Ice2sea North / South Glacier Workshop

GEUS, Copenhagen, Denmark

Monday 14th – Wednesday 16th January, 2013

Nick Barrand (British Antarctic Survey)
Horst Machguth (GEUS / University of Zurich)
Jon Ove Hagen (University of Oslo)

Contents

1. Schedule

Monday 14th January, 2013

14:00 - 14:30	Coffee and registration (room: Tove Birkelund)
14:30 - 14:40	Nick Barrand (room: Theodor Sorgenfrei) *Welcome and introductory comments*
14:40 - 15:00	Jon Ove Hagen (room: Theodor Sorgenfrei) *Science introduction to North / South workshop*

15:00 - 17:00 **Global glaciers** (room: Theodor Sorgenfrei). Convener: Ted Scambos

15:00 - 15:20	Alex Gardner *A consensus estimate of glacier contributions to sea-level rise: 2003-2009*
15:20 - 15:40	Valentina Barletta *Mass changes estimates in glaciated regions with low-viscosity mantle: Patagonia, Iceland and the Antarctic Peninsula.*
15:40 - 16:00	Aslak Grinsted *An estimate of global glacier volume*
16:00 - 16:20	Matthias Huss *Ice volume and thickness distribution of all glaciers and ice caps around the globe: a new physically-based estimation method*
16:20 - 16:40	Regine Hock *Assessing and projecting global scale glacier mass changes*
16:40 - 17:00	Per Wikman Svahn *Implications of scientific uncertainty on future sea level rise for planning and the role of scientist qua advisor*
17:00	Session close.

19:00	Workshop meal 1: DagH restaurant, Dag Hammarskjölds Allé 38, 2100 Copenhagen.

Tuesday 15th January, 2013

09:00 - 10:40 **Regional glaciers 1** (room: 'Theodor Sorgenfrei'). Convener: Guðfinna Aðalgeirsdóttir

09:00 - 09:20 Matthias Braun
Mapping glaciological parameters from multi-mission SAR data and field observations

09:20 - 09:40 Alison Cook
Spatial and temporal patterns of recent area change of marine-terminating glacier systems on the Antarctic Peninsula

09:40 - 10:00 Ted Scambos
Altimetry-determined mass balance of the northern Antarctic Peninsula

10:00 - 10:20 Helgi Bjornsson
Contribution of Icelandic ice caps to sea level rise. Trends and variability since the Little Ice Age

10:20 - 10:40 Marius Schaefer
Modelling past and future surface mass balance of the Patagonian Icefields

10:40 - 11:10 Break and coffee (room: Tove Birkelund)

11:10 - 12:10 **Regional glaciers 2** (room: 'Theodor Sorgenfrei'). Convener: TBA

11:10 - 11:30 Tobias Bolch
Assessing recent mass changes of Greenland's glaciers and ice caps - challenges and results

11:30 - 11:50 Michele Citterio
Mapping, monitoring and modeling of glaciers and ice caps in Greenland

11:50 - 12:10 Faezeh Nick
Future sea-level rise from Greenland's major outlet glaciers in a warming climate

12:30 - 13:30 Lunch, GEUS canteen

13:30 - 13:50 Geir Moholdt

Recent glacier changes in the Russian Arctic

13:50 - 14:10 Andrey Glazovsky
Russian High Arctic glaciers: state of knowledge, needs and gaps

14:10 - 14:30 Jon Ove Hagen
Svalbard glacier changes

14:30 Session close.

14:30 - 15:30 Poster session (room: Tove Birkelund)

15:30 - 16:30 **Discussion session 1**: *Observational needs for improved N/S glacier projections* (room: Tove Birkelund)
Chair: Jon Ove Hagen. Rapporteur: Nick Barrand

16:30 - 17:00 Coffee (room: Tove Birkelund)

17:00 - 18:00 **Discussion session 1**: *Observational needs for improved N/S glacier projections, continued* (room: Tove Birkelund)
Chair: Jon Ove Hagen. Rapporteur: Nick Barrand

18:00 Session close.

19:30 Workshop meal 2: Madklubben, Store Kongensgade 66, 1264 Copenhagen.

