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Abstract Volume

The Current State of Mountain Glaciers and Ice Caps in the Arctic: an Update on the Arctic Council's SWIPA Project

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SWIPA (**S**now, **W**ater, **I**ce and **P**ermafrost in the **A**rctic) is a review of the state of the Arctic Cryosphere commissioned by the Arctic Council for delivery at the end of 2010. The core components of the project deal with Sea Ice, Snow, Permafrost, River and Lake Ice, Mountain Glaciers and Ice Caps (MGIC) and the Greenland Ice Sheet (GrIS). An initial version of the GrIS module was published at COP15 in Copenhagen in December 2009. The rest of the modules are still in preparation, but this talk will present an overview of the major findings of the MGIC module.

Glacier retreat has been widespread across the Arctic in the past century. Fractional reductions in glacier area over the past 50 years have been large in many regions and many glaciers have already disappeared. Mass balance records extend back up to 60 years in some cases, and almost all now show negative cumulative balances. Rates of mass loss have increased substantially over the last 10-20 years, especially in regions like Alaska, the Canadian Arctic, and Iceland where there are large glaciated areas and there has been strong summer warming. Estimates of the regional mass loss from Arctic MGIC suggest rates in excess of 150 GT/yr since the mid 1990s. When added to estimates of mass loss rates from GrIS, the Arctic emerges as a major contributor to the eustatic component of global sea level rise.

It is now clear that iceberg calving is a significant component of the regional mass balance in Alaska, the Canadian Arctic, Svalbard and the Russian Arctic, accounting for as much of 20-35% of total annual mass loss in some cases. The annual specific balance due to calving in these regions is comparable to that for GrIS. There may be large short-term variability in the calving rates of individual glaciers, and also of the total regional mass balance, associated with changes in ice dynamics.

Projections of change over the 21st century in the volume of Arctic MGIC due to surface mass balance alone have been made using output from 10 global climate models driven by the A1b emissions scenario. These suggest total volume reductions of between 15 and 50% depending upon the model used. The largest contributions to sea level are projected to come from Alaska, Arctic Canada and Svalbard, although the range of estimates is also greatest for these regions. Although these projections ignore losses by calving they do suggest that declining glacier volume is unlikely to become a major constraint on contributions to sea level rise before 2100.

The ongoing and projected changes in glacier area, volume and rate of mass loss will have significant implications for glacier contributions to runoff, with consequences for water supply, hydroelectric generation, flood hazard, glacial, freshwater, estuarine and oceanic ecosystems. These will be mediated by changes in runoff volume and seasonality, stream water temperature, turbidity, nutrient and legacy pollutant loading, and the lability of dissolved organic matter. Retreat of tidewater glaciers onto land will remove a habitat that is of particular importance for many seabirds and marine mammals

A new estimate of Arctic glacier volumes derived from statistical upscaling of glacier inventory data

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Very few large scale ice volume estimates are available for mountain glaciers and ice caps although such estimates are crucial for any attempts to project their contribution to sea-level rise in the future. We present a statistical method for deriving regional and global ice volumes from regional glacier-area distributions and volume-area scaling, based on data from a recently extended World Glacier Inventory. We compute glacier volumes and their sea level equivalent (SLE) for all mountain glaciers and ice caps in the Arctic defined roughly as 60°N (excluding the Greenland ice sheet). Based on total glacierized area of 410,000 km^2 we estimate a total ice volume corresponding to 0.43 ± 0.05 m SLE, of which 10% is due to glaciers in Greenland apart from the ice sheets. The Arctic glaciers contain approximately 58% of the sea-level equivalent of all mountain glaciers and ice caps on Earth (0.60 ± 0.07 m SLE). However, our estimate is sensitive to assumptions on volume-area scaling coefficients and glacier-area distributions in the regions that are poorly inventoried such as North America and Greenland. This emphasizes the need for more volume observations, especially of large glaciers, and a more complete Arctic Glacier Inventory in order to reduce uncertainties and to arrive at firmer volume estimates of Arctic glaciers.

Relations between meteorological parameters on Hans glacier and Hornsund Polish Polar Station

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There is great interest in the modelling of Arctic snow dynamics and its dependence on climatic variations. There is a lack of long-term high resolution observations of meteorological parameters on glaciers. This concerns the Hans glacier located in Hornsund fjord, Svalbard. In this study we analyse the temporal variation of snow cover depth and air temperature from Automatic Weather Stations (AWS) located in ablation and accumulation areas on the glacier. Due to difficult weather conditions and equipment failure, many observations are missing, making the application of snow cover models difficult and resulting in a high uncertainty of the predictions. The Hornsund Polish Polar Station (PPS) located close to Hans glacier provides more reliable meteorological measurements (WMO station) than those on the glacier. The aim of this study is to derive of a relationship between measurements at Hansbreen and PPS that would help in interpolation over the missing data. We apply a statistically efficient and less data-demanding lumped parameter time series approach to derive this relationship. We use Data Based Mechanistic (DBM) models, where a stochastic data-based identification of model structure and an estimation of its parameters are followed by a physical interpretation. First, the observations are checked for consistency and data gaps are filled using Dynamic Harmonic Regression (DHR) methods. Second, dynamic Stochastic Transfer Function (STF) models are developed. Apart from the estimation of mean meteorological parameters, the models also provide uncertainty limits. Additionally, we estimate the uncertainty levels to assess the applicability of the models for completion of measured time series.

The snow conditions on selected Svalbard glaciers derived from classical methods and radio-echo soundings.

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The state and evolution of a snow cover on glaciers play a crucial role in many glacial processes, e.g. mass balance, hydroglaciological processes. The work presents the state of snow cover on selected glaciers of Svalbard in last decade with a special attention paid to IPY period. The field studies were carried out on glaciers of southern Spitsbergen (Hansbreen, Renerdbreen, Amundsenisen) and on Vestfonna ice cap (Nordaustlandet). An archive data of stakes readings, from ultrasonic distance sensors and snow pits, performed within Hansbreen monitoring program, have been used. Recent snow cover measurements are based on high frequency radar soundings. The radio-echo sounding of the snow cover allows to determine a spatial variability of the snow layer as well as snow internal structure and stratigraphy (in relation to snow pits data). Specific elements of snow stratigraphy (e.g. ice hoar) have been connected with meteorological events during accumulation season. Repeated measurements of the snow cover thickness on Hansbreen in seasons 1989-2008 allow to indicate regularities in the spatial snow cover pattern and prove interseasonal variability of the snow cover thickness. In scale of Svalbard archipelago the thickness of snow layer is climatologically derived, whereas the spatial variability of snow cover within basins of particular glaciers is strongly determined by local topography. The topography modifies wind field and, in consequence, causes blow out and redeposition of the snow.

