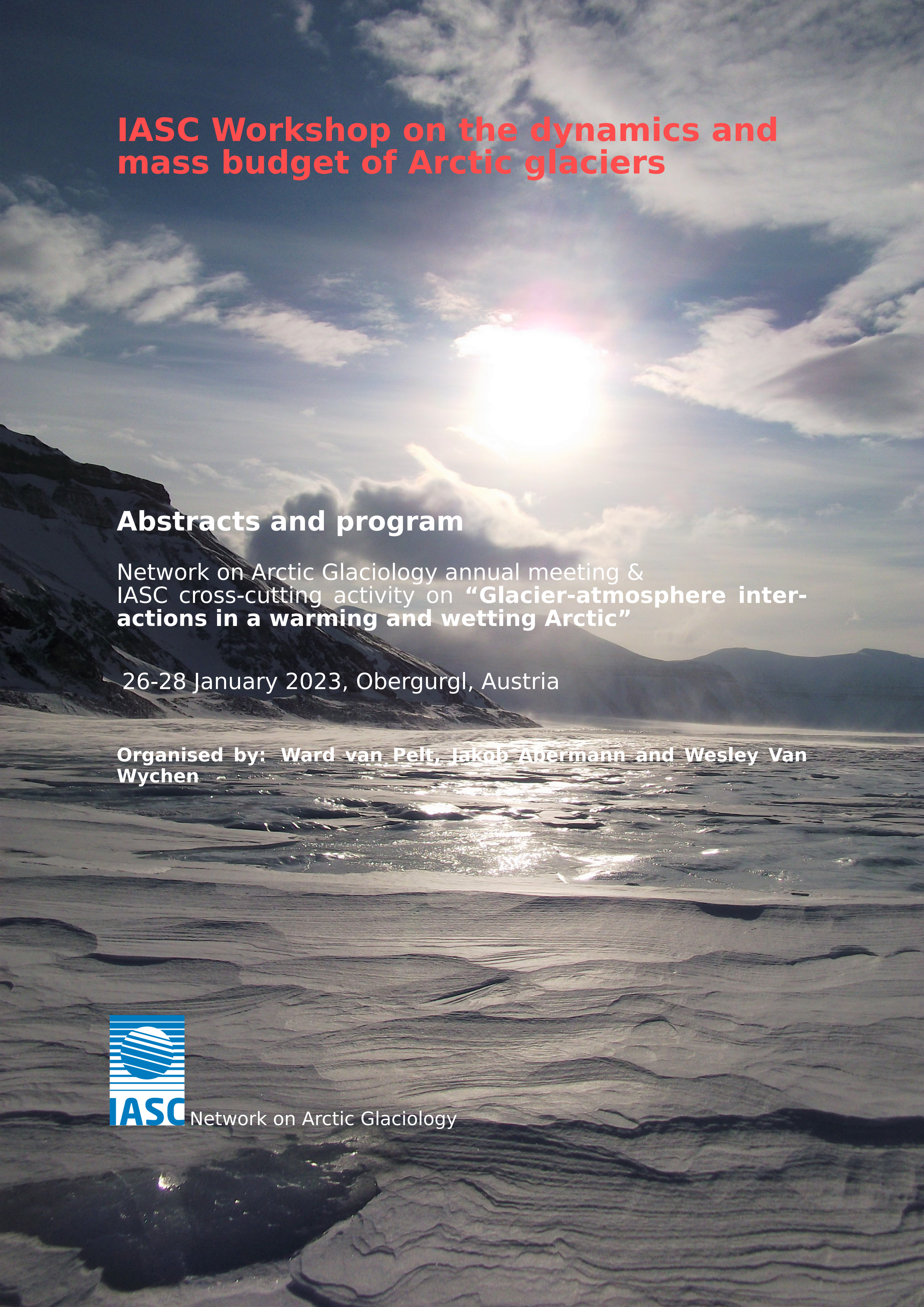

IASC Workshop on the dynamics and mass budget of Arctic glaciers

Abstracts and program

Network on Arctic Glaciology annual meeting &
IASC cross-cutting activity on **“Glacier-atmosphere interactions in a warming and wetting Arctic”**

26-28 January 2023, Obergurgl, Austria

Organised by: Ward van Pelt, Jakob Abermann and Wesley Van Wychen

IASC Network on Arctic Glaciology

Contents

Schedule

The meeting takes place at the University Centre in Obergurgl, Austria, 26 - 28 January, 2023.

Wednesday 25 January

ARRIVAL

19:00 - 20:30	**Dinner**

Thursday 26 January

08:30 - 09:00	Registration: pick up your name badge and copy of program. Please upload your presentations for the morning session.
09:00 - 09:05	**Welcome**
Session I:	**Glacier mass balance**
Convener:	*Madeline Myers*
09:05 - 09:20	Glacier geometry and mass change at Sirmilik and Auyuittuq National Parks, Nunavut, Arctic Canada, 1960-2020 **Wai Yin Cheung**
09:20 - 09:35	Trends in Greenland ice sheet observational records: implications for changing ice volume **Jason Box**, Baptiste Vandecrux, Andreas Ahlstrøm, Nanna Karlsson, Adrien Wehrlé
09:35 - 09:50	Geodetic mass balance of a small glacier in the Canadian High Arctic determined from historical aerial photography **Dorota Medrzycka**, Luke Copland
09:50 - 10:05	15 years Mass Balance Measurements at Freya Glacier, NE-Greenland **Bernhard Hynek**, Daniel Binder, Gernot Weyss, Jakob Abermann, Wolfgang Schöner, Michele Citterio, Signe Larsen
10:05 - 10:20	Mass loss of Qaanaaq Ice Cap in northwestern Greenland from 2012 to 2022 **Shin Sugiyama**, Kaho Watanabe, Ken Kondo
10:20 - 10:50	Coffee break
Session II:	**Glacier dynamics I**
Convener:	*Penelope Gervais*
10:50 - 11:05	Ice stream flow dynamics of Sermeq Kujalleq observed with detailed repeated UAV surveys **Andrea Kneib-Walter**, Guillaume Jouvet, Martin Lüthi

11:05 - 11:20	Some thoughts and observations on basal motion beneath the (still) polythermal McCall Glacier, Alaska **Matt Nolan**
11:20 - 11:35	Hydrothermal structure of Elfenbeinbreen and Sveigbreen, Sabine Land, Svalbard, and its changes for Sveigbreen during 2014-2022 **Francisco Navarro**, Ivan Lavrentiev, Evgeny Vasilenko, Unai Ietamendia, Beatriz Benjumea, Alexandr Borisik
11:35 - 15:45	Lunch & ski break
15:45 - 16:15	Coffee break
16:15 - 16:45	**Poster introductions** (1-2 slides and max. 2 minutes per person)
Convener:	*Wesley Van Wychen*
16:45 - 18:30	**Poster session**
19:00 - 20:30	Dinner

Friday 27 January

Session III:	**Cross-cutting session (part I)**
Convener:	*Jakob Abermann*
09:00 - 09:25	[Keynote] Resilience of the Greenland ice sheet firn layer under future climate warming **Brice Noël**, Jan Lenaerts, William Lipscomb, Katherine Thayer-Calder, Michiel van den Broeke
09:25 - 09:40	Evolving Ice Fraction in the Shallow Firn Layer of Devon Ice Cap, Nunavut between 2011 to 2022 **Danielle Hallé**, Wesley Van Wychen, Richard Kelly, David Burgess, Bradley Danielson, Luke Copland, Peter Bezeau, Brice Noël
09:40 - 09:55	Impact and evaluation of improved ice surface roughness formulation in RACMO 2.3p2 on Greenland surface melt modelling **Maurice Van Tiggelen**, Paul Smeets, Carleen Reijmer, Christiaan van Dalum, Brice Noël, Willem Jan van de Berg, Dirk van As, Jason Box, Robert Fausto, Michiel van den Broeke
09:55 - 10:10	The Greenland Climate Network v.2 - a new era of monitoring the Greenland ice sheet **Andreas Ahlstrøm**, Jason Box, Nanna Karlsson, William Colgan, Robert Fausto, Signe Andersen, Baptiste Vandecrux, Anja Rutishauser, Penny How, Ken Mankoff, Jakob Jakobsen, Chris Shields, Allan Pedersen, Michele Citterio, Alexandra Messerli, Anne Solgaard, Signe Larsen, Niels Korsgaard, Kristian Kjeldsen, Derek Houtz
10:10 - 10:35	Coffee break

