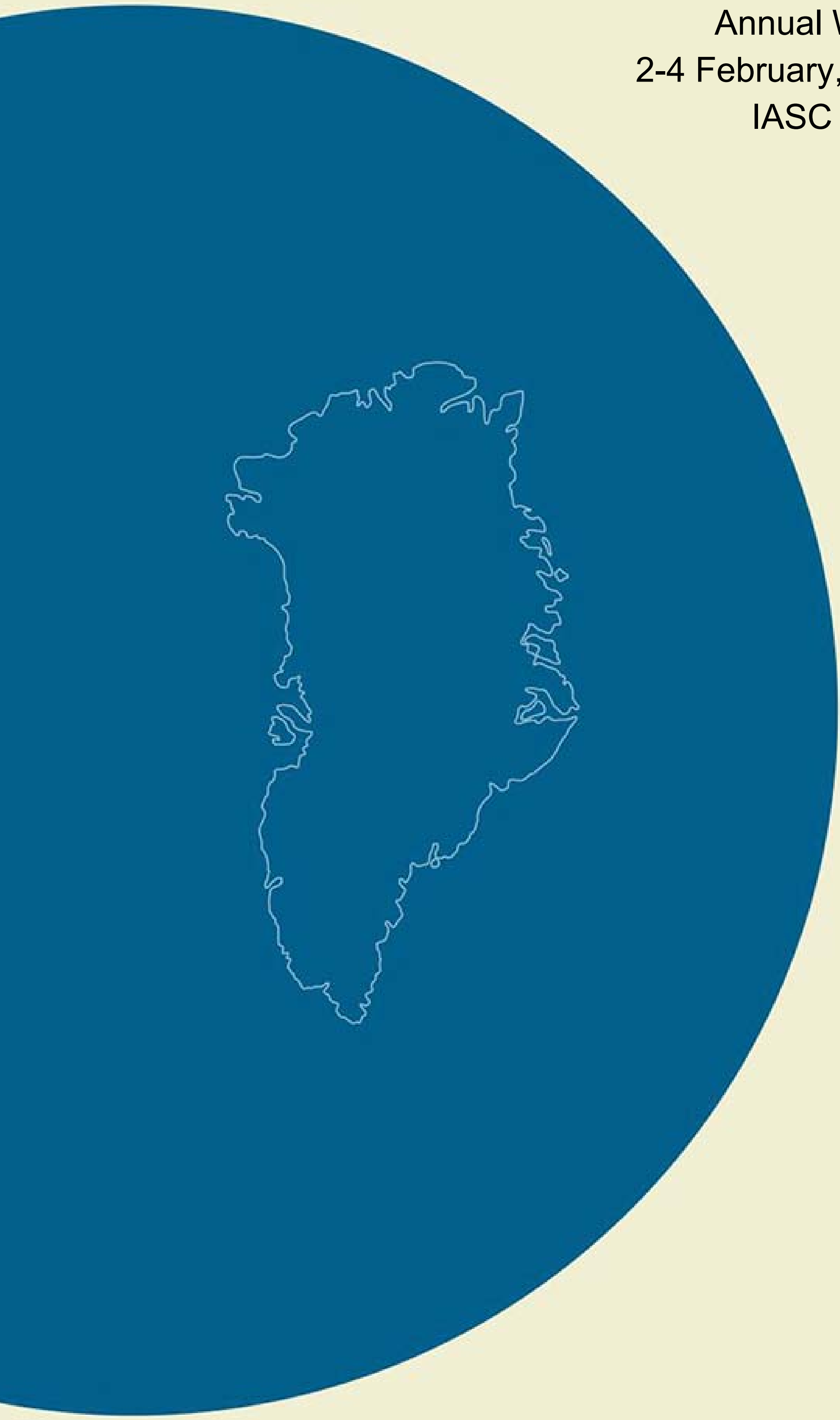
DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2014/5

The Dynamics and Mass Budget of Arctic Glaciers

Abstracts
Annual Workshop/Glaciodyn Meeting
2-4 February, Winter Park, Colorado, USA
IASC Network on Arctic Glaciology

A. P. Ahlstrøm & M. Sharp (eds)



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

G E U S

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Preface

The 2011 annual workshop on the dynamics and mass budget of Arctic glaciers of the Network for Arctic Glaciology was held at Winter Park, Colorado, USA, 2-4 February, 2011.