Seasonal Variability of Mass and Energy Exchanges in the Dry Snow Zone of the Greenland Ice Sheet

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Recent progress has been made in understanding the seasonal variability of energy and mass exchanges in the ablation area of the Greenland ice sheet (GrIS) but little is still known about the atmospheric processes that govern these exchanges in the dry snow zone. A number of detailed experiments have been carried out on the top of the GrIS, which have improved our understanding of the characteristics of the atmospheric boundary layer, in particular the weak instability of the atmosphere in summer, the processes controlling the divergence of longwave radiation and the intermittent nature of turbulence in stable conditions, but no detailed attempt has yet been made to characterize the exchanges of mass and energy beyond a summer season. The motivation to do this is to address a key uncertainty; whether mass is being lost or gained at the higher elevations through water vapour exchange. To investigate this we use meteorological and glaciological data obtained over an intensive 2 year measurement period to run a physically based mass balance model to characterize seasonal variability in the mass and energy exchanges at Summit, Greenland. The surface module of the MB model computes snow-atmosphere energy and mass fluxes from meteorological variables obtained from high quality radiation and atmospheric data, while the vertical temperature distribution in the snow layers beneath the surface is solved using a numerical subsurface module to obtain the subsurface energy flux. The MB is obtained through an assessment of modelled sublimation and deposition, together with input of measured accumulation from stake measurements and surface height changes from sonic ranging sensors. Our observations and modelling allow us to carefully assess the seasonal variabilty in sublimation, and to demonstrate why determining the sign of this flux remains critical in the assessment of the mass balance of the GrIS.

Long-term mass- and energy balance of Kongsvegen glacier, Svalbard

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We consider meteorological and glaciological data measured at the equilibrium line of Kongsvegen glacier during the period 2000 to 2008. The data encompass quite different mass balance regimes and were used for input and validation of local mass- and energy-balance simulations. The meteorological conditions at the ELA are characterized by a coreless winter and summer temperatures around 0°C. Winds are preconditioned by katabatic winds and topographically channelled upper-air winds. Annual net short-wave radiation is determined by polar-day cloudiness and the seasonal evolution of surface albedo. Long-wave radiation fluxes withdraw an almost equivalent amount of energy throughout the year. The turbulent sensible heat fluxes constitute a comparatively strong and continuous source of energy, which is partly offset by latent heat fluxes. Most of the energy available from the atmosphere is used for melt and only a small amount goes into heating the near surface ice layers. Similar investigations were performed at the tongue of the glacier for a shorter period. There is enhanced input from the atmospheric fluxes and correspondingly increased melt. Accumulation is comparatively small and melt can also occur during winter. We further investigate the relationship between the meteorological conditions measured at the glacier and outside. Regression models were developed to derive model input from climate data measured at a nearby research station. Driving the mass balance model with correspondingly interpolated data yields less accurate results. The shortcomings can mainly be traced back to insufficient parameterisation of precipitation and albedo.

Six centuries of Greenland ice sheet mass balance: years 1700-2300

Jason E. Box, E. Rignot, E. Burgess, D.H. Bromwich, E. Mosley-Thompson

Instrumental air temperature records from meteorological stations around Greenland and from northwestern Europe regressed with calibrated Polar MM5 output to develop empirical coefficients to describe the spatial patterns of Greenland air temperature. The same approach is applied to annual ice core accumulation data. Runoff is estimated using a simple retention function. Ice discharge is taken to be a function of surface mass balance. The total ice sheet mass balance is thus reconstructed using past observations. Future projections are made based on IPCC AR4 scenarios and evaluating possible non-linear responses of glacier ice discharge. As such, a simple empirical estimate of the Greenland ice sheet sea level contribution is made, one that spans 6-centuries with 3-year time resolution.

A surface mass balance history of Austfonna, Svalbard, derived from reanalysis data

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Spatial Ablation Model of the Werenskiold Glacier, SW Spitsbergen

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Khodakov formula, which simply describe water equivalent of ablation was combined with r.sun model of the total solar radiation and with information of albedo derived from the LANDSAT images. Finally, spatial patterns of ablation and seasonal runoff were computed and altitudinal zones of this process were quantified.

26 year mass balance simulation for Belcher Glacier (Devon Island ice cap) 1980-2006

Martin Sharp and Alex Gardner
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Belcher Glacier is the largest tidewater glacier draining the Devon Island ice cap in Arctic Canada, and was the focus of investigations for the GlacioDyn project during the 4th IPY. Here we report on the results of a simulation of the surface mass balance of the glacier for the period 1979-2006, which was conducted at 1 day resolution using a degree day model with 1 x 1 km spatial resolution driven by statistically downscaled temperature and precipitation data from the North American Regional Reanalysis. The goal was to explore interannual variability and trends in the catchment mass balance (and its constituent terms), and the spatial pattern within the glacier catchment of the mean, standard deviation, and trend of all mass balance terms. The model was run for the entire Devon Island ice cap and validated against mass balance data for the northwestern sector of the ice cap.

The surface mass balance was positive in all years except 1988, 1991, 2001 and 2006, but iceberg calving likely made the overall balance negative in most years. Results suggest a weak trend towards longer melt seasons over the 26 year period, mainly due to “infill” of cold periods within the melt season. Snowfall increased over the period of record, especially in the southeast of the catchment and above 1600m, while annual positive degree day totals increased at elevations below 1200m. Summer melt tended to increase over the period, especially between 700m and 1200m elevation probably due to progressive upward migration of the ELA over time and resulting albedo-related feedbacks. Although internal accumulation increased over time above 1300m due to increased melt, net balance became more negative over time below 1200m, and especially between 700m and 1100m due to albedo feedbacks associated with displacement of the end of summer snowline to higher elevations. The region in which summer melt increased and net balance became more strongly negative is at the head of the main valley into which the glacier drains, and the changes simulated may have had a significant influence on meltwater drainage and ice flow in this part of the glacier.

Greenland ice sheet snow line variability: 2000-2009

Jason E. Box, Russel J. Benson, Ian M. Howat, and Jeff Morgan

Each year on an ice mass, at the end of the melt season, the maximum altitude where winter snow survives is a useful indicator of the combined effects of melting and snow accumulation. As such, snow line is an excellent holistic variable to indicate a glacier's health. In this study, Greenland ice sheet snow lines are mapped using optical satellite imagery for cloud-free scenes available just prior to the return of winter snow. We use NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) to classify Greenland ice sheet snow lines using reflectance thresholds and iterative statistical modeling. Inter-annual snow line variations spanning 10 seasons, that is, years 2000-2009 are presented. The accumulation area ratio magnitude and it's variability are assessed. To provide a longer context, pre-2000 Landsat imagery are analyzed. The spatial patterns of snow line are also evaluated in relation to precipitation and melt anomalies simulated by the Polar MM5 regional climate data assimilation model.

