IASC Workshop on the dynamics and mass budget of Arctic glaciers & proglacial marine ecosystems

Abstracts and Programme

IASC Workshop, 21-23 January 2019
Bardola Hotel, Geilo, Norway.

IASC Network on Arctic Glaciology

IASC Workshop on the dynamics and mass budget of Arctic glaciers & proglacial marine ecosystems

Abstracts and program

Network on Arctic Glaciology annual meeting & IASC cross-cutting activity on the importance of Arctic glaciers for the Arctic marine ecosystem
21-23 January 2019, Geilo, Norway

Organised by Thorben Dunse (NAG chair) and members of local organizing committee: Pierre-Marie Lefeuvre, Bas Altena and Jon Ove Hagen

Steering committee of cross-cutting activity:
Thorben Dunse (NAG), Renate Degen (MWG), Monika Kędra (MWG), Marit Reigstad (MWG), Martin Sharp (CWG/NAG) and Shin Sugiyama (CWG)

IASC Network on Arctic Glaciology

Cover photo: A fishing boat navigates through stranded icebergs at the mouth of Illulisat Isfjord in Western Greenland. Glacier fjords provide rich fishing grounds for men, seabirds and marine mammels alike. (Photo: T. Dunse)

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Photo of the participants in front of the hotel at −10°C. (Photo: T. Dunse)

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Preface

The 2019 IASC Workshop on the dynamics and mass balance of Arctic glaciers and the annual meeting of the Network on Arctic Glaciology took place in Geilo, Norway, 21-23 January 2019. Bardøla Hotel had already served earlier as meeting venue for the 2004 IGS symposium on Arctic Glaciology, which was co-sponsored by IASC. This year's meeting integrated a follow-up of the cross-cutting activity "The importance of Arctic glaciers for the Arctic marine ecosystem", endorsed by the Cryosphere (CWG) and Marine working group of IASC (MWG). The meeting brought together 58 participants from 16 countries (67 had registered). 11 early-career scientists (ECS) received travel support provided by CWG and MWG.

During two–and–a–half days of scientific sessions, participants presented oral presentations and posters on a wide-range of topics related to glacier dynamics and mass balance. The cross-cutting activity featured presentations on the glacial impacts on marine ecosystems, with special emphasis on biogeochemistry of water masses and primary production in glacial fjords. Two keynote speakers shed light on aspects that were little discussed during the first cross-cutting activity: (1) physical oceanographic processes, which modulate the effects of glacier runoff and nutrient distribution; and (2) past changes in species composition in response to environmental changes inferred from marine sediment records. Scientific discussions continued during joined meals and on the ski slopes/cross-country tracks during extended lunch breaks. Thereby, the workshop offered a good framework for the glacier and marine communities to get to know each other better and establish networks for future interdisciplinary collaboration.

Thanks to all participants contributing to the workshop. Special thanks to Pim Lefeuvre and Bas Altena, who helped to run the sessions smoothly and to Gerlis Fugmann from the Association of Polar Early Career Scientists (APECS) for handling of travel funds. I hope to see many of you again at the next year's workshop in Obergurgl, Austria, 28-30 January 2020.

Thorben Dunse

February 2019

Program

The meeting takes place at Bardøla Hotel in Geilo, Norway, 21 - 23 January, 2019.

Sunday 20 January

ARRIVAL

19:00	**Dinner** 19:00 or any time upon arrival; the kitchen closes at 21:00

Monday 21 January

08:15 - 08:40	Prepare your name badge, pick up the program and/or upload your presentation
08:40 - 08:50	**Welcome** *Thorben Dunse & Jon Ove Hagen*
08:50 - 10:00	**Cross-cutting session I**
Convener:	*Thorben Dunse*
08:50 - 09:15	**Keynote talk** Marine ecosystem responses to climate change in Greenland - a view from below, **Ribeiro, Sofia**
09:15 - 09:30	The impact of melting glaciers on coastal productivity, **Meire, Lorenz**
09:30 - 09:45	Impact of glacially-derived Fe(III) on carbon mineralization pathways in Arctic fjord sediments, **Laufer, Katja**, Alexander B Michaud, Hans Røy, Bo Barker Jørgensen
09:45 - 10:00	Biogeochemical surveys near the fronts of marine-terminating glaciers in Inglefield Gulf, Northwestern Greenland, **Kanna, Naoya**, Shin Sugiyama, Takuto Ando, Izumi Asaji, Yoshiki Fujishi
10:00 - 10:30	**Coffee break**
10:30 - 12:00	**Cross-cutting session II**
Convener:	*Nicole Treholm*
10:30 - 10:55	**Keynote talk** Challenges to understanding ice-ocean interactions and their impact on marine biogeochemistry, **Cape, Mattias**, Fiamma Straneo, Maria Vernet
10:55 - 11:10	Contrasting the effects of glaciers and icebergs on marine primary production, **Hopwood, Mark**, Stephan Krisch, Dustin Carroll

11:10 - 11:25	Fjord-shelf dynamics control Fe fluxes from the 79N glacier, **Krisch, Stephan**, Mark Hopwood, Janin Schaffer, Pablo Lodeiro, Shao-Min Chen, Torsten Kanzow,Eric P. Achterberg
11:25 - 11:40	Daily freshwater and weekly ice fluxes into Greenland fjords, Mankoff, Kenneth, **Andreas Ahlstrøm**, Anne Solgaard, William Colgan, Sofia Ribeiro
11:40 - 11:55	Glacier change, ice-ocean interaction, and their impacts on human society in Qaanaaq, northwestern Greenland, **Sugiyama, Shin**, ArCS Greenland Project members
12:00 - 14:00	**Lunch & health break**
14:00 - 14:45	**Cross-cutting break-out session: How do glaciers affect marine primary production in the ocean?**
Moderator:	*Shin Sugiyama and Mark Hopwood*
14:45 - 15:45	**Glaciology session I**
Convener:	*Chris Nuth*
14:45 - 15.00	Glaciological and geodetic mass balance of Norway's glaciers – an overview, **Andreassen, Liss Marie**, Hallgeir Elvehøy, Bjarne Kjøllmoen
15:00 - 15:15	Response of Norwegian plateau icefields to climate warming since the Little Ice Age, **Weber, Paul**, Liss M. Andreassen, Clare M. Boston, Harold Lovell
15:15 - 15:30	Is the frequency of glacier floods in Norway increasing?, **Jackson, Miriam**, Hallgeir Elvehøy
15:30 - 15:45	Into the Ice, **Haarloev, Caspar**, Lars Ostenfeld
15:45 - 16:15	**Coffee break**
16:15 - 16:45	**Poster introduction by authors** (1-2 slides and max. 2 minutes per person
Convener:	*Bas Altena*
16:45 - 18:30	**Poster session** Note: posters remain up until Wednesday
19:00	**Dinner**

Tuesday 22 January

09:00 - 10:15	**Glaciology session II**
Convener:	*Ward van Pelt*
09:00 - 09:15	Projecting Svalbard glacier mass balance for future climate, **Schuler, Thomas V.**, Andreas Dobler, Julia Lutz

09:15 - 09:30	Elevation and mass changes of glaciers and ice caps in Svalbard, Norwegian High Arctic, **Morris, Ashley R.**, Geir Moholdt, Laurence Gray
09:30 - 09:45	Closing the mass budget of a tidewater glacier: the example of Kronebreen, Svalbard, Deschamps-Berger, Cesar, **Christopher Nuth**, Ward van Pelt, Etienne Berthier, Jack Kohler, Bas Altena
09:45 - 10:00	Mass balance of Devon Ice Cap: comparing in-situ and geodetic measurements, **Bernard-Grand'Maison, Claire** , Burgess, David, Copland, Luke
10:00 - 10:15	Structure-from-Motion DEMs of glaciers in northeast Spitsbergen, **Gjermundsen, Endre Før**, Geir Moholdt, James Lam
10:15 - 10:45	**Coffee break**
10:45 - 12:00	**Glaciology session III**
Convener:	*Jakob Abermann*
10:45 - 11:00	Estimate of current dynamic discharge from Northern Hemisphere glaciers and ice caps to the ocean, **Dalton, Abigail**, Luke Copland, Wesley Van Wychen
11:00 - 11:15	Dynamic discharge and mass balance of the Academy of Sciences Ice Cap, Severnaya Zemlya, Russian Arctic, Sanchez-Gomez, Pablo, **Francisco Navarro**, Toby J. Benham, Andrey F. Glazovsky, Robin P. Bassford, Julian A. Dowdeswell
11:15 - 11:30	Monitoring and modeling a recurrent calving event at Bowdoin Glacier, Greenland, **van Dongen, Eef**, Andrea Walter, Guillaume Jouvet, Daniel Farinotti
11:30 - 11:45	Acceleration prior to calving controlled by ice damage, **Lefeuvre, Pierre-Marie**, Christopher Nuth, Tom Rune Lauknes, Line Rouyet, Michał Petlicki, Tazio Strozzi
11:45 - 12:00	Analysing calving activity using continuous direct observations, **Walter, Andrea**, Martin P. Lüthi, Andreas Vieli
12:00 - 16:00	**Lunch & ski break**
16:00 - 16:30	**Coffee break**
16:30 - 17:30	**Cross-cutting session III**
Convener:	*Katja Laufer*
16:30 - 16:45	Impact of tidewater glacier retreat on the fjord system: present and future circulation in Kongsfjorden, Svalbard, **Kohler, Jack**, Tomas Torsvik, Jon Albretsen, Arild Sundfjord, Pedro Duarte, Philipp Assmy, Sebastien Deschamps, Alistair Everett, Katrin Lindbäck, Ankit Pramanik, Anne Dagrun Sandvik , Jofrid Skarðhamar, Hallvar Strøm
16:45 - 17:00	Climatic mass balance and associated freshwater runoff in Kongsfjord basin, northwest Svalbard, **Pramanik, Ankit**, Jack Kohler, Ward Van Pelt, Thomas V. Schuler

17:00 - 17:15	Depth profiling of the particle size distribution in glacial meltwater using laser diffractometry in the Svalbard archipelago, **Sandven, Håkon**, Arne Kristoffersen, Yi-Chun Chen, Børge Hamre
17:15 - 17:30	Greenland land ice surface physical properties from Sentinel-3 optical retrievals, **Box, Jason**, Maxim Lamare, Kenneth Mankoff, Alex Kokhanovsky, Olaf Danne, Carsten Brockmann
17:30 - 17:40	**Short break**
17:40 - 18:45	**IASC Network on Arctic Glaciology open forum meeting** *Thorben Dunse, Guðfinna Aðalgeirsdóttir, ...*
19:00	**Dinner**

Wednesday 23 January

09:15 - 10:15	**Glaciology session IV**
Convener:	*Abigail Dalton*
09:15 - 09:30	Kangerdlugssuaq Glacier primed for runaway retreat by ocean warming, **Bevan, Suzanne**, Adrian Luckman, Doug Benn, Tom Cowton, Joe Todd
09:30 - 09:45	Observing glacier dynamics in the Southern Alaskan mountain ranges, **Altena, Bas**, Ted Scambos, Andreas Kääb, Mark Fahnestock
09:45 - 10:00	Surge controls at Donjek Glacier, Yukon, Canada from 1935 to present, **Kochtitzky, Will**, Hester Jiskoot, Ellyn Enderlin, Erin McConnell, Luke Copland, Seth Campbell, Robert McNabb, Karl Kreutz, Christine Dow, Brittany Main
10:00 - 10:15	Bridging the trenches – ice sheet monitoring for the atmosphere and oceans in PROMICE and INTAROS, **Ahlstrøm, Andreas**, Robert S. Fausto, Michele Citterio, Jason Box, Kenneth Mankoff, Anne M. Solgaard, Liam Colgan, Roberta Pirazzini, Anders Kusk, Jørgen Dall
10:15 - 10:45	**Coffee break**
10:45 - 12:00	**Glaciology session V**
Convener:	*Liss Andreassen*
10:45 - 11:00	Spatio-Temporal Variations of Firn Properties on the Western Greenland Ice Sheet, **Hock, Regine**
11:00 - 11:15	Utilization of satellite-derived surface snow physical properties to improve the performance of the SMAP physical snowpack model, **Niwano, Masashi**, Jason E. Box
11:15 - 11:30	The need for water vapor fluxes in long-term modeling of the Greenland ice sheet , **Zolles, Tobias**, Andreas Born

11:30 - 11:45	Hypersaline subglacial lakes beneath the Devon Ice Cap, **Sharp, Martin**, Anja Ruitishauser
11:45 - 12:00	Closing remarks *T. Dunse, ...*
12:00 - 13:00	**Lunch / Skiing / Side events / Early departure**
19:00	**Dinner**

