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Ny-Ålesund Glaciology Flagship Programme – future opportunities and constraints

Workshop Report

Svalbard Science Forum – SSF

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The SSF also organizes workshops and administers funding schemes targeted towards the polar research community, while continuously working to minimize the environmental footprint of research activities.

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Ny-Ålesund Glaciology Flagship Programme - future opportunities and constraints

Based on the Svalbard Science Forum workshop 30 May-1 June 2011 in Sommarøy, Norway.
Editors: Jack Kohler & Christiane Hübner

In June 2011 a Svalbard Science Forum (SSF) workshop was held to discuss the current state and future opportunities for glaciological research cooperation in the Ny-Ålesund area and to initiate the Glaciology Flagship Programme for Ny-Ålesund. SSF, a part of the Research Council of Norway, organised and financed the workshop.

Ten glaciologists with extensive fieldwork and research experience from Ny-Ålesund gathered in Sommarøy, Norway, for three days to present their current and planned work, identify gaps in knowledge and discuss the potential for and constraints on collaboration.

The workshop was designed to strengthen collaborative research that focuses on complementarity and incorporates the expertise found in all active research groups, as well as to identify opportunities for joint research activities aimed at reducing the logistical footprint in Ny-Ålesund.

Participating institutions
France: CNRS, TheMA - Université de Franche-Comte; **Japan**: National Institute of Polar Research; **Norway**: Norwegian Polar Institute, Norwegian University of Life Sciences, University of Oslo; **Poland**: Nicolaus Copernicus University; **United Kingdom**: Scott Polar Research Institute - University of Cambridge, Swansea University, University of Sheffield

Workshop goals
1. Create stronger cooperative bonds between glaciology research groups working in and near Ny-Ålesund.
2. Identify potential areas of collaboration (either field-based research or remote sensing/modelling) in order to minimise the logistical footprint in Ny-Ålesund and its surroundings.
3. Work towards reducing (and eventually eliminating) research duplication in Ny-Ålesund – create alternatives in current research focus and new opportunities for the future – promote complementary research and identify niche expertise for each group.
4. Achieve better synchronisation with planned activities within the SIOS framework.

Workshop planning group
- Dr. Jack Kohler, Norwegian Polar Institute, Norway (chair)
- Dr. Andy Hodson, University of Sheffield, UK
- Dr. Irek Sobota, Nicolaus Copernicus University, Poland
- Dr. Jon Ove Hagen, University of Oslo, Norway
- Dr. Marzena Kaczmarska, Svalbard Science Forum, Norway

Ny-Ålesund flagship initiation workshops (organised by SSF):
- Glaciers in Kongsfjorden – "Ny-Ålesund glaciology - future opportunities & constraints" (2011)
- Terrestrial Systems Research (2009)
- Atmosphere research in Ny-Ålesund – a flagship programme (2008)
- The Kongsfjorden System – marine research (2008)

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Workshop participants (from left to right): Back: Christiane Hübner, Adrian Luckman, Hideaki Motoyama, Jon Ove Hagen, Andy Hodson, Jack Kohler, Madeleine Griselin, Florian Tolle, Cecilie Rolstad Denby, Neil Arnold Front: Irek Sobota, Marzena Kaczmarska

1 Glaciology in Ny-Ålesund

Ny-Ålesund is an ideal site for glaciological research; despite its remote location, it provides an excellent logistical base for fieldwork programmes. Apart from large ice caps, most types of glaciers found in Svalbard and even the High Arctic are located around Ny-Ålesund: fast-flowing, surge type, polythermal, and calving glaciers. Some of the longest Arctic mass balance time series have been recorded for two Ny-Ålesund glaciers, Midtre Lovénbreen and Austre Bøggerbreen, and many other relevant long-term measurements are available as well.

2 Knowledge gaps

In terms of the overall science, many processes crucial for future glacier behaviour are still relatively poorly understood. In particular, such important processes as calving, surging, sliding, and glacial drainage are still important open research topics. Ny-Ålesund glaciers provide a useful laboratory for studying these.

In terms of our local knowledge, a handful of glaciers have been studied extensively in the Ny-Ålesund area, mostly with respect to mass balance and hydrology. However, there are still gaps in our knowledge. We know little about spatial and temporal distribution of snow on the landscape and regional scale. While there are a number of mass balance programmes established in the areas immediately adjacent to Ny-Ålesund, we still know little about ice and meltwater fluxes from glaciers outside of this immediate area, and such basic information as bed topography is still missing for most of the glaciers around Ny-Ålesund.

3 Main topics to be addressed in the future

The workshop identified several topics to be focused on in the future, based on the knowledge gaps, existing long-term series and advantages of Ny-Ålesund's location:

3.1 Mass balance

Glacier mass balance is the amount of snow and ice lost or gained on a particular glacier during a certain time period. It is usually reported as a single number which reflects the loss or gain for the glacier as a whole. Mass balance is a lumped climate signal influenced primarily by winter precipitation and summer temperature.