Session IV:	**Cross-cutting session (part II)**
Convener:	*Ward van Pelt*
10:35 - 11:00	[Keynote] North Atlantic cooling and the impact on Icelandic glacier mass balance **Guðfinna Aðalgeirsdóttir**, Brice Noël, Finnur Pálsson, Steingrímur Jónsson
11:00 - 11:15	Reconnaissance of Alfred Wegener's West Greenland Expedition: bridging a century of climate change work: 1929 to 2022 **Jakob Abermann**, Baptiste Vandecrux, Sebastian Scher, Florina Schalamon, Andreas Trügler, Robert Fausto, Wolfgang Schöner
11:15 - 11:30	Present changes of Jostedalsbreen, Norway's largest ice cap **Liss Marie Andreassen**, Mette Gillespie, Kjetil Melvold, Kamilla Sjursen, Benjamin Robson, Hallgeir Elvehøy, Bjarne Kjøllmoen, Jacob Yde
11:30 - 12:00	Cross-cutting discussion
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15:45 - 16:15	Coffee break
Session V:	**Glacier hydrology**
Convener:	*Maiken Kristiansen Revheim*
16:15 - 16:30	Modelling lateral meltwater flow atop the Greenland Ice Sheet's near-surface ice slabs **Nicole Clerx**, Horst Machguth
16:30 - 16:45	Greenland slush limits; comparing remote sensing and RCM simulations **Horst Machguth**, Andrew Tedstone
16:45 - 17:00	Glacier recession vs. water drainage at a forefield (Werenskioldbreen, Svalbard) **Katarzyna Stachniak**, Krzysztof Janik, Dariusz Ignatiuk, Elzbieta Łepkowska, Jacek Jania
17:00 - 17:15	Supraglacial lake evolution on Tracy and Heilprin Glaciers in northwestern Greenland from 2014 to 2021 **Yefan Wang**, Shin Sugiyama
17:15 - 17:20	Short break
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19:00 - 20:30	Dinner

Saturday 28 January

Session VI:	**Glacier dynamics II**
Convener:	*TBD*
09:00 - 09:15	Dynamics throughout a complete surge of Iceberg Glacier on western Axel Heiberg Island, Canadian High Arctic **Benoît Lauzon**, Luke Copland, Wesley Van Wychen, William Kochtitzky, Robert McNabb, Dorthe Dahl-Jensen

09:15 - 09:30	Little Kluane Glacier, Yukon: a tributary-trunk surge **Brittany Main**, Luke Copland, Will Kochtitzky, Sergey Samsonov, Gwenn Flowers, Christine Dow
09:30 - 09:45	Recent patterns of velocity and elevation change, and their associated drivers, Hubbard Glacier, Alaska **Courtney Bayer**, Wesley Van Wychen, Anna Wendleder
09:45 - 10:00	Terminus area changes of all Northern Hemisphere marine-terminating glaciers since 2000 **Luke Copland**, Will Kochtitzky
10:00 - 10:15	Crystal fabric orientation of the NEGIS ice stream **Olaf Eisen**, Tamara Annina Gerber, David Lilien, Nicholas Rathmann, Steven Franke, Tun Jan Young, Fernando Valero-Delgado, Reza Ershadi, Reinhard Drews, Ole Zeising, Angelika Humbert, Nicolas Stoll, Ilka Weikusat, Aslak Grinsted, Christine Hvidberg, Daniela Jansen, Heinrich Miller, Veit Helm, Daniel Steinhage, Charles O'Neill, John Paden, Prasad Gogineni, Dorthe Dahl-Jensen
10:15 - 10:45	Coffee break
Session VII:	**Frontal processes**
Convener:	*Erika Brummel*
10:45 - 11:00	Calving response to the propagation of a speedup pulse through the ice stream of Sermeq Kujalleq in Kangia (Jakoshavn Isbræ), Greenland **Adrien Wehrlé**, Martin Lüthi, Andrea Walter, Ana Nap, Guillaume Jouvet, Hugo Rousseau, Fabian Walte
11:00 - 11:15	Factors controlling terminus position of tidewater glaciers in Hornsund fjord (Svalbard) **Małgorzata Błaszczyk**, Mateusz Moskalik, Mariusz Grabiec, Jacek Jania, Waldemar Walczowski, Tomasz Wawrzyniak, W. Tad Pfeffer
11:15 - 11:30	The control of short-term ice mélange weakening episodes on calving activity at major Greenland outlet glaciers **Martin Lüthi**, Adrien Wehrlé
11:30 - 11:45	Frontal ablation modulated by hydropower regulation? A case study from Austdalsbreen, Western Norway **Thorben Dunse**, Hallgeir Elvehøy, Even Loe, Gernot Seier, Jakob Aberman, Mette Kusk Gillespie, Jacob Yde
11:45 - 12:00	Frontal ablation of Northern Hemisphere glaciers for 2000-2020 **Will Kochtitzky**, Luke Copland, Wesley Van Wychen, Romain Hugonnet, Regine Hock, Julian Dowdeswell, Toby Benham, Tazio Strozzi, Andrey Glazovsky, Ivan Lavrentiev, David Rounce, Romain Millan, Alison Cook, Abigail Dalton, Hester Jiskoot, Jade Cooley, Jacek Jania, Francisco Navarro
12:00	**Final words** followed by lunch / skiing / side events / early departure
19:00 - 20:30	Dinner

Posters

- Multidecadal reconstruction of the surface mass balance of an Arctic glacier using reanalysis data, **Anna Rohrböck**, Bernhard Hynek, Leopold Haimberger, Wolfgang Schöner
- Crustal Uplift: a regional response to contemporary ice mass loss **Bradley Danielson**, David Burgess, Thomas James, Maximilian Lauch, Michael Craymer
- Changes in the extent and velocity of the Hornbreen - Hambergbreen system (S Spitsbergen) **Dawid Saferna**, Małgorzata Błaszczyk, Bogdan Gadek
- Assessing the 2021-2022 surge behaviour of Lowell Glacier **Erika Brummell**, Luke Copland, Christine Dow, Wesley Van Wychen, Dorota Medrzycka, Adam Garbo
- Reconstructing the past two surges of Fisher Glacier, Yukon **Gabriel Partington**, Luke Copland, Dorota Medrzycka, William Kochtitzky, Benoît Lauzon
- Vertical ice - morphology of the terrestrial ice margin in Greenland **Jakob Steiner**, Jakob Abermann, Rainer Prinz
- Hypsometric control on basin sensitivity under rising equilibrium line altitudes in the Northern Canadian Arctic Archipelago **Madeline Myers**, Laura Thomson
- Greenland ice sheet surface water vapour fluxes from automatic weather station records **Maiken Kristiansen Revheim**, Jason Box, Baptiste Vandecrux, Christine Hvidberg
- Changes in Glacial Hydrology in Response to Recent Increases in Surface Melt on Ellesmere Island, Canadian High Arctic **Penelope Gervais**, Luke Copland
- A novel large-scale ice thickness inversion method tested on Kronebreen, Svalbard Thomas Frank, **Ward van Pelt**
- The surge of high-Arctic Chapman Glacier, 1999-2018 **Wesley Van Wychen**, Hester Jiskoot

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Abstracts

Calving response to the propagation of a speedup pulse through the ice stream of Sermeq Kujalleq in Kangia (Jakoshavn Isbræ), Greenland

Adrien Wehrlé[1], Martin P Lüthi[1], Andrea Walter[1], Ana Nap[1], Guillaume Jouvet[2], Hugo Rousseau[1], Fabian Walter[3]

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[2] University of Lausanne, Switzerland
[3] WSL, Switzerland

Sermeq Kujalleq in Kangia (Jakobshavn Isbræ), Greenland is one of the most studied glaciers in the world mainly due to its recent retreat associated with extremely fast ice stream flow and high solid ice discharge. However, large limitations remain in the understanding of its short-term dynamics as the study of sub-daily variations, undetectable in spaceborne observations, requires high-rate field measurements that are challenging to acquire. Here, we present glacier surface velocities computed in Post-Processed Kinematic (PPK) mode from eight autonomous GNSS stations deployed in July 2022 along the ice stream at a distance of 4 to 30 kilometers from the calving front. During this field campaign, we identified an 8-hour-long glacier speedup recorded at all GNSS stations representing up to 10.5% of the pre-event velocity, followed by a 12-hour-long slowdown of similar magnitude. We further found the peak velocity was first measured at a GNSS station 15.8km away from the calving front, then further recorded at the three other downstream GNSS stations with a positive time lag corresponding to a 2.8km/h downstream wave propagation speed. At the station the closest to the calving front, the timing of peak velocity corresponded to the occurrence of large-scale calving events. We further present line-of-sight glacier surface velocities determined along three shear margin transects with a terrestrial radar interferometer deployed simultaneously with the GNSS array. We show a simultaneous response of the fast- and slow-moving ice across all profiles, the glacier speedup being recorded throughout the entire length of the shear margins up to almost immobile ice. As a result, we determined the ice stream to have widened by more than 200 meters during the event.