The planning of the workshop was unfortunately delayed substantially due to unexpected illness in the organizing committee. Accordingly, attendance was lower than normal. The silver lining to the reduced attendance was that the discussions were highly engaging and inspiring, with everyone on the front row.

The support from IASC covering travel expenses for a number of students and young investigators attending the workshop was crucial for the international attendance of young researchers and students. The fortunate grant recipients experienced and participated in the true spirit of sharing scientific insights among a group of top scientists in the field of glaciology.

The National Representatives present led the Open Forum discussion open to all participants in the workshop. The minutes from the Open Forum are included in this volume.

The workshop was attended by 17 registered participants and featured 8 talks and 3 poster presentations. This volume presents the abstracts submitted for presentation at the workshop. It was judged that a volume of extended abstracts would not be substantial enough and thus only the regular abstracts are published in this volume.

We would to like to thank Prof. Tad Pfeffer from INSTAAR, University of Colorado, for taking on the local organizing of the meeting at Winter Park, Colorado and giving us an opportunity to bring the IASC-NAG to the US for the first time.

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

Programme

Wednesday, February 2

TALKS

9.00: Joel Harper, Neil Humphrey, Tad Pfeffer, Joel Brown: Melt-water refreezing on the Greenland Ice Sheet: Implications for models of ice sheet mass balance
9.20: Sebastian H. Mernild and Glen E. Liston: Surface melt extent and trends for the Greenland Ice Sheet since 1960
9.40: Sebastian H. Mernild, Glen E. Liston and Niels T. Knudsen: Mass loss and runoff from Greenland's longest-observed local glacier, Mittivakkat Glacier
10.00: Malgorzata Błaszczyk, Jacek A. Jania, Mateusz Moskalik, W. Tad Pfeffer, Grzegorz Żołna: New estimation of calving flux from Southern Spitsbergen tidewater glaciers

10.20-10.40: Coffee

10.40: Alberto E. Behar: Technology for autonomous monitoring and investigations of polar environments
11.00: Megan O'Sadnick, Jack Kohler, K. Langley, Chris Nuth, L. Kehrl, E. Berthier, M. Winsborrow, K. Andreassen: Basal topography of Kronebreen, NW Svalbard
11.20: Ethan Welty, Tad Pfeffer, Shad O'Neel, Yushin Ahn: Emerging photographic methods for quantifying tidewater glacier retreat at Columbia Glacier
11.40: Ursula K. Rick, Waleed Abdalati, Irina Overeem, Maureen M. Berlin, Scott B. Luthcke, Michiel van den Broeke: Evidence for Substantial Englacial Retention of Surface Meltwater

POSTER SESSION

Piotr Glowacki, Agnieszka Izykowska-Pietrzak: Polish Polar Station Hornsund - unique research platform

Keiko Konya, Tsutomu Kadota, Fumio Nakazawa, Hironori Yabuki, Davaa Gombo, Purevdagva Khalzan and Tetsuo Ohata: Mass balance of Potanin glacier, Mongolian Altai

Tetsuo Ohata, Keiko Konya, Tsutomu Kadota and Hironori Yabuki: Consideration of the study on the variability of Arctic glaciers in the Eastern Sector of Arctic Region

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Minutes from the IASC Network on Arctic Glaciology Open Forum

Present at Open Forum:

Tad Pfeffer, Martin Sharp, Gabriel Wolken, Agnieszka Pietrzak, Malgorzata Blatzczyk, Piotr Glowacki, Jason Box, Keiko Konya, Megan O'Sadnick, Liam Colgan, Andreas P. Ahlstrøm

Left early: Joel Harper, Sebastian Mernild, Alberto Behar, Irina Overeem

Agenda:

1. Tad Pfeffer on the need to produce an updated estimate of the contribution to sea level rise from glaciers and ice caps for the IPCC 5AR
2. Martin Sharp on the new IASC structure and the future possibilities of the NAG
3. The IASC workshop on glacier instrumentation in Pontresina 23-26 March
4. Extended Abstracts from this meeting
5. Presentation of the venue for the IASC NAG in 2012
6. Workshop structure for 2012 and the future

Open Forum Discussion topics:

Ad 1.

