IASC Workshop on the dynamics and mass budget of Arctic glaciers

Abstracts and Programme

IASC Workshop, 23-25 January 2017
Bethel, Maine, USA

IASC Network on Arctic Glaciology

IASC Workshop on the dynamics and mass budget of Arctic glaciers

Abstracts and program

IASC Workshop &
Network on Arctic Glaciology annual meeting,
23-25 January 2017, Bethel, Maine, USA

Organised by Gordon Hamilton, Ellyn Enderlin and Thorben Dunse

THE UNIVERSITY OF MAINE CLIMATE CHANGE INSTITUTE

IASC Network on Arctic Glaciology

Cover photo: Waves break upon an iceberg calved off from Breiðamerkurjökull, Iceland. Photo by T. Dunse.

ISBN: 978-90-393-6780-3

Contents

Preface

The 2017 annual workshop and open forum meeting of the IASC Network on Arctic Glaciology took place in Bethel, Maine, USA. 27 participants from 8 countries came together to discuss a broad range of topics in Arctic Glaciology, from glacier-atmosphere and glacier-ocean interactions, including impacts on the marine ecosystem, to ice-dynamics and advancements in methodology to monitor glacier processes and glacier change.

Discussions continued outside the meeting room at joined meals, as well as on the the local cross-country ski tracks and nearby downhill-ski slope. The open forum meeting provided an opportunity to discuss further activities and development of the Network on Arctic Glaciology. An overview of the meeting, the program and abstracts of the presented work, can be found in this book.

A key person of the meeting was deeply missed by all participants: Gordon Hamilton, the initial local host of the meeting. Gordon tragically passed away in October 2016, doing fieldwork in Antarctica. I am very grateful to Ellyn Enderlin, for taking over Gordon's responsibilities as a local organizer. The meeting would not have happened without the help from Ellyn and her team from the University of Maine, including Jessica Scheick, Lynn Kaluzienski, and Will Kochtitzky.

The next year's meeting will take place in Obergurgl, Austria, 21 - 25 January, 2018. I hope to meet you all there.

Thorben Dunse
April 2017

Program

The meeting took place at The Bethel Inn, Bethel, Maine, USA, 23-25 January, 2017.

27 participants representing 8 IASC-NAG member countries came together in Bethel Maine to discuss a broad range of topics in Arctic Glaciology.

Sunday 22 January

ARRIVAL

Monday 23 January

08:30 - 09:00	**Registration**
09:00 - 09:10	Welcome *Ellyn Enderlin and Thorben Dunse*

09:10 - 11:40	**Special session on glacier-atmosphere interactions**
Convener:	*Shin Sugiyama*
09:10 - 09:30	Retrieving fog thickness and inversion characteristics from radiosonde data in coastal East Greenland ***Gaëlle Gilson***, *H. Jiskoot*
09:30 - 09:50	The current state and potential for fog investigations in the Hornsund ***Ewa Łupikasza***, *A. Migała, T. Niedzwiedz*
09:50 - 10:10	Fog on Arctic Glaciers from Time-lapse Photography and Energy Balance Stations ***Hester Jiskoot***, *A. Fossheim, B. Fox, T. Fox, M. Hierath, B. Danielson, M. Nolan*
10:10 - 10:30	Study on importance of winter liquid precipitation for mass balance of Spitsbergen glaciers *Katarzyna Cielecka, E. Łupikasza,* ***Jacek Jania***, *M. Grabiec, D. Ignatiuk, B. Luks, A. Uszczyk*
10:30 - 11:00	**Coffee break**
Convener:	*Hester Jiskoot*
11:00 - 11:20	Contemporary patterns and trends in water isotope composition of snow and ice across the Queen Elizabeth Islands, Canadian high Arctic ***Brittany Main***, *F. Delaney, L. Copland, D. Lacelle, D. Fisher, L. Thomson, J. Zheng, D. Burgess*
11:20 - 11:40	Industrial-age doubling of snow accumulation in Alaska linked to tropical ocean warming ***Dom Winski***
11:40 - 12:00	Mass balance of the Austfonna Ice Cap, Svalbard, 2004-2015 ***Jon Ove Hagen***, *T. Dunse, T. Eiken, J. Kohler, G. Moholdt, T.V. Schuler, T. Østby, C. Reijmer*
12:00 - 12:20	Recent glacier changes at Novaya Zemlya based on remote sensing, ice thickness and ice flow velocity measurements *I.I. Lavrentiev, A.F. Glazovsky,* ***Stanislav S. Kutuzov***, *Yu.Ya. Macheret*
12:20 - 16:30	**Very long lunch break / Skiing**
16:30 - 17:00	**Coffee break**
17:00 - 17:15	**Poster presentations by authors**
17:15 - 19:00	**Poster session**
	Dinner

Tuesday 24 January

09:00 - 12:10	**Special session on glacier-ocean interactions**
Convener:	*Ellyn Enderlin*

09:00 - 09:20	Coupling glacier dynamics and fjord circulation models through submarine melt at the glacier front *Eva de Andrés, J. Otero,* ***Francisco Navarro****, A. Prominska, J. lapazaran, W. Walczowski*
09:20 - 09:40	Spring submarine melt rate estimates for a seasonal ice tongue in Kangersuneq Fjord, southwest Greenland, from high-resolution satellite imagery ***Alexis N. Moyer****, P. Nienow, N. Gourmelen, A. Sole*
09:40 - 10:00	Tidewater glaciers, ocean and atmosphere interactions in Hornsund Fiord ***Małgorzata Błaszczyk****, J. Jania, A. Prominska, W. Walczowski, D. Ignatiuk, T. Wawrzyniak, M. Ciepły, M. Grabiec, M. Moskalik*
10:00 - 10:20	Multi-year surface velocities and sea-level rise contribution of the Basin-3 and Basin-2 surges, Austfonna, Svalbard ***Thomas Schellenberger****, T. Dunse, A. Kääb, T. V. Schuler, J. O. Hagen, C. H. Reijmer*
10:20 - 10:50	**Coffee break**
Convener:	*Jessica Scheick*
10:50 - 11:10	Mass loss of outlet glaciers and ice caps in the Qaanaaq region, northwestern Greenland ***Shin Sugiyama****, S. Tsutaki, D. Sakakibara, E.Podolskiy, M. Minowa, Y. Ohashi., M. Funk, G. Jouvet, J. Seguinot, Y. Weidmann, R. Genco*
11:10 - 11:30	Turbid meltwater discharge and its impact on phytoplankton growth in the fjord of Bowdoin Glacier in northwest Greenland ***Naoya Kanna****, S. Sugiyama, Y. Ohashi, D. Sakakibara, B. Nishizawa, I. Asaji, Y. Fukamachi*
11:30 - 11:50	Freshwater discharge from glaciers in Svalbard and possible implications for the marine ecosystem ***Thorben Dunse****, K. S. Aas, K. Dong, J. O. Hagen, T. V. Schuler, T. Schellenberger, L. C. Stige*
11:50 - 12:10	Submarine iceberg melting measurements using high-spatial resolution remote sensing observations in Greenland fjords ***Will Kochtitzky****, E. Enderlin*
12:10 - 13:30	**Lunch**
13:30 - 15:00	**Workshop session on the importance of calving (frontal ablation) for the mass budget of Arctic glaciers**
Convener:	*Ellyn Enderlin, Luke Copland (via skype) and Thorben Dunse*
13:30 - 13:50	Introduction to the Pan-Arctic ice discharge session ***Luke Copland, Ellyn Enderlin***
	Overview, status and results from the various regions
13:50 - 14:10	Svalbard ***Thorben Dunse*** *on behalf of the Svalbard group*
14:10 - 14:20	Hornsund, Svalbard ***Jacek Jania*** *on behalf of the Hornsund-Svalbard group*

14:20 - 14:35	Canadian Arctic ***Alison Cook and Luke Copland*** *on behalf of the Canadian-Arctic group*
14:35 - 14:50	Greenland peripheral glaciers ***Ellyn Enderlin*** *on behalf of the Greenland-peripheral-glaciers group*
14:50 - 15:10	General discussion ***Ellyn Enderlin, Luke Copland***
15:10 - 15:30	**Coffee break**
17:00 - 18:30	IASC Network on Arctic Glaciology Open Forum meeting *Thorben Dunse*
	Dinner

Wednesday 25 January

	Ice Dynamics
Convener:	*Thomas Schellenberger*
09:00 - 09:20	High-Resolution Analysis of Columbia Glacier Dynamics ***Ellyn Enderlin****, G. Hamilton, I. Joughin, S. O'Neel, T. Bartholomaus*
09:20 - 09:40	Changes in velocity of White Glacier, Axel Heiberg Island, Canada, over the past 50 years ***Luke Copland****, S. Thomson*
09:40 - 10:00	Glacier Velocity Variation and Surge Type Glaciers on Manson Icefield, Southeast Ellesmere Island 1999 - 2016 ***Danielle Hallé****, L: Copland*
10:00 - 10:30	**Coffee break**
	Methods
Convener:	*Francisco Navarro*
10:30 - 10:50	Enhancing Greenland fjord bathymetry maps using remotely sensed data ***Jessica Scheick****, E. Enderlin*
10:50 - 11:10	Towards automated glacier monitoring using open-access satellite data ***Tereza Smejkalová****, R. D. Briggs*
11:10 - 11:30	Improvements to the processing of the interferometric mode of CryoSat radar altimeter using results from Devon Ice Cap and west Greenland ***Laurence Gray****, D.Burgess, L. Copland, T. Dunse, K. Langley, G. Moholdt*
11:30 - 11:40	Final words *E. Enderlin / T. Dunse*
11:40 -	**Lunch / Departure / Skiing / Side events**
Convener:	*Hester Jiskoot*
TBD	Side event: Fog in the Atlantic sector of the Arctic
	(Dinner)

Posters

- Pushing the boundaries of UAV monitoring on Arctic glaciers ***Eleanor Bash***
- Rapid Shrinkage of the Grise Fiord Glacier, Nunvaut, Canada ***Dave Burgess***
- Multi-decadal frontal change rates of 300 tidewater glaciers in the Canadian Arctic Archipelago ***Alison Cook***
- Monitoring of mass balance at Austre Grønfjordbreen, Nordenskjöld land, Svalbard ***Nelly Elagina****, S. Kutuzov, R. Chernov, I. Lavrentiev, T. Vasilyeva, B. Mavlyudov, A. Kudikov*
- Glacial loading of persistent organic pollutants ***Kimberly Miner***
- Glacier surface velocities of the Svalbard Archipelago ***Thomas Schellenberger****, W. Van Wychen, Luke Copland, A. Kääb and L. Gray*