Ice stream flow dynamics of Sermeq Kujalleq observed with detailed repeated UAV surveys

Andrea Kneib-Walter[1], Guillaume Jouvet[2], Martin P. Lüthi[1]

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Outlet glaciers and ice streams transport ice from the ice sheets to the ocean. Sermeq Kujalleq (JI, Jakobshavn Isbræ) is one of the largest and the most dynamic ice stream of the Greenland Ice Sheet with velocities up to 40 m/day. JI's ice stream is separated from

the slower flowing ice sheet by a highly crevassed shear margin. This project aims at understanding the complex glacier flow and the processes occuring at the shear margin and the calving front of JI. Such processes are often neclected in numerical models inducing uncertainties in projections of the ice sheet evolution. Drone photogrammetrical surveys were conducted in July 2022 at JI within the framework of the COEBELI project along other field measurements including in-situ GPS, GPRI, seismometers and time-lapse imagery. Despite challenging weather conditions and constraints due to flying restrictions, we acquired more than 10 repeated long-range flight surveys over the calving front of JI as well as along and perpendicular to the shear margins during about two weeks. As a result, we produced a large imagery data set, which was processed to infer high-resolution orthoimages and digital elevation models (DEM). Comparing the different products enables us to estimate changes in surface topography and ice dynamics. With this we can capture processes such as hydrological or tidal effects on the horizontal and vertical ice dynamics, speed-up events or the reaction of the glacier to large calving events. Several such large calving events occurred during the observation period enabling us to investigate the interaction between frontal processes and the ice flow dynamics of the ice stream. Having several ice stream profiles with increasing distance to the calving front allows us to further investigate how far upstream frontal processes can influence ice stream dynamics.

The Greenland Climate Network v.2 - a new era of monitoring the Greenland ice sheet

Andreas Ahlstrøm[1], Jason Box[1], Nanna Karlsson[1], William Colgan[1], Robert Fausto[1], Signe Andersen[1], Baptiste Vandecrux[1], Anja Rutishauser[1], Penny How[1], Ken Mankoff[1], Jakob Jakobsen[1], Chris Shields[1], Allan Pedersen[1], Michele Citterio[1], Alexandra Messerli[2], Anne Solgaard[1], Signe Larsen[1], Niels Korsgaard[1], Kristian Kjeldsen[1], Derek Houtz[3]

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The Greenland Ice Sheet plays an important role in the global climate system by influencing the global radiation budget and the circulation of the atmosphere and ocean, with a contribution of 16 mm to global sea level rise in the last 50 years and accelerating. While satellites currently enable deriving total ice mass changes, ice movement and ice sheet elevation change and regional climate models provide constraint for the key mass fluxes of snow accumulation and meltwater runoff, only in-situ observations can reliably reveal if these remote assessments are accurate. Automatic weather stations (AWS) deliver ground-truth near real-time data for the study of local surface mass balance processes, for the evaluation of satellite-derived products and regional climate models and for assimilation within weather forecast models. The Greenland Climate Network, currently consisting of 16 AWS on the Greenland ice sheet, primarily established in the period 1995 to 1999, with the Swiss Camp station beginning June 1990, through the initiative of the late Prof. Konrad Steffen. Prof. Steffen led the effort gaining funding from NASA Polar Program, the US National Science Foundation and the Swiss Federal Institute for Forest, Snow and Landscape until 2020, at which point the Geological Survey of Denmark and Greenland (GEUS) was invited to continue the operation. With GEUS, partnering with Asiaq Greenland Survey, GC-Net will become part of a Greenland-wide network of 40 AWS on Greenland ice, consisting of 16 AWS situated in the accumulation area and 24 in the ablation area, with 34 AWS placed on the ice sheet and 6 on local glaciers and ice caps. Here, we present the development initiated to carry GC-Net into the future, describing changes in instrumentation, open data processing and availability policies under the FAIR principles, field procedures as well as novel activities and initiatives reaching beyond AWS maintenance.

Multidecadal reconstruction of the surface mass balance of an Arctic glacier using reanalysis data

Anna Rohrböck[1], Bernhard Hynek[1], Leopold Haimberger[2], Wolfgang Schöner[3]

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[2] Universität Wien, Austria
[3] Universität Graz, Austria

The mass balance of Freya glacier in Northeast Greenland is monitored since 2007. Our goal is to extend the understanding of the mass balance of Freya glacier into the past, by using reanalysis data to reconstruct the surface mass balance. The aim of this study is to use statistical downscaling to approximate the glacier surface conditions from reanalsysis data and output of regional climate models. The rate of mass loss is determined to evaluate if effects of climate change have an impact in recent years. To examine the data for spatial variability, data from the climate station in Zackenberg is compared with data from the automatic weather station (AWS) on Freya glacier. The spatial downscaling is done with the ERA5-Land hourly data from 1950 to present and the Arctic regional reanalysis from 1991 to present. The former enables to reconstruct the surface mass balance further into the past, the latter, however, provides a higher spatial resolution.

Dynamics throughout a complete surge of Iceberg Glacier on western Axel Heiberg Island, Canadian High Arctic

Benoît Lauzon[1], Luke Copland[1], Wesley Van Wychen[2], William Kochtitzky[1,3], Robert McNabb[4], Dorthe Dahl-Jensen[5,6]

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[2] University of Waterloo, Canada
[3] University of New England, USA
[4] Ulster University, UK
[5] University of Manitoba, Canada
[6] University of Copenhagen, Denmark

This study provides the first comprehensive reconstruction of the dynamics of Iceberg Glacier, located on western Axel Heiberg Island, and reveals detailed observations of a complete surge for the first time in the Canadian Arctic. Historical aerial photographs, declassified intelligence satellite photographs, optical satellite imagery, and synthetic aperture radar data were used to quantify changes in terminus position, ice velocity, and glacier thickness since the 1950s. A surge initiated at the terminus in 1981 and terminated in 2003, suggesting an active phase duration of 22 years. High surface velocities, peaking at 2300 m a^{-1} at the terminus in 1991, were accompanied by a terminus advance of >7 km from 1981 to 1997 and a large transfer of mass down-glacier, causing significant median surface elevation changes reaching $>3 \pm 1$ m a^{-1} across the entire trunk width. We suggest that the retreat from a pinning point, flotation of the terminus, and the removal of sea-ice from the ice front likely contributed to surge initiation.The ensuing quiescent period has seen a continual decrease in flow rates to an average centreline velocity of 11.5 m a^{-1} in 2020–2021, a gradual steepening of the glacier surface, and a >2.5 km terminus retreat.

15 years Mass Balance Measurements at Freya Glacier, NE-Greenland

Bernhard Hynek[1], Daniel Binder[2], Gernot Weyss[1], Jakob Abermann[3], Wolfgang Schöner[3], Michele Citterio[4], Signe H. Larsen[4]

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[2] University Potsdam, Germany
[3] University of Graz, Austria
[4] GEUS, Denmark

We present main results of 15 yeas of glaciological monitoring at Freya Glacier in Northeast Greenland next to Zackenberg Research Station. The monitoring started in 2007 with direct seasonal observations, and encludes now an automatic weather station and two automatic cameras. Elevation changes and geodetic mass balance between 2013 and 2021 can be determined from two high resolution DEMs using a structure from motion approach, and bedrock topography is deduced from a GPR survey in 2008.

Crustal Uplift: a regional response to contemporary ice mass loss

Bradley Danielson[1], David Burgess[2], Thomas James[2], Maximilian Lauch[3], Michael Craymer[4]

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[4] Canadian Geodetic Survey, Canada

Fluctuations in mass of the Earths glaciers, ice caps and ice sheets can have significant, real-time changes in vertical land motion, which in turn can affect relative sea-level rise, and changes to the Earths geoid, ie. model of global mean sea level. Canada holds a large concentration of ice mass, yet the impacts of glacier mass loss on vertical land motion of Canada's land mass are currently unknown. The Geological Survey of Canada's National Glaciology Project is currently in the process of establishing a network of GNSS stations on bedrock locations adjacent to monitored ice caps and glaciers in Canada, in order to quantify rates of vertical land motion in response to ongoing increases in mass loss from Canada's glaciers. These measurements are required for regional assessments of glacier mass change, generating robust projections of relative sea-level rise, and constraing Canada's near real-time geoid model. This poster will outline the projects goals, current status, and preliminary observations.

Resilience of the Greenland ice sheet firn layer under future climate warming

Brice Noël[1], Jan T. M. Lenaerts[2], William Lipscomb[3], Katherine Thayer-Calder[3], Michiel van den Broeke[4]

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Firn, the compressed snow layer covering 90% of the Greenland ice sheet (GrIS), currently retains about half of rain and meltwater through refreezing, hence mitigating mass loss from surface runoff. The loss of firn could mark a tipping point for sustained GrIS mass loss since decades to centuries of cold summers would be required to rebuild a healthy firn buffer. Such threshold has not been passed for the GrIS, at least since the beginning of the satellite era.

In contrast, Greenland peripheral ice caps, detached from the main ice sheet, and other neighbouring Arctic glaciers have progressively lost their firn buffer since the mid-1990s. First, we identify the drivers of reduced firn refreezing capacity for these glaciers and investigate the impact on contemporary mass loss. Next, we explore the resilience of GrIS firn in a future warming climate.

To that end, we use climate simulations under multiple emission scenarios to project the long-term GrIS firn layer evolution in the period 1850-2300. We predict that GrIS firn refreezing stabilises under low warming scenarios, while it peaks and permanently declines under high-end warming trajectories in the early 22nd century. Finally, we quantify the warming required for the GrIS to cross this threshold and estimate the resulting ice sheet contribution to global sea level rise.