Tad Pfeffer: Sea level contribution from glaciers and ice caps

- A present-day compilation of mass balance of glaciers and ice caps is needed (Question for Tad: what about the WGMS report? Is publishing mass balance records not their primary reason to exist? -> Michael Zemp)
- Next step is to upscale mass balance to all glaciers and ice caps (= GIC)
- GIC are quite likely to still surpass the Greenland and Antarctic ice sheets in terms of present contribution to sea level rise, but it is hard to know -> we need a targeted assessment of current GIC contribution to find out
- It is a significant problem that the community seems to think – and often express – that the GIC problem is known, small and generally insignificant. This argument is often put forward in studies relating to the ice sheets to justify leaving them out of the analysis
- What is needed to deal with GIC in future assessments is:
  1. An inventory of outlines giving area
  2. A GIC DEM to produce hypsometry
  3. A area-volume scaling function
  4. A response-function to climate change

A complication arises with the significant fraction of GIC that are in contact with the ocean as tidewater dynamics cannot be described through a response function to climate change in the atmosphere

To solve the inventory problem, GLIMS should be reinforced in order to solve the problem of actually uploading already outlined GIC's to the database and expand the remaining coverage. An idea could be to make outlining glaciers and ice caps a theme for undergraduate classes in GIS (Geographical Information Systems) worldwide (or at least in university departments with glaciologists around). Maybe there is already training material available from Bruce Raup and Frank Paul? This effort could also in-

volve GoogleEarth if proper satellite imagery was made available (e.g. from ASTER – other? Landsat?). An idea was to involve the company Google in the effort somehow as the effort is image-driven an relates well to GoogleEarth. Jason Box suggested maybe discussing this along with the EIS when James Balog talks to Google. JB will hear what James Balog thinks about this idea. EW: sometimes individuals at Google can make things happen if communications at the institutional level are not effective.
Establishing a sort of Wiki-structure to the GLIMS delineation effort could provide a platform.

GW: To involve non-specialists in delineating basins, we would need a strong Quality control (QC)-structure.
EW: an idea could be to have the contributions of individuals weighed by their performance in replicating a delineation done by professionals. This idea is useful if a large number of delineations are made.
Short term funding could possibly be obtained from NASA or NSF for helping to solve the perceived bottleneck in the GLIMS work flow. Training of technicians from groups delivering - maybe funding for a person to lead a wiki-like GLIMS effort?
A letter of support signed by scientists from the NAG community (and others) to support the claim for relevance towards NASA/NSF is desirable. Tad will work on getting this out.

Ad 2.
Martin Sharp informed the Open Forum Participants on the new IASC structure and the future possibilities of the NAG. In short it seems that the new structure will accommodate the NAG in its present form and that the funding level is fairly stable.

Ad 3.
The IASC workshop on glacier instrumentation in Pontresina 23-26 March was seen as a great success, but also timed somewhat unfortunately as it would imply a much lower attendance to the IASC-NAG workshop. Would have made more sense to maybe combine the two workshops.

Ad 4.
Extended abstracts will be requested from workshop participants. Regular abstracts will be published if no extended abstract is submitted by deadline.
<u>Production timeline:</u>

Circulated non-abstract content ready:	February 28
Abstract submission:	March 15
Production finalized (PDF avail. from website):	April 15
Paper version ready (available free of charge for all, shipped to first-authors):	May 1

Ad 5.
A venue in Poland was presented by Piotr Glowacki for the 2012 IASC NAG workshop on behalf of Prof. Migała, Wroclaw University. Details on workshop dates, location, access from major airports, local attractions, accommodation expenses and deadlines were given. A timeline for the IASC NAG 2012 workshop will be sent in a first circular in Spring 2011 (well before end of March), including:

1. First circular in Spring 2011, urging potential participants to sign up early to obtain reduced hotel rates (valid until end of March)

2. Explaining the conceived thematically focussed structure of the 2012 workshop (as opposed to the preceding few years) and specifying a) participant preparation for themes, and b) the possible follow-on activities envisioned/proposed
3. Invitation for submitting abstracts for poster and fewer oral presentations, preferably with a focus on problems over results
4. Details on the publishing of extended abstracts from the workshop as a GEUS Report, incl. a timeline and statement of no-cost policy
5. Details on the expected opportunity for early-career scientists and students to apply for funding to cover travel and workshop expenses, incl. a tentative timeline

Ad 7.

Suggestions for the future structure of the IASC-NAG workshop:

- Fewer oral and more poster presentations
- More opportunity for discussions
- "Seed" talks focussed on problems to solve, rather than results
- Inviting for 30 minute time slots with only 15 minutes talking to spur discussions
- Suggest that the angle is more to provoke discussion than to report results
- Focus on grant proposals, also for North American & EU coordination

Discussion on the format of the workshop should be continued in subsequent years were attendance would be more representative for the entire IASC-NAG, but the above provides some constructive ideas to strengthen the impact of the NAG.

Abstracts

Melt-water refreezing on the Greenland Ice Sheet: Implications for models of ice sheet mass balance

Joel Harper[1], Neil Humphrey[2], Tad Pfeffer[3], Joel Brown[1]

[1] University of Montana, USA
[2] University of Wyoming, USA
[3] University of Colorado, USA

We present a study of meltwater infiltration in the percolation zone of western Greenland. Field data were collected during 2007-2009 along a 90 km transect extending from 2000-1300 m elevation. Fifteen intensive study sites were spaced 5-10 km along the transect. Near-surface heat flow was measured at each site with 33 channel thermister strings extending to 10 m depth and logging year-round on a 30 min time base. Firn stratigraphy and density were measured in 10 m deep ice cores, with 2 or more cores at each study site for a total of 34 cores. Ground-based radar surveys were conducted at each site and between sites. Radar data imaged firn stratigraphy and are used to characterize firn/ice density to a depth of ~80 m from analysis of electromagnetic velocity. We used two methods to solve for velocity: 1) common mid-point reflection analysis solving for velocity with a ray-based model inversion technique, and 2) multi-offset, single line acquisition solving for velocity with a reflection tomography inversion technique. We find that from 2000-1625 m elevation surface melt is minimal and melt water infiltrates vertically to form thin ice layers. Strong surface melt infiltrates to fill about half of the available pore space of the upper 10 m from ~1625-1475 m elevation. Infiltration shows a high degree of spatial variability in this elevation zone, with some water moving vertically and some water moving horizontally on top of decimeter to m thick ice layers of irregular extent. In places, melt water infiltrates to more than 10 m depth, and through multi-decade old firn. Below ~1475 m elevation, nearly all pore space is filled by infiltrated meltwater and excess water runs off. Both our thermal and density measurements indicate that the runoff limit is above the equilibrium line about 300 m in elevation and a distance of 30 km. Our results have implications for the representation of retention/runoff in models used to estimate Greenland mass balance. Further, we present simple calculations for the time constant associated with upward migration of the runoff limit.

Surface melt extent and trends for the Greenland Ice Sheet since 1960

Sebastian H. Mernild[1] and Glen E. Liston[2]

[1] Climate, Ocean, and Sea Ice Modeling Group, Computational Physics and Methods, Los Alamos National Laboratory, New Mexico, USA

[2] Cooperative Institute for Research in the Atmosphere, Colorado State University, Colorado, USA