Changes in Central East Greenland Glaciers from a new Glacier Inventory and DEM.

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About 50% (~50,000 km^2) of the mountain glaciers peripheral to the Greenland Ice Sheet are located in central East Greenland (67º-72ºN). This region is assumed to be highly sensitive to climate change because of the specific character of its glaciers: many are tidewater terminating, polythermal and/or of surge-type. Since the neoglacial and the 1980s, most landbased glaciers receded up to a few kilometres, but there were no noticeable changes in most calving fronts. Between 1978 and 1991, major tidewater glacier termini showed at most a slight loss (0.1-0.5 km^2). However, with 30-70% surge-type glaciers it is unclear whether these losses are glaciodynamic or glacioclimatic responses. Extreme glaciodynamic terminus fluctuations associated with surges have resulted in advances of 3-10 km in <10 years and high multi-annual calving fluxes (~5 km^3 a^{-1}).

In order to assess glacier characteristics, recent changes, and glacier sensitivity, we compiled a detailed glacier inventory of the Geikie Plateau region, using semi-automated digitization from a mosaic using 68 ASTER scenes and 6 Landsat7 scenes. Glaciers were identified using a supervised Mahalanobis distance classification, small polygons were removed using the Lee Filter, and moraine covered termini, nunataks and ice divides were manually improved. The new ASTER Global DEM was used to calculate standard glacier inventory data and generate hypsometries. The glacier inventory contains 300 glaciers, with a total area of 41470 km^2. With a minimum area threshold of 2 km^2 we underestimate the glaciated area by only 0.5- 1%. About 90% of the total glaciated area drains through 124 tidewater glaciers. The total calving front length is 242 km. Differing calving margin positions between the mid-1990s and 2000-2005 indicates a net loss of 140 km^2 calving front area. Case studies show high interannual variability. The central East Greenland glacier inventory will be available through GLIMS.

New results from Swiss-Camp project and from Eqip Sermia glacier

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Swiss-Camp and ST2

The geodetic program to determine flow velocity, deformation and elevation change of the inland ice in the western part of the Greenland ice sheet was continued by the 2008 summer campaign. There are two main research areas. The first research field at Swiss Camp (ETH/CU-Camp) was started in 1991. Until 2008 a total of 10 campaigns were carried out. The second research field (ST2) was established in 2004. It is situated 170 m lower than Swiss-Camp. Here we have now four campaigns in 2004, 2005, 2006 and 2008. Recent results between the last campaigns (2006-2008) in both areas show an extremely big lowering of the ice surface of -1.04 resp. –1.40 m/a. The recent ice thickness loss is more than three times greater than the long-term trend in former years. The flow velocities and therefore the ice mass transports are different. At Swiss-Camp we still get a slightly increased velocity, while at ST2 the velocity is slightly decreasing.The digital terrain models are used for evaluation and validation of ICESat satellite elevation data. Height comparisons are possible after several reductions due to coordinate systems and time lapse between measuring times. The results along one track show in average a discrepancy of 0,13 m.

Eqip Sermia glacier

In 2005 and again in 2008 the recent flow velocity of the Eqip Sermia was determined by repeated terrestrial photogrammetry. In summer 2008, in average the glacier flows with a speed of 4,1 m per day, in 2005 we got 3,1 m/d. Compared to 3,5 m/d in 1959 (BAUER 1968) and 3,6 m/d in July/August 1971 (ZICK 1972) there is only little change in velocity. Compared to other authors and other methods, we cannot confirm the results from satellite radar interferometry observations, e.g. by RIGNOT et al. 2006, who reported an acceleration from 1,9 m/d in October 2000 up to 2,5 m/d in April 2005.

Inter-annual Variations in Surface Elevation across the Devon Ice Cap, Nunavut (2004-2008)

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Knowledge of inter-annual variations in water equivalent mass of polar ice caps is essential for proper discrimination between short term fluctuations and long term trends in mass balance of these features. Annual spring surface elevation measurements acquired from airborne laser altimetry and ground based differential kinematic GPS surveys along a 50 km transect reveal significant inter-annual variability in height across the Devon Island ice cap, Nunavut, Canada. Average surface height variations range from +0.63 +/- 0.1 m (2004-2005) to -0.61 +/- 0.1 m (2007-2008), with a net thinning rate of -0.19 +/- 0.1 m a^{-1} over the entire 5 year period. Net annual mass change for the entire ice cap is derived from a combination of *in-situ* pole measurements of mass balance acquired from the North-West sector, and the water equivalent changes in ice mass as derived along our 50 km survey transect which spans the southern portion of the Devon Ice cap. In this talk, recent fluctuations in mass of the Devon ice cap are put into a longer term (40 year) perspective, and challenges associated with interpreting measurements of surface elevation change in terms of changes in water equivalent ice mass will be discussed.

Recent elevation change of Vestfonna, Svalbard Archipelago, comparing surface DGPS campaigns with ICESat and NASA altimetry

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During IPY4 (2007-2009) DGPS ground elevation profiles where accomplished by snow-mobile traverses across the 2,500 km^2 sized Ice Cap Vestfonna situated in the northeast of the Svalbard Archipelago (80° N, 19° W). The repeated campaigns show local spatial and temporal changes of the ice cap elevation, most likely caused by changes in the wind patterns over the ice cap. Our ground profiles was aimed to follow ICESat profiles (2003-2008) and airborne NASA altimetry (1996, 2002) that criss-crosses the ice cap. Comparisons between ground DGPS altimetry and ICESat altimetry during near-in-time campaigns for both platforms in 2008 show good agreement between both series. Analyzing all the available elevation time series suggest only local changes, but brings no coherent trend in elevation change for the whole ice cap. Thus it seems Vestfonna is anomalous compared to other glaciers in Svalbard, and the Arctic by being conservative to mass changes during the last decades.

Climate impact on ice dynamics and temperature distribution on Swedish glaciers

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A survey of 45 polythermal glaciers in Sweden show increased mass loss and also ice warming over the last decade. Since the mid 1990s thermal information received from high resolution radar soundings are available for a large number of Swedish glaciers. A resurvey in 2008 and 2009 show how the temperature distribution within the glaciers matches the increased melt off during the last decade. All these glaciers have a polythermal temperature distribution with a perennial cold surface layer in the ablation area. In continental parts of the mountain range high ablation rates have caused a warming of the ice masses as a consequence of thinning cold surface layer. In wetter parts of the range the temperature distribution has remained more or less unchanged, while the ice mass has thinned. The net effect of such a change is a net cooling of the glacier tongue which influences the flow rates. In this paper an overview is given of the status of a number of Swedish glaciers, both in terms of size changes and in thermal changes.

