 (Werenskioldbreen, Spitsbergen).
- **Jakub Małecki:** The mass balance of Svenbreen, Dickson Land, Svalbard, in 2010/11.
- **F.J. Navarro, J. Otero, E.V. Vasilenko, J.J. Lapazaran, A.F. Glazovskiy:** 3D Modeling of the dynamics of Amundsenisen icefield, Svalbard.
- **Grzegorz Rachlewicz:** Depositional efficiency related to glaciers snout dynamics changes after Little Ice Age on Svalbard.
- **Sunal Ojha, Shreedhar Maskey, Stefan Uhlenbrook:** An analysis of snow cover changes in the Himalayan region using MODIS snow products and in-situ temperature data .
- **Allen Pope Lauren Grey, Ian Willis, Neil Arnold, Gareth Rees, Finnur Pálsson, Richard Hodgkins:** Surface Topography and Change of Langjökull, Iceland from 1997 to 2007.
- **Tymoteusz Sawiński, Magdalena Korzystka, Jacek Piasecki, Jan Zelinka:** Underground "glaciation": – a case study from Dobšinská Ice Cave (Slovakia).
- **Sikora S., Ignatiuk D., Jania J., Kostka S., Głowacki P., Puczko D.:** Seasonal and short term changes of ice cliff position of a Spitsbergen tide water glacier on Hans Glacier as an example.
- **Sikora S., Budzik T., Puczko D., Ignatiuk D., Głowacki P., Jania J., Migała K.:** Meteorological and glaciological data acquisition system of Hornsund area (SW Spitsbergen).
- **Ireneusz Sobota, Marcin Nowak:** Waldemar River discharge variations in selected time scales during summer seasons 2009-2011, Svalbard.
- **Ireneusz Sobota:** Changes in dynamics and runoff from the glacial catchment of Waldemarbreen, Svalbard.

- **Joanna Szafraniec:** Outwash surfaces as indicators of dynamic state of Spitsbergen glaciers.
- **Antonie Kies, Zornitza Tosheva:** Werenskioldbreen, August-September 2011.
- **Zagórski Piotr, Grzegorz Gajek, Franczak Łukasz, Demczuk Piotr:** Post Little Ice Age evolution of the Recherchebreen marginal zone.
- **Zbigniew Zwoliński, Grzegorz Rachlewicz, Józef Szpikowski, Marek Marciniak, Marlena Makowska:** Glacier recession and activation of water flows and matter fluxes, Ebbadalen, Spistbergen.

17.00-18.30: The NAG, IASC Business Meeting

Chair: Andreas Peter Ahlstrøm

Wednesday 11 january

9.30-11.00: Morning session I

Chair: Regine Hock

1. **Jay Zwally:** Mass balance and seasonal Variations of Greenland Ice Sheet 2003 – 2008.
2. **Manfred Stober:** Long-term observations (1991-2011) of elevation change and ice flow velocity in the Swiss-Camp area (West Greenland).
3. **Ethan Welty, Tad Pfeffer, Shad O'Neel, Nathan Jacobs:** Calving Dynamics of the Columbia Glacier, AK (2000-2011 Update).
4. **Martin Lüthi:** Short term dynamics of the Greenland Ice Sheet observed with sensors in deep boreholes.
5. **Faye Wyatt, Martin Sharp:** Flow regimes, velocity variability, and the surface hydrology of the Devon Ice Cap.

11.00-11.30: Coffee break

11.30-13.00: Morning session II

Chair: Jay Zally

1. **Andreas Peter Ahlstrøm:** Programme for Monitoring of the Greenland Ice Sheet (PROMICE).
2. **Regine Hock:** Degree-day melt modeling of the Greenland ice sheet in the Parallel Ice Sheet Model (PISM).
3. **David Brugess:** Recent elevation changes across Devon Ice Cap, Canada.

4. **Wesley Van Wychen, David Burgess, Laurence Gray and Luke Copland:** Dynamics of ice caps and tidewater glaciers in the Canadian Arctic determined with a speckle tracking method.
5. **Selena Raven Cordeau:** The Agloolik Expedition - tracking the 'spirit' of snow on Axel Heiberg Island

13.00-15.00: Lunch break

15.00-17.00: Special session on tidewater glacier research in the arctic

Chair: Jon Ove Hagen

17.00-19.00: Movie session

19.00-22.00: Workshop dinner

Thursday 12 January

9.30-12.00: Morning session

Chair: Francisco Navarro

1. **Josef Rehak, Stanislav Řehák, S. Kostka, A. Haczek, Klára Řeháková:** Glaciospeleology - tool for the survey of polythermal glaciers.
2. **Antoine Kies, Zornitza Tosheva:** Overview on radon measurements in glacier meltwater.
3. **Jarosław Hałat, Dariusz Ignatiuk, Joanna Szafraniec, Elżbieta Majchrowska:** Discharge from the Werenskiold Glacier catchment based upon measurements and surface ablation in summer 2011.
4. **Selena R. Cordeau** Tracking synoptic weather signatures in glacial snow pack in the Swedish mountains.
5. **Piotr Owczarek, Adam Nawrot:** Application of the dendrochronological methods to estimate past changes of the valley glacier front (as example the Arie Valley, Spitsbergen).
6. **Marta Kondracka:** Permafrost distribution in coastal zone in Hornsund (Southern Spitsbergen).
7. Plenary summary/concluding discussion.

12.00-13.00: Lunch break

13.00-22.00: Guided tour or skiing (optional)

Friday 13 January

8.00: Departure to Wrocław

List of participants

Ahlstrøm Andreas Peter	Denmark	Geological Survey of Denmark and Greenland
Błaszczyk Małgorzata	Poland	University of Silesia
Brugess David	Canada	Natural Resources Canada
Ciepły Michał	Poland	University of Silesia
Cordeau Selena Raven	Sweden	University of Victoria, Canada and Uppsala University, Sweden
Dunse Thorben	Norway	University of Oslo
Finkelnburg Roman	Germany	Technische Universität Berlin
Franczak Lukasz	Poland	Maria Curie-Skłodowska University in Lublin
Gajek Grzegorz	Poland	Maria Curie-Skłodowska University in Lublin
Głowacki Piotr	Poland	Institute of Geophysics Polish Academy of Sciences
Grześ Marek	Poland	Nicolaus Copernicus University
Hagen Jon Ove	Norway	University of Oslo
Hałat Jarosław	Poland	University of Silesia
Hock Regine	USA	University of Alaska
Ignatiuk Dariusz	Poland	University of Silesia
Ingle Alexander	UK	University of Edinburgh
Jania Jacek	Poland	University of Silesia
Keiko Konya	Japan	Japan Agency for Marine-Earth Science and Technology
Tetsuo Sueyoshi	Japan	Japan Agency for Marine-Earth Science and Technology
Kies Antoine	Luxemburg	University of Luxembourg
Kondracka Marta	Poland	University of Silesia
Krystyna Kozioł	UK	University of Sheffield
Kuhn Michael	Austria	University of Innsbruck
Kuhn Barbara	Austria	University of Innsbruck
Laska Michał	Poland	University of Silesia
Luks Bartłomiej	Poland	Institute of Geophysics PAS
Lüthi Martin	Switzerland	VAW Glaciology, ETH Zurich
Macheret Yuri	Russia	Lomonosov Moscow State University
Majchrowska Elzbieta	Poland	University of Silesia
Maharian Cerey	Nepal	Caribbean College, Lalitpur
Małecki Jakub	Poland	Adam Mickiewicz University

Marszałek Henryk	Poland	University of Wrocław
Martin Alba	Spain	Technical University of Madrid
Martma Tõnu	Estonia	Tallinn University of Technology
Migała Krzysztof	Poland	University of Wroclaw
Navarro Francisco	Spain	Technical University of Madrid
Muskala Piotr	Poland	University of Wroclaw
Navarro Lucia	Spain	Technical University of Madrid
Nowak Marcin	Poland	Nicolaus Copernicus University
Ojha Sunal	Nepal	Nepal Electricity Authority, Ministry of Energy
Owczarek Piotr	Poland	University of Wroclaw
Piechota Agnieszka	Poland	University of Silesia
Pope Allen	UK	Scott Polar Research Institute
Promińska Agnieszka	Poland	Institute of Oceanology PAS
Rachlewicz Grzegorz	Poland	Adam Mickiewicz University
Rachold Volker	Germany	IASC Secretary, Potsdam
Řeháková Klára	Czech Republi	Institute of Botany AS CR
Rehak Josef	Czech Republi	Speleo-Řehák
Rehak Stanislav	Czech Republi	Speleo-Řehák
Tijm-Reijmer Carleen	Netherlands	Utrecht University
Tosheva Zornitza	Luxemburg	University of Luxembourg
Schäfer Martina	Finland	Arctic Centre, University of Lapland, Rovaniemi
Scherer Dieter	Germany	Technische Universität Berlin
Sawiński Tymoteusz	Poland	University of Wroclaw
Sikora Sebastian	Poland	University of Wroclaw
Smyrak – Sikora Aleksandra	Poland	University of Wroclaw
Sobota Ireneusz	Poland	Nicolaus Copernicus University
Stober Manfred	Germany	University of Applied Sciences, Stuttgart
Szafraniec Joanna	Poland	University of Silesia
Walczak Michał	Poland	Nicolaus Copernicus University
Walczowski Waldemar	Poland	Institute of Oceanology PAS
Welty Ethan	USA	University of Colorado
Faye Wyatt	Canada	University of Alberta
Van Wychen Wesley	Canada	University of Ottawa, Ottawa
Zwally Jay	USA	NASA Goddard SFC

Zagórski Piotr	Poland	Maria Curie-Skłodowska University in Lublin
Zwoliński Zbigniew	Poland	Adam Mickiewicz University

Minutes from a special session on tidewater glaciers research in the Arctic

The meeting was chaired by Jon Ove Hagen. Three speakers gave brief presentations future research directions related to improve understanding how tidewater glaciers will respond to climate warming. A discussion amongst speakers and attendees (~30 in total) took place throughout the meeting.

Introduction – Jon Ove Hagan: Models unanimously predict acceleration of sea level rise throughout the 21st century resulting from glacier melt and ice sheet dynamical process IPCC(2007 and AMAP(2011). A major source of uncertainty in these estimates however, is the rate at which mass loss will occur from ice caps and ice sheets through iceberg calving. As the processes related to changing dynamics of tidewater glaciers are still not well understood, future research on Arctic tidewater glaciers should be focused on processes influencing glacier acceleration, ie. increased basal sliding resulting from larger supplies of meltwater to the glacier bed (also due to water pressure influence on crevasses), calving and bottom melting under the floating ice due to less backpressure, sea water temperature and circulation. Such glacier acceleration could be the symptom of surge initiation, and what follows, larger calving flux into the sea.

For years to come, investigations should focus on the use of remote sensing for improving our spatial and temporal coverage of geophysical measurements of these features. Field-based studies of calving mechanics (the relationship between glacier dynamics, ocean/atmosphere forcings and calving occurrence), model-development requirements, and targeted modeling studies are also required. Future research should continue in a fashion similar to those established through Glaciodyn.

Speaker 1 - Francisco Navarro: Future research should focus on factors controlling the calving processes related to atmosphere, ocean, glacier/basin geometry and dynamics. Necessary research related to controls of calving should be carried out by observational efforts addressed to estimating and/or quantifying the contribution of the different processes. Some examples are: use of time-lapse cameras (shift from qualitative to quantitative results) and other means of measuring front position changes with high temporal frequency, measuring of basin bathymetry and amount of water filling the frontal crevasses (by pressure transducers), etc. For modeling purposes, further research on the implementation of proper calving laws numerical models of glacier dynamics, model sensitivity experiments, as well as feedbacks and instability mechanisms are necessary.

Speaker 2 - Martin Lüthi: Increased knowledge of factors that determine flow speed such as ice deformation, basal motion and ocean stress boundary conditions is essential. Tidal modulation of ice flow may also be important. Current models for ice flow, ice deformation, and for solid bedrock sliding are quite good. The physics of calving rate, melting under terminus, sediment deformation and sliding over sediment however needs improvement. Controls on tidewater glaciers transient sub-glacial hydrology and processes under floating ice /

calving front (ocean currents and fjord circulation, melt, refreeze) also require further research.

Speaker 3 - David Burgess and Martin Sharp (not present): Future research should focus on gaining a greater understanding of hydrological processes that control movement of the of tidewater glacier termini, importance of submarine melting of glacier termini, and linkages to up-glacier flow. Improvements in our understanding of tidewater termini hydrology requires measuring the sub-glacial drainage structure through targeted drilling or seismic measurements, and analysis of water discharge (quality, quantity, and discharge location) from the glacier terminus. As ocean waters continue to warm, increased knowledge of the relationship between melt rates and warming ocean waters must be investigated. Measurements required for this analysis include repeat sonar of the ice cliff and accurate measurements of the flow rates at depth. The impact of preconditioning of the ice through internal fracturing on the timing and magnitude of ice bergs calved should also be examined. Knowledge of the effect of flow rate variations of tidewater glaciers on inland ice is essential to understanding the impact of changing ice dynamics on mass balance of an ice cap (or sheet) as a whole. For this analysis, time sensitive measurements of glacier velocity (through in-situ GPS and 2-D InSar) over large areas are required. Another related issue is that many tidewater glaciers have over-deepenings several hundred meters below sea-level up-glacier of their termini, so how much thinning can these termini sustain before floatation and rapid destabilization / retreat occurs? – To address this we need continuous 3D maps of glacier bed geometry of selected tidewater termini, and knowledge of local thinning rates through melt and dynamic thickness changes.

Final Remarks – Jon Ove Hagan: The process of ice-berg calving, and the associated impact on ice cap / ice sheet mass balance should be studied on a decadal time scale. These issues will be discussed in greater depth during the "Workshop on tidewater glaciers", which is to be held for members of the CRYOSPHERE Group of International Arctic Science Committee (IASC) on board of Polish ship "Horyzon II", 26-31.08.2012. Field tours to tidewater glaciers in Hornsund, Kongsvegen and Billefjorden are planned.

Questions / comments raised in further discussion related to the most important directions in further tidewater glaciers research:

Calving law:

- Is it possible to apply the universal calving law for all types of glaciers?
- Need to understand ice physics at the glacier front and processes at the glacier base
- Concentrate further research on physics but with differentiation on glacier type, thermal regime, frontal characteristic, etc.
- Do the water in crevasses have such impact on calving as in recent models?
- Problem of under/over estimation of calving flux – keeping in mind the connection with the mass balance of the ice cap (or sheet) as a whole.

Dynamics:

- Determine all factors (in addition to climate) that influence dynamics and calving

- What determines glaciers flow speed?
- Sensitivity of glaciers to varying depth of ocean water?

Focusing on ocean trigger – glacier response

- Water exchange (ocean – subglacial discharge) at the glacier front
- Methodology of measuring of sea water properties (current directions, salinity, temperature)
- Oceanographers have already been measuring water flux from submarine channels along tidewater glaciers
- Conveying of interaction between sea and glaciers waters from ocean scale into fjords, and further, to the glaciers fronts.
- Observation of discharges of water at the calving front on time lapse photos

Need for 3D glacier geometry was emphasized

- Underlying of potentials of free satellite images and use new techniques

Role of interdisciplinary research is crucial

Predicting further dynamical processes (velocity, calving, retreat) on Greenland – will they calm down?

Abstracts

Seasonal and multi-year fluctuations of tidewater glaciers cliffson Southern Spitsbergen

M. Błaszczyk, J. Jania, L. Kolondra

Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland

Climate warming accelerated recently causes changes in extension, thickness and dynamics of glaciers during last decades. Svalbard glaciers are located in the area of Arctic very sensitive to climatic changes. Continuous retreat of Hornsund tidewater glaciers (Southern Spitsbergen), similarly to others Svalbard glaciers, has been noted sometime after c. 1920 as an answer for the sudden temperature increase, known as the early 20th century warming in Svalbard.

The main objective of the poster is to present studies on state of tidewater glaciers terminating in Hornsund Fjord basing upon topographical maps, field measurements, aerial and satellite images in different time slices. Front retreat of fourteen tidewater glaciers were analyzed in the following periods: 1899 – 1960/1961 – 1976 – 1990 – 2001 – 2005 – 2010. First results of studies on seasonal fluctuations of glacier termini basing upon SAR satellite images are also presented. Their amplitude might be similar or even higher than annual front recession.

Results show that retreat rate increased in recent decades. The total area of glacier cover diminishing in Hornsund Fjord amounts to about 171 km^2 with an average aerial retreat rate of 1.6 km^2a^{-1}. Recession rate increased from c. 1 km^2a^{-1} in the first part of the 20th century up to c. 3 km^2a^{-1} in the first decade of the 21th century. The average linear retreat rate of all tidewater glaciers in Hornsund in 2001-2010 amount to c. 70 ma^{-1} and is higher from average retreat (c. 45 ma^{-1}) for all Svalbard tidewater glaciers. That is probably influenced by increasing amount of heat transport in waters of West Spitsbergen Current into Hornsund area.

Recent changes in elevation across the Devon Ice Cap, Canada

D. Burgess

Natural Resources Canada

Changes in surface elevation along a near stagnant 50 km transect of the Devon Ice Cap (DIC) Canada are derived from Airborne Laser Altimetry and ground based kinematic GPS surveys conducted annually between 2004 and 2011. Analysis of this 7 year time series reveals that the ice cap has thinned by an average of 2 m along the entire transect, with min/max rates of thinning by ~ 0.5 m and 5 m having occurred at the ice cap summit region (1800m a.s.l.) and southern margin (650m) respectively. In this study, independent measures of particle path motion, ice dynamics, firn densification, and surface mass balance data collected along the 50 km transect are analysed in order to identify the dominant controls on the elevation changes observed.

Estimation of iceberg to the Hansbukta (Southern Spitsbergen) based on time-lapse photos

M. Ciepły[1], D. Ignatiuk[1], A. Promińska[2]

[1]Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
[2]Institute of Oceanology PAS, Sopot, Poland

Complex measurements of calving events and ice bergs in fjord have been analyzed and presented in this work. The research was carried out on Hans Glacier ice cliff and on Hansbukta. Hans Glacier 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 Hansbukta (Hornsund Fjord).
Data of ice bergs in bay have been collected from Canon EOS 1000D time lapse cameras located at Fugleberg slop and Baranowski Peninsula. Cameras make photos every 3 hours. In this work data from 16th of July to 15th of August 2011 are presented. Data of calving events frequency have been collected from new gauge stations (Schlumberger Cera Diver) in Hansbukta. Stations were localized on both side of bay on front of Hansbreen. Schlumberger sensors measured changes in sea level. Very short time of sampling allow to observe spread of tsunami wave after calving events, variability of the waves and tides in bay.
Daily changes in amount of calving events and presence of ice bergs in bay have been correlated with glacier velocity from continuously measurements of Leica 500 GPS receiver located about 4 km upstream of the terminus and with meteorological data from Polish Polar Station in Hornsund and AWS on Hansbreen.

