DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2013/XX

The Dynamics and Mass Budget of Arctic Glaciers

Extended Abstracts
Annual Workshop/Glaciodyn Meeting
7 -10 March 2010, Obergurgl (Austria)
IASC Network on Arctic Glaciology

A. P. Ahlstrøm & M. Sharp (eds)

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE END ENERGY

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Extended Abstracts

Preface

The 2010 annual workshop on the dynamics and mass budget of Arctic glaciers of the Network for Arctic Glaciology was held at the Universitätszentrum Obergurgl, University of Innsbruck, Obergurgl, Austria.

The workshop was proof that an informal setting and a relatively limited amount of participants provide the best opportunities for increasing the collaboration among glaciologists across the Arctic and supports the inclusion of new generations of polar scientists in a way larger scale conferences cannot. Again, we were fortunate to have support from IASC for covering travel expenses for a number of students and young investigators attending the workshop.

Following the change decided at the annual workshop in 2009 in Canada, the National Representatives led an Open Forum discussion open to all participants in the workshop. The minutes from the Open Forum are included in this volume.

The workshop was attended by 55 registered particpants and featured a total of 34 oral presentations and 9 poster presentations. This volume presents the 25 extended abstracts submitted from the workshop. The extended abstracts have not been reviewed, but provide useful information on the research being conducted and serve as an inspiration for collaboration and further studies.

We would to like to thank Dr. Michael Kuhn from the University of Innsbruck for making it possible for the IASC NAG to return once again to the Universitätszentrum Obergurgl. Thanks to Trine Schmidt Jensen for helping with the editorial work.

Andreas P. Ahlstrøm & Martin Sharp
Chairman & Vice-chairman, IASC Network on Arctic Glaciology

Programme

Monday 8th of March

Chair: Andreas P. Ahlstrøm

8.40: Martin Sharp et al.: The Current State of Mountain Glaciers and Ice Caps in the Arctic: an update on the Arctic Council's SWIPA project.
9.00: Valentina Radic and Regine Hock: A new estimate of Arctic glacier volumes derived from statistical upscaling of glacier inventory.
9.20: Bartek Luks et al.: Relations between meteorological parameters on Hans glacier and Hornsund Polish Polar Station.
9.40: Mariusz Grabiec et al.: The snow conditions on selected Svalbard glaciers derived from classical methods and radio echo soundings.

Chair: Johannes Oerlemans

10.30: Nicholas Cullen et al.: Seasonal Variability of Mass and Energy Exchanges in the Dry Snow Zone of the Greenland Ice sheet.
10.50: Thomas Krismer et al.: Long term mass- and energy balance of Kongsvegen glacier, Svalbard.
11.20: Jason box et al.: Six centuries of Greenland ice sheet mass balance: years 1700-2300.
11.40: Thomas Shuler: A surface mass balance history of Austfonna, Svalbard, derived from reanalysis data.

Chair: Per Holmlund

13.30: Krzysztof Migala et al.: Spatial ablation model of the Werenskiold Glacier, SW Spitsbergen.
13.50: Martin Sharp and Alex Gardner: 26yr mass balance simulation for Belcher Glacier (Devon Island Ice cap) 1980-2006
14.20: Jason Box et al.: Greenland Ice sheet snow line variability: 2000-2009.
14.40: Hester Jiskoot and Dan Juhlin: Changes in Central East Greenland Glaciers from a new Glacier Inventory and DEM.

Chair: Jon Ove Hagen

15:30: Manfred Stober: New Results from Swiss-Camp project and from Eqip Sermia glacier.

15.50: David Burgess et al.: Inter-annual Variations of in Surface Elevation Across the Devon Ice Cap, Nunavut (2004-2008)
16.20: Veijo Pohjola et al.: Recent elevation change of Vestfonna, Svalbard Archipelago, comparing surface DGPS campaigns with ICESat and NASA altimetry.
16.40: Per Holmlund: Climate impact on ice dynamics and temperature distribution on Swedish glaciers.

Tuesday 9th of March

Chair: Veijo Pohjola

8.40: Liss M. Andreassen et al.: Recent mass, area and volume change of langfjordjøkelen, northern Norway.
9.00: Chris Nuth et al.: Combining mass balance measurements/modeling with geodetic elevation changes: A case study from Kongsvegen and Holtedahlfonna/Kronebreen.
9.20: Antoine Kies et al.: Multiparameter studies in the meltwater of Werenskioldsbreen, hints for supercooling.
9.40: W. van Wychen et al.: Seasonal Variations in Ice Motion, Belcher Glacier, Nunavut; Canada.

10.00-12.00: Poster Session: Includes 2 minutes introduction by each poster presenter

Chair: Martin Sharp

Ireneusz Sobota: The near-surface ice thermal structure of selected glaciers of Kaffiøyra Region, Svalbard.
Ireneusz Sobota: Snow accumulation, melt, mass loss and near-surface ice temperature structure of the Irenebreen, Svalbard.
Elisabeth Stuetz et al.: Evaluation the WRF model in Svalbard on the basis of a case study: First tests and preliminary results.
Dariusz Puczko et al.: Sensitivity of tidewater glacier movement to environmental parameters (Hansbreen, Southern Spitsbergen).
Ward van Pelt et al.: Numerical modeling of the dynamics of Nordenskiöldsbreen, Svalbard.
Thorben Dunse et al.: Insights into the dynamics regime of the Austfonna ice cap, Svalbard, from numerical modeling and observation.
Keiko Konya: Mass balance of Potanin Glacier, western Mongolia.
Alison Banwell: Subglacial Meltwater Drainage at Paakitsoq, West Greenland: Insights from a Distributed, Physically Based, Numerical Model.
Rickard Pettersen et al.: Investigating basal conditions and thermal regime on Vestfonna Ice Cap, Svalbard.

Wednesday 10th of March

Chair: Carleen Tijm-Reijmer

9.00 John Moore et al.: Dating ice cores by wavelets.
9.20: Matt Noland et al.: IPY research on McCall Glacier, Alaska.
9.40: Miriam Jackson and Richard Norland: Simultaneous measurements of surface motion and basal pressure changes on Engabreen glacier, northern Norway.

Chair: Regine Hock

10.30: Thorben Dunse et al.: Insights into the dynamic regime of the Austfonna ice cap, Svalbard from numerical modeling and observation.
10.50: Monica Sund et al.: Surge dynamics related to climate change response of Svalbard glaciers.
11.20: Jacek Jania et al.: Recent state of tidewater glaciers in Southern Spitsbergen.
11.40: Faye Wyatt and Martin Sharp: Multi-year glacier velocities across Devon Island and Price of Wales ice caps, Canada.

Chair: Jason Box

13.30: Jacek Jania et al.: New survey of dynamics of the frontal zone of Hansbreen, Svalbard tidewater glacier, Preliminary results.
13.50: Johannes Oerlemans: Application of a minimal glacier model to Hansbreen, Svalbard
14.20: Brad Danielson: Seasonal and Inter-Annual Variations in Ice Flow of a High Arctic Tidewater Glacier.
14.40: Ian Bartholomew: Hydrology and dynamics of a land-terminating Greenland outlet glacier.

Chair: Jacek Jania

15.30 Andreas P. Ahlstrøm: The Programme for Monitoring of the Greenland Ice Sheet - recent developments.
15.50: Carleen Tijm-Reijmer et al.: Temporal and spatial variations in the flow speed of Kronebreen, Svalbard
16.20: Anne Chapuis: On the nature of iceberg calving: s self-organized critical state?

Participant list

First name	Surname	E-mail
Artur	Adamek	artex_pl@yahoo.com
Andreas P.	Ahlstrøm	apa@geus.dk
Signe B.	Andersen	siba@geus.dk
Liss M.	Andreassen	lma@nve.no
Lisa	Baier	n/a
Alison	Banwell	afb39@cam.ac.uk
Ian	Bartholomew	ian.bartholomew@ed.ac.uk
Malgorzata	Blaszczyk	mbl4@wp.pl
Jason	Box	box.11@osu.edu
David	Burgess	daburges@nrcan.gc.ca
Anne	Chapuis	anne.chapuis@umb.no
Michele	Citterio	mcit@geus.dk
Nicolas	Cullen	njc@geography.otago.ac.nz
Brad	Danielson	bdd@ualberta.ca
Piotr	Glowacki	glowacki@igf.edu.pl
Mariusz	Grabiec	mariusz.grabiec@us.edu.pl
Jon Ove M.	Hagen	j.o.m.hagen@geo.uio.no
Regine	Hock	regine@gi.alaska.edu
Per	Holmlund	per.holmlund@natgeo.su.se
Dariusz	Ignatiuk	dignatiuk@gmail.com
Hajime	Ito	hajime@nipr.ac.jp
Miriam	Jackson	mja@nve.no
Jacek	Jania	jjania@us.edu.pl
Hester	Jiskoot	hester.jiskoot@uleth.ca
Florian	Karner	florian.karner@student.uibk.ac.at
Antoine	Kies	antoine.kies@uni.lu
Leszek	Kolondra	leszek.kolondra@us.edu.pl
Keiko	Konya	conya@jamstec.go.jp
Michael	Kuhn	michael.kuhn@uibk.ac.at
Bartek	Luks	luks@igf.edu.pl
Daniela	Mansutti	d.mansutti@iac.cnr.it
Krzysztof	Migala	migalak@meteo.uni.wroc.pl
John	Moore	john.moore.bnu@gmail.com
Francisco	Navarro	fnv@mat.upm.es
Matt	Nolan	matt@drmattnolan.org
Chris	Nuth	christopher.nuth@geo.uio.no
Friedrich	Obleitner	friedrich.obleitner@uibk.ac.at
Johannes	Oerlemans	j.oerlemans@uu.nl
Michal	Petlicki	petlicki@igf.edu.pl
Rickard	Pettersson	rickard.pettersson@geo.uu.se

Veijo	Pohjola	veijo.pohjola@geo.uu.se
Darius	Puczko	dp@igf.edu.pl
Kirsten	Rüchardt	Kirsten.Ruechardt@ovgu.de
Dieter	Scherer	dieter.scherer@tu-berlin.de
Thomas V.	Schuler	t.v.schuler@geo.uio.no
Martin	Sharp	martin.sharp@ualberta.ca
Ireneusz	Sobota	irso@geo.uni.torun.pl
Manfred	Stober	manfred.stober@hft-stuttgart.de
Elisabeth	Stuetz	Elisabeth.Stuetz@uibk.ac.at
Carleen	Tijm-Rejmer	c.h.tijm-reijmer@uu.nl
Rein	Vaikmae	rein.vaikmae@ttu.ee
Ward	van Pelt	W.J.J.vanPelt@uu.nl
Wesley	Van Wychen	wvanw046@uottawa.ca
Gernot	Weyss	gernot.weyss@zamg.ac.at
Faye	Wyatt	f.r.wyatt@gmail.com

Minutes from the IASC Network on Arctic Glaciology Open Forum

March 2010, University Centre, Obergurgl, Austria

Agenda

1. Other items for the agenda

2. (Added) IASC-NAG website

3. (Added) Delivering to IPCC?

4. (Added) Reporting from field season 2009

5. Next meeting 2011 – place and time (North America?) and possibly the subsequent meeting in 2012 (Andreas Ahlstrøm)

6. Planning of the Fairbanks Summer School supported by IASC (Regine Hock)

7. Restructuring of IASC and the implications for this Network (IASC-NAG) (Martin Sharp)

8. Ideas from the Network for initiatives to seek support from IASC – maybe a workshop? (call for proposals came in May last year, but it may be different in 2010 due to the restructuring) (Martin Sharp)

9. Future funding oportunities

10. Publication of Extended Abstracts

Item 1. Agenda items added (marked as such in the Agenda)

Item 2. Website development needed... no current volunteers or suggestions.

Item 3. Regine – Ice2Sea, aim to deliver to the IPCC report, but perhaps adaptable for this group?

Item 4. Anyone who has anything to report from field Season 2009 should contact Martin Sharp for the ‘The State of the Climate Report’ This links to the Arctic Field Report. Jason Box – Try Cryolist to ask for help on this?

Item 5. Jason Box suggests Kananaskis or Salt Lake City. But perhaps shouldn't be in North America every other year as over 50% are Europeans, maybe 2 yrs in Europe then two in N America? Martin Sharp has points out that based on last years attendees, there may infact be two similar sized groups. Jacek Jania suggests meeting in a ski resort in Wroclaw, Western Poland, or maybe Iceland if not too expensive. It's pointed out that Jan/Feb is probably a better time for the conference than March. Andreas Ahlstrøm notes that Boulder could be an option, but limited accommodation may be a problem (at Mountain Center). Ask Tad Pfeffer about this. So: North American location for 2011, but no decision for location/date made as yet. 2012 option in Poland?

Item 6. Regine Hock - Summer school in June 2010 in Fairbanks, taught by 6 faculty members from Univ. of Alaska Fairbanks (UAF). Perhaps IASC could sponsor it in future years? Planned to happen every other year (lots of work to get lecturers every year). Similar structure and context to Karthaus summer school.

Item 7. Martin Sharp - Restructuring of IASC – new IASC structure did not get approved last April in Nuuk. Interim solution required to allow to operate in short term, IASC currently discussing. Series of working groups will be created, one focussed on the Cryosphere. Funding applications will in future go direct to these working groups. Applications need to provide some sort of support to young scientists if any sort of success if expected.

Item 8. Workshops (other than this one) are a possibility for funding applications from IASC. No current thoughts.

Item 9. Future funding opportunities: Jacek Jania suggests Polar Climate (call within ESF), but very complicated, Jacek Jania has been involved for 3-4 yrs with no major development to start a proficient funding system. Possible North American funding sources, but often hard to combine the funding across the Atlantic – Greenland may be an exception (i.e. NSF – Jason box can maybe investigate).

Item 10. Abstracts are ready from 2009 but not yet published as a PDF. Extended abstracts for this meeting should be submitted by late April (It is thought better to submit earlier rather than later).

Abstracts

The Programme for Monitoring of the Greenland Ice Sheet – recent developments

Andreas P. Ahlstrøm[1], Signe B. Andersen[1], Dirk van As[1], Michele Citterio[1], Robert S. Fausto[1], John Peter Merryman[2], Jørgen Dall[2], René Forsberg[2], Steen Savstrup Kristensen[2], Erik Lintz Christensen[2], Dorthe Petersen[3]

[1]GEUS - Geological Survey of Denmark and Greenland
[2] National Space Institute, DTU
[3] ASIAQ Greenland Survey

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

The PROMICE programme comprises of three main observational activities: 1) Establishment and maintenance of a network of automatic mass-balance stations (AMS) on the margin of the Greenland ice sheet, 2) Conduct of airborne surveys, yielding surface elevation and ice depth along the entire margin of the Greenland ice sheet and 3) Derivation of ice sheet surface velocity from satellite synthetic aperture radar (SAR). In combination these data sources should give us both the surface melt and dynamic mass loss by calving which are the two main mechanisms responsible for the mass loss from the Greenland ice sheet. Mass loss by melting may be calculated from the AMS network. Each station measures the climate factors causing melt as well as the subsequent local mass loss. The final station network will include a total of 14 stations located in seven climatically different regions of the Greenland ice sheet and is intended to be fully operational from 2011 and onwards. At each location, one station will be placed in the lower ablation zone, another in the higher ablation zone. Currently, twelve of these stations are operational in six regions of the ice sheet margin. The mass loss by iceberg calving is obtained from the airborne surveys and satellite observations allowing us to determine the thickness and flow speed of the ice from the interior of the ice sheet towards the ice sheet margin, giving us the flux from the inland towards the ocean via Greenland's outlet glaciers.