Roughly 60% of Svalbard is covered by glaciers, and these glaciers have been retreating from their last maximal front positions since about 1920. An important motivation for measuring mass balance is to determine the contribution of Svalbard glacier loss to sea-level rise. Roughly half of the current observed sea-level increase is attributed to "small" glacier melting, that is, all glaciers besides Greenland and Antarctica, but there are still relatively large error bars on these estimates. It is therefore important to determine the contributions to sea level from the different glaciated areas around the world. Svalbard is not an insignificant contributor, since it constitutes about 10% of the total Arctic glacier area (again, excluding Greenland). Furthermore, ice melt rates on Svalbard are relatively high due to its location in a relatively warm part of the Arctic.

Two of the longest Arctic mass balance time series are from Ny-Ålesund; together with the available ancillary meteorological data, this provides a useful data foundation for conducting retrospective studies of mass balance. Furthermore, with its easy logistical access, the glaciers around Ny-Ålesund provide an ideal ground-truthing platform for mass balance models, from simple degree-day type models to full energy balance models, as well as downscaling and upscaling experiments using large-scale climate model output.

3.2 Dynamics

One of the significant problems in glaciology with respect to understanding future cryosphere behaviour concerns the dynamical component, chiefly through the process of glacier calving. Physical calving laws are needed to improve our ability to model future ice volume changes and the resultant effect on sea-level rise.

One glacier calving model is currently being developed and tested on the fast-flowing tidewater glacier Kronebreen, at the mouth of Kongsfjord. Kronebreen is an ideal platform for calving studies, again because of the logistical ease of conducting research there, but also because of the wealth of available data such as basal topography, velocity distribution and surface mass balance. Kronebreen has been thinning in recent years, and it is predicted that the glacier will undergo acceleration and rapid retreat through a basal overdeepening once the ice margin thins to a critical threshold thickness.

A less urgent but related issue in studies of glacier dynamics concerns surging. Surge-type glaciers alternate between long periods of relative dynamic quiescence and short duration surges lasting 1-3 years, in which the glacier speeds increase dramatically and the glacier front advances, often by kilometres or more.

Estimates for the number of surging glaciers in Svalbard vary, ranging from 13% to 90%; however, only a limited number of glaciers in the Ny-Ålesund area have been observed to have surged. These include Kongsvegen (ca. 1948), Blomstrandbreen (ca. 1966, ca. 2009), and Comfortlessbreen (ca. 2008). Surge frequency on Svalbard is observed for a few glaciers to vary from decades to one century or more.

The exact cause of surging remains an unsolved problem in glaciology, but is thought to be related to developments in the subglacial drainage system (see below).

3.3 Hydrology

Glacier hydrology exerts the dominant control on glacier sliding in temperate glaciers, primarily through flow of surface meltwater down to the bed and through the subglacial drainage system. Svalbard glaciers are polythermal, that is, they consist of both cold and temperate ice. Glaciers that are entirely cold (on Svalbard, glaciers are relatively thin, less than ca. 70 m thick on average) do not have subglacial drainage, and so their dynamics are relatively static throughout the year. Larger, and therefore thicker, Svalbard glaciers have temperate bases and are thus affected by summer melt. Glacier hydrology is also thought to be a key factor in glacier surging (see above).

Beyond its effect on dynamics, glacier hydrology is important for fluxes of sediment, chemistry, and nutrients. Glaciers that flow all the way down into fjords typically drain relatively large accumulation areas; combined summer melt and rain can lead to high concentrated discharge amounts at the glacier front. This has a significant impact on the freshwater budget for fjord circulation, on sedimentation processes, and as a result on the ecosystem.

Accordingly, studies of glacier hydrology are of importance both for glaciologists and for other disciplines. This includes melt studies, through energy balance modelling and deployment of automatic weather stations, through studies of the development of the summer drainage system, e.g. tracing studies, and through monitoring of sediment, chemistry and water fluxes at proglacial site. At present there is one permanent hydrology station in Ny-Ålesund, on Bayelva near the airport. A temporary station is located at Austre Lovenbreen, closer to the glacier front.

3.4 Snow

Snow is the dominant component in the winter land water cycle; it provides insulation for plants and soils, it is a source of soil moisture in the growing season, and it provides shelter for animals and protection from predators. Snow changes the albedo of land surface and alters the energy balance of the land surface significantly. The Arctic climate is changing, but what the effect will be on snow cover and the potential cascading effects of changes to patterns of snowfall in the hydrological cycle and in Arctic ecology remain important topics of research.

Despite the importance of snow, regular measurements of one of the most basic snow parameters, snow depth, or the related quantity snow water equivalent (SWE) are largely lacking in Ny-Ålesund. Regular measurements of snow depth have only started recently as part of the routine synoptic observations conducted by the Norwegian Meteorological

Institute. There are no longer-term records at daily, weekly, or even monthly time scales. Annual data have been available on the mass balance glaciers, with records of average spring SWE made on the four NPI mass balance glaciers. SWE amounts have been available digitally since 1999, with map coordinates and elevations collected on a roughly regular grid. However, a broader set of measurements is desirable.

Over the past decade, an ad hoc set of springtime snow measurements was initiated by NPI around the Brøgger peninsula, with data for most years since 2000. Snow depths were measured at ca. 200-500 m intervals along a series of more or less coincident profiles. This is useful long-term data, although they only represent a single picture of the snowpack in each year.

A key goal would be to continue snow transects on Brøggerhalvøya, to systematize them and to make these measurements available to the larger research community.

In addition to better measurements of the spatial and temporal aspects of snow cover evolution, it will be important to conduct research on snow chemistry, physical characteristics such as density, crystal evolution and albedo, and on the impact of snowpack on ecology.

