IASC Workshop on the dynamics and mass budget of Arctic glaciers

Abstracts and Programme

IASC Workshop, 26-28 February 2013, Obergurgl (Austria)

IASC Network on Arctic Glaciology

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IASC Workshop &
Network on Arctic Glaciology annual meeting,
26-28 February 2013, Obergurgl (Austria)

Organised by C.H. Tijm-Reijmer

IASC Network on Arctic Glaciology

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Contents

Preface

In 2013 the annual workshop and open forum meeting of the IASC Network on Arctic Glaciology took place in Obergurgl, Austria, from February 26 - 28, 2013. The meeting attracted 51 participants from 15 different countries and five young scientists received support from IASC to cover part of their costs in attending the meeting.

In all, 30 talks and 14 posters were presented. One afternoon was devoted to the discussion of tidewater glacier research, which is part of an effort started by the Network and the IASC Working Group on the Cryosphere to develop an ongoing research and training program in this area of science. The initiative already resulted in a very succesful training workshop for young scientists on board the Polish Research Vessel MV Horyzont II in Svalbard in September 2012, and the next workshop is planned for May 2014 and will focus on modelling and observing the calving proces. During our meeting another possible initiative was discussed, to initiate a mass balance inter-comparison exercise for glaciarised regions outside the ice sheets, similar to the Imbie initiative. These actions show that we are an active comunity!

The activities are not limited to the conference room, but extent, as always, to the skiing slopes around the conference facility. On the slopes and afterwards in the bar, the discussions related to, amongst others, science and fieldwork continued resulting in once again a succesful and informal event. Next year the meeting will be hosted by the University of Ottawa and will take place from 3 - 5 February, 2014.

C.H. Tijm-Reijmer
July 2013

Program

Monday 25 February

	ARRIVAL
19:00 -	**Diner**

Tuesday 26 February

Convener:	*L. Copland*
08:30 - 08:40	Welcome *C.H. Reijmer*
08:40 - 09:00	Dynamics of Skálafellsjökull, Iceland, from the 2012 Glacsweb Sensor Network Deployment *A. Clayton and J. Hart*
09:00 - 09:20	A.P. Olsen Ice Cap - Ice Thickness, Dynamics and Mass Balance *D. Binder, S.H. Larsen, M. Citterio, H. Skourup, S.S. Kristensen and W. Schoener*
09:20 - 09:40	Precise Point Positioning (PPP) and its application to studies in ice dynamics in West Greenland *M. Stober, J. Hepperle and R. Wössner*
09:40 - 10:00	Seasonal velocities of eight major marine-terminating outlet glaciers of the Greenland ice sheet from continuous in situ GPS instruments *A.P. Ahlstrøm, S.B. Andersen, M.L. Andersen, H. Machguth, F.M. Nick, I. Joughin, C.H. Reijmer, R.S.W. van de Wal, J.P. Merryman Boncori, J.E. Box, M. Citterio, D. van As, R.S. Fausto and A. Hubbard*
10:00 - 10:30	**Coffee break**
Convener:	*T. Dunse*
10:30 - 10:50	Temporal variability of flow of Hansbreen a tidewater glacier in Southern Spitsbergen *D. Puczko, P. Głowacki, M. Grabiec and J.A. Jania*
10:50 - 11:10	Modeling Nordaustlandet's ice-caps *M. Schäfer, R. Gladstone, T. Zwinger, V. Pohjola, R. Pettersson, T. Dunse, M. Möller and J. Moore*
11:10 - 11:30	Recent disintegration and mass losses from the Petersen and Milne Ice Shelves, Ellesmere Island, Canada *L. Copland, A. White, D. Mueller and C. Mortimer*
11:30 - 11:50	GPS and hydrological observations during an autumn flood event and spring speed-up at Engabreen, Norway 2012 *A. Messerli, A. Grinsted and M. Jackson*

11:50 - 12:10	Observations of caterpillar-like motion in the Greenland Ice Sheet *M. Lüthi, C. Ryser, G. Catania, M. Hoffman, B. Hawley, M. Funk, T. Neumann, A. Bauder, L. Andrews and B. Moriss*
12:10 - 15:30	**Lunch**
Convener:	*C.H. Reijmer*
15:30 - 16:00	Poster presentations by authors
16:00 - 16:30	**Coffee break**
16:30 - 17:30	Special session on tidewater glaciers research in the Arctic *J. Jania and J.O. Hagen*
17:30 - 18:30	**POSTER SESSION**
18:30 - 21:00	**Diner**
21:00 - 22:30	Svalglac business meeting

Wednesday 27 February

Convener:	*M. Schäfer*
08:15 - 08:35	Sediment in basal ice of Engabreen *M. Jackson*
08:35 - 08:55	The influence of thermal structure of glaciers on their response to climate change *P. Holmlund and C. Clason*
08:55 - 09:15	20 years of basal pressure measurements at Engabreen, Norway and insights into the hydrological system. *P.M. Lefeuvre, M. Jackson, G. Lappegard*
09:15 - 09:35	Response of subglacial drainage network in western Greenland to changing boundary conditions revealed from space *K. Scharrer, T. Nagler, M. Hetzenecker, D. Floricioiu, H. Rott*
09:35 - 09:55	Increasing meltwater discharge from the Greenland ice sheet into Nuuk Fjord and implications for glacier mass balance (1989-2012) *D. van As, M. Langer Andersen, D. Petersen, X. Fettweis, J.H. van Angelen, J.T.M. Lenaerts, M.R. van den Broeke, J. Lea, K. Steffen, N. Bayou, C.E. Bøggild and A.P. Ahlstrøm*
10:00 - 10:30	**Coffee break**
Convener:	*L. Andreassen*
10:30 - 10:50	A new inventory of all Alaska glaciers *C. Kienholz, S. Herreid, J. Rich, A. Arendt and R. Hock*
10:50 - 11:10	The 2000s glacier inventory of Svalbard and glacier change patterns *C. Nuth, J. Kohler, M. König, J.O. Hagen, A. Kääb, G. Moholdt, R. Pettersen*
11:10 - 11:30	Mass balance of Greenland and Arctic Ice Caps from GRACE and ICESat *R. Forsberg, L. Sørensen and J. Nilsson*

11:30 - 11:50	Projections of 21st century contribution of Alaska glaciers to rising sea level *A.C. Beedlow V. Radić, A.K. Bliss, R. Hock, A.A Arendt, J.L. Rich, D.F. Hill, D.F., S.E Calos, and J.G. Cogley*
11:50 - 12:10	Projecting 21st century glacier runoff of all Alaskan glaciers *R. Hock, A. Bliss, C. Beedlow, V. Radic, E. Hood*
12:10 - 15:00	**Lunch**
Convener:	*D. van As*
15:00 - 15:20	Ice volume estimates from ground-penetrating radar surveys, western Nordenskiöld Land glaciers, Svalbard *A. Martín-Español, E.V. Vasilenko, F.J. Navarro, J. Otero, J.J. Lapazaran, I. Lavrentiev, Y.Y. Macheret, F. Machío, A.F. Glazovsky*
15:20 - 15:40	Ice volume estimates from ground-penetrating radar surveys, Wedel Jarlsberg Land glaciers, Svalbard *F.J. Navarro, A. Martin-Español, J.J. Lapazaran, M. Grabiec, J. Otero, E.V. Vasilenko, D. Puczko*
15:40 - 16:00	On the climate forcing of glacier mass-balance variability at Vestfonna ice cap, Svalbard *M. Möller, O. Käsmacher, R. Finkelnburg, M. Braun, D. Scherer and C. Schneider*
16:00 - 16:30	**Coffee break**
16:30 - 18:00	IASC Network on Arctic Glaciology Open Forum meeting *C.H. Reijmer*
18:30 - 21:00	**Diner**

Thursday 28 February

Convener:	*R. Hock*
08:15 - 08:35	Homogenization of a long term mass balance record *L.M. Andreassen*
08:35 - 08:55	Surface mass balance feedbacks of the Greenland ice sheet in recent decades *J.E. Box*
08:55 - 09:15	Five consecutive years of mass balance observations to understand glacier reaction to present climate change (Austre Lovénbreen, Spitsbergen, 79°N) *E. Bernard, F. Tolle, J.M. Friedt, Ch. Marlin and M. Griselin*
09:15 - 09:35	An overview of IMAU observations along the K-transect at the Greenland ice sheet margin *P. Smeets, W. Boot, M. van den Broeke, J. Oerlemans, H. Snellen, R. van de Wal and many more*
09:35 - 09:55	Ten years of research on McCall Glacier (2003-2012) *M. Nolan*
10:00 - 10:30	**Coffee break**
Convener:	*M. Nolan*

10:30 - 10:50	Interaction between surface albedo variations and snow cover ablation on glaciers of Wedel Jarlsberg Land, Svalbard *M. Laska*
10:50 - 11:10	Understanding links between snow cover and mass balance using a dense monitoring network in a small Arctic glacier basin (Austre Lovénbreen, Svalbard 79°N) *F. Tolle, E. Bernard, J.-M. Friedt, C. Marlin, M. Griselin*
11:10 - 11:30	First drifting snow observations on the Greenland ice sheet - framework, results & perspectives *J. Lenaerts, P. Smeets, M. van den Broeke, K. Nishimura, M. Eijkelboom and W. Gorter*
11:30 - 11:50	Towards quantifying the uncertainty of glacier energy and mass balance calculations *F. Obleitner, F. Karner and J. Kohler*
11:50 - 12:00	Final words *C.H. Reijmer*
12:00 -	**Lunch / Departure / Skiing**

Posters

- Estimation of equilibrium line altitude on glaciers in Southern Spitsbergen by a simple remote sensing method *M. Błaszczyk*
- Monitoring of calving processes at Hansbreen (Southern Spitsbergen) *M. Ciepły*
- X-ray Computed Tomography scanning of till *A. Clayton*
- Ground-based monitoring of firn extent and thickness of Austfonna, Svalbard, to enhance interpretation of satellite-derived altimetry data *T. Dunse*
- Snow cover distribution derived from multi-temporal LiDAR application in high alpine catchments *K. Helfricht*
- Recent changes in glacier facies zonation on Devon Ice Cap, Nunavut detected from SAR imagery and field validation methods *J.T. de Jong*
- A snowpack model to improve ice-sheet melting on millennial time scales *M. Krapp*
- Preliminary Hydroglaciological Research on Nannbreen, SW Spitsbergen *E. Majchrowska and M. Laska*
- Local effects of depth-dependent water content of ice and snow and firn layers temperature on a conjectured subglacial lake below Amundsenisen Icefield (Svalbard). *D. Mansutti*
- Monitoring calving and crevasse opening rates *F. Nick*
- Quality assessment of MODIS land surface temperatures over an Arctic ice cap *T. Østby*
- Morphological and morphometric features of sandar as proxy records of extreme discharges of glacier rivers *J. Szafraniec*
- An inter-comparison of techniques for determining glacier velocities over Svalbard *W. Van Wychen*
- Regional glacier velocity distribution across Kluane National Park, St. Elias Mountains, Yukon Territory, Canada *A. Waechter*

Participants

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(Young scientists receiving support are marked *).

Photo: The participants.

Minutes of the Open Forum Meeting

Chair: Carleen Tijm-Reijmer
Vice Chair: Martin Sharp (not present)
Minutes: Cody Beedlow
Invited to attend: all participants of the workshop.

Agenda

1. Other items for the agenda
2. Background on IASC and NAG
3. Minutes of last years meeting
4. Location IASC-NAG workshop in coming years
5. Network activities
6. National contacts
7. Website
8. Abstracts
9. Anything else

Ad. 1

No one wishes to add anything to the agenda.

Ad. 2

IASC: International Arctic Science Committee
A non-governmental organisation that aims to encourage, facilitate and promote cooperation in all aspects of Arctic research in all countries engaged in Arctic research and in all areas of the Arctic region.

The core elements of IASC are its Working Groups (WGs): Terrestrial, Marine, *Cryosphere*, Atmosphere, and Social & Human. In addition, IASC endorses thematic groups with a specific scientific mission. The Network on Arctic Glaciology was founded in 1992 and endorsed by IASC since 1994 as the working group on Arctic Glaciology (Fig.1). Because of political reasons the name changed to Network on Arctic Glaciology in 2010. The network/working group therefore exist about 20 years and it is decided to include some sort of celebration in next years meeting.

Ad. 3

Brief overview was given of the contents of last years open forum meeting. The minutes of that meeting are available on request from the Chair.

Ad. 4

Proposal is North America in 2014, Europe (Spain) in 2015.

Question: would anyone actually come to North America?
Since 2005 the meeting was held twice in North America: 2009 in Kananaskis,

Figure 1. The participants of the first meeting of the IASC Working Group on Arctic Glaciology, Wisla, Poland, September 1994.

Canada, which was a well attended workshop, and in 2011 in Winter Park, Colorado, USA, which was not well attended due to the late announcement of the meeting.

Question: Can Martin Sharp organize the meeting in Canada in 2014?
Martin is already organising another meeting, but David Burgess is willing to organise the meeting in Kananaskis if no one else offers to organise the meeting.

Luke Copland proposes to organise the meeting in Eastern Canada: Ottawa. He emphasises the benefits of having the meeting in Ottawa: it is the capital city of Canada with all the embassies and convenience of traveling to this location (plane flights, etc). He also mentions the Winterlude, a winter festival held in February with lots of activities including ice skating. Draw back is that skying possibilities are perhaps limited, especially compared to Obergurgl. Luke proposes that the meeting can be at the university and people can stay in local hotels. He feels like it seems to tie in with other events at the university (e.g. day long arctic meeting) that would be good for young researches to see what other areas of research there are.
It is decided to investigate this offer further.

Mat Nolan offers to check the possibilities in Anchorage and Juneau in February 2014 in case Ottawa does not work out.

Extra information since the meeting:
Ottawa will go through. The workshop will be part of an Arctic week that includes several Arctic-themed events including our workshop, such as:
- A GlacioEx project meeting. GlacioEx is a project is funded by the Norwegian Government and designed to improve collaboration in studies of the terrestrial

cryosphere between the Universities of Oslo, Ottawa, Svalbard, Alberta, Simon Fraser and Alaska-Fairbanks.
- The annual meeting of the Ottawa-Carleton Student Northern Research Symposium (OCSNRS)
- The 125th Anniversary of the Faculty of Arts at the University of Ottawa, which includes the Department of Geography
- The 500th meeting of the Arctic Circle
- The 36th Winterlude Festival

Spain in 2015: Francesco (Paco) Navarro proposes Benasque in the Pyrenees. There is a scientific center (Centro de Ciencias de Benasque). They have a good infrastructure for meetings such as this. Fees of the center are relatively high with 100 Euros but compensated by low rates for lodging (e.g. 75 Euros per day in a single room with half board, *** hotel). Paco talks of other hotel/lodging possibilities, and the local ski resort (Cerler-Ampriu Ski Resort) which is roughly 10 minutes away via bus. There are also cross-country skiing opportunities near by as well. Transport to the Pyrenees will be by bus from Barcelona, thiw will require some organisation. Paco, stresses the advantages of the close proximity to Barcelona. The people are excited about the skiing.

Ad. 5

Over the years the Network has initiated or has participated in several initiatives, most notably GLACIODYN during IPY and more recent the Tidewater glacier initiative which was a synergy initiative between the network and the Cryosphere Working Group of IASC.

Recently The ice sheet mass balance inter-comparison exercise (IMBIE) published its main result in Science. The question has arisen whether we could initiate something similar for glaciarised regions outside the ice sheets.

Expressed Opinions about this:
People feel like it could be interesting. Questions arise about the problems with applying GRACE to the smaller glaciers and ice caps. One answer is that there are possibilities in the future. It is not quite there yet, but possibly in the future. One proposal from Matt Nolan is to track changes in the wet snow line via remote sensing. One comment to this proposal is that it is possibly too specific. Paco suggests focusing on ice caps instead of small glaciers. One person asks, 'is this useful to do?' Killian thinks it is a good idea. In general the participants think it is a good idea.

The next step: Jon Ove proposes the possibility to have a special session at the next meeting. Paco feels like that would be too far away. Carleen suggest organizing a small group. One suggestion is to find motivated young scientist to take the initiative. Jon Ove says to raise this idea at the Cryosphere working group meeting and possibly have a special session on it. One suggestion is to support Jon Ove's idea but have a special write up/report on this topic. Paco clarifies his statement about the next meeting being too late, he means that we should start asking for money as soon as possible, again supporting the proposal at the next working group meeting. He stresses the importance of having a group of young interested scientists to take the initiative. One question arises about the timing issues with such a proposal. Regine feels like it can be part of the workshop and bringing in the various scientists from these various disciplines that would possibly be interested and get possible funding agencies involved.

Conclusion: Rene Forsberg offers to write a small abstract to be presented by Paco at the working group meeting in Krakow and take it from there.

Ad. 6

A list of national contacts is available on the website. There are three countries without contacts: France, Japan and China. Florian Tolle agrees to act as national contact for France. Japan and China remain a question. Jon Ove confirms being contact for Norway. Prof. Jacek Jania steps down for Poland, however another representative from Poland volunteers for the position (Mariusz Grabiec).

Ad. 7

What should the role of the website be?
Jason Box suggests the use of social media (e.g. Facebook). He suggests in making an IASC Facebook page. Linkedin is another possibility since it is more professional. Jason again pushes Facebook since many organizations are using it. He also suggests using the ’invite’ feature for Facebook for upcoming events. He feels that a lot of people are using Facebook, admitting that he uses it as well (guilty). He state, "social media is mainstream media." Luke gives the example that IGS uses Facebook and lists the benefits of it. Paco is not a user of Facebook and suggests that someone should push it forward (i.e. maintain and update). Jason comments that someone needs to be actively posting on the Facebook. Carleen comments on how difficult it is to keep up with social media since it could be possibly time consuming and it could possibly require someone to maintain them (who has time for that with research, grants, etc.). We conclude that it is a possibility since it is so easy to start, but mainaining remains an issue.