Here we present some of the most recent developments within PROMICE including ice velocities derived for the Kangerlussuaq region from 2007/08 ALOS PALSAR data and the new online data base with climate data from the PROMICE AMS network.

Recent mass, area and volume change of Langfjordjøkelen, northern Norway

Liss M. Andreassen[1], Bjarne Kjøllmoen[1], Al Rasmussen[2], Øyvind Nordli[3], Kjetil Melvold[1] and Solveig H. Winsvold[1]

[1]Norwegian Water Resources and Energy Directorate (NVE), Oslo, Norway.
[2]University of Washington, Seattle, USA
[3]The Norwegian Meteorological Institute, Oslo, Norway.

Langfjordjøkelen (70º10'N, 21º45'E) is a small ice cap (7.7 km2) in northern Norway and is one of the target glaciers in the IPY-project Glaciodyn. Mass balance measurements have been carried out on the east-facing part (3.2 km2) since 1989. Results reveal that the mean summer balance (−2.9 m w.e.) exceeds the winter balance (2.1 m w.e.) giving an annual deficit of −0.8 m w.e. for the period 1989- 2009. The cumulative net balance for this period (estimated values for 1994 and 1995 included) is thus −18 m w.e. The balance year 2008/2009 was the thirteenth successive year with substantially negative net balance. Measurements of the ice thickness and recent maps reveal that the glacier has lost about 20 % of its volume and 10 % of its area over the last two decades. The recent increased thinning of Langfjordjøkelen is stronger than observed for any other glacier in mainland Norway. The negative summer balance is consistent with an increased temperature in the melting season by 0.55 °C during the 21 years of mass balance measurements. The geodetic mass balance has been obtained for the period 1994-2008 by comparing digital terrain models (DTM) from 1994 (map constructed from vertical aerial photographs) and 2008 (laser scanning data) by subtracting the DTMs and adjusting for additional melting. The geodetic mass balance for the eastern part for 1994-2008 was −16.1 m w.e. The cumulative direct mass balance for that part over the same period was -15.7 m w.e. Hence, the results from the direct and geodetic compare well. A mass balance model using upper-air meteorological data was used to reconstruct annual balances back to 1948; their 1948-2008 total was −41 m w.e. Sensitivity of annual balance to 1 °C warming is −0.53 m w.e. and to 10 % increase in precipitation is +0.20 m w.e.

Subglacial Meltwater Drainage at Paakitsoq, West Greenland: Insights from a Distributed, Physically Based Numerical Model

A.F. Banwell*[12], I. Willis[1], N. Arnold[1], A.P. Ahlstrom[3].

[1]Scott Polar Research Institute, University of Cambridge, UK
[2]University Centre in Svalbard (UNIS), Norway
[3] Geological Survey of Denmark and Greenland (GEUS), Denmark.

Recent studies indicate that surface meltwater is reaching the bed of the Greenland Ice Sheet (GrIS) and modulating glacier sliding rates at the ice sheet margin. However, the hydrological characteristics of this drainage system and the degree to which variations in subglacial water pressure enhance or impede ice flow remain uncertain. As the subglacial hydrological system beneath the GrIS is physically inaccessible and beyond the resolution of geophysical imaging techniques, numerical models are an important tool for investigating the stability of plausible hydrological systems. We present preliminary results of a numerical model that investigates theoretically-constructed hydrological systems of the Paakitsoq region of W. Greenland, north of Jakobshavn Isbrae. Subglacial drainage system structures (the location, alignment and interconnection of major drainage channels) are defined from patterns of subglacial hydrological potential derived from surface and bed DEMs. Discharge and hydraulic head within subglacial channels are modelled using a component of the US EPA Storm Water Management Model (SWMM), modified to allow for enlargement and closure of ice walled channels (Arnold et al., Hydrol. Processes, 12, 1998). We assess the model's ability to deal with two types of input: rapid lake drainage events; and diurnally varying melt inputs calculated from a degree-day model. We perform sensitivity tests to determine the effects of individual model parameters on modelled channel cross-sectional area, water pressure and subglacial flow. Finally, we simulate drainage beneath the ice sheet for a summer melt season and compare the results with measured proglacial stream discharges. Through a recent code modification allowing subglacial water pressures to reach values in excess of ice overburden pressures, we find that consistently high inland subglacial water pressures assist with keeping marginal conduits full and counteract the effects of creep closure, allowing conduits to stay open. Although channelised flow is often assumed to only be possible close to the ice sheet margin where ice is thin and water inputs are large, we show that channelised flow is also possible further inland than expected if inland water pressures are kept consistently high by high rates of recharge to constricted conduit systems.

Hydrology and dynamics of a land-terminating Greenland outlet glacier

Ian Bartholomew

University of Edinburgh

Recent observations show that the Greenland ice sheet (GrIS) is currently losing mass, the result of accelerated surface melting and ice motion (Pritchard et al., 2009). In land-terminating sections of the GrIS margin, increased annual flux is caused by seasonal variations in ice-velocity that are initiated by inputs of surface melt-water to the ice-bed interface (Zwally et al., 2002). A positive relationship between surface melting and ice velocities has been used to propose a feedback between climate warming and dynamic mass loss for the GrIS, although the net effect remains equivocal (Shepherd et al., 2009, van de Wal et al., 2008). Most recently, on the basis of correlations between ice motion and surface melting, it has been suggested that the relationship between surface melting and ice velocity is moderated by the structure and hydraulic efficiency of the subglacial hydrological system (ibid.), which develops spatially and temporally on a seasonal basis.

Observations of proglacial discharge, electrical conductivity and suspended sediment concentration from an outlet glacier in W. Greenland (~67°N), are used to characterise the development of the hydrological system in the ablation zone of this part of the GrIS, following the onset of melting until late summer. These observations document the evolution of a hydrological system which expands upglacier and increases in hydraulic efficiency over the course of the summer melt-season. In conjunction with satellite observations and a simple temperature-index melt model, we show for the first time that water generated at the surface of the ice sheet, up to 1200 m elevation and 50 km inland, is transported via the subglacial hydrological system to the ice sheet margin. We also observe several flood events which correspond in timing, magnitude and water quality characteristics with the drainage of supraglacial lakes from the surface of the GrIS to the ice sheet margin.

Greenland ice sheet snow line variability: 2000-2009

Jason E. Box, Russel J. Benson, Ian M. Howat, and Jeff Morgan

Each year on an ice mass, at the end of the melt season, the maximum altitude where winter snow survives is a useful indicator of the combined effects of melting and snow accumulation. As such, snow line is an excellent holistic variable to indicate a glacier's health. In this study, Greenland ice sheet snow lines are mapped using optical satellite imagery for cloud-free scenes available just prior to the return of winter snow. We use NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) to classify Greenland ice sheet snow lines using reflectance thresholds and iterative statistical modeling. Inter-annual snow line variations spanning 10 seasons, that is, years 2000-2009 are presented. The accumulation area ratio magnitude and it's variability are assessed. To provide a longer context, pre-2000 Landsat imagery are analyzed. The spatial patterns of snow line are also evaluated in relation to precipitation and melt anomalies simulated by the Polar MM5 regional climate data assimilation model.

Six centuries of Greenland ice sheet mass balance: years 1700-2300

Jason E. Box, E. Rignot, E. Burgess, D.H. Bromwich, E. Mosley-Thompson

Instrumental air temperature records from meteorological stations around Greenland and from northwestern Europe regressed with calibrated Polar MM5 output to develop empirical coefficients to describe the spatial patterns of Greenland air temperature. The same approach is applied to annual ice core accumulation data. Runoff is estimated using a simple retention function. Ice discharge is taken to be a function of surface mass balance. The total ice sheet mass balance is thus reconstructed using past observations. Future projections are made based on IPCC AR4 scenarios and evaluating possible non-linear responses of glacier ice discharge. As such, a simple empirical estimate of the Greenland ice sheet sea level contribution is made, one that spans 6-centuries with 3-year time resolution.

On the nature of iceberg calving: a self-organized critical state?

Anne Chapuis

Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, PB 5003, 1432 Ås, Norway.

Calving activity at the front of a tidewater glacier is characterized by long quiescent periods punctuated by sudden release of icebergs. Are those iceberg calving events predictable? What drives the calving process? To get more insight into the nature of iceberg calving we visually monitored the magnitude and frequency of icebergs at Kronebreen, Svalbard, during two summer periods in August 2008 and August 2009. In total, we collected 18 days of observations, which represented more than 7000 calving events, ranging from small ice blocks (1 m3) to entire ice walls (25 000 m3). Magnitudes have been assigned based on the size of the resulting icebergs. Both the magnitude and interevent times are well fitted by power-law relations. These power-law relations suggest that calving process is self-organized in a critical state. A self-organized critical state is a state that emerges spontaneously and that can respond to external perturbations on all time and length scales. This hypothesis is supported by further glaciological data. The fact that calving process is self-organized in a critical state implies that calving events are unpredictable but not random which means that the physics of iceberg calving is deterministic, but neither the time of the next event nor its magnitude can be predicted. Another consequence is that the same processes control both the small and the large events and that there might be no specific explanation for the largest events. In this view, the occurrence of a “catastrophic” event, i.e., the entire calving front collapsing, can be expected and characterizes a large response of the system. This last consequence is very relevant for the modeling of calving processes since efforts should be made to model all sizes and types of events if one wants to get a correct picture of what is happening at a calving front.

Seasonal Variability of Mass and Energy Exchanges in the Dry Snow Zone of the Greenland Ice Sheet

[1]Nicolas J. Cullen, [2]Thomas Mölg and [3]Konrad Steffen

[1]Department of Geography, University of Otago, PO Box 56, Dunedin, New Zealand,
[2]Center for Climate and Cryosphere, University of Innsbruck, Innrain 52, 6020 Innsbruck, Austria,
[3]CIRES, CB 216, University of Colorado, Boulder, Colorado 80309, USA

Recent progress has been made in understanding the seasonal variability of energy and mass exchanges in the ablation area of the Greenland ice sheet (GrIS) but little is still known about the atmospheric processes that govern these exchanges in the dry snow zone. A number of detailed experiments have been carried out on the top of the GrIS, which have improved our understanding of the characteristics of the atmospheric boundary layer, in particular the weak instability of the atmosphere in summer, the processes controlling the divergence of longwave radiation and the intermittent nature of turbulence in stable conditions, but no detailed attempt has yet been made to characterize the exchanges of mass and energy beyond a summer season. The motivation to do this is to address a key uncertainty; whether mass is being lost or gained at the higher elevations through water vapour exchange. To investigate this we use meteorological and glaciological data obtained over an intensive 2 year measurement period to run a physically based mass balance model to characterize seasonal variability in the mass and energy exchanges at Summit, Greenland. The surface module of the MB model computes snow-atmosphere energy and mass fluxes from meteorological variables obtained from high quality radiation and atmospheric data, while the vertical temperature distribution in the snow layers beneath the surface is solved using a numerical subsurface module to obtain the subsurface energy flux. The MB is obtained through an assessment of modelled sublimation and deposition, together with input of measured accumulation from stake measurements and surface height changes from sonic ranging sensors. Our observations and modelling allow us to carefully assess the seasonal variabilty in sublimation, and to demonstrate why determining the sign of this flux remains critical in the assessment of the mass balance of the GrIS.

Seasonal and Inter-Annual Variations in Ice Flow of a High Arctic Tidewater Glacier

Brad Danielson and Martin Sharp

University of Alberta, Canada

The Belcher Glacier is a tidewater glacier that drains the North East quadrant of the Devon Island Ice Cap in Nunavut, Canada. The ~45km long glacier terminates in approximately 300m of water, and the ice cliff rises 20-40m above the water surface.

Continuously recording GPS stations have been installed on the ice to measure displacement at several points along the glacier. Continuous observations were collected from 3 stations during the spring and summer of 2008, and from 4 stations during a similar period in 2009. The stations were operated at a reduced duty-cycle for most of the intervening winter. The spring-summer GPS observations have been processed using a kinematic method to produce continuous glacier motion timeseries from May through August of both years. The winter GPS observations have been used to produce a timeseries of sequential static points.

During the two years of observation, this glacier has demonstrated distinct seasonal flow regimes. During winter and early spring, glacier motion is relatively stable, with little variability. In summer, horizontal ice velocity increases during periods of intense surface meltwater production. Vertical motion of the ice (uplift) coinciding with prolonged periods of positive air temperatures and increased horizontal ice velocity provides a strong indication that surface meltwater is reaching the glacier bed, increasing subglacial water pressure and thereby enhancing basal sliding.

In this presentation I will examine the differences between the seasonal ice flow responses observed in 2008 vs. 2009, in order to explore the dynamic sensitivity this glacier exhibits to variations in the intensity and timing of the summer melt season.

Insights into the dynamic regime of the Austfonna ice cap, Svalbard, from numerical modelling and observation

Thorben Dunse[1], Ralf Greve[2], Thomas V. Schuler[1], Jon Ove Hagen[1], Francisco Navarro[4], Evgeniy Vasilenko[3], Carleen Reijmer[5]

[1]Department of Geosciences, University of Oslo, Oslo, Norway.
[2]Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan.
[3]Institute of Industrial Research Akadempribor, Academy of Sciences of Uzbekistan, Tashkent, Uzbekistan.
[4]ETSI Telecomunicación, Universidad Politécnica de Madrid, Madrid, Spain.
[5]Institute for Marine and Atmospheric Research, Utrecht University, Utrecht, Netherlands.

The Austfonna ice cap covers an area of 8120 km^2 and is by far the largest glacier on Svalbard. Almost 30% of Austfonna is grounded below sea-level, while the figure is as large as 57% for the known surge-type basins in particular. Marine ice dynamics, as well as flow instabilities presumably control the flow regime, form and evolution of Austfonna. These issues are our focus in numerical simulations of the ice cap.
We employ the dynamic/thermodynamic, large-scale ice sheet model SICOPOLIS (*http://sicopolis.greveweb.net/*) which is based on the shallow-ice approximation. We present improved parameterizations of (a) the marine extent and calving and (b) processes that may initiate flow instabilities. The dynamic boundary condition at the glacier bed is given by a Weertman-type sliding law. Sliding is enabled when the temperature at the ice base is at or approaches the pressure melting point, while no-slip conditions prevail for a cold ice base. Sub-melt sliding in a defined temperature range, along with enhanced sliding of marine ice, control the dynamic behaviour of the ice cap and provide a switch between quasi-permanent fast flow or cyclic surge behaviour. The model results indicate that cyclic surges of some drainage basins are required to explain the present size and shape of Austfonna.
Space-borne interferometric snapshots of Austfonna revealed a velocity structure of a slow moving polar ice cap (< 10m/a) interrupted by distinct fast flow units with velocities in excess of 100m/a. However, observations of flow variability are scarce. In spring 2008, we established a series of stakes along the centrelines of two fast-flowing units. Repeated DGPS and continuous GPS measurements of the stake positions give insight in the temporal flow variability of these units and provide constrains to the modeled surface velocity field.
Austfonna's thermal structure is described as polythermal. However, direct measurements of the temperature distribution are available only from a single borehole at the summit area. The vertical temperature profile shows that the bulk of the 567m thick ice column is cold, only underlain by a thin temperate basal layer of approximately 20m. To acquire a spatially

extended picture of the thermal structure (and bed topography), we utilized low-frequency (20 MHz) GPR profiling across the ice cap and the particular flow units. The measurements indicate that the gross volume of Austfonna is cold. This observation is supported by model results which suggest that regional fast flow occurs despite the lack of considerable temperate-ice volumes. This in turn indicates that fast flow is accomplished exclusively by basal motion in regions where the glacier base is at pressure-melting conditions, and not by enhanced deformation of considerable volumes of temperate ice.