3.5 Ice cores

Our knowledge of climate variability over time scales of 100 years or greater is still incomplete. The relative brevity and scarcity of historical and contemporary instrumental records necessitate the use of various proxy-based sources of climate information. Studies of ice cores from glaciers and ice caps have developed into a powerful and successful paleoclimatic tool.

Since the 1970s a number of ice cores have been drilled on glaciers and ice caps in Svalbard. While most of these ice core records either cover short time periods or have time gaps created by negative balances at the drill sites during past warm periods, Svalbard ice core research has improved knowledge about climate variation in this part of the Arctic during the last 800 years. New ice cores will not only be important for furthering our knowledge of past climate, but will also be valuable in increasing the spatial distribution of high resolution ice cores around Svalbard for climate reconstruction.

Ice cores provide archives not only of climate proxies but also of a wide range of chemical species, including black carbon, organic contaminants and heavy metals. Furthermore, new techniques make it possible to improve some of the previous work, making it of interest to obtain new cores from previous drill sites.

Using data from deep ice cores, shallow cores and snow pits it is possible to investigate links between atmospheric circulation, transport and deposition in snow/ice and to investigate the aerosol-temperature link through the ice cores proxies. For example, the atmospheric transport of black carbon to Svalbard was studied by connecting atmospheric soot measurements to back-trajectory calculations. Linking the observed atmospheric equivalent black carbon BC concentration at the Zeppelin station with air mass trajectories shows that generally higher concentrations are observed when the air comes from the east rather than from the west. Ice cores can then be linked to concurrent measurements at Zeppelin and used to extend our understanding of long-term variability in atmospheric circulation and transport.

3.6 Biochemistry

What are the implications of sustained glacier mass balance change for the timing, magnitude and release of nutrients to aquatic and terrestrial ecosystems? In particular, how do glacial and permafrost melting influence the downstream transfer of nutrients and organic matter to aquatic ecosystems? How will the carbon economy of glacier forefields and permafrost change as climate changes continue to influence winter and summer thermal conditions? How will contaminants delivered to glaciers and snowpacks in extreme events influence downstream ecosystems following their storage and release?

4 Integrated Glacier Observatory IGLO

Currently, research groups are not well integrated across national boundaries, and research activities at the different glaciers are often not coordinated. A joint programme to coordinate those activities would facilitate integration, reduce costs and minimise the environmental footprint of glaciological research. Ultimately with better integration and coordination, larger projects with a potentially higher scientific value would be possible. Ideally, more could be accomplished through teamwork than through the uncoordinated efforts of individual scientists or small research groups.

The suggested IGLO observatory would facilitate sharing of data (including e.g. satellite data), seek to avoid research duplication, and develop new methodology. Integration could be achieved within glaciological systems (e.g. regional catchment studies) or with other systems, such as marine and terrestrial systems.

An essential component of such a joint observatory would be a mechanism for sharing logistics, methodology, instruments, data, education and outreach activities.

4.1 Improving integration

One means to achieve better integration between groups and activities would be for groups to make more efficient use of data repositories (such as those planned in SIOS) and the RiS database. In addition, links should be established between external data providers such as eKlima or NVE and localities outside of the immediate area of Ny-Ålesund (e.g. Kaffiøyra, Austfonna, Barentsburg, Hornsund, etc).

4.2 Communication between the groups

An important contribution to enhanced collaboration and coordination is a simple communication system. Two relatively simple measures were suggested:

- Regular (e.g. semi-annual, annual, or biannual) funded workshop meetings;
- IGLO email group.

With respect to the latter, it was agreed to establish a mail group comprised of all glaciologists working in the Ny-Ålesund area. In that way, information about planned research, logistical coordination, data sharing and requests can easily be distributed to the research community.

The IGLO mail group was established in autumn 2011 and is administered by SSF. Email can be sent to all group members by using the common address iglo@rcn.no. To become a member of the group, the researcher must send a request to SSF (ssf@rcn.no).

4.3 Suggestions for joint efforts

Joint efforts could be joint campaigns, joint investments or integrated large-scale projects. The importance of including studies on permafrost, sedimentology and other related topics in joint studies was also pointed out. The group discussed several potential initiatives:

- Combine long-term mass balance monitoring efforts of the different groups.
- Jointly improve techniques for mass balance calculations and process studies.
- Develop new monitoring techniques for calving.
- Establish a permanent hydrological station at Austre Lovénbreen, similar to Bayelva: these would serve as reference sites for two different types of glaciers. Make seasonal hydrographs available for other researchers.
- Conduct airborne LIDAR and radar campaigns for the entire area.
- Update Kongsfjorden bathymetry to include new areas exposed by retreating glaciers.
- Combine maps of Svalbard glaciers where mass balance measurements are conducted.
- Use the small and medium glaciers in Kongsfjorden/Kaffiøyra as a laboratory for modelling, etc.
- Study the linkage between hydrology and calving dynamics.
- Integrate glaciological and marine studies (Kongsfjorden System flagship):
  - Kongsfjorden is the only fjord system where enough information of freshwater, inflow and icebergs are available to establish a water balance;
  - Conduct organic and inorganic matter outflow studies.
- Integrate glaciological and terrestrial studies (Terrestrial Ecosystem flagship):
  - Colonisation of glacier forelands;
  - Snow remote sensing.
- Permafrost/active layer coupling to glacier retreat.
- Develop a uniform DEM for the Kongsfjorden area that is open, accessible and integrated with the glacier database by NPI.