Ad. 8

Should we continue making books of extended abstracts?
Jason asks what is the value of these past books? Answers: it is a nice collection. Regine questions the value. She feels like that the extended abstracts are still full of preliminary results and numbers are subject to change. She feels that the abstracts and the authors with their contact information are enough. Paco feels like it is still important: shows you presented at an international conference and it is helpful for asking for funding (or renewal for funding). Carleen suggest it be optional as a compromise, thus if you are interested in making an extended abstract then you can submit it by 30 March 2013. To increase possibilities for referencing, the next volume will have an ISBN number. Jason says that it does have value for demonstrating the activity of the network.
Should we print them or is PDF enough? Funding is an issue.
The people (multiple people) feel that PDF is enough. If you need it, you can always print it.

Ad. 9

Jacek Jania presents a gift to Carleen. Matt suggests a group photo in between the sessions (plus we can post it on the new Facebook page).

Closing of the meeting and thank you to Cody for writing the minutes.

Report of the Open Session on Tidewater Glaciers

Jon Ove Hagen, University of Oslo, Norway
Jacek A. Jania, University of Silesia, Poland

Over the last decade the dynamic response of glaciers and ice sheets has received growing attention.

Besides its direct impact on the surface mass balance, climate change may also trigger glacier dynamic feedbacks, e.g. through meltwater-driven basal lubrication and flow acceleration. Dynamic feedbacks have the potential to significantly amplify glacier response to climate change and affect the rate of sea level rise (SLR) through iceberg calving at much higher rates than through surface mass balance, alone. The observed rapid mass loss is partly due to widespread acceleration of ice discharge into the ocean, which has not been accounted for in the projections. The IPCC (2007) deliberately did not make an attempt to assess the dynamic mass loss because governing processes were not sufficiently well understood. However, the importance of dynamics may be highly significant; substantive calving played for instance a key role in the rapid disintegration of former ice sheets. Presently, increased mass loss due to more calving substantially impacts on the overall mass balance of Greenland (AMAP, 2011).

There are dynamic feedback-mechanisms that amplify glacier response to climate change both on short and long time-scales. Acceleration and dynamic instabilities of marine-terminating glaciers result in enhanced iceberg calving that allows for larger and more rapid ice mass loss than surface melt and runoff. The mechanisms are not well described and understood, pointed out as key challenges that pose large uncertainties in estimates of current and future contribution of glaciers and ice sheets to sea level rise (IPCC, 2007; AMAP, 2011). Marine-terminating glaciers also pose a risk to shipping and exploration of natural resources in Arctic waters, through calving of icebergs that may collide with vessels, platforms and other infrastructure. This is the background for the initiative in IASC NAG to establish a program on Arctic tidewater glaciers. During the special session on tidewater glaciers at the IASC Network on Arctic Glaciology (IASC-NAG) meeting in Obergurgl in February 2013 an update on the progress was discussed.

The tidewater glacier focus was started through a proposal to organize a workshop on Arctic tidewater glaciers during the IASC Cryosphere Working Group (CWG) meeting in Utrecht, The Netherlands on 6 - 7 October 2011 and developed further in a special session on tidewater glacier research in the Arctic during the annual Workshop on the Dynamics and Mass Budget of Arctic Glaciers of the IASC-NAG meeting that was held on 11 January 2012 in Zieleniec, Poland.

The IASC CWG workshop "Field Workshop on Studies of Tidewater Glaciers" was held on board the Polish ship r/v Horyzont II during its cruise to Svalbard fiords from 26 - 31 August 2012. A report from that workshop will be produced and made available for NAG.

During the session there were discussions on the importance of improving our understanding of the non-linear dynamic response of glaciers and ice caps to a warming climate and thereby reduce uncertainties in their future contribution to sea level rise. Two main points were stressed:

- calving loss from global glaciers and ice caps is still not very well quantified
- the calving processes are still not very well understood.

During IPY the project GLACIODYN stressed the importance of 1) including calving in mass budget calculations, 2) improving process understanding of calving and basal sliding and 3) including dynamics in modeling of future glacier response. These three points are still valid.

Fast glacier flow is almost entirely achieved by basal motion, i.e. sliding of the ice base over the bed, enhanced deformation of temperate basal ice or of water-saturated subglacial sediments. However, the subglacial environment is difficult to access and processes are therefore poorly understood. The SWIPA report (AMAP, 2011) identified sparse observations, poor process understanding and modeling capabilities of ice dynamics and calving as key knowledge gaps in assessments of glacier mass balance. We still miss the fundamental understanding of the calving process and the dynamic feedbacks, necessary to construct realistic models for prediction of iceberg calving in a future climate.

During the discussions some of the points raised could be listed:

- Glacier fluxes and calving rates vary at many temporal and spatial scales.
- There are large gaps in regional ice fluxes and calving rates
- Annual time-series have shown strong seasonality of glacier velocities
- Fast glacier flow is achieved by basal motion, rather than ice deformation. A large part of the temporal variability in glacier flow is attributed to changes in basal conditions.
- Impact of summer melt on glacier hydrology and dynamics should be improved
- The impacts of Sea ice and ice mŐlange terminus buttressing is not well known
- The contribution of surging glaciers to annual ice fluxes
- Ocean properties, fjord circulation and basal melt
- We need the synergy produced by the interaction between modelers and observational scientists.
- Estimation of regional calving fluxes throughout the Arctic would be extremely valuable for evaluation of the contribution of Arctic tidewater glaciers to the global ocean level rise.

The aim of the IASC-NAG is to follow up the tidewater initiative and support and actively encourage the community to take part in and develop a tidewater glacier research program on Arctic glaciers. The NAG will support a cooperative Circum-Arctic program focused on the analysis of selected key tidewater glaciers using recommended uniform methods and instruments for in situ data collection, coupled with data acquired from remote sensing techniques. Such a collaborative international program should have two objectives: (1) to monitor the mass loss due to calving in relation to the total glacier mass budget for multiple years on the key study glaciers and (2) to collect high temporal resolution data on changes in glacier dynamics and calving processes. The IASC CWG in co-operation with the IASC-NAG should provide a platform for coordination of these studies.

References

AMAP. 2011. Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate change and the Cryosphere, Arctic Monitoring and Assessment Program (AMAP). Oslo, Norway. xii, 538pp.

IPCC. 2007. Climate Change 2007: [Solomon, S., et al., (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Abstracts

Seasonal velocities of eight major marine-terminating outlet glaciers of the Greenland ice sheet from continuous in situ GPS instruments

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We present 17 velocity records derived from in situ stand-alone single-frequency Global Positioning System (GPS) receivers placed on eight marine-terminating ice sheet outlet glaciers in South, West and North Greenland, covering varying parts of the period summer 2009 to summer 2012. Common to all the observed glacier velocity records is a pronounced seasonal variation, with an early melt season maximum. The GPS-derived velocities are compared to velocities derived from radar satellite imagery over six of the glaciers to illustrate the potential of the GPS data for validation purposes. Three different velocity map products are evaluated, based on ALOS/PALSAR data, TerraSAR-X/Tandem-X data and an aggregate winter TerraSAR-X data set. The velocity maps derived from TerraSAR-X/Tandem-X data have a mean difference of 1.5% compared to the mean GPS velocity over the corresponding period, while velocity maps derived from ALOS/PALSAR data have a mean difference of 8.3%. The velocity maps derived from the aggregate winter TerraSAR-X data set have a mean difference of 9.5% to the corresponding GPS velocities.

Homogenization of a long term mass balance record

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The Norwegian Water Resources and Energy directorate’s glacier surface mass-balance series contain annual (net), winter and summer balances. The accuracy of glacier surface mass-balance measurements depends on both the accuracy of the point observations and inter- and extrapolation of point values to spatially distributed values. Long series of measurements will seldom be perfectly homogeneous because of changes in personnel and procedure, and as there will be changes in glacier area (and elevation) when averaging the data. Moreover,

systematic errors may cause large cumulative errors in long term mass balance series. On Hellstugubreen (Fig. 1), mass balance has been conducted since 1962 producing a continuous 51 year record of annual, winter and summer balances up to and including 2012. The glacier has been mapped repeatedly; detailed maps and digital terrain models (DTMs) exist for 1962, 1968, 1984, 1997 and 2009. The glacier has been shrinking steadily in length, area and volume during the whole period of measurements. In this study we discuss approaches to homogenise the long term mass balance record of Hellstugubreen, and we compare the direct mass balance measurements with the geodetic observations.

Figure 1. Hellstugubreen in 2011. Mass balance investigations has been carried out every year since 1962. Photo: Liss M. Andreassen.

Projections of 21st century contribution of Alaska glaciers to rising sea level

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Alaskan glaciers contain much of the ice mass outside of the Greenland and Antarctic ice sheets, and they are projected to be significant contributors to 21st century sea level rise. Here we present modeled surface mass-balance simulations and projections for all Alaskan glaciers using an elevation-dependent temperature index model. The model uses climate inputs of temperature and precipitation, the hypsometry of over 26,000 Alaskan glaciers (8.90 x 10^4 km^2 of ice area), as well as volume-area scaling to account for the feedback between the changes in glacier mass balance and hypsometry. The model is calibrated and validated using available mass-balance measurements from past decades. For 21st century projections, the model uses temperature and precipitation downscaled to 0.5°x0.5° resolution from 14 CMIP5 general circulation models (GCMs) running under the RCP4.5 and RCP8.5 emission scenarios. For 1961-2000, the model simulates Alaskan glacier volume loss (by surface ablation only) to be approximately 5% from an initial volume of 2.79 x 10^4 km^3. The 21st century projected volume loss ranges between 18-45% (RCP4.5) and 26-56% (RCP8.5). Model runs at these spatial resolutions, however, simulate the mass budgets of individual glaciers poorly. To investigate this problem, we use high-resolution (2 km) temperature and precipitation fields for Alaska and Western Canada in order to simulate surface ablation and accumulation processes adequately for single glaciers. For model calibration and validation, we compare these simulations to observations for specific glaciers having in situ and/or altimetry data.

Five consecutive years of mass balance observations to understand glacier reaction to present climate change (Austre Lovénbreen, Spitsbergen, 79°N)

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Since 2008, mass balance is measured on the Austre Lovénbreen (Spitsbergen, Norway, 79°N) as part of the Hydro-Sensor-FlOWS program. The observations are made at a very fine scale: on the 4.5 km^2 glacier, mass balance is measured each September with 36 stakes. Snow cover is measured at the end of April. 20 air-temperature loggers give hourly data on the thermal state of the glacier. In addition automatic cameras provide 3 pictures per day. These pictures are used to determine whether ice is visible or snow covered all over the glacier. Climate parameters provided by the nearby Ny-Alesund weather station are also used.

The influence of climatic parameters on mass balance has been explored. Over the last five years, Austre Lovénbreen's mean mass balance is -17 cm. Four of the five years are between -9 and -26 cm. One year (2010-2011) clearly stands out with a value of -123 cm corresponding to a very important ablation on the entire glacier. There is no clear correlation between mass balance values and yearly climatic parameters. Seasonal variations seem to explain more. High temperatures and consequent liquid precipitation are partially explaining mass balance results.

A "warm" winter with important precipitation (like in January 2012) will give rain at sea level but huge amounts of snow on the glacier at higher altitude (100-550 masl). A hot summer will result in important ablation, even more so if it is rainy too. The five-year survey also shows the importance of short-term warm and rainy events. Strong events can account for an important part of a year's mass balance. Considering the longest mass balance series of the neighbouring glacier (Midtre Lovénbreen), we will also discuss the relationship between mass balance and the North Atlantic Oscillation or the Arctic Oscillation.

A.P. Olsen Ice Cap - Ice Thickness, Dynamics and Mass Balance

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A.P. Olsen Ice Cap (74°38'N, 21°26'W) is a small ice cap (300km^2) in the North-East of Greenland, adjacent to the Danish research station Zackenberg. Since 2008 mass balance is monitored with the glaciological method (stakes and snow pits) and snow radar surveys for a sector of the ice cap. Preliminary results from distributed surface energy balance modelling of the entire A.P. Olsen Ice Cap yield surface mass balance of -0.32 m/yr, -0.34 m/yr and -0.39 m/yr for 2009-2011, respectively. Furthermore, a general decreasing trend in mass balance found over the 1996-2011 period.

In 2008 and 2012 ground-penetrating radar (GPR) surveys were performed to determine ice thickness distribution, especially for the South-East outlet glacier (SEOG), which shows annually glacial lake outburst floods due to an ice-dammed side valley. Beside basic ice depth information, GPR data revealed persistent englacial and subglacial features most likely connected to the glacial water routing during the seasonal GLOF initiation.

GlacioBasis and DTU airborne data from 2011 produced an accurate digital elevation model (DEM) and gathered additional ice depth data, next to the GPR data of the SEOG, over the rest of the ice cap. Following a well-established ice depth interpolation approach, based on the minimization of the spatial variation of basal shear stresses, a complete ice thickness map for the A.P. Olsen Ice Cap was produced. Based on the ice depths and optimum smoothed surface slopes, a complete basal shear stress map was calculated to determine surface velocities due to internal deformation of the ice column. Further built on the accumulation and ablation data, balance velocities were calculated. These dynamic products are discussed in relation to mean annual flow velocities delivered by remote sensing data (InSAR). The different dynamic products as well as the gathered GPR data build the base for a discussion about the thermal state of the A.P. Olsen Ice Cap.

Estimation of equilibrium line altitude on glaciers in Southern Spitsbergen by a simple remote sensing method

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Introduction

Svalbard glaciers are located in the area of Arctic very sensitive to climatic changes. Temperature rise of air and increasing amount of heat transport in waters of West Spitsbergen Current into Hornsund area (Southern Spitsbergen) causes changes in extension, thickness and dynamics of glaciers during last decades. Position of the equilibrium line altitude (ELA) and the accumulation area ratio (AAR) are commonly used to describe "health" of glaciers. But data on the ELA on other than monitored glaciers are difficult to obtain in the Arctic. Sophisticated remote sensing attempts were tested earlier for determination of the ELA on Svalbard glaciers (König *et al.*, 2000, 2001; Engeset, 2002). In this study a simple remote sensing method to estimate the ELA on Southern Spitsbergen (Fig. 1a) glaciers has been developed. The approach is based upon detection of transient snow line (TSL) on cloud free satellite images (Landsat, Aster, Alos Avnir, Spot, acquired in the period 2000-2011; Fig. 1b) and positive degree days (PDD) coefficient from the Polish Polar Station in Hornsund. The maximum elevation of the TSL at the end of ablation (TSLmax) can be used as a proxy for the ELA position. Although one has to remember the importance of the superimposed ice zone between them. An average height of every TSL was calculated using the SPOT DEM 2008. In areas with data gaps the DEM 1990 (from the NPI aerial photos) was used. Results on shrinkage of glacier's area are also presented (Fig. 1a).

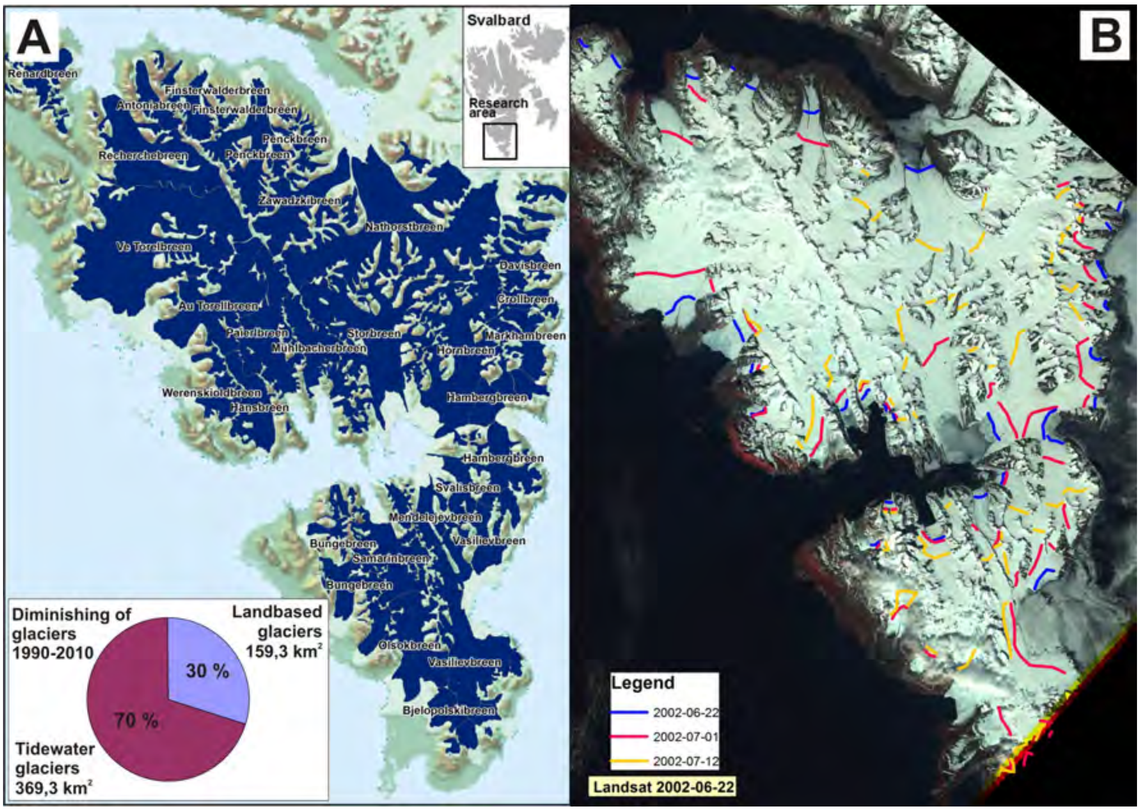

Figure 1. a. Inventory of glaciers on Southern Spitsbergen and retreat of glaciers; b. Changes of the TSL position during the first part of the melting season in 2002.

Data calibration - Hansbreen

Data from field measurements on Hansbreen (Table 1) have been used for calibration of determination of the TSL by remote sensing. Correlation between the observed ELA and PDDend (the coefficient of positive degree days until the end of ablation season) was low (R^2=0.19). Application of the coefficient PDDend/wa (the coefficient of positive degree days until the end of ablation season divided by winter accumulation for a given year) and removing data from the extraordinary year 2004 has improved the correlation (R^2=0.58). Ablation in the summer 2004 was extreme and TSL in the middle ablation season (7.08.2004) reached the

Table 1. Field data for Hansbreen and maximum TSL from regression line - courtesy of IGF PAS (P. Głowacki, D. Puczko).