The snow conditions on selected Svalbard glaciers derived from classical methods and radio-echo soundings

Mariusz Grabiec[1], Dariusz Puczko[2], Tomasz Budzik[1], Grzegorz Gajek[3]

[1] Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
[2] Institute of Geophysics, Polish Academy of Sciences, Warszawa, Poland
[3] Maria Curie-Sklodowska University, Institute of Earth Sciences, Lublin, Poland

The state and evolution of a snow cover on glaciers play a crucial role in many glacial processes, e.g. mass balance, hydroglaciological processes. The work presents the state of snow cover on selected glaciers of Svalbard in last decade with a special attention paid to IPY period. The field studies were carried out on glaciers of southern Spitsbergen (Hansbreen, Renerdbreen, Amundsenisen) and on Vestfonna ice cap (Nordaustlandet). An archive data of stakes readings, from ultrasonic distance sensors and snow pits, performed within Hansbreen monitoring program, have been used. Recent snow cover measurements are based on high frequency radar soundings. The radio-echo sounding of the snow cover allows to determine a spatial variability of the snow layer as well as snow internal structure and stratigraphy (in relation to snow pits data). Specific elements of snow stratigraphy (e.g. ice hoar) have been connected with meteorological events during accumulation season. Repeated measurements of the snow cover thickness on Hansbreen in seasons 1989-2008 allow to indicate regularities in the spatial snow cover pattern and prove interseasonal variability of the snow cover thickness. In scale of Svalbard archipelago the thickness of snow layer is climatologically derived, whereas the spatial variability of snow cover within basins of particular glaciers is strongly determined by local topography. The topography modifies wind field and, in consequence, causes blow out and redeposition of the snow.

Climate impact on ice dynamics and temperature distribution on Swedish glaciers

Per Holmlund

Department of Physical Geography and Quaternary Geology, Stockholm University, Se106 91 Stockholm, Sweden

A survey of 45 polythermal glaciers in Sweden show increased mass loss and also ice warming over the last decade. Since the mid 1990s thermal information received from high resolution radar soundings are available for a large number of Swedish glaciers. A resurvey in 2008 and 2009 show how the temperature distribution within the glaciers matches the increased melt off during the last decade. All these glaciers have a polythermal temperature distribution with a perennial cold surface layer in the ablation area. In continental parts of the mountain range high ablation rates have caused a warming of the ice masses as a consequence of thinning cold surface layer. In wetter parts of the range the temperature distribution has remained more or less unchanged, while the ice mass has thinned. The net effect of such a change is a net cooling of the glacier tongue which influences the flow rates. In this paper an overview is given of the status of a number of Swedish glaciers, both in terms of size changes and in thermal changes.

Simultaneous measurements of surface motion and basal pressure changes on Engabreen glacier, northern Norway

Miriam Jackson[1] and Richard Norland[2].

[1]Hydrological department, Glacier, snow and ice section, Norwegian Water Resources and Energy Directorate (NVE), PO Box 5091 Majorstua, N-0301 Oslo, Norway;
[2]ISPAS, P.O. Box 219, NO-1501 Moss, Norway

Continuous measurements of glacier surface motion and subglacial pressure at Engabreen glacier in northern Norway were made over a seven day period in the spring of 2008. Somewhat surprisingly, there was typically little correlation between subglacial events where there was a sudden change in subglacial pressure and changes in motion on the glacier surface, although a few events showed good correlation.
Surface motion was measured using both dGPS receivers and ground based interferometric radar using a frequency of 5.7 GHz and recording distance to reflectors twice a second. GPS receivers and reflectors were placed at three different points on the lower part of the glacier at elevations of 320, 340 and 398 m a.s.l. Motion was smooth over the seven-day period, but showed variations at shorter time scales, as well as an approximately sinusoidal variation in motion at all stakes that was generally of 30 – 35 seconds periodicity. This sinusoidal signal may be a feature of the radar system, rather than a feature of the glacier motion, but the changing relationship of the amplitude, phase and frequency for movement at each stake suggests it may be a real feature.
Simultaneous measurements were made of subglacial pressure at earth pressure sensors that are installed at the Svartisen Subglacial Laboratoy under 200 m of ice. These sensors are approximately 1.7 km upstream of the highest of the surface stations. Six sensors recorded data at 90 second intervals, although only four sensors have unbroken records for the whole period. Changes in subglacial pressure recorded at the sensors are due to several factors including large clasts embedded in the ice being dragged over a sensor (which is then recorded at only one sensor) and changes in the water pressure at the bed (which is then registered at several sensors). Records show that major changes (of up to 30%) in the subglacial pressure occurred during the study period, but generally did not show a corresponding change in surface motion. Also, major changes in surface motion did not necessarily have a corresponding signal in the subglacial record.

Recent state of tidewater glaciers in Southern Spitsbergen

J. Jania, M. Blaszczyk, L. Kolondra, M. Grabiec

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

Tidewater glaciers in Spitsbergen undergo an alteration since beginning of last century. Accelerated changes have been noted during last two decades. Paper describes recent diminishing of extension and elevation of glaciers in Southern Spitsbergen derived from satellite remote sensing and field studies. Rate of changes has been measured. Glacier's hydrothermal structure and dynamic state are discussed either. The area is highly glaciated in comparison to other regions of Spitsbergen. More than two dozens of tidewater glaciers of different size are located there. Glaciers with susceptibility to surge type behavior were identified from direct and indirect evidence. The major changes are observed on larger tidewater glaciers with low longitudinal slope. Mass turnover has been estimated for Hansbreen - the best studied glacier in the area. Various importance of mass loss due to calving has been noted for different types of glaciers. A simple functional model of evolution of glacier systems in Spitsbergen is proposed.

New survey of dynamics of the frontal zone of Hansbreen, Svalbard tidewater glacier - preliminary results

J.A. Jania[1], L. Kolondra[1], D. Ignatiuk[1], M. Blaszczyk[1], P. Głowacki[2], S. Sikora[2], S. Kostka[2], D. Puczko[2], A. Adamek[3],

[1]Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
[2]Institute of Geophysics, Polish Academy of Sciences, Warszawa, Poland
[3]Faculty of Geodesy and Cartography, Warsaw University of Technology, Poland

Hansbreen is a medium size (56 sq. km) tidewater glacier in southern Svalbard. Thanks to proximity to the Polish Polar Station, Hansbreen has been monitored by different methods since 1982. The main objective of long term studies is survey of its flow dynamics and contribution of calving flux to the overall mass balance. During the IPY, the GLACIODYN project has enticed application of additional tools for survey of the Hansbreen frontal zone dynamics. Time lapse cameras of the IQvision type were used during daylight periods in 2007 – 2009. Experimental photos were also taken during polar night in November and December 2009 with use of the Canon A530. Long range scanner Riegl LPM-321 (reach up to 6 km) was used for acquisition of high resolution data on the glacier front in August and September 2009. Obtained data show changes of positions of ice cliff and crevasses during period of two and 11 days and are source for calibration of repeated pictures from digital cameras. The Riegl FG21-LR laser distance ranger has been placed close to the glacier front. The laser measures distance to the active cliff every 10 minutes since mid of September 2009. After summer retreat winter advance of the terminus has been recorded since late November. Precise periodic GPS survey has been conducted on new stakes close to calving front. ASTER images from 2008 – 2009 were used for measurements of glacier velocity by the feature tracking method. New tools and methods applied for glacier superficial velocity are giving more detailed picture of spatial and temporal variability of Hansbreen front dynamics than before known. Flow speed at the calving front is higher than measured in previous years and notable changes of glacier cliff velocity has been detected in the time of polar night. Preliminary results shows consistency of velocity data measured by different methods.

Changes in Central East Greenland Glaciers from a new Glacier Inventory and GDEM

Hester Jiskoot and Dan Juhlin

Department of Geography, University of Lethbridge, Lethbridge , AB, Canada.

Introduction and background

About 50% (~50000 km^2) of local glaciers peripheral to the Greenland Ice Sheet (GIS) are located in central East Greenland (67º-72ºN) and drain into Scoresby Sund, Kangerlussuaq fjord and Blosseville Kysten. This region of extreme topography contains a variety of glacier types. The largest local icecap, Geikie Plateau, is 300-500 m thick (Christensen et al., 2000), and has frequent melt events even at higher elevations (Dall et al., 2001). The largest tidewater outlet glacier, Kong Christian IV Gletscher, drains both from the Geikie Plateau and the GIS. This central East Greenland region has very limited glaciological research and only few recent quantitative remote sensing studies. No mass balance or other monitoring programs exist. However, the regional runoff from East Greenland to the North Atlantic is important in global thermohaline circulation, salinity and sea ice dynamics (Mernild et al., 2008), hence it is important to establish (i) the glaciated area, so that ice volume can be extrapolated, (ii) the retreat/advance rates of the glaciers and (iii) their sensitivity to predicted climate change.

The central East Greenland region is sensitive to climate change because of the specific character of its glaciers and regional climate change predictions:

1) About 2/3 of the total area drains through tidewater glaciers (Jiskoot et al., 2003).
2) Between 30-70% of glaciers are of surge-type and can advance, redistribute their volume, and cause extreme calving events (Jiskoot et al., 2001 and 2003).
3) Many of the Scoresby Sund glaciers are polythermal, hence changes in temperature and precipitation rates might affect their thermal regime and ice dynamic behaviour.
4) Climate models using scenario A1B predict 2.8-4.3°C temperature increase for Greenland over the next century and radiative forcing models show central East Greenland as a ‘hotspot’ (IPCC, 2007).
5) The timing of break-up of sea ice in this region is positively correlated with increased surface melt, especially with early break-up in July (Rennermalm et al., 2009).

Since the neoglacial, most land teminating glaciers in the Geikie Plateau region have receded up to a few km, but most calving fronts were quite stationary up to the early 1990s or showed at most a slight loss (Weidick, 1995; Dwyer, 1995). Since the majority of the tidewater glaciers are of surge-type it is unclear whether these losses are glaciodynamic or glacioclimatic responses. In the late 1970s, the regional transient snowline was at 700 m asl in southern parts and 1000-1300 m asl in northern parts (Weidick, 1995). It had risen to

1000-1500 m asl by 1999-2000 (Jiskoot et al., 2001 and 2003), which agrees with the range of 1200-1500 m asl suggested for modern Scoresby Sund glaciers (Lie & Paasche, 2006).

Methods

We compiled a detailed glacier inventory of the Geikie Plateau region, using semi-automated digitization from a mosaic using 68 ASTER scenes and 6 Landsat7 scenes. Glaciers were identified using a supervised Mahalanobis distance classification, small polygons were removed using the Lee Filter, and moraine covered termini, nunataks and ice divides were manually improved. Calving glacier margins were manually extracted by retracing margin lines and snapping these to the glacier margin polygons derived from the semi-automated method. Calving margins from a glacier inventory based on InSAR images and topographic maps of the mid-1980s to mid-1990s (Jiskoot et al., 2003) were also manually retraced. Differences in area (positive or negative; retreat and advance) were summated, so that for each glacier a calving margin area change between 1985/1995 and 2004/5 was obtained. Finally, the new ASTER Global DEM (GDEM) was used to generate glacier hypsometries for individual glaciers and an overall hypsometry for all land terminating glaciers, following the Raster Planar Surface Area procedure. Seasonal snowlines were extracted from interactively-stretched ASTER scenes from July/Aug 2003-05. See Jiskoot et al. (2009) for both methods.

Results

Inventory

The glacier inventory contains 298 glaciers, with a total glaciated area of 41463 km^2. Glaciers range in size from 2 km^2 (thresholded) to 11079 km^2 for Kong Christian IV. Glacier area is log-normally distributed, and the minimum area threshold underestimates the total glaciated area by only 0.5-1%. Most glaciers drain from the Geikie Plateau (max. 2895 m asl) to sea level and end in tidewater margins. The total length of the calving fronts is 235 km, and roughly 90% of the total glaciated area drains through 118 tidewater glaciers (Fig 1). The widths of calving margins range from ~0.1-13 km. It is the first time that such importance of calving in this region has been recognised.

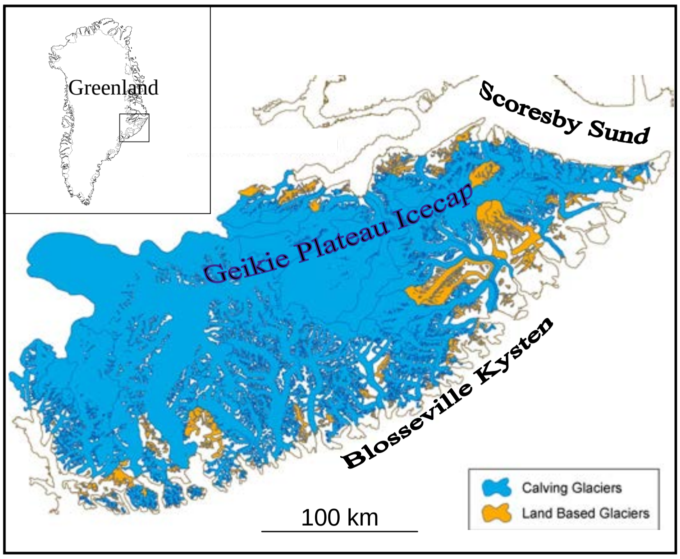

Figure 1: *Glacier inventory with 90% of glacier area draining though tidewater margins.*

Calving margin dynamics

Differing calving margin positions between the mid-1990s and 2000-2005 indicates an areal loss of 148 km^2, a gain (advance) of 4.3 km^2, and a net calving area loss 144 km^2 (7-14 km^2 a^{-1}). Large interannual margin fluctuations are likely related to the presence of sea ice. Analysis of possible patterns in calving margin fluctuations, aided by case-studies (e.g. Fig 2), show no correlation between calving width and terminus retreat/advance rates nor N-S or E-W spatial patterns in terminus retreat/advance rates. However, there appears to be a correlation between surge-type glaciers and increased retreat, suggesting that some of the calving margin retreat could be a dynamic effect rather than directly related to mass balance or ocean water temperature.