Recent mass, area and volume change of Langfjordjøkelen, northern Norway

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Langfjordjøkelen (70º10'N, 21º45'E) is a small ice cap (7.7 km2) in northern Norway and is one of the target glaciers in the IPY-project Glaciodyn. Mass balance measurements have been carried out on the east-facing part (3.2 km2) since 1989. Results reveal that the mean summer balance (−2.9 m w.e.) exceeds the winter balance (2.1 m w.e.) giving an annual deficit of −0.8 m w.e. for the period 1989 - 2009. The cumulative net balance for this period (estimated values for 1994 and 1995 included) is thus −18 m w.e. The balance year 2008/2009 was the thirteenth successive year with substantially negative net balance. Measurements of the ice thickness and recent maps reveal that the glacier has lost about 20 % of its volume and 10 % of its area over the last two decades. The recent increased thinning of Langfjordjøkelen is stronger than observed for any other glacier in mainland Norway. The negative summer balance is consistent with an increased temperature in the melting season by 0.55 °C during the 21 years of mass balance measurements. The geodetic mass balance has been obtained for the period 1994-2008 by comparing digital terrain models (DTM) from 1994 (map constructed from vertical aerial photographs) and 2008 (laser scanning data) by subtracting the DTMs and adjusting for additional melting. The geodetic mass balance for the eastern part for 1994-2008 was −16.1 m w.e. The cumulative direct mass balance for that part over the same period was -15.7 m w.e. Hence, the results from the direct and geodetic compare well. A mass balance model using upper-air meteorological data was used to reconstruct annual balances back to 1948; their 1948-2008 total was −41 m w.e. Sensitivity of annual balance to 1 °C warming is −0.53 m w.e. and to 10 % increase in precipitation is +0.20 m w.e.

Combining mass balance measurements/modeling with geodetic elevation changes: A case study from Kongsvegen and Holtedahlfonna/Kronebreen.

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Kongsvegen (105 km2) and Holtedahlfonna/Kronebreen (370 km2) are two dynamically different glaciers located in Northwest Spitsbergen (79°N 13°W). Velocities on Holtedahlfonna/Kronebreen range from 40 to 400 m yr-1 while on Kongsvegen velocites are only 1 – 10 m yr-1. Mass balance has been measured on the two glaciers since 1986 and 2003, respectively. Meteorological data collected by the Norwegian Meteorological Institute in Ny Ålesund are used to drive a distributed temperature-index model. The model is calibrated by the multi-year mass balance measurements to provide spatially distributed surface mass balances for each glacier. Geodetic data, including topographic maps in 1966, 1990 and 1995, differential GPS profiles acquired since 2000, and a modern satellite DEM from 2008, are differenced to provide elevation and volume changes for various time epochs. The residuals between the cumulative modeled surface mass balance and the geodetic volume changes provides an estimate of the flux divergence for each pixel. For Kongsvegen, these residuals are essentially zero due to the fact that at present the glacier is in the quiescent phase of its surge cycle. On the other hand, the flux divergence on Holtedahlfonna is larger and more important in explaining elevation changes. When integrated over the entire glacier, these residuals represent a 10 to 20 year average calving loss estimate.

Multiparameter studies in the meltwater of Werenskioldbreen, hints for supercooling.

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To recognize subglacial outflow in proglacial streams and improve the understanding of Svalbard polythermal glaciers, radon, electrical conductivity (EC), total dissolved gas pressure (TDGP), CO_2, temperature, pH and chemical compounds were measured during April-May sampling campaigns on outflows in the forefields of Werenskiolbreen. Radon showed levels up to 29 Bq/L, documenting significant contact of water with sediment and bedrock at the glacier bed. Those data, together with continuous measurements of radon, EC, temperature, TDGP and CO_2 in the melting period, give information on drainage footpaths and hints to the draining system.

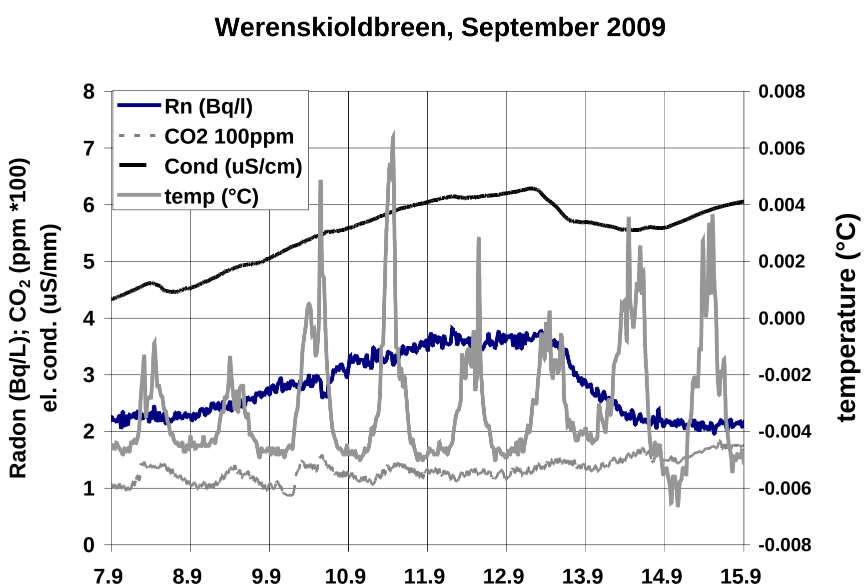

Fig. 1: Example of continuous measurements at an outflow at Werenskioldbreen.

At the largest outflow in the central part of Werenshioldbreen radon concentrations were up to 8 Bq/L in the middle of the melting period (2007). Temperatures lower than 0 °C were measured in artesian outflows during both investigated seasons. Observed was the presence and formation of frazil ice thus documenting the presence of supercooled meltwater. Radar sounding results presented in the 2009 IASC-NAG Meeting , Kananaskis Country, Alberta, Canada by Mariusz Grabiec et al. show parts of overdeepening under Werenskiodbreen. Meltwater ascending the adverse slope from the overdeepening toward the glacier margin at a faster rate than it can be heated by friction may be supercooled (Alley,2003; Evenson,1999; Knight, 2008; Tweed, 2005) . Supercooled meltwater that emerges from this overdeepened basin via artesian vents (the only ones we investigated), cause growth of the observed frazil ice at the glacier margin.

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Simultaneous measurements of surface motion and basal pressure changes on Engabreen glacier, northern Norway.

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Continuous measurements of glacier surface motion and subglacial pressure at Engabreen glacier in northern Norway were made over a seven day period in the spring of 2008. Somewhat surprisingly, there was typically little correlation between subglacial events where there was a sudden change in subglacial pressure and changes in motion on the glacier surface, although a few events showed good correlation.