Period	1999/ 2000	2000/ 2001	2001/ 2002	2002/ 2003	2003/ 2004	2004/ 2005	2005/ 2006	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	Average
winter acc. (m w.e.)	0.93	0.78	0.97	0.69	0.91	1.23	1.30	1.03	1.22	0.74	1.06	1.12	1.00
ELA (m a.s.l.)	500	500	380	380	390	320	300	330	300	400	350	330	373
PDDend	485.3	455.9	521.5	412.1	367.1	375.8	437	399.6	422.4	442	390.6	444.6	429
PDDend/wa	521.8	584.5	537.6	597.2	403.4	305.5	336.2	388.0	344.8	595.2	367.3	396.0	448
TSLmax	390	420	395	425	330	285	300	325	300	425	315	330	353

highest parts of almost all glaciers of the area.

In the next step correlation between the TSL elevation acquired on satellite images and the PDDacq/wa (the coefficient of positive degree days until date of acquiring of the satellite image divided by winter accumulation for a given year) were calculated for Hansbreen. Correlation was high (R^2=0.69), therefore based on the linear regression, heights of TSLmax (height of transient snow line calculated for every year based on regression line) were calculated for every year between 2000-2011 (Table 1). The average value of TSLmax for Hansbreen amounts to 353 m a.s.l. and is 20 m lower than the average ELA. Therefore TSL position at the end of ablation season has been treated as the estimated ELA (with the accuracy of ca. ±20 m in elevation).

ELA on Southern Spitsbergen

Data from field studies on Hansbreen have been used for the calibration of determination of the TSL by remote sensing on Southern Spitsbergen. Similarly to Hansbreen, correlations between TSL and PDDacq/wa were calculated for the other glaciers with at least 6 observations of TSL. Based on regressions lines for each glacier the height of TSLmax was estimated (Fig. 2). Resultant values have been treated as the average ELA for the last twelve years, with the accuracy of ca. ±20 m in elevation. When results of this estimation are compared with the estimated ELA values in Svalbard by Hagen *et al.* (1993), a general increase of elevation by 35-310 m is observed during some thirty years or so. Isolines of the mean TSLmax elevation (ELA) for the studied period are presented on Fig. 2.

Results

- The simple method for the estimation of the ELA position by use of the optical satellite images and meteorological data from the coast station has been developed.
- Quite good relation between elevation of the TSL and the PDD coefficient corrected by the winter accumulation can be observed.
- The best correlation between the ELA and the PDD/winter accumulation coefficient has been noted for the western part of research area and for large glaciers. Differences in results for eastern and western parts of Southern Spitsbergen are related to diverse climatic conditions in the region and deglaciation history from the end of the 'Little Ice Age'. Meteorological data and field observations of winter accumulation in eastern part of Southern Spitsbergen are needed for better estimation of the TSLmax in the area.
- Rising of equilibrium line altitudes together with retreat of glaciers is well visible on glaciers of Southern Spitsbergen during last three decades and influence

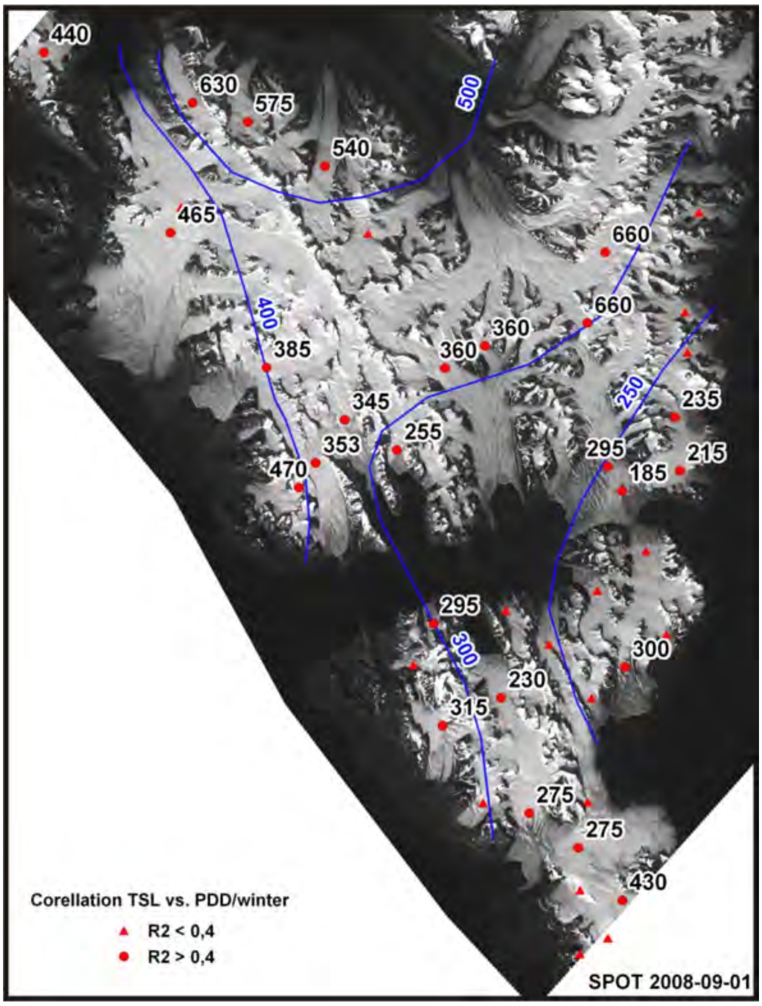

Figure 2. Fig. 2. The average ELA on glaciers in Southern Spitsbergen estimated by use of TSLs from satellite images (2000-2011).

glaciers mass balance. That is probably caused by longer duration of the summer seasons in the last decade. Large glaciers with low slopes of a longitudinal profile made a major contribution to the shrinkage of glaciers (70% of glacier shrinkage). The scale of diminishing of land terminated glaciers is distinctly lower (30%).

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References

Engeset. 2002. Title. *Journal*, **Volume**, xx–xx.

Hagen J.O., Liestøl, O., Roland, E. and Jørgensen, T. 1993. Glacier Atlas of Svalbard and Jan Mayen *Norsk Polarinstitutt Meddelelser*, **129**, 141 pp.

König. 2000. Title. *Journal*, **Volume**, xx–xx.

König. 2001. Title. *Journal*, **Volume**, xx–xx.

Surface mass balance feedbacks of the Greenland ice sheet in recent decades

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Snowfall, melt, and albedo variations all contribute as important multipliers or dampers of Greenland ice sheet mass balance variability. This study examines these variations using a fusion of satellite and in-situ observations and regional climate modeling. The observations are critical in model constraint. Numerous surface energy and mass budget quantities of importance are described at regional and glacier basin scales. Statistical signals are examined in the pursuit of identifying physical mechanisms. The surface albedo feedback, for one, is shown to be associated with a doubling in surface melt in the 13 year period, 2000-2012. Snowfall variability is shown to have important spatial patterns on surface melting. Changes in the surface energy budget of different ice sheet locations are presented. A detailed understanding of the sensitivity of ice sheet mass balance emerges from this multi-data source perspective.

Local effects of depth-dependent water content of ice and snow and firn layers temperature on a conjectured subglacial lake below Amundsenisen Icefield (Svalbard).

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It is known that the Amundsenisen Icefield in Southern Spitzbergen (Svalbard achipelago) is temperate with an upper layer of snow and firn. It is an accumulation area and, though ice/water mass balance is clearly subject to time evolution, observation data on the long-term elevation changes over the past 40 years (Nuth *et al.*, 2010) allow to assume constant icefield surface. Within our study of the plausibility of a subglacial lake (Glowacki *et al.*, 2007), here, we focus on the sensitivity of the system to the thermal effect of the firn and snow layers.

As water content of ice have significant consequences on its rheology and dynamics but direct quantitative measurements of it are not presently available to our knowledge, in this work we adopt a continuous fit between water content and the fourth power of the normalized depth along with the procedure adopted by Vallon *et al.* (1976), for the temperate glacier Vallee Blanch, French Alps, and by Breuer *et al.* (2006), for the King George Island ice cap in Antarctica. We support our investigation with simulation via an in-house numerical code (Bucchignani *et al.*, 2012) based on a thermomechanical transient model with dynamics given by a full Stokes system for the icefield and Large Eddy Simulation formulation for the water basin. Ice rheology is represented by Glen's law (n=3) with flow rate factor depending both on water content and temperature according to Breuer *et al.* (2006), for similar environments. Firn and snow thermal profiles are assumed to be steady. Their numerical values are partly (firn) available from Zogorodnov *et al.* (1985) and completed by matching the annual average air temperature at the surface. We compare simulations performed with and without firn and snow layers.

References

Bucchignani, E., D. Mansutti, F.J. Navarro, J. Otero, P. Glowacki. 2012. Arguments from modelling about the existence of a subglacial lake at Amundsenisen Icefield (Svalbard). *IGS-NB Meeting*, 25-27 October, Stockholm.

Breuer, B., M.A. Lange, N. Blindow. 2006. Sensitivity studies on model modifications to assess the dynamics of a temperate ice cap, such as that on King George Island, Antarctica. *J. Glaciol.*, **52**(177), 235–247.

Glowacki, P., A. Glazovsky, Y. Macheret, E. Vasilenko, J. Moore, J. O. Hagen, D. Puczko, M. Grabiec, J. Jania, F. Navarro. 2007. Dynamics and mass budget of Amundsenisen, Svalbard: interpretation of surface elevation and radar data. *IUGG-2007*. Perugia.

Nuth, C., G. Moholdt, J. Kohler, J. O. Hagen and A. Kaab. 2010. Svalbard glacier elevation changes and contribution to sea level rise. *J. Geophys. Res.*, **115**.

Vallon, M., J.R. Petit and B. Fabre. 1976. Study of an ice core to the bedrock in the accumulation zone of an Alpine glacier. *J. Glaciol.*, **17**(75), 13–28.

Zogorodnov, V.Z. 1985. Glaciology of Spitzbergen. (V.M. Kotlyakov, ed.) Nauka, Moskow.

Monitoring of calving processes at Hansbreen (Southern Spitsbergen)

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The aim of this study was to determine significance of the marine factors on ice cliff during ablation period. Research hypothesis assumes a dominant role of the marine factors such as: undulation, tides and sea water temperature on the process of glacier calving. Interaction between marine factors, meteorological factors and glacier dynamics have been analyzed. The research was carried out on Hans Glacier, which is a medium size (area of c. 56 sq. km, up to 400 m thick) polythermal tidewater glacier located in South Spitsbergen. The glacier extends from more than 500 m a.s.l. down to calving cliff in Hornsund Fjord. Since measurements of movement of the calving events are very difficult, new techniques have been used to observe calving. Measurements of sea level and water temperature were carried out by Schlumberger Cera divers located at bottom of Hansbukta on rocky costal near the ice cliff. Divers made measurements with intervals of 10 seconds from 16th of July to 15th of August 2011 and from 17th of July to 22th of August 2012. All data have been compared with time lapse photos from the Canon Eos 1000D camera has been taken from the Baranowski Peninsula every 1 hour.

The results obtained from divers show a high correlation with the pictures from the cameras. The combination of these two methods allows the registration of calving in different weather conditions. The relationship between wave height and the occurrence of large calving events has been observed. The increase in average wave height contributed to the growth of (especially large) calving events within the glacier face as a result from increased marine abrasion abrasive niche within the ice cliff.

Dynamics of Skálafellsjökull, Iceland, from the 2012 Glacsweb Sensor Network Deployment

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The Glacsweb research group at the University of Southampton has been monitoring Skálafellsjökull since 2008, and in the 2012 field season deployed a new sensor network comprising of subglacial wireless probes, geophones and five dGPS units. Data is transmitted daily back to Southampton allowing for monitoring of the glacier's behaviour throughout the year.

The key element of the project, the subglacial probes, has seen a major revision in 2012 with the introduction of new hardware. The variables measured remain unchanged and include pore pressure, case strain, temperature, movement and conductivity, but new sensors and an ARM processor have improved performance. The geophones are new additions to the project custom built this year and include triaxial sensors recording at 500 Hz situated at 90% of the glacier's depth.

Here we present the data gathered so far and consider the temporal variability of the variables measured and the dependence of surface velocity on subglacial processes. We also present new geotechnical work led by the data Glacsweb data and demonstrate the roles of field and lab work in producing a holistic understanding of the subglacial environment at Skálafellsjökull.

X-ray Computed Tomography scanning of till

Alex Clayton and Jane Hart

Southampton University

X-ray computed tomography (CT) offers a non-destructive way to quantify the internal structure of glaciogenic sediments. A 3D reconstruction is created of the variations in density throughout the sample from a series of 2D X-rays. This reconstruction can then be manipulated with image processing software in order to quantify elements of the internal structure such as clast size and orientation.

The new μ-VIS (Multidisciplinary, Multiscale, Microtomographic Volume Imaging) at Southampton University provides opportunities for any researchers to study various materials, up to 1.5 x 1 x 1 m in size, at a resolution of up to 3 μm. The CT Scanning facilities are backed by a visualisation and image analysis suite which contains a number of high performance desktops with programmes such as VGStudio Max, Avizo and ImageJ.

Results from scanning an Icelandic modern till, and a British palaeo till demonstrate that geology is a significant factor on the ability to accurately produce useful results, primarily due to the relative densities of the matrix and clasts which impacts the amount of contrast between them. However in favourable geology tills segmentation and measurement of particle sizes and orientations is possible and here is achieved with use of the Matlab image processing toolbox and Avizo Fire. Establishing a consistent and robust evaluation of error remains problematic due to the complexity and variety of the image processing and level of user supervision but even as a qualitative technique the results are extremely useful in areas such as geotechnical experiment validation.

Recent disintegration and mass losses from the Petersen and Milne Ice Shelves, Ellesmere Island, Canada

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There are currently three ice shelves left along the northern coast of Ellesmere Island (Milne, Petersen, Ward Hunt), down from a total of six which were present prior to 2005. A major concern is whether these remaining ice shelves have changed recently, and whether they are likely to survive long into the future. ASTER and Radarsat-2 satellite images indicate that the Petersen Ice Shelf decreased in area from >50 km^2 in 2003 to <20 km^2 by the end of summer 2012. This coincided with the breakup and disconnect of a glacier that used to provide input to the south side of the ice shelf. The Petersen epishelf lake, a feature formed from the damming of buoyant freshwater behind the ice shelf, completely drained in 2005/2006, with the formerly perennial freshwater ice cover in this area now replaced with a sea ice cover which breaks up annually. For the Petersen Ice Shelf, comparison of current surface mass balance (-1.18 m yr^{-1}) with remaining ice thickness and glacier inputs (7.89 to 13.55 cm yr^{-1} averaged over 2011 area) suggest that it will not last beyond ~20 years. However, recent calving events make it likely that complete loss will actually occur much sooner. Ground-penetrating radar measurements on the Milne Ice Shelf indicate that it thinned by an average of 8.1 +-2.8 m between 1981 and 2008/2009, equating to a total volume loss of 13% (1.5 +-0.73 km^3 w.e.). Its rate of loss is less than the Petersen Ice Shelf and it still receives significant mass inputs from some tributary glaciers, but given this long-term thinning and recent calving from its rear, it is still unlikely to survive beyond the middle of the 21st century.

Recent changes in glacier facies zonation on Devon Ice Cap, Nunavut detected from SAR imagery and field validation methods

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Glacier facies represent distinct regions of a glacier surface characterized by near surface structure and density that develop as a function of the spatial variations in surface melt and accumulation. In post freeze-up (autumn) SAR imagery, the glacier ice zone and dry snow zone have a relatively low backscatter due to the greater penetration of the radar signal into the surface. Conversely, the saturation and percolation zones are identifiable based on their high backscatter due to the presence of ice lenses and pipes acting as efficient scatterers to reflect the signal. Temporal changes in the location of glacier facies are often interpreted as a climate indicator, with facies zones typically increasing in elevation over time in response to atmospheric warming. In this study, ERS-2 SAR and EnviSat ASAR imagery is used to monitor the progression of facies zones across Devon Ice Cap (DIC) from 2000 to 2011. This data is validated against in situ surface temperatures, mass balance data, and ground penetrating radar surveys from the northwest sector of DIC. Based on calibrated (sigma nought) EnviSat and ERS-2 backscatter values, imagery from autumn 2000 to 2011 shows the disappearance of the 'pseudo' dry snow zone at high elevations, the migration of the glacier and superimposed ice zones to higher elevations, and reduction in area of the saturation/percolation zone. In 2011, the glacier and superimposed ice zone were at their largest extent, occupying 92% of the ice cap, leaving the saturation/percolation zone at 8% of the total area. This is indicative of anomalously high summer melt on DIC, which results in the infilling of pore space in the exposed firn and consequent densification of the ice cap at higher elevations. In addition, the changes in facies directly contribute to the increasingly negative mass balance of DIC.

Ground-based monitoring of firn extent and thickness of Austfonna, Svalbard, to enhance interpretation of satellite-derived altimetry data

T. Dunse, K. Langley, A.T. Aasen, T. Eiken, J.O. Hagen, T.V. Schuler

Satellite altimetry missions such as CryoSat or ICESat are designed to monitor surface elevation changes of the world's ice masses. One ultimate goal, quantification of global ice mass changes and the assessment of eustatic contribution to sea level rise, requires assumptions on glacier-wide density-depth distributions. Density variations within the firn, e.g. due to compaction or internal refreezing of surface melt, as well as changes in the depth of the firn-ice transition (FIT) may bias the results and lead to both over- and underestimation of mass changes.

Here we present annually repeated ground-penetrating radar (GPR) measurements from Austfonna (∼8000 km^2), the largest ice cap on Svalbard, and target glacier for calibration and validation activities of ESA's CryoSat-2 radar altimetry satellite. The GPR system, operating at a centre frequency of 800 MHz, reveals information on winter snow cover and characteristic radar zones, associated with three glacier facies present on Austfonna: firn (mainly from wet snow), superimposed ice and bare ice of the ablation area. The GPR data is supplemented with information on stratigraphy and density from snow pits, shallow cores, neutron probe, borehole video and sonic ranger. Monitoring the distribution of firn in horizontal and vertical directions help to interpret satellite radar observations and reduces uncertainties related to the conversion of volume to mass changes.