Participants

1. Eleanor Bash* (eleanor.bash@gmail.com)
2. Małgorzata Błaszczyk (malgorzata.blaszczyk@us.edu.pl)
3. Dave Burgess (david.burgess@canada.ca)
4. Alison J. Cook (alison.cook@durham.ac.uk)
5. Luke Copland§ (luke.copland@uottawa.ca)
6. Thorben Dunse (thorben.dunse@geo.uio.no)
7. Nelly Elagina* (nelly.e.elagina@gmail.com)
8. Ellyn Enderlin (ellyn.enderlin@gmail.com)
9. Gaëlle Gilson* (gaelle.gilson@uleth.ca)
10. Laurence Gray (laurence.gray@sympatico.ca)
11. Jon Ove Hagen (j.o.m.hagen@geo.uio.no)
12. Danielle Hallé (dhall058@uottawa.ca)
13. Jacek Jania (jacek.jania@us.edu.pl)
14. Hester Jiskoot (hester.jiskoot@uleth.ca)
15. Lynn Kaluzienski (lynn.kaluzienski@maine.edu)
16. Naoya Kanna (kanna@arc.hokudai.ac.jp)
17. Will Kochtitzky* (william.kochtitzky@maine.edu)
18. Ewa Łupikasza (ewa.lupikasza@us.edu.pl)
19. Brittany Main* (bmain018@uottawa.ca)
20. Kimberly Rain Miner (kimberley.miner@maine.edu)
21. Alexis Moyer* (a.moyer@ed.ac.uk)
22. Francisco Navarro (francisco.navarro@upm.es)
23. Jessica Scheick* (jessica.scheick@maine.edu)
24. Thomas Schellenberger* (thomas.schellenberger@geo.uio.no)
25. Tereza Smejkalová (tereza.smejkalova@c-core.ca)
26. Shin Sugiyama (sugishin@lowtem.hokudai.ac.jp)
27. Dom Winski (dominic.winski@gmail.com)

(Young scientists receiving support are marked *).
(§attended via skype)

Minutes of the Open Forum meeting

Chair: Thorben Dunse
Invited to attend: all participants of the workshop.

Agenda

1. Other items for the agenda?
2. Background on IASC and NAG
3. NAG structure and national contacts
4. NAG website
5. IASC Network review
6. Recent activities
7. Funding
8. Extended Abstracts
9. Upcoming IASC-NAG workshops
10. Anything else

Ad. 1

See point 10.

Ad. 2

Short Introduction to International Arctic Science Committee (IASC):
- Background to IASC
- IASC has 5 working groups representing the different disciplines involved in Arctic Research
- IASC encourages multi-disciplinary research in order to foster a greater scientific understanding of the Arctic region and its role in the Earth system
- The Network on Arctic Glaciology (NAG) is closely affiliated with the Cryosphere Working Group but can cross-cut the IASC working groups
- NAG objectives: address rapid changes in Arctic land-ice masses and links to atmospheric and oceanic drivers; initiate scientific programs; facilitating international cooperation
- Jazek Jania presented the initiation of the Working Group on Arctic Glaciology during a workshop in Poland, 1994, which later became the Network on Arctic Glaciology

Ad. 3

Network organization:
- Thorben Dunse, University of Oslo, Norway, nominated as new chair during the 2016 NAG annual meeting in Benasque, Spain. He took over after Carleen Tijm-Reijmer from the University of Utrecht, The Netherlands who served as chair for four years.
- Martin Sharp, University of Alberta, Canada, remains vice-chair of NAG, ensuring continuity

Changes in national contacts from 18 member countries:
- Finland: Thomas Zwinger, CSC, steps in for John Moore
- Japan: Shin Sugiyama, Hokkaido University, new Japanese contact
- UK: Poul Christoffersen, University of Cambridge, steps in for Julian Dowdeswell
- USA: Ellyn Enderlin, University of Maine, accepts nomination as new US national contact (taking over after Matt Nolan)

Ad. 4

NAG website:
- updates include listing of recent workshops (Activities) and workshop reports (Publications), as well as changes in national contacts

Ad. 5

IASC network review:
- all networks are reviewed by the IASC executive committee every 5 years
- IASC executive committee is currently developing an IASC strategic plan for the next five years which includes some
structural changes that also affect the IASC networks
- the executive committee was pleased with the NAG report and that IASC will continue supporting and endorsing NAG
- planning to simplify the IASC structure and to better link the Networks to the IASC Working Groups (WG). Therefore, NAG could become a program of the Cryosphere WG
- A draft will be discussed at the next meeting of the Executive Committee, late January in Iceland, and the final version will be presented to the IASC Council at Arctic Science Summit Week in Prague, 31 March – 7 April, 2017

Ad. 6

Recent activities - thematic workshops in 2016:
- Importance of Calving for the Mass Balance of Arctic Glaciers, Sopot Poland, 15-17 October, 2016
- Observing and modelling meltwater retention processes in snow and firn on ice sheets and glaciers, Copenhagen. Danmark, 1-3 June 2016

Ad. 7

Funding:
- During the past year, NAG received a total of 8000 EUR from the Cryosphere working group for the proposed activity: *Understanding glacier-atmosphere-ocean interactions and their implications for the pan-Arctic glacier mass budget*
- the meeting in Sopot, Poland received 2000 EUR for Early-career scientists travel funds
- for this 2017 NAG annual meeting, 5000 EUR are allocated for ECS travel fund and 1000 EUR for general workshop funding
- an application for direct IASC funding (cross-cutting call) was not successfull

Ad. 8

Extended abstracts:
-deadline for submission of extended abstracts is 1. March 2017
- The book of extended abstracts will be published in digital form on the IASC-NAG website (http://nag.iasc.info/publications).

Ad. 9

Location for future meetings:
- the next Workshop on the dynamics and mass budget of arctic glaciers and the 2018 NAG annual meeting will be held in Obergurgl, Austria, 21 - 25 January 2018 (the meeting venue was already booked by Michael Kuhn)
- Japan and Norway were presented as candidates for 2019
- Norway was favoured by the majority, partly in order to keep the meeting in Europe for two subsequent years. Possible location is Skeikampen north of Lillehammer, which earlier served as venue for an IGS conference.

Ad. 10

- update on the publication policy of the Journal/Annals of Glaciology (Hester Jiskoot, University of Lethbridge, Canada): as of 1 January 2016, the Journal/Annals are published by Cambridge University Press (CUP) under a partnership agreement and published as Gold Open Access and under a Creative Commons Attribution 4.0 International Licence.

Abstracts

Abstracts

Pushing the boundaries of UAV monitoring on arctic glaciers

Eleanor Bash*, Brian Moorman, Allison Cully

Department of Geography, University of Calgary, Calgary, Canada
*Corresponding author: eleanor.bash(at)gmail.com

Monitoring glacier change in the Arctic can be challenging, due to the expense of fieldwork and remoteness of glaciers. Recent advances in computing software and unmanned aerial vehicle (UAV) technology present the possibility of new monitoring techniques that address these challenges. In fact, the use of UAVs in glaciological research is growing rapidly. This project tests the limits of UAV capabilities in monitoring glacier melt on difficult to access arctic glaciers. Specifically we focus on detecting changes at short (daily) timescales and fine spatial resolutions. In July and August 2016, a field campaign was conducted on Fountain Glacier, Bylot Island, Canada. Surveys were conducted on July 21, 23 and 24 over a portion of the toe, using a 6-propeller electric helicopter carrying a 12 MP digital camera. An automatic weather station (AWS) and a grid of 17 ablation stakes were also set up in the same area and stakes were measured prior to each UAV survey. A grid of 26 ground control points were installed in the study area, and were measured prior to each UAV survey using differential GPS.

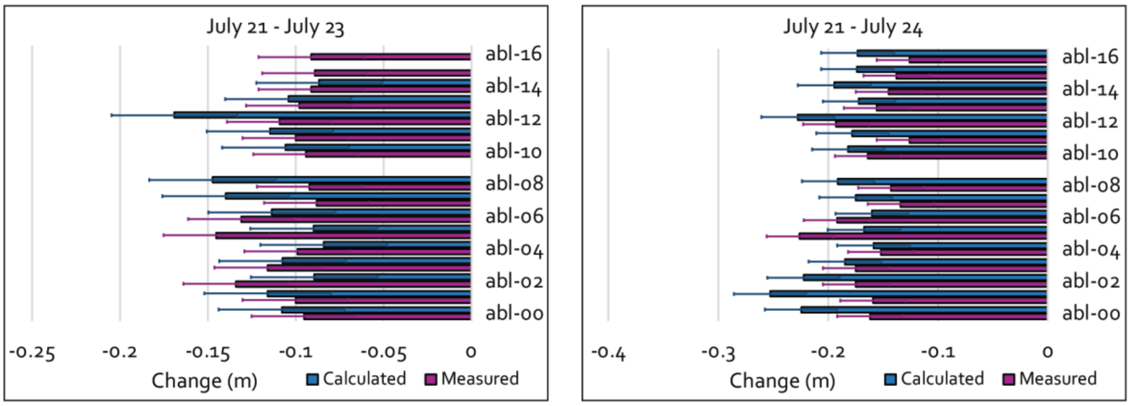
Imagery from the UAV surveys was used to produce three dense point clouds using Agisoft Photoscan Professional. These point clouds were oriented in a real-world coordinate system using a subset of 13 ground control points. The remainder of the points were used to determine the error in final point clouds. The vertical error ranged from 0.027 m to 0.047 m (July 24 and 23), and horizontal errors were 0.033 m and 0.038 m (July 24 and July21, 23). The differences between point clouds were computed using Cloud Compare and the Multiscale Model to Model Cloud Comparison tool (Lague et al, 2013). Differences were computed for July 21-23 and July 21-24. The average computed difference was calculated in the vicinity of the AWS and each ablation stake for comparison (Fig.1).