4.4 IGLO instruments

The observatory could invest in instruments which could be shared by the glaciology research community in Ny-Ålesund. These might include:

- Brandalpynten as an instrumental platform, with power supply (e.g. small wind plant);
- Glacier AWS system (with live data transfer to web);
- Cryospheric toolkit:
  - hot water drill system;
  - gauging stations;
  - terrestrial LIDAR;
  - ground-based interferometric radar;
  - dGPS;
  - ice-coring equipment;
  - AWS;
  - relative gravity instrumentation.

4.5 IGLO "management"

How such a joint observatory could be managed and administered in practical terms remains an open question. Possible solutions could involve SSF and/or SIOS.

Appendix 1: Abstracts

Glaciology in Ny-Ålesund

Presented by Jack Kohler
Jack Kohler, Max König, Chris Nuth, Geir Moholt, Jon Ove Hagen, Etienne Berthier, Carleen Tijm-Reijmer
[1]Norwegian Polar Institute, Tromsø
[2]Department of Geosciences, University of Oslo, Oslo, Norway
[3]LEGOS, Grenoble
[4]IMAU, University of Utrecht

I describe recent NPI glaciological activities, which include the following:

Svalbard glacier database
Jack Kohler, Max König, Chris Nuth

Svalbard has ~35,000 km^2 of glaciers, ranging from small valley glaciers to large areas of contiguous ice fields and ice caps. More than 1,500 glaciers are larger than 1 km^2. While a glacier inventory was first compiled in 1993, there has not been a readily available digital version. We are finishing work on a new digital glacier database, which will be available through an NPI website as well the GLIMS project. Glacier outlines have been created for the years 1936, 1966-1971, 1990, and 2007-2008. For most glaciers, outlines are available for more than one of these years. For the 20th century data, glacier outlines were created from cartographic data in the original Norwegian Polar Institute topographic map series of Svalbard. We delineate individual glaciers and ice streams, assign unique identification codes relating to the hydrological watersheds, digitise centre lines, and provide a number of attributes for each glacier mask. The 2007-2008 glacier outlines are derived from orthorectified satellite images acquired from the SPOT-5 and ASTER satellite sensors. In areas with three more or coverages, the overwhelming majority of glaciers are observed to have been in sustained retreat during the period from 1936 to 2008.

Mass balance
Jack Kohler

NPI measures mass balance on four glaciers around Ny-Ålesund: Austre Brøggerbreen (BRG), with measurements from 1967; Midtre Lovénbreen (MLB), starting in 1968; Kongsvegen (KNG), starting in 1987; and the combined glacier system Kronebreen (KRB) and Holtedahlfonna (HDF), with measurements starting in 2003. Field data are obtained during two visits to a glacier, in the spring and in the autumn. These data are used to derive the winter balance (Bw) and the summer balance (Bs). These are added to yield the net balance (Bn), the annual state of the glacier's health as measured between two consecutive autumns.

Low-lying BRG and MLB have experienced mostly negative mass balances, as witnessed by their ongoing frontal retreat. KNG and KRB/HDF are generally more positive, since their accumulation areas are both higher and larger than the two smaller glaciers. On all four glaciers, summer ablation is more variable than winter accumulation, so that summer temperatures provide most of the control on the net balance.

Svalbard contribution to sea level
Chris Nuth, Geir Moholt, Jack Kohler, Jon Ove Hagen

Satellite altimetry from the Ice, Cloud, and Land Elevation Satellite (ICESat, 2003–2007) was compared to older NPI topographic maps and digital elevation models (1965–1990) to calculate long-term elevation changes of Svalbard glaciers. Results indicate significant thinning at most glacier fronts with either slight thinning or thickening in the accumulation areas, except for glaciers that surged, which show thickening in the ablation area and thinning in the accumulation areas. The most negative geodetic balances occur in the south and on glaciers that have surged, while the least negative balances occur in the northeast and on glaciers in the quiescent phase of a surge cycle. The average volume change rate over the past 40 years for Svalbard, excluding Austfonna and Kvitøya, is estimated to be -9.71 ± 0.55 km^3 a^{-1} or -0.36 ± 0.02 m a^{-1} w. eq., for an annual contribution to global sea-level rise of 0.026 mm a^{-1} in sea-level equivalent.

Kronebreen dynamics
Jack Kohler, Etienne Berthier, Carleen Tijm-Reijmer, Chris Nuth

Glacier response to climate change is often heralded by changes in the velocity field. Remote sensing can be used to detect changes in glacier speed, with visible satellite imagery providing the highest resolution products in the most convenient-to-use format. While visible imagery is hampered by the presence of clouds, the high-resolution (2-m pixel nominal resolution in black-white mode) FORMOSAT-2 satellite has a daily revisit capability, allowing programmed acquisition to capture occasional periods with few or no clouds. We use FORMOSAT-2 to derive glacier-wide velocities on the lower 10 km of Kronebreen, one of Svalbard's fastest-moving glaciers, with peak summer season speeds of over to 3 m d^{-1}. FORMOSAT-derived velocity fields for the summer melt seasons 2007-2011 were compared to GPS data from 2009-2011, 3-hourly measurements of speed made using in situ code-phase GPS units deployed at various points on the glacier tongue. The latter provide data with a high temporal resolution, showing how the glacier reacts to meltwater inputs, while the FORMOSAT-derived data provides a view of the spatial dimension, showing how velocity increases start at the front of the glacier and move upstream.