Wednesday 16th January, 2013

09:00 - 11:00 **Discussion session 2**: *Modelling needs for improved N/S glacier projections* (room: Tove Birkelund)
Chair: TBA. Rapporteur: Horst Machguth

11:00 - 11:30 Coffee (room: Tove Birkelund)

11:30 - 13:00 **Discussion session 2**: *Modelling needs for improved N/S glacier projections, continued* (room: Tove Birkelund)
Chair: TBA. Rapporteur: Horst Machguth

Summary and closing remarks (room: 'Theodor Sorgenfrei')

13:00 Meeting close.

2. Local Directions

From the Airport to the First Hotel Østerport:
- Take the Metro to Nørreport (approx. 15 Minutes)
- Change at Nørreport to any S-Train in direction of Østerport (there are only two directions at Nørreport: either to the Main Station or to Østerport).
- At Østerport you leave the S-Train and walk into the Østerport station building. From the exit of the building (on the street level) you will see the “First Hotel Østerport” to your left (located on the other side of the street)

As an alternative you can take the train at the airport directly to Østerport station. All the trains from the airport going into the direction of the main station stop at Østerport.

*You need a ticket for **three zones** to go from the airport to Østerport.*

From the Main Station to the First Hotel Østerport:
Take any S-Train in direction of Østerport.
From Nørreport to the hotel see above.

*You need a ticket for **two zones** to go from the airport to Østerport.*

From First Hotel Østerport to GEUS
When you leave the hotel through the main entrance, you turn right and immediately afterwards you turn right again into a small gravel road that leads you along the hotel. At the end of the gravel road (150 m) you reach the Øster Volgade that you follow in the same direction you came (still along the rail tracks). After about 150 m on the Øster Volgade you see the Geocenter building to your left with the parking space in front of it. Standing on the parking space take the small entrance on the left (GEUS main entrance).

Upon arrival at GEUS
Upon arrival on Monday, everybody has to pick up her/his badge at the GEUS reception. Before you take the GEUS and workshop entrance, go through the main entrance of the Geocentre and to the GEUS reception, which is to the left, directly after the entrance. There you can pick up your badge.