The average melt measured (calculated) at ablation stakes was 0.10 (0.11) m and 0.16 (0.19) m for the July 21-23 and 21-24 periods. Similarly, at the AWS measured (calculated) melt was 0.11 (0.08) m and 0.17 (0.23) m. Given the registration errors and errors associated with insitu measurements of surface melt, surface change calculated from UAV imagery is in agreement with measurements taken in the field.

Results of this project indicate that UAVs may be useful tools for monitoring small-scale glacier phenomena, such as daily melt. This has implications for improving modelling of glacier change through employment of large training and validation datasets.

References

Lague, D., Brodu, N., & Leroux, J. (2013). Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (NZ). ISPRS Journal of Photogrammetry and Remote Sensing, 82, 10-26.



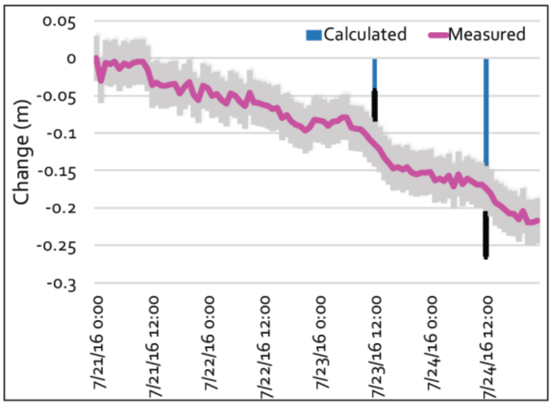


Figure 1: Surface change calculated from UAV imagery compared to surface melt measured at ablation stakes for (a) July 21-23 and (b) July 21-24. (c) Surface change calculated from UAV imagery compared to surface melt measured at the AWS. Error bars are based on point cloud error (for calculated change) and literature suggestions (for measured melt)

Tidewater glaciers, ocean and atmosphere interactions in Hornsund Fiord

Małgorzata Błaszczyk (1), Jania Jacek (1), Promińska Agnieszka (2), Walczowski Waldemar (2), Ignatiuk Dariusz (1), Wawrzyniak Tomasz (3), Ciepły Michał (1), Grabiec Mariusz (1), Moskalik Mateusz (3)

1) University of Silesia, Faculty of Earth Sciences, Centre for Polar Studies, Sosnowiec, Poland;
2) Institute of Oceanology, Polish Academy of Sciences, Centre for Polar Studies, Sopot, Poland
3) Institute of Geophysics Polish Academy of Sciences, Centre for Polar Studies, Warszawa, Poland

Arctic fjords - being a link between a land and ocean - are highly vulnerable to warming and are expected to exhibit the earliest environmental changes resulting from climate changes. Improved understanding of the interaction between tidewater glaciers, atmosphere and ocean within Arctic fjords is of a highest importance for assessments of input of fresh water into the fjord system. Seasonal variability of fresh water input into the fiord is correlated with surface melting and glacier retreat due to calving processes. Whilst surface melting is governed mainly by atmospheric conditions, ice-cliff position and fronts dynamics is influenced by a group of different agents.

This work presents results of studies on multi-year and seasonal variability of front positions of tidewater glaciers terminating into the Hornsund (Southern Spitsbergen) in period 1992-2015. Observations of ice-cliff positions were based on satellite data. Results were validated using precise location of Hansbreen front obtained by panoramic radar, time lapse camera, distance meter and laser scanner. Results show clear seasonal cycle of fluctuations with winter/spring advance and summer & fall retreat related to more intense calving. Minimal extension of tidewater glaciers in Hornsund occurs in December-January.

Seasonal and inter-annual changes in the cliffs positions were analyzed taking into account the air temperature measured in Polish Polar Station in Hornsund and sea water temperature collected during RV Oceania summer cruises every July. Other agents such as PDD+ index, precipitation, temperature of Atlantic Water, sea-ice condition in the fiord and bathymetry were used to distinguish between primary and secondary factors responsible for long- and short-term fluctuations of tidewater glaciers.
Studies were conducted within the frame of the Polish-Norwegian project 'Arctic climate system study of ocean, sea ice and glaciers interactions in Svalbard area' (AWAKE-2) aimed to understand the interactions between the ocean, atmosphere and cryosphere.

Re-analysis of the Glacier Mass Balance Time Series From Meighen Ice Cap, Nunavut, Canada (1960-2016)

David Burgess

Natural Resources Canada

Mountain glaciers and ice caps currently represent one-half of the total contribution to eustatic sea-level rise and are expected to become increasingly important to 2100 (IPCC, 2014). In-situ glacier mass balance monitoring provides a primary measurement for (i) detecting the rate and magnitude of glacier change, (ii) the causes of the changes measured, and (iii) calibration and validation of remote sensing observations of glacier change. Recent attempts to reconcile measurements of glacier change from a variety of sources (Gardner et al., 2013) have revealed discrepancies between glaciological (in-situ) and geodetic measurements of glacier change. As a result, an internationally coordinated effort to re-analyze in-situ glacier mass balance time series data through comparisons with independent geodetic observations has been initiated to identify systematic biases or sampling errors that may be over (or under) estimating rates of regional and/or global glacier change (Zemp et. al., 2014). In this study, reanalysis of the in-situ glacier mass balance time series reveals no significant bias for the Meighen ice cap (1960-2016) which is one of the longest mass balance time series for an Arctic glacier or ice cap.

Study on importance of winter liquid precipitation for mass balance of Spitsbergen glaciers

K. Cielecka[1], E. Lupikasza[2], J. Jania[3], M. Grabiec[3], D. Ignatiuk[3], B. Luks[4], A. Uszczyk[1]

[1]University of Silesia in Katowice, Faculty of Earth Sciences, Centre for Polar Studies KNOW, Leading National Research Centre
[2]University of Silesia in Katowice, Faculty of Earth Sciences, Department of Climatology
[3]University of Silesia in Katowice, Faculty of Earth Sciences, Department of Geomorphology
[4]Institute of Geophysics Polish Academy of Sciences

Climate warming results in more frequent winter liquid precipitation on glaciers as observed in the last decades. The impact of this phenomenon on mass budget of Spitsbergen glaciers is not entirely understood. Our research aims at estimating the frequency and amount of liquid precipitation fed to a glacier system in cold season (October – May) considering Hansbreen (S Spitsbergen) as an example. The frequency of liquid and mixed (sleet or snow and rain) winter precipitation was analyzed at Hornsund and other meteorological stations in Spitsbergen with respect to atmospheric circulation types. Long-term variability in the frequency of the precipitation types was also studied. Due to the lack of data on precipitation type on the glaciers, air temperature gradients were used to

assess the possible precipitation type in the accumulation area when rainfall was observed in the shore station. Liquid and mixed precipitation frequency was combined with winter mass balance measurements and snow cover structure. One can speculate that liquid precipitation in the colder part of the winter season (thick and cold snow cover) affects snow cover structure and thus conditions for internal feeding but hardly impacts the total accumulation. This implies that potential contribution of winter rainfalls to accumulation depends on snow cover conditions. The problem requires further development of instrumental studies to be solved.

Multi-decadal frontal change rates of 300 tidewater glaciers in the Canadian Arctic Archipelago

Alison J. Cook

Durham University, UK

Recent studies of post-2000 observational data have shown that many tidewater glaciers in the Canadian Arctic Archipelago (CAA) are currently in retreat. Expanding this to all tidewater glaciers in the region on a decadal time scale using earlier records can help identify when glacier retreat began, and determine longer-term temporal trends in frontal retreat rates.

Our study shows that over 94% of 300 tidewater glaciers in the CAA (from southern Baffin Island to Ellesmere Island, excluding those on the northern coast) have retreated since the earliest observational records (aerial photographs acquired in 1959/60). Mean overall length change rate of the 211 glaciers in the Queen Elizabeth Islands (QEI) is -9.3 ma^{-1} (± 1.38 SE), and of the 89 glaciers on Baffin and Bylot Islands (BBI) is -7.1 ma^{-1} (± 0.72 SE). Mean frontal widths of tidewater glaciers in the QEI are greater than those on islands to the south, resulting in greater mean area loss from this region. Each glacier has ~6 frontal positions digitised from a range of image sources at approximately decadal intervals. Length change rates have been calculated across each time interval for each glacier, based on area changes divided by frontal width. Results indicate a similar temporal pattern throughout the region, whereby glaciers show minimal change in early years with retreat rates slowly increasing, followed by an acceleration in retreat rates since the late 1990s (QEI) and early 2000s (BBI). Mean change rates in the QEI and BBI in the 1960s were -6.92 ma^{-1} and -0.51 ma^{-1} respectively, increasing to -28.96 ma^{-1} and -24.84 ma^{-1} since 2010. The same trend (at differing magnitudes) has been observed within each latitudinal degree band, and for glaciers of differing frontal widths. Further observations of decadal trends are revealed on the poster.

Changes in velocity of White Glacier, Axel Heiberg Island, Canada, over the past 50 years

Luke Copland[1], Laura Thomson[2]

[1]Department of Geography, Environment and Geomatics, University of Ottawa, Ottawa, Canada
[2]Department of Earth Sciences, Simon Fraser University, Vancouver, Canada

A major unresolved question in glaciology is whether glaciers will speed up or slow down in response to increased surface melt. To investigate this, a comparison of long-term changes in glacier velocity has been undertaken for White Glacier. Historical velocity measurements at three locations on the glacier were made by Almut Iken and co-workers using theodolites between 1960-1970. The surface velocity at these sites was remeasured with differential GPS units between 2012 and 2016. Mean annual velocities reduced by >30% at lower elevations, likely due to increased ice deformation driven by ice thinning and reduced basal motion due to increased efficiency of the subglacial hydraulic system. At higher elevations, near the historical equilibrium line altitude, there was no detectable change in annual velocity despite significant surface thinning, with the expected decrease in ice deformation likely offset by increased basal motion. This increased basal motion likely reflects supraglacial melt accessing a still inefficient subglacial drainage system, and highlights the complexity in velocity response that polythermal glaciers can have in a warming climate.