The GPR timeseries starts in 2004 and shows large interannual variations in firn volume. After two negative mass balance years had reduced the firn extent, firn area extent and thickness increased steadily from 2006 to a maximum in 2008, as a result of three positive mass balance years. Since 2009, the firn volume reduced once again, especially at lower elevations. Observed rates of change in firn-thickness amount up to 1 m yr^{-1}. This potentially introduces an uncertainty of about 0.25 m w.e. yr^{-1} to geodetic mass balances that assume a constant density distribution.

Mass balance of Greenland and Arctic Ice Caps from GRACE and ICESat

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Ten years of GRACE data are analyzed for a revised estimate of the Greenland Ice Sheet and the ice caps of eastern Canada, Svalbard and Iceland. New higher-resolution release-5 GRACE data are inverted using point mass modelling, in a simultaneous solution for all the ice caps. It is apparent that estimates of the Greenland ice sheet mass balance, when only taking into account the Greenland area, gives too high value due to leakage from the rapidly shrinking Canadian ice caps. A revised Greenland mass loss of -218 GT/yr for the period 2003-2012 is obtained, somewhat on the low side of other recent estimates. The northern and southern Canadian ice caps gives a mass loss of -25 GT/yr and -42 GT/yr, with changes of Iceland and Svalbard being close to zero. The record melts on the Greenland ice sheets in 2010 and 2012 is clearly seen be GRACE, confirming the usefulness of ice sheet monitoring by GRACE, and is consistent with recent ICESat mass change estimates.

Snow cover distribution derived from multi-temporal LiDAR application in high alpine catchments

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The snow cover as storage of winter precipitation is a substantial source for runoff generation in high mountain catchments. Redistribution of solid precipitation, caused by wind and gravity, leads to a characteristic spatial distribution of snow accumulation. Complex relations exist between the spatial patterns of snow accumulation and the presence of glaciers and vice versa.

For proper hydrological modelling in high mountain catchments, knowledge about snow cover distribution is an important requirement. Generally only a small number of precipitation measurements are available in these remote areas. These measurements are affected by considerable errors accumulating solid precipitation. Measuring the snow cover distribution by in situ measurements in terms of snow probing and snow pits delivers spatially limited data due to the restricted accessibility in the rough terrain. On catchment scale, optical space-borne remote sensing techniques deliver areal extent of snow cover, but no snow depths and hence no volume of snow cover can be derived. Multi- temporal application of airborne laser scanning (ALS) is an active remote sensing method to obtain surface elevation changes for e.g. snow cover studies in a high spatial resolution even in inaccessible alpine terrain. Due to ice flow and firn compaction, surface elevation changes observed by ALS at glacier surface can locally deviate from real snow depths. To estimate the significance of the deviations between ALS derived surface elevation changes and "ground truth" snow depths, ground penetrating radar (GPR) measurements were conducted simultaneously to the ALS acquisitions. The results show a significant underestimation of snow depth derived from ALS data in the accumulation zones of the glaciers. Along the glacier tongues relative deviations are small. With those information the spatially distributed surface elevation changes can be transferred into SWE and be used as a basis for calibration and validation of hydro-meteorological models.

Projecting 21st century glacier runoff of all Alaskan glaciers

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Glaciers significantly modify streamflow both in quantity and timing, even with low percentages of catchment ice cover. Glaciers cover roughly 90,000 km^2 in Alaska and have been thinning and retreating during the last decades dramatically, recently at an accelerating rate. These changes will have profound effects on river runoff quantity, seasonality and peak flows in Alaskan drainage basins. Annual runoff from a glacierized basin is a function of glacier mass balance, with years of negative balance producing more runoff than years of positive balance. As climate changes and causes glacier mass balances to become progressively more negative, total glacier runoff will initially increase followed by a reduction in runoff totals as the glaciers retreat. With high percentage of ice cover the initial increase in runoff can be substantial, considerably exceeding the runoff changes to be expected from any other component of the water budget. However in the long term the loss of ice will lead to lower watershed yields of water.

Using a new complete glacier inventory and an elevation dependent temperature-index model we compute the glacier mass changes and resulting glacier runoff (defined as melt - refreezing + rain) of all Alaskan glaciers (including adjacent Canadian glaciers) until 2100. We force the model with monthly temperature and precipitation output of the global climate model BCC-CSM1. We find that all glaciers lose mass over the 21st century, however, the glacier runoff response of individual glaciers varies widely. Some glaciers show an increase in runoff, while others show a decrease or an increase followed by a decrease in runoff. We analyze the runoff response for different glacier sizes and elevation ranges and also for different regions in Alaska. We find that while all regions show substantial mass loss, some of the regions show an increase in glacier runoff, while others show a decrease. Results indicate the importance of modeling accurately glacier retreat and thinning in addition to glacier mass balance.

The influence of thermal structure of glaciers on their response to climate change

Per Holmlund and Caroline Clason

Differences in the thermal structure is believed to cause the uneven response to climate change of the glaciers in Sweden. Though the trend is regional, neighbouring glaciers may show large differences in their response which cannot easily be described by differences in local climates. In addition, the number of frontal moraines vary significantly (1-20) indicating substantial differences in dynamic response to climate signals. The thermal structure of 70 Swedish glaciers was mapped during 2008-2012, among which 25 are in the national monitoring program for front changes and mass balance. The thermal structure was mapped by the use of a high-frequency (770-870 MHz) radar from an airborne platform. Though all glaciers in the area are polythermal there are large differences in the thermal structure of the individual glaciers which may explain their different response patterns. The new data is also very useful in forecasting future geometry changes and adds inspiring information to the difficult issue of how glaciers frozen to the ground can advance their front positions.

Sediment in basal ice of Engabreen

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Introduction

The basal ice of glaciers can have up to several metres thickness of sediment-rich ice. This can occur as several alternating layers of sediment-rich and sediment-poor or clean ice, and the transition from sediment-rich to clean ice may be abrupt. The exact pattern of the layers depends on several factors, including over-deepening at the glacier bed and water availability.

The Svartisen Subglacial Laboratory in northern Norway is the ideal place to study sediment content of basal ice (Jansson *et al.*, 1996). The laboratory lies under Engabreen, an outlet glacier of Svartisen, and has an overburden of 200 m of glacier ice (Lappegard *et al.*, 2006). It is located at the end of a rock tunnel and allows direct and relatively easy access to the base of this hard-bedded, temperate glacier. This makes it relatively straightforward to take several samples of basal ice at different times but at exactly the same place each time, a task which is all but impossible when drilling through the thickness of a glacier from the surface, and also ensures that the basal topography immediately surrounding the sampled ice is known.

Vertical sections of the basal ice have been extracted and measured in spring and late autumn in different years, in order to study whether there is a seasonal signal (e.g. the sediment-rich layer(s) is consistently thicker at certain times of the year) and to study the variation from year to year.

Results and Discussion

Samples of the basal ice were taken in March 2007, March and November 2009 and March and November 2010. Samples taken in different years show a significant variation in the thickness of the basal ice, the number of sediment-rich layers and the sediment content (total volume and grain size distribution) of the layers. The total thickness of the sediment-rich basal ice layers varied from 30 cm up to 2 m at different epochs.

Figure 1 shows an example of a basal ice profile that was extracted from the basal ice in November 2007. The total thickness of the basal ice was 111 cm

Figure 1. Profile of basal ice from November 2007.

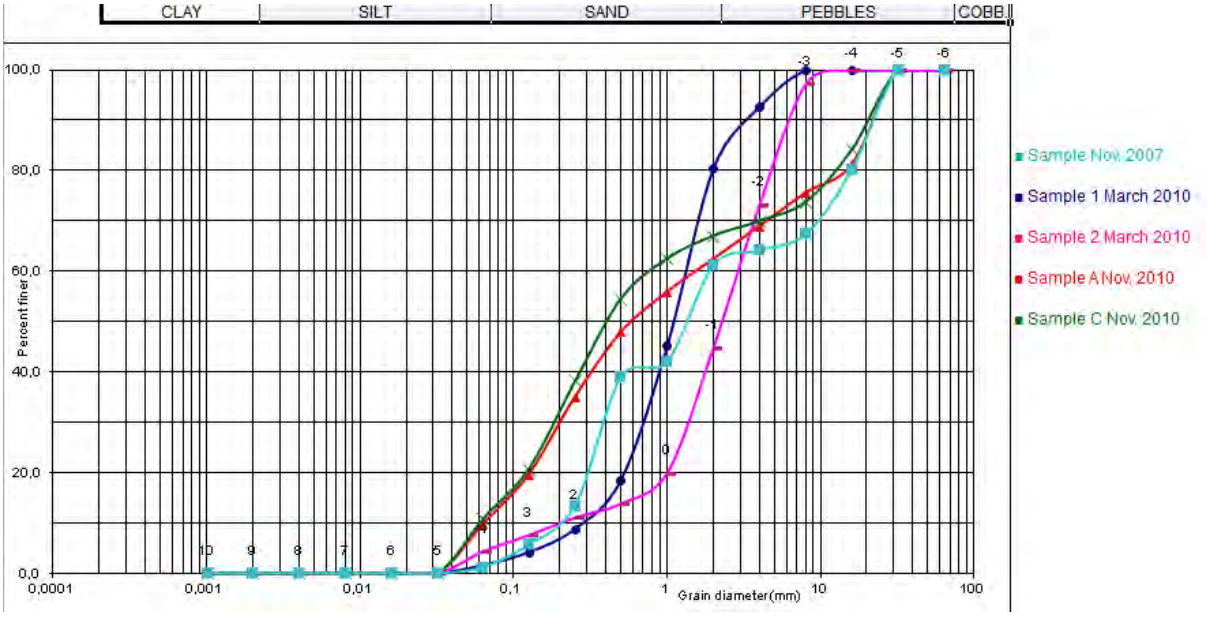

Figure 2. Grain size disbtribution for sediment samples taken in March and November 2010, and November 2007.

and the figure shows several features that are typically seen in the basal ice at different times. Visible are several distinct layers of varying sediment content, the transition between the different layers tends to be quite sharp and sizeable clasts are visible (both near the base and near the top of this profile). The largest clast found in the bottommost layer was 9 cm, and the thickness of the most sediment-rich ice at the base of the profile was 20 cm. Typical concentrations by weight of the sediment-rich layers from all the samples were 20-40 g/l, but some layers had almost 200 g/l of sediment.

Figure 2 shows the grain size distribution for samples taken in March and November 2010, as well as November 2007. The autumn samples are similar with 50% or the material being medium-sized sand (0.6 mm) or finer. For the spring samples, there is more coarse material, with the 50Th percentile about 2 mm. The November 2009 curve (not shown here) shows that the sediment material then was finer than all the other samples taken (the grain size distribution was not measured for March 2009).

Summary

Sediment samples of the sediment-rich basal ice of a temperate glacier in northern Norway were taken at five different epochs, in spring and summer for three different years. The samples show a slight trend with the thickness of sediment-rich ice being least in the spring, and the grain size of the sediment was also coarser. Samples taken in the autumn showed multiple layers and finer sediment generally, although also a more heterogenous sediment distribution. This suggests that fewer large clasts are incorporated into the basal ice after the melt season. These results also suggest that caution should be used in making generalisations from a single ice core. Much variation is seen from year to year, and even for different samples taken during the same visit to the subglacial laboratory, but a few metres from each other.

Acknowledgements We acknowledge the support of Statkraft who own the rock tunnel system

in which the subglacial laboratory lies and allow us access to the laboratory as well as logistical assistance.

References

Jansson, P., J. Kohler, and V. Pohjola. 1996. Characteristics of basal ice at Engabreen, northern Norway. *Ann. Glaciol.*, **22**, 114–120.

Lappegard, G., J. Kohler, M. Jackson and J.O. Hagen. 2006. Characteristics of subglacial drainage systems deduced from load-cell measurements. *J. Glaciol.*, **52**(176), 137–148.

A new inventory of all Alaska glaciers

Christian Kienholz, Sam Herreid, Justin Rich, Anthony Arendt and Regine Hock

We report on a new complete glacier inventory for Alaska and adjacent Canada (Region 1 of the Randolph Glacier Inventory) which is based on modern (post 2000) satellite imagery. We detail tech- niques used to outline glacier complexes under challenging conditions, e.g., extensive supraglacial debris or persistent cloud coverage. We present a new automated algorithm that allows for dividing glacier complexes into single glaciers, requiring only glacier complexes and a digital elevation model as input. We also describe automated algorithms to map supraglacial debris, delineate annual snowlines, and determine glacier types (e.g., land-terminating, lake-terminating, or tidewater), all of which are based on spectral classification of Landsat imagery. Combining the inventory with the best available digital elevation models, we derive a variety of glacier parameters including location, area, compactness, slope, aspect, and hypsometry. Glacier type, percentage debris cover, and sur- face velocity fields for selected glaciers complete the inventory. Geostatistical methods are applied to examine the relationships between the derived parameters.

A snowpack model to improve ice-sheet melting on millennial time scales

Mario Krapp

Greenland melt is a major contributor to global sea level rise for the next millennium. Therefore, melting processes need to be considered in a more physically-based manner. We use a snowpack model that accounts for snow metamorphism and for meltwater refreezing, both processes that have not been addressed for Greenland melting on longer time scales. The snowpack model is coupled to the ice-sheet model SICOPOLIS and forced with climatological atmospheric fields from regional climate models. In this study, we present the response of the ice-sheet to different melting parametrisations: positive degree day, insolation-temperature melt, and the snowpack melt.

Interaction between surface albedo variations and snow cover ablation on glaciers of Wedel Jarlsberg Land, Svalbard

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Surface albedo is one of the major parameter affecting on solar energy transfer in the atmosphere. Fresh snow as the most reflective natural material can bounce up to 90% of incoming shortwave radiation, K↓. During ablation gradual decrease of the snow albedo is stimulating increase of melting processes.

Aim of presented studies was to determine spatial and temporal changes in albedo of snow cover on South Spitsbergen glaciers during ablation season and subsequently to define variability of snow melting in all glacier zones.

Fieldwork took place from June to August 2012. Author selected different types of glaciers on Wedel Jarlsberg Land, Svalbard: tidewater one (Hansbreen), land based (Werenskioldbreen, Nannbreen) and cirque glaciers (Ariebreen), including their tributary glaciers. Importance of altitude, slope and aspect of glacier surface for value of albedo and intensity of snow melting has been studied.

Detailed survey included 17 field sessions and 45 test points. Following instruments were used: net radiometer (Campbell Scientific NR-LITE), pyranometer (Skye SKS1110) and temperature probe (Campbell Scientific 107) in solar radiation shield. Observation were performed in various type of cloudiness but during windless weather, which could disrupt results. For an environmental background basic information of snow cover reduction and fluctuations of daily mean air temperature were included.

Measured albedo values for glaciers surface ranged from 0,13 (very dirty snow) to 0,90 (fresh snow). Albedo is a very sensitive parameter to changes of clouds type and cloudiness rate. The most stable observations occurred during cloudless sky or low Stratus clouds. Studies conducted at steep parts of glaciers confirmed increasing field measurements error with increase of inclination. Furthermore, differences during one field session (25.06.2012) between western and eastern side glaciers of Hansbreen, situated at similar altitude and inclination exceeded 0,20. It seems that it was rather caused by main wind circulation from East, than by the impact of exposure.

20 years of basal pressure measurements at Engabreen, Norway and insights into the hydrological system.

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Introduction

The subglacial environment is one of the most unknown domains in glaciology and yet processes at the glacier bed are crucial for behaviour of the glacier. At the Svartisen Subglacial Laboratory (SSL) located in Northern Norway, pressure sensors installed in bedrock have recorded the interaction between water, ice and the bed since 1993 to present. We investigate those long-term non-continuous time series using simple statistical algorithm in order to extract patterns in the development and the dynamics of the subglacial hydrological system. Time scale is a major factor of variability and analysis on a daily, seasonal, annual basis is presented. The final aim is to quantify how often the bed responds simultaneously or independently to supposed water input and to hypothesize its impact on ice flow.

Methods

The Svartisen Subglacial Laboratory is situated in a rock tunnel underneath Engabreen, a hard-bedded glacier. This facility enables access to the glacier base from two openings or research shafts. The first load cells that measure normal basal pressure were emplaced in the bedrock in 1992-93. At present, two of them (LC4 and LC6) still work perfectly. Another good record comes from a pair of load cells (LC97_2 and LC97_1) installed later in 1997, which became faulty around 2008 and 2011. Contrary to studies undertaken in often marginal natural cavities, the ~200m of overlying ice gives to those time series a more realistic picture of the general conditions at the glacier bed. The sensors used are P-105 Earth Pressure Cells that consist of a vibrating-wire attached to a plate in contact with the ice. This plate will bend as function of the load, thus varying the frequency at which the wire vibrates. Individual calibration curves for each sensor are used to convert frequency (Hz) into pressure (MPa) up to 5MPa with an error of less than 1%. The left-hand side of Fig. 1 presents the Raw daily pressure data. There are several gaps in the dataset, mainly caused by battery failure. A good coverage is nevertheless reached thanks to the long time span of the time series. The time interval between measurements is commonly 15 min, but can be lower up to 1 min interval.

To compare temporal changes in basal pressure, a rolling correlation with a window size of 12 hours is run for several pairs of load cells. At this time scale, daily variation is captured and individual events, observed to occur for several hours (i.e. stress bridging) are smoothed. Correlation with longer and shorter time windows confirmed the robustness of the results. Each pair differs according to distance and local topography, which influences water flow.