Seasonal and interannual velocity variations of two outlet glaciers of Austfonna, Svalbard, inferred by continuous GPS measurements

T. Dunse[1], T.V. Schuler[1], J.O. Hagen[1], and C.H. Reijmer[2]

[1]Department of Geosciences, University of Oslo, Oslo, Norway
[2]Institute for Marine and Atmospheric Research Utrecht, Utrecht University, Utrecht, The Netherlands

Austfonna, the largest ice cap on Svalbard, currently experiences net mass loss mainly attributed to calving and retreat of the marine ice margin, while its surface mass-balance is close to zero. A large part of the ice flux from the ice-cap interior towards the margin occurs through spatially limited flow units that may operate in a mode of steady flow or cyclic surge behavior. Previous ice-surface velocity maps rely on data acquired in the mid-1990s with limited information concerning the temporal variability.
Here, we present continuous Global Positioning System (GPS) observations since 2008, along the central flowlines of two fast flowing outlet glaciers of Austfonna, Basin-3 and Duvebreen. The data shows prominent summer speed-ups with ice-surface velocities as high as 240% of the pre-summer mean. Acceleration follows the onset of the summer melt period, indicating enhanced basal motion due to input of surface meltwater into the subglacial drainage system. The record of Basin-3 also shows considerable annual acceleration. The observed flow instability may be associated with the onset of renewed surge activity and has strong implications on the ice flux towards the calving front and hence, the ice cap's mass balance.

Discharge from the Werenskiold Glacier catchment based upon measurements and surface ablation in summer 2011

J. Hałat, J. Szafraniec, D. Ignatiuk, E. Majchrowska

University of Silesia, Faculty of Earth Sciences, Sosnowiec, Poland

Increase of fresh water inflow from glaciers to the sea is one of factors of global sea rise in response to climate warming. Detailed studies of Werenskiold Glacier in SW Spitsbergen have in focus relation between meteorological parameters, ablation of the glacier and water discharge from the basin to build up a model of meltwater supply to the sea. Discharge measurements with SEBA F1 hydrometric current meter were carried out from 17th of July to 16th of August 2011 in the gorge (in frontal moraine) of the Glacier River draining the Werenskiold Glacier basin. Making use of a strong correlation with water level in the Glacier River, discharges were calculated (at 10 minutes' intervals) for two periods: 22 June-27 August, 2011 and 9-16 September, 2011. Mean discharge for the June-August period was 8.59 m^3s^{-1}. During that time, three distinct peaks were registered. Fourth, the absolute one reaching 28.72 m^3s^{-1}, occurred on 10 September. All high waters were ablation-foehn type with characteristic increase of temperature. Precipitation was another factor inducing high discharges. Diurnal cycle in the discharge course, visible on a hydrograph after 27 June, did not use to disappear due to the period of flow rising stages. Absolute daily discharge amplitudes reached the highest value of 12 m^3s^{-1}, while mean daily amplitude was 3.8 m^3s^{-1}. Taking into account hourly mean, the highest discharge values occurred at 16:00 GMT and the lowest at 5:00–6:00 GMT. However, during the season both the maximum and minimum were shifted. Changes in surface ablation measured on Werenskiold Glacier were reflected in discharges calculated for the Glacier River with ca four hours' delay. Mean daily outflow from the Werenskiold Glacier catchment was 7.7 x 105 m^3 and it varied from 4.3 x 105 m^3 to 1.8 x 106 m^3. Total outflow in this period was 58.5 mln m^3 in comparison with 56 mln m^3 w.e. of total ablation (without internal accumulation).

The mass balance of Austfonna Ice Cap, 2004-2010

J. O. Hagen[1], T. Dunse[1], T. Eiken[1], J. Kohler[2], G. Moholdt[1], C. Nuth[1], T. V. Schuler[1]

[1]Department of geosciences, University of Oslo, Oslo, Norway
[2]Norwegian Polar Institute, Tromsø

As part of the IPY GLACIODYN project (The response of Arctic glaciers to e period 199global warming) the mass balance of the Austfonna Ice Cap has been studied. The Austfonna ice cap (8120 km^2) is by far the larges ice cap in Svalbard. Studies have been focused on 1) Surface mass balance 2) Elevation changes by satellite data, airborne laser profiles and ground-based GPS 3) Dynamics; surge and calving.

The surface mass balance has been measured by traditional, direct method, by about 20 stakes over the ice caps, by snow soundings, snow pits and GPR profiles of the snow distribution.

The net surface mass balance on Austfonna is slightly negative (-0.1 m water eq. y^{-1}) for the period 2004-2010. The mean specific winter accumulation is only 0,52 m w.eq. y^{-1}, and the mean summer melting has been -0,63 m w.eq. y^{-1}. These numbers are not precise since accumulation may occur also during the summer months. It is not possible to give any trend for the data for only seven years. 2004 was the most negative year, while 2008 was the only year with positive surface mass balance. The surface mass balance results fits quite well with former estimates from shallow ice cores giving close to zero surface mass balance for the period 1986-1999. This indicate only small changes in the entire period 1986-2010.

The elevation change measurements on Austfonna show a thickening in the interior of c. 0.5 my-1, and an thinning closer to the coast of 1-2 my-1, indicating a large dynamic instability.

The calving is important (2.5 km^{3}y^{-1}) and stands for 30-40 % of the total mass loss, giving an overall loss of -0.4 m w.eq. y^{-1}.

Overview on radon measurements in glacier meltwater

A. Kies[1], A. Nawrot[3], O. Hengesch[1], Z. Tosheva[1], J. Jania[2]

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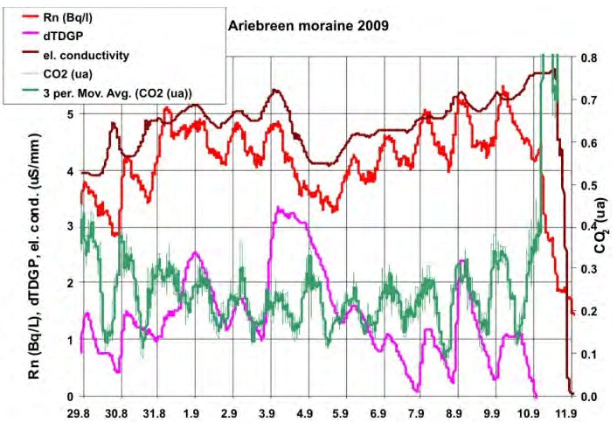
Keywords: glacier, meltwater, radon, monitoring

First radon measurements September 2006 showed unexpected high radon concentrations in an artesian outflow of Werenskioldbreen. This initiated the interest for further studies on radon in glacier meltwater. For practical and logistics reasons, investigations were done mainly on the outflows of Werenskioldbreen and the moraine of Ariebreen. We report of 5 years investigations from 5 April missions 2007-2011, together with summer measurements, continuous and on grab samples. The radon signature can be interpreted in terms of flow through the subglacial drainage system, via hydraulically pathways with slow transit speeds and involving much contact with large amounts of freshly eroded debris. In contrast, low ionic/radon concentrations are consistent with no, or only a short period of, flow at the glacier bed, via a hydraulically effective drainage pathway characterized by large water fluxes and rapid transit velocities.



The review aims to be critical, discussing what radon could add in combination with classical parameters like temperature (very sensitive detectors), electrical conductivity, pH, total dissolved gas pressure, chemistry data. Even a single radon measurement on an artesian outflow can have interesting insights: if radon is present, it can be deduced that this water has been very recently, less than some 15 days, in intense contact with the glacier basement. Repetitive measurements and especially when continuous give further interesting insights.

Permafrost distribution in coastal zone in Hornsund (Southern Spitsbergen)

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The measurements were performed on tworaised marine terraces in the vicinity of Polish Polar Station in Hornsund in Southern Spitsbergen. The lower marine terrace is placed at about 2-6 m a.s.l., and upper one is placed at 8-12 m a.s.l., theirs width reach 650-800 m. Three geophysical methods: electrical imaging, seismic refraction and GPR measurements were used to characterize the permafrost distribution in coastal zone on the distance of 720 m. The electrical resistivity of sediments was 890 Ωm to 12.5 kΩm for lower terrace and 25 Ωm to 278 kΩm for the upper marine terrace. Seismic velocity varied in range of 570 m/s to 4000 m/s for both terrace. GPR results gave the best resolution of the subsurface (the depth of 2m) but the permafrost near the coastal is not clearly visible. Obtainedgeophysical results show the clear difference between upper and lower terrace. Electrical imaging gave the most interesting differentiationof the terraces physical properties. The lower terrace is characterized by two layers – upper one with high electrical resistivity (400 – 10 kΩm) and lower one with low electrical resistivity (25 – 400 Ωm). Specific high electrical conductivity on the depth of 5 m can be result of saline water occurrence in pores.Conduction took place in the unfrozen portion of the pore water with high salinity on closes to the sea. High values of electrical resistivity (above 7000 Ωm) and seismic velocity (about 3000 m/s) indicate the presence of the permafrost. The presented results show that the permafrost distribution in the coastal zone is strictly connected with the distance from the sea (what is connected with the occurrence of the saline water in the pores), type of landforms and topographic conditions.

Glacial environment of De Long Archipelago in the Siberian Arctic

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Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

There are many glaciers in Russian arctic. De Long Islands in Siberian arctic are composed of three islands and 50 % of the area is covered by glaciers (Kadota et al., in prep). Bennett Island, one of DeLong Islands, is of 30km long and 10km wide. There are three icecaps on the island. The altitude of each icecap is 384m, 426m and 200m, respectively (World Atlas of Snow and Ice Resources). Mass balance of Toll glacier, which is the largest glacier in Bennett Island, in 1986/87 was -0.303 m w.e. (Verkulich et al., 1992) and during 1956-1972 was -0.10 w.e. (Jania and Hagen, 1996). Glacier area shrinkage revealed by satellite images are 20 % in 1951-2010 for Bennett Island and 40-50% for the other two islands in De Long Islands (Yabuki, personal communication). Meteorological observation is continued at Ostrov Kotelnj (76.0N, 137.9E) in New Siberian Island since 1937. Air temperature in 1960s was lowest since 1930's. The warming in 1990s was rapid and the warming trend is continued after 2000. Siberian arctic is the area where the largest sea-ice-area change was seen. Although the sea ice came across to the continent even in September until 1996, sea ice in September was apart far from the coast since 2004. In 2007, in which the sea ice was in minimum, most of Siberian arctic was free from sea ice except for a small part.Southern most position of sea ice in September is plotted for the range of 135-155° East during 1979-2010 with SSMI data. The southern-most position was correlated to annual and monthly mean temperature in September.

Underground “glaciation” – a case study from Dobšinská Ice Cave (Slovakia)

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One of the components of Earth’s cryosphere is the ice accumulated inside cave systems. An example of this phenomenon is the Dobšinská Ice Cave (Slovakia, Slovak Paradise region, 48° 52′ 19″ N, 20° 17′ 41″ E), which is the second largest ice cave in the world. The amount of ice accumulated in the cave interior was estimated at 110 000 m^3.
The altitude of cave entrance is 967 m a.s.l., which is well below the snow line for the area, and conditions for ice accumulation are determined by specific morphological features of the cave (descending profile of the cave favors accumulation of cold air in winter period, which allows freezing of infiltration water).
Ice accumulated in the cave takes the form of a large monolith, which almost completely fills the main chamber of the cave. The area of the monolith is 9722 m^2, its average thickness is 13 m with maximum of 26.5 m. The feature which assimilates the monolith to the classical glaciers is the movement of ice mass induced by its plastification. Differences between them manifests in the course and nature of accumulation/ablation processes. Climatological and glaciological studies conducted in the cave since 2002 have shown that within a year we can distinguish the following phases associated with the formation or loss of ice mass:

1. Winter phase of ice degradation, associated with the sublimation of ice surface, caused by an intense influx of outside air;
2. Spring phase of ice growth, when large amount of snow-melt water infiltrate and freeze in the cave interior, which is cooled after the winter;
3. Summer phase of ice degradation, influenced by:
   (a) thermal impact of the air flowing through the cave due ventilation processes;
   (b) thermal impact of precipitation water infiltrating into the cave;
   (c) impact of additional energy supply caused by tourism (the cave is open to the public from May to October).

In addition, through the whole year, in the walls and the bottom of the monolith ice degradation takes place, caused by thermal impact of the rock massif.
The factors responsible for the processes of degradation and accumulation of ice mass in the cave are: seasonal variability of air exchange (responsible for winter cave cooling and partially, summer ablation), pluvial conditions in the cave surroundings, the course of the infiltration processes (determined by the number, size and arrangement of clefts supplying water to the cave), thermal impact of rock massif and impact of tourism. Based on the survey it was found that the most influential factor in the mass balance of ice monolith is the course of air exchange in the winter period. Duration and intensity of this process determines the degree of cave cooling in winter and hence potential for ice accumulation in

spring period. The degree of cave cooling also determines the moment when ablation starts, and as a consequence, the duration of ablation period. An example of such effects we can see by comparing the data from winter seasons 2005/2006 and 2006/2007. During the first of them, between November and April there were 124 days with winter air exchange, in the second only 65, and the average air temperature in the cave surroundings was, respectively, -2.25 and 1.65 °C. In addition, in 2006 the ablation process in the cave began in the middle of June, and in 2007 approximately 1.5 month earlier. Such dissimilarity resulted in significant differences in the annual mass balance of ice in both seasons. In May 2006 the accumulation of 425 m^3 of ice was recorded on the surface of the monolith, while in the corresponding period of 2007, the mass balance of ice was negative and amounted to approximately -125 m^3.

Do glaciers accumulate organic matter?

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The mass balance of Arctic glaciers is closely watched by the research community. However, hardly any studies pay attention to the consequences of its changes for other ‘glacial budgets’. Glaciers are a significant storage of organic matter and living cells, thus they should also be monitored for their ‘organic mass balance’, as they release recently vast amounts of labile organic matter to the sea (Hood et al., 2009). The characteristics of input of organic matter into the glacial system remains unknown and poorly documented. Thus, it is unknown, whether the release of organic matter can be compensated by its accumulation; the accumulation itself is a worth understanding source of nutrients for microorganisms on glaciers as well.

The accumulation of snow during the winter season and its organic carbon content were estimated for the accumulation season 2010/2011 on Foxfonna glacier, Svalbard; summer deposition of organic matter was also captured by means of dust trapping and summer snow collection. A spatially distributed study was produced, so as to avoid results biased by the central orientation of sampling points. Indeed , the data show highly differentiated inputs according to location on the glacier, borders of the glacier being more exposed to windblown organic matter. On average, per m^2 of glacier surface, there was 12.8 mg TOC (total organic carbon) accumulated in snow in the end of April 2011. Summer months also bring significant deposition of organic carbon, on average 1.1 mg/m^2 during two months, even with assumption of comparatively high (20%) dust trap efficiency. Thus, the accumulation of organic carbon is far from negligible and may provide an important source of nutrients for glacial ecosystems.

Influence of ablation upon temperature changes in vertical and longitudinal profile of snow cover on the Hans Glacier (S Spitsbergen)

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Input of energy to the glacier surface and heat transfer in a vertical profile affects changes of snow cover physical properties. Data of the temperature variations and heat flux flow inside snow cover are important to understand processes within snow pack. Such changes are stimulating snow metamorphosis or creation various forms of internal accumulation and release of latent heat during melt-water refreezing. These processes are not properly known in Svalbard.

Observations were conducted to determine changes in temperature distribution in vertical and longitudinal profile of snow cover on glacier (as an indicator of processes within it) and to define temporal delay of heat transfer in snow profile during the period of snow cover dynamic changes.

Field work was conducted on Hans Glacier from April to June 2010. The glacier is 16 km long, tidewater type and terminates in Hornsund Fiord, nearby Polish Polar Station, South Spitsbergen, Svalbard.

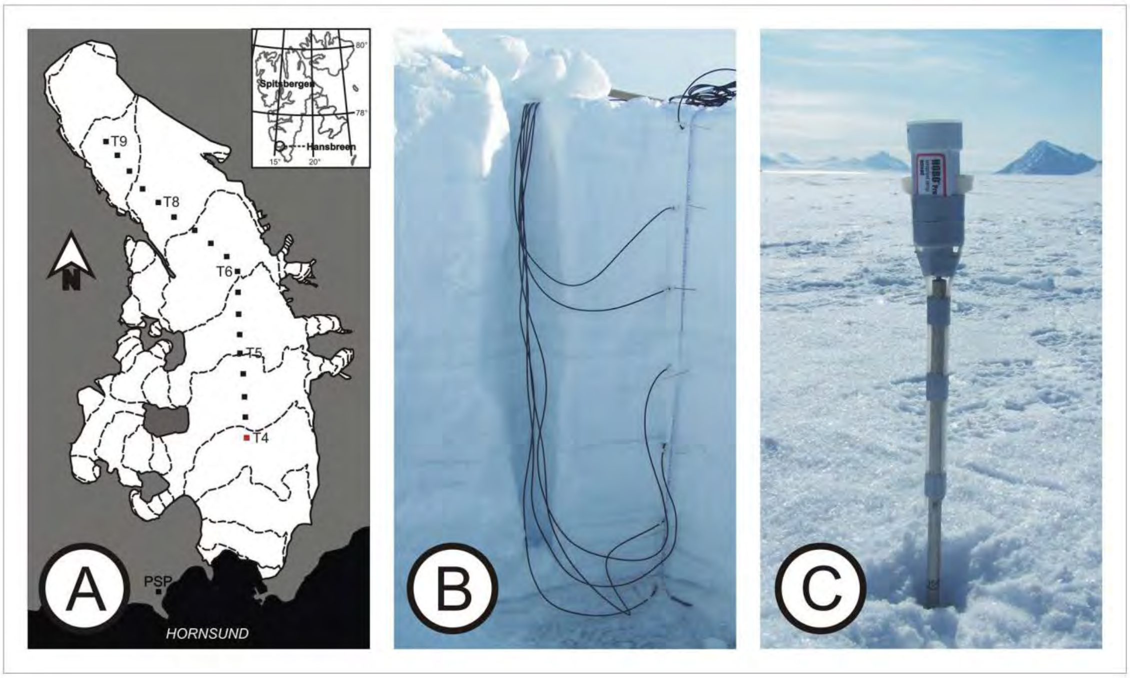

Figure 1: *A: study site, B: vertical string of thermistors in snow pack, C: temperature probe.*

Vertical temperature and heat flux changes were recorded in ablation zone, near the mass-balance stake T4 (Fig. 1A, red square). String of seven Campbell Scientific 107 thermistors was mounted in snow pack down to the glacier ice surface. Dynamax Inc. HFP01 heat flux plate was placed 20 cm below the snow surface (Fig. 1B). For interpretation, data on air temperature (ta) from nearby automatic weather station were used.