Kronebreen bed topography was recently mapped. Radar data were obtained in 2009 and 2010 using 10 Mhz radar flown by helicopter over the glacier. Other data sets were combined with the radar data to create a comprehensive DEM of both the fjord and glacier. Bathymetry for most of Kongsfjord was compiled from older sources. Bathymetry toward the present Kronebreen terminus was obtained from swath bathymetry obtained by University of Tromsø and the Norwegian Mapping Authority.

Brøggerhalvøya snow
Jack Kohler

Snow is the dominant component in the Arctic land water cycle, and yet regular measurements of one of the most basic snow parameters, snow depth, or the related quantity, snow water equivalent (SWE), are largely lacking in Ny-Ålesund. Snow depth has only been a part of the regular meteorological observations conducted by the Norwegian Meteorological Institute since 2010. Longer-term records of daily, weekly, or even monthly data are simply lacking, and there are few data collected outside of Ny-Ålesund proper.

Annual data are available on the glaciers, records of average spring SWE on the four NPI mass balance glaciers. SWE amounts have been available digitally since 1999, with map coordinates and elevations collected on a roughly regular grid. There is a strong relationship between snow amounts and elevation. Over the past decade, a more ad hoc set of springtime snow measurements has been collected around the Brøgger peninsula, with data for most years since 2000. Snow depths were measured at ca. 200-500 m intervals along a series of more or less coincident profiles. This is useful long-term data, although they only represent a single picture of the snowpack in each year.

To quantify spatial and temporal variations of snow properties and characteristics on the Brøgger peninsula, we will simulate snowpack evolution in the future using a spatially distributed snow-evolution modelling system. The main long-term goal of our measurement programme will then be to collect necessary field data to drive and validate the landscape-scale snowpack. A longer-term goal, beyond looking at the Ny-Ålesund area, would be to implement such a model over larger regional scales, e.g. for all or parts of Svalbard.

Austfonna mass balance and dynamics

Presenter: Jon Ove Hagen
Jon Ove Hagen[1], Thorben Dunse[1], Trond Eiken[1], Jack Kohler[2], Geir Moholdt[1] and Thomas V. Schuler[1]
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The polythermal Austfonna ice cap (8200 km^2) on Nordaustlandet contains more than 25% of all the ice on Svalbard and was a target glacier for a comprehensive field programme within the IPY project GLACIODYN and later the EU ice2sea program, which is co-sponsored by ESA for Cal-Val activities for the coming CryoSat 2 satellite. The project aims at reducing the uncertainties in Arctic Glaciers and Ice Cap (GIC) contribution to sea-level changes by: i) including the calving flux in mass budget calculations, ii) improving process understanding of calving and basal sliding and including dynamics in modelling of future glacier response. In detail, our studies have been focused on: (1) Surface mass balance; (2) Elevation changes (volume changes) by satellite data, airborne laser profiles and ground-based GPS; and (3) dynamics, e.g. surging and calving.

The surface mass balance has been measured by the traditional, direct method, by about 20 stakes over the ice caps, by snow soundings, snow pits and GPR profiles of the snow distribution. The net surface mass balance on Austfonna is slightly negative (-0.1 m water eq. y^{-1}) for the period 2004-2010. The mean specific winter accumulation is only 0.52 m w.eq. y^{-1}, and the mean summer melting has been -0,63 m w.eq. y^{-1}. These numbers are not precise since accumulation may also occur during the summer months. It is not possible to give any trend for the data for only seven years. 2004 was the most negative year, while 2008 was the only year with positive surface mass balance. The surface mass balance results fits quite well with former estimates from shallow ice cores, giving close to zero surface mass balance for the period 1986-1999. This indicates only small changes in the entire period 1986-2010.

The elevation change measurements on Austfonna show a thickening in the interior of c. 0.5 m y^{-1}, and a thinning closer to the coast of 1-2 m y^{-1}, indicating a large dynamic instability. The calving is important (2.5 km3y-1) and accounts for 30-40 % of the total mass loss, giving an overall loss of -0.4 m w.eq. y-1.

The dynamics of Austfonna are investigated using a numerical model and accompanying, continuous GPS surveys of flowlines along some of the most active flow units. The results suggest that vast parts of Austfonna are dynamically inactive, and consequently, accumulated mass is not transported away but builds up in the interior. This behaviour may be interpreted as the quiescent phase of a surge-cycle, which is typically ended by a surge, i.e. a flow instability that quickly discharges massive amounts of ice to the ablation area. In this case, calving and increased melting at low elevations would considerably increase the rate of mass loss of Austfonna within a short time.