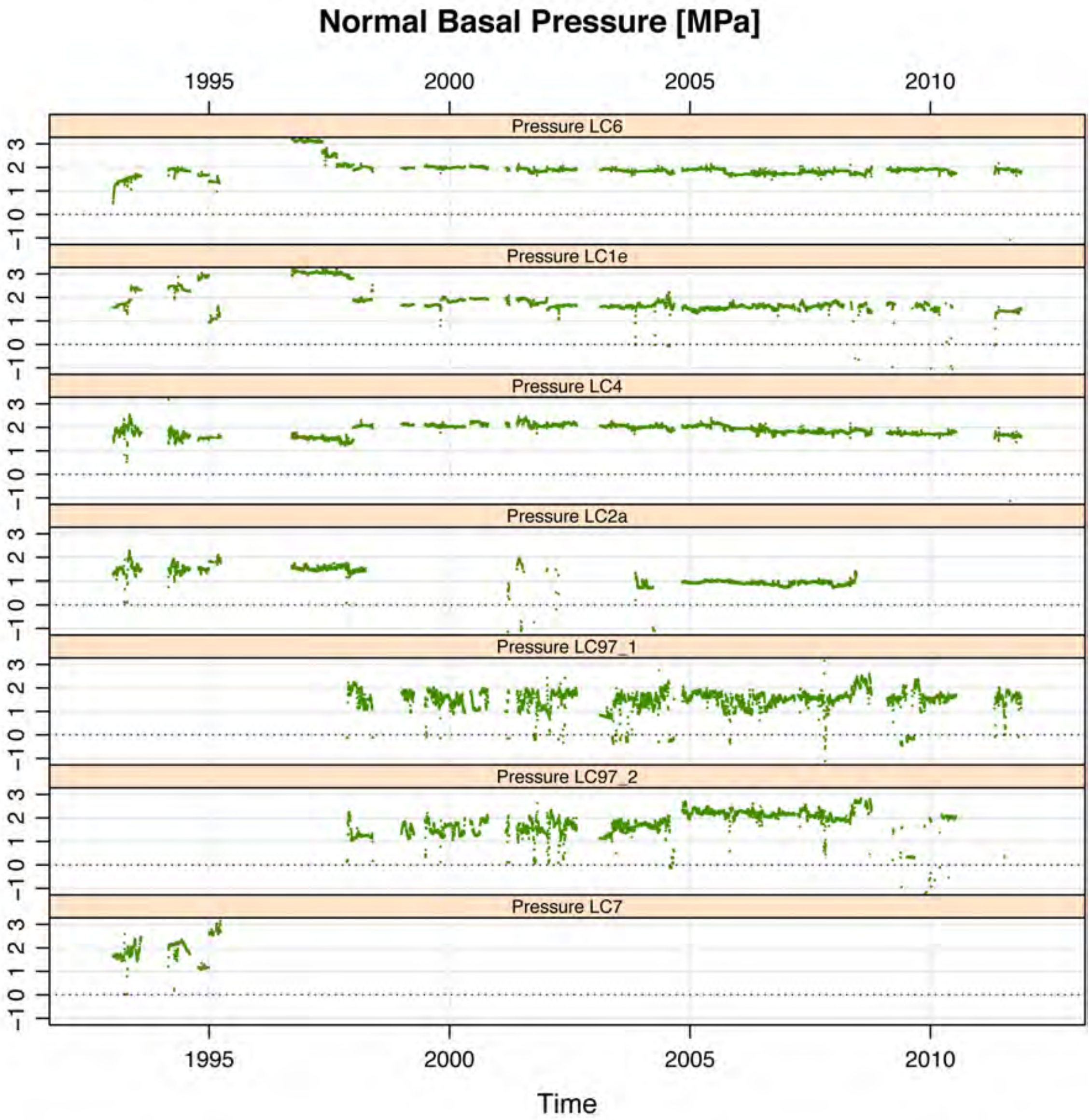

Figure 1. Time Series of Normal Basal Pressure is shown for the seven different load cells (left-hand side).

Results

Observations of normal basal pressure confirm variation on a daily, seasonal and annual time scale. The long-term pressure evolution (1998-2011) shows a decrease of about 0.1 to 0.2 MPa for LC1e, LC4 and LC6, whereas the other time series have more noise. This generally agrees with published mass balance data (discussed in the following part). Interestingly, in 2006 year of the most negative mass balance for our study period, the pressure drops by 0.2 MPa for LC4 and LC6. This was partially compensated by a rise in pressure previous to that event. This could demonstrate the sensitivity of the subglacial system to one particular year of strong melting.

Concerning the daily and seasonal pressure variations, there is a marked difference between an opened summer system and a closed winter system. Following the main concepts of development of the hydrological system (Schoof, 2010), increasing melting and precipitation in spring and summer is the cause of this evolution. This is also in accordance with previous studies of pressure time series at

Engabreen (Lappegard *et al.*, 2006). Basal pressure or effective pressure is indeed sensitive to water pressure at the bed. For instance, a diurnal signal is clearly measured in response to surface melting. In the case of a developed drainage system, all load cells mimic a decrease in pressure as meltwater is routed to the bed and then as melt stops pressure returns to its background level (close to the mean overburden pressure). Figure 2 shows this diurnal signal between July and August 2002 and the results of the statistical analysis. The lower graph demonstrates that the rolling window correlation captures well similar daily variations. Anti-correlation or no correlation is mainly observed in periods of low-amplitude pressure variation, although this is not systematic.

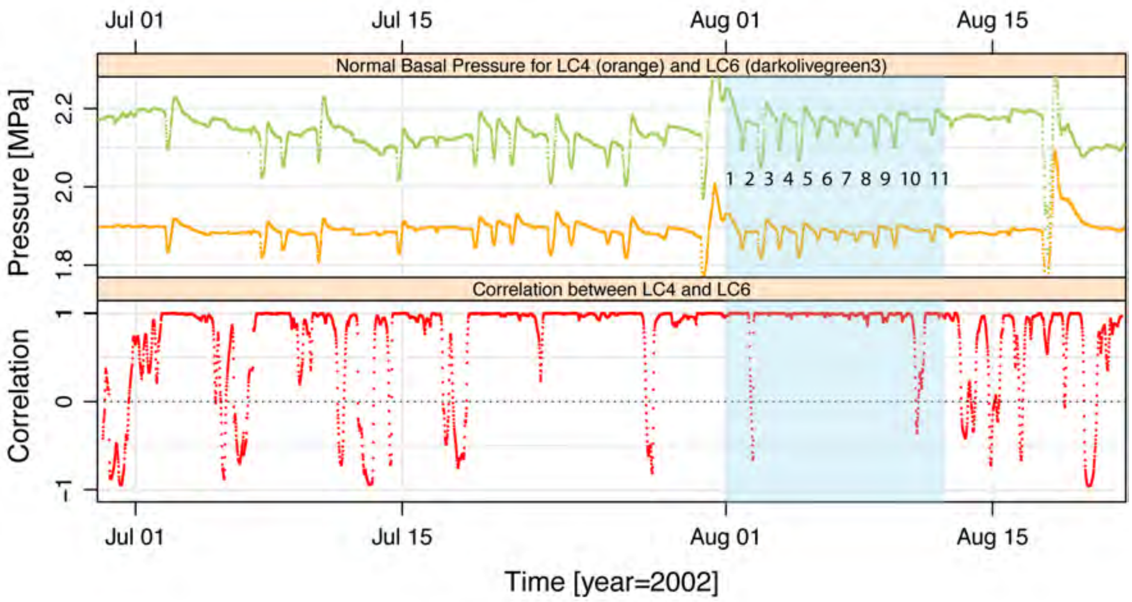

Figure 2. Time Series of Normal Basal Pressure from Load Cells LC4 (orange) and LC6 (green) and their correlation with a rolling window of 12 hours (plotted below). The part highlighted in blue indicates a strong diurnal signal with the observed number of cycles.

We observe here two types of connectivity. The first is a connection between the glacier surface and the bed, and the second is a bed connectivity, when the the load cells respond almost simultaneously. The former can be analysed through the lag between diurnal melt and its related response, whereas the latter can be investigated by looking at the correlation between the load cell records. The box-plots in Fig. 2 present the correlation results for three pairs of load cells: LC4-LC6, LC97_1-LC97_2 and LC4-LC97_1. The distance separating each pair is respectively ~1m, ~0.45m and ~22m and their local settings is shown on the right-hand side of Fig. 3. The difference between winter and summer (blue and red, respectively) is rather sharp. The winter mean correlations are about 0.6, 0.15 and 0.05 respectively, in contrast to the summer mean correlations, which are about 0.9, 0.55, 0.1-0.4. A higher water supply in summer and maybe faster glacier increases the connectivity and thus the seasonal correlation.

Hence, a comparison between these results and the bedrock topography could partially resolve this issue. Although LC97_1 and LC97_2 are the closest load cells to each other and are installed on flat down-sloping bedrock, their correlation is much lower than the pair LC4-LC6. However, it should be noted that LC97-1 and -2 are quite exposed and, except when there is high water flow at the base and large channels, tend to react more to local variations. LC 4 and LC 6 are quite sheltered (at different orientations on a sheer rock face) and tend to react to events on a large scale (occurring across tens of metres or more of the glacier bed) only.

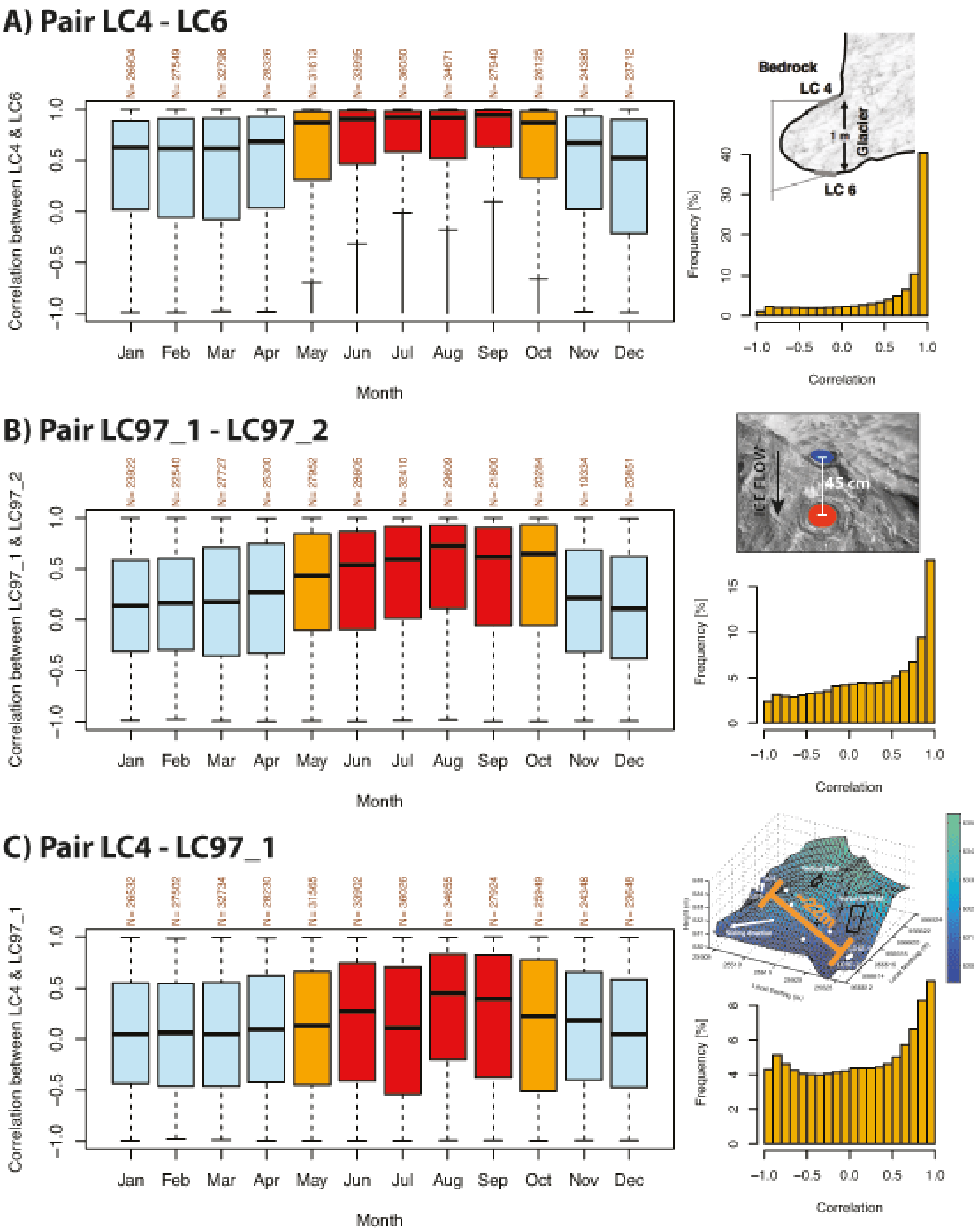

Figure 3. Seasonal Trends in Correlation for different pair of load cells. On top of the boxplot, the used number of observations is shown. The colours indicate deduced winter (blue), summer (red) and their transition (orange). In the boxplot, the thick black line indicates the mean correlation. The first quartile is contained in the filled box, the whiskers define the third quartile, and outliers are drawn with black points. On the right-hand side, the frequency of the correlation is shown for the total dataset and above the sketch/picture/map presents the topography settings of the load cells.

Conclusion

The multi-annual trend seems globally coherent with the current retreat of Engabreen, and a slightly negative net balance from 2000 to 2012 (Kjøllmoen *et al.*, 2011). Haug *et al.* (2009) also showed a lowering of 0 to >-6 m.w.e. in surface elevation of the plateau, located right above the SSL for the period 1985-2002. A continuing trend could be expected for the following years. In 2006, we hypothesize that a reconfiguration of the drainage system due to enhanced melting has triggered a rapid drop in Pressure.

The analysed load cell records show that the connectivity is a response to hydrological forcing. Lappegard and Kohler (2005) proved that the artificial injection of water at the glacier base can disturb the load cell signal, confirming our interpretation. The correlation analysis suggests a strong dependency of pressure on local topography as well as changes in flow pathways. The question of sheltering of some parts of the bed appears important in relation to their potential to respond simultaneously to water injection. This would mean that glacier sliding and reduced friction is more likely to occur in those areas. The issue remains in assessing how can we determine those zones, at which spatial scale do they occur and what are their extent.

In conclusion, by using the unique access to the glacier bed offered by the subglacial laboratory, we are able to directly investigate processes that highlight the importance to consider the glacier bed as a very dynamical environment.

References

Haug, T., C. Rolstad, H. Elvehøy, M. Jackson and I. Maalen-Johansen. 2009. Geodetic mass balance of the western Svartisen ice cap, Norway, in the periods 1968-1985 and 1985-2002. *J. Glaciol.*, **50**(50), 119–125.

Kjøllmoen, B. (Ed.), L.M. Andreassen, H. Elvehøy, M. Jackson and R.H. Giesen. 2011. Glaciological investigations in Norway 2010. (Updated 2012). *NVE Report*, **3**, 89 p + app.

Lappegard, G. and J. Kohler. 2005. Determination of basal hydraulic systems based on subglacial high-pressure pump experiments. *Ann. Glaciol.*, **40**, 37–42.

Lappegard, G., J. Kohler, M. Jackson, and J.O. Hagen. 2006. Characteristics of sub- glacial drainage systems deduced from load-cell measurements. *J. Glaciol.*, **52**(176), 137–148.

Schoof, C. 2010. Ice-sheet acceleration driven by melt supply variability. *Nature*, **468**(7325), 803–806.

First drifting snow observations on the Greenland ice sheet - framework, results & perspectives

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Drifting snow is a frequently occurring process in windy regions of Antarctica and Greenland. It enhances sublimation and redistribution of surface snow, thereby contributing significantly to local and ice sheet wide SMB. To resolve this process on a continental scale, regional climate models are useful tools, but these heavily rely on evaluation using high-quality observations. Observing drifting snow, however, is extremely challenging in these harsh weather conditions. We have developed a stand-alone measuring system that consists of two Snow Particle Sensors, which measure the size and amount of drifting snow crystals, and an 8 m high turbulence tower that, among others, accurately measures the vertical profile of wind speed. This system was installed in August 2012 at an elevation of ∼1850 m on the western Greenland ice sheet, at a location in the accumulation zone where model results suggest drifting snow to occur frequently (∼40%) in winter. In this talk, we present the simulated drifting snow climate and show preliminary results of the measurement setup.

Observations of caterpillar-like motion in the Greenland Ice Sheet

Martin Lüthi, Claudia Ryser, Ginny Catania, Matt Hoffman, Bob Hawley, Martin Funk, Thomas Neumann, Andreas Bauder, Lauren Andrews and Blaine Moriss

Current understanding of ice dynamics predicts that increasing amount and variability of melt water supply will likely have a major influence on basal motion, and therefore on the evolution and future behavior of the Greenland Ice Sheet. To better understand the processes controlling seasonal and episodic flow velocity variations in the marginal zone, we drilled a total of 13 boreholes to the glacier base at two drill sites in the western marginal zone, downstream of Swiss Camp, named FOXX and GULL. At each drill site we instrumented two boreholes with sensor systems measuring pressure, temperature, tilt and azimuth at different depths. Important surface parameters such as GPS position, stream and moulin discharge, and meteo data were recorded as well.

Subglacial water pressure and ice deformation show periodic and episodic variations on several time scales, which are superimposed on long term trends. Interestingly, tilt sensors at different depths show a delay of up to half a period. Figure 1 shows data from drill site FOXX. The higher ice layers react immediately to subglacial pressure variations, while sensors closer to the bed show a delayed response. This delayed reaction is only found at drill site FOXX, while at site GULL the reaction is synchronous.

We interpret these observations as ice motion in a caterpillar-like fashion, as opposed to the conventionally assumed shear flow. Using a time-dependent, Full-Stokes ice flow model we find that spatially and temporally varying basal motion can explain the observed variations in deformation, and the delayed reaction at different depths. These new data show that the reaction to basal motion is not uniform throughout the ice column, but varies with depth. As the model results show, this variation is due to longitudinal stress coupling, transferring the sliding signal unevenly at different depths. Depending on the position of the drill sites with respect to the fast-sliding portion, or basal topography, different variations in vertical shearing can be expected.