Posters

- Recent changes in the continental ice margin in Northwest Greenland, **Abermann, Jakob**, Jakob Steiner, Rainer Prinz
- Winter rain induced soft-bed warming - A potential acceleration mechanism, **Alexander, Andreas**
- Development of phosphorus forms in soil chronosequence of the Nordenskioldbreen glacier (Svalbard), **Allaberdina, Adel**
- Application of digital elevation models produced from satellite and aerial images to estimation of geodetic mass balance over southern Spitsbergen, **Błaszczyk, Małgorzata** , Dariusz Ignatiuk, Leszek Kolondra, Mariusz Grabiec, Michał Laska, Bartłomiej Luks, Leo Decaux, Mateusz Czapla, Etienne Berthier, Barbara Barzycka, Jacek Jania
- Observations of vertical mixing and nitrate fluxes at four marine terminating glaciers in NE Greenland, **Carlson, Daniel**, Lorenz Meire, Mikael Sejr
- Wintertime sea-ice chemistry and effect of glacial freshwater runoff during two contrasting years in a Spitsbergen fjord, **Chierici, Melissa**, Agneta Fransson, Daiki Nomura, Mats Granskog, Svein Kristiansen, Tonu Martma, Gernot Nehrke
- Glacier meltwater runoff as a potential driver of phytoplankton dynamics around Svalbard, **Dunse, Thorben**, Kaixing Dong, Kjetil Schanke Aas, Leif Christian Stige
- Influence of glacial water on carbonate chemistry and biogeochemical processes in Svalbard fjords with different characteristics, **Fransson, Agneta**, Melissa Chierici, Ylva Ericson, Eva Falck, Svein Kristiansen
- Experimental design of in-situ mass-balance measurement networks, **Flowers, Gwenn**, Alexandra Pulwicki, Derek Bingham, Sonja Surjanović
- Impacts of Greenland Ice Sheet melt on heterotrophic processes in adjacent fjords, **Holding, Johnna**, Mikael Sejr, Mathias Middelboe
- The role of winter rains in glacial system on Svalbard, **Ignatiuk, Dariusz**, Ewa B. Łupikasza, Mariusz Grabiec, Katarzyna Cielecka, Michał Laska, Jacek Jania, Małgorzata Błaszczyk, Bartek Luks, Aleksander Uszczyk, Tomasz Budzik
- Geodetic mass balance evolution of surge-type glaciers in Svalbard and Yukon, **Main, Brittany**, Luke Copland, Jack Kohler, Christine Dow, Robert McNabb, Adrian Luckman, William Kochtitzky, Christopher Borstad, Philip Porter
- Climate, and Surface energy and mass balance of Ulvebreen, Svalbard, **Reijmer, Carleen**, P. Kuipers Munneke, S. Ligtenberg, W.J. van de Berg, M.R. van den Broeke
- 2020 Expedition to for Interactions between Ocean Forcing with the Marine Ecological Response at Arctic Glacier Termini, **Treholm, Nicole**, Josh Willis
- A multidecadal simulation of climatic mass balance, snow conditions and runoff across Svalbard, **Van Pelt, Ward**, Jack Kohler, Veijo Pohjola, Rickard Pettersson, Sergey Marchenko, Bartek Luks, Jon Ove Hagen, Carleen Reijmer
- Water discharge changes of the rivers with glacier feeding due to climatic fluctuations in Arctic region, **Volkova, Daria**, Volkova Daria, Rasputina Valeria, Kovalenko Alla, Saleeva Daria

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Young scientists receiving IASC travel support are marked *;
Researchers contributing to a poster, but not physically present are marked **).

Minutes of the cross-cutting break-out session: How do glaciers affect marine primary production in the ocean?

Moderator: Shin Sugiyama and Mark Hopwood
Minutes: Carleen Reijmer, Mark Hopwood and Katja Laufer

Shin introduces the topic by presenting the IASC call for cross-cutting initiatives and a summary of our activity: The importance of Arctic glaciers for the Arctic marine ecosystem, endorsed by the IASC Cryosphere and Marine working groups.

Last year's discussion on cross cutting issues was centered around three questions:

- What glaciological information/data are useful for the marine biology/ecology community and vice versa?
- What data/information can glaciologists provide to the marine biology/ecology community and vice versa?
- Collaborations between glacier and marine ecology communities in field work, etc.?

The proposal of the activity contained further research questions, three of which were reformulated by **Mark Hopwood** and used as the backbone of a synthesis paper, *"How do glaciers affect marine primary production in the ocean?"* for which he, together with **Andy Hodson**, has taken the initiative to write. The reformulated questions are:

- Where and when does glacial freshwater promote marine primary production and where and when does it retard marine primary production?
- How do variations in glacial discharge timing and location affect marine organisms?
- How far reaching are glacial effects of glaciers on marine biogeochemistry?

A draft version of the paper has been made available and the group is asked for input, either to provide contents, or comments on the current draft. **Lorenz Meire** already offered to write parts of it.

Mark Hopwood
Welcomes comments on a circulating synthesis text either in form of general comments, in-depth reviews or requests for new/missing topics to be covered. Co-authors very welcome to propose new material. Current focus is heavily biogeochemical following input from Mark Hopwood and Andy Hodson since last year's meeting.

Agneta Fransson (NPI) and **Melissa Chierici** (IMR) will contribute to the paper with data from Kongsfjorden, Svalbard (nutrients and carbonate chemistry).

Daniel Carlson
Glacial discharge and iceberg discharge is presently treated as lagrangian process whereas it would be more appropriate to be treated as eulerian. This

should now be within our modelling capabilities. Advection/diffusion can be monitored using natural or synthetic tracers to link chemistry/physics to biology.

Andreas Ahlstrøm
How can glaciologists help? In the conclusion of the manuscript there are 2 statements:

a) What is the fractional composition of glacier discharge (in terms of surface runoff, subsurface discharge and solid ice) and how does this very seasonally, interannually and between glaciated catchments?
b) How do these different discharge components (surface runoff, subsurface discharge and solid ice) affect stratification and mixing in the marine environment? How does this affect water column structure and resource availability to marine ecosystems locally (around glaciers, fjords and icebergs) and on broader (e.g. pan-Arctic) scales?

Ad a) This should now be possible, but is not easy. Ad b) Not really a question for glaciologists, but more for fjord oceanographers. A general conclusion of this year and last years meeting seems to be the need for physical oceanographers to work closely with glaciologists to resolve the fate of discharge in when it first enters the water column, fortunately this collaboration is now happening. But unfortunately, there are not many / none of those present at the meeting.

Daniel Carlson
Mixing due to icebergs has now been monitored using microstructure profiles, definitely an area of interest and topical research, but no work yet published in the field.

Thorben Dunse
The synthesis paper describes model simulations of nutrient cycling in front of marine-terminating glaciers. The scenarios for glacier discharge volumes are highly simplified, e.g. a constant discharge rate over a 2-month period. Glaciologists can help establish more realistic scenarios for glacial discharge volumes, which vary on diurnal to seasonal and interannual timescales. Mattias Cape pointed out in his keynote talk that nutrient entertainment in subglacial discharge plumes strongly depends on the volume of the discharge. If nutrient entertainment does not scale linearly with discharge volume, than it is important to use timeseries-data of discharge, rather than a constant mean value.

Lorenz Meire
Indeed timing does matter, there are complexities associated with tidal mixing, fjord circulation, light availability and extreme events to consider alongside discharge rates. Lorenz comments that extreme events may be short lived, but have large effects on fjord water column structure. These events can only be detected from field observations and are missed by models. Data from moorings, such as those in Godthabsfjord, may be useful for determining the extent to which such events occur and their significance. Such problems exemplify why it is better to focus on few glacier-fjord systems, rather than many, as only intensive field campaigns can reveal the significance of these processes.

Thorben Dunse
Comments that pro-glacial stream discharge can now be modelled relatively well (Andreas comments, maybe not as well as he would like!). However, partioning into supraglacial and subglacial discharge is more challenging to model and verify.

Thomas Schuler
Asks for clarity in what resolution of data is useful for biological and biogeochemical purposes. Does the biological/biogeochemical community want broader scale information, or a focus on fewer fjords?

Mattias Cape
Stresses the importance of integrated observing system: atmosphere, ocean, (sea)ice, biochemistry. In the call for a Greenland Observational system white paper, Straneo proposes a focus on few systems where comprehensive work from different disciplines should be conducted (atmospheric, glacial, marine). This enables longterm measurements more easily than scattered field campaigns.

Andreas Ahlstrøm
The recent AGU workshop on Ice/Ocean interaction was heavily attended by physical oceanographers, but lacked any biogeochemical/biological focus. Andreas comments the opposite seems to be the case for IASC meetings!

Shin Sugiyama
Suggests we need to be more welcoming to physical oceanography colleagues at any further ice-ocean themed interactions within IASC.

Sofia Ribeiro
What about sea-ice? How do discharge and sea-ice interact to affect marine primary production?

Lorenz Meire/Mark Hopwood
Suggest an intention focus on summertime effects of discharge to narrow the scope of the synthesis paper, but welcome some comments exploring the significance of sea-ice/runoff interaction.

Nicole Treholm
Suggests contacting colleagues at JPL to gain insight into how fjord-scale circulation operates and links to glacial processes and fjord-scale marine biogeochemistry.

Mattias Cape
Highlights ongoing American work at Sermilik Fjord where 10 years of data now available. In addition to the benefits of focusing on a few large sites for coordinating cross-disciplinary longterm data, suggests smaller systems are inevitably harder to work with as their “signal” is quickly lost on a broader scale and cannot be traced to the shelf or ocean.

Mark Hopwood
Thanks audience for constructive comments and proposes to circulate an updated text following comments by March.

After discussion of the synthesis paper, **Lorenz Meire** presented a slide on ‘What we need from glaciologists’. It contained the following points, which were not discussed much further in detail but they could be a basis for future discussions.

- Total freshwater flux to individual fjords (both ice and liquid runoff)
- Daily runoff estimates for individual catchments
- Field runoff estimates
- Volume of subglacial discharge
- Data on large events/lakes

Minutes of the IASC-NAG open forum meeting

Chair: Thorben Dunse
Minutes: Eef van Dongen, Thorben Dunse
Invited to attend: all participants of the workshop.

Agenda

a) Introduction to IASC, IASC-CWG and NAG
b) Funding
c) Activities (ongoing and future)
d) Upcoming meetings
e) Book of extended abstracts
f) Anything else?

Ad. 1

Thorben Dunse presents an overview of the International Arctic Science Committee (IASC) and its 5 working groups. IASC is a non-governmental organization promoting all aspects of Arctic research. IASC provides no research funding, but supports workshops that stimulate research activity and knowledge exchange. During the past years, interdisciplinary work is particularly encouraged by support of cross-cutting activities. These are endorsed by at least 2 WGs, and ideally bridge between social/human and natural sciences. Networks operate within the framework of the working groups and have a specific research focus. The Network on Arctic Glaciology is a program of the Cryosphere WG and formed out of the Working Group on Arctic Glaciology (1994-2011). The organizational structure consists of a chair (Thorben Dunse, since 2016) and vice-chair (Martin Sharp, since 2008) and 18 national contacts.

Thorben Dunse notes that India does not have a national representative yet, and suggests Ankit Pramanik, present at the meeting. This point is followed up at the end of the meeting. **Ankit Pramanik** cannot commit at this point, as he doesn't have a permanent job in India. He will consider the offer and let IASC-NAG know, in case he can commit at a later stage.

On Wednesday, following the last scientific session, some changes in the networks organization are discussed. **Martin Sharp** has been serving as vice-chair for the network since 2008 and agreed to step back. Thorben Dunse thanks Martin for 11 years of service and suggests Ward van Pelt as new vice-chair. There are no objections, but broad acceptance of the proposition. Ward van Pelt accepts the offer.

Ad. 2

Funding for this 2019 IASC-NAG meeting is provided by the Cryosphere and Marine WGs, supporting the cross-cutting activity "The importance of Arctic Glaciers for the Arctic Marine ecosystem" with 3500 Euros, each. The majority of the funding, 6800 Euros, is used for early-career scientists (ECS) travel support, and the remaining 200 Euros for workshop logistics. This year, 11 ECS received

partial travel support. Travel funds were handled by Gerlis Fugmann on behalf of the Association of Polar Early Career Scientists (APECS).

Concerning future funding opportunities, **Guðfinna Aðalgeirsdóttir** notes that we should continue with cross cutting activities, and have proposals ready asap. **Thorben Dunse** remarks that funding is available for both cross-cutting activities and core themes of CWG, with the advantage of the cross-cutting activities to receive funding from several involved WGs.

Francisco Navarro mentions the most important is to show results of activities e.g. progress on papers. Good examples are current progress on the paper on pan-Arctic ice discharge, lead by Luke Copland and followed up by Abigail Dalton during this meeting. **Thorben Dunse** highlights the synthesis paper pushed forward by Mark Hopwood et al.: *“How do glaciers affect marine primary production in the ocean?”* (see minutes from open discussion with regards to the cross-cutting activity). This paper follows directly up on questions raised during the first cross-cutting activity. Participants of the workshop are invited as co-authors. Another product of the workshop is the "Book of abstracts", which will be published on the IASC-NAG website.

Thorben Dunse suggests that since NAG is an integral part of the WG we should apply for money from the CWG. **Francisco Navarro** mentions any proposal, even if directed to CWG, only, should stress a significant cross-cutting component, since WG’s have to spend a certain amount of their budget on XC activities. **Jacek Jania** agrees with Francisco but suggest not to wait for a call but to report the activity and ask for direct funding of future activities from IASC. **Francisco Navarro** remarks that funding for networks has officially disappeared, but may be available for special activities.

Ad. 3

Ongoing activities include “Understanding atmosphere-glacier-ocean interactions and their implications for the pan-Arctic glacier mass budget”, a core activity of CWG. Abigail Dalton reported in her presentation on the status of efforts to provide a consistent estimate of pan-Arctic frontal ablation/ice discharge. The cross-cutting activity “The importance of Arctic glaciers for the marine ecosystem”, endorsed by CWG and MWG is run for second time now. **Thorben Dunse** considers the cross-cutting activity a great success. This year’s activity attracted more participants than last year and a synthesis paper is being pushed forward by Mark Hopwood and colleagues. The cross-cutting activity has been run as an integral part of the annual meeting workshop on the mass balance and dynamics of Arctic glaciers. Do we want to follow up on the cross-cutting activity and in what form? A follow up as official cross-cutting activity also depends on the continued interest of MWG and endorsement by its members. This year, no representative of MWG is attending the meeting. **Nicole Treholm** mentions she did just join the marine working group, although not active yet. She is willing to report on results of this meeting.

Guðfinna Aðalgeirsdóttir suggest to include the Athmosphere WG in the cross-cutting activity. Many scientist within CWG-NAG are working on atmospheric topics, and that ice-ocean interactions are also forced by the atmosphere and regional climate models are already used. **Jon Ove Hagen** supports Guðfinna’s suggestion to seek collaboration with AWG and continue addressing glacier-atmosphere as well as ice-ocean interactions. **Thorben**

Dunse reminds that we had earlier considered to extent the cross-cutting activity, to also address terrestrial ecosystems. Thus inclusion of the Terrestial WG may be an option. Another option would be to include the Social and Human WG. **Andreas Ahlstrøm** remarks that it is important to keep focus of the cross-cutting activity. There is need for a stronger involvement of physical oceanographers. Physical oceanography is also relevant for ice-ocean in general, such as ocean-induced frontal ablation, and therefore of broad interest to the glaciological community. **Daniel Carlson** notes that it is very hard to look at physical oceanography without any atmosphere. There is a high interest to address social impacts on fishing operations Greenland, to see how changes in stratification influence fishing.