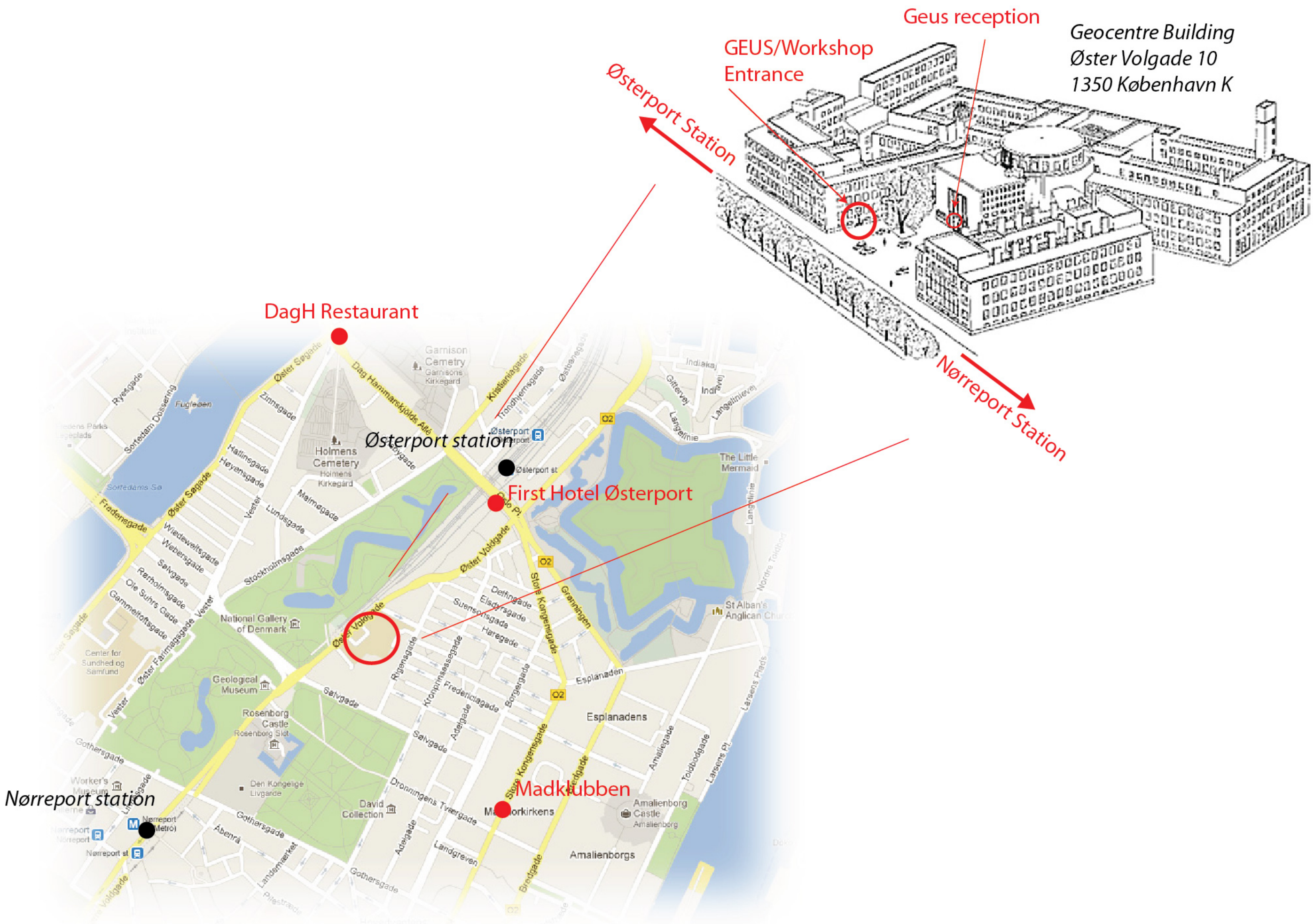
Addresses

GEUS
Øster Volgade 10
1350 København

First Hotel Østerport
Oslo Plads 5,
2100 København Ø

Dag H Cafe og Restaurant
Dag Hammarskjölds Allé 38,
2100 København Ø

Madklubben
Store Kongensgade 66
1264 København



Map of Copenhagen (left) with Nørreport and Østerport train stations, workshop venue (GEUS, right) and restaurants DagH and Madklubben.

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4. Abstracts

Alex Gardner, Geir Moholdt, J. Graham Cogley, Bert Wouters and John Wahr

A consensus estimate of glacier contributions to sea-level rise: 2003-2009

Mass wasting of glaciers outside of the ice sheets contributes greatly to present rates of sea level rise. There is however a large disagreement between recent global estimates derived from satellite gravimetry (Jacob et al., 2012) and those derived from the interpolation of local-scale mass balance and geodetic measurements (Cogley et al, 2009). Adding to this uncertainty are poorly constrained estimates of mass changes of the peripheral glaciers surrounding the Greenland and Antarctic Ice Sheets. Here we compare alternative estimates of regional glacier mass changes for 19 glacierized regions and derive a new global estimate from GRACE and estimates for the peripheral glaciers of Greenland and Antarctica using ICESat. We identify uncertainties and potential biases in existing global assessments and show how the large gap between them can be narrowed by combining results from the best available techniques in each glacier region.

Alison Cook

Spatial and temporal patterns of recent area change of marine-terminating glacier systems on the Antarctic Peninsula

Understanding the response of glaciers to warming air temperatures and ocean circulation changes in the Antarctic Peninsula (AP) region is critical for understanding future mass balance changes, and yet there is little quantification of change in the mass balance of individual basins and the processes controlling changes in their extent. One reason for this is that the AP is a complex mountainous glacier system and without a topographic model at sufficient resolution the boundaries between individual glacier systems have been difficult to identify.

We present an assessment of changes in area of marine-terminating glacier systems on the Antarctic Peninsula from the 1940s to 2010. We explain the methods used in obtaining these results: the production of a new high-resolution Digital Elevation Model (DEM) of the region derived from ASTER GDEM, and semi-automated drainage basin delineation using the DEM. This approach resulted in outlines for 1598 glacier systems: these include outlet and mountain glaciers, ice caps, piedmonts, ice- covered islands and 'ice walls' (indistinct marine-terminating ice mass). For calculation of changes in marine-terminating glaciers, those that are small ice-covered islands (<500-m wide), ice-walls, ice-shelf nourishing or land-terminating were removed, resulting in 903 glaciers with coastal-change data at various time periods since the 1940s. Area calculations, along with other attributes, were assigned to individual basins, thus enabling comparative statistical analyses.