The Greenland Ice Sheet (GrIS) is the largest reservoir of permanent snow and ice in the Northern Hemisphere (~7 m sea-level equivalent) and is highly sensitive to climate changes. An altered melting regime can produce substantial differences in surface albedo and energy and moisture balances, especially because wet snow absorbs up to three times more incident solar energy than dry snow. Observed meteorological data and a high-resolution (5-km) model were used to simulate GrIS surface melt extent and trends before the satellite era (1960–1979) and during the satellite era through 2010. The period 1960–1972 had a 6% average decrease in melt extent, and 1973–2010 had an increase of 13%, with record melt extent in 2010. The trend in simulated melt extent since 1972 indicated the melt area in 2010 averaged twice that in the early 1970s. A maximum and mean melt extent for 2010 of 52% (~9.5×105 km2) and 28% (~5.2×105 km2) occurred, respectively, due to higher-than-average winter and summer temperatures. For 2010, the SW Greenland melt duration was 41–60 days greater than the 1960–2010 average, and up to 20 days shorter in NE Greenland. Also, from 1960–1972 the melting period (with a melt extent >10%) decreased by an average by 3 days y-1. After 1972, the period increased an average of 2 days y-1, indicating an extended melting period for the ice sheet of approximately 70 days by 2010.

Mass loss and runoff from Greenland's longest-observed local glacier, Mittivakkat Glacier

Sebastian H. Mernild[1], Glen E. Liston[2] and Niels T. Knudsen[3]

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Warming in Greenland during the past several decades has caused local glaciers peripheral to the Greenland Ice Sheet to thin and retreat, resulting in increased freshwater runoff to the ocean. Few mass-balance observations are available to quantify the retreat and determine the extent to which these glaciers are out of equilibrium with present-day climate. Here, we document record mass loss in 2009/10 for the Mittivakkat Glacier, Southeast Greenland, the only local glacier in Greenland for which there exist long-term observations of both the surface mass balance (since 1995) and glacier front fluctuations (since 1931). We attribute this mass loss to record high mean summer (June–August) and higher-than-average winter (September–May) temperatures and to lower-than-average winter precipitation. Also, we use the 15-year mass-balance record to estimate present-day and equilibrium accumulation-area ratios for the Mittivakkat Glacier. We show the glacier is significantly out of balance and will likely lose approximately 70% of its current area and 80% of its volume even in the absence of further climate changes. Presently, we lack detailed information about the spatial and temporal runoff distribution to the ocean from non-glaciated and glaciated areas of Greenland such as Mittivakkat Glacier. To help remedy this deficiency we have developed *IceHydro*, a multi-layer snow and ice evolution and runoff routing model that simulates relatively high-resolution (100-m horizontal grid) runoff from glaciers and ice caps peripheral to the Greenland Ice Sheet, and from the Ice Sheet itself.

New estimation of calving flux from Southern Spitsbergen tidewater glaciers

Malgorzata Błaszczyk[1], *Jacek A. Jania*[1], *Mateusz Moskalik*[2], *W. Tad Pfeffer*[3], *Grzegorz Żołna*[1]

[1] Faculty of Earth Sciences, University of Silesia, Poland
[2] Institute of Geophysics, Polish Academy of Sciences, Poland
[3] Institute of Arctic and Alpine Research, University of Colorado at Boulder, USA

The paper presents an updated estimation of mass loss due to calving by tidewater glaciers in Southern Spitsbergen. Inventory of tidewater glaciers in Svalbard and estimation of ice-berg flux from the whole archipelago was recently presented (Blaszczyk *et al.*, 2009). Flow velocity for particular glaciers was estimated basing on simple statistical relation between measured velocity on a set of 33 glaciers and average length of the near terminus crevassed zone (along flow lines). Further, all glaciers were divided into classes of different length of such zone and therefore dynamics. Other necessary data for calculation of calving flux, as average thickness of glaciers at the terminus and its mean annual recession rate were collected from limited number of studied glaciers. Both flow velocity and recession were extracted from repeated ASTER imagery acquired in period 2000-2005. Having in mind uncertainty in estimation of mean ice thickness at termini of glaciers, echo soundings of fiords close to their ice-cliffs in the Hornsund Fiord have been done in last years, together with simple measurements or photogrammetric survey of ice-cliff face elevations. One received new set of data on thickness of tidewater glaciers at their front. Recent Terra/ASTER satellite images have been acquired for Southern Spitsbergen from 2006, 2008 and 2009. Feature tracking on them enable to obtain flow velocities in recent years. Similarly, superimposed front positions from the geocoded images permitted to obtain recent mean annual recession rate of them. Newly obtained data shows, that previous assumption of the average ice thickness in the Hornsund area was to low. The recession rate was also much higher than taken into account in the earlier work. One can expect acceleration of glacier retreat in the second half of the last decade (excluding advances of surging glaciers). Neglecting reasons of differences new estimation of calving mass loss from glaciers of Southern Spitsbergen is higher by more than 50% than calculated previously. Taking into account some additional data for individual glaciers in other regions of Svalbard from the same recent period, new estimation of total calving flux from the whole archipelago has been done. Results need fine-tuning by larger number of data more equally distributed over the archipelago. The obtained results suggest that mass loss by calving has been accelerated in last years.