Thorben Dunse acknowledges a general interest to continue the cross-cutting activities. He lists 3 options on how the the cross-cutting activities could be followed up on: (1) as part of NAG annual meeting, (2) hosted as an integral part of a workshop organized by the MWG, or (3) as a separate meeting? Since the latter option is likely to attract mainly those already involved in the theme, the interdisciplinary effect may be small. With regards to the options 1 or 2, it is important to get a confirmation from MWG with regards to their interest on a follow-up of the activity.

Regine Hock suggest to also look at other topics, because IASC-NAG members have different interests. There are other important topics and other WGs may be interested to work with us. **Nicole Treholm** suggest to consider a series of cross-cutting activities, keep the CWG-NAG primary, but rotate the other WGs every year. **Guðfinna Aðalgeirsdóttir** suggests that some continuation of activities is important, e.g. a period of 2 to 3 years.

Ad. 4

The next annual meeting will be held in Obergurgl, Austria, 28-30 January. 24 double rooms have already been reserved by Austrian contact Michael Kuhn (27-31 January 2019). A local organizing team is formed. **Jakob Abermann** volunteers to support Michael Kuhn.

Shin Sugiyama offers to host the 2022 meeting in Niseko, Hokkaido, Japan. Concerns are the long travel distance and high costs. **Regine Hock** mentions that IACS jointly with IAMAS and IAPSO has a meeting in Busan, South Korea, summer 2021, which may be to close to the IASC workshop in Japan. Other suggestions are Nuuk, in Greenland, by **Lorenz Meier**.

Thorben Dunse reminds that there is an agreement to have the meeting every 4th year in North America (NA), which would be 2021 (after Maine, 2017). **Francisco Navarro** stresses that it is important to have the NA community involved. **Martin Sharp** will discuss possibilities of hosting a meeting in NA with Luke Copland. **Regine Hock**, notes that a NAG meeting in NA may collide with the PARCA meeting, which many NA glaciologists do attend. Obergurgl in Austria, Benasque in Spain, and Poland are considered as alternative venues in upcoming years. It seems that an equal amount of people in the room would be willing to travel to either NA or Japan.

Thorben Dunse mentions that a 2022 IGS meeting in Juneau Alaska may include a session on glacier impacts on marine ecosystems. **Andreas Ahlstrøm** considers this a good opportunity to show present the outcome of 2-3 years of IASC cross-cutting activity on the subject.

After the open forum meeting, Polish colleagues **Jacek Jania** and **Mariusz Grabiec** suggest to host the meeting in Poland, for example in Zakopane, either in 2021, or one of the following years.

Ad. 5

A book of abstracts, including program, participant list and minutes from both the open forum meeting and XC discussion will be published on the IASC-NAG website. Participants are encouraged to submit updates, corrections and/or an extended abstract. Extended abstracts or corrections should be send to Pierre-Marie Lefeuvre until 31.01.2019. Participants may fill out a latex-template when submitting extended abstracts.

Ad. 6

Jacek Jania informs about the next Svalbard Science Conference in Oslo, November 2019. He suggests to arrange a side meeting in glaciology. The conference will also feature cross-cutting presentations which may be of relevance to Svalbard colleagues in this room.

Francisco Navarro, new president of the International Glaciological Society, asks workshop participants to fill in an open survey about the organization of the IGS. The survey is open also to non-members, and feedback very much appreciated. He encourages early-career scientists to join the IGS. There are efforts to form a committee with the aim to promote early-career scientists. It has not been easy to recruit young researchers to join such a committee. Anyone interested should contact Regine Hock or himself.

Abstracts

Recent changes in the continental ice margin in Northwest Greenland

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Keywords: Glacier changes, Greenland, High Arctic

We investigate changes in the land-based ice margin in Northwest Greenland where the Nunatarssuaq Ice Cap (NIC) connects with the Greenland Ice Sheet (GIS). The margin of NIC terminates in steep cliffs of about 25 m height. Since 1985 the NIC margin locally advanced by several dozens of meters despite a marked thinning. Thinning has accelerated in recent years as high-resolution DEMs reveal. Adjacent ice areas of NIC and GIS show recent differences in thinning rates which we explain with spatial albedo and dynamic variability. We review historical data of ice temperature and cliff position and put it into context with data acquired during a reconnaissance expedition in 2017. We find short-term changes of the cliff's mass balance that are rather independent of weather conditions while the horizontal part's mass and energy balance appears more variable. We hypothesize radiative fluxes to be the largest difference and drivers for these variations. Finally, the results are set into larger spatial context in North Greenland, where steep land-based ice margins are an abundant feature.

Bridging the trenches – ice sheet monitoring for the atmosphere and oceans in PROMICE and INTAROS

Ahlstrøm, Andreas[1], Robert S. Fausto[1], Michele Citterio[1], Jason Box[1], Kenneth Mankoff[1], Anne M. Solgaard[1], Liam Colgan[1], Roberta Pirazzini[2], Anders Kusk[3], Jørgen Dall[3]

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While it is often professed that scientific breakthroughs are more likely to occur between traditional fields of research rather than within them, the reality is often that existing structures prevail. The INTAROS Project is dedicated to unleash the potential of integrating Arctic monitoring efforts across traditional disciplines by taking a different view. While the PROMICE programme for monitoring of the Greenland ice sheet was born out of a need to quantify a major contribution to sea level change, a leap across the trench reveals that important variables of the atmosphere and oceans are addressed and may be utilized for entirely different purposes than originally intended. Here we present our PROMICE monitoring effort, enhanced through INTAROS, and why we think it might turn out to be useful for you. Moreover, we hope to learn from discussions with you, how our 20+ Arctic ice sheet weather stations and remote sensing programme could service your particular science or monitoring needs.

Winter rain induced soft-bed warming - A potential acceleration mechanism

Alexander, Andreas[1,2]

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Keywords: Winter rain, surge, thermal switch, subglacial hydrology

Thermal switches from cold-based to temperate bed conditions are an often used theory to explain glacier surges. The exact reasons for such thermal switches remain however under discussion and in the recent years the theory of cryo-hydrological warming has become more important, connecting heat-input from meltwater to glacier surges. This work presents bedrock temperature measurements of a small cold-based valley glacier on Svalbard and shows the influence of winter rain events on the thermal regime of the glacier bed. Building on these direct observations, the work develops a conceptual model for a soft-bed acceleration mechanism, which is initiated by winter rain events.

Development of phosphorus forms in soil chronosequence of the Nordenskioldbreen glacier (Svalbard)

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Nordenskioldbreen is located between Dickson Land and Bunsow Land. The glacier flows roughly southwestwards and is 25 km (16 mi) long and 11 km (6.8 mi) wide. It has its terminus in Adolfsbukta, a branch of Billefjorden.

After the expedition to the glacier in 2015, soil samples were brought to the Czech University of Life Sciences Prague. We have 42 samples from the south and north of the glacier. With each of them we worked in the laboratory during several months, made a filtration and with the help of robotics got the complete chemical composition of each samples.

At our work we determined the amount of P-form and other soil properties in soils after the Nordenskioldbreen glacier (Svalbard).

The soil properties after the retreat of the Nordenskioldbreen glacier vary with the age of the soil. The amount of accessible P decreases with the age of the soil and the amount of crystalline Fe forms increases. All results of the study are presented in spreadsheet format.

Observing glacier dynamics in the Southern Alaskan mountain ranges

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Keywords: Glacier velocity, optical remote sensing, time-series, short-term kinematics

During the last few decades our understanding of Arctic glaciers has advanced considerably. At the same time, spaceborne sensors and data services have greatly advanced and matured, exemplified by the Landsat and the Sentinel constellations and processing services that provide products in near-real-time online. These systems make it possible to extract surface topography, glacier facies or ice velocity. However, to a large extent the generated products are scattered and have only partial spatial or temporal overlap, due to operational or sensor constrains. In order to make them more useful for glacier monitoring, we have developed a workflow that merges glacier velocity data of different time spans. This merged dataset covers several Alaskan mountain ranges (and could be extended to global coverage) and has a regular time step of 32 days. This consistent time-series make it possible to observe short duration glacier dynamics changes more readily. As the dataset spans several years, the dynamics of tidewater glaciers or (partial) surges can be observed and analyzed. This study therefor shows the great potential of current satellite systems and the derived monitoring data sets. Furthermore, the consistency of the merged and interpolated dataset makes integration into glacier modelling efforts easier.

Glaciological and geodetic mass balance of Norway's glaciers – an overview

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Keywords: Glacier, mass balance, geodetic, maps

The Norwegian glaciological mass balance record is extensive. More than 40 glaciers have been observed for shorter and longer period. Here we report on glaciological and geodetic mass balance of mainland Norway. Glaciological mass balance for 10 glaciers over 1989-2017 show a mean deficit of -0.37 m w.e. To access mass balance for a larger sample of glaciers we have used laser-scanning covering 1/3 of the glacier area and compared with topographic surveys and recent satellite imagery. The geodetic measurements reveal an overall mass loss from the 1950/1960s to 2010s: preliminary values indicate a mean change of -0.25±0.5 m w.e./a. for the surveyed area. Since 2000, both geodetic and glaciological measurements show a remarked mass loss with glaciers shrinking in area, length and thickness.

Mass balance of Devon Ice Cap: comparing in-situ and geodetic measurements

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Keywords: Devon Ice Cap, geodetic mass balance, ice dynamics, in-situ record

With a notable increase since 2005, strongly negative mass balances have been observed for glaciers and ice caps in the Canadian Arctic over the past three decades. A major uncertainty in assessing glacier contribution to sea level rise is how their dynamics are changing under a warming climate, and whether glaciers are speeding up or slowing down, yielding different dynamic responses. Traditionally, mass balance estimates have been based on in-situ glaciological measurements, which do not account for dynamic processes. Geodetic mass balance measurements obtained from remotely sensed surface elevation datasets better account for the effects of changing glacier motion by capturing thickness change over entire glacier systems but have not previously been available for many regions.

This study forms part of a recent effort initiated by the World Glacier Monitoring Service (WGMS) to validate long-term glaciological mass balance series with geodetic measurements. Our focus is the Devon Island Ice Cap (DIC), one of the largest ice masses in the Canadian Arctic, where glaciological mass balance has been measured on the northwest basin since 1960. We present a revised in-situ mass balance series with updated basin area and hypsometry. To calculate most recent elevation changes, we use the TanDEM-X digital elevation model (DEM). We investigate the elevation bias of this DEM due to radar penetration in snow and firn by comparing it with differential GPS elevation field measurements from 2011 and 2018. Our aim is to calculate geodetic mass balance from 1960 to 2010 for the entire ice cap, to compare it to the glaciological time series and to address significant deviations following the WGMS reanalysis methodology. Results from this study will improve understanding of the inter-relationships between ice dynamics and surface mass balance on DIC, and their control on its contributions to non-steric sea level rise since the 1960s.

Kangerdlugssuaq Glacier primed for runaway retreat by ocean warming

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Keywords: Greenland, tidewater glacier, ocean, dynamics

Kangerdluqssuaq Glacier in south-east Greenland has now retreated further inland than at any time in the 33-year satellite record and is fast approaching a region of retrograde bedslope meaning that continued rapid retreat is likely. We show that the current retreat was driven by anomalously warm shelf water in 2016 which likely entered the fjord and weakened the mélange which normally inhibits calving in winter. Two years of continuous calving with no significant winter advance has led to an overall retreat of 8 km and an acceleration of 35%. A thinning trend is superimposed on the seasonal dynamic thinning pattern, with the tongue having thinned by over 35 m during the recent retreat phase (Fig. 1).

For more detail see Bevan, et al. (2019). ‘Warming of SE Greenland shelf waters in 2016 primes large glacier for runaway retreat’. The Cryosphere Discussions pp. 1-16.

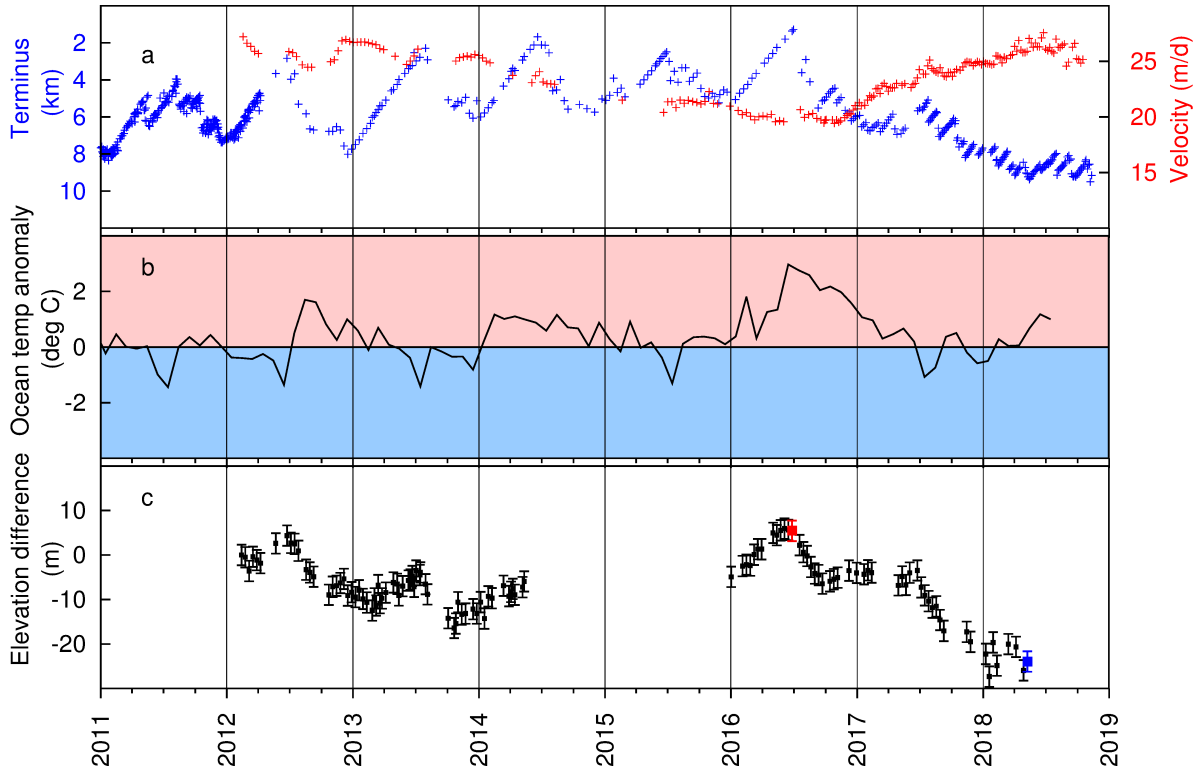

Figure 1. Time series of a) front position and surface velocity, b) Kangerdlugssuaq trough ocean potential temperature anomaly at 5 m, and c) cross-glacier mean surface elevation difference based on TanDEM-X DEMs, the error bars represent the relative accuracy of ±2.3 m.