Measurements of snow temperature and snow depth were also carried out at 18 points in the longitudinal profile of glacier during six trips, approximately every 10 days. Snow temperature was recorded at a depth of 150 cm below the surface with HOBO Pro V2 U23-004 sensor (Fig. 1C).

Based on daily mean air temperature three periods of snow cover thermal structure were determinated (Fig. 2):

1. Before-melting period: up to 7.05.2010. Characterized by major fluctuations in air temperature, and consequently in the snow temperature.
2. Early-melting period: from 7.05.2010 (first strong signal of melting) to 13.05.2010. Melt-water processes started.
3. Melting period: from 13.05.2010. Intensive melt-water percolation through profile, snow temperature tends to homogeneity.

Values of heat flux flow in the snow cover are highly correlated with daily mean air temperature.

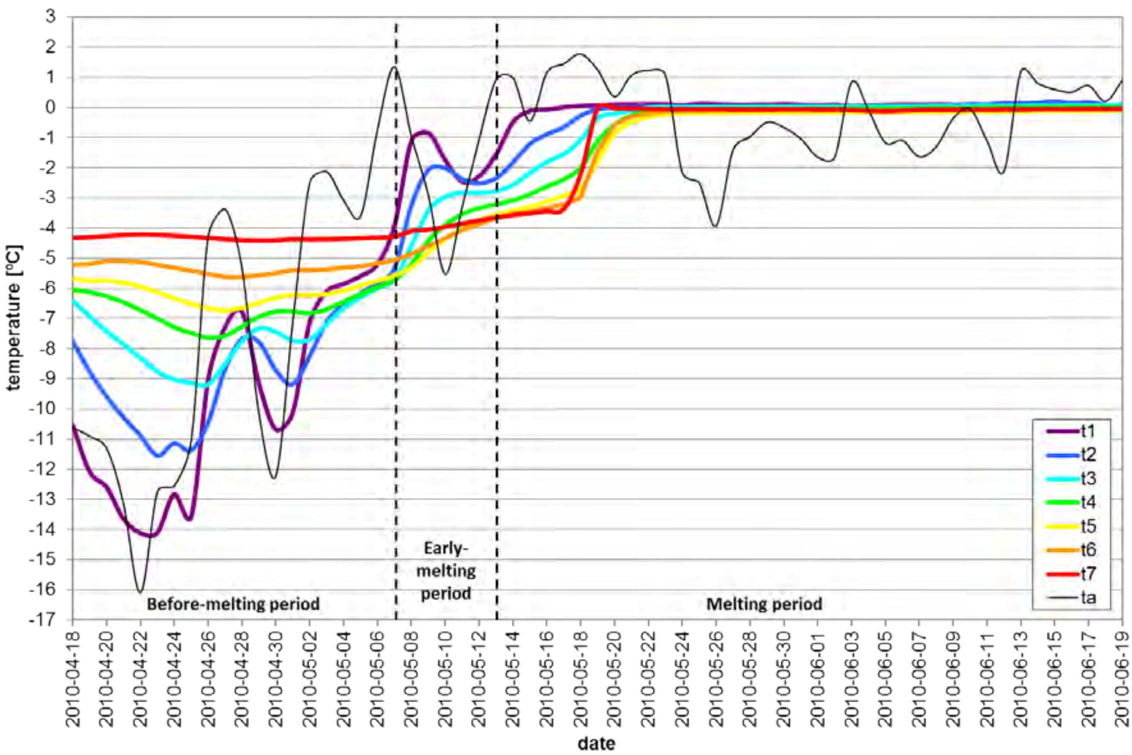

Figure 2: *Changes of daily mean snow temperature at different levels (t1-t7) and daily mean air temperature (ta).*

At the beginning of melting period (8.05.2010) snow temperature gradient in the longitudinal profile was -1.3°C/100 m. Gradual homogenity of snow temperature in analysed profile influenced on increase of this value (Fig. 3). During the last series of measurements (19.06.2010) gradient was equal -0.4°C/100 m.

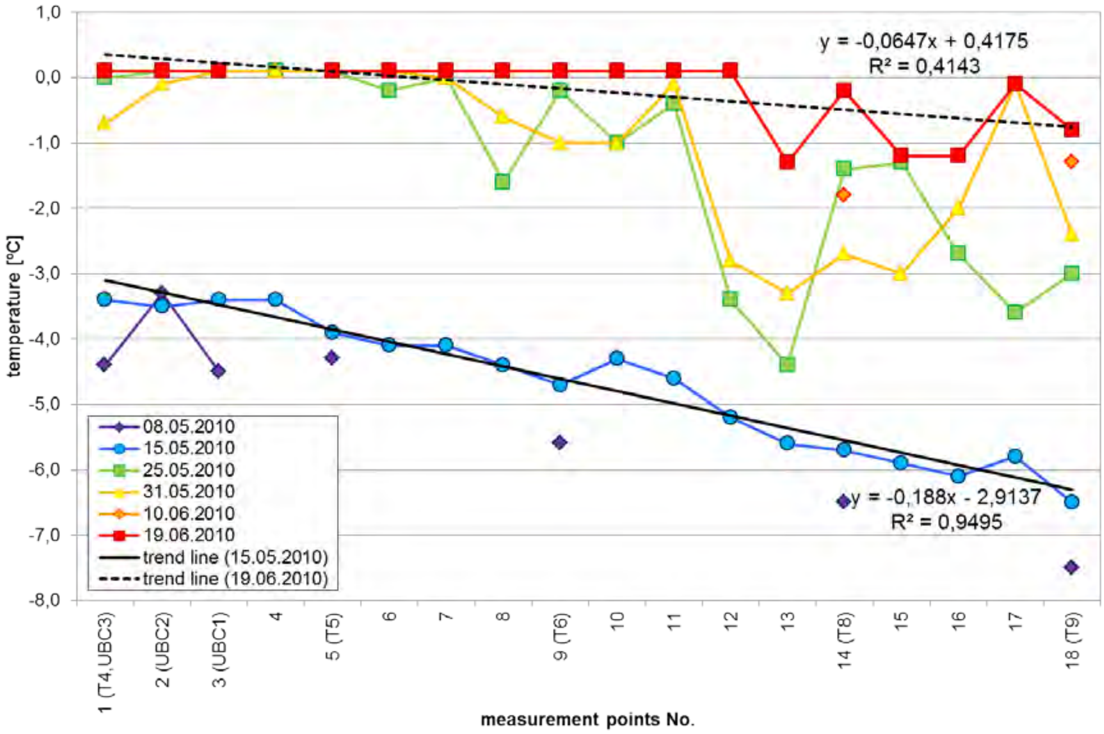

Figure 3: *Snow temperature changes in the longitudinal profile of Hans Glacier at a depth of 150 cm below the snow surface.*

Obtained results confirmed that the driving factors affecting vertical distribution of snow temperature are air temperature and insolation. Other important factor is release of latent heat from melt-water refreezing, which rapidly increases temperature of surrounded snow.

Influence of water refreezing was marked in the whole snow profile, but to a depth of approximately 32 cm snow temperature variation was closely related to air temperature fluctuations (correlation coefficient> 0.90).

In the initial period of registration air temperature changes reflected in the snow temperature with delay of approximately one day for each 25 cm of deep of the snow cover. This value depends mainly on snow density and air temperature.

Snow temperature in the longitudinal profile of Hans Glacier decreases with the altitude, but this trend is progressively reduced during melting period.

Acknowledgements:

Author sincerely thank the Members of 32nd Polish Polar Expedition PAS and Members of the IGF PAS - US spring expedition to Hornsund 2010 for field work assistance. This research has been supported from the Polish-Norwegian Research Found on the project: “Arctic Climate and Environment of the Nordic Seas and the Svalbard - Greenland Area – AWAKE” (PNRF–22–AI–1/07), coordinated by Prof. Jan Piechura from Institute of Oceanology PAS.

Uncertainty analysis of UEB snow energy mass balance model

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We applied Utah Energy Balance Snow Accumulation and Melt Model (UEB) to modelling snow cover dynamics at the Polish Polar Station at Hornsund. The model uses a lumped representation of the snowpack with two primary state variables: snow water equivalence and energy. Its main driving inputs are: air temperature, precipitation, wind speed, humidity and radiation (estimated from the diurnal temperature range). Those variables are used for physically-based calculations of radiative, sensible, latent and advective heat exchanges with a 3 hours time step.

We focus on the analysis of uncertainty of the UEB model outputs. The applied UEB model is deterministic; it assumes that the observations are without errors and the model structure perfectly describes the processes within the snowpack. To take into account the model and observation errors, we applied a combination of the Generalized Likelihood Uncertainty Estimation technique (GLUE). These techniques also provide estimates of the modelling errors and the uncertainty of the model parameters. The observed snowpack water equivalent values are compared with those simulated with 95% confidence bounds. The results show a good agreement with observations.

Short term dynamics of the Greenland Ice Sheet observed with sensors in deep boreholes

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We present new results from measurements in an array of boreholes to the bedrock in the marginal parts of the Greenland Ice Sheet, downstream of Swiss Camp, with the aim of better understanding the processes responsible for peripheral thinning and seasonal flow velocity variations. Two newly devised borehole sensor systems, DIBOSS and FiberScale, allow us to monitor subglacial water pressure, ice temperature, and shearing/stretching deformation of the ice body. DIBOSS is a digital borehole sensor system consisting of multi-sensor units (pressure sensor, inclinometer, magnetometer, thermistor), operated through a digital bus over a special extendable cable. We present high time resolution data on the interaction between subglacial water pressure, ice deformation, and surface flow speed.

The dynamics of suspended and dissolved transport from Werenskiold Glacier (Spitsbergen) during the ablation season 2011

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Suspended sediment yields are the one of the most sensitive indicators of changes in glacial environments which inform about interaction between glacier, climate and landscape change (Hodgkins et al..2003). This poster presents data from investigation carried out on the proglacial Glacier River (Werenskioldbreen) located in southern part of Spitsbergen. The main purpose of measurements was to observe the seasonal and diurnal fluctuations of matter concentration and stream discharge.

Field and analytical methods
All samples were collected during the late spring and summer of 2011 (23 May - 8 July). Field measurements were carried out in a hydrometric profile with the water gauge which closes the drainage basin.
An automatic water level recorder (diver DI 261) was installed for continuous monitoring of variation in water level. For estimation of discharge, the velocity-area method was used (calculation from salt dilution data, from current meter data and from surface float data).
Suspended sediment concentration was determined by the filtration of water samples using an automatic pump sampler (MILIPORE). Sample volumes of 1000 ml were automatic collected and filtered through pre-weighed Whatman cellulose nitrate filter papers (retention size 0,7μm.) and then through filter papers (0,45μm) for chemical analysis (CEN 1996). Normal sampling frequency was 2 samples a day.
Meteorological data (air temperature, humidity, radiation, wind speed and direction of the wind) come from automatic weather station in the Werenskioldbreen catchment. Meteorological time series stored by a Campbell CR1000 data logger. Furthermore, IQvision camera was worked all the time.

Conclusions
The final results of measurements revealed the compact dependence between the mater fluxes and water discharges.
Daily mean SSC varied between 1,15 and 1353,65 mg/l with an average being 406,11 mg/l (Fig.3.). The SSC is relatively higher in the initial ablation period (compared to the later part of ablation - the author's observations from previous seasons). Relationship between mean daily SSC and discharge shows a high degree of correlation (R^2=0,94).

The daily SSL for Werenskiold Glacier ranges between 0,1 and 703,6 ton with the average being 205,2 ton/day (Fig.2.). The average sediment yield for the beginning of the melt season in the basin is found 219,1 t/km².The measured period contribute ~20% of the total sediment during the all ablation season. The erosion rate for Werenskioldbreen is estimated to be 0,37 mm (2007 yr). Given the beginning of the ablation season (measured for the first time) erosion rate is 0,46 mm.
Investigations on chemical composition of glacial meltwaters were carried out simultaneously with observations of suspended sediments to estimate the participation of chemical denudation in the total rate of catchment denudation (Fig.5.)
Researches from the beginning of 2011 observation seasons enable to present the detailed image of the meteorological and hydrological conditions of seasonal and diurnal variations in suspended sediments and solute transport in Werenskioldbreen catchment (Fig.1-4).

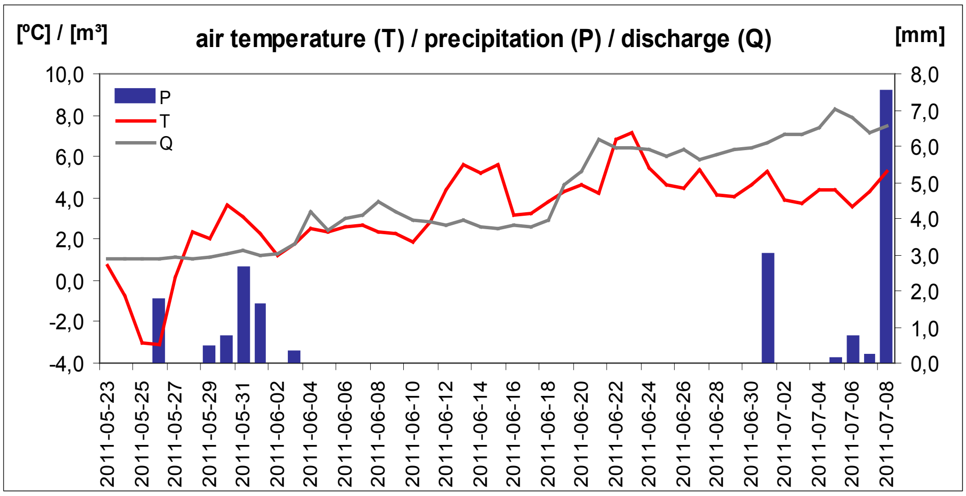

Figure 1: *Meteorological condition in the Werenskioldbreen catchment.*

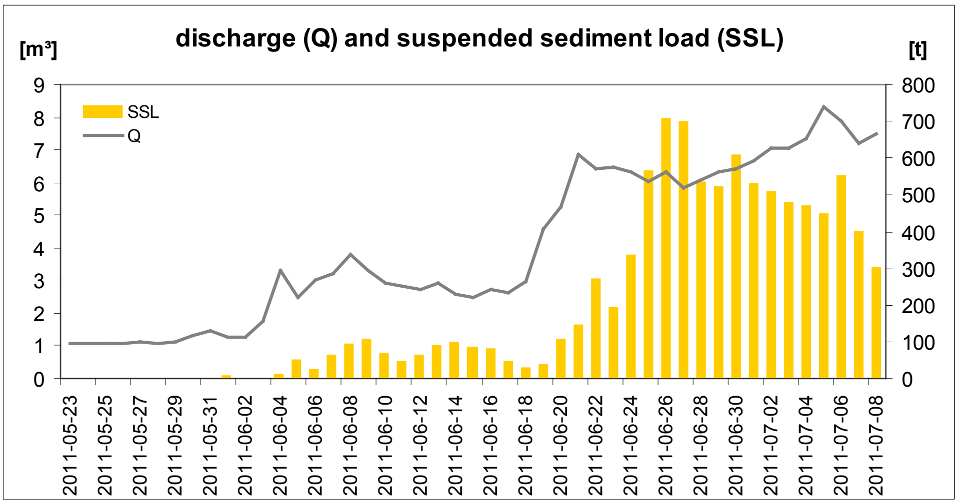

Figure 2: *Suspended sediment load (SSL) and discharge(Q) in Glacier River (23 May - 8 July 2011).*

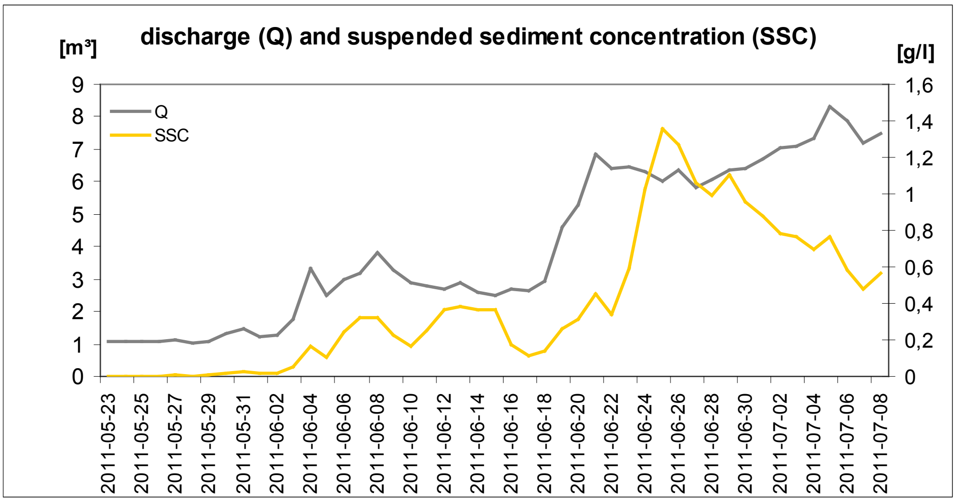

Figure 3: *Suspended sediment concentration (SSC) and discharge in Glacier River (23 May - 8 July 2011).*