We present a summary of these changes both by overall area change and by change in extent at 5-year time intervals, and describe patterns of ice loss both spatially (by latitude and by specific regions), and temporally (trends across time intervals). Although 90% of the 903 glaciers have reduced in size since the earliest recorded date, the area lost varies considerably between glaciers. 253 have shown minimal relative change (±1% of basin size), 355 have retreated between 1-5%, whereas others have retreated up to 45%. The relative area reduction is well-correlated with basin size although there are a number of outliers. We examine spatial differences in ice loss and compare regions that differ in consistency of retreat. A statistical analysis of glacier changes alongside glaciological controls obtained from the drainage basin outlines and the DEM can help us to understand why some glaciers behave anomalously, and here we discuss initial findings.

Andrey Glazovsky

Russian High Arctic glaciers: state of knowledge, needs and gaps

Glacial changes are reflected in number of parameters as geometry, mass balance, surface properties, hydrothermal structure, iceberg flux, dynamic instability. Glaciers and ice caps on the Russian High Arctic archipelagoes (FJL, NZ, SZ - Franz Josef Land, Novaya Zemlya, Severnaya Zemlya) cover more than 50,000 km2. Recently published results of GRACE and ICESat analyses show their slightly negative total mass balance in last decade.

Remote sensing data on duration of melt condition on glacier ice surface as indirect evidence of mass balance state show regional and interannual variability. Improvement of future projections of glacial state and behavior is strongly depends not only on climate component but also on deeper understanding of sea ice and ocean conditions as governing mechanism of iceberg discharge, local precipitation, cloudiness, heat fluxes.

Aslak Grinsted

An estimate of global glacier volume

I asses the feasibility of multi-variate scaling relationships to estimate glacier volume from glacier inventory data. Scaling laws are calibrated against volume observations optimized for the specific purpose of estimating total global glacier ice volume. I find that adjustments for continentality and elevation range improve skill of area-volume scaling. These scaling relationships are applied to each record in the Randolph Glacier Inventory which is the first globally complete inventory of glaciers and ice caps. I estimate that the total volume of all glaciers in the world is 0.35±0.07 m sea level equivalent, including ice sheet peripheral glaciers. This is substantially less than a recent state-of-the-art estimate. Area volume scaling bias issues for large ice masses, and incomplete inventory data are offered as explanations for the difference.

Christian Rodehacke, U. Mikolajewicz, M. Vizcaino

Greenland's response and impact in near-future projects: Fully coupled ice sheet-earth system simulations

As ice sheets belong to the slowest climate components, they are usually not interactively coupled in current climate models. Therefore, long-term climate projections are incomplete and only the consideration of ice sheet interactions allows tackling fundamental questions, such as how do ice sheets modify the reaction of the climate systems under a strong CO2 forcing?

The earth system model MPI-ESM, with the atmosphere model ECHAM6 and ocean model MPIOM, is coupled to the modified ice sheet model PISM. The ice sheet model represents the Greenlandic ice sheet at a horizontal resolution of 10 km. The coupling is performed by calculating the surface mass balance based on 6-hourly atmospheric data to determine the surface boundary condition for the ice sheet model. Furthermore, we've implemented ice sheet-ocean interaction. The response of the ice sheet to these forcings, which includes orographic changes and fresh water fluxes, are passed back to the ESM. In contrast to commonly used strategies, use a mass conserving scheme and do therefore neither apply flux corrections nor utilize anomaly coupling.

Under a strong CO2 forcing a disintegrating Greenlandic ice sheet contributes to a rising sea level and has the potential to alter the formation of deep water masses in the adjacent formation sites Labrador Sea and Nordic Seas. We will present results for selected scenarios and for idealized forcings, such as a growing atmospheric CO2 concentration that rises by 1% per year until four-times the pre-industrial level has been reached. We will discuss the reaction of the ice sheet and immediate responses of the ocean to ice loss.

Faezeh Nick

Future sea-level rise from Greenland's major outlet glaciers in a warming climate

Mass loss from the Greenland Ice Sheet has increased rapidly over the past decade, as a result of both increased ice discharge to the ocean and increased surface melting and runoff. Over the last decade, much of the increased ice loss is from calving of icebergs as several of Greenland's fast-flowing marine outlet glaciers have undergone sudden flow acceleration, extensive thinning and large retreat. Quantifying the future dynamic contribution of such glaciers to sea-level rise remains a major challenge since outlet-glacier dynamics are poorly understood. Here we present model simulations that include a fully dynamic treatment applied to four major ocean-terminating outlet glaciers, collectively draining ~22% of the ice sheet. Using an atmospheric and oceanic forcing from a mid-range future warming scenario, we project 19 to 30 mm sea-level rise from these glaciers by 2200. This contribution is largely dynamic in origin (80%) and is caused by several episodes of retreat into the overdeepened marine outlet glacier troughs. In our simulations, by 2200, Helheim, Kangerdlugssuaq and in particular Jakobshavn have retreated only halfway up the deep marine based troughs, and so mass loss of similar magnitude is likely to continue.