Application of digital elevation models produced from satellite and aerial images to estimation of geodetic mass balance over southern Spitsbergen

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Keywords: DEM from Very High Resolution Satellite, DEM from aerial photos, geodetic and glaciological mass balance

In the study we present the results of accuracy assessment of DEMs produced from four Very High Resolution Satellite (VHRS) stereo images over the period 2012-2017 and DEM generated from aerial photographs acquired in 2011 by Norwegian Polar Institute. The research were conducted over three glaciers in southern Spitsbergen: Hansbreen, Werenskioldbreen and Hornbreen. The overall goal is to assess the relevance of such type elevation models for estimation of geodetic mass balance and compare the result with the glaciological mass balance.

The satellite based DEMs from WorldView-2 and Pléaides were processed using the Rational Function Model (RFM) developed in OrthoEngine module of PCI Geomatica 2016. Both types of stereopairs (WorldView-2 and Plé aides) contain the rational polynomial coefficient (RPC) files. It allows to generate DEM without any ground control point (GCP).

Additionally DEMs based on GCP-enhanced RPC (using one GCP) were created and output improvement has been evaluated. The elevation accuracy of DEMs over glaciated areas were validated with static and kinematic dGPS survey.

DEMs are then coregistered and subtracted to estimate the geodetic mass balance for the studied area. Results show that glaciers surface in southern Spitsbergen has been lowering in recent years at an average rate of 2 m/yr. The largest reduction of ice thickness (up to 10 m/yr) was observed at the front of two tidewater glaciers: Hansbreen and Hornbreen. Comparison of results with the classical superficial mass balance data were done and differences have been interpreted taking into account estimated frontal ablation as well.

Greenland land ice surface physical properties from Sentinel-3 optical retrievals

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Keywords: Sentinel-3, Petermann, Albedo, SSA

For much of the pre-melt and melt season, sunlight absorption can be the dominant melt energy source for snow and ice on glaciers, land, sea, and lakes. The Copernicus ESA Sentinel-3 A and B platforms host two sensors with optical bands: the Ocean Land Color Instrument (OLCI) and the Sea and Land Surface Temperature Radiometer (SLSTR). This work examines along-glacier and into wide (6+ km) fjord (sea ice/snow) profiles of optical properties pre-melt and melt season for sufficiently clear sky cases. Snow and ice optical products in development by the European Space Agency (ESA) Scientific Exploitation of Operational Missions (SEOM) Sentinel-3 for Science, Land Study 1: Snow include:

- snow extent
- fractional snow cover
- spectral planar albedo
- broadband albedo
- specific surface surface area or effective grain diameter
- snow impurity content (biological, mineral, elemental)

The examination spans the 2017 and 2018 melt seasons: May to September for a select glacier.

Challenges to understanding ice-ocean interactions and their impact on marine biogeochemistry

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Keywords: Ice-ocean, nutrients, glacier, observation

Rapid changes in the dynamics of glaciers and ice sheets at both poles have in past decades led to a renewed interest in the interplay between the ocean and cryosphere. While the physical consequences of ice-ocean interactions have been the subject of intense study, their impact on marine ecosystems have only recently come into greater focus. As a source of nutrients (i.e., iron, silica), a driver of coastal circulation (e.g., upwelling), and forcing on ocean stratification, glacial meltwater export plays a critical role in regulating biogeochemical cycling at high latitudes. The scope and timing of the biological response to freshwater export is in part mediated by physical and chemical processes governing the distribution and availability of nutrients discharged in meltwater or upwelled at the glacial margin. However, significant uncertainty remains as to how, and over what scales, these processes interact to modulate nutrient distributions. Leveraging studies in Antarctic and Greenland fjords, including Sermilik Fjord, a system that has been well-sampled from a physical oceanographic perspective, we explore physical processes at play in these systems and their impact on nutrient availability. We highlight that differences in the magnitude of subglacial discharge, as well as the structure of the water column, play important roles in modulating vertical nutrient distributions in glacial fjords, and thereby their availability to primary producers both locally and in downstream ecosystems. While the magnitude of estimated nutrient exports from systems like Sermilik suggest that glacially modified waters may act as significant sources of nutrients to the continental shelf, their pathway and timing of release from fjords to the large-scale ocean remain poorly constrained. We argue that sustained biogeochemical observations (i.e., moored observations) from Antarctic and Greenland fjord systems, coupled to high resolution physical measurements, are ultimately necessary to better constrain variability in these system, and gain a better understanding of the coupling between local (fjord) and large scale processes.

Observations of vertical mixing and nitrate fluxes at four marine terminating glaciers in NE Greenland

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Keywords: Vertical mixing, nutrients, productivity, marine terminating glaciers

Melting of marine terminating glaciers and injection of subglacial freshwater discharge at depth can drive upwelling of nutrient-rich water to the photic zone. As a result, marine terminating glaciers are 'hotspots' of biological activity and support critical commercial and artisanal fisheries in Greenland. Recent accelerated mass loss from the Greenland Ice Sheet suggests that marine ecosystems may undergo drastic changes in the near future as marine terminating glaciers retreat onto land. Efforts to understand turbulent vertical mixing processes at marine terminating glaciers in Greenland have relied largely on theory, numerical simulations, and laboratory models. Here we present observations obtained from a tethered, free-falling vertical micro-scale turbulence profiler (Rockland Scientific VMP-250) that were obtained near the termini of four marine terminating glaciers in northeast Greenland in August 2018. Concurrent and co-located nitrate profiles are used to estimate nitrate fluxes. These observations reveal enhanced mixing near glacier termini, as expected, as well as small-scale spatiotemporal variability due that we attribute to changes in subglacial discharge plume behavior. These observations provide critical

observational benchmarks for models of fjord circulation and marine ecosystems. This cross-cutting study combines rare observations of vertical mixing and nutrients in high latitude fjords and, as such, is a contribution to the activity on "The Importance of Arctic Glaciers for the Arctic Marine Ecosystem."

Wintertime sea-ice chemistry and effect of glacial freshwater runoff during two contrasting years in a Spitsbergen fjord

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Keywords: Sea ice chemistry and nutrients, freshwater component in sea ice, glacial

Several fjords on Svalbard are affected by glacier meltwater. We investigated the sea-ice carbonate (or CO_2) chemistry in Tempelfjorden, a west-Spitsbergen fjord, and the influence of different processes such as ice-brine rejection, calcium carbonate precipitation and glacial meltwater during two winters in 2012 and 2013. The two contrasting years clearly showed that the influence of freshwater affected the chemical and physical characteristics of the sea ice. We found large variability of sea-ice total alkalinity (A_T), total dissolved inorganic carbon (C_T), pCO_2, dissolved inorganic nutrients, oxygen isotopic ratio ($\delta_{18}O$) and freshwater fractions, from the glacier front to the outer part of the fjord. Processes within the sea ice such as calcium carbonate formation (ikaite) and brine rejection also affected the sea-ice carbonate chemistry. The variability in the sea ice showed the lowest A_T in 2012 near the glacier front coinciding with the highest freshwater fractions (glacial water). Relatively high A_T in relation to salinity was observed mainly in 2012, which could either be a result of ikaite precipitation in the sea ice (dissolved during analysis) or calcite and dolomite minerals originating from the bedrock/glacial freshwater. We found crystals of ikaite, calcite and aragonite (forms of calcium carbonate) in the snow/frost flowers in 2013 as a result of to sea-ice processes.

Estimate of current dynamic discharge from Northern Hemisphere glaciers and ice caps to the ocean

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Over the last several decades, glaciers and ice caps in the Arctic have lost mass at accelerating rates. However, there is currently a poor understanding of the relative importance of surface mass balance vs. changes in ice discharge to the ocean in accounting

for these losses, partly due to lack of knowledge of discharge estimates outside of the Greenland Ice Sheet. In this presentation, we describe the progress of an ongoing project that brings together international experts to provide the first estimate of total Northern Hemisphere dynamic discharge (outside of the Greenland Ice Sheet) from the compilation of discharge data from all tidewater glaciers and ice caps in this region over the period ~2000-2015. Data compilation is almost complete for Alaska, Canadian Arctic Archipelago and the periphery of Greenland, but is ongoing for Svalbard and, in particular, for the Russian Arctic. This comprehensive data collection will also help to standardize terminology and methods in relation to glacial mass loss at the termini of tidewater glaciers.

Glacier meltwater runoff as a potential driver of phytoplankton dynamics around Svalbard

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Keywords: Glacier runoff, phytoplankton

Glacial freshwater discharge into the ocean 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. Pilot studies in Greenland revealed a second primary-production bloom, coincident with the peak meltwater runoff from the Greenland ice sheet. The spatial extent at which glacial runoff may fertilize the marine ecosystem is poorly constrained.

Here, we focus on Svalbard in the Eurasian Arctic, where glaciers cover 34000 km2 or 57% of the total land area. Tidewater glaciers drain 68% of the glacierized area, with a total calving-front length of ~740 km. We divide Svalbard into 14 hydrological regions for each of which we investigate the relationship between surface chlorophyll-a concentrations (an indicator of phytoplankton biomass) and glacier meltwater runoff. We also consider other known drivers of phytoplankton dynamics, such as sea-ice fraction, sea-surface temperature and mixed-layer depth. Freshwater runoff for the period 2003 to 2013 is extracted from a 10-year simulation of the climatic mass balance of all glaciers on Svalbard using a coupled atmosphere-glacier model. Surface chlorophyll-a concentrations derived from ocean colour, as well as physical ocean and sea-ice variables for the period 1998-2014 are provided by the Copernicus Marine Environmental Monitoring Service. We use a statistical model to identify significant relationships between chlorophyll-a concentrations and the various environmental factors during summer months. Significant positive correlation between chlorophyll-a and glacier runoff exists for 6 out of 14 regions and within 10km distance from the coast. These 6 regions can be characterized as sheltered fjord systems, with a wide range of glacier coverage and fraction of tidewater glaciers.

Experimental design of in-situ mass-balance measurement networks

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Keywords: Experimental design, glacier mass balance, accumulation, ablation, Yukon

In-situ mass-balance measurement networks are often designed on an ad-hoc basis with the general notion of sampling a broad range of elevations. We borrow principles and methods from optimal design in statistics to approach this problem in a more objective way. Using field data collected on glaciers in the St. Elias Mountains of Yukon, Canada, from 2007–2016, we are able to test various "experimental designs" (the number and spatial configuration of measurements). For both summer and winter balance, we make use of simple models to generate numerous synthetic spatial distributions of mass balance in order to evaluate designs across a range of realizations of these fields. In the case of summer balance, we use an enhanced temperature-index model to generate synthetic data, which are approximated using a Gaussian Process emulator. A particle-swarm algorithm is then used to seed the domain with a prescribed number of measurement points, and the optimal configuration of these points determined by minimizing the integrated root means squared error. In the case of winter balance, we use a linear regression on topographic parameters to generate synthetic data and evaluate actual sampling configurations used in the field. In both cases we are able to quantify the number of measurements needed to achieve a prescribed accuracy or precision of b_w or B_w and evaluate the usefulness of different sampling patterns.

Influence of glacial water on carbonate chemistry and biogeochemical processes in Svalbard fjords with different characteristics

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Keywords: Carbonate chemistry, calcium carbonate, Arctic Ocean, glacial meltwater

Svalbard fjords on the west-Spitsbergen are influenced by Atlantic water in the outer parts and by glacial water and sea-ice processes in the inner parts. The fjords also have different characteristics depending on the sill depth, seasonal sea-ice coverage, and the presence of tidal glaciers and rivers. Here, we present the distribution and variability of the carbonate chemistry and ocean acidification state in several Spitsbergen fjords based on data collected at several seasons between 2012 and 2016. For the study, we used total alkalinity (AT), total dissolved inorganic carbon (DIC), dissolved inorganic nutrients, salinity, temperature and calculated calcium carbonate (CaCO3) saturation state (Ω), pH and calculated freshwater fractions to investigate the seasonal and interannual variability and the biogeochemical processes driving the carbonate chemistry, air-sea CO2 flux and ocean acidification state in the different fjords. Changes in the inflow of different water masses and freshwater directly influenced ocean acidification state, but also indirectly by

affecting the biological drivers of carbonate chemistry in the fjords. The seasonal variability showed the lowest and pH values in winters coinciding with the highest freshwater fractions. The highest and pH were found in fall, mostly due to CO2 uptake during primary production. In the climatically sensitive Kongsfjorden, glacial water decreased Ω by the same amount as the biological effect increased Ω. The seasonal increase in temperature only played a minor role on the increase of Ω. Overall, we found that increased freshwater supply decreased , pH and AT. On the other hand, we observed higher AT relative to salinity in the freshwater end-member in mild and rainy winters in Tempelfjorden. Observations of calcite and dolomite crystals in the glacial ice suggested supply of carbonate-rich glacial drainage water to the fjord. This implies that winters with a large amount of glacial drainage water partly provide a lessening of further ocean acidification, which will also affect the air-sea CO2 exchange.