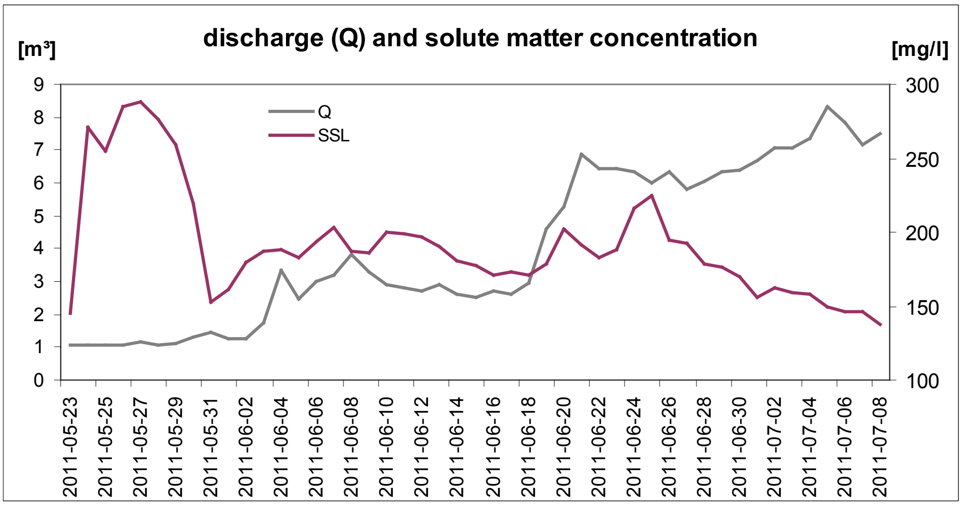

Figure 4: *Solute matter concentration and discharge (Q) in Glacier River (23 May - 8 July 2011).*

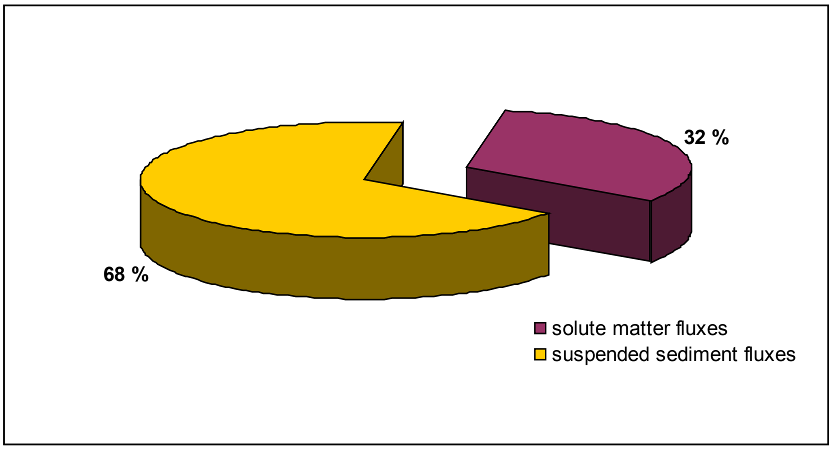

Figure 5: *Proportional participation of suspended sediment fluxes and solute matter in the total matter flux from the Glacier River catchment, 23 May - 8 July 2011.*

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The mass balance of Svenbreen, Dickson Land, Svalbard in 2010/11

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The number of Spitsbergen glaciers with mass balance monitoring varied in time. In the period 1977-1982 seven glaciers from different regions were studied. Glacier with the most negative balance was Bertilbreen, with the lowest accumulation (Bw=0.4 m w.eq., mean for the period mentioned) and high melting (Bs=1.1 m w.eq.).
Bertilbreen was the only surveyed glacier in Dickson Land – an arid region with warm summer seasons in central Spitsbergen. Its mass balance record terminates in 1984/85 and since then no works has been continued. In 2010/11 mass balance measurements on a neighbouring glacier, Svenbreen (3.8 km^2), were started. It was expected to observe high mass loss from this glacier as well.
Winter accumulation of Svenbreen has been measured in May and total summer melt in mid-September. Glacier-wide net balance of Svenbreen has been estimated to be -0.7 m w. eq., what seems to be a typical value for this region.
The fieldworks were sponsored by Polish National Science Centre as grant N N306 062940.

Progress in the development of techniques for estimation of the ice volume of Svalbard glaciers from GPR data

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One of the main objectives of SvalGlac project is to obtain a reliable estimate of the total ice volume stored in Svalbard. This will be accomplished by deriving area-volume relationships specific for Svalbard glaciers of different typology [*Bahr*, 1997; *Radić and Hock*, 2010].

There is a lack of knowledge concerning the main parameters of Svalbard glaciers, among them, the ice thickness and an accurate and updated ice volume estimation.

Given the limited number of Svalbard glaciers for which accurate volume estimates are available, a fundamental aspect to be elucidated is whether a volume-area relationship based on such a limited number of glaciers (even if these share a common morphology) will perform better than a general relationship based upon a huge number of glaciers.

For this purpose, an inventory of radio-echo sounded glaciers in Svalbard has been compiled using a GIS-based interface, containing the GPR profiles performed in every glacier, orthorectified satellite images (contribution of Dept. Geomorphology, Faculty of Earth Sciences, University of Silesia) and glacier boundaries for the period when the glacier was echo-sounded (personal communication of Christopher Nuth, from Norsk Polarinstitutt, 2012). Also, general glaciological information of individual glaciers is stored in the database, such as surge events or the glacier thermal regime, which can be useful to achieve a reliable volume estimate.

Ice thickness data has been gathered from different sources and formats. Two main types of GPR-retrieved thickness data can be distinguished. First, data from glaciers for which a rather complete set of GPR profiles is available, usually from ground-based echo sounding. Second, airborne echo sounding data which usually covers only the central flow line of the glacier.
In the first case, when several GPR profiles are available for a glacier, an ice thickness map is built using spatial interpolation routines. We chose ordinary Kriging as interpolation method. It is a geostatistical technique that analyses the spatial structure of the data, yielding the variogram model. Afterwards, this spatial continuity function is used to determine weights for the neighboring measured points that will be averaged at every unknown location. The reason for our choice are the advantages of this technique, the smoothness and the unbiasedness condition [*Cressie*, 1990]. We worked with a spherical model, and its

parameters (sill, nugget and range) were calculated to get the best fit to the variogram. Anisotropy was applied in the cases where the ice thicknesses showed higher autocorrelation in a particular direction, a fact that usually occurs in glaciers with a main flow direction.
A special attention is paid to the analysis of errors involved, both regarding the radar data and the interpolation and volume computation. For the interpolation error, we present a method adapted to GPR data which are usually anisotropically distributed over the surface, densely sampled along the tracks but widely spaced between them. Well known methods such as cross-validation or Jackknifing techniques [*Davis*, 1987; *Isaaks and Srivastava*, 1989] have often been used to quantify the accuracy of interpolation algorithms. However, they are not good estimators of the interpolation error when dealing with GPR–like data because of their sparse and unevenly distribution. Errors will not be representative for the areas without profiles. The aim of this new method is to calculate an average error following the basis of cross-validation, but taking into account the variance of the error with the distance to the nearest neighbor. Errors grow gradually with the increase of the distance to the nearest measure. This method searches a function to relate the interpolation error at every grid node with the distance to the nearest measurement point. This is done by the artificial generation of blanked circumferences of different radius among the data. Interpolation is carried out after blanking once at a time, and validation is performed only at the central point of the blanked surface. After completing the whole process, the RMS of all the errors is calculated for each radius.

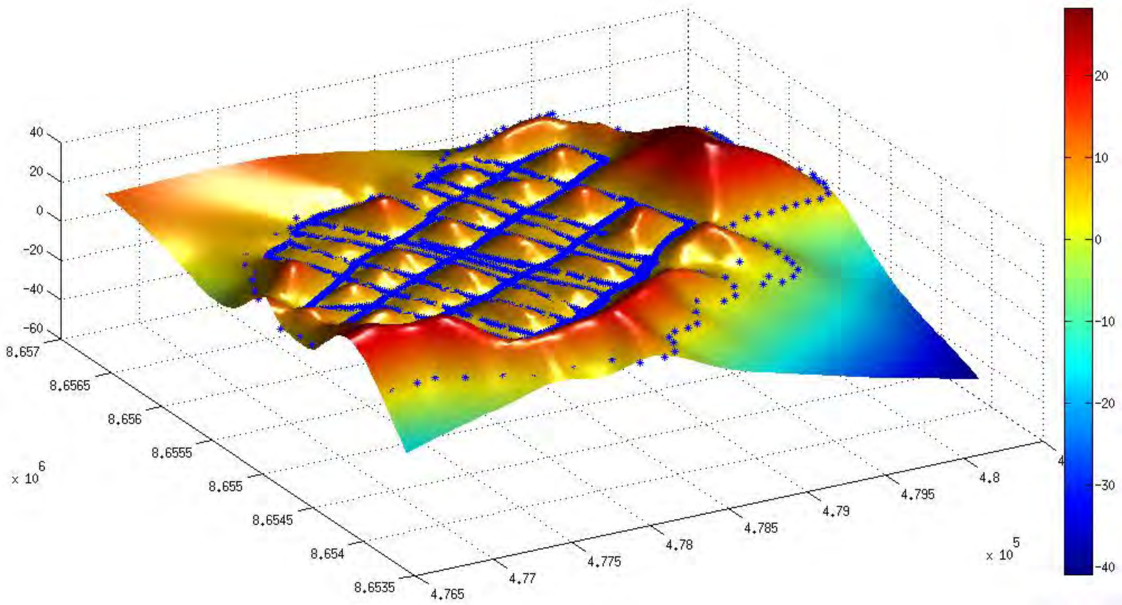


Figure 1: *Interpolation error map (m) for Aldegondabreen, with a display of the GPR profiles and the glacier boundary (in blue) made in 1999 [Navarro et al., 2005].*

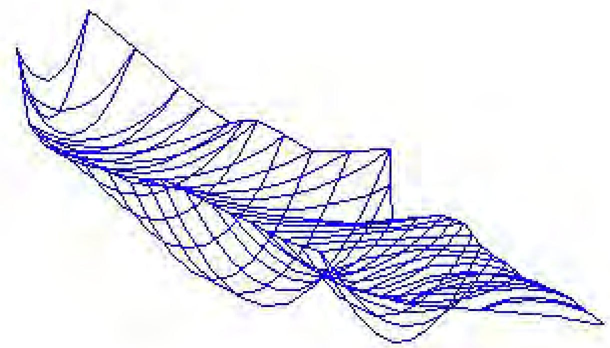
Figure 1 shows the interpolation error map of Aldegondabreen, a glacier in central Spitsbergen. Higher error peaks correspond to areas without measurements. This validation method is independent on the interpolation algorithm used, and can also be used to choose the interpolation method that best fits your data.

The measurement error is calculated following [*Navarro, F.J. and Eisen, O.*, 2010] and combined with the interpolation error to form the thickness error map.

Measurement error is dependent on GPR frequency and thickness. In this example, the whole echo-sounding was made using the same equipment at the same frequency, so it turns out to be only thickness-dependent. Measurement error (of the observations) is 5.93 ± 0.25 m and interpolation error (of the grid) is 8.78 ± 4.59 m.

In the case of airborne echo sounding, the volume calculation involves some assumption about the shape of the cross section of the glacier valley. At the early state of our work we approximated the cross-section by a parabola (fig.2), but this resulted in an underestimate of the volume by about 20%. Further work is in progress to improve such estimates; one of the approaches that we have considered takes into account geomorphological aspects of the glacier valley.

Figure 2: *Parabolic approximation of a glacier*



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An analysis of snow cover changes in the Himalayan region using MODIS snow products and in-situ temperature data

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Amidst growing concerns over the melting of the Himalayas' snow and glaciers, we strive to answer some of the questions related to snow cover changes in the Himalayan region covering Nepal and its vicinity using Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover products from 2008 to 2008 as well as in-situ temperature data from two high altitude stations and net radiation and wind speed data from one station. The analysis consists of trend analysis based on the Spearman's rank correlation on monthly, seasonal and annual snow cover changes over five different elevation zones above 3,000m. There are decreasing trends in January and in winter for three of the five elevation zones (all below 6,000m), increasing trends in March for two elevation zones above 5,000 m and increasing trends in autumn for four of the five elevation zones (all above 4,000 m). Some of these observed trends, if continue, may result in changes in the spring and autumn season river flows in the region. Dominantly negative correlations are observed between the monthly snow cover and the in-situ temperature, net radiation and wind speed from the Pyramid station at 5,035 m (near Mount Everest). Similar correlations are also observed between the snow cover and the in-situ temperature from the Langtang station at 3,920 m elevation. These correlations explain some of the observed trends and substantiate the reliability of the MODIS snow cover products.

3D-modelling of the dynamics of Amundsenisen icefield, Svalbard

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Amundsenisen is an icefield, 80 km^2 in area, located in Southern Spitsbergen, Svalbard. Radio-echo sounding measurements suggest a mostly temperate ice body, though at certain locations there are cold ice patches at the upper part of the ice column. The radar data also show high intensity returns from a nearly flat basal reflector at several zones (see Figure 1), all of them with ice thickness greater than 500 m. These reflections suggest

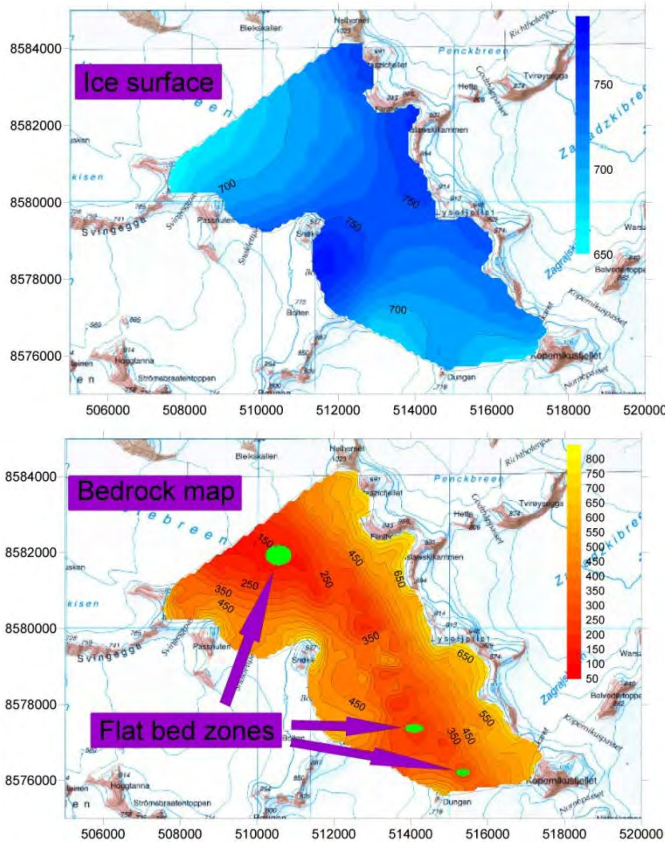

Figure 1: *Surface and bedrock topography of Amundsenisen. The bedrock topography was determined by subtracting the GPR-measured ice thickness from the upper surface topography.*

possible subglacial lakes. To determine whether basal liquid water is compatible with current pressure and temperature conditions, we aim to apply a thermo-mechanical model with a free boundary at the bed defined as solution of a Stefan problem for the interface ice-subglacial lake. The complexity of the problem suggests the use of a bi-dimensional model, but this requires that well-defined flowlines across the zones with suspected subglacial lakes are available. The main goal of the present contribution is to define these flowlines, and their corresponding velocity fields, from the solution of a three-dimensional full-Stokes dynamical model (Otero et al., 2010).

We are mostly interested in the plateau zone of the icefield, so we define artificial vertical boundaries at the heads of the three main outlet glaciers draining Amundsenisen icefield: Høgstebreen, Bøygisen and Nornebreen. At these boundaries we set velocity boundary conditions based on field-measured velocities. Only velocities at the centres of the outlets are available. The velocities at depth are calculated according to a SIA velocity-depth profile, and those at the rest of the transverse section are computed following Nye's (1965) model. The upper boundary is a traction-free boundary. Because the basal ice is temperate, and due to the lack of information on subglacial conditions, we set basal sliding boundary conditions dependent on the hydraulic potential at the glacier bed (Shreve, 1972).

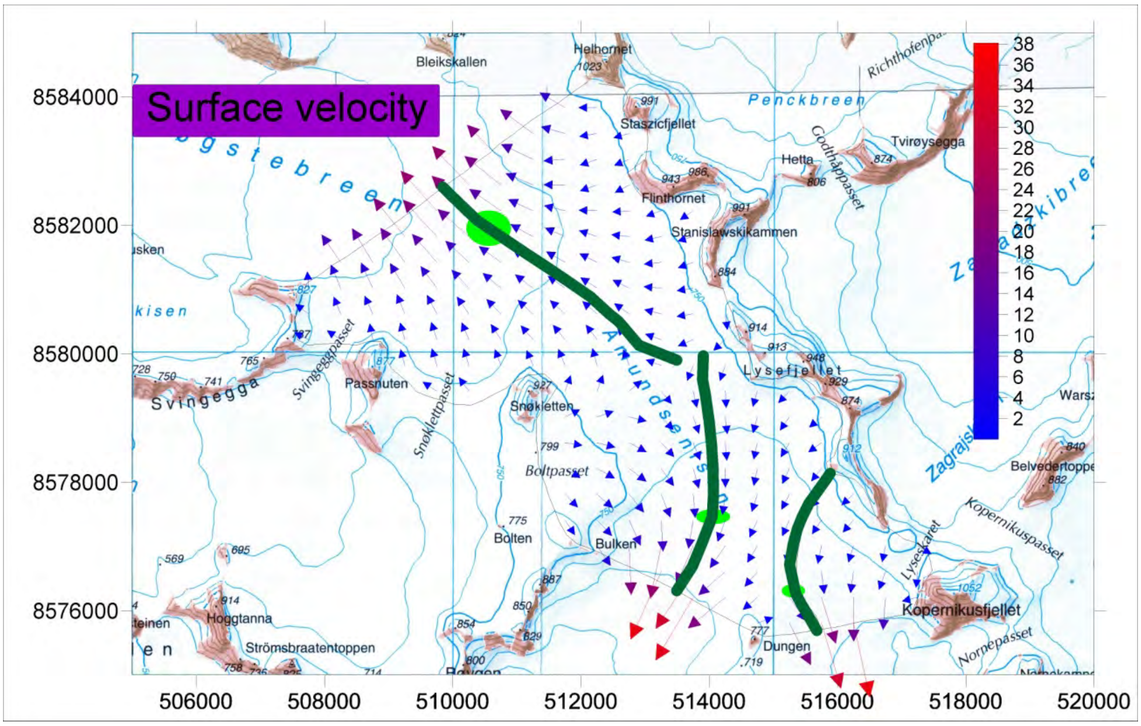

Figure 2: *Modelled surface velocity field of Amundsenisen. Three flow lines, each crossing above one of the zones of suspected subglacial lakes, are shown.*

The results for the modelled velocities at the surface of Amundsenisen are shown in Figure 2, where three flow lines, each crossing above of the zones of suspected subglacial lakes, are shown. The velocity field makes apparent the position of the ice divide approximately located along a line joining Snøkletten and Lisefjellet. The surface velocities increase towards the outlets, taking on each of the outlet boundaries the values specified by the corresponding velocity boundary conditions. The geometry of these flowlines, together with the corresponding along-flow- and depth-dependent velocity fields, will allow further thermo-mechanical modelling of these flowlines, with emphasis on the solution of the Stefan problem for the interface between the basal and the hypothesized subglacial lakes, aimed to ascertain whether the existence of such lakes is compatible with the present basal conditions.