Little Kluane Glacier, Yukon: a tributary-trunk surge

Brittany Main[1], Luke Copland[1], Will Kochtitzky[2], Sergey Samsonov[3], Gwenn Flowers[4], Christine Dow[5]

[1] University of Ottawa, Canada
[2] University of New England, USA
[3] Canadian Centre for Mapping and Earth Observations, Canada
[4] Simon Fraser University, Canada
[5] University of Waterloo, Canada

Little Kluane Glacier (unofficial name), a previous tributary of Kluane Glacier, Yukon, underwent a dramatic surge from 2015-18. No previous reports of surges from this glacier are available, so the characteristics of the quiescent phase and recent active phase were reconstructed using a combination of historical air photos, remote sensing and field observations since the 1940s. Only a single full surge was identified in this period, although it appears that a partial surge occurred between 1963 and 1972.

Mapping of looped moraines from 1951 to present suggests that at least 6 surges have initiated from the northern tributary in the historical past. Terminus positions were mapped using a combination of historical aerial imagery and optical satellite imagery (Landsat series, Sentinel-2, Planet), which show a long-term retreat from 1949-2017, followed by rapid advance of over 2 km in 2018. Velocities of up to 5000 m yr-1 during the surge were obtained from speckle tracking of synthetic aperture radar images, and long-term annual average velocities were obtained from the ITS_LIVE dataset. Differencing of repeat Digital Elevation Models (DEMs) created from stereo satellite imagery demonstrate that the most recent surge initiated from near the top of the accumulation area in the northern tributary beginning in 2015, which then triggered a surge of the main trunk from 2017-18. During the surge the surface lowered by 100-150 m in the northern tributary, along with a corresponding thickening in the receiving zone. This study provides an example of a surge-type glacier that is highly influenced by valley geometry, as well as insight into how a tributary surge can instigate fast flow in the main trunk.

Recent patterns of velocity and elevation change, and their associated drivers, Hubbard Glacier, Alaska

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Hubbard Glacier is a large, Alaskan tidewater terminating outlet measuring 123 km in length, making it both the biggest calving glacier inside North America and the biggest non-polar tidewater glacier globally. Previous research has found that Hubbard Glacier experiences a unique seasonal cycle in glacier flow, with distinct slowdowns observed in the late summer and variations in flow speeds of up to 6 m d^{-1} through the year. To this date however, the quantification of this seasonality has been sparsely studied largely due to a lack of available datasets to enable its characterization. But, with the recent launch of a number of openly available remote sensing datasets, this study investigates the seasonality of Hubbard Glacier in unprecedented detail. Specifically, using surface velocities derived from SAR (Sentinel-1, TerraSAR-X, ERS-1/ERS-2) and optical imagery (Landsat, Sentinel-2), Hubbard Glacier's flow speeds are detailed at the highest temporal resolution possible to allow for an in-depth exploration of its seasonality. This work aims to densify Hubbard Glacier's seasonality record and extend velocity observations to present day. The velocity trends are compared to temperature reanalysis data to determine links between climate and flow speeds, which are used to hypothesize how Hubbard Glacier's velocity may evolve in the future with a warming climate. Elevation change of Hubbard Glacier is also quantified over the 2000-2020 period (in five-year epochs). This allows us to determine if thickening or thinning of the glacier has occurred and how glacier dynamics may be responsible for the observed geometry changes. This research is a major update of our knowledge of how Hubbard Glacier is behaving dynamically and of critical importance for understand how climate change may impact large tidewater glaciers in Alaska and elsewhere.

Evolving Ice Fraction in the Shallow Firn Layer of Devon Ice Cap, Nunavut between 2011 to 2022

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The firn layer of glaciers and ice caps is important for absorbing and storing melt water through infiltration and refreezing within the porous material. As meltwater refreezes and creates larger ice layers within the firn it can inhibit the future abilitity of the firn layer to

store melt water. Monitoring the evolution of ice fractions within the firn layer over time gives important insights into the intensity and severity of melt, melt water storage and impacts of a warmer climate. The objective of this project is to evaluate how the firn layer on Devon Ice Cap has responded in the past two decades to a more variable climate, which has consisted of some of the warmest periods on record in the Canadian Arctic Archipelago (CAA). Results will be presented from four field campaigns on Devon Ice Cap, where shallow firn cores were extracted along two transects in spring 2012, 2018, 2021 and 2022. Between 2012 and 2022, the ice fraction within the first 200 cm of the firn layer was observed to decrease by 40% at the lowest elevation site (1400 m a.s.l) and by 9% at the highest elevation site (1800 m a.s.l). Across all sites, ice content had decreased, and the content of icy and fine-grain firn has increased. The results of this study show the variability of climate change in the CAA and specifically how surface glacier changes in a warming climate are responding in a non-linear manner.

Changes in the extent and velocity of the Hornbreen - Hambergbreen system (S Spitsbergen)

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The ongoing warming in the Arctic contributes to increased ablation of glaciers, their retreat, and changes in dynamics. Hornbreen and Hambergbreen are the two tidewater glaciers that close the Hornsund fiord (southern Svalbard). Their progressive recession may open the strait between the Torell Land and Sørkapp Land, impacting the regional environment. This study aimed to determine the long-term and seasonal velocities and positions of glaciers' termini based on remote sensing data and their relations with climatic and oceanographic factors during the period 1985 – 2021. Velocities were derived from 129 satellite scenes from different sensors (Landsat 5, 7, 8, ASTER, and Sentinel 2) with a feature tracking method (Glacier Image Velocimetry software). This method splits successive images into chips and compares them by searching for the same surface features (e.g. crevasses), then calculates velocity by dividing displacement with time between the acquisition of scenes. Glacier Termini Tracking plug was used to calculate the fluctuation of the glacier extent with a 2-dimension method (non-linear). Climatic and oceanographic data were retrieved from the Polish Polar Station (air temperature, precipitation, positive degree days) and the European Space Agency (sea surface temperature) databases. The results show an increased rate of the average annual velocity of 2.85 m/year for the Hornbreen and 0.8 m/year for the Hambergbreen. Differences in the annual velocities are manifested in the time delay of the maximum speed on the Hambergbreen compared to the Hornbreen. The statistically significant correlations between the rate of changes of the front positions, the sea surface temperature, and the seasonal sum of the positive degree days were also proven. According to the studies, the opening of the Hornsund strait is expected in 2053.

Geodetic mass balance of a small glacier in the Canadian High Arctic determined from historical aerial photography

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Despite rapid losses of glacier ice cover in the Canadian Arctic, there are few detailed studies concerning the geodetic mass balance of small glaciers in the region over multi-decadal timescales. In this study, we assess the long-term changes in ice extent and determine the geodetic mass balance of Bowman Glacier, a small remnant ice mass in Tanquary Fiord, northern Ellesmere Island. Using historical and recent aerial photography and structure from motion (SfM) photogrammetry coupled with multiview stereo (MVS) techniques, we reconstruct glacier surface topography in 1959 and 2018, and calculate ice surface elevation change over six decades. This is combined with optical satellite imagery to reconstruct the evolution in extent of the ice cap over the past 60 years, and ground penetrating radar measurements of ice thickness to estimate the remaining ice volume.

Between 1959 and 2020, Bowman Glacier lost 78% of its original extent (reducing from 2.75 km2 to 0.61 km2), while average annual area loss rates have nearly tripled in the past two decades. Over the 1959–2018 period, glacier-wide ice thickness change averaged -22.7 $\pm$ 4.7 m, corresponding to a mean specific annual mass balance of -347.0 $\pm$ 71.4 mm w.e. a^{-1}. Bowman Glacier currently consists of several stagnating ice masses. Projecting the average rates of area and volume change into the future indicates the glacier will likely entirely disappear between 2030 and 2060. This study demonstrates the use of SfM-MVS processing techniques to generate elevation products from 1950s-60s historical photographs in the Canadian Arctic, which creates the potential to extend regional observations of ice elevation and glacier volume change prior to the satellite record.

Assessing the 2021-2022 surge behaviour of Lowell Glacier

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The St. Elias Mountains, located between Alaska, British Columbia and the Yukon contains a significant number of surge-type glaciers, of which Lowell Glacier is one of the largest. There is evidence to suggest that Lowell Glacier has repeatedly surged over time, with raised beaches and mega bed landforms indicating that previous surges during the neoglacial blocked the flow of Alsek River and resulted in catastrophic downstream floods. In this study we report on the ongoing surge of Lowell Glacier, which appears to have started in 2021. Using a combination of satellite images and high-resolution air photos the surge initiation can be identified near the terminus, while further observation indicates that the surge propagated upglacier over time. Glacier velocity mapping from the ITS_LIVE dataset, pairs of Radarsat Constellation Mission images, and in situ GNSS receivers indicate that velocities reached >10 m day^{-1} in the lower ablation area and >4 m day^{-1} in the upper ablation area in summer 2022. Changes in glacier extent recorded

by satellite imagery indicate that the terminus advanced by approximately 1.36 km between summer 2021 and summer 2022, reaching a peak position in July 2022. Historical air photos and satellite images indicate that the glacier previously surged around 1948-50, 1968-70, 1983-84, 1997-98 and 2009-10. The current surge follows the pattern of a general reduction in the period between each subsequent surge since 1948, as well as a reduction in the maximum terminus extent reached during each surge. These results provide new insights into the surge dynamics of Lowell Glacier, while improving knowledge of regional surge history.