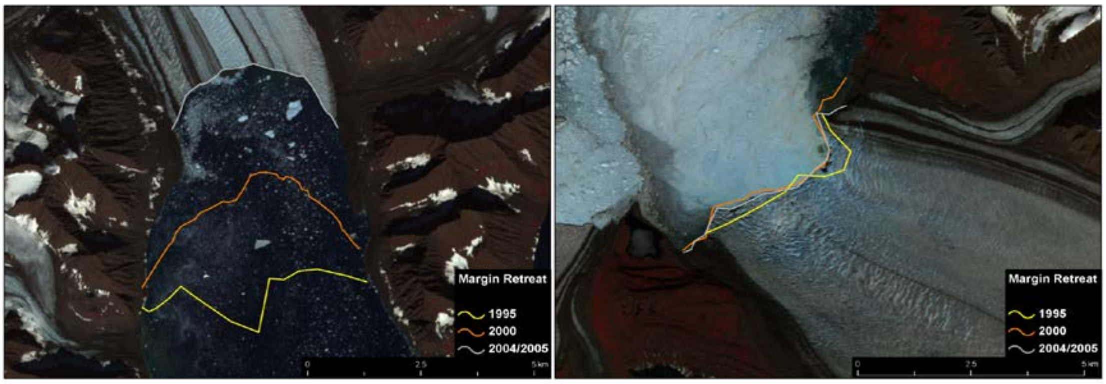

Figure 2: *Case studies of tidewater margin dynamics of Sortebrae (L), where the 1992-1995 surge (Jiskoot et al., 2001) was followed by a margin areal loss of 22.7 km^2 since 1995, and Magga Dan (R), a fast flowing (6.5-14.0 m d^{-1}: Luckman et al., 2003) normal glacier which was virtually unchanged (-0.02 km^2) between 1995 and 2004/5.*

Hypsometry and sensitivity to rise in snowline

The average snowline elevation of glaciers for which snowlines could be established (60% of the total of 298 glaciers in the Geikie Plateau region) was at 1092 m asl, which is a rise of 82 m as compared to the average snowline derived from late summer Landsat images of 1999/2000 (Jiskoot et al., 2003). The hypsometry of all land terminating glaciers combined (180 glaciers representing ~9% of the total regional glaciated area) is near equidimensional (Fig 3). Combining the average snowline elevation of land terminating glaciers (1050 m asl) with their hypsometry reveals an accumulation area ratio (AAR) of 56% in 03-05 (Fig 3). With the predicted regional temperature increase of 2.8-4.3°C over the next century, the predicted rise in snowline would be in the order of 200-400m, and the resulting AAR would be reduced to 42% and 29% respectively (Fig 3). Thus, with the present prediction of regional warming (IPCC, 2007), combined with the sensitivity of surface melt to earlier break-up of sea ice (Rennermalm et al., 2009), the land terminating glaciers will have a low viability for survival under the predicted climate conditions.

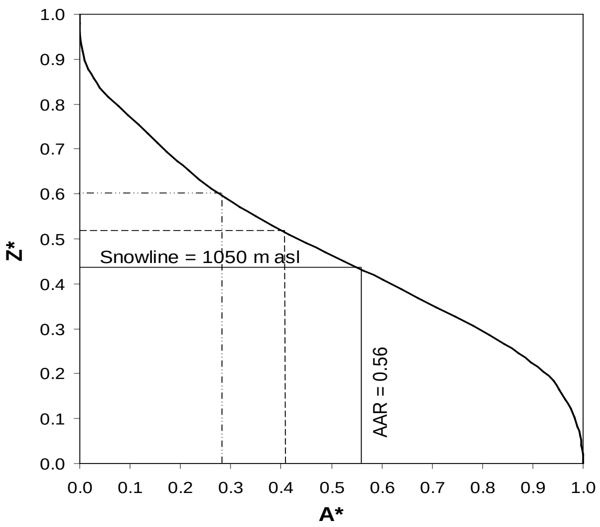

Figure 3: *Normalized hypsometric curve of 180 land terminating glaciers with average late summer snowline in 2003-2005 (1050 m asl) and a corresponding AAR of 56%. A rise in snowline of 200 and 400 m correspond to AARs of 42% and 29% respectively.*

Acknowledgements

Access to ASTER imagery was facilitated through HJ’s affiliation with GLIMS, through which this glacier inventory will ultimately be available.

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Multiparameter studies in the meltwater of Werenskioldbreen, hints for supercooling

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

[1]Laboratoire Physique des Radiations (LPR), University of Luxembourg, Luxembourg
[2]Institute of Geoecology and Geoinformation, Adam Mickiewicz University, Poland
[3]Faculty of Earth Sciences, University of Silesia, Poland

To recognize subglacial outflow in proglacial streams and improve the understanding of Svalbard polythermal glaciers, radon, electrical conductivity (EC), total dissolved gas pressure (TDGP), CO_2, temperature, pH and chemical compounds were measured during April-May sampling campaigns on outflows in the forefields of Werenskiolbreen. Radon showed levels up to 29 Bq/L, documenting significant contact of water with sediment and bedrock at the glacier bed. Those data, together with continuous measurements of radon, EC, temperature, TDGP and CO_2 in the melting period, give information on drainage footpaths and hints to the draining system.

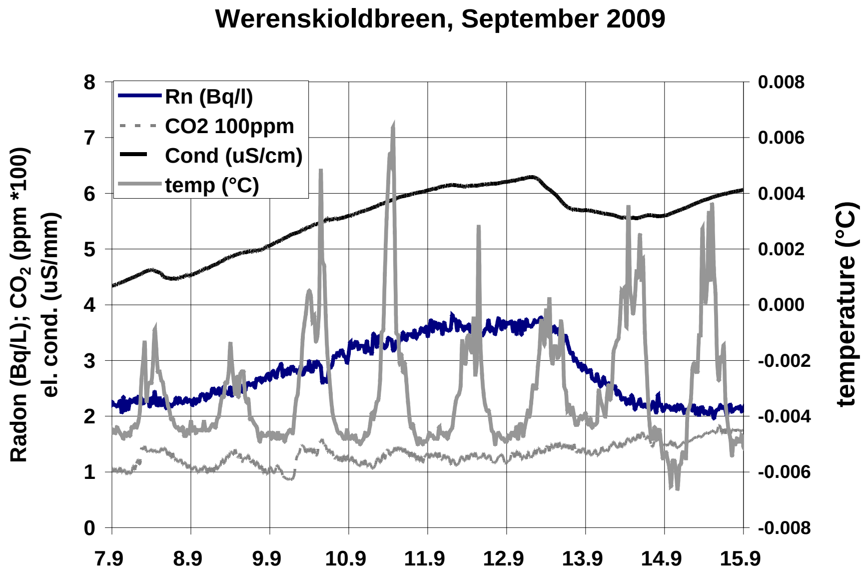

Figure 1: *Example of continuous measurements at an outflow at Werenskioldbreen.*

At the largest outflow in the central part of Werenshioldbreen radon concentrations were up to 8 Bq/L in the middle of the melting period (2007). Temperatures lower than 0 °C were measured in artesian outflows during both investigated seasons. Observed was the presence and formation of frazil ice thus documenting the presence of supercooled meltwater. Radar sounding results presented in the 2009 IASC-NAG Meeting , Kananaskis Country, Alberta, Canada by Mariusz Grabiec et al. show parts of overdeepening under Werenskiodbreen. Meltwater ascending the adverse slope from the overdeepening toward the glacier margin at a faster rate than it can be heated by friction may be supercooled (Alley,2003; Evenson,1999; Knight, 2008; Tweed, 2005) . Supercooled meltwater that emerges from this overdeepened basin via artesian vents (the only ones we investigated), cause growth of the observed frazil ice at the glacier margin.

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Mass balance of Potanin Glacier, Mongolia Altai

Keiko Konya*, Tsutomu Kadota, Fumio Nakazawa, Hironori Yabuki and
Tetsuo Ohata

*JAMSTEC, Japan

There are glacier region in Altai Mountains situated at central-north Asia. This region is thought to be receiving the influence of the present Arctic Change. Study related to mass balance of glaciers in the Mongolian district will be reported. It is reported that Potanin glacier in western Mongolia is retreating. However, there were few glaciological observations. Furthermore, meteorological observations around the glacier have not been done yet. For mass balance analysis, we conducted observation of surface height change in ablation area and net balance estimation using pollen analysis at accumulation area. It revealed that ablation rate in summer is large in ablation area and accumulation occurred in winter. We estimated the specific mass balance from the data. Mass balance of Potanin glacier in year 2007/08 was estimated to extensive negative which was comparable to Russian Altai glaciers. Naturally, cumulative mass balance of glaciers in Altai show different tendency from world average. Annual air temperature shows warming trend whereas precipitation does not show the significant increase/decrease. Therefore, it is probable that precipitation as snow or rain had an influence on mass balance.

Long-term mass- and energy balance of Kongsvegen glacier, Svalbard

Thomas Krismer[1], Friedrich Obleitner[1] and Jack Kohler[2]

[1]Insitute of Meteorology and Geophysics, Innsbruck University; Austria
[2]Norwegian Polar Institute, Tromsoe; Norway

We consider meteorological and glaciological data measured at the equilibrium line of Kongsvegen glacier during the period 2000 to 2008. The data encompass quite different mass balance regimes and were used for input and validation of local mass- and energy-balance simulations. The meteorological conditions at the ELA are characterized by a coreless winter and summer temperatures around 0°C. Winds are preconditioned by katabatic winds and topographically channelled upper-air winds. Annual net short-wave radiation is determined by polar-day cloudiness and the seasonal evolution of surface albedo. Long-wave radiation fluxes withdraw an almost equivalent amount of energy throughout the year. The turbulent sensible heat fluxes constitute a comparatively strong and continuous source of energy, which is partly offset by latent heat fluxes. Most of the energy available from the atmosphere is used for melt and only a small amount goes into heating the near surface ice layers. Similar investigations were performed at the tongue of the glacier for a shorter period. There is enhanced input from the atmospheric fluxes and correspondingly increased melt. Accumulation is comparatively small and melt can also occur during winter. We further investigate the relationship between the meteorological conditions measured at the glacier and outside. Regression models were developed to derive model input from climate data measured at a nearby research station. Driving the mass balance model with correspondingly interpolated data yields less accurate results. The shortcomings can mainly be traced back to insufficient parameterisation of precipitation and albedo.

Spatial model of ablation on the Werenskiold Glacier, SW Spitsbergen

Migała Krzysztof[1], Kryza Maciej [1], Szymanowski Mariusz[1], Puczko Dariusz[2]

[1] University of Wrocław, Institute of Geography & Regional Development
[2] Institute of Geophysics, Polish Academy of Sciences

The main objective of the study was to apply GIS techniques to estimate spatial pattern of glacial processes and to verify the results by comparison with manual, field measurements. he verification of the results enables this method to be applied in analyzing the impact on a regional scale of glaciological process.

The research was carried out on Wedel Jarlsberg Land (SW Spitsbergen) and focused on Werenskiold Glacier situated on the west coast, about 12 km north of Hornsund Fjord, where the Polish Polar Station (PPS) is located.
The west coast is characterised by the most favourable thermal conditions, where air temperature is largely determined by warm, open waters of Greenland Sea and frequent foehn processes, which occur on the coast. The air temperature here is 0.8^{o}C higher on average than that of the Polish Polar Station (Migała et al. 2008).
Land terminated Werenskiold Glacier is a subpolar maritime type of valley glacier (Baranowski 1977). Contemporary area of the glacier is c.a. 27 km2 .The glacier is exposed mostly to the west and upper parts exceed 600 -700m a.s.l. During summer all over the surface of the glacier snow and ice are melting. During the summer months snow and ice melt all over the surface of the glacier The outflows take place during the whole hydrological year. The putflow of subglacial water form „naledi” type of ice in the winter.

Ablation was modeled for the summer seasons of 2008 and 2009. To calculate water equivalent of seasonal ablation, the Khodakov formula Ab (1982) was combined with GIS based r.sun model of total radiation for Hornsund (Kryza et al. (2010).

$$Ab = 0{,}001*(T+1{,}3*\sqrt{Ia} + 4)^3 \quad [m\ w.e.]$$

where,
Ab , water equivalent of ablation [m]
T, mean air temperature of summer season (June – August)
Ia, sum of absorbed solar radiation in summer (June – August)

Air temperature (T) applied in the model was measured with AWS (CR10X, Campbell) located on the frontal moraine of the glacier (26m a.s.l.) and with logger HOBO PRO situated on the summit of Angellfjellet (591m a.s.l), in close proximity to the glacier's front. Both sites were used to calculate vertical gradient of temperature. Absorbed radiation (Ia) was calculated with the r.sun model of total radiation and albedo obtained from the satellite image as the reflectance of panchromatic band 8 of Landsat ETM+ data. GIS based r.sun model of total radiation for Hornsund was evaluated based on the actinometric data from the Polish Polar Station.

Relations between meteorological parameters on Hans glacier and Hornsund Polish Polar Station

B. Luks[1], M. Osuch[1], R. Romanowicz[1], T. Budzik[2], S. Sikora[3], D. Puczko[1]

[1]Institute of Geophysics, Polish Academy of Sciences, Warszawa, Poland
[2]Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
[3]Institute of Geography, Wrocław University, Poland

There is great interest in the modelling of Arctic snow dynamics and its dependence on climatic variations. There is a lack of long-term high resolution observations of meteorological parameters on glaciers. This concerns the Hans glacier located in Hornsund fjord, Svalbard. In this study we analyse the temporal variation of snow cover depth and air temperature from Automatic Weather Stations (AWS) located in ablation and accumulation areas on the glacier. Due to difficult weather conditions and equipment failure, many observations are missing, making the application of snow cover models difficult and resulting in a high uncertainty of the predictions. The Hornsund Polish Polar Station (PPS) located close to Hans glacier provides more reliable meteorological measurements (WMO station) than those on the glacier. The aim of this study is to derive of a relationship between measurements at Hansbreen and PPS that would help in interpolation over the missing data. We apply a statistically efficient and less data-demanding lumped parameter time series approach to derive this relationship. We use Data Based Mechanistic (DBM) models, where a stochastic data-based identification of model structure and an estimation of its parameters are followed by a physical interpretation. First, the observations are checked for consistency and data gaps are filled using Dynamic Harmonic Regression (DHR) methods. Second, dynamic Stochastic Transfer Function (STF) models are developed. Apart from the estimation of mean meteorological parameters, the models also provide uncertainty limits. Additionally, we estimate the uncertainty levels to assess the applicability of the models for completion of measured time series.

Dating ice cores by wavelets

J. Moore[1,2],[3], E. Beaudon[1], V. Pohjola[4], T. Martma[5], R. Van de Wal[-], E. Isaksson[7]

1 Arctic Centre, University of Lapland, P.O. Box 122, 96101 Rovaniemi, Finland
2 Thule Institute, University of Oulu, Finland
3 College of Global Change and Earth System Science Beijing Normal University, 19 Xinjiekou Wai Street,Beijing, 100875 China
4 Uppsala University, Uppsala, Sweden
5 Institute of Geology, Tallinn University of Technology, Tallinn, Estonia
6 Institute for Marine and Atmospheric Research Utrecht, 3508TA Utrecht, The Netherlands
7 Norwegian Polar Institute, N-9296 Tromso, Norway

Ice cores are often dated by reference horizons such as volcanic acid deposits, some may also be dated by annual cycle counting, or flow models. However in deeper ice cores, or in cores that lack good annual cycles, it is common to "wiggle match" the variability seen in one record with that seen in another well-dated. A similar approach is tuning the observed variability in a record with known spectral power associated with Earth's orbital variations. Here we show that poorly dated paleoclimate proxies may be dated with more confidence by observing the wavelet coherence between a well dated reference record and a set of proposed chronologies of the problematic record. The idea is that if the two chronologies are well dated, then the phase relationships between the wavelet decomposition of the two records should match reasonably well over a variety of frequency bands and at many points in the timescale. This makes no assumptions about the particular type of climate signal that will be recorded at the two sites, except that on average the climate will be tend to be spatially more coherent than random noise at all scales. We show that the approach works for two ice cores from Svalbard where the wavelet coherence between nine chemical ions is examined. The timescale can then be verified by extracting the volcanic record from the sulphate concentration record as spikes in the residual from fitting the sulphate variability to empirical regression on other ions. This process accounts for terrestrial, marine, biogenic and anthropogenic sulphate deposition fractions as well as post-depositional relocation of ions, leaving only stochastic sources, effectively volcanic fallout.