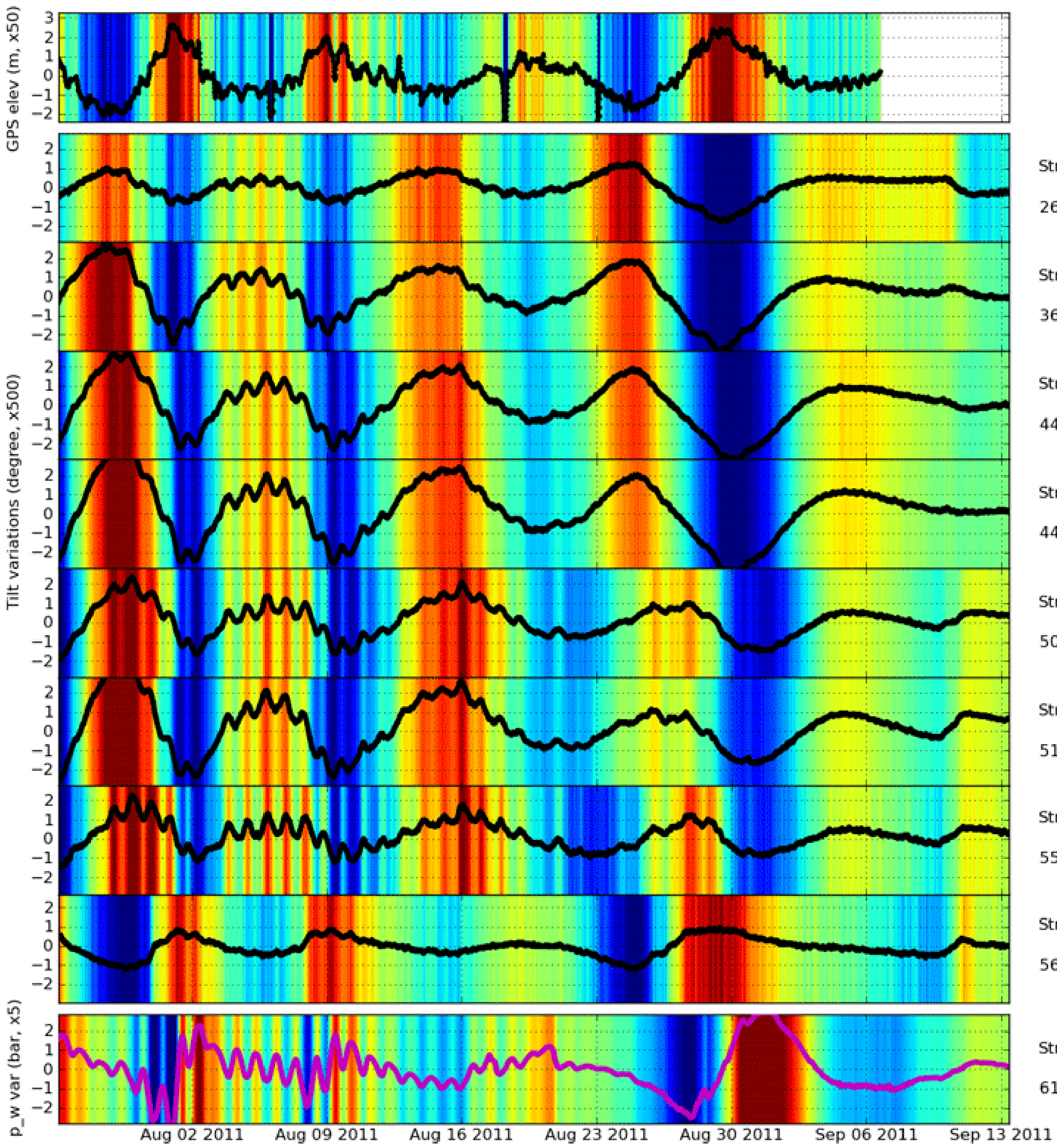

Figure 1. Borehole observations from drill site FOXX on the Greenland ice sheet. Shown are vertical surface displacement (top stripe), sensor tilt variations (extra motion superimposed on long-term trend), and basal water pressure (bottom stripe). Background coloring highlights the variability of the plotted curves, ranging from blue (low values) to red (high values).

Preliminary Hydroglaciological Research on Nannbreen, SW Spitsbergen

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Paper presents first study of water drainage structure on poorly recognized glacial and proglacial area of Nannbreen. Main objective focused on determination of meltwater circulation and its spatial distribution from glacier basin.

Nannbreen is a small land based glacier in Wedel Jarlsberg Land, SW Svalbard. It is 6,7 km long, descending from 700 to 100 m.a.s.l. at the end. Short part of glacier frontal (∼95 m) is terminated in a big proglacial lake, closed by over 100 m.a.s.l. high moraine complex. In the last decade actual snow line derived from satellite images has been calculated on 400-450 m.a.s.l. During 1999-2012 glacier frontal retreated about 400 meters, reducing glaciated surface of this zone by 0,6 km^2.

Research methods includes GPS mapping of glacier terminus and proglacial creeks, water sampling for chromatographic analyses (in preparation), and discharge estimation using SEBA F1 current meter. Measurements were conducted by Authors in August 2012. In addition basic precipitation and meteorological data were collected constantly from mid- July to late August 2012.

Obtained results presents simplified frontal drainage structure and quantitative distribution of meltwater from glacier system. The balance of incoming and outgoing volume of water from the lake shows that about 8% of measured water states underground outflow or comes from other sources. Proglacial drainage of Nannbreen is determined by its southern part, mainly by the intensive subglacial Eleo outflow (73,5%). Water circulation system in this part of forefield is complicated. Multi-point outflow with major stream is similar to the neighboring, well known Werenskiold Glacier. In view of recent research prospective using geophysical methods such as GPR sounding for more accurate hydrological recognition (especially glacial drainage systems) and to verify presented measurements is particularly important.

Ice volume estimates from ground-penetrating radar surveys, western Nordenskiöld Land glaciers, Svalbard

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As part of ongoing work within the SvalGlac project aimed to obtain a reliable estimate of the total ice volume of Svalbard glaciers and their potential contribution to sea level rise, in this contribution we present volume calculations, with detailed error estimates, for ten glaciers on western NordenskioÌĹld Land, central Spitsbergen, Svalbard. The volume estimates are based upon a dense net of GPR-retrieved ice thickness data collected over several field campaigns spanning the period 1999-2012, all of them except one within 2010-2012. The total area and volume of the ensemble are 113.38±0.09 km^2 and 10.439±0.185 km^3, respectively, while the individual areas, volumes and average ice thickness lie within 2.5-49.1 km^2, 0.08-5.48 km^3 and 29-108 m, respectively. The maximum recorded ice thickness, 265±15 m, corresponds to Fridtjovbreen, which has also the largest average thickness (108±1 m). Available empirical formulae for Svalbard glaciers overestimate the total volume of these glaciers by 24% with respect to our calculation. On the basis of the pattern of scattering in the radargrams, we also analyse the hydrothermal structure of these glaciers. Nine out of ten are polythermal, while only one is entirely cold.

GPS and hydrological observations during an autumn flood event and spring speed-up at Engabreen, Norway 2012.

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Introduction

It is widely accepted that basal hydrology plays an important role in the dynamics of glaciers, in particular of hard bedded glaciers, as it controls the lubrication of the ice-bed interface (Zwally *et al.*, 2002). In particular, the variability of water input into the subglacial environment regulates changes to the hydrological system, and determines the amount of basal sliding (Bartholomous *et al.*, 2008; Schoof, 2010). The sensitive relationship between variable water input and ice flow through the study of both surface and subglacial conditions has been explored at Engabreen, a small outlet glacier from the Svartisen Ice cap in Northern Norway.

For the past twelve months, a variety of field campaigns have been undertaken to investigate the impact and relationship between the subglacial hydrology and ice dynamics of this unique field site. Engabreen offers the opportunity to study the subglacial environment in the Svartisen Subglacial Laboratory which is located under ∼200 m of ice. Direct measurements of the basal hydrological conditions, in combination with a variety of surface measurements, allow us to address the relationship between surface and basal characteristics of hard bedded glaciers in a more complete fashion than previously reported. The range of datasets include continuous discharge datasets from gauging stations both subglacially and, air temperature data also collected at one of the gauging stations, surface velocities from three differential GPS', and continuous time-lapse imagery for August and September 2012.

Precipitation event

Between the 2^{nd} (Day of year 246) and the 6^{th} (day 250) of September 2012 an autumn storm caused a significant sizeable flood (33.62 m^3/s), which was recorded in both the river and lake gauging(data not shown here) stations (see Fig. 1 for location of river station). The peak of the flood appeared in the river hydrograph just after midday on day 249 (Fig. 2a). The highest daily rainfall of over 42 mm in 24 hours also fell on day 249 (Fig. 2b).

It is anticipated that there is some delay between the maximum input of rainfall and the maximum discharge in the river, depending on the efficiency of the subglacial drainage system. Possible reasons for this delay are discussed below.

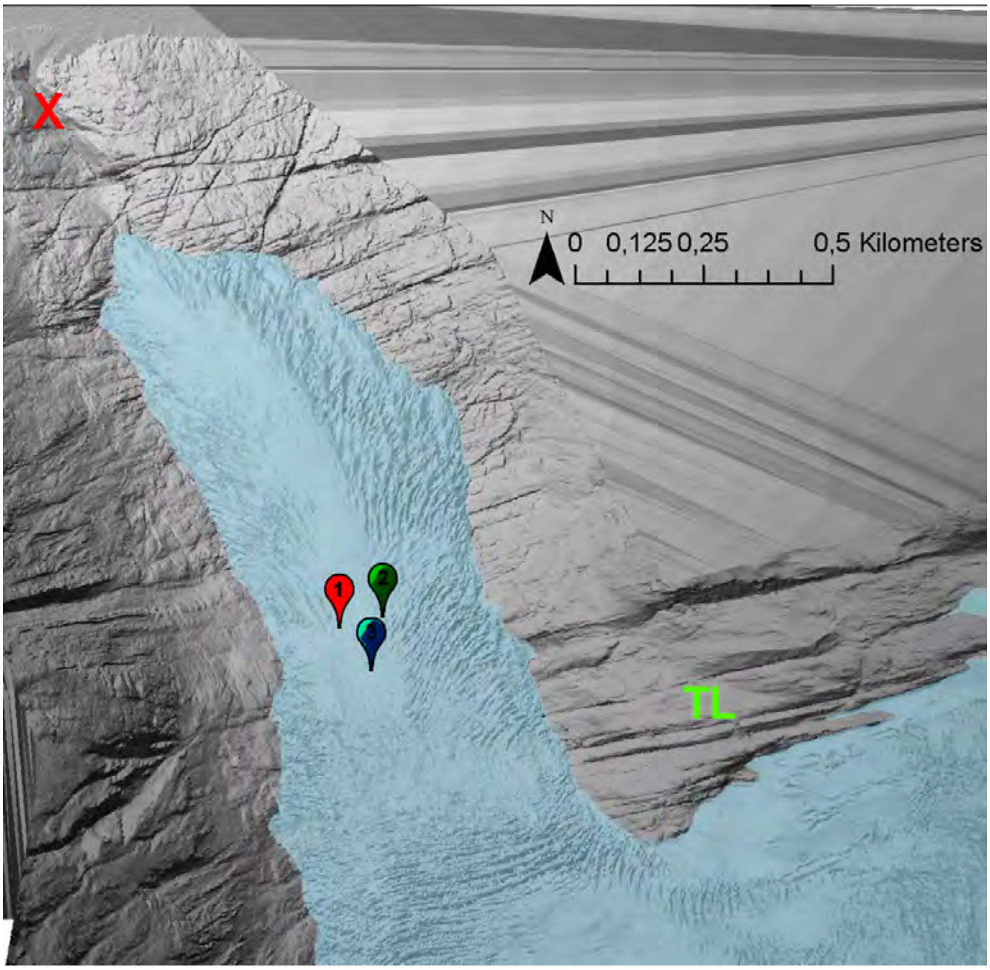

Figure 1. This is the most recent (2008) laser scan of the glacier and immediate proglacial area. The high resolution of the scan allows minor variations in the exposed bedrock to be highlighted, for example the cross-cut characteristic of the bed. The blue shaded area outlines the glacier extent in 2008. Since then the margins have receded slightly. The markers indicate the positions of the three GPS'. The marker colours correspond to the speed graph in Fig. 2b. The discharge station used in Fig. 2a is indicated in the top left of the figure with a red "X". The rough location of the time lapse camera is highlighted as a green "TL".

The precipitation event extends over a few days with a gradual build up in precipitation over the three days preceding the peak, with a range in rainfall between 8 and 18 mm/day. According to the hydrograph in Fig. 2a, the background discharge for this period is between 1.5 and 6 m^3/s. The spike of the flood stands out very clearly from the background value, indicating a 5-fold increase in run-off. From temperature recorded at a nearby meteorological station (data not shown here), the increase in melt rates was not temperature-driven. The onset of enhanced discharge at the end of day 248 signals the transition from a melt dominated to a rain dominated hydrograph. Whilst floods and elevated precipitation are not uncommon in this region, the steep rising limb on the hydrograph is indicative of a "flash flood" and one that is more likely to overwhelm the subglacial drainage system (Schoof, 2010).

During the time of the flood, 3 GPS instruments were recording surface motion on the lower tongue of the glacier. The GPS were approximately ~150 m apart, in a triangle type configuration (Fig. 1). The GPS data in Fig. 2c display interesting differences in speed between the three instruments, despite them being relatively close.

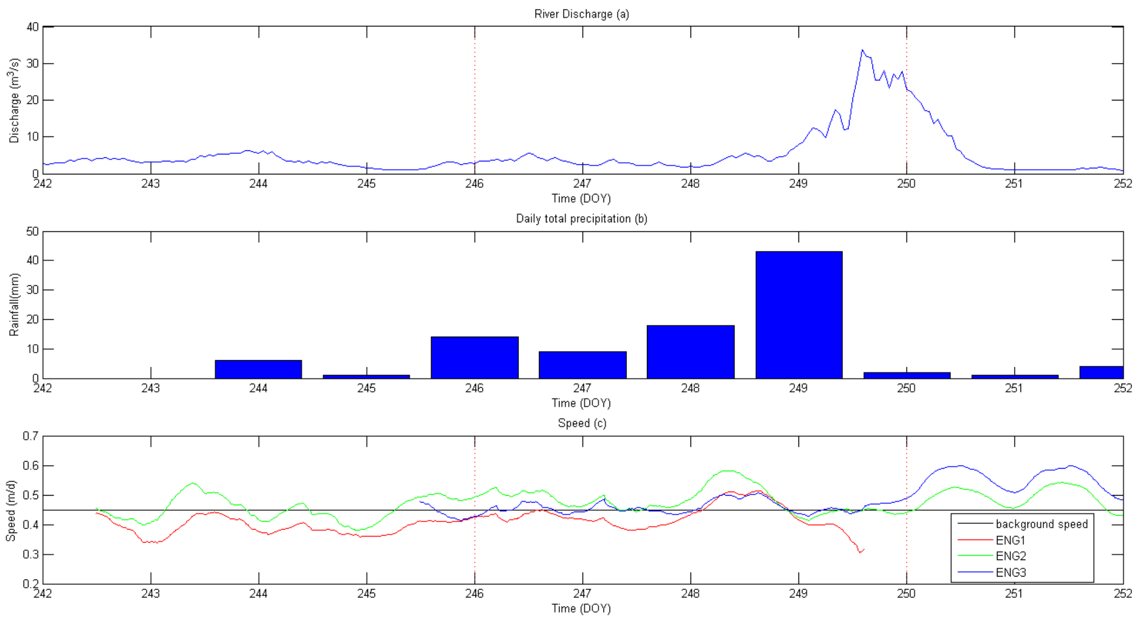

Figure 2. The different time-series of observations from around and on Engabreen during the flood. (a) is the hydrograph from the proglacial river, which is marked as a red "X" in fig. 1. The red vertical lines mark the precipitation period. (b) is a bar chart of total daily rainfall data from a meteorological station nearby. (c) Horizontal ice surface speeds from the three GPS instruments for the days leading up to, during and after the passing of the flood. A twelve hour moving median filter was applied to the GPS dataset. The black horizontal line at 0.45 m/d marks the background speed of the glacier at the lower tongue section. Unfortunately ENG1 suffered some instrument failure after midday on day 249.

One significant observation is the slight increase in speed of all the GPS' on day 248, which occurs before the peak in both rainfall and discharge. On reason for this may be due to the visible build up in precipitation from day 246 to 249 (Fig. 2c). From day 246 to 248 speeds of ENG2 and ENG3 remain elevated at approximately background speed; 0.45 m/d (Jackson *et al.*, 2005), suggesting a possible pressurisation period in the subglacial drainage network. The higher than background speed for ENG2 and ENG3 is likely to be caused by the continuous precipitation and water input during this period. ENG1 on the other hand has the lowest speed between day 246 and 248. The cross-cut nature of the subglacial topography may play a role in the funnelling of water into the drainage system, and as a result lead to spatial variations in pressurisation of the bed and as a result sliding.

A further plausible reason for the delay in the hydrograph in response to rainfall is the significant storage of water in the glacier. It is unlikely that large volumes are stored in firn layers this late in the season, and a visit prior to the flood indicated that a blue ice surface existed. There was also little evidence of surface ponding or a supraglacial stream network. We are therefore led to assume that water was collected in the englacial and subglacial system, brought about by the inability of the drainage system to accommodate the sudden increase in water input. The effects of water input and temporary storage at the ice-bed interface can lead to significant changes in lubrication and as a result sliding of the ice (Zwally *et al.*, 2002). Although our data is indicative of a limited response to this interaction, the signal produced suggests a more complex relationship than that described. One explanation could be due to the local bed conditions found at Engabreen. There seems to be a slight discrepancy in the speeds of the different

GPS'; for example ENG1 appears to have overall the slowest speed throughout the period. Previous studies and a preliminary assessment of the bed geometry suggest an over deepening under ENG1 (Fig. 2b). Were this to be the case, then ENG1 would be situated directly above a subglacial drainage channel, and potentially have the most efficient hydrological conditions at the underlying bed Although this does not exclude possible pressurisation in this region, the timing may be slightly later than in other areas. ENG2 appears to respond first to the input of water which could suggest a direct funnelling of water underneath this region. ENG3 responds similarly to ENG1, however beyond day 249, its variations in speed are better correlated to ENG2. Unfortunately ENG1 malfunctioned after day 249 so any further interpretation of their combined relationship is not possible.

Before any further more concrete conclusions can be drawn from these datasets, a more complete exploration of the bed under Engabreen is needed. A longer GPS dataset would also offer a better background motion. This will allow significant changes in surface speeds to be identified more clearly. In addition, a further extension of ice flow data to other areas of Engabreen will further strengthen our interpretations. The aforementioned suggestions are the main goals of the 2013 field season.

Additional data and further work

In addition the GPS', a time-lapse camera recorded up to 10 daily images over the icefall area directly above the laboratory. A lot of interesting additional information has been obtained from these images; such as timing of the first snowfall and elevation, further weather information and observations of an evolving marginal glacial lake at approximately ∼700 m a.s.l. The main purpose of the time-lapse data is to get a velocity field in the rather inaccessible icefall area above the lab. These images are currently being processed with feature tracking software to extract velocity data for September 2012, which we hope will provide further insights into ice flow variations over the subglacial laboratory, which is situated almost directly underneath the ice fall.