Surface motion was measured using both dGPS receivers and ground based interferometric radar using a frequency of 5.7 GHz and recording distance to reflectors twice a second. GPS receivers and reflectors were placed at three different points on the lower part of the glacier at elevations of 320, 340 and 398 m a.s.l. Motion was smooth over the seven-day period, but showed variations at shorter time scales, as well as an approximately sinusoidal variation in motion at all stakes that was generally of 30 – 35 seconds periodicity. This sinusoidal signal may be a feature of the radar system, rather than a feature of the glacier motion, but the changing relationship of the amplitude, phase and frequency for movement at each stake suggests it may be a real feature.

Simultaneous measurements were made of subglacial pressure at earth pressure sensors that are installed at the Svartisen Subglacial Laboratoy under 200 m of ice. These sensors are approximately 1.7 km upstream of the highest of the surface stations. Six sensors recorded data at 90 second intervals, although only four sensors have unbroken records for the whole period. Changes in subglacial pressure recorded at the sensors are due to several factors including large clasts embedded in the ice being dragged over a sensor (which is then recorded at only one sensor) and changes in the water pressure at the bed (which is then registered at several sensors). Records show that major changes (of up to 30%) in the subglacial pressure occurred during the study period, but generally did not show a corresponding change in surface motion. Also, major changes in surface motion did not necessarily have a corresponding signal in the subglacial record.

Evaluating the WRF model in Svalbard on the basis of a case study: First tests and preliminary results

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The polar version of the Advanced Weather Research and Forecasting Model (Polar WRF) has been evaluated on the basis of a case study (15 March 2008). The goal was to test its applicability for studying airflow over and around Svalbard at the meso and micro scale. Specifically, we were interested in boundary layer processes such as the interaction between the lowest air layer and the glacier, the sea surface, and the sea ice as well as orographic effects such as gravity waves and katabatic winds. This study was also motivated by the idea to use Polar WRF output to drive future mass balance simulations of polar glaciers.

For the event on 15 March 2008 the WRF model is initialized with ECMWF analysis data and compared to measurements taken by the Deutsches Zentrum fur Luft und Raumfahrt (DLR) on board of the Falcon aircraft during the IPY THORPEX field campaign in February and March 2008. These airborne observations, which include in-situ flight-level data, dropsondes and lidar data, are used to evaluate the mesoscale structure simulated by the model over and around Svalbard. Further, the model is validated against ground-based measurements from automatic weather stations on the Kongsvegen glacier and from routine stations and soundings near Ny-Alesund. Preliminary results will show, amongst others, the sensitivity of the simulated boundary layer structure on the model setup (parameterizations) based on a comparison of measured and simulated radiation and heat fluxes at the surface.

Numerical modeling of the dynamics of Nordenskiöldbreen, Svalbard

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A numerical ice sheet model, the Parallel Ice Sheet Model (PISM), is applied to Nordenskiöldbreen, a tidewater glacier in the central part of Svalbard. In PISM, two approximations of the full-Stokes equations are considered and combined, leading to a thermomechanically coupled shallow 'hybrid' model (Bueler and Brown, 2009). Velocity solutions of the non-sliding shallow ice approximation (SIA) and the shallow shelf approximation (SSA), which incorporates membrane stresses, are averaged and weighted to yield final velocity estimates. The model is capable of simulating a large range of ice velocities as a result of both internal deformation and basal sliding. The till is assumed to behave plastically and the strength of the basal material is dependent on the amount of liquid water present at the base as a result of basal melting. Since 2006, the Institute for Marine and Atmospheric research Utrecht (IMAU), has carried out ice velocity measurements using GPS stations situated at multiple locations on the glacier. These data will be used to validate modeled ice flow velocities. The research will focus on investigating the interaction between glacier hydraulics, sediment deformation and basal sliding on different time scales.

Insights into the dynamic regime of the Austfonna ice cap, Svalbard, from numerical modelling and observation

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The Austfonna ice cap covers an area of 8120 km^2 and is by far the largest glacier on Svalbard. Almost 30% of Austfonna is grounded below sea-level, while the figure is as large as 57% for the known surge-type basins in particular. Marine ice dynamics, as well as flow instabilities presumably control the flow regime, form and evolution of Austfonna. These issues are our focus in numerical simulations of the ice cap.

We employ the dynamic/thermodynamic, large-scale ice sheet model SICOPOLIS (*http://sicopolis.greveweb.net/*) which is based on the shallow-ice approximation. We present improved parameterizations of (a) the marine extent and calving and (b) processes that may initiate flow instabilities. The dynamic boundary condition at the glacier bed is given by a Weertman-type sliding law. Sliding is enabled when the temperature at the ice base is at or approaches the pressure melting point, while no-slip conditions prevail for a cold ice base. Sub-melt sliding in a defined temperature range, along with enhanced sliding of marine ice, control the dynamic behaviour of the ice cap and provide a switch between quasi-permanent fast flow or cyclic surge behaviour. The model results indicate that cyclic surges of some drainage basins are required to explain the present size and shape of Austfonna.

Space-borne interferometric snapshots of Austfonna revealed a velocity structure of a slow moving polar ice cap (< 10m/a) interrupted by distinct fast flow units with velocities in excess of 100m/a. However, observations of flow variability are scarce. In spring 2008, we established a series of stakes along the centrelines of two fast-flowing units. Repeated DGPS and continuous GPS measurements of the stake positions give insight in the temporal flow variability of these units and provide constrains to the modeled surface velocity field.

Austfonna's thermal structure is described as polythermal. However, direct measurements of the temperature distribution are available only from a single borehole at the summit area. The vertical temperature profile shows that the bulk of the 567m thick ice column is cold, only underlain by a thin temperate basal layer of approximately 20m. To acquire a spatially extended picture of the thermal structure (and bed topography), we utilized low-frequency (20 MHz) GPR profiling across the ice cap and the particular flow units. The measurements indicate that the gross volume of Austfonna is cold. This observation is supported by model results which suggest that regional fast flow occurs despite the lack of considerable temperate-ice volumes. This in turn indicates that fast flow is accomplished exclusively by basal motion in regions where the glacier base is at pressure-melting conditions, and not by enhanced deformation of considerable volumes of temperate ice.

Mass balance of Potanin Glacier, Mongolia Altai

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There are glacier region in Altai Mountains situated at central-north Asia. This region is thought to be receiving the influence of the present Arctic Change. Study related to mass balance of glaciers in the Mongolian district will be reported. It is reported that Potanin glacier in western Mongolia is retreating. However, there were few glaciological observations. Furthermore, meteorological observations around the glacier have not been done yet. For mass balance analysis, we conducted observation of surface height change in ablation area and net balance estimation using pollen analysis at accumulation area. It revealed that ablation rate in summer is large in ablation area and accumulation occurred in winter. We estimated the specific mass balance from the data. Mass balance of Potanin glacier in year 2007/08 was estimated to extensive negative which was comparable to Russian Altai glaciers. Naturally, cumulative mass balance of glaciers in Altai show different tendency from world average. Annual air temperature shows warming trend whereas precipitation does not show the significant increase/decrease. Therefore, it is probable that precipitation as snow or rain had an influence on mass balance.