Geir Moholdt

Recent glacier changes in the Russian Arctic

The Russian Arctic archipelagos contain more than 50 000 km^2 of glaciers, but have no long-term mass balance records. We have made a complete glacier inventory over which we have analyzed ICESat laser altimetry, GRACE gravimetry and multi-temporal satellite imagery. Between 2003 and 2009, the region lost ice at an average rate of 9.1 +/- 2.0 Gt/y. Most of the mass loss occurred at low elevations in Novaya Zemlya due to high surface melt rates. Dynamic influences seem to be small although there has been an acceleration in the retreat of marine-terminating glaciers. The two other archipelagos, Franz Josef Land and Severnaya Zemlya, experienced small glacier changes except from a few dynamically active drainage basins. The most active of them is the eastern part of the Academy of Sciences Ice Cap which has thinned by about 40 m at average during the last two decades, corresponding to an iceberg calving of 40-50 Gt in total. The ice shelves of the region have been considered to be relatively stable until last summer when the largest one of them (the former Matusevich Ice Shelf ~200 km^2) broke up within short time. These recent changes will make it interesting to follow the Russian Arctic glaciers in nearest future.

Helgi Björnsson, Finnur Pálsson, Sverrir Gudmundsson, Eyjólfur Magnússon, Guðfinna Aðalgeirsdóttir, Tómas Jóhannesson, Oddur Sigurdsson, Thorsteinn Thorsteinsson and Etienne Berthier

Contribution of Icelandic ice caps to sea level rise. Trends and variability since the Little Ice Age

In total, Icelandic ice caps contain ~3,600 km^3 of ice, which if melted would raise sea level by ~1 cm. Here, we present an overview of mass changes of Icelandic glaciers since the end of the 19th century. They have both gained and lost mass during this period. Changes in ice volume have been estimated both through surface mass balance measurements (performed annually since ~1990) and digital elevation models derived from various satellite and airborne observations. While the glaciers showed little mass loss as the 20th century began, losses increased rapidly after 1925 and remained significant until the 1960s. After being near-zero or even positive in the 1980s and early 1990s, glacier mass budgets declined considerably, and have since the mid-1990s shown an average annual loss of 9.5 ± 1.5 Gt a^{-1}, contributing ~0.03 mm a-1 to sea level rise. Inter-annual variability in mass loss was high, from 2.5 to 25.0 ± 3 Gt a^{-1}, corresponding to surface mass balances of -0.2 to -2.2 m w.e. a^{-1} This variability is driven by climate fluctuations and also by transient albedo-reducing impact of volcanic eruptions.

H.Machguth, P.Rastner, T.Bolch, N.Mölg, L.S.Sørensen, G. Adalgeirsdottir, J. van Angelen, M. van den Broeke and X. Fettweis

Future Sea Level Rise Contribution of Greenland's Glaciers and Ice Caps

Glaciers and ice caps (GIC) on Greenland have yet received limited attention, mainly because a complete glacier inventory was missing until recently. We calculate future sea level rise contribution from surface mass balance of all of Greenland's GICs (~89000 km2) using a simplified energy balance model which is driven by three climate scenarios from the regional climate models HIRHAM5, RACMO and MAR. Glacier extent and surface elevation are modified during the model run according to a glacier retreat parameterization. Mass balance and glacier surface change are both calculated on a 250 m resolution digital elevation model yielding a high level of detail and ensuring that important feedback mechanisms are considered. Mass loss of all GICs by 2098 is calculated to be 2016±129 Gt (HIRHAM5 forcing), 2584±109 Gt (RACMO) and 3907±108 Gt (MAR). This corresponds to a total contribution to sea level rise of 5.8±0.4, 7.4±0.3 and 11.2±0.3 mm, respectively. Sensitivity experiments suggest that mass loss could be higher by 20—30 % if a strong lowering of the surface albedo would take place in the future. It is shown that the sea level rise contribution from the north-easterly regions of Greenland is reduced by increasing precipitation while mass loss in the southern half of Greenland is dominated by steadily decreasing summer mass balances. In addition we observe glaciers in the north-eastern part of Greenland changing their characteristics towards greater activity and mass turnover.