Hydrothermal structure of Elfenbeinbreen and Sveigbreen, Sabine Land, Svalbard, and its changes for Sveigbreen during 2014-2022

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The polythermal glaciers of Svalbard are expected to undergo changes in its hydrothermal structure as a consequence of current climate change. Ground-penetrating radar (GPR) has been shown to be an effective tool to infer the hydrothermal structure of polythermal glaciers. Despite extensive radar campaigns in Svalbard, the eastern coast of central Spitsbergen has been devoid of GPR surveys until very recently. In spring 2014 we carried out extensive radar measurements on Elfenbeinbreen and Sveigbreen, in Sabine Land, close to the eastern coast of central Spitsbergen. The GPR profiling, using a radar with central frequency of 25MHz, covered a total length of 105 km on Elfenbeinbreen, and 36 km on Sveigbreen. Average ice thickness were 85 $\pm$ 9 m (Elfenbeinbreen) and 74 $\pm$ 7 m (Sveigbreen), while maximum thickness were 285 $\pm$ 7 and 212 $\pm$ 5 m, respectively. The relative thickness of the cold ice layer was larger than that usually found by the authors for glaciers of similar size in central and western Nordenskiöld Land and in Wedel Jarlsberg Land. The thickness of the upper cold-ice layer of Elfenbeinbreen varies between roughly 80 and 250 m, though generally is about 120-150 m thick. By contrast, the thickness of the cold layer of Sveigbreen is much thinner, typically 60-80 m. In Spring 2022 we repeated nearly the same GPR profiles for Sveigbreen, using the same radar equipment. This allowed us to compare both the total ice thickness changes and the changes in thickness of the cold and temperate ice layers. Our preliminary results suggest a decrease in the total ice thickness of the same order as the decrease in the thickness of the temperate ice layer (both in the order of 2-3 m a^{-1}), with the cold ice layer showing little change in thickness. This contrasts with the results obtained by the authors and colleagues in western Nordenskiöld Land glaciers such as Fridtjovbreen and Erdmanbreen, where the cold ice layer thickness increased, at rates of ca. 1.6 m a^{-1} for the upper western basin of the Fridtjovbreen, while its temperate ice layer experienced thinning rates similar to those found in Sveigbreen for a similar period.

Reconstructing the past two surges of Fisher Glacier, Yukon

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Fisher Glacier is a large surge-type glacier located in the southeastern portion of the St Elias Icefield in Kluane National Park, Yukon. While several previous studies have focused on the surge behavior of other glaciers in the vicinity, Fisher's surge history and behavior has yet to be investigated in detail. An analysis of ice surface velocities, surface elevation changes, and changes in terminus extent, derived from satellite imagery and historical air photos, have allowed for the identification of two surges over the past 70 years. The oldest documented surge initiated in the late 1960s or early 1970s, which was marked by a significant terminus advance and an increase in terminus area, as well as the appearance of large crevasses extending upglacier into the upper ablation area. This period of active surging was followed by a quiescent phase of >40 years, significantly longer than the 10-20 year quiescent phase typical of other glaciers in this area, such as Lowell and Donjek. The glacier entered a new active phase between early 2015 and late 2016. This second surge was characterized by a terminus advance of nearly 2 km in some water-terminating areas, an increase in velocities in the lower ablation zone from approximately 100 m yr^{-1} during the quiescent phase to about 1700 m yr^{-1} in late 2015, when the surge seems to have peaked, and a rapid displacement of surface features (e.g., supraglacial lakes and looped moraines) in the ablation zone. In late 2016, ice surface velocities dropped from 1400 m yr^{-1} to 50 m yr^{-1} in a span of 2-3 months. Since then, the terminus has remained largely unchanged, although the crevasses that formed during the surge have largely disappeared as the ice surface has slowed during the present quiescent phase.

North Atlantic cooling and the impact on Icelandic glacier mass balance

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Greenland slush limits; comparing remote sensing and RCM simulations

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Streams and lakes develop each summer over the marginal regions of the Greenland ice sheet. These hydrological systems reach well into the accumulation area and indicate that surface runoff of meltwater is an important component of the mass balance of the Greenland ice sheet. Here we map daily slush limits, a proxy for the extent of surface runoff, using daily MODIS data (500 m spatial resolution). Our automated algorithm relies, among other parameters, on spatial variability of surface albedo. The algorithm is applied to all of Greenland for the years 2000 to 2021. Albeit MODIS' spatial resolution is too coarse to resolve streams or lakes, the results highly agree to surface runoff mapping from higher resolution satellite imagery. The data document significant increasing trends in slush limits until the year 2012, but not thereafter. The slush limit typically rises quickly early in the melt season, but upward migration halts before melting ceases. We utilize the high spatial and temporal resolution of the data as a means of validation of state-of-the-art regional climate models (RCMs). The comparison of MODIS daily slush limits and RCM runoff limits indicates that the RCMs overestimate runoff area. This observation is also confirmed by auxiliary satellite and field data. Validating RCMs using slush limit elevations has the potential to further improve regional climate models and our estimates of Greenland's contribution to sea level rise. However, we also show that the comparison is challenged by the very different characteristics of “modelled” and “real-world” runoff.

Reconnaissance of Alfred Wegener's West Greenland Expedition: bridging a century of climate change work: 1929 to 2022

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The cryosphere in Greenland is currently undergoing strong changes. While remote sensing improves our understanding of spatial and temporal changes across scales for recent decades, particularly our knowledge during the pre-satellite era is scarce and thus valuable in a climate change perspective. At Graz University, the last work-place of Alfred Wegener, we have access to the extensive expedition results from their epic 1929-1931 expedition to Greenland. This coincides with a particularly warm phase particularly in the Arctic. Local conditions at the Qaamarujup glacier have changed dramatically since then with a length reduction of more than 2 km, a rise in terminus position and thickness reduction by several hundreds of meters. During a reconnaissance expedition in summer 2022 we installed autonomous weather and ablation stations at the same locations as Wegener did in the 1930s, based on their excellent documentation. In order to connect the ablation rates at the changed surface conditions over the course of a century, we performed innovative UAV-based atmospheric measurements. In addition to the in-situ work, we challenge reanalysis products with high-quality ground-truthing from the pre-satellite era. Applying machine learning algorithms, we assess the potential for using historical meteorological and glaciological data together with reanalysis products and contemporary measurements in order to determine long-term geometrical feedback processes.

Vertical ice - morphology of the terrestrial ice margin in Greenland

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The terrestrial ice margin of the Greenland ice sheet and its ice caps vastly exceeds the relative fraction of the total ice margin made up by ocean terminating glaciers. While of course of relatively minor importance in the total ice flux it provides meltwater to terrestrial ecosystems along the ice sheet. It also provides a unique opportunity to study the history of the ice sheet through the visible layers emerging and its dynamics could potentially tell us something about the sensitivity of the ice sheet to regional climatic change. Exploiting the high resolution ArcticDEM and relying on insights from field studies at the northernmost ice margin, we present an analysis of the geomorphology of the terrestrial ice margin. Comparing the dataset to ice velocity and mass balance products allows first answers to the question why the margin oscillates between ramp like structures of very shallow angles and steep vertical sections. We hypothesize that the margin morphology is primarily linked to ice dynamics but that the perseverance of vertical sections is also linked to the peculiar energy fluxes at play in this setting. The dataset will allow us to upscale insights from field investigations of ice dynamics and energy fluxes to the regional scale.

Trends in Greenland ice sheet observational records: implications for changing ice volume

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This work examines trends in Greenland ice sheet air temperature, snow accumulation and snowline elevation. Air temperature records are from Swiss Camp and other GC-Net sites, extended as far back in time as 1987 in the case of Summit using U Wisconsin data. The scientific question is what physical processes are behind observed trends. Snow accumulation data are from snow/firn cores, supplemented by recent snow profiles obtained by GEUS. The scientific question is what sites contain statistically significant accumulation trends and what records correlate with regional air temperatures. Ice sheet snowline is retrieved from MODIS and Sentinel-3. The snowline variations are mapped regionally and examined for trends in context of changing equilibrium line altitude and the implied ice area and volume changes to reach dynamic equilibrium with recent climate.