Structure-from-Motion DEMs of glaciers in northeast Spitsbergen

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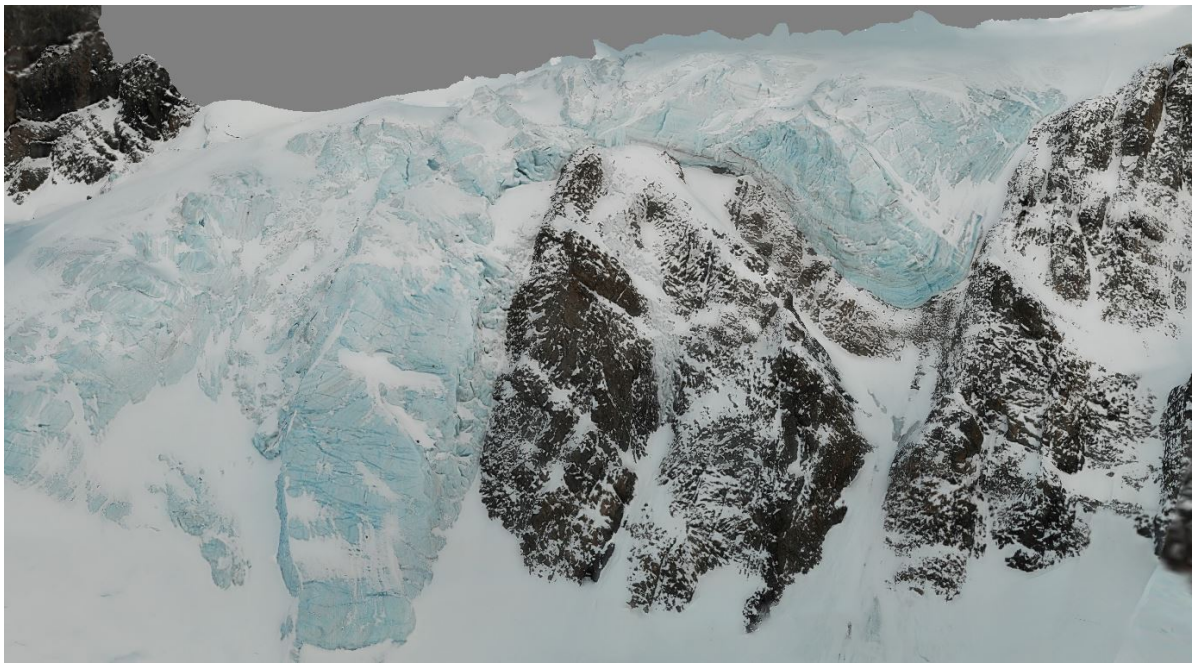
Keywords: Alpine Arctic glaciers, UAS, Structure-from-Motion

In 1923 a sledge party from an University of Oxford expedition landed on the East Spitsbergen ice cap with a view to making the first east-west crossing of this section of the island. Over the course of thirty days they overcame terrible conditions to achieve both their goal and a detailed topographical survey of the unexplored interior. Ninety-three years later to the day, another Oxford expedition arrived on the eastern shores of Svalbard's "cold coast" to repeat the 1923 journey. With more advance tools, the 2016 expedition did among others acquire image data from small unmanned aircraft systems (sUAS) to produce 3D models of glacier surface with Structure-from-Motion (SfM) photogrammetry. Several sections across Chydeniusbreen (named the Bear Bay glacier by the 1923-expedition) were flown at different altitudes along the glacier length, primarily in the same regions as transects of ICESat laser altimetry. The DEM results were compared to DEMs from the Norwegian Polar Institute and will be compared to the ICESat data as well as to the more recent DEMs from the ArcticDEM project. A retreat and thinning of the terminus between 2011 and 2016 was detected, whereas the other transects were harder to interpret due to a large offset between the datasets.

Historical photos taken by the 1923 expedition of glacier state along the route were also retaken in 2016, showing minor differences in glacier size along the coast, but the appearance of new snowfields in the interior in 2016. During the spring of 2018 new sUAS data along the same sledge route were compiled, this time from steep icefalls in the Atomfjella area, providing SfM DEMs of steep glacier terrain that has not been previously studied. An annual or biennially revisiting of these small and steep glacier icefalls is planned.



Structure-from-Motion (SfM) 3D model of Pruvostbreen icefall in northeastern Spitsbergen, spring 2018

The terminus of Bear Bay Glacier (Chydeniusbreen), viewed from Raudberget taken by the University of Oxford expeditions to Spitsbergen in 1923 and 2016 (at the same dates). Whereas the terminus has retreated and thinned in the period, more high-elevated snow-fields are present in 2016.

Into the Ice

Haarloev, Caspar[1], Lars Ostenfeld[1]

1 Lars Ostenfeld Film

Keywords: Documentary, Greenland, Ice, Climate change

We’re working on a documentary on Ice and the scientists who explore it. We’ll be

following Jason E. Box on the Greenland inland ice, climb down ice crevasses with Alun Hubbard and explore icebergs underwater with a robot.

Spatio-Temporal Variations of Firn Properties on the Western Greenland Ice Sheet

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A large portion of surface meltwater on the Greenland ice sheet refreezes as it percolates into firn. Increased melting in recent years has caused the formation of thick (>5 m) ice layers in the lower part of the percolation zone. These layers can effectively seal off the underlying porous firn, allowing meltwater to runoff instead of refreezing in the firn, and thus affecting the ice sheet mass balance.

To investigate the spatio-temporal variability of refreezing in firn, we conducted two field seasons in the spring of 2017 and 2018 in the percolation zone of the southwestern part of the Greenland Ice Sheet at elevations between 1963 and 2355 m a.s.l.. Field observations included 20 m deep firn cores, ground-penetrating radar surveys, and full energy balance automatic weather stations equipped with thermistors strings to measure the evolution of the vertical temperature profile of the firn over time.

During summer 2017 air temperature at all three sites exceeded 0°C for only very short periods between May and August and observations indicate considerably less melt compared to previous years. Firn temperatures at the deepest thermistor located 17 meters below the snow surface remain constant year round at -19.2°C for site EKT (2355 m a.s.l.) and -13.5°C for Site J (2060 m a.s.l.). Firn temperatures at 1 m below the surface varied between -17.1°C and -11.9°C at EKT and -12.6°C and -4.1°C at Site J between May and November 2017.

We used the Distributed Energy Balance Model DEBAM model which includes a multilayer snow model to investigate the energy fluxes at all three sites. The model computes subsurface temperature, water content and refreezing, and results are compared to the thermistors string measurements. Preliminary results show that melting, percolation, and refreezing is largely restricted to the lower elevation sites. These results agree well with the firn-core stratigraphies and ground-penetrating radar profiles, which show increasing frequency and thickness of ice lenses toward lower ice-sheet elevations.

Impacts of Greenland Ice Sheet melt on heterotrophic processes in adjacent fjords

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Keywords: Carbon cycling, Ecosystem metabolism, Greenland Ice Sheet melt

The Greenland Ice Sheet (GrIS) is melting at unprecedented rates contributing to the freshening of fjords and the coastal ocean around Greenland, though the effects of freshening on primary production along the Greenland coast are still unclear. Here we present patterns of primary productivity in a Northeast Greenland fjord (Yound Sound), which receives run-off from the Greenland Ice Sheet via land-terminating glaciers. This fjord system has previously been deemed low productive due to light limitation from late break-up of sea ice. Through increased spatial and temporal resolution of observations over the ice-free season we have found that it is rather the interplay among low light availably - by late ice break-up, turbid river inputs in the summer and short day length in the fall - and strong vertical stratification coinciding with a deep nitracline that restrain primary production to a minimum in Young Sound. Apart from a brief under-ice bloom during summer, primary production remains low (between 50-200 mg C m^{-2} day^{-1}) however steady throughout the growing season even into the fall. Plankton communities in Young Sound are adapted to low light conditions as evidenced by the low values of saturating irradiance (5.8-67 μmol photons m^{-2} s^{-1}) for primary production measured in this study. Nitrate is depleted in the euphotic zone down to ∼30m throughout the year. In the summer months in the inner fjord, turbidity moves production and biomass of phytoplankton nearer to the surface as is typical for turbid estuaries, while in the outer fjord a typical deep chlorophyll maximum is established. The chlorophyll maximum moves higher in the water column towards the end of the growing season, to approximately 15 m, most likely due to low light availability as day length shortens and sun angle decreases. With its but low but consistent production across the growing season, Young Sound offers an alternative picture to the established construct of seasonal succession of Arctic phytoplankton communities present in other fjords around the Arctic (e.g. spring and late summer blooms and limited fall production). The light and nutrient limitation and strong vertical stratification controlling productivity are not only due to the influence from the local land-terminating glaciers but are also consequences of the coastal boundary currents and the shallow entrance sill. Features which should also be considered when making generalizations about how primary production will be affected by glacier retreat in the future.

Contrasting the effects of glaciers and icebergs on marine primary production

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Keywords: Ocean nutrients icebergs productivity

How will increasing meltwater from Ice Sheets affect the biogeochemistry of the ocean? Release of freshwater into the ocean has multiple chemical and physical effects upon the water column. With respect to nutrient availability, meltwater from glaciated catchments supplies the bio-essential nutrients iron and silicic acid to the ocean yet is deficient in nitrate and phosphate. However, despite the low concentrations of nitrate and phosphate in meltwater, pronounced summertime phytoplankton blooms are observed in many, but not all, large glaciated Arctic fjord systems where nitrate is likely a limiting nutrient for

phytoplankton growth. A critical variable determining the effect of meltwater on the marine environment is the depth at which it is released into the water column.

When meltwater is released below sea level beneath large marine-terminating glaciers, the resulting buoyant discharge plumes entrain large quantities of deep seawater. This vertical transport, or 'pumping', of deep macro-nutrient rich seawater to the surface provides the nitrate that sustains unusually strong summertime productivity in some Arctic fjords. Conversely, when meltwater is released at the ocean surface from land-terminating glaciers, the effect on primary production is generally reduced or even negative because the meltwater itself lacks the nitrate and phosphate required to fuel phytoplankton blooms. This critical difference between land- and marine- terminating glaciers is now well established by both field studies and conceptual models, but what about icebergs? Icebergs have long been speculated to behave as an important source of nutrients to the marine environment, but the magnitude of this flux is challenging to determine due to a paucity of data. Here we will present a new dataset with global coverage and demonstrate that, as is the case with glaciers, the depth of meltwater release from icebergs is a critical factor affecting the potential fertilization of the ocean.

The role of winter rains in glacial system on Svalbard

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Keywords: Precipitation, winter rains, mass balance, Hansbreen, glacier dynamic, Arctic, rain-on snow

Rapid Arctic warming results in increased frequency of winter rains that may impact glacial systems. This paper examines the influence of winter rainfalls (Oct-May) on both mass balance and dynamics of Hansbreen (Svalbard) and discusses the climatology and trends in precipitation forms as a background. We used the data from regularly operating Hornsund station (010003 WMO) and original meteorological and glaciological data from 3 measurement points on Hansbreen. Precipitation phase at Hornsund station was identified based on notation of weather phenomenon and then used, together with information on lapse rate, to estimate the occurrence and altitudinal extend of winter rainfall over the glacier. We found an increase in the frequency of winter rains in Hornsund and their influence on both glacier mass balance with average contribution of 9% and glacier dynamics. However, the latest differs depending on development of snow cover and drainage system. In early winter with initial and thin snow cover and inefficient drainage system rainfalls increase glacier motion. Full season winter rainfalls falling on well-developed snow cover effectively stored in glacier and contribute to its mass balance.

Is the frequency of glacier floods in Norway increasing?

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Keywords: jøkulhlaups GLOFs

Jøkulhlaups or GLOFs (Glacier Lake Outburst Floods) are a common occurrence in Norway with over 130 separate events registered from 26 different glaciers. The oldest known events date back to the 18th century.

The number of jøkulhlaups has increased in recent years, which is partly explained by glacier retreat. Conversely, some glaciers where glacier floods occurred previously have now thinned to such an extent that the water can now flow freely underneath the glacier, or have retreated so that there is no longer a dammed lake at the side of the glacier.

However, the ability to detect jøkulhlaups has also increased, such that events that earlier would have gone unnoticed are now documented. Several events have been detected only from repeat satellite images or aerial photographs showing drained lakes. Increased air travel and ski touring have also encouraged reporting of events. There are reports from previous centuries from communities downstream of glaciers that flood events were almost annual, but unless there was material damage, an individual event was often not recorded. Thus, easier and more efficient means of reporting such events has led to an apparent increase in activity.

Global studies on this topic are also ambiguous. There is no clear trend and the different mechanisms for glacier floods elsewhere, such as the prevalence of floods from moraine-dammed lakes in certain areas and the connection between volcanism and floods on Iceland, further complicate the matter.