Błaszczyk M., Jania J.A., Hagen J.O., 2009. *Tidewater glaciers of Svalbard: Recent changes and estimates of calving fluxes*. Polish Polar Research. *Polish Polar Research,* 30(2): 85-142.

Technology for autonomous monitoring and investigations of polar environments

Alberto E. Behar

Jet Propulsion Laboratory, USA

Recent advances in low-power communications using either the new Iridium data capabilities now available (SBD, SMS) or spread spectrum RF low cost radios has allowed the development of a plethora of systems that can stream transmit data (and receive commands) reliably in real time from very remote locations. This has allowed the development of sites or systems where one can put up instruments (cameras, gps, weather monitors, etc.) to collect data and not need to return to the site for data download. This has then expanded the possibilities where sites can be located by either removing the logistical costs of returning or being able to put sites where it would be too dangerous to return (tip of surging glaciers, crevasse locations, volcanoes, etc.). This talk will present the multitudes of devices built (or in design) so far by us for the polar regions (Greenland/Antarctica/Alaska)

Polish Polar Station Hornsund - unique research platform

Piotr Glowacki, Agnieszka Izykowska-Pietrzak

Institute of Geophisics Polish Academy of Sciences, Poland

The Polish Polar Station Hornsund located in the centre of Spitsbergen Archipelago is a part of the Institute of Geophysics, Polish Academy of Sciences. As an international research platform, the Station cooperates with many scientific institutions from whole world. Due to the constant year-round activity and observations, modern laboratories and equipment, logistic possibilities for field work in summer and winter times the Station and the glaciers placed nearby the Station are an excellent research polygon for glaciological investigation.

The main scopes of the poster are to present the logistic support, research equipment operating in the Station and the data witch will be available for the researchers.

The technical specifications of the equipment e.g. meteorological station, GPS permanent station, laser total station, radioechosonding, stereographic digital lapse cameras, automatic glaciological stations will be presented. Furthermore some measurement data as: the mass balance data, the movement of the glacier surface, the flow velocity of Hans Glacier, glaciers' fronts monitoring data, the poster will be contained.

Basal topography of Kronebreen, NW Svalbard

M. O'Sadnick[1,6], J. Kohler[1], K.Langley[1], C. Nuth[2], L. Kehrl[3], E. Berthier[4], M. Winsborrow[5], K. Andreassen[5]*

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Kronebreen is a tidewater outlet glacier draining the icefield Holtedahlfonna, in the Kongsfjord area of NW Svalbard. Like most glaciers in Svalbard, Kronebreen has been in retreat since the first front positions were recorded, with the exception of a brief advance during the surge of the neighboring glacier Kongsvegen around 1948. Kronebreen is one of the fastest non-surging glaciers in Svalbard, with average annual velocities near the calving front of around 450 m/yr. It has not been possible until recently to calculate ice fluxes, however, since the bottom topography of Kronebreen has been unknown. In 2009, ice thickness data were obtained using low frequency radar from helicopter over the heavily crevassed Kronebreen. These new thickness data are combined with surface elevation maps, older ice depth data, and fjord bathymetry data to create an expanded bed map of the Kongsfjord area. Velocity data of Kronebreen derived from feature tracking of high-res visible imagery is also combined with thickness data to calculate estimates of flux throughout the glacier. Analysis of this new data will give a better understanding of Kronebreen's retreat history, its mass balance and flux into Kongsfjord, and help in making predictions of when and how quickly future glacier advance may occur.