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Application of the dendrochronological methods to estimate past changes of the valley glacier front (as example the Arie Valley, Spitsbergen)

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From the end of the Little Ice Age, the climate change has had a big impact on the polar regions. In Arctic, the progressive glacier recession, sea ice withdrawal, warmer summers and winters have been observed since the beginning of the 20th century. Also the spatial distribution of fauna and flora species are changing in time. The aim of this research are: 1) to determine the rate of the Arie glacier recession, 2) to use dendrochronological methods to reconstruct geomorphic processes on the glacier forefield.
The Arie Valley (2.04 km^2) is located 2.5 km from the north-west from the Polish Polar Station and the Hornsund fjord, in south-western part of Wedel Jarlsberg Land (Svalbard). The valley is divided on northern part covered by a small Arie glacier and on non-glaciated southern part with clearly visible two levels of fluvioglacial terraces. The steep slopes of the valley are free face in upper- and debris with large solifluction lobes in lower part. The present-day area of the cold-based Arie Glacier is 0.36 km^2. The glacier is in high recession. The rate of this glacier recession is reflected by activity of geomorphic processes on its forefield.
To dendrochronological date of geomorphic processes in the ice-free part of the Arie Valley were used two species of dwarf shrubs: Salix polaris and Salix polaris. Theses species have clearly visible and countable annual growth rings. The samples were collected in two summer seasons 2007 and 2008. The age of samples was used to determine minimum age of geomorphic forms and to reconstruction of the dynamic of the fluvioglacial and glacial processes. In the light of dendrochronological research can be distinguished three stages of the Arie valley development: 1) before 1930: aggradation (the glacier front is stable), 2) from the turn of 1930 and 1940: erosion (fast retreat of the glacier), 3) from the 1975: stabilization of the non-glaciated part of the valley and further fast retreat of the glacier.
The new for polar regions dendrochronological methods can be an additional proxies for recognition the glacier front recession. This method gives precise information about the geomorphic processes in the past.

2D-modelling of the variations of the calving front positionof Hansbreen, Svalbard

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Hansbreen is a tidewater glacier in Svalbard, about 16 km in length and 2.5 km in width at its tongue. The calving front position shows, over the recent decades, a general retreating trend, often rather smooth but with some occasional abrupt changes. We apply a full-Stokes model of glacier dynamics, using Elmer code and incorporating a crevasse-depth-based calving model, with the aims of: 1) reproducing the glacier front position changes observed since 1936, and 2) analyzing the sensitivity of the model to environmental parameters. The model is able to reproduce quite closely the observed front position changes, though not all of the abrupt changes are captured by the model. The amount of water filling the crevasses and the bed geometry act jointly in controlling the front position changes. The front position gently evolves when the front is located in nearly-flat bed areas, while abrupt front position changes occur where the bed shows a sharp change in slope, with different amounts of water implying different timing for the abrupt changes in front position. We have also analyzed the influence of setting the amount of water in crevasses as a function of summer temperature and changes in mass balance function.

Surface Topography and Change of Langjökull Iceland from 1997 to 2007

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Langjökull is Iceland's second largest ice cap (~925 km^2). Digital elevation models (DEMs) from 1997 (dGPS snowmobile transects), 2001 (photogrammetry of largest outlet Hagafellsjökull Vestari), 2004 (SPOT stereoimaging), and 2007 (airborne LiDAR interpolated by photoclinometry) are used to investigate topographic changes across Langjökull and its major outlet glaciers. The geodetic mass balance is calculated for these epochs and compared to in situ mass balance measured with a traditional 22 stake network across the ice cap. Spatial variation of the surface mass balance of Langjökull was also simulated using a model which calculates precipitation, snow accumulation, and surface melting as a function of altitude based on observed temperature and precipitation at a nearby meteorological station. The model is calibrated with annual mass balance measurements and data from two on-glacier automatic weather stations. By comparing the surface elevation change and modeled melt across the various epochs, a vertical velocity component of the glacier is calculated. Regional variations in volume change and velocity show differing characteristics of the four major outlet glaciers, including visualization of the 1998 surge of outlet Hagafellsjöjull Eystri and relative contribution of each outlet to the volume change of the ice cap.

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Hydrological regime of Hornsund Fjord based on 10 years of observations

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Key words: Hornsund, temperature, salinity, Winter – cooled Water, Atlantic Water

Hornsund (southwest coast of Spitsbergen) as a specific kind of estuary constitute a link between ocean and land. In this sense , the hydrological regime of the reservoir is dictated by a dynamics and intensity of processes occurring in the boundary conditions (ocean – fjord and fjord – land). From summer to summer variations of hydrological conditions in Hornsund has been observed. Seasonal variations of water mass properties are investigated, as well. Data on physical parameters (temperature, salinity, density) were collected every summer since 2001 aboard the S/Y Oceania, during Arctic experiments performed by Polish Academy of Sciences. Data from last two years were collected during spring until late summer from a boat under the AWAKE Project.

Differences in hydrological characteristics from year to year has been observed. As a result of mixing of Atlantic Water with Arctic water on the shelf, water masses which enter the fjord are strongly modified. There is no pure Atlantic Water in the reservoir. 10 years of observations show the highest values of temperature and salinity in 2002 and 2006, which is related with maximum of temperature and salinity of Atlantic Water flowing northward with the West Spitsbergen Current. Since 2007 decrease of temperature and accompanying decrease of salinity are noticed. In 2010 decrease of temperature is accompanied with increase of salinity which can indicate the importance of local processes in this period. 2010 and 2011 are the coldest years. Investigations focused on region near glaciers of the fjord (Hansbreen and Storbreen in Brepollen) show the seasonal variations of water mass properties.

Depositional efficiency related to glacier snouts dynamics changes after Little Ice Age (LIA) on Svalbard

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On the base of the analysis of archive photogrammetric materials and observations of glacier snouts in the vicinity of Petuniabukta (Billefjorden, central Spitsbergen), the model of sediments delivery changes and ice margin relief development was proposed.
The aerial pictures from 1936 revealed glacier fronts visible as convex ice surfaces covering almost the entire area of the maximum extent of LIA. However, a certain amount of mineral admixtures and the initiation of sediments outcrops generation could be noticed on glacier snouts. The estimation of sediment transfer from subglacial to supraglacial position for post – LIA was performed. Assuming steady conditions of the ice flow after LIA and an average debris amount in a single debris band associated with the thrust plane, the transfer of sediments to the surface was almost balanced with the retreat during 60 years of decay (1900–1961). It was followed with the change of ice slope inclination from above 20° of the transgressional profile down to the actual value of less than 5°. At a given point of the debris band outcrop inclined 40° on average with the upward movement of sediments, the supraglacial release of till initially gave 0.6 to 3.0 m of thickness as the effect of approximately 30–40 m of the melted glacier ice. At the present-day retreat conditions of the accelerated ablation, the same volume of ice decay and the actual thickness of forming supraglacial covers did not exceed during one decade 0.2–0.3 m. These results are in agreement with direct observations and the georesistivity measurements in marginal zones, showing the layer of morainic covers on buried ice reaching up to 2.5 m.

5 Years of mass balance and velocity observations on Nordenskiöldbreen, Svalbard

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Introduction

Enhanced ice flow following surface melt has been reported for Alpine glaciers (Iken and Bindschadler, 1986), Arctic glaciers (e.g. Copland et al., 2003), as well as the Greenland ice sheet (e.g. Zwally et al., 2002; Van de Wal et al., 2008, Bartholomew et al. 2010). The velocity increase is caused by an increase in basal water pressure due to a large input of water into the subglacial drainage system. The relationship between surface melt and glacier acceleration is not linear. It depends on the surface conditions because a time delay

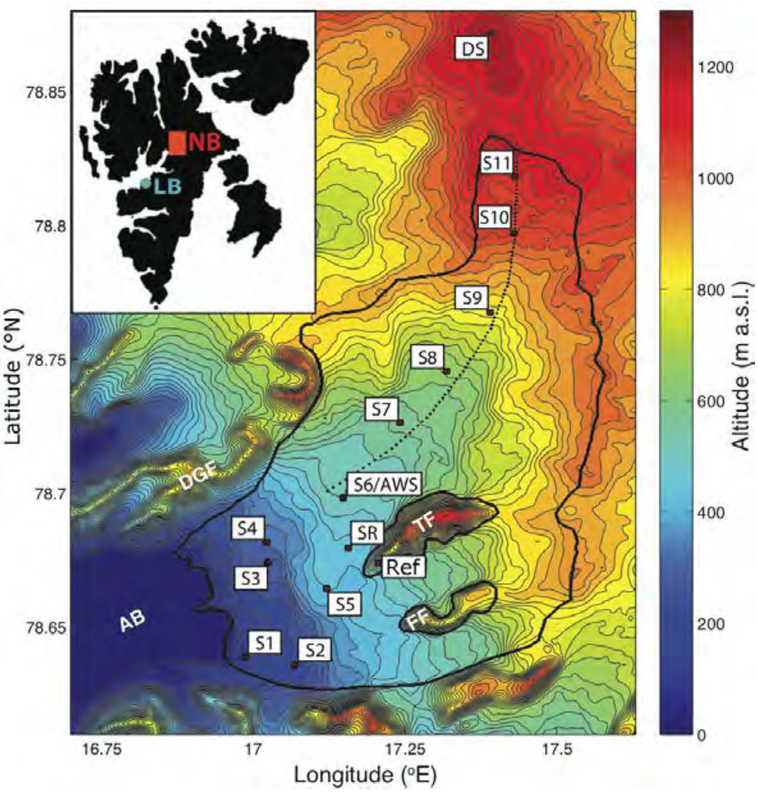

Figure 1: *The surface topography of Nordenskiöldbreen, Svalbard. Dots mark the locations of stake and velocity observations (S1-S11). AWS marks the location of the Automatic Weather Stations, SR marks the location of the Sonic Ranger. The black line is the glacier outline as used in the energy balance computations.*

exists between the onset of summer melt and the onset of runoff, related to melt water re-freezing in a cold snowpack. In addition, it depends on the capacity of the basal hydraulic system and its response time to adapt to changes in water input. The latter results in an initial increase in water pressure, and thus velocity, followed by pressure drop when the hydraulic system has adjusted to the increased input of melt water.

In the framework of the IPY-GLACIODYN project 'Meltwater input, flow and calving of Arctic glaciers' ice velocity and mass balance observations are carried out on Nordenskiöldbreen, Svalbard (Fig. 1). Here we report on five years of observations which we combine with energy balance modelling results to investigate the relation between melt water and ice velocity for this glacier.

Methods

The ice velocity measurements are carried out with relatively low cost stand-alone single frequency GPSs (Den Ouden et al., 2010). The GPSs store hourly data from which flow velocities are calculated. The mass balance is determined by traditional stake measurements and by means of sonic height ranger data. Both the stake and the sonic height ranger data are converted to mass balance values using density observations. Measurements presented here cover the period 2006-2011.

The energy balance model is a two-dimensional model based on Klok and Oerlemans (2002) and presented in Van Pelt et al. (2012). It includes a multi-layer snow model (Greuell and Konzelman, 1994) and is driven by output of a regional climate model (RACMO2) (Ettema et al., 2010) and Svalbard airport observational data. The model run covers the period 1989-2010.

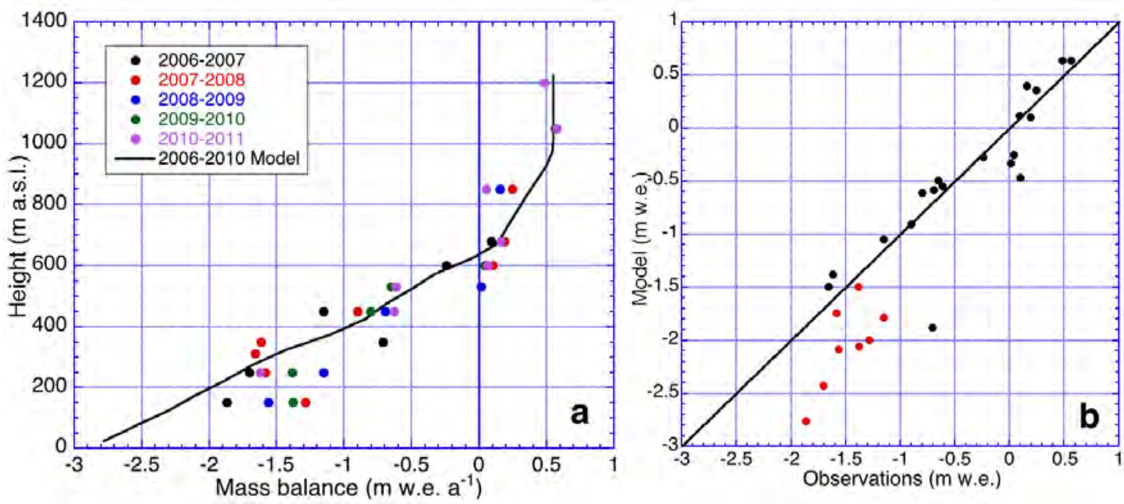

Figure 2: *a) Mass balance observations as a function of elevation. Black line denotes the modelled mass balance profile averaged over 2006-2010. b) Modelled annual mass balance as a function of the observations. Red dots are sites S1 and S2, black dots sites S3 to S11 (Fig. 1).*

Results

The annual mass balance ranges from about 2.5 to 3 m w.e.yr^{-1} ice loss near the snout to about 0.5 m w.e.yr^{-1} accumulation on the Lomonosovfonna plateau, with the average equilibrium line altitude at about 600 m a.s.l. (Fig. 2a). The modelled mass balance at the stake locations corresponds well with the observations (Fig. 2b), as does the resulting mass balance profile (Fig. 2a).

Nordenskiöldbreen is not a very fast flowing glacier. The annual average velocity at the stake locations varies from 50 m yr^{-1} near the snout (S3, S4), to 60 myr^{-1} on the steep slope towards the plateau (S9), dropping to less than 3 myr^{-1} on the plateau (S11). When correlating the annual average velocities with modelled melt/runoff we do not find a significant relation between the velocities and mass balance.

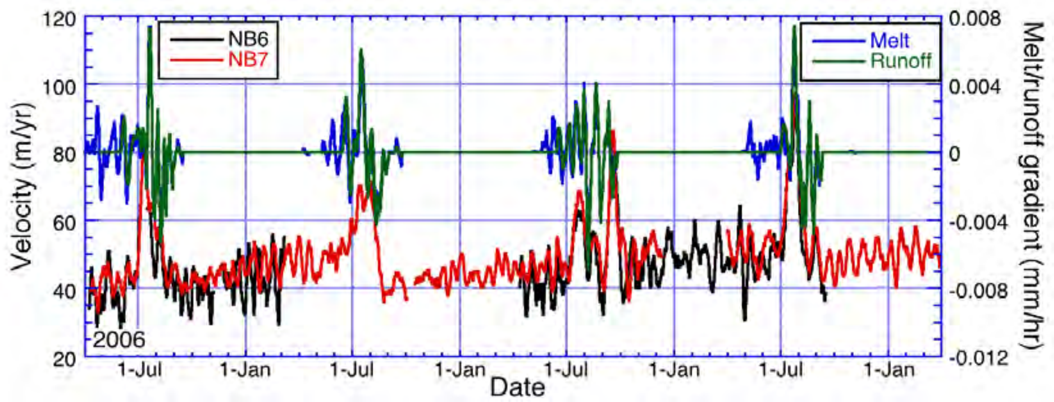

Figure 3: *Observed velocities at sites S6 and S7 (Fig. 1) (left axis) and modelled gradient in melt and runoff at site S6 (right axis), as a function of time starting in April 2006.*

Figure 3 shows that on short time scales the seasonal speed up of the glacier is related to the maximum in melt/runoff increase at the start of the melt season with no significant time delay. Although melt/runoff occurs till the end of September, the velocity decreases from August onwards. The increase in velocity is related to an increase in basal water pressure which lasts until the hydraulic system has adjusted its transmissivity to the increased input of melt water. Therefore, an increase in annual amount of melt does not necessarily result in an increase in annual mean velocity since it depends on how fast the hydraulic system will adjust to changes. This relation on short time scales and lack of correlation on longer time scales was also found for e.g. the Greenland ice sheet (Van de Wal et al., 2008).

Conclusions and outlook

Comparison to observed stake readings shows that the energy balance model is well capable of representing the mass balance of the glacier. The observed velocities show that Nordenskiöldbreen is not a very fast flowing glacier. No correlation of annual average velocity with annual amount of runoff/melt is found. On shorter time scales most stations show melt related increase in ice velocity, with the maximum velocities related to the maximum in melt/runoff rate with no significant time delay. The latter is as expected since water transport through crevasses and Moulin's is very efficient.

The next step in this project is dynamical modelling of the glacier. We will use the Parallel Ice Sheet Model (PISM) for that, which is currently modified to include the effect of water on the hydraulic system.

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The Agloolik Expedition - tracking the ‘spirit’ of snow on Axel Heiberg Island

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The proposed project is a unique combination of local physical data documentation, Inuit knowledge and ground truth measurements. A team of four are planning to travel over a transect of 475 km in a six week traverse of Axel Heiberg Island, in Nunavut the Canadian Arctic. This project is aiming to record valuable in situ qualitative and quantitative data about the current cryospheric state of Axel Heiberg Island. This will then offer the opportunity to improve Arctic climate simulations by computer-based models and better assess the impacts of climate change in the so fragile Northern spheres and on Arctic natural resources.

The recorded field data will include snow density, GPS ground truth obtained from measurements performed along the transect with specialized field instruments and associated place names from local (Ellesmere Island) Inuit knowledge. This research will then be paired with historical climate and weather records, satellite imagery analysis and photography to provide an interdisciplinary approach for evaluating climate change on Axel Heiberg Island’s icefields. This will then allow the development of an integrated spatial distribution of snow cover and climatological model for the area. The regional and local reference to weather stations, satellite imagery and cryospheric models will be combined with universities and government organizations.

Glaciospeleology – tool for the survey of polythermal glaciers

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Glaciospeleology is the technique, which brings in situ data about temperature of ice, air and water from inside of glacier mass. Also could be used for the installation and maintenance of the dataloggers, sampling of the different types of glacial water and soil. The observation and documentation of subglacial and supraglacial systems could be done. Obtained data could explain hydrology of polythermal glaciers and development of glacial systems. Glaciospeleology together with other modern techniques of survey of glacier can bring unique results about ice ecosystems.