Biogeochemical surveys near the fronts of marine-terminating glaciers in Inglefield Gulf, Northwestern Greenland

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Subglacial meltwater upwelling at the front of marine-terminating glaciers plays a critical role in the entrainment of nutrient-rich deep water as well as submarine ice front melting. Because the fresh meltwater is buoyant, it rises along the glacier front as a plume that carries relatively warm and nutrient-rich waters from deeper layers. Despite increased interest in the processes occurring near the glacier fronts, it remains challenging to measure hydrological properties of near a glacier terminus. In the summer 2018, we performed biogeochemical surveys in Inglefield Gulf, a 100 km long fjord system in northwestern Greenland. Inglefield Gulf is fed by ∼10 marine-terminating glaciers, which terminate at depths from several ten to over 600 m. We conducted boat-based ocean measurements using a conductivity-temperature-depth profiler equipped with fluorescence, turbidity and dissolved oxygen sensors near the terminus of three marine-terminating glaciers (Melvill, Sharp, and Hart glaciers). Seawater was sampled to analyze biogeochemical components (macro- and micro-nutrients (e.g., iron), chlorophyll a, phytoplankton assemblages, particulate organic matter). Zooplankton samples for microscopic analysis were also collected with a single-NORPAC net (mouth diameter 45 cm, mesh size 335 μm) through a water column of 100 m. Early results from the survey showed distribution of highly turbid waters near the glacier termini at depths of 10 m and 50–100 m. High abundance of phytoplankton (as chlorophyll a) was observed in the highly turbid water layer at the depth of 10 m. In this contribution, we present an overview of the field activities in Inglefield Gulf, and show details of results obtained by the campaign.

Surge controls at Donjek Glacier, Yukon, Canada from 1935 to present

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Keywords: Surging, remote sensing, GPR, ice core

Donjek Glacier has an unusually short and regular surge cycle, with eight surges identified since 1935 from aerial photographs and satellite imagery with a ∼12 year repeat interval and ∼2 year active phase. The surge frequency, number of cloud free satellite observations, elevation data and ice core records make Donjek Glacier an excellent location to examine underlying controls on surging. Recent surges occurred during a period of long-term negative mass balance and cumulative terminus retreat of 2.5 km since 1874. We find that a constriction where the valley narrows and bedrock lithology changes, 21 km upstream of the terminus, represents the upper limit of surging, with negligible changes in surface speed or elevation up-glacier from this location. This positions the entire surge-type portion of the glacier in the ablation zone. During the 2012–2014 surge, the average lowering rate in the lowest 21 km of the glacier was 9.6 m a^{-1}, while during quiescence it was 1.0 m a^{-1}. Although limited to one glacier, these observations suggest that surging can profoundly alter the geodetic mass balance over the surge-type portion of the glacier between surge and quiescent phases.

To understand climate controls on surging, we analyzed three ice cores taken from Donjek's accumulation zone on Eclipse Icefield as well as ice-penetrating radar data. Using ice cores to reconstruct past accumulation since 1935, we find that Donjek Glacier has a consistent cumulative accumulation of 15.5 m w.e. (standard deviation = 2.26 m) before a surge event occurs. While this consistent cumulative accumulation could control the remarkably consistent repeat surge interval, it could also be indicative of consistent annual average precipitation or another, unknown, process. Ice penetrating radar results indicate a bedrock overdeepening near the glacier terminus and at the dynamic balance line, which could impound subglacial water and influence surge dynamics.

Impact of tidewater glacier retreat on the fjord system: present and future circulation in Kongsfjorden, Svalbard.

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Tidewater glaciers in Svalbard are retreating, and will eventually terminate on land at some time in the future. Plumes, the upwelling of subglacial freshwater runoff emerging at

the bases of tidewater glacier fronts, contribute to large-scale circulation within the inner fjord. Once a fjord only has land-terminating glaciers, fjord circulation will be affected, with implications for the biogeochemistry and ecosystem. Here we assess the impact on fjord circulation of the tidewater glaciers in Kongsfjorden in northwestern Spitsbergen. The future fjord bathymetry of the five tidewater glaciers in Kongsfjorden is based on airborne and ground-based ice-penetrating radar profiles. Bed data for the tidewater glaciers Blomstrandbreen, Conwaybreen, Kongsbreen, Kronebreen, and Kongsvegen and are merged with bathymetric and land DEMs for non-glaciated areas. Three of the glaciers, Kongsbreen, Kronebreen, and Kongsvegen, have the potential to retreat by ∼10 km before becoming land-terminating.

We compare present and future circulation using the ocean model system ROMS, and identify and quantify changes resulting from the altered forcing. Removal of subglacial discharge due to retreating tidewater glaciers causes substantial reduction of subsurface volume fluxes in the inner fjord, and results in enhanced stratification during summer. The increase in fjord extent due to glacier retreat results in a slight increase in tidal velocities, but this effect is not strong enough to compensate for the reduction in current velocities due to the loss of the plumes. Freshwater content in the fjord during the melting season is predicted to increase in the future, primarily due to enhanced retention of freshwater in the inner parts of the fjord. However, freshwater in the future will mostly be confined to a relatively thin surface layer, whereas at present freshwater is found in a thicker layer, particularly near the tidewater glacier fronts.

Fjord-shelf dynamics control Fe fluxes from the 79N glacier

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Keywords: NE-Greenland, Trace Metals, Shelf-fjord dynamics

The North East Greenland Shelf (NEGS) is influenced by two marine-terminating glaciers: Zacharias IsstrØm and Nioghalvfjerdsbrae ('79°N glacier', 79NG). With an annual regional freshwater discharge of ca. 200km^3, the entire shelf area is strongly influenced by GrIS discharge, which drives seasonal changes in surface and sub-surface currents and nutrient inventories. Among the glacial catchments, the 79°N glacier is exceptional in its extent. Its 60 km long floating ice-tongue covers most of Nioghalvfjerdsfjorden and gives rise to a ∼900m deep cavity under which warm waters of Atlantic origin circulates for 6-12 months before being released to the shelf as glacial modified water. It is now clear that the discharge rates are rising from 79NG due to increased warm Atlantic Water entering the shelf's trench system from the east, being directly guided underneath the floating ice-tongue.

In August 2016, cruise PS100 proceeded to within 1 km of the ice-tongue and was able to deploy instruments to investigate the physical and chemical properties of modified water immediately adjacent to the glacier - a zone which is usually impenetrable due to heavy ice cover. This new dataset therefore presents a unique opportunity to investigate the role of meltwater in marine biogeochemistry. We investigated trace metal nutrient inventories and show their export behaviour from the 79NG to the ocean by means of different size fractions: Soluble (< 0.02 μM), dissolved (< 0.2 μM) and total dissolvable TM (unfiltered/particulate). The non-conservative removal upon freshwater-seawater mixing

limits the vast majority of Fe advection to close proximities near the glacial terminus. Evidence suggests that solubilized far-field Fe export is limited by ligand availability. Whilst it is widely hypothesized that colloidal Fe from glaciers is a large source of Fe to the ocean, here we demonstrate that most of this Fe is removed close to the glacial terminus, suggesting that glacier-to-ocean Fe budgets may have to be revised down dramatically. We propose that Fe export is primarily a function of current patterns rather than a function of freshwater properties.

Impact of glacially-derived Fe(III) on carbon mineralization pathways in Arctic fjord sediments

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Keywords: Svalbard, iron, sulfur, marine biogeochemistry

Runoff from glacial catchments is a significant source of Fe minerals to high-latitude marine environments and an important source of iron, a limiting nutrient, to phytoplankton. Supply of Fe to fjord sediments depends on bedrock lithology and glacial comminution. Much of the Fe from glacial sources will end up in fjord sediments in close proximity to the glaciers. Iron and sulfate reduction are the most significant carbon mineralization pathways in Arctic fjord sediments, but the balance between these two processes is regulated by Fe(III) mineral reactivity. We hypothesize that glacial runoff supplies microbially-reactive Fe(III) minerals to fjord sediments and allows iron-reducers to outcompete sulfate-reducers. We measured the reactivity of Fe(III) minerals from sediments and glacial sources (meltwater plume, meltwater streams, icebergs) of three different fjords at the west coast of Svalbard. Using sequential and time-course extractions we found that Fe(III)-oxide reactivity increased with distance from the head of the fjords and decreased with depth in the sediment within a station. Suspended Fe(III)-oxides from glacial sources were less reactive compared to surficial sediments distal to the fjord head. The gradient of Fe(III)-oxide reactivity mirrored the change of microbial activity from predominantly sulfate reduction near the head of the fjord to iron reduction at the mouth of the fjord. We conclude that glacial catchments supply large quantities of Fe minerals to fjord sediments, but benthic recycling of Fe by microorganisms appears to be required to transform the glacially-derived Fe(III)-oxides to a reactive form in which the iron reducers can compete with sulfate reducers for common organic carbon substrates. Recycling of reactive Fe(III)-oxides by iron reducing microorganisms may play role in liberating Fe to the water column, predominantly at the mouth of the fjord, and might represent an unquantified source of Fe to marine phytoplankton.

Acceleration prior to calving controlled by ice damage

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Keywords: Calving, damage, Svalbard

Ice loss by calving is a major contributor to recent sea level rise and a risk for local tourism. Mechanisms of individual calving events are poorly understood due to its difficulty to measure and monitor, and therefore models are not well developed. High resolution velocity measurements of the entire ice calving face (every 15 minutes) was obtained from terrestrial radar interferometry during a two-week campaign in 2016 at Kronebreen, a polythermal glacier in North-West Svalbard. We show that horizontal velocity at the calving front accelerates hours to days before ice-break off. The accelerations and calving events are captured with high temporal time lapse imagery provides details about the geometry and fall mechanism of the blocks. By monitoring the entire ice face, we captured spatial and temporal trends in calving over the two week period with over hundreds of events showing acceleration. It is likely that block rotation and fracture propagation dictate this acceleration hours to days before calving occurs. Our findings support the development of high-resolution models to understand fracture propagation and physical calving laws for tidewater glaciers.

Geodetic mass balance evolution of surge-type glaciers in Svalbard and Yukon

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Keywords: Surge glaciers, remote sensing, glacier dynamics, mass balance

While limited to ∼1% of glaciers globally, surge-type glaciers dominate regions such as Svalbard, the St. Elias Mountains, and the Canadian Arctic Archipelago. While the exact mechanisms behind surging phenomena are not yet fully understood, it appears that cumulative mass balance may have a role in surge event frequency and/or timing. To infer cumulative mass balance during a surge cycle for Kongsvegen, we have derived repeat digital elevation models (DEMs) of the glacier surface from stereo satellite imagery, Structure from Motion processing of air photos, and ground surveys. Differencing of these DEMs illustrates how the geodetic mass balance of a glacier evolves during the quiescent phase, and provides insight into the build-up that occurs pre-surge. The geodetic mass balance patterns are combined with velocities determined from feature-tracking of optical imagery to analyze how the glacier surface elevation and ice dynamics evolves throughout the quiescent surge phase. Results will be compared with a similar study of Donjek Glacier, Yukon, which has surged approximately every 12 years since at least 1935, and which appears to show surge initiation at a point with a topographic constriction ∼21 km upglacier from the terminus.

Daily freshwater and weekly ice fluxes into Greenland fjords

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Keywords: Fjord, Freshwater, Flux

Greenlandic fjords are where the ice/ocean boundary is often located, are productive ecosystems, and help sustain local communities. Quantifying the ongoing changes in Greenlandic fjord water properties is important for cryospheric, oceanographic, ecosystem, and socio-economic domains. We introduce three data sets relating to freshwater fluxes into Greenlandic fjords: 1) land-based daily liquid runoff from precipitation, ice, and snow melt model outputs covering 1980 through 2017, 2) ice-based daily liquid runoff from the same time period, and 3) solid-ice discharge from 1990 to to 2018, with weekly outputs in 2016 and 2017. Land catchments are defined using the new GIMP DEM, and subglacial catchments using GIMP plus BedMachine v3 subglacial topography. Liquid runoff comes from the MAR model. Solid ice discharge comes from MEaSUREs and Sentinel-1 6-day velocity products and ice thickness from BedMachine and GIMP.

The impact of melting glaciers on coastal productivity

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Keywords: Arctic Ecosystems, melting glaciers

The Greenland Ice Sheet is melting at an unprecedented rate, and as a result, fjords and continental shelves around Greenland are exposed to an increasing freshwater runoff. Yet the impact of high meltwater input on the biogeochemistry remains largely unquantified. To resolve the effect on Greenland's fjord, sampling was conducted in several fjords impacted by melting glaciers in Greenland and physical, chemical and biological gradients were studied from close to the glaciers towards the open sea. Hydrographic and biogeochemical data from several fjord systems adjacent to the Greenland ice sheet, suggest that marine ecosystem productivity is very differently regulated in fjords influenced by either land-terminating or marine-terminating glaciers. Rising subsurface meltwater plumes originating from marine-terminating glaciers entrain large volumes of ambient deep water to the surface. The resulting upwelling of nutrient-rich deep water sustains a high phytoplankton productivity throughout summer in the fjord with marine-terminating glaciers. In contrast, fjords with only land-terminating glaciers lack this upwelling mechanism, and are characterized by lower productivity. These results suggest that a switch from marine-terminating to land-terminating glaciers can substantially alter the productivity in the coastal zone around Greenland with potentially large ecological and socio-economic implications.

Elevation and mass changes of glaciers and ice caps in Svalbard, Norwegian High Arctic

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Keywords: Svalbard CryoSat-2 Altimetry

The Norwegian Arctic archipelago of Svalbard lies at the confluence of cold, dry air masses from the sea ice covered Arctic Ocean to the north, and warm, humid air masses from the Atlantic. The fjords of the west coast are kept relatively ice-free by the influence of the northern extremity of the warm North Atlantic Current. This climatic setting results in strong gradients in precipitation and temperature, and results in an ice cover that varies from cirques, valley glaciers and icefields on the mountainous island of Spitsbergen, to large ice caps on the eastern islands. The mass balance of Svalbard glaciers is highly sensitive to heat transport from the south and sea ice conditions to the north and east. We use swath processing of CryoSat-2 radar altimetry to map glacier elevation change across Svalbard. We briefly detail results of calibration/validation activities conducted on the Austfonna ice cap, comment on our modifications to conventional processing strategies, and discuss the extrapolation to unsurveyed areas. We calculate a mass loss of around 16 Gt/yr for the period 2011 to 2017. This represents a considerable increase compared to a previous assessment using ICESat-1 laser altimetry. We show that whilst the total mass imbalance has increased, the general pattern of elevation change has persisted. The greatest rates of thinning are found in the south and west of Spitsbergen. To the northeast, the interior of the Austfonna ice cap, and Lomonosovfonna and Åsgardfonna icefields are thickening slightly, whilst the margins are thinning. The surface mass balance driven changes are superimposed on elevation changes driven by glacier dynamics, this includes known surges and thinning related to the retreat of marine-terminating margins.