Freshwater discharge from glaciers in Svalbard and possible implications for the marine ecosystem

Thorben Dunse[1], Kjetil Schanke Aas[1], Kaixing Dong[2], Jon Ove Hagen[1], Thomas V. Schuler[1], Thomas Schellenberger[1], Leif Christian Stige[2]

[1]Department of Geosciences, University of Oslo, Oslo, Norway
[2]Centre for Ecological and Evolutionary Synthesis, University of Oslo, Oslo, Norway

Socio-economic impacts of glacier-mass loss are not limited to sea-level rise. Glacial freshwater discharge into the ocean also affects the physical and chemical properties of the fjord systems and adjacent shelves and enhances estuarine circulation and nutrient input, with effects on biological productivity. Ocean primary production, i.e. the production rate of organic carbon or phytoplankton, is an important measure of biological productivity and its dynamics commonly linked to seasonal changes in sea ice cover and solar radiation. Within the project GreenMAR (Green growth based on marine resources: ecological and socio-economic constraints) we investigate possible links between glacial-derived freshwater and the marine ecosystem.

Here, we focus on Svalbard in the Eurasian Arctic. 34000 km^2 or 57% of the total land area on Svalbard is covered by glaciers and ice caps. 68% of the glacierized area drains through tidewater glaciers with a total calving-front length of ~740 km. A 10-year simulation of the climatic mass balance of Svalbard-glaciers using the Weather Research and Forecasting model (WRF) coupled to a climatic mass balance model shows large interannual variation, especially in terms of the summer balance. This variability is also reflected in annual runoff curves, computed for 14 hydrological subregions of the archipelago. Preliminary results show that primary production in Svalbard fjord systems and adjacent shelves was low in summer 2008, coincident with low rates of meltwater runoff, whereas it was high and more widespread in August 2013, coincident with high rates of meltwater runoff. The possible correlation of meltwater runoff and ocean primary production remains to be confirmed by considering changes in sea-ice fraction, sea-surface temperature and sea-surface salinity.

Monitoring of mass balance at Austre Grønfjordbreen, Nordenskjöld land, Svalbard

Nelly Elagina, Stanislav Kutuzov, Robert Chernov, Ivan Lavrentiev, Tatiana Vasilyeva, Bulat Mavlyudov, Arseny Kudikov

Department of Glaciology, Institute of Geography, Russian Academy of Sciences, Moscow, Russia.

The glaciers of the Arctic archipelago Svalbard undergo an increase in average summer temperature and duration of melt period along with the impact of early summer and late autumn rainfalls. Due to the recent warming Svalbard glaciers significantly contribute to sea level rise outside of Greenland and Antarctica.

Since the 1960s, the glaciers of Nordenskiöld land were studied by Soviet scientists from Institute of Geography RAS, Moscow until the late 1980s, when the monitoring was stopped due to the collapse of the Soviet Union. In 2003 the direct observations of winter accumulation and summer ablation were resumed on some glaciers in Nordenskiöld land. However, until recent times snow pit and stake data was very inconsistent and randomly reported. Recent glaciological observations of Institute of Geography RAS in Nordenskiöld land have been aimed, in particular, at the study of mass balance of Austre Grønfjordbreen glacier (7 km2) located 16 km south of Barentsburg.

The survey have been conducted with following efforts. Starting from 2014 the ablation observations have been supplemented by additional 15 stakes network measured twice a year along with two new automatic weather stations at the glacier tongue and at the accumulation zone.

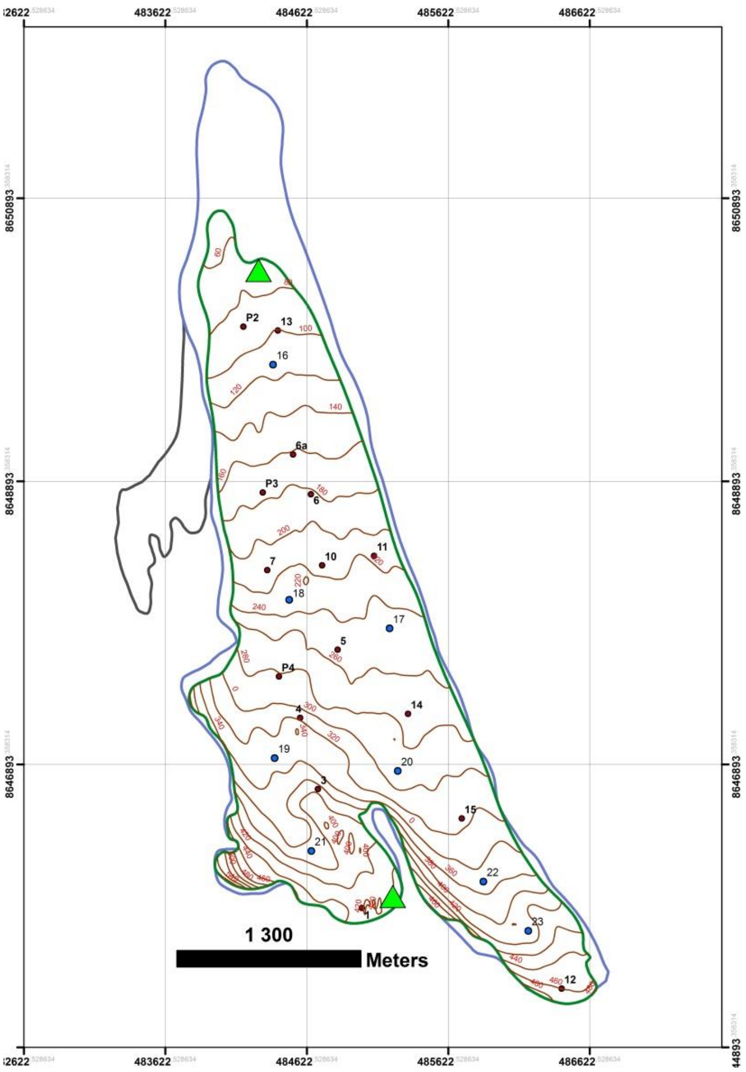


Figure 1. The area of Austre Grønfjordbreen glacier in 2016 (green line) and in 1985 (blue line + grey inflow). The stakes location is shown by the red points and two portable weather stations - by the green triangles. Blue points show the additional stakes to be installed in 2017.

Active layer (10 m) borehole temperatures are measured annually at stake locations. The obtained mass balance gradients are compared with the geodetic mass balance changes in 1990-2005 and recent Arctic DEM data. The high resolution GPR surveys of snow thickness together with snow pit measurements are provided annually each spring. The glacier bedrock, polythermal structure and surface topography maps have been supplemented with recent GPR data and DGPS measurements. The changes in snow line level have been reconstructed using all available satellite images from 1986 to 2016. Noteworthy a full absence of accumulation zone was pointed out in recent years.

Overall, the glacier has been in a permanent state of negative mass balance (cumulative mass balance 2013-2016: -6054 mm w.e.). The ELA was located at 450 m a.s.l. (AAR=1,6%) in 2014, at 368 m a.s.l. (AAR= 1,5%) in 2015 and at 421 m a.s.l. (AAR= 2,0%) in 2016 respectively. Current plans are to apply a spatially distributed mass balance model to seasonal mass balance surveys.

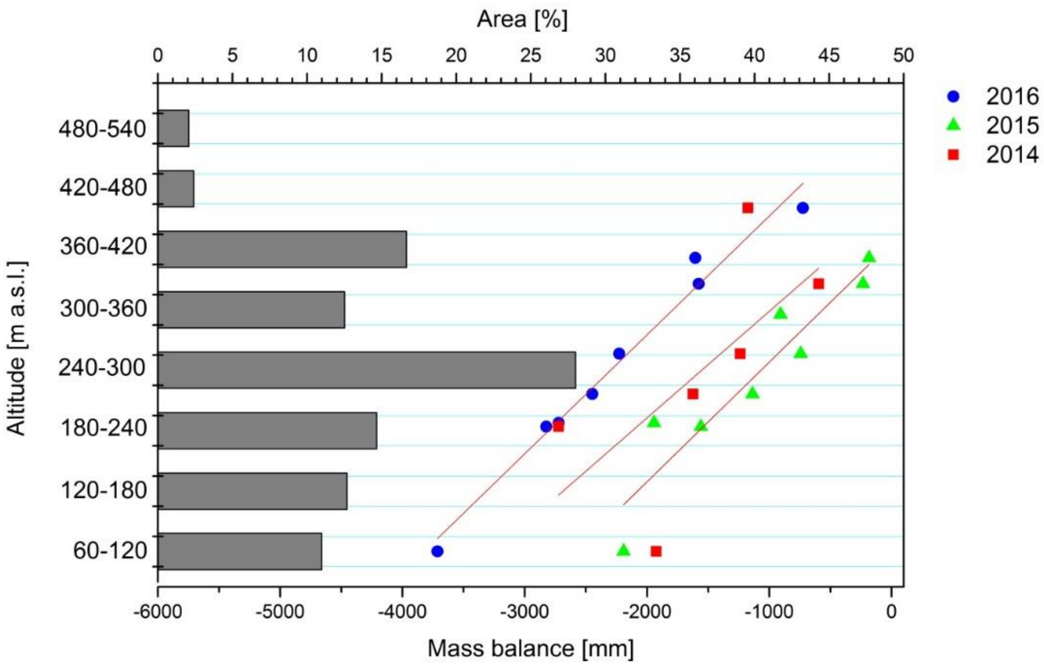


Figure 2. Mass balance of Austre Grønfjordbreen glacier versus altitude.

High-Resolution Analysis of Columbia Glacier Dynamics

Ellyn M. Enderlin[1,2], Gordon S. Hamilton[1,2], Ian Joughin[3], Shad O'Neel[4], Tim Bartholomaus[5]

[1]Climate Change Institute, University of Maine, Orono, ME, USA 04469
[2]School of Earth and Climate Sciences, University of Maine, Orono, ME, USA 04469
[3]Applied Physics Laboratory, University of Washington, Seattle, WA, USA 98105
[4]US Geological Survey, Alaska Science Center, Anchorage, AK, USA
[5]Department of Geological Sciences, University of Idaho, Moscow, ID, USA

Columbia Glacier, Alaska, has served as the archetype for the retreat phase of the tidewater glacier cycle for the past three decades. Since the mid-1980s, the terminus has retreated ~16 kilometers and the two major tributaries have thinned by > 400 m. This retreat and thinning led to separation of a major, western tributary, Post Glacier, from the larger Columbia Glacier in the late 2000s. Since their separation, the two glaciers have exhibited strikingly different dynamic behaviors over seasonal to inter-annual time scales as they continue to adjust to the long-term changes in geometry.