Continuous GPS receivers were installed in spring 2009 on two fast-flowing outlets on Austfonna, Basin 3 in the south and Duvebreen in the north. In each of the two drainage basins five GPS units were installed along the central flow line. The lower station is approximately 4 km from the calving front and then each 4 km upstream covering the lower 20 km of each basin. The continuous GPS data showed very interesting results with a clear link between melt events and velocity. The summer season speed-up in the beginning of the melt season is followed each year by a slow deceleration over several months. The winter velocity in Basin 3 decreases from about 300 m yr^{-1}, 4 km from the front, to 100 m yr^{-1}, 20 km from the front. The summer speed-up in the beginning of the summer is up to about 600 m yr^{-1} in the lower point and up to 150 m yr^{-1} 20 km upstream. The data suggest renewed surge activity of Basin-3. The observed dynamic changes of Basin-3 have important implications for the mass balance of the entire ice cap.

Japanese Glaciological Activity in Svalbard

Presenter: Hideaki Motoyama
National Institute of Polar Research, Japan

For the purpose of clarifying the climate and environmental changes over the past 100 years in the Arctic, the Japanese Arctic Glacier Expedition conducted a large number of ice coring exercises at a number of glaciers from 1987 to the present. During the same period, surface snow pit observations were carried out near ice coring sites to reveal the regional characteristics of environmental conditions. The global warming in the 1920's occurred conspicuously in the Arctic. The stable isotope of ice core indicates the common features of climate change. We discuss the warming mechanism using ice core data from various glaciers in the Arctic.

Hydro-glaciology research on the Austre Lovénbreen 2011 - 2014

Presenters: Madeleine Griselin and Florian Tolle
Madeleine Griselin[1], Eric Bernard[1], Florian Tolle[1], Jean-Michel Friedt[2], Christelle Marlin[3]
[1] TheMA CNRS, Université de Franche-Comté, Besançon, France
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Since 2006, the basin for the glacier Austre Lovénbreen has been monitored in order to follow the hydrological and glaciological response of this 5 km^2 glacier to climatic parameters. Several loggers have been set on the Austre Lovénbreen since the beginning of the programme. A very accurate state of the glacier was recorded regarding air temperature (22 loggers), wind (9 loggers), precipitation (9 loggers), snow depth (40 drilling points), and a set of 10 automatic camera stations, yielding 3 photos per day covering the whole basin, were used. Air temperature loggers collected hourly (daily, monthly) data that were used to derive thermal states of the glacier. Three automatically-acquired daily photos were used to monitor snow and ice conditions on the glacier. This daily set of photos covering the basin was geographically corrected in order to provide a mosaic of zenithal views: these projected images allow us to follow the equilibrium line and to define, day by day, the snow- and ice-covered areas on the glacier. Finally, the combination of snow-ice maps and thermal state maps provided the daily melting potential. This potential was expressed in water equivalent through a degree-day model. Additional information on the evolution of the snow cover was also provided by recurrent drilling campaigns conducted in 40 points on the glacier.

Results were compared to the melting processes occurring on and around the glacier. Mass balance of the glacier is computed using a 36 ablation stakes network. In an effort to precisely compute the volume of ice constituting today's glacier, a DGPS-derived surface DEM had to be complemented with a model of the bedrock on which the glacier is flowing. Ground Penetrating Radar (GPR) was used to get precise elevation values of the ice-rock interface. The difference between surface and bedrock DEM allowed us to evaluate the ice volume of the glacier. Bedrock DEM also gave us a unique view of underlying geomorphology and of its potential consequences on hydrology. The programme currently underway still focuses on Austre Lovénbreen but will emphasise new and rather little known aspects of the melting processes. In particular, it will attempt to monitor water equivalent volumes coming from the slopes and the permafrost in the glacier basin.

Ground based interferometric radar data for calving monitoring

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Data on temporal variation of calving events and velocity directly from the calving fronts are very valuable because they provide insight into calving processes, which are still poorly understood. However, such data are rare due to the dangers and difficulties connected to measuring. Ground-based interferometric radar at high temporal rate (2 Hz) has successfully been used in the IPY GLACIODYN project for velocity measurements and monitoring of calving events at Kronebreen, Svalbard for four test seasons (2007, 2008, 2009 and 2010). The radar is placed ~4 km from the glacier, and the antenna lobe covers a width of ~700 m of the front. Daily terrestrial optical photogrammetry and continuous visual observation are conducted to facilitate the interpretation of a 116-hour radar data record from August/September 2008. The calving front geometry is extracted from the optical images, and its effect together with the movement of the glacier is identified in a plot of the amplitude of the radar return signal. Detection of calving events is demonstrated by change detection image processing in the radar data set, and 92 % of the total calving events are confirmed from visual observations and registration. Velocities determined from tracking of permanent scatters in the radar data give an average velocity for the period of 3.2 md^{-1}, and we find generally good agreement between our measurements and visual observations. In our experimental data set we have observed electromagnetic interference in the radar back scatter data from the calving front, and we explain this as being due to multipath scattering and tidal cycles. The radar has also successfully been tested from the Ny-Ålesund research station, 15 km from the glacier front. Continuous radar monitoring of the calving activity of Kronebreen is therefore possible, and seasonal variations can be identified. A new and improved version of the radar is under development, and will be able to map velocities in range and cross range.