Dynamic discharge and mass balance of the Academy of Sciences Ice Cap, Severnaya Zemlya, Russian Arctic

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Keywords: Calving, mass balance, glacier velocity, temporal variability

We analyse, using feature tracking, 54 pairs of Sentinel-1 synthetic-aperture radar (SAR) images of the Academy of Sciences Ice Cap, Severnaya Zemlya, Russian Arctic, from the period November 2016-November 2017. Seasonal velocity variations up to 20% (peak-to-peak) of the yearly-averaged velocity are observed. Shorter-term intra-annual velocity variations have average deviations up to 32% and maximum up to 64% (peak-to-peak). This illustrates the magnitude of the errors that could be incurred when extrapolating to the whole year discharge values determined from a single pair of SAR images. Average ice discharge for 2016-2017 was 1.93±0.12 Gt/yr. We attribute the difference from an estimate of 1.4 Gt/yr for 2003-2009 to the initiation of ice stream flow in a southern

basin. The total geodetic mass balance for the ice cap over 2012-2016 was -1.72±0.67 Gt/yr (-0.31±0.12 m w.e./yr). The climatic mass balance is not significantly different from zero, at 0.21±0.68 Gt/yr (0.04±0.12 m w.e./yr), and has remained at this level for the last four decades Therefore, the total mass balance is governed by the variations in ice discharge, whose long-term changes do not appear to respond to environmental changes but to intrinsic characteristics of the ice cap.

Utilization of satellite-derived surface snow physical properties to improve the performance of the SMAP physical snowpack model

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Keywords: Greenland, surface mass balance, regional climate model, MODIS albedo

The Greenland ice sheet has had a significant loss of ice mass since the early 1990s. The accelerating mass loss can be partly attributed to the recent rapid reduction in the surface mass balance (SMB) of the ice sheet. To understand governing physical processes of the changes in the ice sheet SMB, Niwano et al (2018) developed a spatially and temporally high-resolution non-hydrostatic atmospheric model (NHM) coupled with a detailed physical snowpack model called SMAP. According to verification work conducted on the ice sheet during 2011-2014, NHM-SMAP overestimated SMB especially in the lower ablation area. Niwano et al (2018) pointed out that one possible cause of the bias was model overestimation of bare ice albedo. The albedo overestimation is the result of the snow/ice part of NHM-SMAP, which does not consider the effects of background light-absorbing impurities such as black carbon, dust, and microbes at all. In the present study, we utilize MODIS snow/ice albedo data after Box et al (2017), and try to constrain the SMAP model calculations, and investigate whether the model can reproduce a more realistic SMB. This approach will allow us to consider the effects of such light-absorbing impurities implicitly. As a first step of this study, we use the PROMICE automated weather station data in the Q-Transect area of the southern ice sheet (Hermann et al., 2018).

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Closing the mass budget of a tidewater glacier: the example of Kronebreen, Svalbard

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Keywords: Mass Balance, Tidewater glacier, geodetic mass balance, dynamic ice flux

In this study we combine remote sensing, in-situ and model-derived datasets from 1966 to 2014 to calculate the mass balance components of Kronebreen, a fast-flowing tidewater glacier in Svalbard. For the well-surveyed period 2009-14, we are able to close the glacier mass budget within the prescribed errors. During these five years, the glacier geodetic mass balance was -0.169 ±0.12 m w.e. a^{-1}, while the mass budget method led to a total mass balance of -0.192 ±0.16 m w.e. a^{-1}, as a consequence of a strong frontal ablation (-0.178 ±0.11 m w.e. a^{-1}), and a slightly negative climatic mass balance (-0.114 ±0.11 m w.e. a^{-1}). The trend toward more negative climatic mass balance between 1966-1990 (+0.20 ±0.05 m w.e. a^{-1}) and 2009-14 is not reflected in the geodetic mass balance trend. Therefore, we suspect a reduction in ice-discharge in the most recent period. Yet, these multidecadal changes in ice-discharge cannot be measured from the available observations and thus are only estimated with relatively large errors as a residual of the mass continuity equation. Our study presents the multidecadal evolution of the dynamics and mass balance of a tidewater glacier and illustrates the errors introduced by inferring one unmeasured mass balance component from the others.

Climatic mass balance and associated freshwater runoff in Kongsfjord basin, northwest Svalbard

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Keywords: Energy balance, Seasonal snow, Runoff, Glacier modeling

In recent warming climate glaciers and ice caps are the major contributors to sea level rise. They are very susceptible to changing climate, therefore, investigating long-term evolution of mass balance and runoff of glaciers is essential. On a regional scale, runoff from tidewater glaciers modulates ocean circulation and affects biological activities. Arctic region is experiencing greater warming than rest of the world. In northwest Svalbard, Kongsfjord basin is a hotspot for interdisciplinary studies, many of which addressing the significance of freshwater from glaciers and seasonal snow.

We use a coupled energy balance-subsurface snow/firn model to simulate long-term (1980-2016) evolution of mass balance and runoff from entire glacierized area of Kongsfjord basin. A subsurface soil model is used to simulate seasonal snow development at the non-glacierized area. Meteorological data from the nearby station at Ny-Ålesund is used for climate forcing in the model domain, with mass balance data at four glaciers in the Kongsfjord watershed used to calibrate model parameters. Precipitation forcing in the model comes from downscaled ERA-Interim precipitation data. We find an area-averaged climatic mass balance of +0.23 m w.e. a^{-1} for the entire glacierized area over the simulation period, with a substantial spatial variability in mass balance between south, east and north regions of the fjord. We find a non-significant, yet negative trend for mass balance of entire glacierized area as well as for three subregions (south, east and north) for the period 1980-2016. Refreezing equals 0.24 m w.e. a^{-1}, which is equivalent to 17% of the total mass gain from precipitation and moisture deposition. Total runoff comprises contributions from seasonal snow in the non-glacierized area (16%) and glacier discharge

(84%). Runoff time series of the entire basin shows a significant and increasing trend ($6.83x10^6$ m^3 a^{-1}) over the simulation period.

Climate, and Surface energy and mass balance of Ulvebreen, Svalbard

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Keywords: Weather station, Svalbard, climate

In August 2015 an automatic weather station (AWS) was placed on Ulvebreen, Svalbard as part of the Netherlands Scientific Expedition Edgeøya Spitsbergen (SEES.nl). Ulvebreen is a glacier on the Central East coast of Spitsbergen. The station measures air temperature, wind speed and direction, relative humidity, air pressure, and short and long wave incoming and outgoing radiation. In addition, the station is equipped with a sonic height ranger in combination with a draw wire to measure snow accumulation and ice melt, respectively, and a GPS to monitor glacier velocity.

The AWS is located at ∼135 m a.s.l., about 2 km from the glacier front. At the AWS site the average annual temperature is ∼-3.8°C, which is ∼2.5°C lower than measured at Svalbard airport, Longyearbyen, and can be explained by the elevation difference in combination with the location of the AWS on the eastern side of Spitsbergen where the influence of the North Atlantic drift is smaller and the amount of sea ice in winter larger. Annual mean wind speed is ∼4.8 ms-1 and is predominantly from the North or South West. The South west flow coincides with the downslope direction of Buckfallet, a tributary of Ulvenbreen. The Northern flow is likely more influenced by the large scale circulation since a katabatic flow from Ulvebreen is expected to be more from the North west. The site is in the ablation area and experiences about 1.5 to 2 m snow fall in winter and 1.6 to 1.8 m ice melt in summer.

The AWS observations can be used to calculate the individual surface energy fluxes using a surface energy balance model. First results show that from all energy fluxes, net radiation contributes most to melt, which is not unexpected given the low surface albedo of the ice (∼0.3).

Marine ecosystem responses to climate change in Greenland - a view from below

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Keywords: Sediment proxies, Greenland fjords, primary productivity

Greenland fjords, modulated by ice-ocean interactions, are among the most productive ecosystems in the Arctic, and have sustained the livelihood of local communities in Greenland for millennia. Marine primary producers in the Arctic are both light and nutrient limited, and although recent climate change has generally triggered productivity due to a positive effect on light availability, the long-term response of primary producers

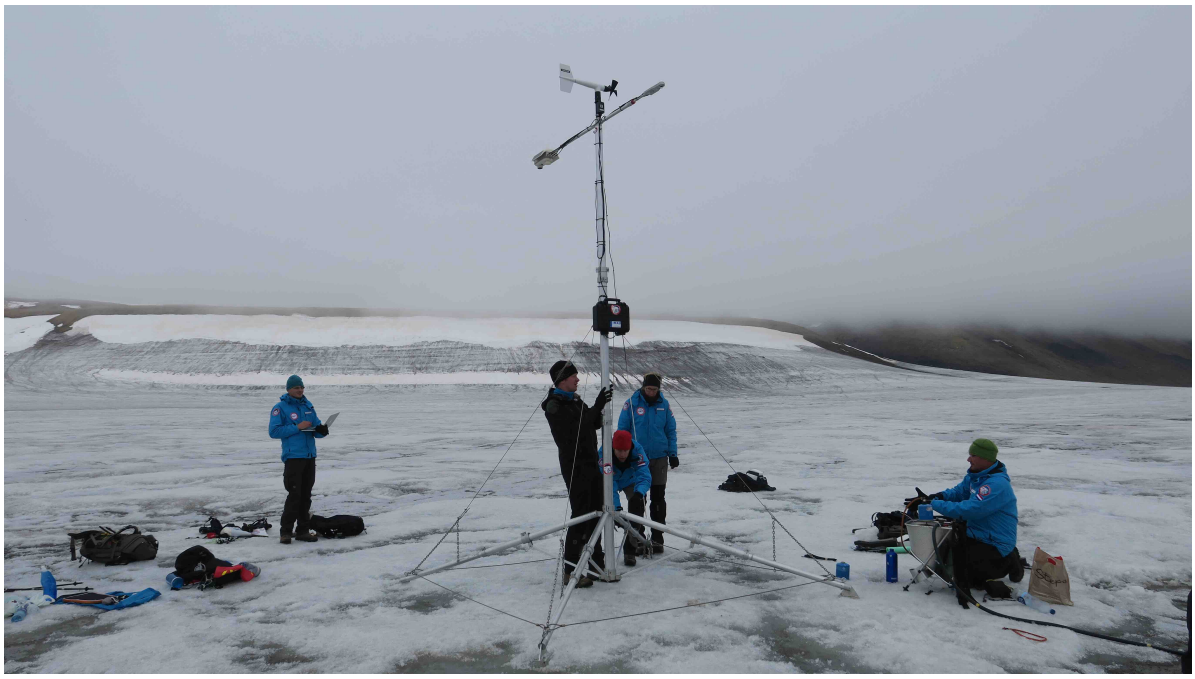

Photo of the Automatic weather station on Ulvebreen in August 2015. (Photo: H. van Leur)

in fjord systems influenced by glacier discharge is not straightforward, as it results from the interplay of e.g. turbidity, water column stability, and nutrient availability. In order to interpret recent changes, it is crucial to assess fjord productivity over multi-annual to centennial time scales encompassing natural variability. Marine sediment records, including sediment trap records, are valuable archives of environmental change. Key parameters such as sea-surface temperature, salinity, sea ice extent, and productivity can be reconstructed using a network of geochemical, sedimentological and micropaleontological proxies. Moreover, the main phytoplankton groups (diatoms and dinoflagellates) have a rich sediment record, from which changes in diversity and community structure can be inferred.

I will give an overview of our previous and ongoing work with the overarching goal of "unlocking" archives of long-term ecosystem responses (focusing on primary producers, from the population to the community level) based on sediment archives. I will introduce our approach to reconstruct and project long-term changes in primary productivity for two contrasting fjord systems impacted by Greenland Ice Sheet melt bridging satellite, historical and paleo-records, and results from a detailed study on diatom inter-annual variability based on sediment traps.

Depth profiling of the particle size distribution in glacial meltwater using laser diffractometry in the Svalbard archipelago

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Keywords: Laser diffraction, sediment transport, ocean optics

We present results from optical measurements done in fjords with significant glacial meltwater in the Svalbard archipelago, measured during the INTAROS 2018 cruise. Laser

diffractometry is a technique for in-situ measurements of the particle size distribution (PSD), which is an important quantity for observation of sediment transport. The angular distribution of light scattered in the forward direction is strongly dependent on the size of the scattering particles. This is utilized in laser diffractometry, where an inversion method is used to calculate the PSD from forward scattering measurements. Vertical profiling using the submersible instrument LISST-200X (Sequoia Scientific Inc.) gives a high spatial resolution and is non-invasive such that fragile flocs of particles may be investigated. The instrument obtains the PSD for equivalent spherical diameter 1-500 micrometers in 36 size bins. Data collection was done by lowering the instruments down to a depth of 50 meters.

One section with three measurement stations using the LISST-200X and a CastAway CTD (Xylem Inc.) was done in Rijpfjorden, at different distances to the terminus of the tidewater glacier Rijpbreen. The results show significant spatial variations. A distinct surface layer with high particle concentration and low salinity can be seen. The particle concentration decreases rapidly for all sizes with distance from the terminus. In addition, distinct peaks in the PSD can be seen deeper in the water column, in particular in the outer fjord. This may be an indication of phytoplankton presence. There are still uncertainties connected to laser diffractometry, especially connected to particle shape and refractive index, which will be subject of further research connected to both phytoplankton and inorganic particulate matter.