Subglacial Meltwater Drainage at Paakitsoq, West Greenland: Insights from a Distributed, Physically Based Numerical Model

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Recent studies indicate that surface meltwater is reaching the bed of the Greenland Ice Sheet (GrIS) and modulating glacier sliding rates at the ice sheet margin. However, the hydrological characteristics of this drainage system and the degree to which variations in subglacial water pressure enhance or impede ice flow remain uncertain. As the subglacial hydrological system beneath the GrIS is physically inaccessible and beyond the resolution of geophysical imaging techniques, numerical models are an important tool for investigating the stability of plausible hydrological systems. We present preliminary results of a numerical model that investigates theoretically-constructed hydrological systems of the Paakitsoq region of W. Greenland, north of Jakobshavn Isbrae. Subglacial drainage system structures (the location, alignment and interconnection of major drainage channels) are defined from patterns of subglacial hydrological potential derived from surface and bed DEMs. Discharge and hydraulic head within subglacial channels are modelled using a component of the US EPA Storm Water Management Model (SWMM), modified to allow for enlargement and closure of ice walled channels (Arnold et al., Hydrol. Processes, 12, 1998). We assess the model's ability to deal with two types of input: rapid lake drainage events; and diurnally varying melt inputs calculated from a degree-day model. We perform sensitivity tests to determine the effects of individual model parameters on modelled channel cross-sectional area, water pressure and subglacial flow. Finally, we simulate drainage beneath the ice sheet for a summer melt season and compare the results with measured proglacial stream discharges. Through a recent code modification allowing subglacial water pressures to reach values in excess of ice overburden pressures, we find that consistently high inland subglacial water pressures assist with keeping marginal conduits full and counteract the effects of creep closure, allowing conduits to stay open. Although channelised flow is often assumed to only be possible close to the ice sheet margin where ice is thin and water inputs are large, we show that channelised flow is also possible further inland than expected if inland water pressures are kept consistently high by high rates of recharge to constricted conduit systems.

Investigating basal conditions and thermal regime on Vestfonna Ice Cap, Svalbard

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Although detailed studies have been done about the dynamics of the glaciers in Svalbard, these studies have been focused on few and often small glaciers located close to settlements. Little is known about the ice dynamical responses on climate change on a majority of the glaciers and the larger ice caps in the archipelago. We have initiated a study to investigate the basal conditions and flow dynamics of Vestfonna Ice Cap on Nordostlandet, Svalbard, to study the link between climate dynamics and ice flow. Here we will present the first results of the radio-echo sounding (RES) surveys collected during field seasons in 2008 and 2009.

The RES data was collected to establish a bedrock elevation map and collect for the thermal regime and basal conditions for the ice cap that is a prerequisite for modelling efforts of the flow dynamics of the ice cap. The collected bedrock elevation data is combined with airborne data collected in 1983 and the resulting map indicate an undulating bedrock surface and an average ice thickness of 185 m with a maximum of 405 m. Zones of internal scattering in the RES data indicate temperate conditions. However, it is only present in the upper part of the ice column, indicating that the lower part has cold (dry) conditions and the spatial distribution of the scattering zones are patchy. The strongest reflecting ice-bed interface is found in areas with large ice thicknesses and in onset areas of outlet glaciers. It also coincides with areas of high surface velocities. This suggests that the pressure melting point is reached at the bed where the ice thickness is enough while the lack of internal scattering in the RES data in many areas and indicate that the ice column is cold. The higher reflectivity in the catchments of the outlet glaciers indicate that the onset of the outlet glaciers can be governed by basal conditions or that the ice motion of the outlet glaciers generates enough friction heat to sustain melting conditions

Hydrology and dynamics of a land-terminating Greenland outlet glacier

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Recent observations show that the Greenland ice sheet (GrIS) is currently losing mass, the result of accelerated surface melting and ice motion (Pritchard et al., 2009). In land-terminating sections of the GrIS margin, increased annual flux is caused by seasonal variations in ice-velocity that are initiated by inputs of surface melt-water to the ice-bed interface (Zwally et al., 2002). A positive relationship between surface melting and ice velocities has been used to propose a feedback between climate warming and dynamic mass loss for the GrIS, although the net effect remains equivocal (Shepherd et al., 2009, van de Wal et al., 2008). Most recently, on the basis of correlations between ice motion and surface melting, it has been suggested that the relationship between surface melting and ice velocity is moderated by the structure and hydraulic efficiency of the subglacial hydrological system (ibid.), which develops spatially and temporally on a seasonal basis.

Observations of proglacial discharge, electrical conductivity and suspended sediment concentration from an outlet glacier in W. Greenland (~67°N), are used to characterise the development of the hydrological system in the ablation zone of this part of the GrIS, following the onset of melting until late summer. These observations document the evolution of a hydrological system which expands upglacier and increases in hydraulic efficiency over the course of the summer melt-season. In conjunction with satellite observations and a simple temperature-index melt model, we show for the first time that water generated at the surface of the ice sheet, up to 1200 m elevation and 50 km inland, is transported via the subglacial hydrological system to the ice sheet margin. We also observe several flood events which correspond in timing, magnitude and water quality characteristics with the drainage of supraglacial lakes from the surface of the GrIS to the ice sheet margin.

Surge dynamics related to climate change response of Svalbard glaciers

Sund, M., Eiken, T and Hagen, J. O.

Climate change is expected to have a large impact on Arctic glaciers. In Svalbard up to 90 % of the glaciers are assumed to be surge-type. Glacier surges are short semi-cyclical events of fast flow intersecting long lasting periods of quiescence. During surge the glaciers experience large mass displacements and 10-100 times increase in velocity. Surges are related to internal changes in the dynamics of the glacier system rather than changing climate. Nevertheless a combination of surge and change of climate can have significant long-term impact on the glacier volume. The response time for surge-type glaciers could also be significantly prolonged compared to other glaciers. Currently the Nathorstbreen glacier system (NGS) c. 1.4% of the glaciated area in Svalbard, experiences the largest surge in Svalbard in 70 years with an advance 8 km during one year (2008-09). The mass displaced on the NGS during the advance equals ~40 % of the total annual mass loss from glaciers in Svalbard. Assuming a 50 m lowering of the accumulation area, the surge changed the accumulation area ratio of the NGS from 0.7 to 0.5 during one year. Another example is Skobreen, which displaced approx. half of its volume from higher to lower elevations during its last surge ~2005. This shows the importance of incorporating glacier surge dynamics when evaluating the state of the glaciers in Svalbard to avoid misinterpretation of surface lowering as climate change signal from glaciers. On the other hand glacier surges have a potential of enhancing contribution to sea level rise in proportion to a slight change in climate as more ice will be exposed to low elevations and possibly calving after a surge.