Glacier recession vs. water drainage at a forefield (Werenskioldbreen, Svalbard)

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The consequence of climate change in the Arctic are observing reducing volume and retreat of the glaciers. This results in the expansion of the forefield, thereby increasing its role in the hydrology of glacierised catchment for water cycle. Due to permafrost loss and deeper water infiltration possibility, the forefield sub-surface partis also becoming more important for the entire hydrology balance in the catchment area. Therefore, we aimed to answer the following question: To what extent does the enlarging glacier's forefield affect the catchment's proglacial drainage system and water balance, groundwater flow, and storage capacities? We conducted hydrological research at the Werenkioldbreen catchment in Svalbard. We used the modelling approach to enable both quantitative and spatial analyses, with particular attention to the glacier's forefield role in drainage and water storage, by studying two components: (1) the surface part of the forefield: a hydrological balance and surface drainage, (2) the sub-surface part of the forefield: a hydrogeological balance, groundwater drainage, and storage. We implement a combination of two modelling tools: hydrological model (SWAT) and-hydrogeological model (FEFLOW) enable to obtain a complete overview of the water cycle in the Werenskioldbren glacier's forefield The models are powered by glacier ablation waters data that based on the glaciological ablation model (temperature-index model) and liquid precipitation amount. The modelling studies for hydrological and hydrogeological processes allowed us to synthesise ongoing research and long-term monitoring in the Werenskioldbreen catchment.

Present changes of Jostedalsbreen, Norway's largest ice cap

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The objective of the JOSTICE project is to assess the present and future changes in mass balance, runoff, ice volume and local climate of Jostedalsbreen, and determine the societal impact of these changes on hydropower production, tourism and agriculture. The Jostedalsbreen ice cap is mainland Norway's and Europe's largest ice cap accounting for 20 % (458 km^2 in 2019) of the total glacier area of mainland Norway. It has been divided into more than 80 units and has several distinct glacier outlets. Here we present changes of Jostedalsbreen based on repeated map surveys and glacier inventories from 1966 and 2020. We also present recent ice thickness surveys and glaciological measurements revealing the present state of the ice cap.

Terminus area changes of all Northern Hemisphere marine-terminating glaciers since 2000

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To map and better understand the recent changes of marine-terminating glaciers, we used satellite imagery to manually digitize the terminus position of all glaciers that reached the ocean in the Northern Hemisphere in 2000, 2010, and 2020. A total of 1704 glaciers terminated in the ocean in 2000, with 123 of these ceasing to reach the ocean by 2020. Overall, 85% of glaciers retreated and only 2.5% advanced, while the remaining glacier termini didn't change outside of uncertainty limits. Most of the area losses occurred in Greenland, which experienced 62% of total hemispheric area loss. To understand what causes variations in the rate of retreat we examined a range of environmental and other variables. There was no significant correlation between retreat rates and changes in air temperature, ocean temperature, or sea ice over any time period. Instead, we found that most retreat occurred on glacier termini with ice shelves, reverse bed slopes, particularly wide calving margins, or are surge-type. Of the few glaciers that advanced, most of them are surge type. In all, northern hemisphere glaciers lost 7527.3 $\pm$ 30.7 km^2 (389.7 $\pm$ 1.6 km^2 a^{-1}) from 2000 to 2020, or an average of just over 1 km^2 per day.

Factors controlling terminus position of tidewater glaciers in Hornsund fjord (Svalbard)

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In this study, we investigate seasonal and decadal changes in the terminus positions of eight tidewater glaciers in Hornsund, the southernmost fjord of the Svalbard Archipelago. To observe termini fluctuations we applied multispectral and radar satellite data from 1992 to 2020. We found that the long-term retreat of glaciers was interrupted by small advances or surges. Further, seasonal changes in termini position were compared to basic meteorological data (air temperature, positive degree day index, and liquid precipitation), sea surface temperature, the mean temperature in the bays at the glacier front, fast sea ice coverage, and bathymetry at the glacier front. Overall, we found regional synchrony in glaciers' fluctuations and agreement between terminus advance/retreat and changes in air and sea temperature. Seasonal terminus position fluctuations for the majority of glaciers are sensitive to glacial runoff and related discharge-driven submarine melt and calving. The fastest retreat occurred in the warm years, with relatively high air and sea temperatures. In colder years glaciers slowed their retreat or advanced periodically. Additionally, we present five-year series (2016-2020) of detailed seasonal and annual variations in front positions, ice flux, and frontal ablation, to evaluate processes responsible for changes in termini positions. The contribution of annual ice flux to retreat rate varied from year to year, but showed similarities among the glaciers. Results indicate that changing contribution of individual components affecting the front position (glacier velocity v. frontal ablation) is mainly controlled by air and sea temperature, while water depth at the front plays a secondary role. We also found that the duration of the retreat and advance periods are strongly correlated with the sea temperature in the fjord. Results indicate that the expected increase in air temperature and water temperature of the West Spitsbergen Current will have further implications for glacier velocity and frontal ablation.

Hypsometric control on basin sensitivity under rising equilibrium line altitudes in the Northern Canadian Arctic Archipelago

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Glacier melt production and flux to the Arctic Ocean is important to global thermohaline circulation and local ecosystem dynamics. We present hydrologically-corrected glacier outlines from the Randolph Glacier Inventory and hypsometries derived from the 32m ArcticDEM product. Watersheds are derived from the DEM such that all liquid water would eventually flow to the ocean. We group over 2000 watersheds into 12 basins according to ocean basin or channel and surface water circulation pathways. Within each basin, the equilibrium line altitude (ELA) is increased from the current 60-year average to show the distribution of total melt potential across the NCAA. Accumulation area ratio (AAR) and ablation area are treated as proxies for glacier mass budget sensitivity to rising ELAs. Broadly, the degree of ELA change across the region is unknown. We therefore impose different magnitudes of change to simulate the variability of AARs and ablation areas across NCAA basins. We find a latitudinal trend of ELA position relative to glacier bulk area. For southerly glaciers where the ELA is above the glacier bulk area, sensitivity decreases as the ELA rises. For northerly glaciers where the ELA is below the glacier bulk area, the sensitivity first increases with ELA until a 500 – 600 m ELA rise as the ELA surpasses the glacier bulk area elevation. However, under a regional mean ELA rise of only 200 m as measured by ablation area and ∼300 m for the AAR, northerly glaciers' sensitivity surpasses that of southerly glaciers. Both values are near the standard deviation of a representative glacier, the White Glacier, ELA for the past 60 years (243 m).

Greenland ice sheet surface water vapour fluxes from automatic weather station records

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The mass balance of the Greenland ice sheet is influenced by surface water vapour fluxes. Sublimation and evaporation remove mass from the surface, while condensation and frost deposition adds mass. The energy spent on sublimation and evaporation cools the surface and thus reduces melting, whereas frost deposition and condensation will have the opposite effect. Box and Steffen (2001) estimated the net surface water vapour flux of the ice sheet using data from the Greenland Climate Network (GC-Net) automatic weather station (AWS) from 1995 to 2000. In the last 22 years, the Arctic has been warming at an increasing rate. This project aims to extend the work of Box and Steffen (2001) to the GC-Net AWS data up to 2022 and to investigate how the water vapour fluxes are influenced by arctic warming. The determination of instrument height is crucial for estimating water vapour fluxes but is complicated by the accumulation of new snow at the surface and by the AWS mast being raised periodically to keep the sensors from being buried. Here, we use field notes, photogrammetry and surface height change measured by acoustic sounders to reconstruct the instrument heights. For the time periods with two

working levels of temperature, humidity, and wind speed data, we will estimate the net water vapour fluxes and compare with regional climate models.

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The control of short-term ice mélange weakening episodes on calving activity at major Greenland outlet glaciers

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The dense mixture of iceberg of various sizes and sea ice observed in many of Greenland's fjords, called ice mélange (sikussak in Greenlandic), has been shown to have a significant impact on the stability of several Greenland tidewater glaciers mainly through the seasonal support it provides to the glacier terminus in winter. However, a clear understanding of shorter-term ice mélange dynamics is still lacking, mainly due to the high complexity and variability of the processes at play at the ice-ocean boundary. In this study, we use a combination of Sentinel-1 radar and Sentinel-2 optical satellite imagery to investigate in details intraseasonal ice mélange dynamics and its link to calving activity at three major outlet glaciers: Kangerdlugssuaq Glacier, Helheim Glacier and Sermeq Kujalleq in Kangia (Jakobshavn Isbrae). In those fjords, we identified recurrent ice mélange weakening (IMW) episodes consisting in the up-fjord propagation of a discontinuity between jam-packed and weaker ice mélange towards the glacier terminus. At a late stage, i.e. when the IMW front is in the vicinity of the glacier terminus, these episodes were often correlated with the occurrence of large-scale calving events. The IMW process is particularly well visible at the front of Kangerdlugssuaq glacier and presents a cyclic behavior, such that we further analyzed IMW dynamics during the June-November period from 2018 to 2021 at this location. Throughout this period, we detected 30 IMW episodes with a recurrence time of 24 days, propagating over a median distance of 5.9 km and for 17 days, resulting in a median propagation speed of 400 m/d. We found that 87% of the IMW episodes occurred prior to a calving event visible in spaceborne observations and that 75% of all detected calving events were preceded by an IMW episode. These results therefore present the IMW process as a clear control on the calving activity of Kangerdlugssuaq glacier. Finally, using a simple numerical model for ice mélange motion, we showed that a slightly biased random motion of ice floes without fluctuating external forcing can reproduce IMW events and its cyclic influence, and explain observed propagation speeds. These results further support observations in characterizing the IMW process as self-sustained through the existence of an IMW-calving feedback. This study therefore highlights the importance of short-term ice mélange dynamics in the longer-term evolution of Greenland outlet glaciers.