A longer 6 month dataset of GPS measurements are planned for 2013, and it is hoped that the longer time series will allow us to identify the transition between winter, spring and summer speeds. In addition, a ground penetrating radar (GPR) campaign on the glacier tongue will hopefully provide an insight into the true topography of the bed, and may indicate a dominant flow path for subglacial water routing to the porthole. This data will significantly aid the interpretation of the drainage network, as well as new and old GPS data at Engabreen.

Summary

The GPS dataset presented here in combination with the discharge and precipitation data provides a preliminary insight into the impact that sudden changes in hydrology can have on the ice flow at Engabreen. It is clear that when interpreting velocity data at Engabreen, a good assessment and understanding of the localised bed conditions, including bed topography, is essential. Engabreen has a distinct cross-cut exposed bed topography that is emphasised in the laser scan of 2008. It is believed that these structures play a significant role in the different timing of the responses expressed at the surface. The 2013 field season will address many of these uncertainties, especially the finer details of the bed topography.

The GPR campaign will hopefully provide some positive results and further assist in the interpretation of the 2012 and 2013 GPS datasets.

Ultimately the aim of this project is to collate and interpret supra and subglacial datasets collected throughout this and previous field seasons at Engabreen; with the intention of generating a more complete understanding of the complex interaction between water input and ice flow response. Further modelling endeavours are planned to assist with the up scaling and testing of our overall findings.

Acknowledgements This work was carried out as a part of the Nordic Centre of Excellence SVALI, Stability and Variations of Arctic land Ice, funded by the Nordic Top-level Research Initiative. Many thanks to Pierre-Marie Lefeuvre, Heïdi Sevestre and Tobias Hipp for help collecting the data in this report. Local precipitation data from Neverdal was provided by T. Werningsen.

References

Bartholomous, T.C., R.S. Anderson, and S.P. Anderson. 2008. Response of glacier basal motion to transient water storage. *Nature Geosci.*, **1**, 33–37.

Jackson M., I.A. Brown, and H. Elvehøy. 2005. Velocity measurements on Engabreen, Norway. *Ann. Glaciol.*, **42**, 29–34.

Schoof, C. 2010. Ice-sheet acceleration driven by melt supply variability. *Nature*, **468**(7325), 803–806.

Zwally, H.J., W. Abdalati, T. Herring, K. Larson, J. Saba, and K. Steffen. 2002. urface melt-induced acceleration of Greenland ice-sheet flow. *Science*, 297(5579), 218–222.

On the climate forcing of glacier mass-balance variability at Vestfonna ice cap, Svalbard

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The ice cap Vestfonna located on Nordaustlandet in northeastern Svalbard is one of the largest ice bodies of the European Arctic. We present a modeled climatic mass balance time series for this ice cap for the period 1979-2011 (Möller *et al.*, 2013). Based on this time series we further present an analysis of climate forcing mechanisms responsible for interannual variability of seasonal and annual balances.

Climatic mass balance was modeled by using a temperature-index calculation of ablation that accounts for spatially distributed net shortwave radiation influences in combination with an elevation dependent calculation of accumulation. The contribution of refreezing processes to the mass balance is estimated using the basic Pmax approach. The calculation of net shortwave radiation accounts for cloud cover forcing and altitudinal surface albedo variations that are calculated by a statistical model. The mass balance model is forced with ERA-Interim data (2 m air temperature, total precipitation and total cloud cover) of a grid point just south of the ice cap.

A mean annual climatic mass balance of +0.09 m w.e. was modeled for the period 1979-2011. The standard deviation of ±0.15 m w.e. indicates a high interannual variability of climatic mass balances at Vestfonna. Values of individual years range between -0.25±0.18 m w.e. (2002/2003) and +0.34±0.18 m w.e. (1999/ 2000).

Standardized anomalies of seasonal and annual climatic mass balances were related to anomalies of atmospheric circulation pattern frequencies during the respective mass balance seasons and years. Nine different atmospheric circulation patterns had been identified for the Svalbard region (Käsmacher and Schneider, 2011) and were considered in this analysis.

Especially winter/annual accumulation and thus winter balance anomalies are significantly correlated to the frequency anomalies of two particular atmospheric circulation patterns. Regarding summer balances, only strong anomalies (deviation from the mean of >0.75 sigma) show a significant correlation to one particular atmospheric circulation pattern. Overall, we found that almost 50% of the variance of annual climatic mass balance anomalies can be explained exclusively by anomalies of atmospheric circulation pattern frequencies.

References

Käsmacher, O. and C. Schneider. 2011. An objective circulation pattern classification for the region of Svalbard. *Geogr. Ann. A*, **93**(4), 259–271.

Möller, M., R. Finkelnburg, M. Braun, D. Scherer and C. Schneider. 2013. Variability of the climatic mass balance of Vestfonna ice cap (northeastern Svalbard), 1979-2011. *Ann. Glaciol.*, **54**(63), 254–264.

Ice volume estimates from ground-penetrating radar surveys, Wedel Jarlsberg Land glaciers, Svalbard

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[4] Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland

One of the aims of the SvalGlac project is to obtain an improved estimate, with reliable error estimates, of the volume of Svalbard glaciers and their potential contribution to sea level rise. As part of this work, we present volume calculations, with detailed error estimates, for eight glaciers on Wedel Jarlsberg Land, southern Spitsbergen, Svalbard. The volume estimates are based upon a dense net of GPR-retrieved ice thickness data collected over several field campaigns spanning the period 2004-2011. The total area and volume of the ensemble are $502.9 \pm 18.6\,km^2$ and $80.72 \pm 2.85\,km^3$, respectively. Excluding Ariebreen (a tiny glacier, $< 0.4\ km^2$ in area), the individual areas, volumes and average ice thickness lie within $4.7 - 141.0\,km^2$, $0.30 - 25.85\,km^3$ and 64 - 183 m, respectively. The maximum recorded ice thickness, ca. 619 ± 13 m, is found in Austre Torellbreen. To estimate the ice volume of small non-echo-sounded tributary glaciers, we used a function providing the best fit to the ice thickness along the centre line of a collection of such tributaries where echo-soundings were available, and assuming parabolic cross-sections. We did some tests on the effect on the measured ice volumes of the distinct radio-wave velocity (RWV) of firn as compared to ice, and cold versus temperate ice, concluding that the changes in volume implied by such corrections were within the error bounds of our volume estimate using a constant RWV for the entire glacier inferred from common mid-point measurements on the upper ablation area.

Monitoring calving and crevasse opening rates

Faezeh M. Nick and Doug Benn

In our calving model, calving is assumed to occur when surface and/or basal crevasses reach a specified penetration depth. Crevasse penetration is calculated using a simple relationship between fracture depth and tensile stress, with prescribed depths of infilling water. Here we aim to understand and model a relationship between fracture density and flow rate and available surface runoff. There are very few data available on crevasse fields and their relationship with glacier strain rates and other variables. To develop a comprehensive model we need much more data on the relationship between crevasse penetration depths and variables such as surface strain rates and depth of water inside crevasses. To investigate these relationships, we will monitor crevasse opening rates, penetration depths, and varying crevasse water levels on Tunabreen and Kronebreen in Svalbard. We use crevasse-monitoring units, which measure:

1. Water level and its variation inside a surface crevasse by using three pressure/temperature sensors placed on the glacier surface, floating on the water level inside a crevasse and at a bottom of the crevasse.
2. Crevasse opening rate, by installing a strain rate unit between the crevasse walls
3. Glacier flow speed, using GPS units.

Ten years of research on McCall Glacier (2003-2012)

Matt Nolan

University of Alaska Fairbanks

In this talk I will present an overview of the past 10 years of research on McCall Glacier, in Arctic Alaska.
During this time we have:

- conducted mass balance on a network of 30-60 stakes in spring and fall
- recovered an ice core for paleoclimate and pollutant transport analysis
- measured ice temperatures to bedrock in 3 locations
- extensively mapped the ice thickness and cold/warm ice transition depth using radar

- employed 3D flow modeling to both understand the glacier's history and predict its future
- maintained a network of up to 12 weather stations
- determined surface energy flux balance of the glacier surface
- cored the firn each year from 2008-2012 to directly measure internal accumulation and compare this with coincident thermistor strings
- used lidar to measure surface elevations of over 400 glaciers in the area from 2008-2011
- calculated regional ice volume change from 1957-2008 (and onwards)
- measured river discharge of the glaciated basins here to better understand the impacts of shrinking glaciers on local ecosystems

This work follows in a long tradition of research here which began in 1957 as part of IGY.

The 2000s glacier inventory of Svalbard and glacier change patterns

Christopher Nuth, Jack Kohler, Max König, Jon Ove Hagen, Andreas Kääb, Geir Moholdt, Rickard Pettersen

The newest digital inventory of Svalbard glaciers contains 1583 individual glacier units comprising a total glaciated area of 33,827 km^2, 57% of the archipelago. The inventory design is inherited from the first available inventory of the archipelago but progressively updated and modified through time to accommodate the changing glacier geometries. There are 169 tidewater glaciers that drain 68% of the glaciated area through a glacier terminus width (summed) of about 687 km. The glaciated area decreased by about 78 km^2 a^{-1} on average over the past ≈30 years, a reduction of 7% of the original area. The spatial patterns of change reveal the largest retreats in the central, drier, areas of Spitsbergen and on Edgeøya- Barentsøya. These regions consist mainly of land-terminating glaciers. In addition, land- terminating glaciers of central Spitsbergen generally experience a decelerating retreat as a result of rapid geometrical adjustment to the warmer 1930s-40s after the end of the little ice age where glaciers experienced their maximum extents. For tidewater glaciers, a slight acceleration is apparent on the southeast coast of Spitsbergen where the other regions are mainly showing no retreat rate differences or even slight deceleration. We find that reducing the dimensions of change from an area to a length scale provide a better parameter for spatio-temporal analysis and interpretation of change signals. Moreover, hydrologically defined glacier identifications enhance the analysis of inventory changes which would not be possible using a geometrical identification system.

Towards quantifying the uncertainty of glacier energy and mass balance calculations

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We investigate the long-term energy and mass balance at a site close to the ELA of the glacier Kongsvegen (Svalbard). This was based on meteorological and glaciological data driving a glacier mass balance model throughout a full decade. A reference run is validated by key observations and the calculated mass and energy balance components are analyzed regarding the average daily, seasonal and interannual variations. A primary approach to quantify the uncertainty of the results is based on sensitivity studies applying single parameter perturbations of key model input and parameterization adjustments. The gross results appear most sensitive to uncertainties in input radiation data, while uncertainties in model parameterizations appear less critical. Admittedly, however, this approach is rather simplistic (single parameter and static) though commonly being used. Thus, we now investigate the potential of more sophisticated methods to quantify the uncertainty of mass and energy balance calculations. This firstly concerns a better i.e. statistical description of the effective accuracy of input data and ranges of model parameters based on prescribed PDF functions. We further employ a Monte-Carlo type method yielding a statistical description of the effect of various uncertainty scenarios on the calculated energy and mass balance of the glacier. This also allows consideration of combined parameter uncertainties impacting simultaneously on the results.

Quality assessment of MODIS land surface temperatures over an Arctic ice cap

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Surface temperature is governed by the surface energy balance and therefore a key variable in climate monitoring and in glacier melt observation and modelling. In the data sparse cryosphere, satellite-derived land surface temperature (LST) has a high spatial and temporal coverage. Clear sky LST derived from the Moderate Resolution Imaging Spectrometer (MODIS) has a reported uncertainty of below 1K under most circumstances. The few studies validating the product over snow and ice surfaces indicate a much higher uncertainty of up to 4K.

The MODIS LST level 3 product is compared with 8 years of meteorological data of an automatic weather station (AWS) located on the Austfonna ice cap, Svalbard. The smoothness of the ice cap in terms of topography, temperature and emissivity makes it an ideal site for comparing point measurements with the 1 km MODIS resolution. We find an overall RMS between MODIS LST and measured surface and air temperature of 5.4 and 6.2K, respectively. Clouds are opaque in the thermal spectrum and the MODIS LST product has an internal cloud detection to remove cloud contaminated LST. We derive a cloud index from the AWS data and find that over snow and ice the MODIS procedure detects too few clouds. Of the scenes classified as cloudy according to AWS data, MODIS interpreted 42% as clear sky during winter and 20% during summer. Due to prevailing cloud condition at Austfonna only 22% of the successfully produced LST are acquired under actual clear sky conditions. The deficient MODIS cloud detection is demonstrated by the RMS of 7.0K under actual cloudy conditions, in contrast to the 3.2K under clear sky conditions. The LST-data set has a great potential for glaciological applications on larger glaciers and ice caps. Nevertheless, thermal remote sensing over snow and ice surface in cloud prone areas like Svalbard remains challenging.

Temporal variability of flow of Hansbreen a tidewater glacier in Southern Spitsbergen

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Tidewater glaciers are important contributors to the global sea level rise. Data on flow velocity of this type of glaciers are important for both calculation of ice mass flux into the sea due to calving and for studies on better understanding of calving mechanism. Hansbreen is a grounded, polythermal tidewater glacier in Spitsbergen with relatively long set of data of flow velocity. Systematic high time resolution measurements of surface velocity have been conducted near the mass balance stake T4 since 2005. It is located c. 4 km upstream from the glacier terminus just outside the badly crevassed frontal zone. Precise differential GPS has been used for this kind of record in the time lapse mode (every 3 hours). Additionally, position of every mass balance stake along the glacier centerline has been surveyed manually at least every month.

The paper presents results of flow velocity changes for the period 2005-2010. Processed data show that so called summer acceleration of glacier flow consists of one of couple speed-up events with 2-3 times faster movement than occurred in the anteceded period. Such cases are induced by higher melt rate periods or heavy rainfalls and lasted usually 2-4 days. High speed periods were noted also during fall after heavy rains. They could appear during dark winter too. Significant inter-annual variability of glacier velocities has been noted. Differences are related to changeable weather factors. High sensitivity of glacier dynamics to supply of water from the glacier surface into the basal drainage system has been confirmed. Spatial distribution of flow velocity is also presented. All results show more complicated picture of glacier spatial and temporal flow pattern than previously thought.

Modeling Nordaustlandet's ice-caps

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Nordaustlandet is the second largest island in Svalbard and has two ice-caps: Austfonna and Vestfonna. In the current project we address some aspects of present-day simulations which are of importance for future prognostic simulations. For present-day simulations Vestfonna and Austfonna can simply be treated separately since they are currently not connected. Both feature fast flowing outlet glaciers, many of which are known to exhibit surge behaviour. The ability to simulate surging behaviour is essential in order to carry out accurate quantitative future projections.

The spatial pattern of basal drag is inferred from measured surface velocities using a Robin inverse method for different years (1995, 2008, 2011). The measured surface velocity fields are not all spatially complete, necessitating additional processing. We present the basal drag patterns, focussing on Franklinbreen and Basin 3. Both these outlet glaciers show large speed up between 1995 and 2008. The observed large differences in basal drag highlight the potential weakness of future projections initialised with basal drag fields and kept constant through the simulation.

Motivated by the expectation that temperature plays an important role in the onset of these fast flowing outlets, we investigate its distribution within the ice-body and especially at the basis using the velocity field obtained through inverse modelling. Specifically, surface temperature, geothermal heatflux, friction-, strain- and firn heating all impact on the temperature, and potentially on sliding, a key feature of surge behaviour. We show that basal temperature is most sensitive to friction heat. Firn heating is important in the upper part of the ice at the thicker central parts.

First century-length prognostic simulations as well as the sensitivity to the used basal drag distribution and the coupling to a surface mass balance model will also be presented.

Response of subglacial drainage network in western Greenland to changing boundary conditions revealed from space

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About 50% of the current mass loss of the Greenland ice sheet (GrIS) is attributed to meltwater runoff from the land-terminating parts of the ice sheet. However, the impact of increasing summer melt on the dynamics and stability of the GrIS is not fully understood. Therefore, sub-seasonal information about the icesheets' dynamics and the cyclic evolution and capacity of the subglacial drainage system is crucial, as it links ice sheet acceleration, melting, and supraglacial lake drainage.

We use a time series of 14 ascending and descending TanDEM-X stripmap scenes over Russell glacier in West Greenland covering the melt period in 2011 to study sub-seasonal changes of surface elevation and ice dynamics. We apply a novel approach utilising incoherent offset tracking on SAR amplitude images of crossing ascending and descending orbits. As an improvement over the conventional technique, this method delivers the three components of the displacement vector (x, y, and z).

We will report on the time series of velocity and surface elevation change. We find a gradual slow-down of the ice in the course of the summer, indicating the development of an effective subglacial drainage system. However, the entire area speeds up again in late summer which is due to intensive rainfall. During this event, large areas of the icesheet show high uplift rates indicating the accumulation of water beneath the ice. Furthermore, the spatial pattern of surface elevation changes reveals the seasonal development of a subglacial drainage system in the area which seems to be governed by channel flow.

An overview of IMAU observations along the K-transect at the Greenland ice sheet margin

Paul Smeets, Wim Boot, Michiel van den Broeke, Hans Oerlemans, Henk Snellen, Roderik van de Wal and many more

We present an overview of the observations carried out along the K-transect near Kangerlussuaq (West-Greenland) by the IMAU over the last 21 years. In the summer of 1990 and 1991 the IMAU initiated the Greenland ice margin experiments (GIMEX) and started to perform yearly mass balance and GPS observations ever since. Currently this is the longest record of ground-based surface mass balance measurements in Greenland. Lateron continuous hourly observations by automatic weather stations (2004) and GPS instruments (2006) were added. In addition during the last 10 years many temporary experiments were performed at several locations along the K-transect to study specific processes in more detail. Examples are year-round eddy correlation measurements, short wave satelite band radiation measurements, subglacial pressure and temperature measurements, ground reflector deployment for testing P-band ice sounding radar and a snow drift experiment. Data from the subglacial experiment and IMAU ice velocity measurements will be presented in more detail.

Precise Point Positioning (PPP) and its application to studies in ice dynamics in West Greenland

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Introduction

Traditional evaluation methods for precise GPS measurements are the well-known baseline post-processing using two GPS receivers as reference and rover simultaneously. If only one receiver is used, or if no other external reference station is available, there exists the differential GPS solution (DGPS) like EGNOS, WAAS etc. Their accuracy is limited to "meter".