Recent state of tidewater glaciers in Southern Spitsbergen

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Tidewater glaciers in Spitsbergen undergo an alteration since beginning of last century. Accelerated changes have been noted during last two decades. Paper describes recent diminishing of extension and elevation of glaciers in Southern Spitsbergen derived from satellite remote sensing and field studies. Rate of changes has been measured. Glacier's hydrothermal structure and dynamic state are discussed either. The area is highly glaciated in comparison to other regions of Spitsbergen. More than two dozens of tidewater glaciers of different size are located there. Glaciers with susceptibility to surge type behavior were identified from direct and indirect evidence. The major changes are observed on larger tidewater glaciers with low longitudinal slope. Mass turnover has been estimated for Hansbreen - the best studied glacier in the area. Various importance of mass loss due to calving has been noted for different types of glaciers. A simple functional model of evolution of glacier systems in Spitsbergen is proposed.

Multi-Year Glacier velocities across Devon Island and Prince of Wales ice caps, Canada.

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Optical matching of Landsat 7 ETM+ satellite image pairs is used to determine the surface velocities of major tidewater glaciers across Devon and Prince of Wales ice caps. Optical feature tracking was performed using sequential Landsat images acquired between July 7th 1999 and August 7th 2009, providing near continuous annual velocity estimates over a 10 year period. The surface velocity measurements were compared to published InSAR velocities for Devon Ice Cap. Feature tracking measurements reveal fine details about the ice dynamics in these regions. For example significant interannual variation in velocity is observed for multiple tidewater glaciers, apparently unrelated to surge events. The largest interannual variation in velocity is observed for the North Croker glacier, Devon Island, which flowed at 49 m/yr in 2001-2002 increasing to 162 m/yr in 2005-2006. This study provides a long temporal record of glacier velocities across this region, providing a baseline, and context, against which future changes can be compared.

Temporal and spatial variations in the flow speed of Kronebreen, Svalbard

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Kronebreen is one of the fastest flowing (tidewater) glaciers in Svalbard with annual average speeds up to 1.5 m/dy on the lower parts of the glacier. The glacier drains a large area of about 600 km^2 and is a known surge type glacier. The lower few km of the glacier is heavily crevassed making in-situ observations of the flow velocity difficult. Velocity observations of the lower part of the glacier are therefore mainly based on remote sensing techniques such as terrestrial photogrammetry, satellite speckle tracking and InSar techniques.

We present one year of in situ velocity observations from nine stand-alone GPS receivers. Seven receivers are placed on the central flow line from about 2 km to about 13 km from the front of the glacier. Two receivers are placed on a cross profile at about 4 km from the front.

We will discuss the observed velocities in terms of the temporal variations, e.g. the summer speed up in June and July, and the spatial variations, e.g. velocity variations along the profile. A comparison will be made with available observations from literature.

We will also discuss the results in terms of available meteorological observations and spatial characteristics of the glacier.

New survey of dynamics of the frontal zone of Hansbreen, Svalbard tidewater glacier. Preliminary results.

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Hansbreen is a medium size (56 sq. km) tidewater glacier in southern Svalbard. Thanks to proximity to the Polish Polar Station, Hansbreen has been monitored by different methods since 1982. The main objective of long term studies is survey of its flow dynamics and contribution of calving flux to the overall mass balance. During the IPY, the GLACIODYN project has enticed application of additional tools for survey of the Hansbreen frontal zone dynamics. Time lapse cameras of the IQvision type were used during daylight periods in 2007 – 2009. Experimental photos were also taken during polar night in November and December 2009 with use of the Canon A530. Long range scanner Riegl LPM-321 (reach up to 6 km) was used for acquisition of high resolution data on the glacier front in August and September 2009. Obtained data show changes of positions of ice cliff and crevasses during period of two and 11 days and are source for calibration of repeated pictures from digital cameras. The Riegl FG21-LR laser distance ranger has been placed close to the glacier front. The laser measures distance to the active cliff every 10 minutes since mid of September 2009. After summer retreat winter advance of the terminus has been recorded since late November. Precise periodic GPS survey has been conducted on new stakes close to calving front. ASTER images from 2008 – 2009 were used for measurements of glacier velocity by the feature tracking method. New tools and methods applied for glacier superficial velocity are giving more detailed picture of spatial and temporal variability of Hansbreen front dynamics than before known. Flow speed at the calving front is higher than measured in previous years and notable changes of glacier cliff velocity has been detected in the time of polar night. Preliminary results shows consistency of velocity data measured by different methods.

Application of a minimal glacier model to Hansbreen, Svalbard

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Like many glaciers in Svalbard, during the past century Hansbreen has shown a steady retreat. Hansbreen is located in the relatively maritime climate of W Spitsbergen, has an area of about 57 km^2 and a length of about 16 km (Pälli et al., 2003). The glacier has a small surface slope (mean value of 0.025) and an active calving front. Since 1900 the front retreated over a distance of about 2 km (J. Jania, personal communication). Upstream from the current front position the glacier bed has a reversed slope over several kilometers. The deepest parts of the bed are about 100 m below sea level.

In this contribution the global dynamics of Hansbreen are studied with a minimal glacier model (Oerlemans, 2008). In such a model the glacier mechanics are highly parameterized and the only independent state variable is glacier length. The mean glacier thickness is determined by the glacier length, and the calving rate is related to the water depth. A schematic representation is used for the longitudinal bed profile.

In spite of its simplicity the model is able to simulate the retreat of Hansbreen for a plausible climate change scenario. The model has been calibrated by constructing a history of the equilibrium-line altitude (ELA) that results in a good match of observed and simulated glacier length since the year 1900. It appears that the fast retreat of Hansbreen in the first half of the 19^{th} century can only be explained by a marked rise (~150 m) of the ELA during the first decades of 19^{th} century. This is in agreement with the sparse meteorological observations available for this period (Johannessen et al., 2004).

The model suggests that in the year 2000 the ELA was 122 m higher than in the year 1850. If the rate of rise (0.81 m a^{-1}) is kept constant for the future, the model predicts a further retreat of the glacier front of 4.3 km. The accelerating retreat is partly due to the increasing calving rates when the front moves into slightly deeper water.

The model is also used to study more generally the dependence of equilibrium states on the ELA. The results are used to speculate about the mechanism behind the advance–retreat cycle of Hansbreen.

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Seasonal and Inter-Annual Variations in Ice Flow of a High Arctic Tidewater Glacier

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The Belcher Glacier is a tidewater glacier that drains the North East quadrant of the Devon Island Ice Cap in Nunavut, Canada. The ~45km long glacier terminates in approximately 300m of water, and the ice cliff rises 20-40m above the water surface.