Current and planned Svalbard glaciology research at Swansea University

Presenter: Adrian Luckman
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Recent research into Svalbard glaciology at Swansea University using remote sensing as a primary method has focused on elevation change and controls on calving flux. A series of LiDAR campaigns in 2003 and 2005, in conjunction with historical aerial photogrammetry, has yielded elevation change maps for a number of indicative glaciers. The thinning rate is found to be on the increase, particularly at higher altitudes. The use of SAR sensors on the ERS and Envisat satellites has yielded key information about the relationships between ice-front position, surface velocities and calving flux in surge and non-surge Kongsfjord glaciers. For surge-type glaciers the calving flux is found not to increase during the surge, most likely because compressional flow inhibits crevassing. Non-surge glaciers have been in gradual retreat over the past 20 years, which is particularly pronounced since 2006. The seasonal onset of calving is found to be controlled by the availability of meltwater rather than the loss of sea-ice buttressing.

Current and planned research at the Scott Polar Research Institute, University of Cambridge

Presented by Neil Arnold
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Our main research interest is energy and mass balance of Svalbard glaciers. The main strategy we have adopted for this research is numerical modelling, linked with field data collection to provide boundary conditions and verification data. As well as looking to provide predictions of future mass balance, our modelling strategy also aims to quantify the uncertainty in those predictions that arises from parameter variability within the models. The geographical focus to date has been Kongsfjord, and specifically Midre Lovénbreen and Kongsvegen, as these glaciers have long-term mass-balance records maintained by NPI, and have also been the subject of intense mass balance and ice dynamic fieldwork in the recent past.

Our modelling strategy has focused on the use of multiple rather than single optimisation parameters, including the mean absolute error in modelled mass balance compared with measured; the error in areally-averaged mass balance, and the error in the mass balance gradient. This multiple parameter approach has been applied in hydrological modelling, but is quite novel in glaciology, and initial results are very promising, with optimised model R^2 values of over 0.8 for average annual, winter and summer mass balance for both glaciers over the available mass-balance time series.

Our planned research has three main directions; first, we aim to apply the optimised model with a wider geographical focus, with work underway to model regional mass balance for NW Spitsbergen. Second, we aim to use the model to forecast future regional mass balance by using downscaled GCM results. Third, the optimised model has the potential to be linked with a newly developed hydrological model which can track the movement of surface meltwater over a glacier, into moulins, and through the basal hydrological system, allowing subglacial water pressure to be calculated. This gives the integrated model the potential to be linked to ice-dynamics models, giving us the possibility of assessing the future dynamic response of Svalbard glaciers to ongoing climate change in addition to their “simple” mass-balance response.

Nicolaus Copernicus Polar Station – Glaciological research monitoring; scientific interests and research plans

Presenter: Irek Sobota
Nicolaus Copernicus University, Poland

The Polar Station of the University of Nicolaus Copernicus (Polish: Uniwersytet Mikołaja Kopernika – UMK) is located in the western part of Oscar II Land in the northern part of the coastal Kaffiøyra lowland, which is flanked by the Forland Straight on the west. The N.Copernicus University Polar Station is located in Heggodden, about 150 metres from the seacoast at the foot of the head moraines of the Aavatsmarkbreen.

There were several reasons for selecting the above site for the N.Copernicus University Polar Station. The two main reasons were the great environmental diversity of the area and the relatively short distance from the glaciers being studied. Moreover, in close proximity to the N.Copernicus University Polar Station lies the deep Bay of Hornbaek, which makes a good shelter for ships and enables the expedition members to load and unload during stormy weather. Additionally, as early as mid-June the Forland Strait is free from ice. During the summer season, pack ice does not pose any threat to navigation. Small inter-moraine lakes provide enough drinking water during the polar summer season. Another element that makes the location of the N.Copernicus University Polar Station attractive is its relative closeness to Ny-Ålesund, a settlement that hosts a large international research centre. The Forland Strait serves as a route for small ships that sail between Longyearbyen and Ny-Ålesund. In addition, the N.Copernicus University Polar Station is located outside of the national parks and reserves. As a result, moving from place to place and carrying out research is quite easy.

Scientific exploration of Kaffiøyra dates back to 1938. It was then that the first glaciological expedition to Oscar II Land was inspired by Professor Antoni Dobrowolski, the head of the board of the Polar Section of the Association for Scientific Expeditions. The studies mainly included the foreland of the Kaffiøyra glaciers. For many years this area was researched by Professor Mieczysław Klimaszewski. A group of geographers from the Nicolaus Copernicus University in Toruń decided to organise an expedition to the same area to conduct comparative research. In 1975 the first Toruń Polar Expedition set sail. That year, on the initiative of Professor Czesław Pietrucień, a special building was constructed by the moraines of the Aavatsmark Glacier. It was the beginning of the contemporary polar station.

In 1995 a new cycle of summer expeditions to the polar station began, and in 1996 a series of spring expeditions was initiated. The main aim of these expeditions has been to conduct studies of winter snow accumulation on the glaciers in the Kaffiøyra region, as well as observations of winter outflow from the glaciers, geodesic work undertaken in places inaccessible in the summer, and penetration of glacier caves and tunnels. As many as 300 people have taken part in the expeditions so far. These have mainly included scientists, but climbers, speleologists and scuba-divers have participated as well.

The Kaffiøyra region, together with the adjoining Aavatsmarkbreen (75 km2) and the Dahlbreen (132 km^2) and the six glaciers flowing down into the Kaffiøyra (25 km2), comprises an area of about 310 km^2. It makes up a mere 12% of the area of Oscar II Land. Mountain chains, valley glaciers and their marginal zones, together with the coastal Kaffiøyra, comprise 103 km^2.