Here we use a combination of ground, airborne, and satellite remote sensing datasets to characterize the dynamic behavior of Columbia and Post glaciers. We focus on seasonal to inter-annual changes in dynamics from 2011-2015, when the observational record is most extensive, but also invetigate longer-term changes in dynamics using sparser datasets extending back to the 1980s.

From the mid 2000s through 2012, the glaciers thinned at comparable rates (~25 m/yr) based on repeat DEM differencing. Their behavior diverged in 2012, when Post continued its sustained thinning trend, eventually triggering ~4 km of additional retreat in 2015, but the thinning nearly ceased along Columbia's trunk and the terminus position stabilized. Although differences in near-terminus geometry strongly control the dynamic evolution of the glacier systems, we find that Columbia's recent period of dynamic quiescence is also marked by asynchronous pulses of seasonal ice flow acceleration that originate from the glacier's two largest tributaries and propagate to the trunk. These high spatial and temporal resolution observations reveal complicated surge-type behavior at Columbia Glacier that were previously unresolved but may play an important role in the glacier's dynamic evolution.

Retrieving fog thickness and inversion characteristics from radiosonde data in coastal East Greenland

Gaëlle Gilson and Hester Jiskoot

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

Coastal East Greenland glaciers and the margin of the Greenland ice sheet are influenced by frequent sea fog and temperature inversions. Both influence glacier ablation, but the effects of fog may be complex, and both increase and decrease melt energy. To understand fog's radiative and thermal properties it is important to determine accurate Arctic coastal fog macrophysical properties. In previous research we determined that fog in East Greenland peaks in the melt season, is mostly of the advection type and can be spatially extensive over glacierized terrain. In this study we focus on the quantification of fog height and temperature inversion characteristics. We analyze temperature inversions extracted from the Integrated Global Radiosonde Archive (IGRA) profiles between 1980-2012, coincident with manual and automated fog observations at three synoptic weather stations. We developed a new method, based on air mass saturation and stability, to calculate fog height from IGRA radiosonde profiles. With our automated method we will be able to retrieve fog height from any IGRA data, which we plan to do over Arctic terrain around the entire North Atlantic region. Our results for East Greenland show that fog mostly occurs under stable synoptic conditions characterized by deep and strong low-level temperature inversions, of which the top is often higher than the fog top elevation. Fog is commonly 100-400 m thick, often reaching the top of the boundary layer. Fog is thicker at northern stations, where daily fog duration is longer and relative humidity lower. Fog top elevation range was compared to land-terminating glacier hypsometry in East Greenland, where we calculate the percentage of the ablation zone covered by fog. Preliminary analysis show an approximate range of 1-30%. These results, together with energy balance effects of fog measured on glaciers, will be included in an existing glacier energy-balance model to account for the influence of fog and temperature inversions on glacier melt.

Improvements to the processing of the interferometric mode of CryoSat radar altimeter using results from Devon Ice Cap and west Greenland

Laurence Gray[1], David Burgess[2], Luke Copland[1], Thorben Dunse[3], Kirsty Langley[4], Geir Moholdt[5].

[1]Department of Geography, Environment and Geomatics, University of Ottawa, Ottawa, K1N 6N5, Canada
[2]GSC NRCan, Ottawa, K1A 0E8, Canada
[3]Department of Geosciences, University of Oslo, 0316 Oslo, Norway
[4]Asiaq, Greenland Survey, 3900 Nuuk, Greenland
[5]Norwegian Polar Institute, NO-9296 Tromso, Norway

CryoSat geocoded heights are compared with surface heights from calibration-validation sites on Devon Ice Cap and West Greenland. Using these results, we show that the pre-launch interferometric baseline coupled with an additional roll correction (~0.0075°), or equivalent phase correction (~0.0435 radians), provides an improved calibration of the interferometric SARIn mode.
Using the revised processing scheme we study change in the periphery of Greenland. This represents an important area for the use of the CryoSat SARIn mode: The ice loss in this area is very significant and hard to quantify at high spatial resolution with existing satellite sensors. In the presentation we show that the CryoSat SARIn mode can provide useful information on the summer melt through waveform signature and height change estimates, including height change of supraglacial lakes. An adaptation of 'swath processing' is used for estimating supraglacial lake heights, and height accuracies of order 0.5 m are possible. The CryoSat SARIn mode results from supraglacial lakes complement the use of optical satellite imagery.

Mass balance of the Austfonna Ice Cap, Svalbard, 2004-2015.

Jon Ove Hagen[1], Thorben Dunse[1], Trond Eiken[1], Jack Kohler[2], Geir Moholdt[2], Thomas Schellenberger[1], Thomas V. Schuler[1], Torbjørn Østby[1] and Carleen Tijm-Reijmer[3].

[1]Department of geosciences, University of Oslo, Oslo, Norway, [2]Norwegian Polar Institute, Tromsø, Norway.[3] IMAU, University of Utrecht, The Netherland.

The Austfonna ice cap (~8000 km^2) is the largest ice cap in Svalbard. Direct surface mass balance measurements were started in 2004 and have been run continuously since then. Specific net mass balances are measured at ~20 stakes across the ice cap, and winter balances are inferred from snow soundings, snow pits and GPR profiles of the snow distribution. The south-west facing drainage basin of Etonbreen covering ~640km^2 has the best continuous data indicating a slightly negative mean net surface mass balance of - 0.1 m ± 0.1 m w.eq./yr for 2004-2015. Extrapolated to the entire Austfonna, this corresponds to a total mass loss of - 0.8 ± 0.5 Gt/yr. Yearly variations are large, and mainly driven by the summer ablation. The years 2004 and 2013 were strongly negative while 2008 was strongly positive. The annual net balance is well correlated to that of Kongsvegen on North-West Spitsbergen (R^2 = 0,75) for the 12 years of joint measurements.

The geodetic mass balance of entire Austfonna based on ICESat data for the period 2003-2008 revealed a mean annual balance close to zero of +0.01 m ± 0.04 m w.eq./yr, in good agreement with the direct measurements during the same period.

Calving is important with 2.5 Gt/yr in the period 1990 to 2001 and stands for 30-40 % of the total mass loss. When this number is used the overall mass balance is negative, by ca. 3,3 Gt/yr or - 0.4 m w.eq./yr.

However, many outlets are of surge-type and a recent surge in Basin 3 resulted in a temporary tripling of the calving loss from the entire ice cap with 5,2 Gt/year calving loss during April 2012 to July 2016 and thus has a temporary large impact on the mass balance, giving ~-7,5 Gt/yr or – 0,9 m w.eq./yr during these years.

Glacier Velocity Variation and Surge Type Glaciers on Manson Icefield, Southeast Ellesmere Island 1999 – 2016

Danielle Hallé and Luke Copland

Department of Geography, Environment and Geomatics, University of Ottawa, Ottawa, Canada

Strong summer warming has been known to be a dominant factor influencing the mass balance of glaciers in the Canadian Arctic since the start of the 21st century, but little is currently known about the variability in velocity of these glaciers.

The study is therefore assessing the factors that control glacier motion in the Canadian Arctic, with a particular focus on surge-type glaciers. Manson Icefield has been chosen as the study location, since it contains a high percentage of tidewater glaciers and many have previously been observed to surge. Using feature tracking of repeat pairs of Landsat imagery, the evolution in velocity of glaciers across Manson Icefield has been quantified on an almost annual basis since 1999. This provides information on the spatial and temporal distribution of glacier surges, and information on where along the length of a glacier the surges initiate. Preliminary results have captured the motion of Mittie and Clarence Head South glaciers in their active and quiescent phases, with peak velocities of > 1 km yr^{-1} recorded on Mittie Glacier in the early to mid-2000s.

Fog on Arctic Glaciers from Time-lapse Photography and Energy Balance Stations

Hester Jiskoot (1), Amy Fossheim (1), Benjamin Fox (1), Thomas Fox (1), Mariah Hierath (1), Brad Danielson (2) and Matt Nolan (3)

1Department of Geography, University of Lethbridge, AB, Canada
2Department of Earth & Atmospheric Sciences, University of Alberta, AB, Canada
3Fairbanks Fodar, Fairbanks, AK, Canada

Fog corresponds in part to sea ice breakup and it is unknown how its occurrence will change with sustained warming. Little is known about the local and regional effects of coastal fog on glaciers. We use time-lapse imagery and weather station data to present fog spatio-temporal patterns over two Arctic glaciers and its effect on glacier energy balance components. For tidewater-terminating Belcher Glacier, Devon Island, Canada, 1-6 hourly images from three off-glacier time-lapse cameras were analysed over May-Aug 2007-2009. For land-terminating McCall Glacier, Brooks Range, Alaska, hourly images from an on-glacier camera over May-Sept 2011-2014 were analysed. From thousands of images on both glaciers we extracted over 5000 images with fog, which allowed us to analyse fog frequency, extent, height, temporal and spatial patterns, as well as concurrent cloud types, precipitation, and sea ice break-up. On both glaciers fog occurs on 25-35% of the images in all years. The highest fog frequency on Belcher Glacier occurs in Jun-Jul (>30%) and on McCall Glacier in Jun-Aug (25-45%). On both glaciers fog migrates upglacier, from either the proglacial fjord or the Alaskan North Slope coastal tundra. Maximum extent usually occurs between noon and evening. During significant fog extent most of the ablation areas are under dense fog up to several hundreds of metres thick. Weather and energy balance data below and above the fog layer were analysed to quantify the influence of fog on melt energy, while controlling for overlying cloud conditions. Both case studies and longitudinal studies will be presented, showing both reduction and enhancement of temperature and radiation by fog, while the net effect is likely an overall reduction in melt energy.