Emerging photographic methods for quantifying tidewater glacier retreat at Columbia Glacier

Ethan Welty, Tad Pfeffer, Shad O'Neel, Yushin Ahn

Columbia Glacier, a large tidewater glacier in Alaska's Prince William Sound, has lost approximately 18 of its original 66 km and thinned by nearly 500 meters since entering into rapid retreat in the early 1980s - a volume of ice lost estimated as high as 140 km3. These dramatic changes have been recorded, at roughly annual resolution, in a 35-year record of aerial photogrammetric data.

However, low frequency and high cost restricts our use of satellite and aerial stereophotography both for sustaining our monitoring efforts and for investigating short-term variability in glacier dynamics. In response, we present a flexible, low-cost, automated approach to producing repeat glacier elevation and velocity maps from photographs we take ourselves. We share our early results from using the simplest tools - a consumer camera, handheld GPS and open source software - at the Columbia Glacier in summer 2010.

The method hinges on structure-from-motion (SfM) routines, which harness the depth information implicit in images taken from many camera positions ("motion") to automatically and simultaneously solve for sparse scene and camera geometry ("structure"). As a result, surveyed camera positions are sufficient to convert the model to world coordinates, extremely useful in mountainous, glaciated terrain where access to the scene surface for establishing ground control is often dangerous or costly. Multi-view stereo software then harnesses the camera positions and orientations solved by SfM to construct a full-resolution digital elevation model (DEM) in which nearly every image pixel has a corresponding 3D position. Velocities are obtained by matching features between repeat SfM models (or equivalently, between
images of a contemporaneous ground-based time-lapse sequence), then converting the pixel displacements to velocities by projecting the camera rays onto the associated DEMs.

Evidence for Substantial Englacial Retention of Surface Meltwater

Ursula K. Rick[1], Waleed Abdalati[1], Irina Overeem[2], Maureen M. Berlin[2], Scott B. Luthcke[3], Michiel van den Broeke[4]

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We use satellite gravity measurements of total mass change, observations of ablation at automatic weather stations, and river discharge measurements to explore the relationship between summer mass loss, surface melt and runoff along the western flank of the Greenland Ice Sheet. The Gravity Recovery and Climate Experiment (GRACE) satellite integrates all sources of mass change from Greenland, including the surface mass balance and ice dynamics. In the Kangerlussuaq area the ice sheet terminates on land, and there is no measureable dynamic thickness change, so the GRACE signal in this area should be due to accumulation and runoff. Discharge from the Watson River in Kangerlussauq is a result of runoff from the Watson River basin portion of the ice sheet. The summer mass loss as measured by GRACE is 1/3 of the summer surface melt production as calculated from the observed AWS ablation data, suggesting that not all surface melt becomes runoff. The Watson River discharge data also shows less runoff than the surface melt that is produced within the Watson drainage basin would predict, leading us to the conclusion that a significant fraction of meltwater remains in the englacial and subglacial hydraulic system at the end of the melt season.

Mass balance of Potanin glacier, Mongolian Altai

Keiko Konya[1], Tsutomu Kadota[1], Fumio Nakazawa[2], Hironori Yabuki[1],
Davaa Gombo[3], Purevdagva Khalzan[3] and Tetsuo Ohata[1]

[1] Japan Agency for Marine-Earth Science and Technology
[2] NIPR
[3] Institute of Meteorology and Hydrology, Mongolia

1. Introduction

Fluctuation of glacier mass balance can be an indicator of climate change. In order to understand global climate change, it is necessary to extend the observation network of the mass balance of as many as glaciers in the world. However, long-term monitoring records are biased forwards logistically and morphologically "easy" glaciers (IPCC, 2007). As for Asian regions, mass balance research is not sufficiently done. There are many glaciers in the Tavan Bogd mountain

area, western Mongolia. It has been reported that Potanin glacier is shrinking (Kadota and Davaa, 2007). It is reported that Potanin glacier in western Mongolia is retreating for last some decades. The terminus retreat of Potanin glacier was estimated as 866m by Aster image (Yabuki et al., in preparation). Mass balance was estimated for Potanin glacier where direct mass balance observation has not been done before.