Basal drag pattern inferred from surface velocities for Vestfonna ice-cap (Svalbard) with a Full-Stokes model in 1995 and 2008

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Introduction

Svalbard is an Arctic archipelago at around 80°N. Austfonna and Vestfonna are the two major ice-caps on the second largest island (Nordaustlandet). We focus on the smaller one of the ice-caps which covers about 2400 km^2 and ranges in altitude from sealevel to 630m a.s.l.

It is characterized by a relatively smooth and flat area in the centre (Pohjola et al., 2011b) and fast flowing outlet glaciers (Pohjola et al., 2011b). These fast-flow units and surge type glaciers are the most challenging glaciers to model.

Here, we use the Full-Stokes model Elmer/Ice (Gagliardini and Zwinger, 2008; Zwinger and Moore, 2009) to study in detail the conditions at the bottom of Vestfonna in 1995 and 2008 with an inverse approach. Basal conditions are deducted from the glacier topography and the surface velocities. Recently, several methods have been proposed to solve this particular inverse problem. Here (and in Schäfer et al., 2012) we use the variational approach with a Robin inverse method proposed by Arthern and Gudmundsson (2010); Gudmundsson (2011) and subsequently used in simulations of Variegated Glacier and the Greenland Ice Sheet (Jay-Allemand et al., 2011; Gillet-Chaulet et al., 2012). In this approach the normal forward solution of the Stokes equations can be used in the numerical implementation.

Data used in this study

The digital elevation model of the surface elevation is based on the topographic map from the Norwegian Polar Institute (NPI) (1:100 000, 1990) and completed with the International Bathymetric Chart of the Arctic Ocean (IBCAO) (Jakobsson et al., 2008) in the sea. The surface topography is dominated by clear ridges in its central parts. The fast-flowing outlet glaciers are located between the ridges and the coast.

The bedrock data used is presented in Petterson et al. (2011) and consists of combined ground-based pulsed radar data collected in 2008–2009 and airborne radio-echo soundings data acquired in 1983 and 1986 over the ice-cap.

Tandem Phase ERS-1/2 1-day InSAR scenes acquired between December 1995 and January 1996 and four ALOS PALSAR scenes acquired between January 2008 and March

2008 were used to calculate the ice surface velocity structure of Vestfonna (Pohjola et al., 2011a). We observe two very different flow regimes: a general pattern of very slow ice flow over the central area of the ice cap, with pronounced high velocity areas in the outlet valley glaciers.

The mean annual surface temperature is estimated using the mean annual air temperature at sea-level and an elevation lapse-rate. The temperature profile inside the ice-body is poorly known, since Svalbard glaciers are typically polythermal. Here two limiting extreme cases are studied to proof that a simple estimation for the temperature is sufficient for this study: a steady-state equilibrium line temperature profile and an (unrealistic) isothermal ice-body.

A heat flow value of $63 \mathrm{mWm}^{-2}$, representative of the Post-Precambrian non-orogenic tectonic region (Lee, 1970) is used for Vestfonna in this study.

Ice-flow model

As forward ice-flow model we use the finite element model Elmer (Zwinger et al., 2007; Gagliardini and Zwinger, 2008; Zwinger and Moore, 2009). For the inverse model we use the same approach as Arthern and Gudmundsson (2010). The Stokes equations are solved iteratively with two different sets of boundary conditions. A Neumann condition at the surface represents the case where the surface velocity is freely determined from the ice geometry, basal friction parameter, etc., whereas the Dirichlet condition constrains the model according to the measured ice velocities. The iteration is stopped once the solutions of the Dirichlet and the Neumann problem are close enough. In the presence of noise in observed velocities, this method can lead to small wavelength oscillations in the distribution of the inferred friction parameter. As suggested in Jay-Allemand et al. (2011), but differently from Schäfer et al. (2012), an additional regularisation term with a weighting parameter is added to the cost function.

Finite Element Mesh

The 3-D mesh is a very critical point when using a finite elements model. To face this challenge, we used an inhomogeneous mesh with an horizontal resolution as fine as 250m in the fast-flow areas, but only as coarse as 2.5km in the other areas. This mesh is established using a fully automatic adaptive isotropic surface remeshing procedure (Frey, 2001) accordingly to the 1995 velocities. In vertical direction the mesh has 10 equidistant layers.

Application and sensitivity tests of the inversion of the basal drag force using the 1995 data

First attempts to model the ice-cap with one and the same sliding law and parameter everywhere failed. Then we attempted to differentiate "by hand" areas with different coefficients in the sliding law. This leads to a stable model which reflects the existence of the outlet glaciers, but yet fails to reproduce the correct velocity pattern of those glaciers. Consequently, the next step was the use of the inverse method to adjust at each location the parameter of the sliding law correctly.

The result of the distribution of the basal drag coefficient using the 1995 dataset as velocity forcing is shown in the Figure to the left. The convergence was surprisingly good, only 15 iterations were required. In the Figure blueish colours correspond to areas with little sliding, while the reddish areas correspond to areas with very fast sliding.
Now even the velocity pattern inside the outlet glaciers is very close to what is expected

from the measured surface velocities. The limits of the basal drag are given (naturally) by 0 and (artificially) by 1MPa yrm^{-1}. Introducing a lower threshold of 10^{-6} MPa yrm^{-1} for the basal drag coefficient did not alter the resulting velocity field (used in the Figure).

Different illustrations (histogram of the error between measured and modelled velocities, spatial distribution of the relative error and correlation between the measured and observed velocities) show that the velocities obtained with the model are very close to the observed surface velocities. For most grid points the error is below 20m per year, whereas the error in the observation is about $7myr^{-1}$. There is no noticeable difference in the relative error between fast and slow flow regions.

Simulations with meshes with coarser or homogeneous resolution show that some features then remain unresolved. Also the convergence behaviour was less good illustrating the importance of an adaptive mesh and emphasizing the necessity of a fine resolution in the regions of interest.

As a first prognostic simulation using this basal pattern, a run of 1000years in the future with the average mass-balance of the last years (Möller et al., 2011) was conducted. The resulting ice-cap is fairly close to the present-day ice-cap except in the south-eastern part of the island. In this region we observe an important glacial retreat.

Comparison between 1995 and 2008

The comparison between the 1995 and 2008 dataset (Figure below) is conducted with an older version of the inverse method without the regularisation parameter. Over most of the ice cap very similar values for the basal drag coefficient are obtained. An exception is Franklinbreen where the resulting changes are clearly in agreement with the acceleration observed in the surface velocity data.

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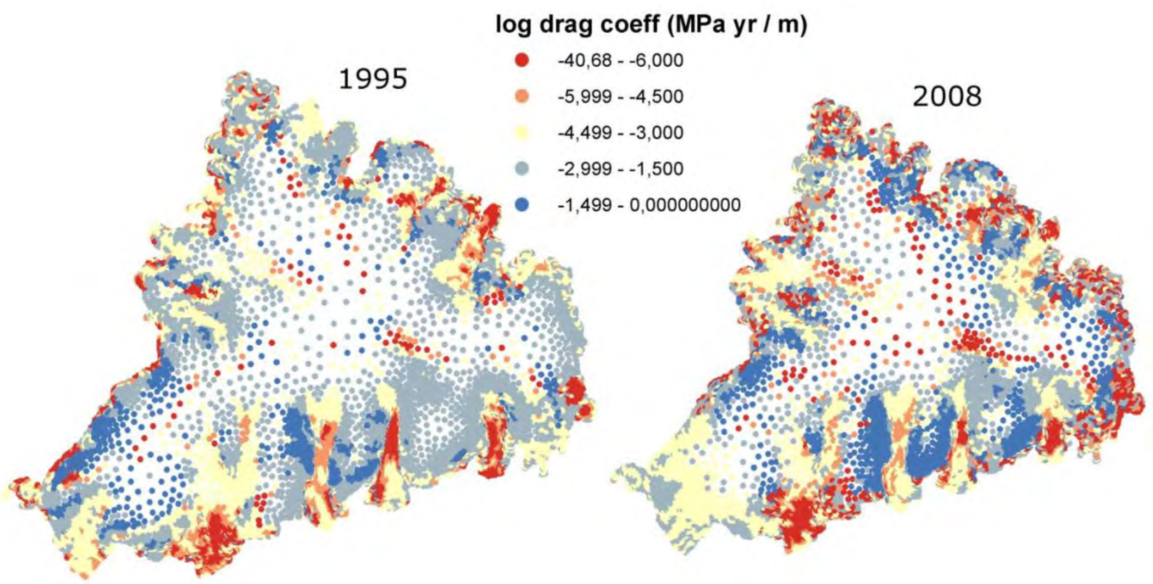

A regional atmospheric reanalysis for studying weather and climate in Svalbard

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Meteorological observations are scarce in the Arctic. The constantly improving capabilities of numerical weather prediction (NWP) models and freely available global data sets offer the opportunity to reduce this problem by providing data on meteorological variables at high spatial and temporal resolution. Longer periods of years to decades can be simulated by NWP models by successive model runs of shorter periods based on assimilated observational data, resulting in a so-called “regional atmospheric reanalysis”.

We present a regional atmospheric reanalysis for Svalbard by using the Polar Weather Research and Forecasting (PWRF) model. Input data sets are the standard final analysis (NCEP GDAS FNL, 1.0°, 6 h) data with additional sea surface temperature (NCEP RTG SST, 0.5°, daily) and sea ice concentration (AMSR-E/Aqua L3 Sea Ice Concentration, 12.5 km, daily). The simulations are composed of daily re-initialised runs. Each run starts at 12:00 UTC, and time integration is performed for 36 hours. Output for the first twelve hours is discarded since model results are negatively affected by spin-up effects. The simulations are conducted with a set of nested domains at three different spatial resolutions of 30, 10 and 2 km. First, we applied a simple two-way nesting approach for the three nesting levels, but tests have shown that improvements in the child domains arising from the two-way nesting are counteracted by artefacts in the parent domains. Therefore, we now use a cascade of simulations: the first simulation is performed for the 30 km grid without nesting, the second one is using a two-way nesting of the 30 km grid as parent domain and the 10 km grid as child domain, while the third simulation uses two-way nesting for the three nesting levels.

Data are stored at hourly intervals for the 10 and 2 km grids and at three-hourly intervals for the 30 km grid. The model period spans from 2000 to 2010. We will continuously update the regional atmospheric reanalysis on a near-real-time basis, and make the data set available to the public as soon as the validation studies are finished.

Meteorological and glaciological data acquisition system of Hornsund area (SW Svalbard)

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Abiotic elements of the environment (e.g. air temperature and humidity, wind velocity, precipitation, solar irradiation) determine the weather conditions and have a strong influence on geophysical processes observed in the Arctic (including glaciological processes). They become the key to their understanding and interpretation of changes in the environment. Since the beginning of the Polish Polar Station special attention is placed on the meteorological measurements and observations. The Hornsund Meteorological Station operates according to WMO standards under the number 01003. Every hour, value of the meteorological parameters are automatically sent to the Norwegian Meteorological Institute in Oslo and every 3 hours, this information is supplemented by visual meteorological observations (cloudiness, meteorological phenomena). Additional measurements include solar irradiation (CNR1 Kipp & Zonnen radiometer), insolation (three Campbell-Stokes sunshine recorders adapted to polar conditions), precipitation (Hellmann's rain gauge, electronic precipitation gauge T200B Geonor equipped with Alter windscreen and Ott Parsivel Disdrometer Present Weather Sensor are used on the Polish Polar Station). Topoclimatic conditions of Hans glacier (located close to the PPS) are investigated using three automatic weather stations equipped with Campbell Sci. loggers (CR1000 or CR3000), air temperature and humidity probe (Vaisala HMP45C), anemometer, pyranometers (reflected and global radiation) and ultrasonic ablatometer (SR50). The meteorological data are measured and logged every 10 minutes. Automatic weather stations are powered by an accumulator charging from photovoltaic cells (during polar night every two weeks batteries are replaced). The glaciological processes of Hans Glacier are investigated using metal ablation sticks which are positioned by a DGPS receiver (Leica GX 1230) every four weeks. In the area of equilibrium line of Hans Glacier are carrying out permanently monitoring of ice flow (DGPS receiver Leica GX 1230). In the final phase of accumulation is carried out profiles of the glacier by GPR measurements. Also snow cover profiles (or core drilling) in this time is done and samples of snow are taken to control its physical and chemical parameters.
From September 2009. position of Hans Glacier's ice cliff is monitored. This is carried out by a laser rangefinder Riegl FG21-LR, which is measured every 10 minutes distance from the glacier front. The results are recorded using the logger CR1000 Campbell Sci. Monitoring changes in the frontal zone of Hans Glacier is also carried out using a digital camera mounted on a slope Fugleberget (surrounding hill), which carry pictures of the one-hour interval.

Seasonal and short term changes of ice cliff position of a Spitsbergen tide water glacier on Hans Glacier as an example

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The surface of Svalbard's tidewater glaciers are more than 60% of the total glaciated surface area and consist of 163 glaciers with 860 km of total length of ice cliffs. This means a significant impact of this type of glaciers on the surrounding seas. Velocity of Svalbard glaciers is not well known. Field survey and analyses of satellite images allow an assessment of speed of some of them. Data on glacier velocity and front position changes are crucial for calculation of calving intensity. Seasonal changes of calving rate are still a puzzle. Changing of the location of ice cliffs, especially during the polar night was not well recognized. This problem has become a reason for installation of device for monitoring changes of the position of Hans Glacier ice cliff at the Baranowskiodden (SW Svalbard, northern shore of Hornsund) in September 2009. An accurate laser distance meter Riegl (FG21-LR) was used for this purpose. It continuously monitored the distance to the ice cliff.

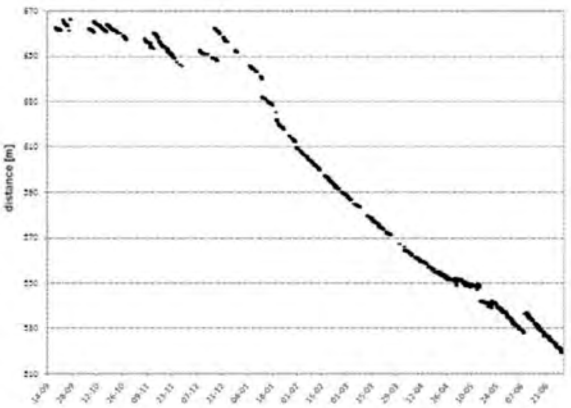

Figure 1: *Seasonal changes of ice cliff position of Hans Glacier as distance to the rangefinder (observation period: 17 September 2009-28June2010)*

The results of his measurements were recorded by a Campbell CR1000 logger every 10 minutes. Observed changes in the speed of movement of the ice cliff ranged from c. 0.5 to 1.5 m per day during the measurements carried out from September 2009 until the end of June 2010. Observations of short-term velocity of ice cliff were disturbed by calving activity until mid-December 2009 and from mid-May 2010. During this period, rapid distance increase up to 14 m was observed.

The total change of ice cliff position in observed period is estimated as an advance by c. 194 m during 285 days, i.e. 0.68 m per day in average. Seasonal front position changes of the glacier were documented.

Changes in dynamics and runoff from the glacial catchment of Waldemarbreen, Svalbard

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The analysis of the changes in dynamics and runoff from the glacial (polar) catchment basin of Waldemarbreen (Svalbard) was made. Since 1996, the runoff from Waldemarbreen catchment basin has been recorded continuously at the gauging station. One of the aims of this study was to try to determine how changes in the size of the glaciation of the catchment influence the volume of the river discharge and runoff. It is directly dependent on the degree of glaciation in the catchment and its changes. Changing the area and the volume of the glacier reduces the size of the discharge even when the intensity of melting does not change. Traditional glaciological investigations of Waldemarbreen are taken since 1996. In the years 1997-2010 the average share of ablation within the outflow was 55%. Selected elements which play some role in dynamics of the glacial catchment basin of Waldemarbreen like e.g. icings, changes in the location of the main river channel or moraine-dammed lake were also examined.

Waldemar River discharge variations in selected time scales during summer seasons 2009-2011, Svalbard

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Discharge variability of the Waldemar River was observed and analyzed in a specific time scale patterns: hourly, daily, seasonal and non-cyclic in summer seasons 2009-2011.
In typical glacier-fed river such features as water stages, discharge, sediment transfer, etc. are controlled by a glacier and its glacio-hydrological state (amount of ablation water, drainage network development) and by the other, local water sources (outflow from snow melting on non-glaciated catchment part and mountain slopes, dead ice melting, icings melting, etc.). There is strong differentiation of each element magnitude in time. That causes specific outflow variability, which is not observed in non-glaciated catchments. Waldemar River is located on the Kaffiøyra Plain, Oscar II Land, north-western Spitsbergen (Svalbard). Gauging profile was located about 800 m from the glacier snout. To this place its catchment occupies an area of about 4 km^2, of which almost 60% is taken by the Waldemar Glacier. Relative proximity between glacier and measurement point combined with the lack of the other water source tributaries and small catchment area allowed to observe all hydrological events that occurred in the glacier system in unmodified form. Each year the research took place in July and August.

Long-term observations (1991-2011) of elevation change and ice flow velocity in the Swiss-Camp area (West Greenland)

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1. Introduction

Since 1991 until 2011 now 11 campaigns had been carried out in order to study ice flow velocity, deformation and elevation change of the inland ice in the Paakitsoq area, West Greenland. It is a long-term project with terrestrial GPS observations of stake networks in two research areas. One area is situated at the Swiss-Camp, where formerly the equilibrium line was supposed. The second research area, called ST2, is located in an altitude 170 meter lower, and situated close to the automatic weather station JAR1 from the GC-Net. This network was established in 2004. Here we have now 5 campaigns in 2004, 2005, 2006, 2008 and 2011. The principal outline of the project with state and results of former campaigns until 2006 were published in *Stober and Hepperle*, 2007.