Turbid meltwater discharge and its impact on phytoplankton growth in the fjord of Bowdoin Glacier in northwest Greenland

N. Kanna[1], S. Sugiyama[1, 2], Y. Ohashi[2, 3], D. Sakakibara[1], B. Nishizawa[4], I. Asaji[2, 3] and Y. Fukamachi[1, 2]

[1] Arctic Research Center, Hokkaido University
[2] Institute of Low Temperature Science, Hokkaido University
[3] Graduate School of Environmental Science, Hokkaido University
[4] Faculty of Fisheries Sciences, Hokkaido University

In Greenland, marine-terminating outlet glaciers discharge turbid subglacial water into the ocean. To elucidate its impacts on nutrient availability and phytoplankton growth in the ocean, observational studies were conducted on Bowdoin Glacier and its fjord in northwestern Greenland during summer 2016. Meltwater sampled on the glacier contained few macronutrients (<0.5 µM for NO_3+NO_2), indicating that supraglacial meltwater is not a significant source of macronutrients in the fjord. In a subglacial discharge plume near the calving front, concentration of surface macronutrients was an order of magnitude higher (~12.8 µM for NO_3+NO_2) than that in surrounding surface waters (<1.6 µM for NO_3+NO_2). The plume water was saltier than the surrounding surface waters, suggesting upwelling of nutrient-rich and saline deep water. Within a vertical cross-section along the centerline of the fjord, highly turbid water was observed in a sub-surface layer at depths of 10–50 m. Less saline water with low macronutrients concentration was lying upon this highly turbid water. Massive phytoplankton bloom (~6.5 µg/L for Chl. a) was observed near the boundary between the less saline water and the turbid water, where a concentration of macronutrients was sufficiently high (~10 µM for NO_3+NO_2) to generate the bloom. Overall, our study results show that turbid meltwater discharge from Bowdoin Glacier affects nutrient availability and the subsequent growth of phytoplankton in the fjord. Entrainment and upwelling of macronutrients associated with subglacial meltwater plume formation is an important process for phytoplankton growth in the near-surface layer.

Submarine iceberg melting measurements using high-spatial resolution remote sensing observations in Greenland fjords

Will Kochtitzky[1] & Ellyn Enderlin[1]

[1] Climate Change Institute and School of Earth and Climate Sciences, University of Maine, USA

Submarine melting of marine-terminating glaciers is an important driver of changes in glacier dynamics and, by association, glacier mass loss and sea level rise. As such, understanding stratification and circulation of glacial fjords is critical because changes in fjord circulation will alter heat transport to the termini of glaciers. Recent studies have shown that variations in iceberg melting (in regard to both magnitudes and locations) can be a key component to the freshwater budget of glacial fjords, necessitating a better understanding of iceberg melting. Here we quantify the submarine freshwater fluxes and melt rates of icebergs from Greenland outlet glaciers using repeat very high-resolution stereo satellite images. Differences in volume between repeat digital elevation models are used to estimate iceberg freshwater fluxes at multiple times in a melt season, which are also converted to area-averaged melt rate estimates. We compare melt rate estimates of several glaciers in NW, NE, and SE Greenland to measure spatial and temporal variations in iceberg melting to explore the possibility of using iceberg melt change as a proxy for variability in fjord circulation and heat delivery to glacier termini.

The current state and potential for fog investigations in the Hornsund

Łupikasza E[1], Migała K[2], Niedźwiedź T[1]

[1]University of Silesia in Katowice, Faculty of Earth Sciences, Department of Climatology, Poland
[2]University of Wrocław, Institute of Geography & Regional Development, Department of Climatology & Atmosphere Protection, Poland

Data from the Hornsund synoptic station and Automatic Weather Stations (AWS) in the ablation zone of Hans Glacier, and data from field campaigns, allow investigation of fog phenomena including type, climatology, development conditions, and its effect on glacier energy balance. Fog is quite frequent over Hornsund – averaging 33 days a year, particularly between April and September with a maximum in July and September. Fog development is related to atmospheric circulation and is most probable (50-60%) on days with south-westerly air advection from the Greenland Sea.
Field measurements carried out in summers 2005 and 2006 indicate a shallow (250-350 m a.g.l.) atmospheric mixing layer over Hornsund, frequent stable conditions, and a multi-layered ABL (Atmospheric Boundary Layer) indicated by lapse rate analysis. During unstable conditions the height of the ABL exceeded 500 m a.g.l. Combined measurements from AWS, HOBO loggers, monostatic Doppler sodar and tethered balloon soundings imply frequent temperature inversions up to about 200 m, and resulting fog formation that probably contributed to the variable ablation on Hans Glacier. AWS data from the ablation zone of Hans Glacier (200 m a.s.l.) in 2004-2006 were used to estimate the contribution of the condensation process (in some cases related to fog formation) to the glacier mass balance. The following estimates were obtained:

- Accumulation due to condensation: 0.86 - 1.6 cm w.e.
- Release of latent heat from condensation contributes 6.4 - 12 cm w.e. to ablation
- The above processes combines increase ablation by 7-8%
- Evaporation only contributes 0.2-0.8% of the total ablation

This study presents current knowledge and potentials for detailed fog investigation and its effect on glacier energy balance in Svalbard. Fog frequency in Svalbard varies spatially (e.g. 33 days in Hornsund and 4 days at Svalbard Airport), but is much lower than over East Greenland (>60 days: see Gilson and Jiskoot, this volume). This regional variability over glacierized regions suggests comparison studies over the Atlantic sector of the Arctic are needed. We, together with the research group of Dr. Jiskoot, suggest this joint research could be structured as shown in figure 1.

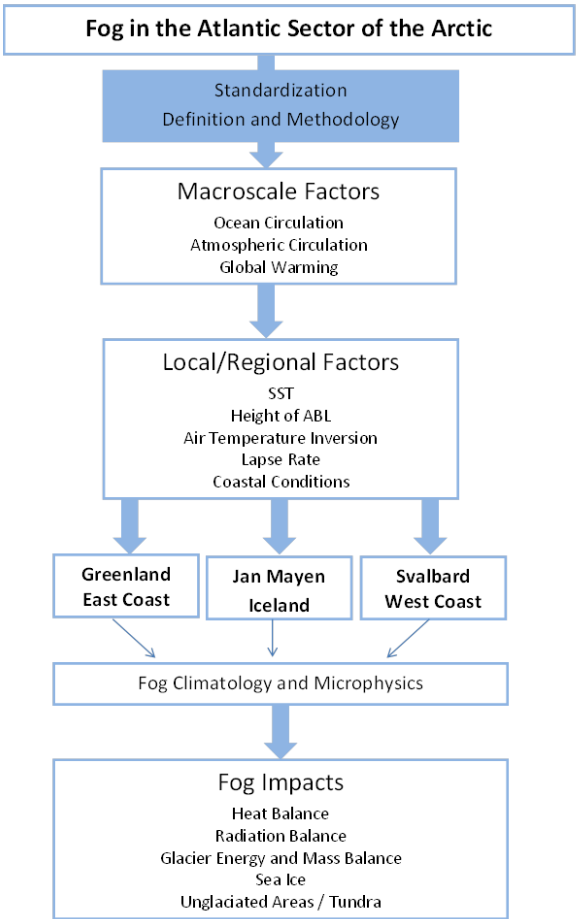


Fig. 1 The structure of joint investigations on fog in the Atlantic sector of the Arctic

Contemporary patterns and trends in water isotope composition of snow and ice across the Queen Elizabeth Islands, Canadian high Arctic

Brittany Main[1], Frances Delaney[1], Luke Copland[1], Denis Lacelle[1], David Fisher[2], Laura Thomson[1], James Zheng[3] and David Burgess[3]

[1]Department of Geography, Environment and Geomatics, University of Ottawa, Ottawa, Canada
[2]Department of Earth Sciences, University of Ottawa, Ottawa, Canada
[3]Natural Resources Canada, Ottawa, Canada

In spring 2014, 84 snow samples were collected from five ice caps and two glaciers across the Canadian Arctic Archipelago, and at every 10 cm in a 10 m ice core from White Glacier, Axel Heiberg Island. In the western Canadian Arctic, the δ18O values in the 2014 snow samples showed a 5‰ increase over those measured in 1974 by Koerner (1979), suggesting warmer temperatures in this area, most likely due to an increase of open water in the Arctic Ocean. The ice core showed an increase in δ18O values through time, further supporting a warming of the climate in the western Canadian Arctic over the past 30-40 years. In contrast, the δ18O values in the eastern Canadian Arctic were similar to those values found in 1974, which can be attributed to the fairly constant annual variability of sea ice in Baffin Bay. Given that the enhanced meridional vapour flux to the QEI best explains the observed increase in δ18O of precipitation, the study provides insights into the potential limitation of using δ18O precipitation (i.e., ice cores) as a proxy of temperature alone without proper correction.

Glacial loading of persistent organic pollutants

Kimberly Miner

University of Maine, USA

Pollutants released by industrialized nations between 1960 and 2004 have been transported northward through atmospheric processes and deposited into glaciated alpine ecosystems. Many of these chemicals retain their original structure and are absorbed into the biota thousands of miles away from where they were originally utilized. With a warming climate increasing the melt of alpine glaciers, these glaciers may be introducing growing amounts of toxins into the watershed. While studies have demonstrated the existence of resident pollutants within glaciated ecosystems, no one has used standard toxicological testing methods to assess the risk posed by these compounds when released in glacial outflows. Therefore, the goal of this study is to develop a framework to assess the conditions under which glacial release of persistent organic pollutants are a risk to the health of downstream communities. In order to get an understanding of the potential risks, multiple disciplines must be integrated to set a baseline for the current state of the problem and test future risks based upon modeled scenarios. Combining toxicology, hydrology, glaciology and climate models this study seeks to understand chemical movement through the glacial watersheds and potential human impacts. Testing glacier outflow to establish a current baseline, and then modeling future discharge as a function of glacier morphology, will allow us to better understand the risk that varying rates of increased melting will pose. Ultimately, a better understanding of the potential for release of stored toxins in glacier watersheds will allow development of relevant management strategies.

Spring submarine melt rate estimates for a seasonal ice tongue in Kangersuneq Fjord, southwest Greenland, from high-resolution satellite imagery

A. N. Moyer[1], P. Nienow[1], N. Gourmelen[1], A. Sole[2]

[1]University of Edinburgh, [2]University of Sheffield

The accelerating dynamic mass loss from the Greenland Ice Sheet has been concentrated around the coastal margins, where marine terminating (‘tidewater’) glaciers are in contact with warm ocean waters. Oceanic forcing around the ice sheet margin leads to the thinning of tidewater glaciers, which promotes increased glacier velocity, calving, and retreat. It has been estimated that approximately 40% of recent mass loss from the ice sheet is due to changes in the dynamics of these tidewater glaciers, the mechanisms of which are unknown. While increasing evidence points towards the influence of submarine melt rates (SMRs), estimates of SMR remain uncertain.