IPY research on McCall Glacier

Matt Nolan, Joe McConnell, and Bernhard Rabus

In 2008 during IPY, we recovered a 152 m ice core to bedrock from McCall Glacier and analyzed it in winter of 2009 for over 35 proxies. We found that despite the potential obscuring influence of meltwater percolation, many of the proxies showed annual fluctuations. We preliminarily dated the bottom of the core to about 1750AD through a combination of layer counting, wiggle matching, and tritium measurements, and found an average layer thickness (water equivalent) of about 550 kg m-3, which was surprisingly uniform until the past 2 decades when it decreased. We have not analyzed the proxies themselves as yet, but have submitted a proposal to do so later this year and are looking forward to comparisons with other cores.

Ice temperatures measurements indicate temperature variations over the past 35 years that relate to climate and surface dynamics. Thermistor strings placed into 3 holes to bedrock in 2008 confirm the polythermal nature of McCall Glacier and that the glacier gets cooler with elevation, due to the influence of internal accumulation in former and current firn areas. In one 200 m deep hole, the surrounding region changed from accumulation to ablation area ? the ice temperature is responding by getting colder from the top down due to the lack of internal accumulation; our modeling indicates this switch occurred about 50 years ago. Shallow ice temperature measurements (<15 m) conducted near the same locations over the past 35 years indicate that air temperatures in the region warmed by over a degree in the 1970s-1990s, but since then air temperatures in the area don't seem to have a strong trend; this is somewhat confirmed by global reanalysis data and local measurements.

As part of our IPY efforts, we created a photographic inventory of nearly all glaciers in the US Arctic to complement volume change studies there made through map comparisons. The volume change studies are still underway, but the photographic inventory is now available online.

Combining mass balance measurements/modeling with geodetic elevation changes: A case study from Kongsvegen and Holtedahlfonna/Kronebreen

Christopher Nuth[1], Thomas Schuler[1], Jack Kohler[2], Jon Ove Hagen[1]

[1]Dept. Of Geosciences, University of Oslo
[2]Norwegian Polar Institute, Tromsø, Norway

Kongsvegen (105 km2) and Holtedahlfonna/Kronebreen (370 km2) are two dynamically different glaciers located in Northwest Spitsbergen (79°N 13°W). Velocities on Holtedahlfonna/Kronebreen range from 40 to 400 m yr-1 while on Kongsvegen velocites are only 1 – 10 m yr-1. Mass balance has been measured on the two glaciers since 1986 and 2003, respectively. Meteorological data collected by the Norwegian Meteorological Institute in Ny Ålesund are used to drive a distributed temperature-index model. The model is calibrated by the multi-year mass balance measurements to provide spatially distributed surface mass balances for each glacier. Geodetic data, including topographic maps in 1966, 1990 and 1995, differential GPS profiles acquired since 2000, and a modern satellite DEM from 2008, are differenced to provide elevation and volume changes for various time epochs. The residuals between the cumulative modeled surface mass balance and the geodetic volume changes provides an estimate of the flux divergence for each pixel. For Kongsvegen, these residuals are essentially zero due to the fact that at present the glacier is in the quiescent phase of its surge cycle. On the other hand, the flux divergence on Holtedahlfonna is larger and more important in explaining elevation changes. When integrated over the entire glacier, these residuals represent a 10 to 20 year average calving loss estimate.

Application of a minimal glacier model to Hansbreen, Svalbard

Johannes Oerlemans

IMAU, Utrecht University

Like many glaciers in Svalbard, during the past century Hansbreen has shown a steady retreat. Hansbreen is located in the relatively maritime climate of W Spitsbergen, has an area of about 57 km^2 and a length of about 16 km (Pälli et al., 2003). The glacier has a small surface slope (mean value of 0.025) and an active calving front. Since 1900 the front retreated over a distance of about 2 km (J. Jania, personal communication). Upstream from the current front position the glacier bed has a reversed slope over several kilometers. The deepest parts of the bed are about 100 m below sea level.

In this contribution the global dynamics of Hansbreen are studied with a minimal glacier model (Oerlemans, 2008). In such a model the glacier mechanics are highly parameterized and the only independent state variable is glacier length. The mean glacier thickness is determined by the glacier length, and the calving rate is related to the water depth. A schematic representation is used for the longitudinal bed profile.

In spite of its simplicity the model is able to simulate the retreat of Hansbreen for a plausible climate change scenario. The model has been calibrated by constructing a history of the equilibrium-line altitude (ELA) that results in a good match of observed and simulated glacier length since the year 1900. It appears that the fast retreat of Hansbreen in the first half of the 19th century can only be explained by a marked rise (~150 m) of the ELA during the first decades of 19th century. This is in agreement with the sparse meteorological observations available for this period (Johannessen et al., 2004).

The model suggests that in the year 2000 the ELA was 122 m higher than in the year 1850. If the rate of rise (0.81 m a^{-1}) is kept constant for the future, the model predicts a further retreat of the glacier front of 4.3 km. The accelerating retreat is partly due to the increasing calving rates when the front moves into slightly deeper water.

The model is also used to study more generally the dependence of equilibrium states on the ELA. The results are used to speculate about the mechanism behind the advance–retreat cycle of Hansbreen.

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Numerical modeling of the dynamics of Norden-skiöldbreen, Svalbard

Ward van Pelt[1], Johannes Oerlemans[1] and Carleen H. Reijmer[1]

[1]Institute for Marine and Atmospheric Research, Utrecht University, The Netherlands

A numerical ice sheet model, the Parallel Ice Sheet Model (PISM), is applied to Nordenskiöldbreen, a tidewater glacier in the central part of Svalbard. In PISM, two approximations of the full-Stokes equations are considered and combined, leading to a thermomechanically coupled shallow 'hybrid' model (Bueler and Brown, 2009). Velocity solutions of the non-sliding shallow ice approximation (SIA) and the shallow shelf approximation (SSA), which incorporates membrane stresses, are averaged and weighted to yield final velocity estimates. The model is capable of simulating a large range of ice velocities as a result of both internal deformation and basal sliding. The till is assumed to behave plastically and the strength of the basal material is dependent on the amount of liquid water present at the base as a result of basal melting. Since 2006, the Institute for Marine and Atmospheric research Utrecht (IMAU), has carried out ice velocity measurements using GPS stations situated at multiple locations on the glacier. These data will be used to validate modeled ice flow velocities. The research will focus on investigating the interaction between glacier hydraulics, sediment deformation and basal sliding on different time scales.

Investigating basal conditions and thermal regime on Vestfonna Ice Cap, Svalbard

Rickard Pettersson[1], Poul Christoffersen[2], Alun Hubbard[3], Veijo Phojola[1], Julian A. Dowdeswell[2]

[1]Department of Earth Sciences, Uppsala University, SE-752 36 Uppsala, Sweden
[2]Scott Polar Research Institute, University of Cambridge, Cambridge, CB2 1ER, UK
[3]Institute of Geography and Earth Sciences, University of Aberystwyth, Aberystwyth, SY23 3DB Wales, UK

Although detailed studies have been done about the dynamics of the glaciers in Svalbard, these studies have been focused on few and often small glaciers located close to settlements. Little is known about the ice dynamical responses on climate change on a majority of the glaciers and the larger ice caps in the archipelago. We have initiated a study to investigate the basal conditions and flow dynamics of Vestfonna Ice Cap on Nordostlandet, Svalbard, to study the link between climate dynamics and ice flow. Here we will present the first results of the radio-echo sounding (RES) surveys collected during field seasons in 2008 and 2009.
The RES data was collected to establish a bedrock elevation map and collect for the thermal regime and basal conditions for the ice cap that is a prerequisite for modelling efforts of the flow dynamics of the ice cap. The collected bedrock elevation data is combined with airborne data collected in 1983 and the resulting map indicate an undulating bedrock surface and an average ice thickness of 185 m with a maximum of 405 m. Zones of internal scattering in the RES data indicate temperate conditions. However, it is only present in the upper part of the ice column, indicating that the lower part has cold (dry) conditions and the spatial distribution of the scattering zones are patchy. The strongest reflecting ice-bed interface is found in areas with large ice thicknesses and in onset areas of outlet glaciers. It also coincides with areas of high surface velocities. This suggests that the pressure melting point is reached at the bed where the ice thickness is enough while the lack of internal scattering in the RES data in many areas and indicate that the ice column is cold. The higher reflectivity in the catchments of the outlet glaciers indicate that the onset of the outlet glaciers can be governed by basal conditions or that the ice motion of the outlet glaciers generates enough friction heat to sustain melting conditions

Recent elevation change of Vestfonna, Svalbard Archipelago, comparing surface DGPS campaigns with ICESat and NASA altimetry

Veijo Pohjola[1]*, Rickard Pettersson[1], Geir Moholdt[2], Chris Nuth[2], Leszek Kolondra[3], Mariusz Grabiec[3], John C. Moore[4] and IPY-KINNVIKA members.

[1]Department of Earth Sciences, Uppsala University, Villavägen 16, SE-752 36 Uppsala, SWEDEN
[2] Department of Geosciences, University of Oslo, NORWAY
[3] Department of Geology, University of Silesia, POLAND
[4] Arctic Centre, University of Lapland, FINLAND

During IPY4 (2007-2009) DGPS ground elevation profiles where accomplished by snowmobile traverses across the 2,500 km^2 sized Ice Cap Vestfonna situated in the northeast of the Svalbard Archipelago (80° N, 19° W). The repeated campaigns show local spatial and temporal changes of the ice cap elevation, most likely caused by changes in the wind patterns over the ice cap. Our ground profiles was aimed to follow ICESat profiles (2003-2008) and airborne NASA altimetry (1996, 2002) that criss-crosses the ice cap. Comparisons between ground DGPS altimetry and ICESat altimetry during near-in-time campaigns for both platforms in 2008 show good agreement between both series. Analyzing all the available elevation time series suggest only local changes, but brings no coherent trend in elevation change for the whole ice cap. Thus it seems Vestfonna is anomalous compared to other glaciers in Svalbard, and the Arctic by being conservative to mass changes during the last decades.

A new estimate of Arctic glacier volumes derived from statistical upscaling of glacier inventory data

Valentina Radić[1,2] and Regine Hock[2]

[1] Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, Canada
[2] Geophysical Institute, University of Alaska, Fairbanks, USA

Very few large scale ice volume estimates are available for mountain glaciers and ice caps although such estimates are crucial for any attempts to project their contribution to sea-level rise in the future. We present a statistical method for deriving regional and global ice volumes from regional glacier-area distributions and volume-area scaling, based on data from a recently extended World Glacier Inventory. We compute glacier volumes and their sea level equivalent (SLE) for all mountain glaciers and ice caps in the Arctic defined roughly as 60 □N (excluding
410,000 km2 we estimate a total ice volume corresponding to 0.43 ± 0.05 m SLE, of which 10% is due to glaciers in Greenland apart from the ice sheets. The Arctic glaciers contain approximately 58% of the sea-level equivalent of all mountain glaciers and ice caps on Earth (0.60 ± 0.07 m SLE). However, our estimate is sensitive to assumptions on volume-area scaling coefficients and glacier-area distributions in the regions that are poorly inventoried such as North America and Greenland. This emphasizes the need for more volume observations, especially of large glaciers, and a more complete Arctic Glacier Inventory in order to reduce uncertainties and to arrive at firmer volume estimates of Arctic glaciers.

Temporal and spatial variations in the flow speed of Kronebreen, Svalbard

C.H. Reijmer[1], J. Kohler[2] and M. Sund[3]

[1] Institute for Marine and Atmospheric Research, Utrecht University, the Netherlands
[2] Norwegian Polar Institute, Tromsø, Norway
[3] University Centre in Svalbard, Longyearbyen, Svalbard

Kronebreen is one of the fastest flowing (tidewater) glaciers in Svalbard with annual average speeds up to 1.5 m/dy on the lower parts of the glacier. The glacier drains a large area of about 600 km^2 and is a known surge type glacier. The lower few km of the glacier is heavily crevassed making in-situ observations of the flow velocity difficult. Velocity observations of the lower part of the glacier are therefore mainly based on remote sensing techniques such as terrestrial photogrammetry, satellite speckle tracking and InSar techniques.
We present one year of in situ velocity observations from nine stand-alone GPS receivers. Seven receivers are placed on the central flow line from about 2 km to about 13 km from the front of the glacier. Two receivers are placed on a cross profile at about 4 km from the front.
We will discuss the observed velocities in terms of the temporal variations, e.g. the summer speed up in June and July, and the spatial variations, e.g. velocity variations along the profile. A comparison will be made with available observations from literature.
We will also discuss the results in terms of available meteorological observations and spatial characteristics of the glacier.

The Current State of Mountain Glaciers and Ice Caps in the Arctic: an Update on the Arctic Council's SWIPA Project

Martin Sharp, Anthony Arendt, Regine Hock, Gabriel Wolken, Edward Josberger, R.Dan Moore, W.Tad Pfeffer, Jon-Ove Hagen, Maria Ananicheva, Alexander Klepikov

SWIPA (Snow, Water, Ice and Permafrost in the Arctic) is a review of the state of the Arctic Cryosphere commissioned by the Arctic Council for delivery at the end of 2010. The core components of the project deal with Sea Ice, Snow, Permafrost, River and Lake Ice, Mountain Glaciers and Ice Caps (MGIC) and the Greenland Ice Sheet (GrIS). An initial version of the GrIS module was published at COP15 in Copenhagen in December 2009. The rest of the modules are still in preparation, but this talk will present an overview of the major findings of the MGIC module.

Glacier retreat has been widespread across the Arctic in the past century. Fractional reductions in glacier area over the past 50 years have been large in many regions and many glaciers have already disappeared. Mass balance records extend back up to 60 years in some cases, and almost all now show negative cumulative balances. Rates of mass loss have increased substantially over the last 10-20 years, especially in regions like Alaska, the Canadian Arctic, and Iceland where there are large glaciated areas and there has been strong summer warming. Estimates of the regional mass loss from Arctic MGIC suggest rates in excess of 150 GT/yr since the mid 1990s. When added to estimates of mass loss rates from GrIS, the Arctic emerges as a major contributor to the eustatic component of global sea level rise.

It is now clear that iceberg calving is a significant component of the regional mass balance in Alaska, the Canadian Arctic, Svalbard and the Russian Arctic, accounting for as much of 20-35% of total annual mass loss in some cases. The annual specific balance due to calving in these regions is comparable to that for GrIS. There may be large short-term variability in the calving rates of individual glaciers, and also of the total regional mass balance, associated with changes in ice dynamics.