Since some years another evaluation method is available: The Precise Point Positioning (PPP) (Zumberge *et al.*, 1997; Kouba and Héroux, 2000; Mireault *et al.*, 2008; Kettemann, 2011; Rizos *et al.*, 2012). Principally this method is a single point solution with the use of precise satellite orbits and precise satellite clock offsets, gained mostly from the products of the International GNNS Service (IGS, 2009). Additionally tropospheric delay and ionosopheric corrections are estimated, and some other biases are incorporated. The accuracy is expected to about 5 cm, depending of observation time and post processing latency. There are several services which offer the data processing via internet (free of charge). We used the Canadian Spatial Reference System (CSRS) from the Natural Resources Canada (NRCan). They offer an automated processing of static and kinematic GPS measurements via Internet.

In the presentation we discuss the accuracy of PPP and the application to our ice reference GPS station, which was standing on the ice for about 8 hours. So we are able to determine the short-term ice flow velocity during our measurements in summer time. This velocity is compared to the all year average velocity and shows the accelerated flow speed in summer. The results are demonstrated with the data at Swiss-Camp and ST2 in the western part of the Greenland ice sheet.

Accuracy assessment of PPP in high latitudes

For glaciological applications in the Arctic it is essential to know the accuracy under the special conditions in high latitudes. In contrary to Central Europe the GPS satellites are only available with low elevation angel which causes worse determination particularly in the height component.

Static GPS observations

In order to study the accuracy of static GPS measurements, we compare the results of PPP results with "true" values provided by AUSPOS (AUSPOS, Online GPS Processing Service) baseline resolutions in the ITRF system. From figure 1 we can see that the deviations for three points in Ilulissat and ST2 (on inland ice) from

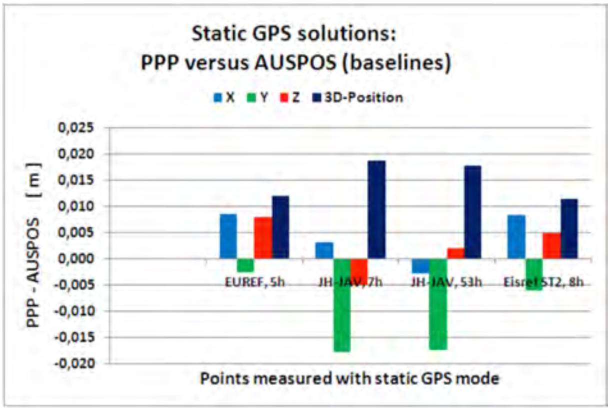

Figure 1. Comparison of Static GPS solutions between PPP and "true" values from AUSPOS baseline processing.

"true" coordinates are within 18 mm (3D-position error). Longer observation time as 5 hours will increase the accuracy only minimal.

The intersection of a 5-hour dataset into five 1-hour datasets shows (Fig. 2) that the accuracy for a 1-hour-observation is limited to about 5 cm. More detailed analysis of the processing summary shows that this accuracy-level could already be achieved after 35 minutes. Anyway, it is recommended to observe at least 1 hour.

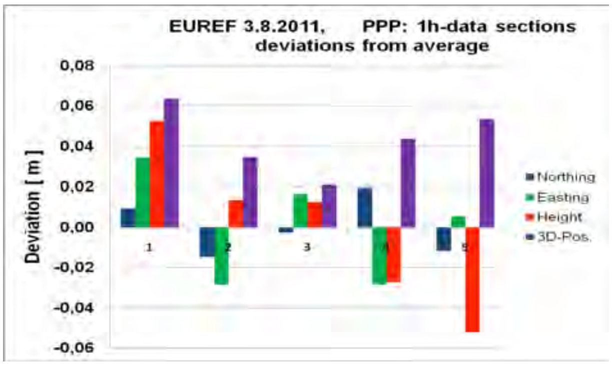

Figure 2. Comparison of 1-hour data sets of Static GPS solutions with PPP.

Kinematic GPS observations

In order to study the accuracy of kinematic GPS with PPP we processed a 52-hour data set on a stable fix point in Ilulissat. Figure 3 shows the variations in coordinates during the observation time. The standard deviations are about 5 cm in Northing and Easting, but 12 cm in height. The largest discrepancies are in the order of 40 cm (height) indicating parts of minor accuracy caused by bad satellite constellation, poor estimation of tropospheric delay and ionospheric disturbances. It should be noted, that these large discrepancies will be filtered out if the data set is processed in the static mode!

Application of PPP in order to determine ice flow velocities

In all our campaigns we had run an ice reference GPS all day for about 8 hours at same place. This receiver moves with the ice during the measuring period. The evaluation of this data in the kinematic mode gives the current ice flow velocity. As the measurements were usually performed end of July or beginning of August, these velocities are representative for the seasonal summer time. They mostly

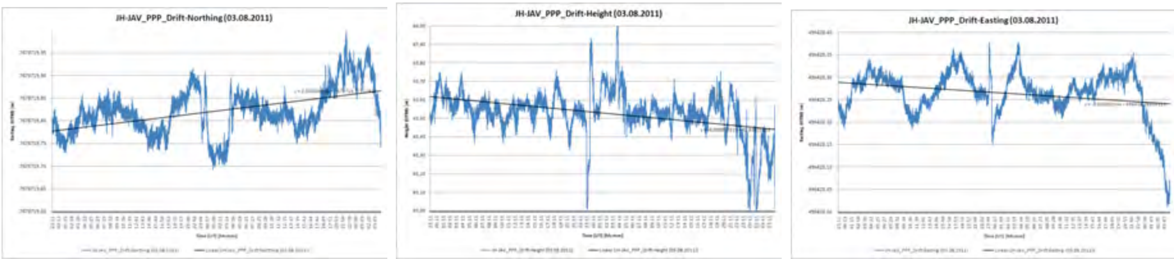

Figure 3. Variations of solutions with PPP in a 52-hour data set (Northing, Easting, Height) of kinematic GPS on a stable fix point.

exceed the all-year average speed by about 30% at Swiss-Camp and even more evidently at ST2. This behavior is typical for the enhanced melt water in the ice body and on the bedrock in summer and it is agreeable with modeling and investigations by Colgan *et al.* (2012). The minor flow speed at Swiss-Camp in summer 2005 is corresponding to the less (negative) geodetic mass balance in the same year (Stober *et al.*, 2013).

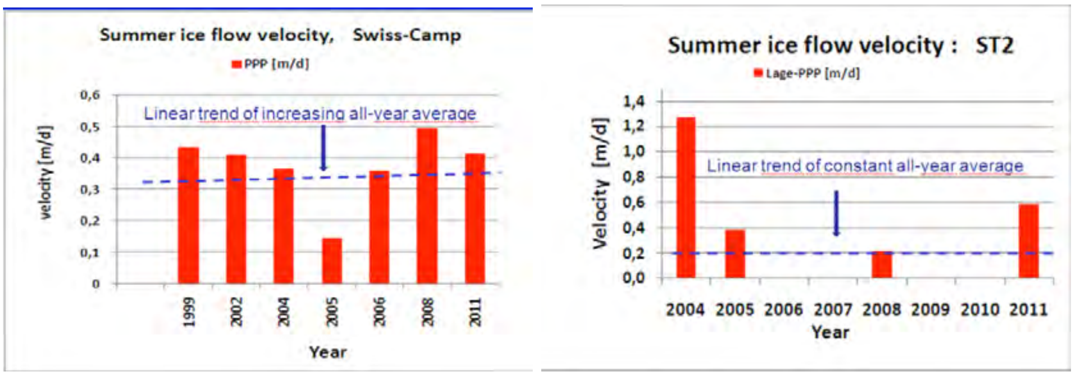

Figure 4. Summer ice flow velocities from solutions with PPP at Swiss-Camp (left) and ST2 (right) and comparison to the long-term all-year average velocities.

Summary

The "Precise Point Positioning" (PPP) is a good tool for evaluation of static and kinematic GPS data and is also suitable in high latitudes. The 3D-position accuracy of a static 1-hour observation could be assessed within 5 cm. The application of PPP in the kinematic mode to an 8-hour observation of the ice reference station gives the current seasonal ice flow velocity. This velocity (summer) exceeds the all-year average significantly and corresponds to modeling.

Acknowledgements The research 2010-2011 was funded by the German Research Foundation (DFG).

References

AUSPOS. Online GPS Processing Service powered by the Australian Government. http://www.ga.gov.au/earth-monitoring/geodesy/auspos-online-gps-processing-service.html

Colgan, W., H. Rajaram, R. S. Anderson, K. Steffen, H. J. Zwally, T. Phillips, and W. Abdalati. 2012. The annual glaciohydrology cycle in the ablation zone of the Greenland Ice Sheet: Part 2. Observed and Modeled Ice Flow. *J. Glaciol.*, **58**(207).

IGS. 2009. IGS products. International GNSS Service. http://igscb.jpl.nasa.gov/components/prods.html

Kettemann, R. 2011. Precise Point Positioning: A GNSS Method for Georeferencing Isolated Regions. *Applied Geoinformatics for Society and Environment (AGSE)*, 36–40. Nairobi, Kenya.

Kouba, J., and P. Héroux. 2000. GPS Precise Point Positioning using IGS orbit products. *GPS Solutions*, **5**(2), 12–28. DOI 10.1007/PL00012883.

Mireault, Y., P. Tétreault, F. Lahaye, P. H'eroux, and J., Kouba. 2008. Online Precise Point Positioning. *GPS World*, Sep. 2008, 59–64.

Natural Resources Canada (NRCan). Canadian Spatial Reference System CSRS. http://www.geod.nrcan.gc.ca

Rizos, C., V. Janssen, G. Roberts and Th. Grinter. 2012. Precise Point Positioning: Is the Era of Differential GNSS Positioning Drawing to an End? *FIG Working Week*. Rome, Italy, 6-10 May 2012.

Stober, M., Rawiel, P. Hepperle, J. and R. W"ossner. 2013. Long-term observations (1991 âĂŞ 2011) of elevation change and ice flow velocity in the swiss-Camp area (West Greenland). *GEUS Rapport*, **3**, 68–72. The Dynamics and Mass Budget of Arctic Glaciers. IASC Network of Arctic Glaciology, 9-12 January 2012.

Zumberge, J.F., Heftin, M. B., Jefferson, D.C. Watkins, M. M. and F. H. Webb. 1997. Precise point positioning for the efficient and robust analysis of GPS data from large networks. *J. Geophys. Res.*, **102**(B3), 5005–5017.

Morphological and morphometric features of sandar as proxy records of extreme discharges of glacier rivers

Joanna Szafraniec

Surge type behavior of ice masses seems to be an important factor of their decay in time of climate warming. Proxy geomorphological records of such type of behavior are very valuable for detection of surges in the past both in contemporarily glaciated areas and in Pleistocene. Distinction between relief features of sandar formed by glacier rivers with "normal" water discharges governed by their diurnal and seasonal fluctuations and those developed by outburst floods are in focus of presented studies. They concern morphology and morphometry of sandar in Svalbard, Iceland and palaeoglaciological reconstructions of the last glaciation in Poland.

Glacial floods are one of the most influencing phenomena on a relief. Their origin could be different but some of them are directly linked with the subglacial drainage instability as it is in the glacier surge case. Ice-cored moraine ridges cut by gorges, outwash fans spread from gorges mouths, covering the distal slopes of moraines with fluvioglacial sediments are characteristic landforms complexes indicating the glacier advance during the active phase of the surge. Their formation were probably initiated by an outburst flood of subglacial water or catastrophic drainage of ice-dammed lake. Fluvioglacial deposits building the interchannel zones of the outwash fan consist of larger grains than analogical, in the same distance from the gorge, forming the channels bottom during the "normal" discharges. Distinct tunnel valleys at the end moraines back, being the extension of gorges, the suspended gorges level over the end depression level, washed-out elder landforms were remains after those extreme processes.

Morphometry of a sandur could be described by the relief intensity factor carried out on the basis of a digital elevation model and the spatial distribution of superficial geologic formations. Sandar linked with the active phase of the surge or formed by the sudden ice-dammed lake drainage are characterized by lower values of this factor - around and below 6 (fragments of Skeidarársandur - Iceland, Elveflya or Gåshamnöyra - SW Spitsbergen, the Gwda outwash plain - Pomerania, NW Poland). During the quiescent phase of the surge the tensed glacier tongue was buried by fluvioglacial deposits. Progression of areal deglaciation caused the dead ice disintegration and melting. It was resulted in very diversifying relief called the knob-and-kettle sandur - with high value of the relief intensity factor above 10 (the inner part of the Werenskiold Glacier marginal zone - SW Spitsbergen, sandar linked with gorges within the next generations moraine ridges in Pomerania). Sediments deposited earlier were cut during the glacier recession forming sandur valleys with typical erosional character. Landforms complexes common for the Spitsbergen, Iceland and Pomerania relief of marginal zones seem to indicate that the glaciers evolution in response to the climate change, where the surge is an important phenomenon, is a typical trend.

Understanding links between snow cover and mass balance using a dense monitoring network in a small Arctic glacier basin (Austre Lovénbreen, Svalbard 79°N).

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Glacier ice is the result of successive transformations of snow. All glaciers are therefore strongly linked with seasonal snowfalls. The frequency of snowfalls, the quantities involved, and the quality of snow all have an influence on the dynamics of glaciers. Snow cover is the prime source of new ice, but it also has a protective role in ablation areas of glaciers. From an hydrological point of view, snow also constitutes an important part of the outflows of glacier basins.

A monitoring protocol based on a network of stakes and complemented with regular snow drilling campaigns has been carried out for 5 years on the Austre Lovénbreen (Spistbergen, 79°N). Overall, 36 measurement points have been distributed at regular intervals over the 4.5 km^2 glacier surface. For each of these points the snow cover was measured at a period close to its yearly maximum (usually late April) and expressed in terms of snow height and water equivalent. Mass balance was also recorded yearly at the end of September.

Results show that there is a strong link between the annual snow maximum and the resulting mass balance. Areas with the strongest ablation are the ones displaying the highest variability. This is particularly true on years when the snow cover at lower elevations disappears early in the season, exposing ice. In the upper reaches of the glacier, the links between snow cover and the resulting balance measurements are not clearly structured. Variability seems related to orientation and more or less sheltered position of the accumulation cirques. On most of the remaining glacier area, and especially near the equilibrium line altitude, snow cover and mass balance display a strong correlation.

Increasing meltwater discharge from the Greenland ice sheet into Nuuk Fjord and implications for glacier mass balance (1989-2012)

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We assessed the runoff and surface mass budget of the glacier catchments in the Nuuk (south-western) region of the Greenland ice sheet, using automatic weather station (AWS) and regional climate model (RCM) data. The region encompasses six glaciers that contribute to the hydrology of Nuuk Fjord, amongst them Kangiata Nunata Sermia, the largest glacier south of Jakobshavn Isbræ. The separate catchments were delineated using a surface velocity map. Hereafter, the coarse-resolution RCM data were inter- and extrapolated to fit the exact ice margin, only using data from the models' ice-masked areas. RCM data were evaluated using AWS and river discharge measurements. Runoff and surface mass budget show large interannual variability due to precipitation, and were trendless roughly up to 2000, when this area is estimated to have been in near-equilibrium. Since 2000, runoff has increased and SMB decreased, causing a negative total mass balance. If conditions in recent years were to set the norm for the remainder of this century, we can expect a SMB contribution to sea level rise of ~5 mm by 2100 from this relatively small section (2.7%) of the ice sheet.

An inter-comparison of techniques for determining glacier velocities over Svalbard

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This study provides a comparison of glacier surface velocities derived from speckle tracking, amplitude feature tracking and interferometry of Radarsat-2 fine beam (9 m resolution) wide imagery over the entire glaciated region of Svalbard. The ice masses of Svalbard provide a variety of glacier flow structures (surge glaciers, tidewater glaciers, ice caps) and terrain conditions (steep/flat slopes, high/low altitudes) which can be used to test each method for determining surface velocities under a wide range of conditions that exist in the Arctic. Speckle tracking has proven an effective method for determining glacier surface flow in the Canadian High Arctic but has yet to be tested in a more maritime region such as Svalbard where loss of coherence is more likely due to snowfall, rain and/or surface melt. Similarly, amplitude feature tracking has been effectively used to determine surface flow on glaciers in Svalbard, but has so far been restricted to lower-resolution Radarsat-2 Wide Beam (20 m resolution) data, and the improvements that may be achieved with higher resolution data are not yet known. In the next stage of this project these velocities will be combined with estimates of ice thickness at

the terminus of tidewater glaciers to improve determination of ice flux into the ocean.

Regional glacier velocity distribution across Kluane National Park, St. Elias Mountains, Yukon Territory, Canada

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Estimates of glacier mass balance suggest that losses from glaciers and ice caps (GICs) account for a greater percentage of sea level rise relative to their total mass than the large ice sheets. The largest GIC losses to date are from the Gulf of Alaska, which includes the St. Elias Icefields in the Yukon Territory and adjoining Alaska and British Columbia [Jacob et al. (2012), *Nature*]. Significant mass losses may be expected to engender changes in the rate and nature of flow of these glaciers, but to date baseline measurements of ice dynamics are extremely limited in the St. Elias Mountains.

In this study we will present the first surface velocity measurements for the eastern portion of the St. Elias Mountains, including the entire glaciated area of Kluane National Park, derived from speckle-tracking of Radarsat-2 imagery acquired in winter 2011 and 2012. This technique uses a cross-correlation approach to determine the displacement of the 'speckle' pattern of radar phase returns between two repeat-pass images. Validation of the remote sensing analysis is provided through comparison with continuous differential GPS measurements at four stations on the Kaskawulsh Glacier and surface flow features such as medial moraines and crevassing. Measured velocities vary from <8 m a^{-1} to >3300 m a^{-1} at the terminus of the tidewater Hubbard Glacier. Results also indicate that several glaciers in the study area (e.g., Lowell, Upper Seward) appear to be experiencing speed-up or surge events, based on comparison with past velocity measurements and aerial observations of active surge features. Other known surge-type glaciers (e.g., Walsh) display very low velocities for their size, suggesting that they are currently in quiescence. Ice fluxes now being derived from these velocity measurements and existing ice thickness measurements will enable improved assessment of the impacts of future mass balance changes in this region.