The Kaffiøyra, which is only 14 km long and 4 km wide, is an excellent location to conduct scientific research due to its biological diversity. Long-lasting measurements were used to create a topographic map of the Kaffiøyra, which includes elements of relief as well as geological structure.

The research conducted has included almost all elements of the geographical environment. Scientific programmes have promoted research in glaciology, glacial geomorphology, permafrost and periglacial processes, as well as climatologic and botanical studies. Since 1995 glaciological research and studies of permafrost in various soil types and seasonal thawing, as well as meteorological observations, have been the major issues on the research agenda.

Glaciers are the dominant feature in the Kaffiøyra region. Since the 19th century their area has decreased by about 30%. Thus, one of the main scientific questions studied in the region is the course of the change in the glaciers' range and the reasons for it. This can be answered by studying mass balance of the glaciers. The mass balance of four glaciers is presently being studied: Waldemarbreen, Irenebreen, Elisebreen and Aavatsmarkbreen. The research encompasses both the summer balance (ablation and runoff from glaciers) and winter snow accumulation. The detailed research plans also mention two large glaciers that meet the sea. These are Aavatsmarkbreen in the north and Dahlbreen in the south of Kaffiøyra. Currently, subaquatic glacial relief of the bays in the Forlandsundet region is under scrupulous investigation. The results of the research can be obtained from the station's website (www.stacja.arktyka.com), from the publications by the World Glaciological Monitoring Service (WGMS- IAHS), and from the website of the Circumpolar Active Layer Monitoring (CALM- IPA).

The research carried out at the N.Copernicus University Polar Station has enabled numerous scientists in most areas of the Earth sciences (glaciology, climatology, hydrology, geomorphology, pedology and botany) to collect material for numerous papers, including master's and doctoral theses. The scientific appeal of Kaffiøyra's geoecosystem has been appreciated by scientists from various research centres in Poland and elsewhere, who take part in interdisciplinary expeditions organised every year. Moreover, the station was used for research conducted under the fourth International Polar Year.

Once the extension has been completed, the station will be able to host 10-15 people at any one time. The new section of the station is 32 sq. m downstairs and 24 sq. m upstairs. This includes a study, workshop, bedroom and two bedroom entresols. The extension is connected to the old section of the station, which includes a living room and bedroom, but there is also a separate entrance to the new part of the station. Additionally, the station gained extra storage floor, a laboratory, a bathroom, and a garage to store boats, snowmobiles and engines. Altogether the station now has about 100 sq. m.

The station is used three to four months annually, but it is possible to stay there for as long as an entire year. It is equipped with the necessary technical facilities, motor generators, solar panels, motorboats and snowmobiles. The more important measurement equipment includes a weather station with the basic measuring instruments (the measurements conducted since 1975); automatic weather stations (with the measurements taken at any interval); limnigraphs and loggers installed in the selected watercourses (measurements of water levels, flow rates and the selected physicochemical features of water since 1975); a system of ablation poles installed on glaciers; ice drills; and loggers for measuring ground temperatures and ice temperatures.

The extension of the station will enable larger groups of scientists to work and conduct research. The fact that both the living and laboratory spaces have been enlarged is especially important, as the station is often visited by scientists from all over the world. As a result, the extension will make it possible to enhance current international contacts, as well as start new cooperative projects in the

Kaffiøyra region. Moreover, most Polish polar research conducted in north-west Spitsbergen is based at the N.Copernicus University Polar Station.

The new investment will enable the scientists to use the station throughout the year. This is especially crucial for research that requires systematic measurements. As a result, the scope of the research topics and the number of expedition members will expand. A larger number of analyses performed directly at the measurement site will reduce research costs and make the work both easier and safer for the expedition members.

The next polar expeditions of the UMK are being planned for the upcoming years, as are scientific conferences and fieldwork based at the N.Copernicus University Polar Station and its facilities.

Glacier Ecology and Biogeochemistry

Presenter: Andy Hodson
University of Sheffield, UNIS

Glaciers and ice sheets are ecosystems in their own right, characterised by a surface microbial community that includes photosynthesising microorganisms and a subglacial community dominated by bacteria. Autotrophic growth upon glacier ice by photosynthesis therefore constitutes a large(ish) global carbon flux (~ 60 gG C/a outside Antarctica). In Svalbard, the results of this biological production are clear: the glacier surface becomes darkened by the additional biomass, resulting in more melting and a change in the delivery of water and nutrients downstream. When inorganic debris mixes with the microbial biomass, aggregate particles form on the glacier (cryoconite). These are effectively protosoils – ready-made ecosystems for the inoculation of glacier forefields following their deposition after glacier retreat. Glaciers in Svalbard therefore regulate when and in what form snowpack and rock- derived nutrients are delivered to downstream ecosystems in glacier forefields and fjords. The importance of microbial activity within the snow and ice also means that glaciers are composed of bacteria – friendly proteinaceous organic matter that is far more favourable than the recalcitrant humics substances that dominate other riverine inputs from tundra. Therefore cryospheric change in localities such as Svalbard cannot be overlooked in a biogeochemical context, and glacier ecology needs to be incorporated into fjord ecosystem models through consideration of their impact upon nutrient delivery and their release of viable microorganisms to new habitats exposed by glacier retreat.

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