2. Results

2.1 Swiss Camp Area

2.1.1 Elevation change and mass balance

Figure 1 shows the cumulative elevation change from concrete (former) stake positions**.**
The adjusted straight line (*figure 1*, dashed line) over the whole period 1991 - 2011 shows an average elevation change of –0.45 m/a. Temporal variations up to a decrease of –0.85 m/a according to higher summer air temperature are clearly visible. All the extremely large elevation changes 1995-1996 and 2002-2004 coincide with the highest summer air temperatures. Between the campaigns 2006-2008 we had found an extreme elevation decrease of –1.04 m per year and for the period 2008 – 2011 we get almost the same decrease of –1,14 m/a. This is three times more than the average from former years. In the period 1991 until 2002 the linear trend was –0.22 m/a. The smoothed polynomial curve (*figure 1*, red) shows an accelerated elevation decrease, especially in the last warm years. Since the beginning of our research in 1991 the ice horizon has been lowered by a total of –10.08 m, corresponding to a cumulative mass balance of –9.17 meter water equivalent in the last 20 years.

The mass balance results from GPS surveys for all periods between our measuring dates (usually around 1st of August) are shown in *Figure 2*. They do not refer to the hydrological year (October 1st – September 30th). The graph contains the results from GPS and as well from stake measurements, which are available for some years, as long as the stakes were not melted out. While GPS represents the complete mass balance containing dynamical and meteorological components as well, the stake measurements give only the specific surface mass balance at few concrete points. Nevertheless, the accordance is quite satisfying.

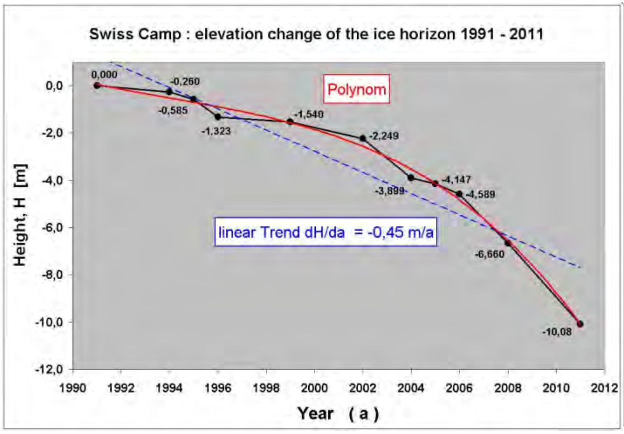


Figure 1: *Swiss Camp: Cumulative elevation change of ice horizon 1991 – 2011*

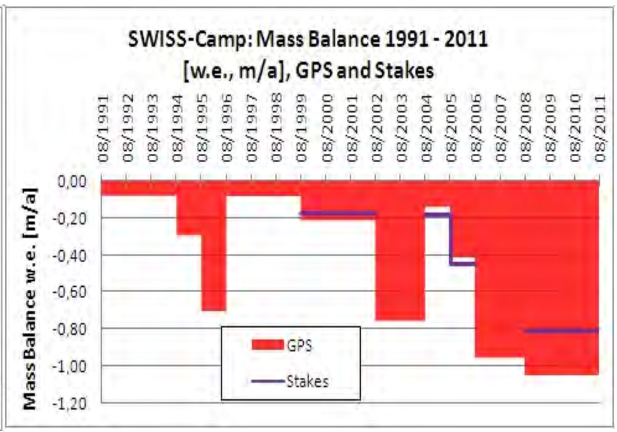


Figure 2: *Swiss Camp: Mass balance in the floating date system between successive surveys, 1991 – 2011*

2.1.2 Ice flow velocity

The ice flow vector was determined by comparison of stake positions in different years. In the period 2008 – 2011, the resulting ice flow velocity in average is 0,329 m/d. With one exception, 1995-1996, we find continuously increasing values (*figure 3*), as a consequence of increased temperatures with more melt water in the glacier and at the bottom (*McGrath 2011)* with increased basal sliding on the bedrock (*Zwally et al*., 2002, *Colgan, 2011 a, Colgan et al. 2011 b).*

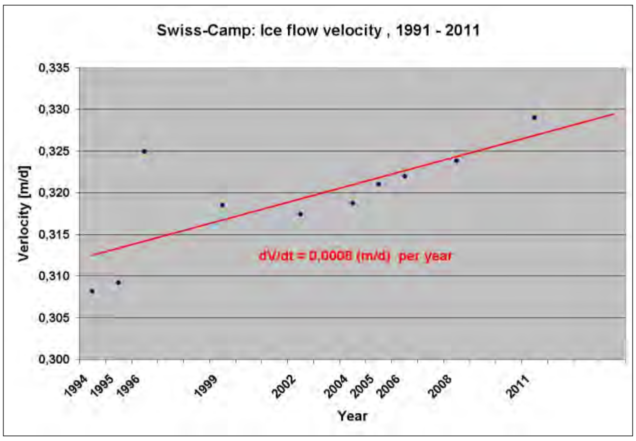
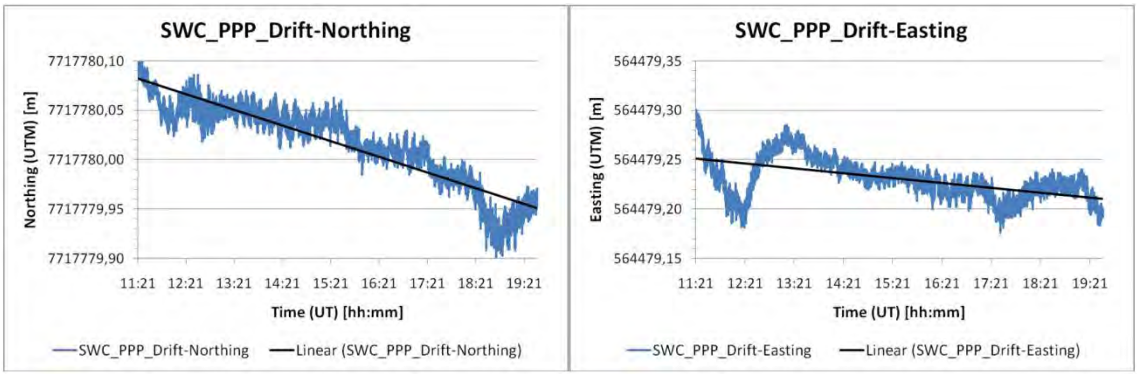


Figure 3: *Swiss Camp: Ice flow velocity [m/d], 1991 – 2011, annual averages.*

The seasonal summer flow velocity for the observation day (01.08.2011) could be derived from the GPS observations of our ice reference station. *Figure 4 and 5* show the temporal variations in position for the two components in Northing and Easting, respectively. The linear trend of the position changes shows a flow velocity for the observation day of 0.40 m/d. This indicates a strong seasonal increase during summer compared to the all-year average velocity of 0.33 m/d.

This is in agreement with the investigations and modeling from (*Colgan 2011a, b*) which show a clear dependency between ice surface velocities and modeled and observed basal sliding velocities at Swiss Camp, JAR1 and at JAR2.



Figures 4+5: *Position changes (Northing, Easting) of ice reference at Swiss-Camp derived from the Precise Point Positioning (PPP) method in the kinematic mode of an eight-hour-observation on the 1st of August, 2011.*

2.2 *Elevation change and mass balance at* ST2 Area

The elevation change was derived from digital elevation models (area 1.6 x 1.6 km^2) in all campaigns. In average, between 2004 and 2005, we had got an elevation decrease of –0.38 m/a, and of –0.30 m/a between 2005 and 2006. Between 2006 and 2008, we got an elevation decrease of –1.40 m/a. The accelerated decrease of the ice surface in the last years was continued in 2008-2011 in the same order of magnitude. *Figure 6* show the cumulative elevation change with temporal variations between 2004 – 2011 at ST2. *Figure 7* show the corresponding mass balance per year between campaigns.

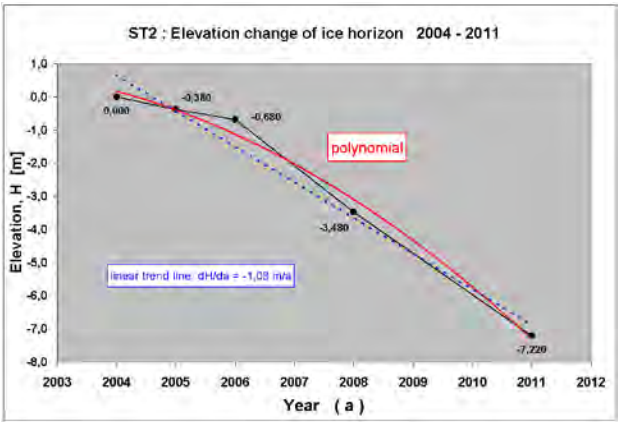


Figure 6: Cumulative elevation change of the ice horizon 2004 – 2011 at area ST2.

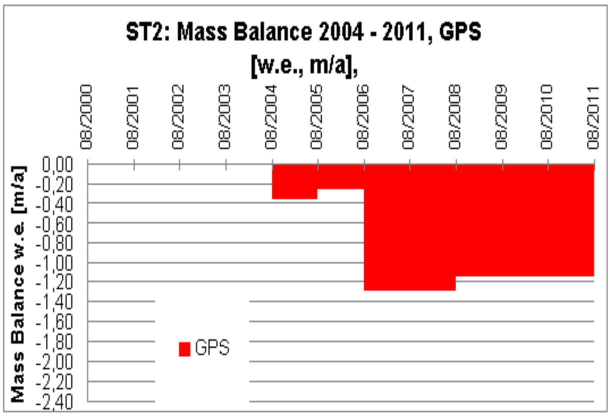


Figure 7: *ST2: Mass balance in the floating date system between successive surveys, 2004 – 2011*

The elevation change at ST2 varies in a wide range over the whole area. Over the whole area we get elevation changes from – 0.4 to – 2.2 m/a, and in average –1.25 m/a.
Obviously there are parts with more and less elevation change. This seems to be not accidentally because a detailed study with difference digital elevation models from older periods show a locally systematic variety. For a better clearness we show (*figure 8)* the relative elevation changes transformed to the mean value (so the sum of relative elevation changes becomes zero). In contrast to the rather uniform area "Swiss-Camp", at ST2 we find distinct topographic structures, with a ridge from North-East to South-West.

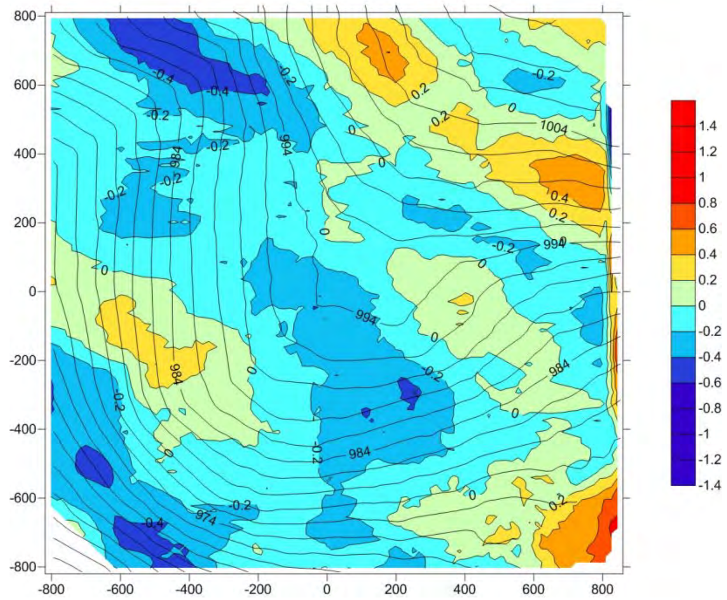


Figure 8*: Relative local elevation changes (m/a) 2005 – 2008 at ST2 and contour lines of topography. Prevailing wind direction from South-East.*

Possible reasons for local variations in elevation changes are:

- Solar radiation in relation to topography (terrain inclination, wind, sun…)
- Surface condition, water content, albedo
- Relocation of accumulated snow by wind
- Apparent elevation change by moving topographical structures (crest, valley)
- Further causes

After special investigations we can exclude moving topographical structures. Further reasons will be studied in future.

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3. Evaluation and validation of CryoSat-2 data

Both research areas, ST2 and Swiss camp as well, are precisely measured parts of the Greenland ice sheet. Therefore they can be also used for evaluation and validation of satellite elevation data, especially for ICESat and CryoSat.

CryoSat-2 from the European Space agency (ESA) was launched in 2010. So in 2011 it was the first chance for us to compare CryoSat data with our terrestrial control survey. In our measuring period 2011 there were no flights directly over Swiss Camp or ST2 available. The temporal and local nearest ground track was a flight on August 14th 5 km west of ST2. Along the predicted track a digital terrain model was derived. At the moment, the ESA is still evaluating the SARin mode level-2-data. Previous results were not satisfying. After a reprocessing in 2012, we hopefully will be able to compare 8 footprints.

4. Summary and acknowledgement

In summary, our results indicate an accelerated elevation decrease and melting (ice thickness decrease), especially in the last years, with some extremely high rates during the latest warm summers. This is agreeable to the general extent and trend of ice sheet melt, particularly at the ice sheet margin (*Mernild et al. 2011*). It also corresponds with the observed global warming and in particular with the increasing temperatures in Polar Regions. Additionally we observed higher flow velocities on our measuring days in summer compared to the all-year average velocity. This is in accordance with the results of *Colgan et al. 2011*.

The campaign 2011 was funded by the German Research Foundation (DFG).

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Outwash surfaces as indicators of dynamic state of Spitsbergen glaciers

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Changes in dynamics of Spitsbergen polythermal glaciers can be related directly to climate by meltwater supply to their bed and thus by basal sliding. Surge events might have indirect linkage to climate by accumulation rate of ice mass in the reservoir area and potential trigger by more intense melting. While increase of melting rate during the ablation season is reflected by water and sediment discharge from glaciers, outburst floods are associated to the glacier surge. Both phenomena should have geomorphic record on marginal zones, especially sandurs. The aim of this study is to prove such relation on examples from couple of marginal zones of Spitsbergen glaciers. Therefore, type of outwash surfaces relief pattern is related to the dynamic state of the glaciers, and consequently, to the type of deglaciation. The analysis of spatial relationships of the forms within the marginal zone of Spitsbergen glaciers was carried out. The ASTER satellite imagery as colour compositions of selected spectral bands were used for forms pattern recognition by means of GIS software. During the glacier advance / surge, terminal moraines range – gorge – outwash fan, covering the distal part of the moraines with fluvioglacial deposits, is characteristic forms complex for marginal zones. Gorges are usually suspended over the terminal moraines hinterland. The subglacial tunnel outlets were then probably located higher, due to more steep glacier front and equipotential surfaces bent upwards within it. It may indicate glacier outbursts of subglacial water during the gorge incision. This is evidenced in terraces with abandoned large boulders visible in the gorges profile (e.g. the Kvisla gorge, the Werensioldbreen forefield). The glacier recession reveals inner part of the marginal zone. The fluvioglacial sediments deposition covers the burried dead glacier ice – a relict of the advance phase. The knob-end-kettle type of the sandur surface is a characteristic form resulting from areal deglaciation. At the same time the proglacial outflow pathways are organized within the end depression, generally parallel to the glacier edge and terminal moraines. It is a consequence of subglacial tunnels outlets and the glacier front lowering and its flattening. The elder outwash levels are cut. The spatial periodicity of the described forms complex is visible in the case of glaciers having experienced several advances (e.g. Austre Torellbreen). The stepwise nature of the glaciers recession, with episodes of relatively short-time advances and long recession periods, is characteristic for many Spitsbergen glaciers. It has to be taken into consideration as a component of a model of glacier's evolution in response to climate change.

Influence of the Atlantic Water variability on the Spitsbergen climate and ice conditions

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One of the most important component of the Arctic marine system is Atlantic Water (AW). AW carried into the Arctic Ocean by the system of oceanic currents – North Atlantic, Norwegian-Atlantic, West Spitsbergen Current (WSC), is the main medium connecting this remote Arctic region with the global system. With its volume, AW carries huge amount of heat, salt, nutrients, plankton. Northward flow, modification, sinking and recirculation of this

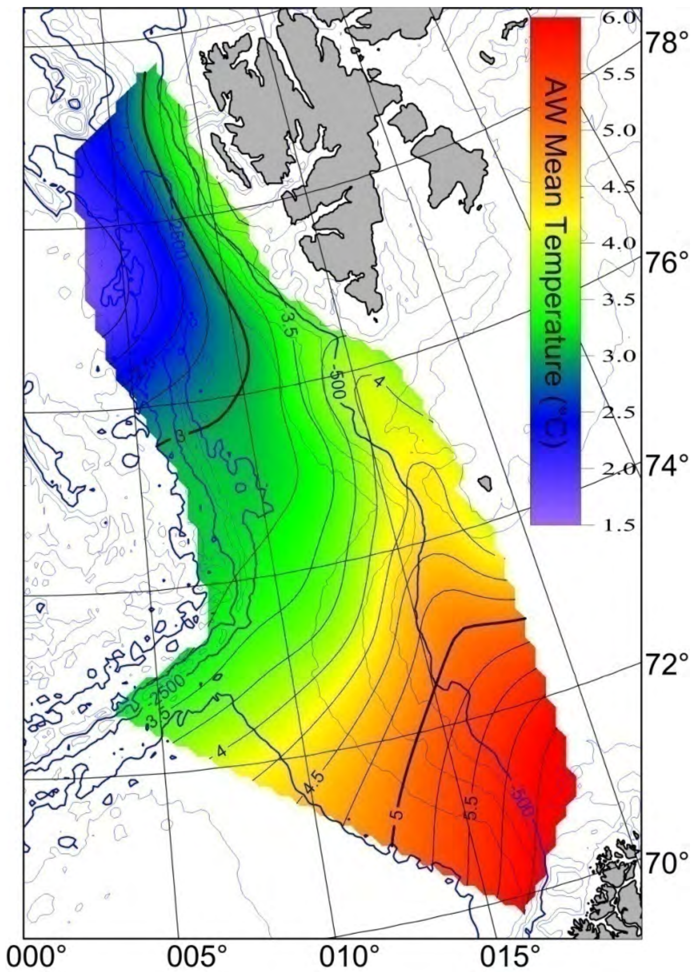

Figure 1: *Summers 2000-2011 mean temperature of Atlantic Water*

warm and salty water is the crucial process shaping Arctic's hydrosphere, atmosphere, cryosphere and biosphere. Nordic Seas plays special role in these processes. During its northward flow through Norwegian, Greenland and Barents Sea, Atlantic Water releases to the atmosphere vast heat amount. In the WSC most of AW properties (temperature, salinity, heat content, AW section surface) changes almost linearly, i.e. temperature decreases 0.24°C/latitude degree. These processes, especially heat exchange with the atmosphere and cryosphere are essential for the Arctic climate and ecosystem Recirculation, densification, and sinking of Atlantic Water initiates deep circulation and forces the Atlantic Meridional Overturning Circulation.
Oceanic northward heat transport is smaller than the atmospheric one, but ocean has large heat capacity and thermal inertia. Ocean acts in different than atmosphere time scales. The slow, order of few centimeters per second mean oceanic advection is capable to provide heat sufficient to maintain large Arctic seas area free of ice. During the winter transmit to the atmosphere heat fluxes reaches up to hundreds Watts per square meter.
Institute of Oceanology Polish Academy of Scie nces (IOPAS) investigates European Arctic for years. Since 2000 every summer IOPAS research vessel 'Oceania' covers by the grid of 170-200 hydrographic stations the same part of the Atlantic Water domine between the northern Norway and Fram Strait. High modification of the AW mean temperature with latitude (Fig. 1) and significant variability in the properties of the Atlantic Water carried by the West Spitsbergen Current (Fig. 2) has been observed.