Some thoughts and observations on basal motion beneath the (still) polythermal McCall Glacier, Alaska

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Over the past 65 years, each research team on McCall Glacier has added to our collective knowledge of its polythermal nature. Ice in the accumulation area is temperate throughout its depth due latent heat released by refreezing of meltwater in firn and a large portion of the ablation area is also temperate at its base due to both advection and geothermal heat flux when the glacier was much larger. Our measurements over the past 20 years show that every location of this glacier experiences a summer speedup and modeling shows that significant basal motion must also be occurring in winter within the temperate zone of the ablation area. The prediction made in 2010 by our thermo-mechanical flow modeling was that as the glacier thins and cools, the basal ice can no longer remain temperate within the sliding area, responding on a time-scale of 100 years after thinning starts in earnest. The ELA began retreating in the late 1800s and this rate began increasing steadily from the 1950s onwards, now often above the top of the glacier and thus eliminating the porous firn area which kept the upper glacier warm. It seems clear that thinning has caused slight decreases in speed throughout the glacier over the past 20 years but that by far the biggest decreases in speed are occurring in the area we believe to be sliding in winter. This decreasing trend started somewhat abruptly 2008 and speeds here have now dropped more than a third – could we have witnessed the beginning of the end of winter sliding on McCall Glacier? Part of our current research is aimed at determining when global warming will turn this polythermal glacier into a cold one and how this will affect its rate of demise under various climate scenarios.

Impact and evaluation of improved ice surface roughness formulation in RACMO 2.3p2 on Greenland surface melt modelling

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Over the Greenland ice sheet, the sensible heat flux (SHF) is a major source of energy for surface melt, especially in the low-lying ablation area where both large temperature gradients, persistent katabatic winds and variable ice surface roughness coexist. Currently, regionals climate models such as RACMO2.3p2 use a constant value for ice and snow surface roughness. Since the surface roughness is highly variable in space and time, this assumption results in a poorly constrained uncertainty for modelled surface melt.

It this study we implement a variable aerodynamic roughness length (z0m) parameterization for bare ice in RACMO 2.3p2, and we perform different sensitivity experiments that vary the z0m model settings. We also test different formulations for the roughness length for heat (z0h) based on in situ eddy covariance observations. We compare the results to both IMAU and PROMICE weather station observations and find that the SHF is systematically underestimated by on average 15 Wm^{-2} (44%), during summer below 1000m elevation. This partly explains the average underestimation of modelled surface melt of 24 Wm^{-2} (22%). While using a more realistic value for z0m only marginally improves the SHF in RACMO2.3p2, we find that the SHF is highly sensitive to the value of the z0h parameter. We conclude an accurate estimate of modelled SHF, and subsequent surface melt, requires realistic values for both the z0m and z0h parameters, especially to capture extreme Greenland melt events.

Modelling lateral meltwater flow atop the Greenland Ice Sheet's near-surface ice slabs

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The Greenland ice sheet is losing mass. Thereby, the location of the runoff limit, the highest elevation from which meltwater finds its way off the ice sheet, plays an important role. Above the runoff limit all meltwater refreezes and does not contribute to mass loss. In recent years surface runoff has increasingly occurred from higher elevations, thereby expanding the area of mass loss: between 1985 and 2020, the maximum runoff limit rose by on average 194 metres, expanding the visible runoff area by around 29

The observed rise in the runoff limit might be related to intensive meltwater refreezing within the firn which leads to the formation of thick ice layers, also called ice slabs. Our field experiments, carried out at around 1750 m a.s.l. on the K-Transect, have shown that meltwater generated over ice slabs is generally forced to flow laterally: initially through a near-surface slush matrix and then forming streams and rivers. It remains unclear, however, how much of the meltwater contributes to runoff, and which percentage refreezes and contributes to ice slab formation or expansion.

Here we present a conceptual quasi 2D-model of runoff, that simulates lateral meltwater flow on top of an ice slab using firn hydrological properties measured on the southwest Greenland ice sheet. We adapted a gridded linear-reservoir runoff routing model to calculate (i) the distance meltwater can travel within one melt season, and (ii) when meltwater breakthrough at the snow surface (i.e. slush formation) occurs. First results provide insight into the evolution of the water table height over time that matches observations made during our summer field campaign. We are exploring ways to incorporate meltwater refreezing, to better understand ice slab evolution and their impact on the fate of meltwater between vertical percolation, refreezing and lateral runoff.

Crystal fabric orientation of the NEGIS ice stream

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Anisotropic crystal fabrics in ice sheets develop as a consequence of deformation and hence record information of past ice flow. Simultaneously, the fabric affects the present-day bulk mechanical properties of glacier ice because the susceptibility of ice crystals to deformation is highly anisotropic. This is particularly relevant in dynamic areas such as fast-flowing glaciers and ice streams, where the formation of strong fabrics might play a critical role in facilitating ice flow. Anisotropy is ignored in most state-of-the-art ice sheet models, and while its importance has long been recognized, accounting for fabric evolution and its impact on the ice viscosity has only recently become feasible. Both the application of such models to ice streams and their verification through in-situ observations are still rare. Ice cores provide direct and detailed information on the crystal fabric, but the logistical cost, technical challenges, particularly in fast-flowing ice and shear margins, difficulty in reconstructing the absolute orientation of the core and their limitation of being a point measurement make ice cores impractical for a spatially extensive evaluation of the fabric type. Indirect geophysical methods applied from or above the ice surface create the link between the small scale of laboratory experiments and ice–core observations to the large-scale coverage required for ice flow models and the complete understanding of ice stream dynamics. Here, we present a comprehensive analysis of the distribution of the ice fabric in the upstream part of the North-East Greenland Ice Stream (NEGIS). Our results are based on a combination of methods applied to extensive airborne and ground-based radar surveys, ice- and firn-core observations, and numerical ice-flow modelling. They show that in the onset region of NEGIS and around the EGRIP ice core drilling site, the fabric is strongly anisotropic, forming a horizontal girdle perpendicular to the ice flow, while anisotropy reduces quickly over distances of less than five ice thicknesses outside of the ice stream's shear margins. Downstream of the drill site, the fabric develops into a more vertically symmetric and almost isotropic configuration on a time scale of around 2 ka, the first in-situ observation of this kind. Our study shows how ice-core based fabric observations, geophysical surveys and ice-flow modelling complement each other to obtain a full spatial view of the spatially strongly varying fabric.

Changes in Glacial Hydrology in Response to Recent Increases in Surface Melt on Ellesmere Island, Canadian High Arctic

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Glacier mass losses, resulting from enhanced surface melt, have more than doubled since the late 1990s in the Canadian Arctic Archipelago (CAA). However, little is currently known as to whether this had an influence on the size or extent of supraglacial hydrological networks. Some studies have mapped these networks and their connection to ice dynamics in the CAA for single points in time, but no previous research has investigated their temporal evolution or variability. In this study we are therefore assessing temporal and spatial changes of the supraglacial hydrology across the 800 km latitudinal gradient of Ellesmere Island. Various semi-automated methodological frameworks for mapping supraglacial hydrological features are being evaluated, using recent optical satellite imagery of varying spatial resolutions like Planet, Sentinel-2 and Landsat-8. Such methodologies generally rely on the calculation of the normalized difference water index to enhance spectral contrast for linear feature enhancement, and are occasionally accompanied by a digital terrain model to identify potential flow routes. Future work will extend these methodologies to map the surface hydrology of glaciers across Ellesmere Island since the 1980s by making comparison with historical ASTER, SPOT and Landsat satellite imagery, and potentially to the 1950s by making comparison with historical air photos. Preliminary results indicate that there have been significant changes in the number and size of supraglacial streams over the past 40 years, with an acceleration in the rate of change over the last decade. Many perennial streams have become wider as well as more sinuous and incised, with greater relative changes in incision in far northern areas. Well established streams have also extended up glacier as accumulation zones shift to higher elevations, increasing overall drainage density especially when paired with the observed increase in channel frequency across Ellesmere Island.

Mass loss of Qaanaaq Ice Cap in northwestern Greenland from 2012 to 2022

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Since 2012, we have conducted surface mass balance measurements on Qaanaaq Glacier, an outlet glacier of Qaanaaq Ice Cap in northwestern Greenland. Annual surface mass balance was measured by using poles installed at six locations distributed at 243–968 m a.s.l. Mean specific mass balance over the entire ice cap was computed for each year, by assuming that surface mass balance is a function of elevation. Glacier surface elevation was measured along the central flowline by kinematic GPS surveys in July–August 2012, 2019 and 2022. The mean specific mass balance from 2012 to 2022 was 0.20 m w.e. a^{-1} at 968 m a.s.l. and ?1.68 m w.e. a^{-1} at 243 m a.s.l. Significant interannual variations of ∼2 m w.e. a^{-1} were observed at each site. The cumulative mass balance of the ice cap from 2012 to 2021 was -4.02 ± 0.22 m w.e. Mass balance was most negative in 2014/15 (-1.08 ± 0.04 m w.e. a^{-1}), which we attribute to relatively high summer temperature and a small amount of snow accumulation. The glacier surface elevation dropped from 2012 to 2022, with a rate greater in 2019–2022 (-0.89 m a^{-1}) than in the earlier period of 2012–2019 (-0.70 m a^{-1}). The magnitude of the rate increased in the later period particularly in the middle of the ablation zone, whereas the change was smaller in the regions near the equilibrium altitude and near the terminus. Our results imply that glaciers and ice caps in the Qaanaaq region are rapidly losing mass over the last decade at a rate varying from year to year. A warming climate is the most important driver of the mass loss, but changes in snow accumulation play a key role as well.