2. Study site

Altai mountain range extends in Mongolia, China, Kazakhstan and Russia. Potanin glacier (49º09'N, 87º55'E) is situated in the Tavan Bogd region which is in the Mongolian Altai. Potanin glacier flows from the top of the valley next to Mt. Huiten which is highest mountain of 4374m in Mongolia. Potanin glacier is 10.44 km in length, km in width and ranges from 4373 to 2900 m a.s.l. and the area was 24.34 km2 in 2003. Precipitation is remarkably large and summer (JJA)

mean temperature is positive,

3. Method and Result

3.1. Stake measurement in ablation area Stakes measurements are done in June and September in 2004, 2005, 2007 and 2008 to know summer and winter balance. The stakes were set with about 100 m elevation interval beginning from 2,900 m a.s.l. with 3 stakes on the same altitude (Konya et al., 2010). The surface height change was continuously measured with an ultrasonic distance sensor on the AWS.

3.2. Pit observation and Pollen analysis in accumulation area For accumulation area, pit observation was done at two sites in September 2008. Each site is at the altitude of 3752 m and 3890 m. Both are near the upper end of accumulation area. Net balance was estimated with pollen analysis from pit samples. Pollen analysis was done based on Nakazawa et al. (2004) which is proven in Sofiyskiy glacier (49º47'N, 87º43'E) in Russian Altai. Betulaceae, Pinus and

Artemisia are used as indicator. Also, snow density measurement and snow sampling were done every 5 cm layers. Summer accumulation was observed in the pit. And the snow deposition in the accumulation area was so large which is due to orographic effect.

3.3. Mass balance

These observations revealed that ablation rate in summer is large in ablation area and shortwave radiation is dominant heat source for surface melt. Accumulation basically occurred in winter. However, snow pit observation in accumulation area shows that it occurs also in summer. The specific mass balance was estimated from those data. Mass balance of Potanin glacier in the mass balance year of 2007/08 was estimated to -1.03 m w.e. which is extensive negative mass balance compared to Maliy Aktru glacier in Russian Altai. Also, mass balance of the glacier in 2004/2005 was estimated to -0.58 m w.e. using the same method.

4. Discussion

Mass balance of glaciers in Mongolian and Russian Altai show different tendency, both of them show decreasing tendency. The difference is due to topography and ELA as well as climate of the region. It is probable that precipitation as snow or rain had an influence on mass balance. Mass balance of glaciers in Altai may continue decreasing in future.

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Consideration of the study on the variability of Arctic glaciers in the Eastern Sector of the Arctic Region

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Climate change is occurring in the Arctic Region on the thermal conditions, hydrological cycle and ocean/terrestrial conditions, more strongly than the other regions on Earth. The climate of the glaciated region is affected by such regional changes, and evidence shows its change and it should be changing in the future depending on the direction of climate change. It is an area which should receive more attention.

The glaciers are considered as important elements of the global environment from two points. One is as an indicator of climate change, since it is very sensitive to the changes in air temperature, precipitation, and other climate system elements such as radiation. It is used as representative of the terrestrial change, and of the global warming. Second is as a contributor to the global water cycle and it is said that shrinkage of glaciers, due to enhanced melting and corruption will raise the sea level. Among the glaciers, Arctic glaciers dominate nearly 40% of the whole earth, and if the strong warming in Arctic continues, it should show more drastic changes.

Under such conditions, it is clear that we need to obtain more and well-balanced knowledge about the "state and fate" of the Arctic glaciers. We need to discuss the following items,

1. How much do we know about Arctic Glaciers.
2. Is the observation network and satellite analysis well organized to discuss about the "state" of glaciers.
3. Do we have knowledge on the processes dominating the variation of the Arctic glaciers to discuss the "fate" of the glaciers.

The presentation will discuss on some of these matters, and also present what we are thinking on the study of the glaciers in the eastern sector (mainly the Russian side) of the Arctic Region.