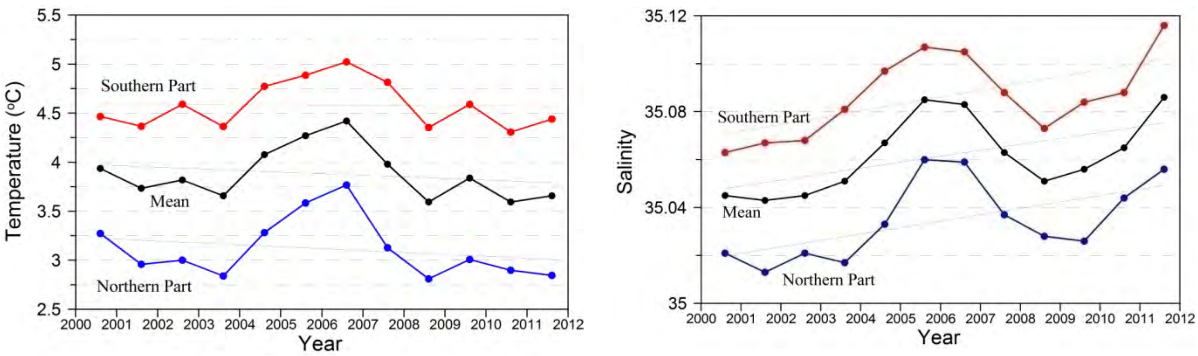

Figure 2: *Temperature, and salinity of the Atlantic Water layer. Mean for entire area – black line, for northern part (north of the 74°30' parallell) – blue line, for southern part – red line.*

16-year long series of summer observations carried by the IOPAS at section along the 76º30'N parallell reveals two 6-year long periods of increasing and falling AW temperature and salinity (Fig. 3). Trends of both properties are positive. There is usually positive correlation between temperature and salinity of AW. In 2010 and 2011 there was negative correlation – while the salinity increased, the temperature has dropped. It probably indicates prevailing of the local processes (winter cooling) over the advection in that time.

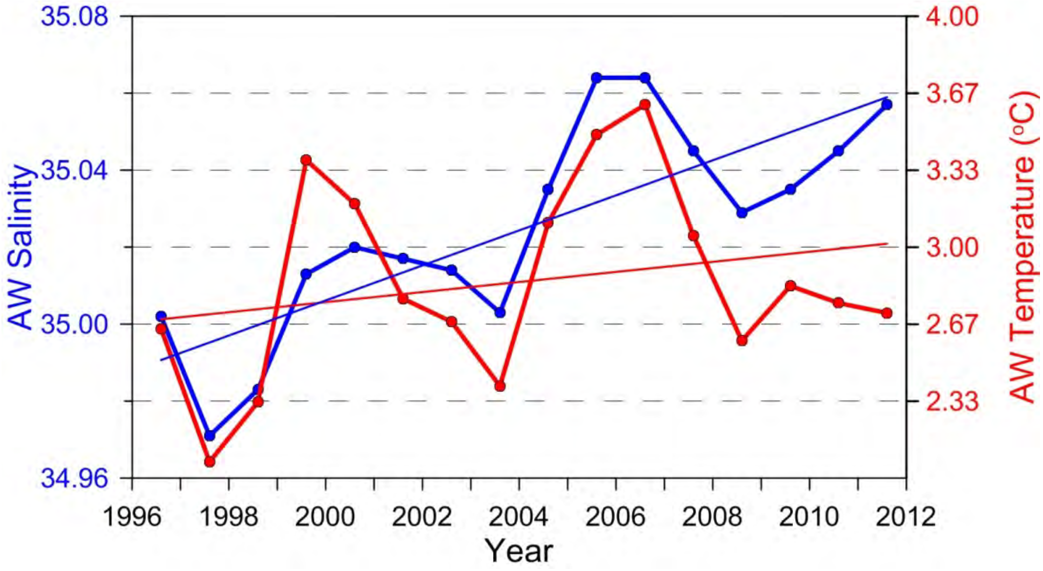

Figure 3: *Time series of mean AW temperature and salinity at section along the 76°30'parallell.*

Horizontal property distributions show that in summers 2004-2006 isotherm 5ºC at depth 100m has moved meridionally 4.5º northward. In 2006 temperature of AW core reached record high, never earlier observed values. Heat content of AW layer in the Nordic Seas was also record-high. Warm AW expanded over the shelves, inflowed into Spitsbergen fjords. Fraction of the warm pulse passed the Fram Strait and flowed into the Arctic Ocean.
Changes of the ocean climate considerable influenced the Arctic winters temperature, sea ice extension, Svalbard glaciers, marine and terrestrial ecosystem. The environmental effects of the northward propagating anomalous events of warm and saline water were clearly observed. There is the high correlation between the AW temperature and air temperature in the Polish Polar Station in Hornsund. In summer, the correlation between the AW temperature and air temperature is very weak, but in winter it rises. The AW temperature signal leads changes in the air temperature. This indicates that oceanic heat release is the main mechanism warming the atmosphere there. Also ice condition north of Svalbard are influenced by the AW temperature (Fig. 4). Also in these case there is strong correlation between AW temperature and subsequent winter ice conditions.

The results show that Atlantic Water influences the climate and ice conditions of Svalbard. By releasing during the winter large heat fluxes into the atmosphere (up to 300 W/m^2), AW significantly influences the air temperature. The oceanic heat stored in the mixed layer during the summer is exhausted by November-December, and winter ocean–atmosphere fluxes are maintained by heat transported from south by oceanic currents. Warm AW water is also the only medium capable melt ice north of Svalbard during the winter.

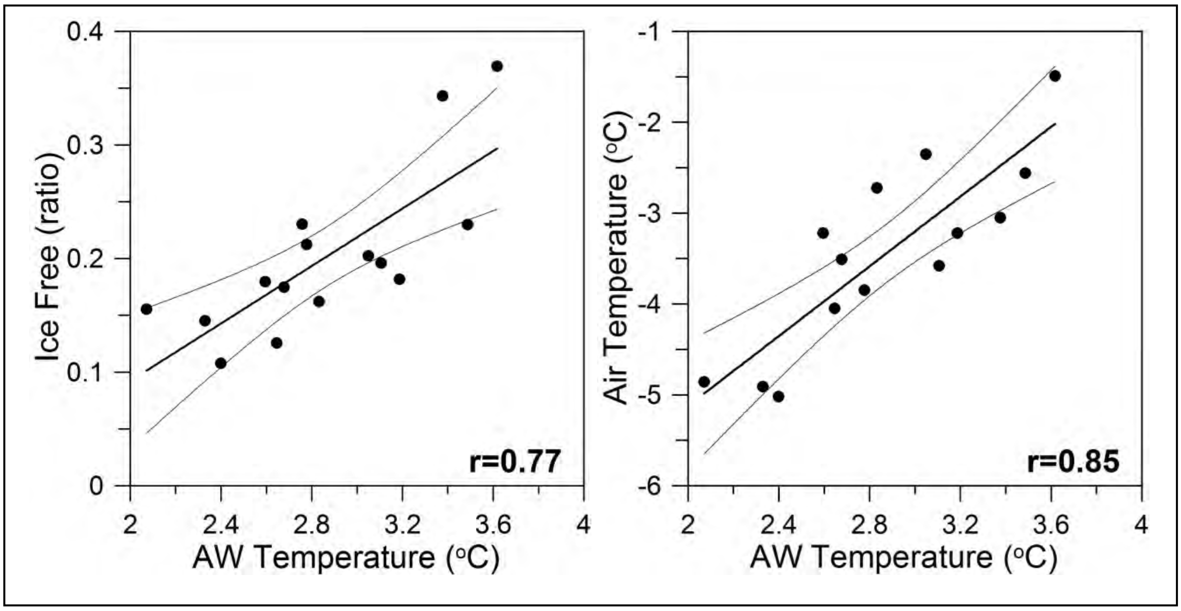

Figure 4: *Linear regression of AW mean temperature at section along the 76° 30 parallell and:*

- *the Hornsund yearly mean air temperature (left panel)*
- *ice condition (the ice free area north of Svalbard) during subsequent winter (right panel).*

Acknowledgments

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Dynamics of ice caps and tidewater glaciers in the Canadian Arctic determined with a speckle tracking method

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Recent studies have shown a rapid increase in glacier loss from the CAA as a direct result of warmer air temperatures (Gardner et al 2011, Sharp et al 2011), with ice core records showing melt rates over the last quarter century at their highest levels in 4200 years (Fisher et al 2011). However, within the CAA there is limited knowledge with regards to baseline glacier velocities and how ice dynamics may change with increased surface melt. This is significant as these ice caps may be more sensitive to external forcing than the large ice sheets given their relatively small size. This study utilizes speckle tracking of Radarsat-2 fine beam imagery collected through winter 2010/11 to produced the first large-scale velocity maps for the major ice caps on Ellesmere and Axel Heiberg Islands (Prince of Wales, Agassiz, Northern Ellesmere, Steacie and Muller Ice Caps). Error for the method is assessed is as <10ma^{-1} based on apparent motion over stationary bedrock outcrops. These maps reveal significant velocity differences between land terminating and tidewater terminating glaciers, and allow for the monitoring of previously identified surge-type glaciers. In general, high velocities (>100 ma^{-1}) occur on topographically constrained glaciers which terminate in the ocean, while lower velocities (~40-75 ma^{-1}) occur on glaciers which terminate in poorly defined lobes on land. These findings are consistent with Burgess et al (2005), who found a similar dynamic structure across Devon Ice Cap, Nunavut. In addition, speckle tracking of newly available Radarsat-2 fine beam wide and ultrafine beam wide images (released in summer 2011) will be presented to define ice dynamics for some of the largest tidewater terminating glaciers of Devon Ice Cap (Belcher, Croker Bay, Southeast-2 and Sverdrup Glaciers). These results will assess the viability of these beam modes for large scale monitoring projects for the glaciated Canadian Arctic.

Calving Dynamics of the Columbia Glacier, AK (2000-2011 Update)

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Since initiating a rapid retreat in the early 1980s, the Columbia Glacier - a large tidewater glacier in Alaska's Prince William Sound - has thus far lost 20 of its original 66km, and thinned by 500m at the present terminus, delivering ~150 km^3 of ice to the Gulf of Alaska. In 2009-2010, volume loss exceeded 9 km^3/yr, approximately 1% of sea level rise globally for that period. Throughout the retreat, calving flux has dwarfed surface mass balance, accounting for 90-100% of total volume loss.

In 2000-2006, the Columbia Glacier retreated past a major constriction in its fjord, grounding the terminus and slowing retreat. By 2007, the terminus came afloat and the glacier reentered a phase of rapid retreat that lasted until grounding of the terminus in 2010. We report on the evolution of calving flux, thinning rate, and terminus retreat during this period of transition from grounded to floating to grounded, and compare to the initial floating to grounded transition of the early 1980s. The spatial and time evolution of ice flotation is inferred from surveyed and modeled subglacial bed topography and photogrammetrically-derived glacier surface elevations.

To gain further insight into the mechanisms regulating and driving calving behavior at the Columbia Glacier, we are working on extracting a multi-year, high time-resolution map of terminus position from the time-lapse photography collection. We present the resulting measurements of calving size distribution, frequency, and flux, and compare these to the in-situ seismic record. Flotation and water depth calving criteria from the literature are evaluated against this timeseries in an early effort to fit tidewater glacier models to detailed observations of dynamics. Finally, we briefly introduce Amazon's Mechanical Turk, the crowd-sourcing platform used to collect traces of terminus position, and the potential of such new tools to difficult-to-automate data processing needs.

Flow regimes, velocity variability, and the surface hydrology of the Devon Ice Cap

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Annual velocity fields were calculated for the major tidewater glaciers draining the Devon Ice Cap using gradient correlation of sequential Landsat7 ETM+ pairs, acquired between 1999 and 2008. The velocity maps reveal significant inter-annual variability in ice velocity. Terminus positions were mapped from the sequential Landsat imagery, and the area change due to terminus advance or retreat between each image pair was calculated. Velocity variability does not correlate with the rate or sign of terminus retreat for any of the glaciers studied. Maps of the standard deviation of annual ice velocity were compared to the map of flow regimes derived by Burgess et al (2005). Velocity variability is highest where basal sliding is inferred to be a major component of ice motion. Maps of supraglacial drainage networks and the location of sink points produced from Landsat imagery also correlate well with velocity variability, and localised areas of high velocity variability are found in close proximity to sink points in the upper and middle reaches of outlet glaciers. This suggests that delivery of meltwater to the glacier bed is a significant factor in both inter-annual flow variability and the distribution of flow regimes. These findings lend support to the hypothesis that hydrological forcing is affecting the dynamics of tidewater glaciers draining the Devon Ice Cap.

Post Little Ice Age evolution of the Recherchebreen marginal zone

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The Recherche Glacier is located in the NW part of Wedel Jarlsberg Land (Bellsund, Svalbard). This glacier is one of the spurs of a vast alimentation field which is also connected with the Torellbreen and the Amundsenisen in the south.
Nowadays two vast outwash plain constitute the mouth of the valley. The fans are close to the slopes of the valley, whereas the head of the glacier in the form of a cliff feeds into the internal lagoon. Recession of Recherche Galcier diminished then from 3-4 dozens of meters per year to less than 10 ma^{-1}. Further melting resulted in retreating of the western part of glacier front to deeper water in the contemporary lagoon (position in 1936) in an average rate of ca. 36 ma^{-1}.The next surge event in the forties resulted probably in overpassing of the threshold. An advance of the front by an average 10 ma-1 was noted between 1936 and 1960. In 1960 glacier front was situated on land. Subsequent retreat into relatively deep waters of the Recherche Lagoon continuing up to nowadays with increasing intensity (13 ma^{-1} in 1960-1990 and 50 ma^{-1} in 1990-2008). The marginal zone of Recherche Glacier has undergone dynamic changes during the last century. Its marginal zone is shaped in a way that is characteristic for glaciers ending in the sea and surge type. The cooling of the LIA and climate warming during the 20th century reflected by very distinct transformations of the landscape. Until the mid 20th century, the accumulation of sediments in the area of the shallow bay was rather of a subaqual character. The biggest discharges of glacier rivers were in the contact zone of ice with lateral moraines. The outwash plain, which is inactive at the moment, began to develop in early 20th century. The period of strongest activity of ablation waters in the area of this fan and its fastest growth took place in the 1950s and 1960s, after a surge episode. As a result, a substantial amount of fluvioglacial sediments was deposited on dead ice (or aufeis), which is currently being uncovered on the internal side of the lagoon. In 1960, the surface of the western outwash plain was 0.38 km^2. The major discharge of waters was concentrated on the eastern side of this fan, whereas in the regions where ablation waters ceased to flow a storm berm which enclosed the shallow lagoons was mounded. The western outwash ceased to function when the internal lagoon, which can be seen on an aerial photograph from 1990, was created. The surface of the fan increased to 0.8 km^2. From that moment on, the fan was exclusively a subject of marine processes. As a result, a very clear-cut storm ridge was created. According to GPS measurements from 2008, the surface of the fan diminished to 0.7 km^2. This is mainly the result of the degradation of ice which was covered by sediments of the fan on the internal side of the lagoon. A second outwash plain was also formed for the last 50 years in the forefield of the Recherche Glacier. However, it is much younger than the western fan, except for its most northward part, which appears on a photograph from 1936. On

an aerial photograph from 1960 this part of the eastern fan, with a surface of 0.08 km^2, already looks inactive. However, the outflow of ablation waters was concentrated in the area close to the outwash plains, which developed in the intertidal zone. It was also at that time when intensive development of this part of the glacier forefield started. Until 1990 the surface of the fan increased to 1.2 km^2. An end of the activity of fluvioglacial waters in the region of the east outwash plains was observed at the beginning of the 21st century. This was combined with a retreat of the front of the glacier and an enlargement of the area of the internal lagoon. At present all of the water discharge from the Recherche Glacier feeds into the internal lagoon. The outwash plains which were formed in the mid 20th century on the internal side are only subject of marine processes. In 1990 the surface of the lagoon was only 0.56 km^2, and 19 years later as much as 3.31 km^2.

Mass Balance and Seasonal Variations of the Greenland Ice Sheet

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Published results based on ICESat measurements showed that the mass loss from Greenland during 2003 to 2007 increased to 171 Gt/yr from the near balance of - 7 Gt/yr during 1992 to 2002. Re-analysis with improved criteria for data-selection gives a slightly revised loss of 173 Gt/yr for 2003 to 2007 and a loss of 174 Gt/yr for 2003 to 2008. Although the overall loss rate is nearly the same for the longer time period, the distribution of losses and gains over the ice sheet differ somewhat. In the northwest, two drainage systems, DS, had increased losses. The loss in DS 8 increased from 31 Gt/yr to 41 Gt/yr and balance in DS 1 changed from a gain of 2.3 Gt/yr to a loss of 2.5 Gt/yr. In the southeast, two DS had decreased losses. The loss in DS 3 decreased from 53.9 Gt/yr to 38.3 Gt/yr and the loss in DS 4 decreased from 77.1 Gt/yr to 68.0 Gt/yr. Above the equilibrium line, EL, observed seasonal variations in surface elevation, H(t), are a combination of seasonal variations in the temperature-dependent rate of firn compaction, CT(t), and variations in the rate of accumulation, A(t). The effective thickness change, I(t) = H(t) - CT(t), removes the variation in the rate of firn compaction that is caused by changes in temperature, which has been increasing in Greenland and causing a surface lowering that does not involve a change in mass. The H(t) and I(t) time-series are constructed from ICESat data for the period from the fall of 2007 to the fall of 2008, for above and below the EL, for eight DS, and the overall ice sheet. The I(t) series below the EL from ICESat data are used to estimate the annual ablation, and are compared to similar series of M(t) from Grace data.

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