Projecting Svalbard glacier mass balance for future climate

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Keywords: Glacier mass balance, Svalbard, projection

In this presentation, we review available meteorologically-driven simulations of climatic glacier mass balance for entire Svalbard, compare the results and discuss their potential use for a wider community. The complete spatial coverage of the climatic mass balance fields allows regional differentiation showing a pronounced gradient of mass balances across the archipelago, from slightly positive values in the Northeast towards more negative values in the Southwest.

We outline requirements for further improving glacier mass balance assessments, especially the need for tailored field measurements to evaluate simulated features that are not captured by conventional monitoring programs. Furthermore, to quantify the total glacier mass loss and hence, the contribution to sea-level rise, the climatic mass balance must be completed with frequently updated assessments of ice discharge.

Based on dynamic downscaling of projected climate evolution (MPI-ESM-LR, RCP 8.5) for two time slices (1970-2000 and 2070-2100) using the regional climate model COSMO-CLM, we simulate changes of the mass balance. A preliminary analysis comparing the two time slices reveals that for the assumed climate projection, the equilibrium line altitude rises in average by 550m, accompanied by a 6-fold intensified mass loss. These dramatic findings are derived from a so-called reference mass balance, assuming no changes in glacierized area and surface elevation. This assumption may compromise the results in either direction and the dilemma cannot be resolved with specific consideration of glacier geometry changes. Nevertheless, we stress that the simulated mass balance represents only the climatic mass balance and neglects the ice discharge component, currently accounting for about 50% of the mass loss from Svalbard.

Hypersaline subglacial lakes beneath the Devon Ice Cap

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Recent (2014 and 2018) airborne radar surveys of the Devon Ice Cap reveal the presence of 3 water bodies beneath the central region of the ice cap (west of the main N/S ice divide and either side of the main east-west divide. These lakes were identified on the basis unusually high bed reflectivity values which indicate areas of high dielectric contrast at the glacier bed, typical of an ice-water interface, and they appear to occupy troughs in the underlying bedrock that are areas of locally low hydraulic head. Overlying ice thicknesses are on the order of 250-400m. Thermal modeling suggests temperatures in the range -14 to -18 deg C at the glacier bed in the surrounding area, consistent with in situ measurements made in 1978 which reveal a basal temperature of -18.5 deg C. Water could only exist at some temperatures if it were highly saline. Geological projection from areas around the ice cap suggests that the Ordovician Bay Fiord Fm may outcrop at the ice cap bed in the area around the lakes. This formation is known to contain a bedded salt sequence that could be the source of the salinity. Given the modeled basal temperatures, a salinity of 140-160 psu would be required for liquid water to be present. These values are not too dissimilar from those of saline groundwater beneath Taylor Glacier in Antarctica, and in permanently ice-covered Lake Vida in the McMurdo Dry Valleys. Since there is no evidence for surface water inputs to the lake, it seems probable that basal melting, resulting from contact between the bedrock-derived salt and the ice is the most likely source of the water in the lake. This might suggest the existence of a hypersaline "swamp" in the area around the lakes, through which water would drain to the lakes. Hydrologic reconstructions based upon the mapped subglacial hydraulic potential field help to define likely drainage catchments and outflow pathways for each lake. An extraterrestrial analogue for the Devon subglacial lakes may exist beneath the South Polar Ice Cap on Mars.

Glacier change, ice-ocean interaction, and their impacts on human society in Qaanaaq, northwestern Greenland

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Keywords: Greenland, ice-ocean interaction, human society

Under the framework of Japanese interdisciplinary Arctic research projects GRENE (Green Network of Excellence) and ArCS (Arctic Challenge for Sustainability), we have been studying changes in glaciers, the ocean and climate in the Qaanaaq region, northwestern Greenland. Our study shows rapid changes in glaciers and ice caps, which are tightly connected to the ocean and coastal environments. One example is an influence of glacier meltwater on ocean environments. Subglacial discharge from tidewater glaciers drives nutrient transport in glacial fjords, and thus changes in the discharge should give an impact on marine ecosystem in the fjord. Further, glacier changes pose a possible impact on human society in the region. For example, a road connecting Qaanaaq Village and Airport was destroyed in July 2015 and August 2016, which were due to floods of meltwater streams from Qaanaaq Ice Cap. Possibly, flood occurs more frequently in recent years because of increasing amount of ice cap meltwater as well as growing number of heavy rain events. In this contribution, we present the overview of our recent research activities in the Qaanaaq region, northwestern Greenland. We show the results of observations at

glaciers and the ocean to discuss the importance of ice-ocean interactions and impacts of glacier changes on coastal environments. We also introduce our activity to investigate the connection of cryospheric environmental changes and human society in Qaanaaq.

2020 Expedition to for Interactions between Ocean Forcing with the Marine Ecological Response at Arctic Glacier Termini

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Keywords: Glacier-ocean interaction, biogeochemical processes, hydrography

Recent studies have vastly improved characterizing the hydrographic environment around the Greenland Ice Sheet. Greater resolution of coastal bathymetry reveal the ocean troughs connecting Greenland's fastest melting glacial fjords with Baffin Bay. Currents of Atlantic origin bring warm water north, then up through the troughs and under dozens of ocean-terminating glaciers (OTG). The often record-breaking Arctic mid-summer atmosphere temperature maximum propels glacial mass ice loss, thus increasing the opportunity for favorable plankton bloom conditions at OTG. Within fjords opposing forces meet. Inbound ocean currents contact OTG discharge which forms an upwell plume. Meanwhile, regional subsistence fishermen take advantage of the nutrient-rich glacial fjords during a longer navigable water season. With Arctic warming projections expected to accelerate, now is an opportune time to relate the natural physical drivers with the current ecological response at the glacier and ocean interface.

In my research, I use recent interannual hydrographic data of OTG fjords of Canada and Greenland to depict the physical ocean backdrop during observed plankton bloom events. This backdrop aides in my design of the data acquisition strategy for a mid-summer survey at select repeat sites for physical and optical ocean measurements and optical aerial drove survey from the schooner, R/V Marie Tharp in 2020. Post-cruise assessment of in situ data with satellite remote sensed ocean color and glacial mÃl'lange plume characteristics will identify uncertainty in satellite-derived algorithms. My presentation will display reconnaissance data considerations towards a strategy for examining the polar marine ecosystem at the dynamic glacier and ocean junction.

Monitoring and modeling a recurrent calving event at Bowdoin Glacier, Greenland

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Keywords: Calving, Greenland, observations, modeling

Calving mechanisms are still poorly understood. The size and the frequency of calving events may vary by several orders of magnitude, making the development of an universal calving model challenging. At Bowdoin Glacier, Northwest Greenland, most of the yearly mass loss by calving is due to a few large events. Here, we analyse two major calving events in detail, which occurred nearly at the same location and followed a strikingly similar fracturing pattern. Our analysis relies on data obtained by interferometric radar and UAV photogrammetry during two summer fieldwork campaigns in July 2015 and July 2017. The crevasses likely deepened by hydro-fracturing, since a supraglacial river supplied them with water. Besides that, our high temporal and spatial resolution data reveals the influence of tides on the opening of the crack.

Here, we used the ice flow model Elmer/Ice to analyse the observations further. Modeling crevasse opening required the development of a dedicated remeshing routine for the crevasse. We use Elmer/Ice as a diagnostic, inverse model to identify key drivers of the crevasse opening and to determine possible combinations of water level inside the crevasse and crevasse depth that prevailed prior to the calving event. As a result, we find that the water level acts as a first-order control on crevasse opening rates.

A multidecadal simulation of climatic mass balance, snow conditions and runoff across Svalbard

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Keywords: Glaciers, mass balance, runoff

The climate in Svalbard is undergoing amplified change compared to the global mean. This has major implications for discharge from glaciers and seasonal snow. We use a coupled energy balance – snow/firn model (EBFM) to simultaneously model the climatic mass balance of glaciers, as well as the seasonal snow pack development across the entire Svalbard archipelago.

The simulation with a 1-km spatial and 3-hourly temporal resolution covers the period 1957-2018, with meteorological input provided by downscaled HIRLAM regional climate model fields. Observational data including stake measurements, automatic weather station data and subsurface data across Svalbard are used for model calibration and validation. Based on the output, we discuss the long-term development and spatial patterns of climatic mass balance and seasonal snow characteristics across Svalbard. Additionally, we quantify runoff from both glacier- and land-covered areas, and discuss spatial patterns and trends in relative contributions. Altogether, the output of the simulation provides a dataset that may be of use in a wide range of applications ranging from runoff modeling, to ground ice studies to ecosystem studies.

Water discharge changes of the rivers with glacier feeding due to climatic fluctuations in Arctic region

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Keywords: Glaciers, climate changes, water discharge, melting

In many mountainous territories, glaciation area is reducing. There is a high probability that this reduction has connection with climate changes. Therefore, glaciers in different parts of the world are studied; data on the current state and dynamics of glaciers are being collected and analyzed. The changes in the water discharge of rivers with glacial headwater directly related to the fluctuations in the size of the glaciation.

The aim of the research is to identify the relationship between climatic fluctuations, changes of the glaciers area and the water discharge of rivers with glacial headwater. The following tasks were performed for achieving this aim:

- Search and analysis of meteorological information;
- Analysis of changes in the area of glaciers using satellite images;
- Analysis of the water discharge of rivers with glacial headwater.

Athabasca glaciers (Canada) and Jostedalsbreen (Norway) were chosen for the research, because they are well known tourists attractions. As a result of the study, it was revealed that climate change affects the studied glaciers, the area of glaciers is reduced. This affects the formation of the water discharge of rivers with glacial headwater.For the air temperature of the studied areas, no significant trends were identified, only an upward tendency.

Due to processing satellite images, glacier areas were calculated for 1984 and 2016-2017 during ablation periods (July - September). The results showed that the area of all glaciers (Athabasca, Justodalsbreen) decreased by 61% and 15%, respectively, which caused the increase in runoff during periods of maximum ablation (July), as well as an increase in average annual runoff during the entire period after 1980.

Analysing calving activity using continuous direct observations

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Keywords: Calving events, direct observations

Recently, many marine-terminating glaciers of the Greenland ice sheet revealed rapid retreat, thinning and flow acceleration. These glaciers lose about half of their mass by calving, a process which can change on short timescales. Despite their importance for global sea level rise, major limitations in understanding the dynamics of these glaciers remain. To overcome such limitations, especially detailed observational data is needed.

We observed an outlet glacier in West-Greenland during an eight-day field campaign in 2018 by using a terrestrial radar interferometer, pressure sensors and a time-lapse

camera. A combination of these technologies provides us with displacement and topographical data with a spatial resolution of 5 meters in one minute intervals, water height data with a temporal resolution of 2 seconds and images of the glacier front every 10 seconds. This continuous very detailed dataset enables us to get new insights of the calving process. We use these data to establish detailed calving event statistics which are compared to environmental forcing like tides or weather conditions. By identifying source areas and ice volumes of individual calving events we quantitatively investigate the relationship between calving front geometry, calving rate and potential drivers. Additionally, the comparison between the individual datasets allows us to link the shape of tsunami wave oscillations to different calving types and event volumes. Therefore, we can extend the individual calving event statistics from short timescale to long timescale over 5 years.

Response of Norwegian plateau icefields to climate warming since the Little Ice Age

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Keywords: Glacier change, Norway, Little Ice Age, Plateau icefields

A significant portion of Norwegian glaciers are plateau icefields. These are highly sensitive to changes in climate because of their top-heavy hypsometry. A small rise in the equilibrium line altitude (ELA) may cause the ablation area to expand significantly, leading to rapid icefield recession. This behaviour deserves particular research attention in light of the current warming of the Earth's climate system. In this study, we assess the response of the icefields Hardangerjøkulen in southern Norway, Svartisen just above the Arctic Circle, and Langfjordjøkelen in northernmost Arctic Norway to climate warming since the Little Ice Age (LIA). These ice masses have been in retreat since they reached their maximum LIA positions between ~AD 1750-1925. We use the glacial landform record of these icefields to reconstruct their maximum LIA extent. In addition, we use historical maps to reconstruct their ~AD 1900 extent. These data sets are compared with data from the latest Norwegian glacier inventory (~AD 2000), revealing substantial changes in icefield size. The greatest area loss occurred at Langfjordjøkelen in Arctic Norway, with an area reduction of ~50 %. Hardangerjøkulen in southern Norway had lost ~34 % of its original LIA area by ~AD 2000, and Svartisen in northern Norway had lost between ~20 and ~30 % of its LIA area. Our study demonstrates how the LIA glacier extent can be employed as a valuable baseline to assess long-term glacier change.

The need for water vapor fluxes in long-term modeling of the Greenland ice sheet

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Keywords: Energy balance, Greenland Ice Sheet, modeling, sensitivity

The surface mass balance is one of the main drivers for the recent mass loss of the Greenland ice sheet (GrIS). Present day short-term mass and energy balance models are helpful tools in the understanding of the GrIS. For longer timescales into the past and future of the Greenland ice sheet it is desirable to also use mass and energy balance models rather than positive degree day approaches, but computational costs are often limiting. We present the Bergen Snow SImulator (BESSI), an efficient mass and energy balance firn model designed for such long-term simulations of the Greenland ice sheet. It allows for a simulation of the daily energy and mass fluxes based on four climatological input components.

The parametrizations present in such models are often calibrated using present-day observations. However, the general invariance of the parameterized process cannot be assumed, which is why we present a sensitivity study of our model for different time periods.

The study simulates the mass and energy balance for 500 years of present day (PD) climate as well as for the last glacial maximum (LGM). While the sensitivity qualitatively stays the same, distinct differences arise mainly from the change in climate. The mass balance in the present day climate is by far the most sensitive to the parametrization of the incoming long-wave radiation, while in the LGM the latent heat fluxes are of equal importance due to the cold and dry temperature and the scarcity of precipitation. We conclude that under different climatological settings, the individual components of the energy balance undergo a drastic variation. For the intended long-term studies of the Greenland ice sheet it is a necessity to include water vapor fluxes for an appropriate simulation of the surface mass balance. The simple parametrization of the long-wave radiation lead to large uncertainty.