Projections of change over the 21st century in the volume of Arctic MGIC due to surface mass balance alone have been made using output from 10 global climate models driven by the A1b emissions scenario. These suggest total volume reductions of between 15 and 50% depending upon the model used. The largest contributions to sea level are projected to come from Alaska, Arctic Canada and Svalbard, although the range of estimates is also greatest for these regions. Although these projections ignore losses by calving they do suggest that declining glacier volume is unlikely to become a major constraint on contributions to sea level rise before 2100.

The ongoing and projected changes in glacier area, volume and rate of mass loss will have significant implications for glacier contributions to runoff, with consequences for water supply, hydroelectric generation, flood hazard, glacial, freshwater, estuarine and oceanic ecosystems. These will be mediated by changes in runoff volume and seasonality, stream water temperature, turbidity, nutrient and legacy pollutant loading, and the lability of dissolved organic matter. Retreat of tidewater glaciers onto land will remove a habitat that is of particular importance for many seabirds and marine mammals.

26 year mass balance simulation for Belcher Glacier (Devon Island ice cap) 1980-2006

Martin Sharp and Alex Gardner

University of Alberta

Belcher Glacier is the largest tidewater glacier draining the Devon Island ice cap in Arctic Canada, and was the focus of investigations for the GlacioDyn project during the 4th IPY. Here we report on the results of a simulation of the surface mass balance of the glacier for the period 1979-2006, which was conducted at 1 day resolution using a degree day model with 1 x 1 km spatial resolution driven by statistically downscaled temperature and precipitation data from the North American Regional Reanalysis. The goal was to explore interannual variability and trends in the catchment mass balance (and its constituent terms), and the spatial pattern within the glacier catchment of the mean, standard deviation, and trend of all mass balance terms. The model was run for the entire Devon Island ice cap and validated against mass balance data for the northwestern sector of the ice cap.
The surface mass balance was positive in all years except 1988, 1991, 2001 and 2006, but iceberg calving likely made the overall balance negative in most years. Results suggest a weak trend towards longer melt seasons over the 26 year period, mainly due to “infill” of cold periods within the melt season. Snowfall increased over the period of record, especially in the southeast of the catchment and above 1600m, while annual positive degree day totals increased at elevations below 1200m. Summer melt tended to increase over the period, especially between 700m and 1200m elevation probably due to progressive upward migration of the ELA over time and resulting albedo-related feedbacks. Although internal accumulation increased over time above 1300m due to increased melt, net balance became more negative over time below 1200m, and especially between 700m and 1100m due to albedo feedbacks associated with displacement of the end of summer snowline to higher elevations. The region in which summer melt increased and net balance became more strongly negative is at the head of the main valley into which the glacier drains, and the changes simulated may have had a significant influence on meltwater drainage and ice flow in this part of the glacier.

The near-surface ice thermal structure of the selected glaciers of Kaffiøyra Region, Svalbard

Ireneusz Sobota

Department of Cryology and Polar Research, Institute of Geography,
Nicolas Copernicus University, Gagarina 9, 87-100 Toruń, Poland, irso@umk.pl

The near-surface ice thermal structure of the selected glaciers of Kaffiøyra Region (Oscar II Land) was studied. The Waldemarbreen (2.5 km^2) and the Irenebreen (4.1 km^2) are located at north-western Spitsbergen, Svalbard. Traditional glaciological mass balance measurements of the Waldemarbreen by stake readings and snow surveying have been con ducted annually since 1996 and the Irenebreen since 2002. Temperature measurements were made in 2007-2009 in both the ablation and accumulation areas of the Waldemarbreen. At one point (WT2), located in the accumulation area of the glacier, temperature thermistors were placed at 2, 5 and 10 m depth. At a second point (WT1), located in the ablation area, the thermistor depths were at 2, 5 and 10 m depth (owing to the surface melting of the glacier, after the end of the ablation season, the thermistor depths used for the analysis were 1, 4 and 9 m). Temperature measurements on the Irenebreen were made in 2008-2009 in the accumulation area (IT1), (Fig. 1).

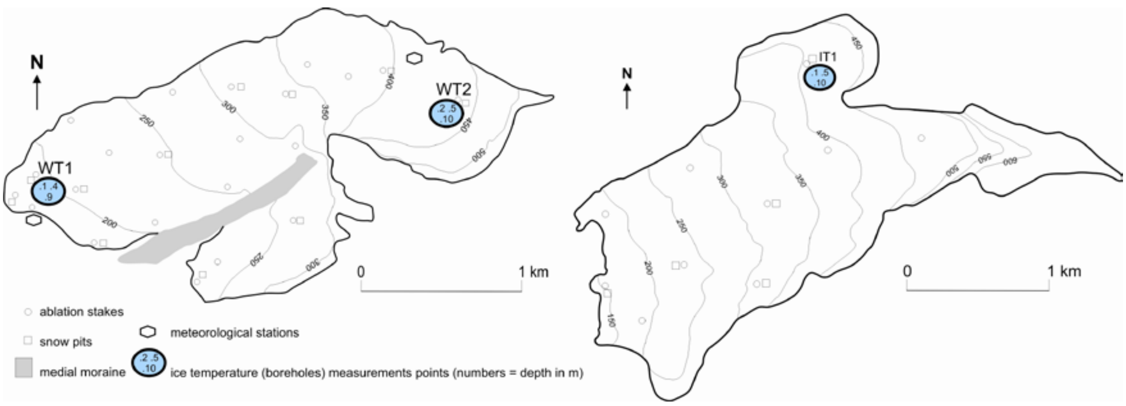

Figure 1: *Ablation stakes, snow pits and the near-surface ice temperature measurement point (boreholes) location on the Waldemarbreen and the Irenebreen.*

The investigation results indicate the importance of the air temperature, as well as that of meltwater and snow cover, for the establishment of the near-surface thermal ice structure of the glacier. These studies enable us to define the temporal and vertical variability of temperatures in the near-surface layers of the glacier. Furthermore, vertical temperature variability of the surface ice could be analysed, *i.e.* measurements were taken at a depth where annual temperature oscillations becomes negligible, and comparing these with the mean annual air temperatures. These studies have enabled to establish what kind of glacier the Waldemarbreen and the Irenebreen are in thermal classification. The near-surface ice thermal structure of these glaciers is an important supplement to the regional studies of the mass balance of the Kaffiøyra glaciers, as carried out since 1996 (Sobota, 2005, 2007a, b, c, d).

The near-surface ice temperatures of the Irenebreen and the Waldemarbreen changed significantly throughout the year. The lowest mean monthly temperature at 1 m depth in the ablation area of the Waldemarbreen in 2007-2008 (September-August), -7.6 °C, was recorded in April (Sobota, 2009). The lowest value at 4 m depth was recorded in May and at 9 m depth, in June.

The lowest mean monthly ice temperature at 2 m depth in the accumulation area of the Waldemarbreen in 2007-2008 was recorded in May, -5.2 °C. At 5 m depth, the lowest value was recorded in June, while at 10 m depth in July, August and September. The ice temperatures amounted to -3.4 °C and −2.5 °C, respectively (Sobota, 2009). In 2008-2009 the lowest mean monthly ice temperature at 2 m depth in the accumulation area of the Waldemarbreen was recorded also in May. At 5 m depth, the lowest value was recorded in June, while at 10 m depth in July (Fig. 2).

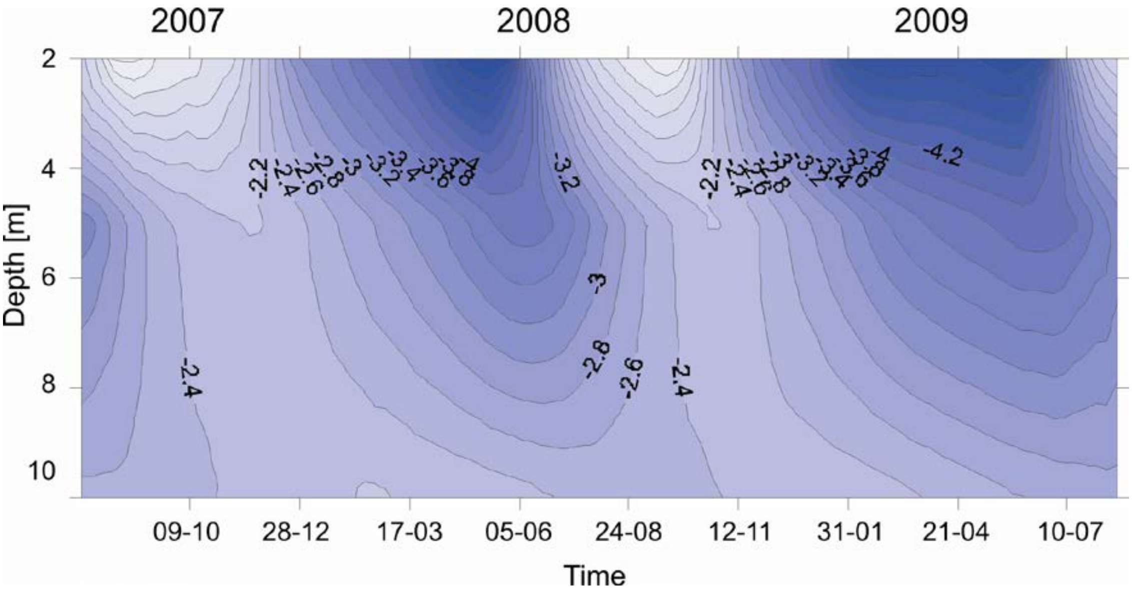

Figure 2: *The near-surface ice temperature in the accumulation area of the Waldemarbreen in 2007-2009.*

The lowest mean monthly ice temperature at 1 m depth in the accumulation area of the Irenebreen was recorded in May, -5.8 ºC. At 5 m depth, the lowest value was recorded in June, while at 10 m depth in July, August, September and October (Fig. 3).

The near-surface ice temperatures of the Waldemarbreen changed significantly during the study years. In the ablation area of the glacier, lower ice temperatures were recorded from October, whereas in the accumulation area from December. In the accumulation area of the Irenebreen it was also from December. This mainly resulted from the fact that the area was covered by snow, which, in the accumulation area, is more intensive and appears earlier than at the snout.

Throughout most of the year the vertical range of mean monthly ice temperature at the accumulation area of the Irenebreen also showed an increase with depth. The largest difference in ice temperatures in the accumulation area of the Irenebreen at 1 m and 10 m depths, 3.0 ºC, was recorded in August, whereas the lowest, 0.1 ºC, was recorded in November.

The snow cover has insulated the near-surface ice temperatures of the glacier against the changes in the air temperatures. It is calculated that the spatial diversity of the near-surface thermal conditions of a glacier related to the size of snow accumulation in the different parts of the glacier in a given winter season.

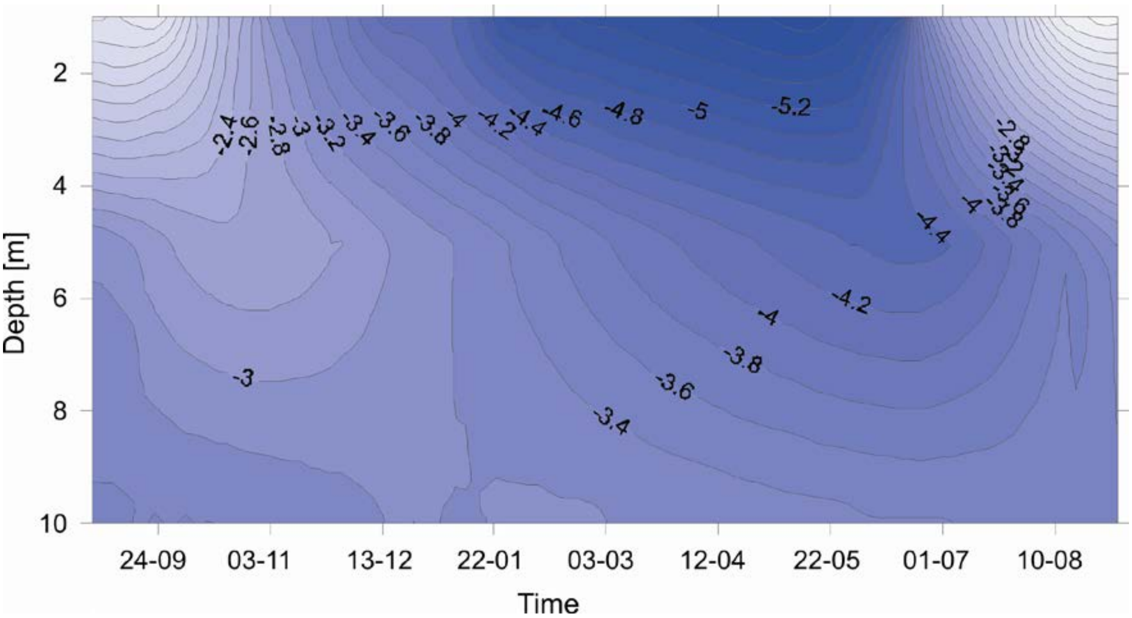

Figure 3: *The near-surface ice temperature in the accumulation area of the Irenebreen in 2008-2009.*

It is also noted that, in the ablation area of the Waldemarbreen in 2007-2008, the mean amplitude (September-June) of monthly ice temperatures at a depth of 9 m was 0.6 ºC. In the accumulation area of this glacier at 10 m depth, the annual amplitude of monthly temperatures was 0.3 ºC (Sobota, 2009) and in 2008-2009 it was 0.4 ºC. In the case of the accumulation part of the Irenebreen it was 0.3 ºC. Similar values of the mean annual amplitudes have been determined by Paterson (1971, 1972), Harrison *et al.* (1975), Hooke (2005), Jania (1997), Zagorodnov *et al.* (1989), Zagorodnov and Arkhipov (1990), who agrees that the near-surface temperature of glaciers range at 10 m depth does not exceed 1 ºC.

The difference between the ice temperatures at the depth, where the seasonal variation of temperature becomes negligible, and mean annual air temperature is characteristic for an area which has air temperatures above 0 ºC, mainly during the summer season.

Between September 2008 and August 2009, the mean annual ice temperature at 1 m depth was -3.7 ºC in the accumulation area of the Irenebreen. At 10 m depth, it was -3.3 ºC. The highest mean monthly ice temperatures at 1 m depth was -0.4 ºC as recorded in August. It is presumed that at a depth of 1 m or less, temperatures are close to the melting point. Thus, only in the summer season, the accumulation area of the glacier at a temperature is close to the melting point. During the other months, and especially in winter, ice temperatures fall to lower than -2 ºC.

During the winter season the near-surface ice temperature of the Waldemarbreen and the Irenebreen was higher than the air temperature at both the accumulation and ablation zones. In the study period, minimum ice temperatures were recorded with a significant delay to the air minimum temperatures both at the snout and in the accumulation zone of the glacier.

Naledies (icings) represent an indication of the thermal regime of a glacier. Naledies in the forefield of the Waldemarbreen and the Irenebreen were also observed in 2008 and 2009. In the case of the Waldemarbreen areas were observed to be significantly smaller than in previous years.

The Waldemarbreen is polythermal, with temperatures at 10 m depth of -2 □-3□C to □C, and both cold ice, that is below the pressure melting point, and a temperate surface layer, though during summer. In winter, all of the ice is below the melting point and temperate layers are present in near-floor sections of the glacier. The Irenebreen similar to the Waldemarbreen is also polythermal. It is emphasized that the designation as a thermal type of Kaffiøyra Region glaciers is based solely on the temperature measurements of the near-surface glacier layer, but an indirect estimation, which is based on a measurement of the elements of the mass balance, morphology, naledies, development of the water system and its drainage network, is generally supportive of this conclusion.