Continuously recording GPS stations have been installed on the ice to measure displacement at several points along the glacier. Continuous observations were collected from 3 stations during the spring and summer of 2008, and from 4 stations during a similar period in 2009. The stations were operated at a reduced duty-cycle for most of the intervening winter. The spring-summer GPS observations have been processed using a kinematic method to produce continuous glacier motion timeseries from May through August of both years. The winter GPS observations have been used to produce a timeseries of sequential static points.

During the two years of observation, this glacier has demonstrated distinct seasonal flow regimes. During winter and early spring, glacier motion is relatively stable, with little variability. In summer, horizontal ice velocity increases during periods of intense surface meltwater production. Vertical motion of the ice (uplift) coinciding with prolonged periods of positive air temperatures and increased horizontal ice velocity provides a strong indication that surface meltwater is reaching the glacier bed, increasing subglacial water pressure and thereby enhancing basal sliding.

In this presentation I will examine the differences between the seasonal ice flow responses observed in 2008 vs. 2009, in order to explore the dynamic sensitivity this glacier exhibits to variations in the intensity and timing of the summer melt season.

Seasonal Variations in Ice Motion, Belcher Glacier, Nunavut, Canada

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This study presents comprehensive surface ice motion patterns and determinations of ice fluxes for Belcher Glacier (the largest tidewater outlet glacier of Devon Ice Cap). Speckle tracking of Radarsat-2 fine and ultrafine beam imagery collected throughout 2008 and 2009 is used to determine seasonal ice motion. Results are validated with in situ differential GPS (dGPS) measurements. The speckle tracking results provide ice motion maps unaffected by satellite look-direction problems associated with earlier ice dynamics studies utilizing SAR interferometry. Results derived from March 2009 fine beam data show a gradual increase in velocity along the centerline of Belcher Glacier, with maximum velocities of ~275 m yr^{-1} achieved at the terminus. Speckle tracking results also agree well with in situ dGPS data (~+/-2 m yr^{-1} of annual motion). Ultrafine Radarsat 2 imagery is also used to determine ice motion and allows for determination of ice velocities at least every 50 metres horizontally across the glacier surface. Results are compared with those of Burgess et al (2005), who provided ice motion maps for the main trunk of Belcher Glacier from the mid-1990s and terminus results from 2000.

Finally, ice thickness for Belcher Glacier and its tributaries were determined using ground penetrating radar (GPR) measurements collected during summer 2007. These results are combined with the speckle tracking velocity results to determine present-day ice fluxes through the basin.

On the nature of iceberg calving: a self-organized critical state?

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Calving activity at the front of a tidewater glacier is characterized by long quiescent periods punctuated by sudden release of icebergs. Are those iceberg calving events predictable? What drives the calving process? To get more insight into the nature of iceberg calving we visually monitored the magnitude and frequency of icebergs at Kronebreen, Svalbard, during two summer periods in August 2008 and August 2009. In total, we collected 18 days of observations, which represented more than 7000 calving events, ranging from small ice blocks (1 m3) to entire ice walls (25 000 m3). Magnitudes have been assigned based on the size of the resulting icebergs. Both the magnitude and interevent times are well fitted by power-law relations. These power-law relations suggest that calving process is self-organized in a critical state. A self-organized critical state is a state that emerges spontaneously and that can respond to external perturbations on all time and length scales. This hypothesis is supported by further glaciological data. The fact that calving process is self-organized in a critical state implies that calving events are unpredictable but not random which means that the physics of iceberg calving is deterministic, but neither the time of the next event nor its magnitude can be predicted. Another consequence is that the same processes control both the small and the large events and that there might be no specific explanation for the largest events. In this view, the occurrence of a “catastrophic” event, i.e., the entire calving front collapsing, can be expected and characterizes a large response of the system. This last consequence is very relevant for the modeling of calving processes since efforts should be made to model all sizes and types of events if one wants to get a correct picture of what is happening at a calving front.

IPY research on McCall Glacier

Matt Nolan, Joe McConnell, and Bernhard Rabus

In 2008 during IPY, we recovered a 152 m ice core to bedrock from McCall Glacier and analyzed it in winter of 2009 for over 35 proxies. We found that despite the potential obscuring influence of meltwater percolation, many of the proxies showed annual fluctuations. We preliminarily dated the bottom of the core to about 1750AD through a combination of layer counting, wiggle matching, and tritium measurements, and found an average layer thickness (water equivalent) of about 550 kg m-3, which was surprisingly uniform until the past 2 decades when it decreased. We have not analyzed the proxies themselves as yet, but have submitted a proposal to do so later this year and are looking forward to comparisons with other cores.

Ice temperatures measurements indicate temperature variations over the past 35 years that relate to climate and surface dynamics. Thermistor strings placed into 3 holes to bedrock in 2008 confirm the polythermal nature of McCall Glacier and that the glacier gets cooler with elevation, due to the influence of internal accumulation in former and current firn areas. In one 200 m deep hole, the surrounding region changed from accumulation to ablation area ? the ice temperature is responding by getting colder from the top down due to the lack of internal accumulation; our modeling indicates this switch occurred about 50 years ago. Shallow ice temperature measurements (<15 m) conducted near the same locations over the past 35 years indicate that air temperatures in the region warmed by over a degree in the 1970s-1990s, but since then air temperatures in the area don't seem to have a strong trend; this is somewhat confirmed by global reanalysis data and local measurements.

As part of our IPY efforts, we created a photographic inventory of nearly all glaciers in the US Arctic to complement volume change studies there made through map comparisons. The volume change studies are still underway, but the photographic inventory is now available online.

Dating ice cores by wavelets

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Ice cores are often dated by reference horizons such as volcanic acid deposits, some may also be dated by annual cycle counting, or flow models. However in deeper ice cores, or in cores that lack good annual cycles, it is common to “wiggle match” the variability seen in one record with that seen in another well-dated. A similar approach is tuning the observed variability in a record with known spectral power associated with Earth’s orbital variations. Here we show that poorly dated paleoclimate proxies may be dated with more confidence by observing the wavelet coherence between a well dated reference record and a set of proposed chronologies of the problematic record. The idea is that if the two chronologies are well dated, then the phase relationships between the wavelet decomposition of the two records should match reasonably well over a variety of frequency bands and at many points in the timescale. This makes no assumptions about the particular type of climate signal that will be recorded at the two sites, except that on average the climate will be tend to be spatially more coherent than random noise at all scales. We show that the approach works for two ice cores from Svalbard where the wavelet coherence between nine chemical ions is examined. The timescale can then be verified by extracting the volcanic record from the sulphate concentration record as spikes in the residual from fitting the sulphate variability to empirical regression on other ions. This process accounts for terrestrial, marine, biogenic and anthropogenic sulphate deposition fractions as well as post-depositional relocation of ions, leaving only stochastic sources, effectively volcanic fallout.