Jon Ove Hagen (with contributions from several)

Svalbard glacier changes

The archipelago of Svalbard has a glaciated area of ca. 35000 km^2. Glaciers range from small cirque glaciers of a few km^2 to large ice fields and ice caps, the largest being Austfonna of ca. 8000 km^2. The mass balance time-series started in 1968 and are among the longest continuous data series from the Arctic. However, they cover only a small fraction (~2%) of the total glaciated area. The time-series show no clear trend. The smaller, low-lying glaciers have had a steady negative mass balance, but no recent increased melt-rate can be clearly detected. The larger glaciers are in general more positive, since their accumulation areas are both at higher elevation and larger. Summer ablation is more variable than winter accumulation, so the summer temperatures provide most of the control on the net balance.

Geodetic mass balance calculations have been used to obtain a spatial cover. Most regions have experienced low-elevation thinning combined with high-elevation balance or thickening, except for glaciers that recently surged which show thickening in the ablation area and thinning in the accumulation areas. Surging has a large, temporary impact on the mass balance. During 2003–2008, the estimated geodetic mass loss was -4.3 ± 1.4 Gt/yr, or -0.12 ± 0.04 m w.e./yr. The largest losses occurred in the west and south, while northeastern Spitsbergen and the Austfonna ice cap have gained mass. However, the mass change over the past 40 years is estimated to be more negative, ca. -10 ± 0.5 Gt/yr. The calving is important, estimated to 4-8 Gty^{-1}, and stands for ca. 30-40 % of the total mass loss.

Marius Schaefer, Horst Machguth, Mark Falvey, Gino Casassa:

Modeling past and future surface mass balance of the Patagonian Icefields

Glaciers are strongly retreating and thinning in Patagonia. We analysed the climatic situation and the surface mass balance on the Patagonian Icefields in the past and the future using a combined modeling approach. The simulations were driven by NCAR/NCEP Reanalysis and ECHAM5 data, which were physically downscaled using the Weather Research and Forecasting regional climate model and simple sub-grid parameterizations. The surface mass balance model was calibrated with geodetic mass balance data of three large non-calving glaciers of the Northern Patagonian Icefieldand with point mass balance measurements. An increase of accumulation on both Patagonian Icefields was detected from 1990-2011 as compared to 1975-1990. Using geodetic mass balance data, calv- ing losses from the icefields could be inferred: the yearly calving fluxes on the Southern Patagonian Icefield increased from 22.4 ± 0.8 km^3 per year in 1975- 2000 to 36.4 ± 1.3 km^3 per year in 2000-2009. On the Northern Patagonia Icefield the calving fluxes were one order of magnitude lower. The 21st century projection of future mass balance of the Patagonian Icefields shows a strong in- crease in ablation from 2050 on and a reduction of solid precipitation from 2080, both due to higher temperatures. The prediction of the future mass balance of the Patagonian Icefield includes several sources of errors due to uncertainties in the prediction of future climate and due to possible variations in ice dynamics which might modify the geometry of the icefields and change the rate of mass losses due to calving.

Matthias Braun

Mapping glaciological parameters from multi-mission SAR data and field observations

Various satellite missions have carried or are still operating Synthetic Aperture Radar (SAR) instruments. They enable the mapping of remote glacier surface independent from solar illumination and are hence important tools for polar and in particular glaciological research. Recent satellite systems like ALOS PALSAR (L-band), TerraSAR-X or TanDEM-X (both X-band) provide high resolution in additional to the existing C-band missions. With the launch of Sentinel-1 and ALOS-2 EU/ESA as well as JAXA will provide continuity to existing time series.
The presentations will show examples from glaciological products (glacier extent, snow/glacier facies, ice dynamics, surface elevation, structural glaciological maps) derived from multi-mission SAR data from the Antarctic Peninsula, the Karakoram-Himalaya region and Alaska.