The research is being continued, and, may later also be possible to learn the seasonal changes and the course of temperatures in the near-surface ice layers of the Kaffiøyra Region glaciers. The thermal regime of glaciers is an important first order control on glacier mass balance, ablation, accumulation, runoff, hydrology and dynamics.

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Snow accumulation, melt, mass loss and the near-surface ice temperature structure of the Irenebreen, Svalbard

Ireneusz Sobota

Department of Cryology and Polar Research, Institute of Geography,
Nicolas Copernicus University, Gagarina 9, 87-100 Toruń, Poland, irso@umk.pl

The mass balance, accumulation, melt and the near-surface ice thermal structure of the Irenebreen, a 4.1-square km glacier located in northwestern Spitsbergen, Svalbard, was studied (Fig. 1). Traditional glaciological mass balance measurements by stake readings and snow surveying have been conducted annually since 2002 (Sobota 2005, 2007a,b,c,d). Apart from the components of the glacier balance, selected meteorological parameters were measured both at Kaffiøyra and on the Waldemarbreen, which is located very close to the Irenebreen. The results of the mass balance studies of Irenebreen are quite similar to other Svalbard glaciers which terminate on land (Hagen et al., 2003; WGMS 2008; Zemp et al., 2009).

The one aim of this research was to take measurements in order to define annual vertical time variation of near-surface ice temperature at the characteristic points (the accumulation area) of the Irenebreen, as well as to define the role of air temperature and the influence of meltwater and snow cover on the near-surface thermal structure during both the ablation and winter seasons. Moreover, by using automatic temperature thermistors, and the facility of conducting the research throughout a whole year, it was possible to study seasonal changes in the near-surface ice thermal structure of the glacier (Sobota, 2009). The near-surface ice thermal structure of this glacier is an important supplement to the regional studies of the mass balance of the Kaffiøyra glaciers, as carried out since 1996.

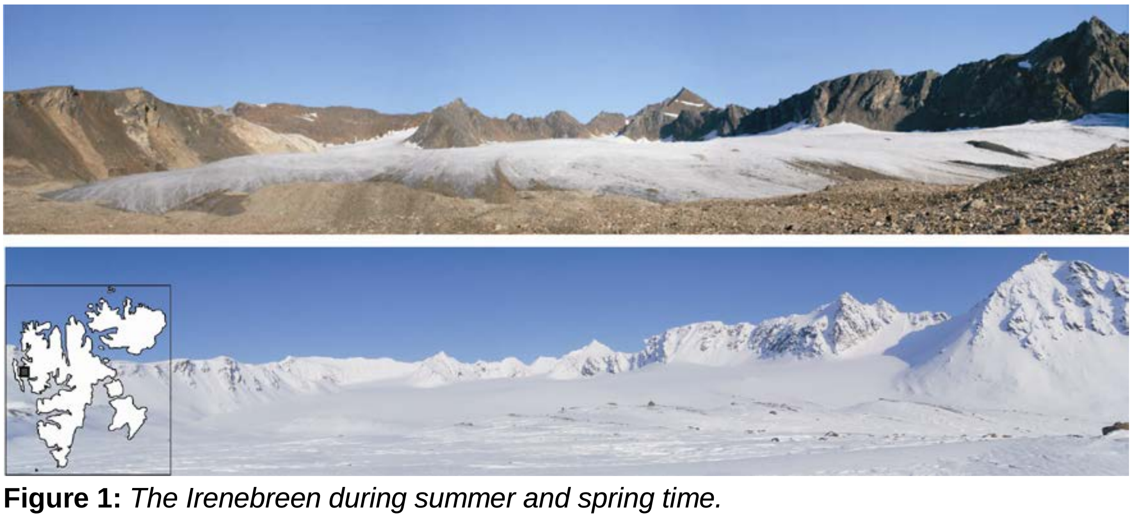

Figure 1: *The Irenebreen during summer and spring time.*

Until recently, determinations of thermal ice structure of the Irenebreen have been based only on indirect studies, *i.e.* the results of the detailed measurements of the elements of the mass balance, as related to our knowledge of glacial zones, morphology, development of the associated river network, naledies and glacier outflow.

The Irenebreen is located in the northern part of the Oscar II Land, Kaffiøyra, north-western Spitsbergen (Fig. 1). Kaffiøyra is a coastal lowland situated on the Forlandsundet. In the north it is bordered by the Aavatsmarkbreen, which terminates in Hornbaek Bay, and, in the south, by the Dahlbreen and the bay of the same name. In the east, Kaffiøyra is bordered by seven glaciers which descend from the Prins Heinrich and Jacobson mountains. The area of the Irenebreen amounts to about 4.1 km^2, its length to 4 km, while its width ranges from about 1 km in its frontal zone to about 1.5 km in the east section. The Irenebreen has two significant accumulation zones (Fig. 1).

Glaciological measurements of the mass balance of the Irenebreen were taken between 2002 and 2009. In this paper in detail was analyzed the 2008/2009 mass balance year. The measurements of surface ablation were made every 7–10 days from July to September each year. The measurements of snow accumulation were taken in April or the early part of May each year (Sobota and Grześ, 2008). Snow density, structure, grain type and hardness values were measured in pits and at representative points with standard methods. Measurements of snow accumulation and surface density were taken also during the summer season.

Ice temperature measurements were made in 2008–2009 in the accumulation area of the Irenebreen. At point (IT1), located in the accumulation area of the glacier, temperature thermistors were placed at 1, 5 and 10 m depth.

Every year the highest ablation values were observed at altitudes below 250 m a.s.l., and especially in the north part of the ablation area. The most intensive ablation was recorded in the northern part of the frontal section of glacier, while the least intensive was recorded on the accumulation fields. Time variations of ablation processes of the Irenebreen at various latitudes was significantly diverse. The mean ablation of the Irenebreen amounted from -90 to -135 cm w.e. for the period of 2002-2009. In 2009 the total ablation of the Irenebreen amounted to -128 cm w.e.

Throughout the entire summer season of the year 2009 only the highest parts of the Irenebreen were covered with snow. In the first half of the summer season the entire zone above the ablation zone was covered with snow, wet snow or slush, which conditioned ablation intensity. During summer season on the Irenebreen the snow cover disappeared quickly. As a result, at the end of the ablation season snow was only visible in the upper parts of the accumulation zones of this glacier and at the foot of the mountain slopes. This was not only the outcome of the weather conditions but, predominantly, larger altitude diversity between the snout of this glacier and its accumulative parts as well (Fig. 2).

The Irenebreen showed great spatial variation of winter balance, over different years. Some asymmetry in the snow cover depth was recorded. In the accumulation areas of the glacier the main factor influencing the depth of the snow cover was precipitation, while in the lower parts of the glacier – local conditions (aspect) as well as wind directions and velocity (snow redeposition). The depth of the snow cover generally lowers from the accumulation areastowards west.

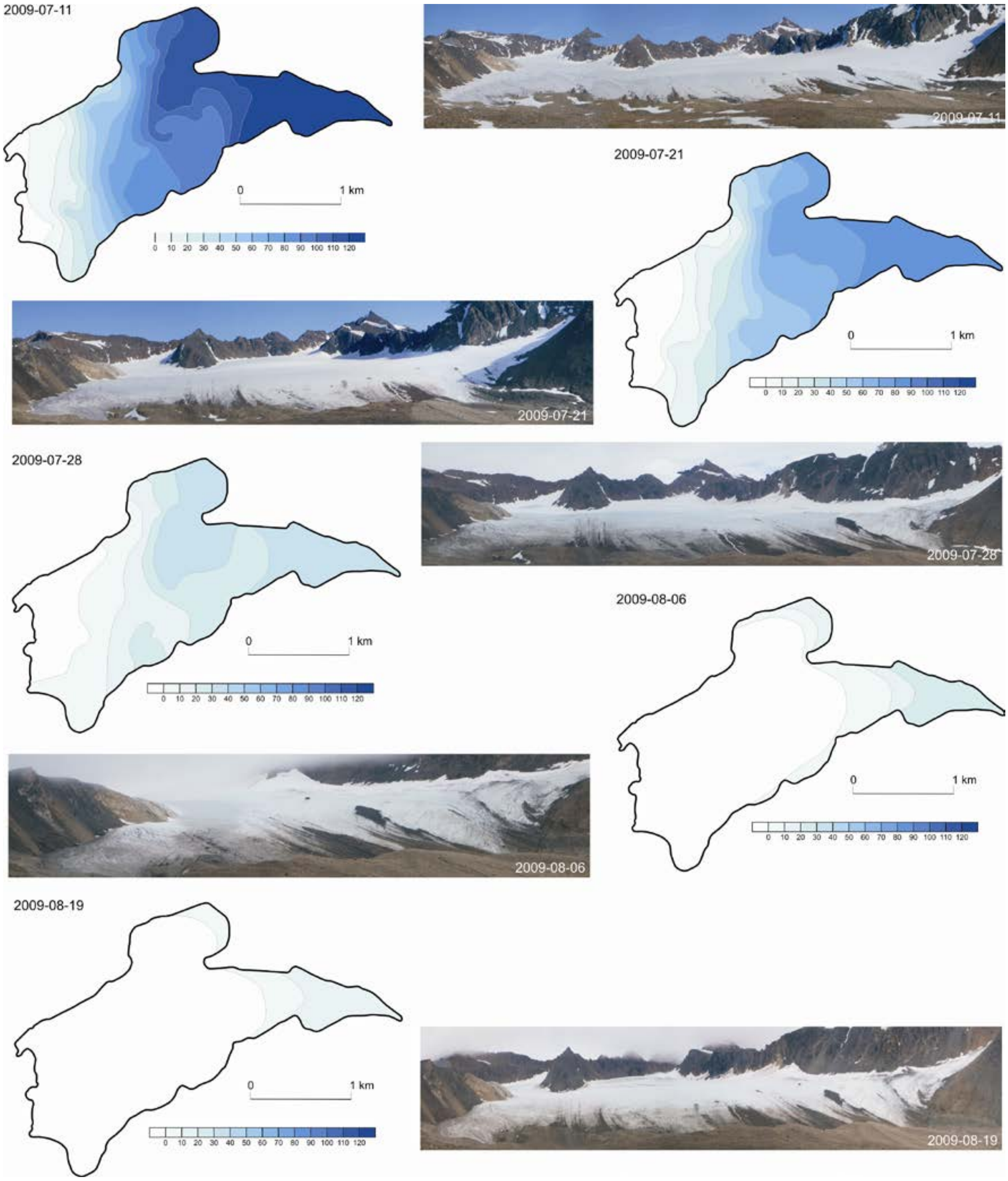

Figure 2: *Snow accumulation maps (in cm) of the Irenebreen during the summer 2009.*

In 2009, the average snow density on the Irenebreen in point IT1 in April was 359 kgm^{-3}, while in July it was 516 kgm^{-3}. In 2009, the average snow density on the whole the Irenebreen was 360 kgm^{-3}. In the individual years the snow cover of the studied glacier was dominated by fine-grained and medium-grained snow, while the layer above ice contained coarse-grained snow. Numerous ice layers were also found.

In 2009 the winter balance of the Irenebreen was 65 cm w.e., while the average winter balance of this glacier for the period of 2002-2009 was 54 cm w.e.

Spatial diversity of mass balance of the Irenebreen is mainly influenced by the weather conditions in a specific part of the glacier and by local morphology. In 2009, the spatial diversity of the net mass balance of the Irenebreen was most negative in the ablation area (Fig. 3). The net mass balance in the ablation area of the glacier was up to -250 cm w.e. At the accumulation areas of the glacier it was also partly negative. The zone of the negative net balance took a larger area if compared to the previous years. Such a situation predominantly resulted from a higher ablation. In 2009 mean annual mass balance of the Irenebreen was -63 cm w.e. and was similar to the mean multi-annual value the net mass balance of this glacier**.**

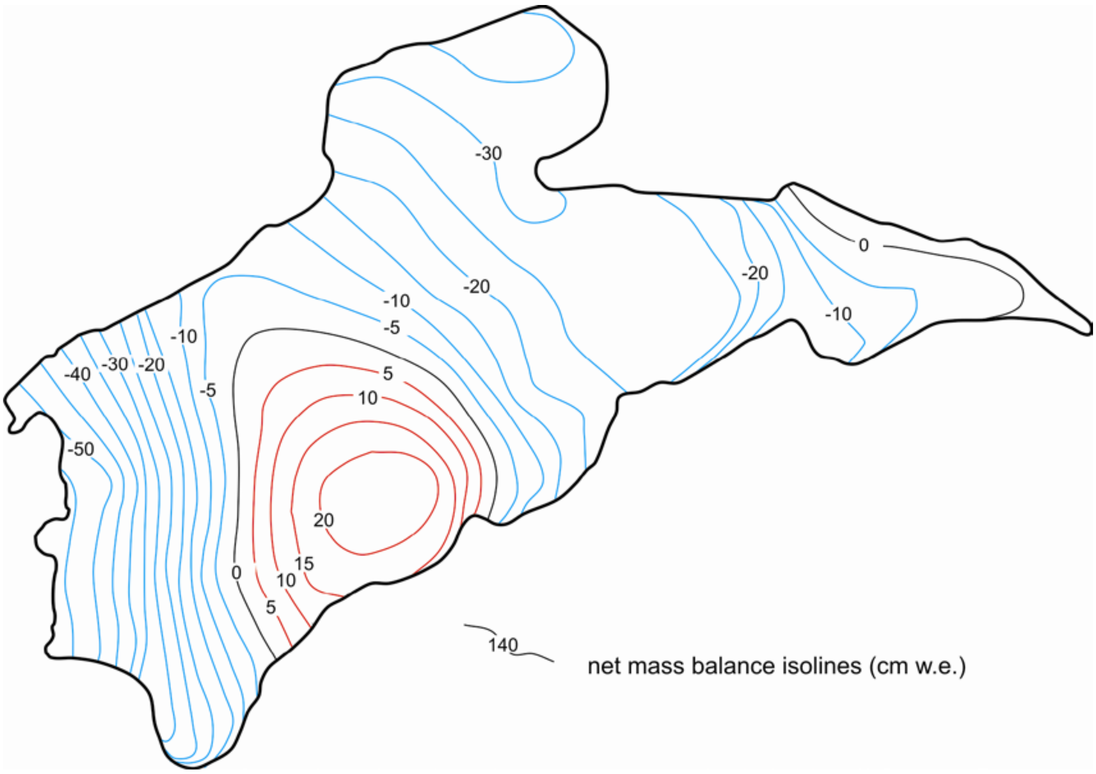

Figure 3: *Map of net mass balance differences on the Irenebreen between the mass balance in 2009 and the average in 2002-2009.*

The negative net mass balance of the Kaffiøyra region glaciers recorded in recent years influences their geometry, especially shrinking area and lowering the surface, as well as changes in the front positions. Between 2000 and 2009, the area of the Irenebreen decreased by about 3%.

The investigation results indicate the importance of the air temperature, as well as that of meltwater and snow cover, for the establishment of the near-surface thermal ice structure of the glacier. These studies enable us to define the temporal and vertical variability of temperatures in the near-surface layers of the glacier.