This study presents a new approach to estimating SMR, by examining freeboard changes in the seasonal ice tongue of Kangiata Nunaata Sermia (KNS) glacier in Kangersuneq Fjord, southwest Greenland. Melt rates from mid-March to mid-May 2013 are derived from high-resolution digital elevation models created from interferometry applied to TanDEM-X synthetic aperture radar imagery and ice velocities from the feature tracking of TerraSAR-X imagery. Along-fjord transects extending up to 2 km from the glaciers grounding line, in conjunction with ice-velocity, allow for the evaluation of spatial and temporal variations in SMR during the spring, when the elevation of the floating tongue decreases with distance seaward from the grounding line of KNS. Initial mean and maximum SMR along 2 km of the seasonal ice tongue are 1.69 ± 0.06 m d-1 and 2.62 ± 0.04 m d-1 respectively, which show reasonable agreement with SMR estimated from modelling using buoyant plume theory.

Coupling Glacier Dynamics to Fjord Circulation Model through Submarine Melt at the Glacier Front

Eva De Andrés[1], Jaime Otero[1], **Francisco Navarro**[1], Agnieszka Prominska[2], Javier Lapazaran[1], Waldemar Walczowski[2]

[1] *Universidad Politécnica de Madrid, Spain*
[2] *Institute of Oceanology Polish Academy of Science, Poland*

1. INTRODUCTION

Among the processes taking place at the front of marine-terminating glaciers the formation of a buoyant plume is one exerting a critical control on submarine melting [*Motyka et al.*, 2013; *O'Leary and Christoffersen*, 2013; *Sciascia et al.*, 2013; *Xu et al.*, 2013]. In this study, a high-resolution fjord circulation model, which incorporates subglacial discharge, is coupled with a flowline glacier dynamics model, simulating a summer period of 4 months. We calculate submarine melt rates at the glacier front and analyze its potential influence on calving processes.

2. METHODOLOGY

2.1 STUDY AREA AND DATA

Hansbreen is a tidewater glacier which flows into Hansbukta forebay, as a part of the Hornsund fjord system in southern Spitsbergen. The glacier is about 16 km long and terminates in a 1.5 km-wide calving front.

For Hansbreen, we use glacier surface topography data from the SPIRIT DEM, subglacial topography from GPR, surface mass balance from the European Arctic Reanalysis (EAR), center line glacier velocities from stake measurements (May 2005-April 2011), weekly terminus positions from time-lapse photos (Sept. 2009-Sept. 2011) and ASTER images, and sea-ice concentrations from time-lapse photos and Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data.

Hansbukta forebay is about 2 km long, with depths varying from 55 m at the glacier front to 80 m in the middle of the basin and a minimum of 25 m at the sill. The bathymetry of the entire system has been determined from ground penetrating radar and sonar data. In the fjord we have got temperature and salinity data measured from April to August of 2010.

2.2 MODEL SET UP (I): FJORD CIRCULATION

Massachussets Institute of Technology general circulation model (MITgcm) solves the Navier-Stokes set of equations in the Boussinesq approximation form (Marshall et al., 1997). We used it in nonhydrostatic configuration and calculate submarine melt rates (SMR) using the icefront package [*Xu et al.*, 2012, slightly modified by *Slater et al.*, 2015], which is based on the parametrization of the thermodynamical equilibrium taking place at the ice-ocean interface [*Holland and Jenkins*, 1999]. 2D fjord domain is around 2 km long, varying according to glacier front position every 1 to 2 weeks. Spatial mesh was divided into 200 cells along the *x* coordinate, with resolution of 1 m for the first 100 m near the glacier front and linearly increasing to the end of the domain. For the *z* coordinate we set 90 levels of 1 m resolution each. Our time step was 0.5 s and total run time was 20 weeks. Sea level was considered as a free surface, the lower (seabed) and left (glacier front) boundaries were implemented as rigid with non-slip conditions and an open boundary was considered at the end of the domain (to the right), with a sponge boundary layer evolving as an oceanic forcing for temperature and salinity profiles. Subglacial discharge was introduced by adding mass of fresh water through one cell (1 m^2) at the glacier front grounding point.

2.3 MODEL SET UP (II): GLACIER DYNAMICS

The glacier model solves the Stokes system using the open-source finite-element software Elmer/Ice [*Gagliardini et al.*, 2013], incorporating a crevasse-depth calving criterion [*Todd and Christoffersen*, 2014]. Terminus position is updated at each time step. Upon calving, a new regular mesh is defined for the updated glacier geometry. For further details see *Otero et al.* [2017*, in review*]. The shape of the calving front is updated with the modelled submarine met rates (SMR) from Hansbukta circulation model.

3. RESULTS AND CONCLUSIONS

Since turbulent entrainment processes are parameterized by constant eddy diffusivity and viscosity, the correct orders of magnitude for these parameters are crucial in our model. We carried out several experiments to fix such coefficients, based on literature [*Xu et al.*, 2013; *Slater et al.*, 2015] and constrained by the Richardson number for water (~10^1). There is no estimation available for the subglacial discharge (Q_{sg}), so we carefully looked at data to figure out how the system might work. We assumed different potential scenarios of Q_{sg} constrained by surface meltwater runoff (calculated from a regional climate model) and compared the results with measured temperature (T) and salinity (S) profiles.

With the minimum addition of fresh water, S profile highly differs from real data, while T fits quite well. The uppermost T-S conditions (1 to 10 m depth) are not properly reproduced by our model for Qsg above 0.1 m^3/s.

We calculated SMR for three different scenarios of Q_{sg} (minimum, maximum and best fit), varying from 0.01 to 1 m^3/s, and introduced them at 1-week steps into the glacier dynamics model. Resulting SMR ranged from 0.05 to 7.9 m/week, increasing with time, and reaching its maximum during August, at 10 to 30 m depth (Figure 1).

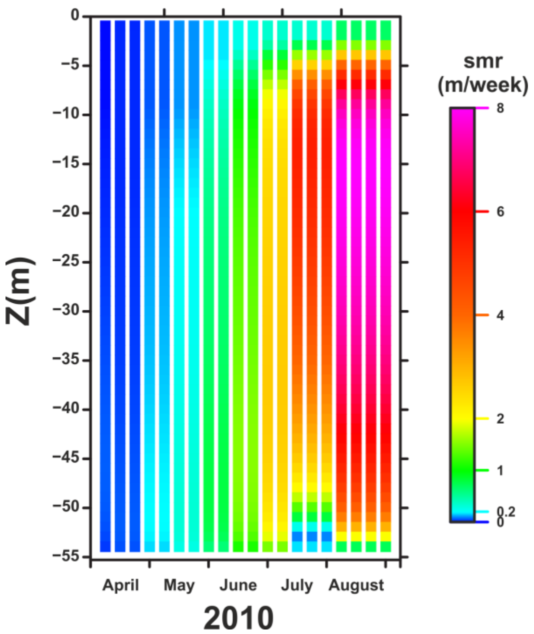


Figure 1. Submarine melt rates calculated at the glacier front as simulated for the best-fit Q_{sg} scenario.

While prescribing variable crevasse depth, the implementation of different SMR generates new calving processes and a retreat trend of about 20 m in the front position with respect to the ice model itself (Figure 2).

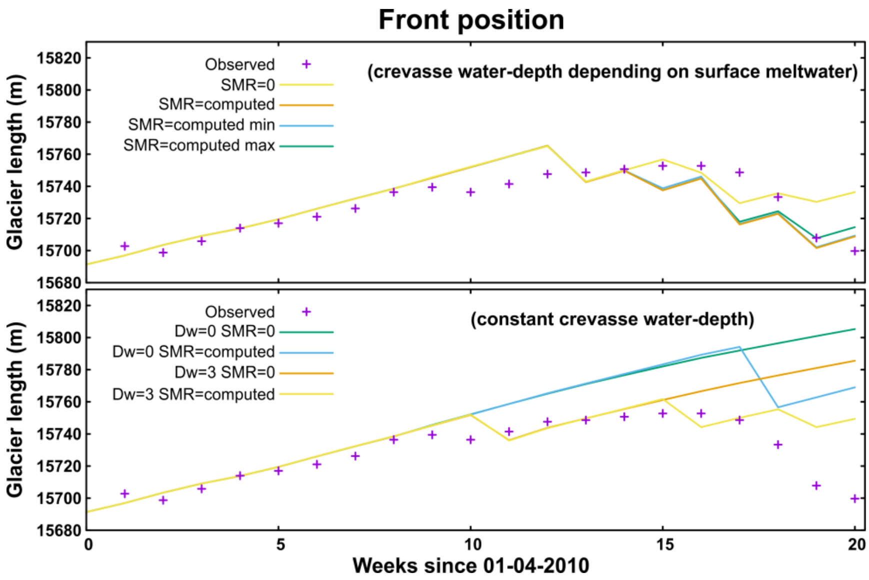


Figure 2. Front position evolution calculated in different experiments and comparison with observed data.

Additionally, with constant crevasse depth and no SMR glacier front tends to move forward with time. However, using the same crevasse conditions and SMR, from best-fit Q_{sg}, calving takes place and the front starts to retreat, although not enough to reproduce real conditions.

In our coupled model, both submarine melting and crevasse water depth influence calving processes. Thus, they both seem to be first-order mechanisms in determining the glacier front position.

REFERENCES

Gagliardini, O. et al. (2013), Capabilities and performance of Elmer/Ice, a new-generation ice sheet model, *Geosci. Model Dev.*, *6*(4), 1299–1318, doi:10.5194/gmd-6-1299-2013.

Holland, D. M., and A. Jenkins (1999), Modeling Thermodynamic Ice–Ocean Interactions at the Base of an Ice Shelf, *J. Phys. Oceanogr.*, *29*(8), 1787–1800, doi:10.1175/1520-0485(1999)029<1787:MTIOIA>2.0.CO;2.

Motyka, R. J., W. P. Dryer, J. Amundson, M. Truffer, and M. Fahnestock (2013), Rapid submarine melting driven by subglacial discharge, LeConte Glacier, Alaska, *Geophys. Res. Lett.*, *40*(19), 5153–5158, doi:10.1002/grl.51011.