Frontal ablation modulated by hydropower regulation? A case study from Austdalsbreen, Western Norway

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Austdalsbreen is a lake-terminating outlet glacier of the Jostedalsbreen Ice Cap in Western Norway. Construction of a dam in 1986, has led to water-level variations due to hydropower regulation of Styggevatn reservoir. The Norwegian Water Resources and Energy Directorate (NVE) has been monitoring the mass balance of Austdalsbreen since 1988. This includes measurements of surface mass balance from a network of mass balance stakes, as well as the annual assessment of frontal ablation. Since 1987, the calving front has retreated by about 720 m.

Here we present a 1-year record of time-lapse photography capturing the calving front, the ablation area and the lake four times a day, from September 2021 to September 2022. Simultaneous measurements of surface air temperature and water-level in the reservoir allow us to study the potential role of weather conditions and hydropower regulation in modulating seasonal variations in glacier dynamics and frontal ablation. Recent calving activity was highest in a central section of the calving front, which is reflected in dynamic thinning and a negative geodetic mass balance within this region.

Glacier geometry and mass change at Sirmilik and Auyuittuq National Parks, Nunavut, Arctic Canada, 1960-2020

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The Canadian Arctic Archipelago hosts one-fifth of the global glacierized terrain (excluding the ice sheets). Under the most rapid Arctic warming scenario, this region has become the third-largest contributor to global mean sea-level rise. However, knowledge of spatial variability of glacier response and associated sea-level rise contributions in this region is still relatively uncertain. Although the highest density of long-term (>50 yrs.) records of glacier surface mass balance in the Arctic is from the Canadian Arctic Archipelago, most data is located above a latitude of 74 degrees. Yet, long-term measurements of glaciers' spatial distribution of ice thickness and volume on the Baffin & Bylot Islands are still largely absent. As such, the regional impact of the glacial changes and the associated geohazards, such as meltwater flooding, still experience significant knowledge gaps. In response to these significant research gaps, this PhD project attempts to expand temporal and spatial coverage of glacier monitoring on the Baffin & Bylot Islands by in-situ, photogrammetrical and remote sensing approaches. This comprehensive study of Baffin & Bylot Islands glacier systems offers a better understanding of regional glacier fluctuations to predict the future dynamics of Canada's northern landscapes. It will furthermore support analysis of the spatial and morphological characteristics of particularly sensitive glaciers. Additionally, the threats related to glaciated terrains are usually characterised by the involvement of surface or subsurface ice, which are highly sensitive to climatic changes. To mitigate the glacier-related environmental, socioeconomic and cultural impact under future wetter and warmer Arctic, those findings of ice volume and areal extent change will help to identify the potential natural hazards associated with the glacial environments. Coupled with local Inuit glaciological knowledge, the outcome of a regional detailed hazard assessment will provide valuable information for the local communities, Parks Canada management and the National Park visitors. These project findings will also contribute to new geodetic mass balance estimation for the World Glacier Monitoring Service (WGMS) and promote the establishment of a new benchmark program. PS: Preliminary finding will be presented as this project is still in the initial stage.

A novel large-scale ice thickness inversion method tested on Kronebreen, Svalbard

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Subglacial topography plays a crucial role in determining the future evolution of glaciers. Although recent progress has been made in producing large scale products of ice thickness, substantial uncertainties for individual glaciers still exist. Here, we present a fast thickness inversion approach that is capable of using advanced physics of state-of-the-art ice flow models to produce maps of subglacial topography that are consistent with external forcing and ice dynamics. We harness the vast amount of available observations, such as surface elevation change and ice velocity, to constrain both bed elevation and subglacial friction. This allows a seamless transition from bed recovery to prognostic simulations. Using the example of Kronebreen, a fast-flowing tidewater glacier on Svalbard, and the ice-flow model PISM, we demonstrate that our approach is capable of dealing with complex settings in a time-efficient manner. Ultimately, our method is of interest for prognostic studies where bed topography needs to be constrained first, as well as for applications on a larger scale.

The surge of high-Arctic Chapman Glacier, 1999-2018

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Surge-type glaciers have been identified throughout the Canadian Arctic but due to the remoteness of the region and the limited availability of remote sensing data at high latitudes, few surge behaviours been studied in detail. However, over the last decade, access to higher spatial and temporal resolution satellite data and derived products (i.e. DEMs, displacement maps) has enabled the study of glacier surging at a level of detail that allow a better process-based understanding of the mechanisms that underpin surging in this region. In this study, we present a multi-decadal record (1999-2018) of annual surface flow velocities and quadrennial elevation changes for Chapman Glacier (81°N, 79°W), Umingmak Nuna (Ellesmere Island), Nunavut. We also use historical satellite imagery to investigate the looped surface moraine patterns from 1975 to 2020 in order to place our velocity records within a longer temporal context. Our results indicate that the surge phase of Chapman Glacier is at least 20-years long, with an increase in flow speed from ∼25 to 200 m a^{-1}. The surge is spatially limited to the trunk and main tributary, each of which experience differing periods of fast flow. The main surge front travels downglacier with no detectable frontal advance and maximum thickening/thinning rates are of the order of 10 m a^{-1}. Overall, these results provide more information about the variety of surge-type behaviours that occur in the Canadian Arctic and contribute to a growing body of literature characterizing the spectrum of dynamic flow instabilities in this region and worldwide.

Frontal ablation of Northern Hemisphere glaciers for 2000-2020

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In the Northern Hemisphere, approximately one third of all mountain glaciers and ice caps end in the ocean, but we have yet to quantify the contribution of iceberg calving, or frontal ablation, to the mass loss of these glaciers in a consistent way. In this study we used a suite of satellite, field, and modeled datasets to quantify the frontal ablation of the 1500 marine-terminating glaciers in the Northern Hemisphere, outside of the Greenland Ice Sheet. This amounted to 44.47 $\pm$ 6.23 Gt a^{-1} from 2000 to 2010, and 51.98 $\pm$ 4.62 Gt a^{-1} from 2010 to 2020. We segregated the two terms of frontal ablation, discharge and terminus volume loss, to understand their relative importance to inform how frontal ablation may change in the future. Ice discharge accounted for 78 $\pm$ 13% of frontal ablation from 2000-2020, while the remainder was from terminus volume loss, which is more transient and only comes from terminus retreat. The Russian Arctic accounted for 40% of frontal ablation, more than any other region, with most of it coming from Franz Josef Land. Svalbard and Alaska were the next two regions with the most frontal ablation at 16.82 $\pm$ 2.48 and 10.68 $\pm$ 0.33 Gt a^{-1}, respectively. These numbers are critically important for glacier mass balance estimates and models, as well as predicting the evolution of glaciers in the coming decades. The data for each glacier is freely available through our corresponding publication in Nature Communications.

Supraglacial lake evolution on Tracy and Heilprin Glaciers in northwestern Greenland from 2014 to 2021

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Supraglacial lakes form during the melt season as meltwater collects within topographic depressions on the surface of glaciers and ice sheets. They affect the mass balance of glaciers and ice sheets in two ways: (1) enhance ice surface melt by lowing the surface albedo, (2) accelerate the ice flow by delivering a large amount of meltwater into the subglacial environment during lake-drainage events and reducing basal friction. Therefore, studying the evolution of supraglacial lakes helps us further understand the effect of meltwater on glaciers and ice sheets. With this background, we analyzed satellite images acquired between 2014 and 2021 to investigate the evolution of lakes on two large marine-terminating glaciers in northwestern Greenland. To generate a high spatiotemporal resolution record of the lake area over Heilprin and Tracy Glaciers, we applied a machine learning method on two medium-resolution optical satellite datasets (Sentinel-2 and Landsat 8) within Google Earth Engine. Although the basin areas of the two glaciers are similar (654 km^2 and 540 km^2), the maximum lake extent on Heilprin Glacier (22.84 km2) was approximately three times larger than that on Tracy Glacier (7.60 km^2). The lakes began forming in early June, which was followed by substantial expansion from the middle of June. After reaching a maximum thereafter, the lake area significantly decreased in August. The lake area peaked at different timing every year, depending on meteorological conditions. In 2016, 2019, and 2020, the lake area reached a peak between late June and the beginning of July. In 2017 and 2018, however, the peaks were observed in late July because of relatively cold summer temperature. Regarding to the inter-annual variation, the maximum lake coverage during the study period was observed in 2019, whereas the lake extents were substantially smaller in 2017 and 2018. The lake area was small in these two years because lakes were undeveloped in the region above 800 m a.s.l.