On the basis of these measurements, which refer only to the near-surface layers of the glacier, it is difficult to define precisely the glacier’s thermal type (Sobota, 2009). However, it is clear that during the summer season, meltwater percolation and refreezing are significant, especially in the accumulation area.

The thermal structure research on the near-surface layer of the Irenebreen indicates that, in the summer season, the glacier's temperature is close to the melting point, and decreases downwards. Throughout the rest of the year, the near-surface layer of the ice is cold, and the temperature increases downwards. This may result from the higher activity of meltwater percolation in the accumulation area and the insulated role of snow.

It may be assumed that the Irenebreen is polythermal with 10 m depth temperatures of -3 ºC with both cold ice (that is below the pressure melting point) and a temperate surface layer, though during summer. In winter, all of the ice is below the melting point and temperate layers are present in near-floor sections of the glacier. This supposition is supported by the presence of naledies in the forefield of the Irenebreen. It should be made clear that the dissertation on the thermal type of the Irenebreen is based solely on the temperature measurements of the near-surface glacier layer, and the indirect estimation is based on the measurement results of the elements of the mass balance, morphology, development of the water system and its drainage network.

The mass balance of the Irenebreen is primarily dependent on the mean air temperature of the summer season, and, secondly, on the winter snow accumulation. The exceptions are the years of significant snowfall and snow accumulation. Such a high dependence on the weather conditions confirms the notion that the mass balance of the Irenebreen can be regarded as an indicator of climatic changes. The thermal regime of glaciers is an important first order control on glacier mass balance elements. The mass balance records on the Irenebreen are important because they are one of only a few long-term mass balance records on Svalbard.

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New results from Swiss-Camp project and from Eqip Sermia glacier

Manfred Stober

University of Applied Sciences, Stuttgart, Germany

Swiss-Camp and ST2

The geodetic program to determine flow velocity, deformation and elevation change of the inland ice in the western part of the Greenland ice sheet was continued by the 2008 summer campaign. There are two main research areas. The first research field at Swiss Camp (ETH/CU-Camp) was started in 1991. Until 2008 a total of 10 campaigns were carried out. The second research field (ST2) was established in 2004. It is situated 170 m lower than Swiss-Camp. Here we have now four campaigns in 2004, 2005, 2006 and 2008. Recent results between the last campaigns (2006-2008) in both areas show an extremely big lowering of the ice surface of -1.04 resp. –1.40 m/a. The recent ice thickness loss is more than three times greater than the long-term trend in former years. The flow velocities and therefore the ice mass transports are different. At Swiss-Camp we still get a slightly increased velocity, while at ST2 the velocity is slightly decreasing.The digital terrain models are used for evaluation and validation of ICESat satellite elevation data. Height comparisons are possible after several reductions due to coordinate systems and time lapse between measuring times. The results along one track show in average a discrepancy of 0,13 m.

Eqip Sermia glacier

In 2005 and again in 2008 the recent flow velocity of the Eqip Sermia was determined by repeated terrestrial photogrammetry. In summer 2008, in average the glacier flows with a speed of 4,1 m per day, in 2005 we got 3,1 m/d. Compared to 3,5 m/d in 1959 (BAUER 1968) and 3,6 m/d in July/August 1971 (ZICK 1972) there is only little change in velocity. Compared to other authors and other methods, we cannot confirm the results from satellite radar interferometry observations, e.g. by RIGNOT et al. 2006, who reported an acceleration from 1,9 m/d in October 2000 up to 2,5 m/d in April 2005.

Evaluating the WRF model in Svalbard on the basis of a case study: First tests and preliminary results

Elisabeth Stuetz[1], Alexander Gohm[1], Friedrich Obleitner[1], Andreas Dornbrack[2] and Robert Baumann[2]

[1]Institute of Meteorology and Geophysics, University of Innsbruck, Austria
[2]Institut fur Physik der Atmosphare, DLR Oberpfaffenhofen, Germany

The polar version of the Advanced Weather Research and Forecasting Model (Polar WRF) has been evaluated on the basis of a case study (15 March 2008). The goal was to test its applicability for studying airflow over and around Svalbard at the meso and micro scale. Specifically, we were interested in boundary layer processes such as the interaction between the lowest air layer and the glacier, the sea surface, and the sea ice as well as orographic effects such as gravity waves and katabatic winds. This study was also motivated by the idea to use Polar WRF output to drive future mass balance simulations of polar glaciers.

For the event on 15 March 2008 the WRF model is initialized with ECMWF analysis data and compared to measurements taken by the Deutsches Zentrum fur Luft und Raumfahrt (DLR) on board of the Falcon aircraft during the IPY THORPEX field campaign in February and March 2008. These airborne observations, which include in-situ flight-level data, dropsondes and lidar data, are used to evaluate the mesoscale structure simulated by the model over and around Svalbard. Further, the model is validated against ground-based measurements from automatic weather stations on the Kongsvegen glacier and from routine stations and soundings near Ny-Alesund. Preliminary results will show, amongst others, the sensitivity of the simulated boundary layer structure on the model setup (parameterizations) based on a comparison of measured and simulated radiation and heat fluxes at the surface.

Surge dynamics related to climate change response of Svalbard glaciers

Monica Sund, Trond Eiken and Jon Ove Hagen

Climate change is expected to have a large impact on Arctic glaciers. In Svalbard up to 90 % of the glaciers are assumed to be surge-type (Lefauconnier and Hagen, 1991; Sund et al., 2009), and a number of new surge-type glaciers are identified also in other Arctic areas (Copland et al., 2003; Grant et al., 2009; Jiskoot and Juhlin op. cit.). Glacier surges are short semi-cyclical events of fast flow intersecting long lasting periods of quiescence. During a surge large masses are displaced and 10-100 times increase in velocity is observed. Surges are related to internal changes in the dynamics of the glacier system rather than changing climate (Meier and Post, 1969). Nevertheless a combination of surge and change of climate can have significant long-term impact on the glacier volume. In Svalbard the quiescent phase varies between 30 and 500 years (Dowdeswell et al. 1991; Solheim, 1991).

Skobreen (Fig. 1a), a ~8 km long and 18.2 km² valley glacier (Hagen et al., 1993) started to advance in 2005 due to surge. No previous surge is known on this glacier, indicating a quiescent phase of more than 100 years (Sund, 2006), and thus part of the build-up occurred during the end of LIA (Hanssen-Bauer et al., 1990). The development of the glacier has been studied by use of Digital Terrain Model (DTM). The estimated precision in the DTM varies from 15 m (2003 from ASTER) to better than 5 m (1990 from aerial photos) (Sund et al., 2009). During the surge approximately half of the glaciers estimated volume ~1km³, was transferred to lower elevations (Fig. 1, 1-3) while in the central part of the glaciers the postsurge surface is lowered by up to 160 m compared to the presurge situation in 1990.

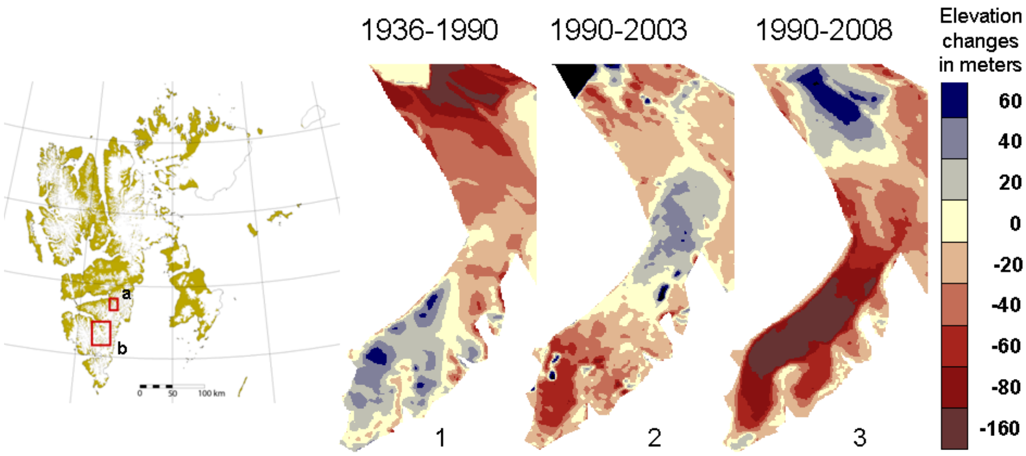

Figure 1: Location of Skobreen in Rindersbukta (a) and Nathorstbreen glacier system in Van Keulenfjorden (b). 1-3: DTM subtractions of Skobreen between various years and the resulting elevation changes due to surge dynamics, in metres. Base data from the Norwe-

gian Polar Institute, ASTER and SPOT-5 HRS. The glacier flows from lower left to upper left.

The Nathorstbreen glacier system (NGS) (Fig. 1b) constitutes of the glaciers Dobrowolskibreen, Ljosfonn, Besshøbreen, Polakkbreen and Zawadzkibreen covering an area of 390 km^2 in 2008, c. 1.4% of the glaciated area in Svalbard. A past surge in the tidewater glacier system in the inner part of Van Keulenfjorden is suggested around 1870 (Liestøl, 1977). Currently NGS experiences the largest surge in Svalbard since the surges of Negribreen and Bråsvellbreen in the 1930's (Liestøl, 1969). The surge caused an advance of 8 km during one year (2008-09) (Sund and Eiken, 2010) through mass displacement from the upper to the lower part. An additional advance of 1.5 km occurred during September 2009-February 2010 (Fig. 2). Assuming a 50 m lowering of the accumulation area, the surge changed the accumulation area ratio of the NGS from 0.7 to 0.5 during one year and a substantially larger area is exposed to ablation conditions through melt and calving. The advanced mass of NGS during the surge so far (~4 km^3), equals ~40 % of the total annual mass loss from glaciers computed by Nuth et al. (2010) for Svalbard. This may potentially be lost during a short period due to increased ablation area, enhanced melt due to crevasses and mass loss from calving.

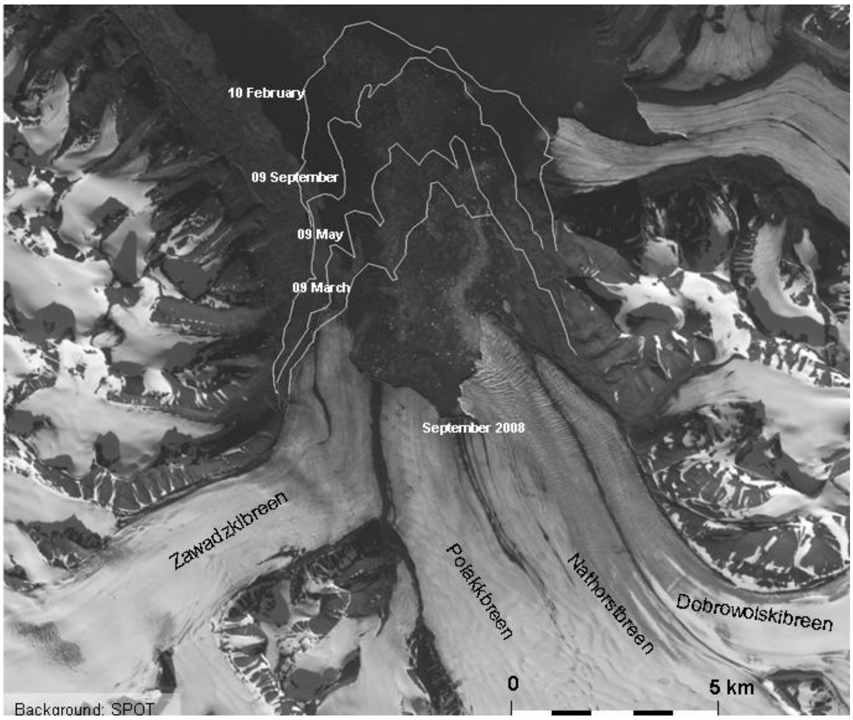

Figure 2: *The advance of Nathorstbreen during 2009-2010 constitutes almost 10 km. Background image: SPIRIT Program © CNES 2008 (2008) and Spot Image (2008) all rights reserved.*

Surface lowering due to glacier surges, especially during partial- or early stage surge, could be misinterpreted as a climate change signal (Sund et al., 2009). On the other hand interaction between a glacier quiescent build-up in past colder climate conditions and large mass displacements due to surge in warmer climate may enhance the contribution to sea level rise in a larger proportion than the initially slight increase in temperature could indicate. During surge more ice will be exposed at low elevations and be subject to increased melt due to heavy crevassing and possibly calving.

Glacier surges may interfere with a potential climate change signal in glaciers. As many of the Svalbard glaciers are of surge-type, it appears that incorporating glacier surge dynamics when evaluating the state of the glaciers is of high importance and may be important to address for other Arctic glaciers as well.

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Multi-Year Glacier velocities across Devon Island and Prince of Wales ice caps, Canada

Faye Wyatt and Martin Sharp

University of Alberta

Optical matching of Landsat 7 ETM+ satellite image pairs is used to determine the surface velocities of major tidewater glaciers across Devon and Prince of Wales ice caps. Optical feature tracking was performed using sequential Landsat images acquired between July 7th 1999 and August 7th 2009, providing near continuous annual velocity estimates over a 10 year period. The surface velocity measurements were compared to published InSAR velocities for Devon Ice Cap. Feature tracking measurements reveal fine details about the ice dynamics in these regions. For example significant interannual variation in velocity is observed for multiple tidewater glaciers, apparently unrelated to surge events. The largest interannual variation in velocity is observed for the North Croker glacier, Devon Island, which flowed at 49 m/yr in 2001-2002 increasing to 162 m/yr in 2005-2006. This study provides a long temporal record of glacier velocities across this region, providing a baseline, and context, against which future changes can be compared.

Seasonal Variations in Ice Motion, Belcher Glacier, Nunavut, Canada

Wesley Van Wychen[1], Luke Copland[1], Laurence Gray[2], Dave Burgess[3], Brad Danielson[4], and Martin Sharp[4]

[1]Department of Geography, University of Ottawa, Canada
[2]Natural Resources Canada, Canada Centre for Remote Sensing, Ottawa, Canada
[3]Natural Resources Canada, Ottawa, Canada
[4]Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Canada

This study presents comprehensive surface ice motion patterns and determinations of ice fluxes for Belcher Glacier (the largest tidewater outlet glacier of Devon Ice Cap). Speckle tracking of Radarsat-2 fine and ultrafine beam imagery collected throughout 2008 and 2009 is used to determine seasonal ice motion. Results are validated with in situ differential GPS (dGPS) measurements. The speckle tracking results provide ice motion maps unaffected by satellite look-direction problems associated with earlier ice dynamics studies utilizing SAR interferometry. Results derived from March 2009 fine beam data show a gradual increase in velocity along the centerline of Belcher Glacier, with maximum velocities of ~275 m yr^{-1} achieved at the terminus. Speckle tracking results also agree well with in situ dGPS data (~+/-2 m yr^{-1} of annual motion). Ultrafine Radarsat 2 imagery is also used to determine ice motion and allows for determination of ice velocities at least every 50 metres horizontally across the glacier surface. Results are compared with those of Burgess et al (2005), who provided ice motion maps for the main trunk of Belcher Glacier from the mid-1990s and terminus results from 2000.
Finally, ice thickness for Belcher Glacier and its tributaries were determined using ground penetrating radar (GPR) measurements collected during summer 2007. These results are combined with the speckle tracking velocity results to determine present-day ice fluxes through the basin.