O'Leary, M., and P. Christoffersen (2013), Calving on tidewater glaciers amplified by submarine frontal melting, *Cryosphere*, *7*(1), 119–128, doi:10.5194/tc-7-119-2013.

Sciascia, R., F. Straneo, C. Cenedese, and P. Heimbach (2013), Seasonal variability of submarine melt rate and circulation in an East Greenland fjord, *J. Geophys. Res. Ocean.*, *118*(5), 2492–2506, doi:10.1002/jgrc.20142.

Slater, D. A., P. W. Nienow, T. R. Cowton, D. N. Goldberg, and A. J. Sole (2015), Effect of near-terminus subglacial hydrology on tidewater glacier submarine melt rates, *Geophys. Res. Lett.*, *42*(8), 2861–2868, doi:10.1002/2014GL062494.

Todd, J., and P. Christoffersen (2014), Are seasonal calving dynamics forced by buttressing from ice m??lange or undercutting by melting? Outcomes from full-Stokes simulations of Store Glacier, West Greenland, *Cryosphere*, *8*(6), 2353–2365, doi:10.5194/tc-8-2353-2014.

Xu, Y., E. Rignot, D. Menemenlis, and M. Koppes (2012), Numerical experiments on subaqueous melting of greenland tidewater glaciers in response to ocean warming and enhanced subglacial discharge, *Ann. Glaciol.*, *53*(60), 229–234, doi:10.3189/2012AoG60A139.

Xu, Y., E. Rignot, I. Fenty, D. Menemenlis, and M. M. Flexas (2013), Subaqueous melting of Store Glacier, west Greenland from three-dimensional, high-resolution numerical modeling and ocean observations, *Geophys. Res. Lett.*, *40*(17), 4648–4653, doi:10.1002/grl.50825.

Enhancing Greenland fjord bathymetry maps using remotely sensed data

Jessica Scheick and Ellyn Enderlin

University of Maine

Glacier-ocean interactions at the marine-terminating boundaries of the Greenland ice sheet are strongly modulated by the bathymetry of the fjords and coastal shelf. Warm, salty water masses are located at depth on the Greenland continental shelf, with colder, fresher waters near the surface. The ability of these warm, dense waters to reach the marine termini of outlet glaciers is strongly influenced by the presence or absence of bathymetric sills. Sills can effectively block warm subsurface water from reaching glacier termini, limiting the impact of changes in ocean temperature on submarine glacier melt.

Despite the importance of these relatively large-scale bathymetric features with respect to glacier submarine melting and terminus position change, they remain largely unresolved for many of Greenland's fjords. We have developed methods to qualitatively and quantitatively improve bathymetry in Greenland's fjords using icebergs as observed in remotely sensed datasets. Specifically, optical images are used to identify locations of iceberg stranding and movement. Then, iceberg keel depths are estimated from iceberg freeboards extracted from digital elevation models (DEMs) constructed using very-high resolution stereo satellite images, allowing us to estimate minimum and maximum water depths at locations of iceberg movement and stranding. This presentation will present the methodology and associated challenges as well as showcase results derived for several fjords around Greenland.

Multi-year surface velocities and sea-level rise contribution of the Basin-3 and Basin-2 surges, Austfonna, Svalbard

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

[1]Department of Geosciences, University of Oslo, P.O. Box 1047, Blindern, 0316 Oslo, Norway
[2]Institute for Marine and Atmospheric Research, Utrecht University, Princetonplein 5, 3584 CC Utrecht, the Netherlands

The surge of Basin-3 which started in summer 2012 is still ongoing as of November 2016. Here we present an extended time series of area wide speed fields based on TerraSAR-X and Radarsat-2 data as well as GPS data. The analysis reveals the evolution of the basin wide surge after its peak in January 2013. The speed slows down to ∼ 8–9 m d −1 at the calving front until April 2016, and is interrupted by yearly summer speed-ups during the melt seasons. The highest speed in July 2016 was 10.2 m d −1 some 22 km upglacier of the calving front.
Next to this, Basin-2 - the basin south-east to Basin-3 - also started to accelerate in autumn 2014. The highest speed of 8.71 m d −1 was measured in summer 2015. We provide an estimate of the frontal ablation and se-level rise contribution of both basins.

Glacier surface velocities of the Svalbard Archipelago

Thomas Schellenberger[1], Wesley Van Wychen[2,3] Luke Copland[2], Andreas Kääb[1] and Laurence Gray[2]

[1]Department of Geosciences, University of Oslo, Oslo 0371, Norway
[2]Department of Geography, Environment and Geomatics, University of Ottawa, Ottawa, ON K1N 6N5
[3]Natural Resources Canada, Ottawa, ON K1A 0Y7

In this study we exploit Radarsat-2 (RS-2) and European Remote Sensing satellites (ERS-1/2) tandem data to determine the surface speed of Svalbard glaciers. The RS-2 WF mode combines the advantages of the large spatial coverage of the Wide mode (150 × 150 km) and the high pixel resolution (9 m) of the Fine mode. Thus it has a major potential for glacier velocity monitoring from space by means of offset and speckle tracking especially for fast moving glaciers.
In the maritime climate of Svalbard surface features and speckle pattern regularly change over the course of the 24-days repeat cycle of RS-2 and lead erroneous velocity estimates.
Therefore we fill these gaps with velocity maps based on ERS-1/2 tandem interferometry. The short time period of only one day between the acquisitions often allows the application of this more accurate technique.

Towards automated glacier monitoring using open-access satellite data

Tereza Šmejkalová[1], Robert D. Briggs[1]

[1]C-CORE, Captain Robert A. Bartlett Building, Morrissey Rd., St. John's, NL A1B 3X5, Canada

This project aims to investigate, develop and refine automated techniques for operational glacier monitoring using open-access satellite data provided by the Copernicus program (namely from Sentinel-1 and Sentinel-2 satellites, and augmented by data from Landsat-8). Two study sites have been selected as representative examples: Store Glacier in Western Greenland, a fast-flowing tidewater glacier where the primary discharge mechanism is calving, and Llewellyn Glacier in Yukon, a slow flowing mountain glacier. Using a combination of SAR imagery and optical imagery we automatically delineate glacier outline and the position of the glacier front and are currently working towards automatic determination of the facies. The extraction of the glacier calving front from SAR is based on smoothed image thresholding. We have tested a number of smoothing and segmentation methods to improve the accuracy of the detection. The presence of ice mélange beyond the calving front during the spring period is especially problematic. Optical imagery is used to delineate the glacier/bare rock boundary. Mass loss time series, based on area-change and velocity, with greater than monthly temporal resolution will be derived for both glaciers. We are currently using predetermined velocity fields from MEaSUREs Greenland Ice Velocity (Version 1) and a dataset compiled using the CIAS Image Correlation Software. For the Store glacier the estimates of mass loss will be used for the prediction of iceberg production statistics (iceberg size distribution and areal density). For Llewellyn Glacier, the computed mass-loss will be integrated into estimates for managing hydro-power generation. The toolsets are being developed such that they can be integrated and operated on the new ESA Polar Thematic Exploitation Platform (P-TEP). P-TEP will provide polar researchers with access to cloud based computing resources, including earth observation (EO) and other related data and software tools.

Mass loss of outlet glaciers and ice caps in the Qaanaaq region, northwestern Greenland

Shin Sugiyama[1], Shun Tsutaki[2], Daiki Sakakibara[3], Evgeny Podolskiy[3], Masahiro Minowa[1], Yoshihiko Ohashi[1], Martin Funk[4], Guillaume Jouvet[4], Julien Seguinot[4], Yvo Weidmann[4], Riccardo Genco[5]

[1]Institute of Low Temperature Science, Hokkaido University
[2]Earth Observation Research Center, Japan Aerospace Exploration Agency
[3]Arctic Environment Research Center, National Institute of Polar Research
[4]Laboratory for Hydraulics, Hydrology and Glaciology, ETH-Zurich, Switzerland
[5]Department of Earth Science, University of Florence
The Greenland ice sheet and peripheral ice caps are rapidly losing mass. Recently, mass loss is increasing particularly in northwestern Greenland (e.g. Kahn et al., 2010 GRL; Enderlin et al., 2014 GRL), but in-situ data are sparse in the northern area of Greenland. To quantify recent ice mass loss in northwestern Greenland and better understand the drivers of the changes, we studied ice caps and outlet glaciers in the Qaanaaq region as a part of a Japanese integrated Arctic research project, GRENE Arctic Climate Change Research Project. Field and satellite observations were performed to quantify ice mass loss of the ice caps and outlet glaciers. We also investigated processes occurring near the front of outlet glaciers to better understand their interaction with the ocean. Our study includes mass balance monitoring on Qaanaaq Ice Cap since 2012, intensive field observations near the front of Bowdoin Glacier since 2013, and ocean measurements nearby outlet glaciers. In this contribution, we present the overview of the results obtained in the GRENE project, and introduce a new project established under the framework of ArCS (Arctic Challenge for Sustainability Project). In the new ArCS project, we focus on the ice-ocean interaction, and extend our study to changing ocean environment and its consequence to human activity in the Qaanaaq region.

Industrial-age doubling of snow accumulation in Alaska linked to tropical ocean warming

Dom Winski,

Dartmouth College, USA

Future precipitation changes in a warming climate will depend regionally on the response of natural climate modes to greenhouse gas forcing. North Pacific hydroclimate is dominated by the Aleutian Low (ALow) pressure system, a semi-permanent feature that is strongly influenced by tropical ocean temperatures through the Pacific-North American (PNA) teleconnection pattern. Indicies that document ALow and PNA variability during the instrumental period demonstrate the interannual-scale downstream impact on North American climate, but are of insufficient length to accurately assess low frequency behavior and trends. Here we present a 1200-year ice core record of snow accumulation from the Alaska Range that shows a doubling of precipitation since 1840, with recent values well outside variability observed over the past millennium. Regional 20th century warming likely accounts for a portion of the observed increase, however the magnitude and seasonality of the precipitation change implies a strengthening of the AL system. The precipitation increase is nearly synchronous with the warming of Western tropical Pacific Ocean temperatures beginning in 1840, attributed to rising greenhouse gas concentrations. Our results indicate that modern central Alaskan precipitation exceeds natural pre-industrial levels, and will likely continue to rise along atmospheric temperature, tropical ocean temperatures, and enhanced tropical-extra tropical teleconnections.Kreutz