Matthias Huss

Ice volume and thickness distribution of all glaciers and ice caps around the globe: a new physically-based estimation method

Most studies determine the volume of mountain glaciers and ice caps based on empirical volume-area scaling that is known to show significant uncertainties for individual glaciers. Moreover, state-of-the-art glacier change models also require information on the spatial distribution of ice thickness. Here, a new physically-based approach for calculating glacier volume and thickness on a fine grid is presented and applied to all glaciers and ice caps worldwide. By combining glacier outlines of the globally complete Randolph Glacier Inventory with terrain elevation models (SRTM/ASTER), distributed thickness of individual glaciers is inverted from surface topography based on ice flow dynamics. Results are validated against a comprehensive set of both volume, and point thickness observations for 300 glaciers across most glacierized regions of the world. For mountain glaciers and ice caps outside of the two ice sheets (Greenland, Antarctica) we find a total ice volume of 170'000 km^3, or 0.42+-0.06 m of potential global sea-level rise. The potential and the uncertainties of our new data set for glaciers in high latitudes are discussed.

Michele Citterio, Signe Hillerup Larsen, Andreas Ahlstrom

Mapping, monitoring and modeling of glaciers and ice caps in Greenland

Per Wikman Svahn

Implications of scientific uncertainty on future sea level rise for planning and the role of scientist qua advisor

Future sea level rise presents planners in costal zones with a new and difficult situation. There are large uncertainties in projections of future sea level rise and many different methods are used (e.g., based on climate- and ice-sheet models, expert assessments of ice sheets and glaciers, semi-empirical models & paleo analogs). To this must be added the potential for rapid changes that could be initiated in the near future. These include "tipping points", such as a rapid collapse of the West Antarctic Ice Sheet or changes in ocean currents. In addition there is the risk of surprises, such as non-linear responses and new phenomena.

Planners in costal zones must deal with this situation today, but even more so in the foreseeable future. It is likely that there will remain considerable uncertainty in sea level projections, multiple methods and models, and difficulties in interpreting signals from potential tipping points and novel phenomena.

This paper discusses the implications of the above for planning. One consequence is that simple "predict-then act" and optimizing approaches becomes more risky. Instead other approaches need to be employed that better can deal with uncertainty in impacts and vulnerability. A review of the methods that been proposed is given, including those that focus on "robustness", "resilience" or "flexibility".

The paper then examines how new scientific studies and results best can be used to inform planning in light of the situation described above. Does it mean any new requirements on "providers" of scientific information to policy-makers and stakeholders? In particular, the role of the scientist qua advisor will be analyzed, based on recent developments in the philosophy of science on the role of values in science and policy.

Regine Hock

Assessing and projecting global scale glacier mass changes

Previous global scale glacier projections suffered from incomplete glacier inventories. Using the new globally complete Randolph Glacier Inventory (RGI) and temperature and precipitation scenarios from 14 GCMs we compute the glacier volume changes of all mountain glaciers and ice caps by 2100. We find volume losses of 17-43% and 25-53% for the rcp4.5 and rcp8.5 emission scenarios, respectively. A major shortcoming in these simulations is the neglect of mass loss by calving and submarine melting. For example, in Alaska 14% of the glacier area terminates in the ocean and 23% in lakes but little is known about the relative contribution of frontal ablation to total mass loss. In addition, volume projections depend on the initial ice volume which is not well known. More ice thickness measurements are needed to reduce the uncertainties in total ice volume.

Signe Hillerup Larsen, Michele Citterio, Regine Hock & Andreas Ahlstrøm

Mass and surface energy balance of A.P. Olsen ice cap (NE Greenland) from observations and modeling.

The A.P. Olsen Ice Cap (74.6° N, 21.5° W) in NE Greenland covers an area of 295 km^2, is composed by two domes, of which the western is the largest, and spans an elevation range between 200 and 1450 m a.s.l. In this study we calculate the 2008-2011 annual glacier mass balance based on observations, we model the surface energy balance over the same period, and we reconstruct annual glacier mass balance since 1995. We use GlacioBasis monitoring programme observations from a network of 15 ablation stakes and three automatic weather stations (AWS) at 600 m (ca. 100 m higher than the terminus) and at 840 m on the main glacier outlet of the western dome, and at 1430 m in the accumulation area. Accumulation is measured every year in springtime by snow radar surveys calibrated with manual probing and density profiles from snow pits. GlacioBasis data start in 2008, but a longer time series starting in 1995 is available from a weather station at 44 m a.s.l. close to Zackenberg Research Station, ca. 30 km further west. Shorter data series from three more AWS on land at 145 m, 410 m and 1283 m a.s.l. are used to estimate monthly average temperature lapse rates outside of the glacier surface boundary layer, and to setect the occurrence of temperature inversion layers. The surface energy mass balance is dominated by the radiative fluxes and shows a significant effect of shadows from the valley side over parts of the tongue, especially early and late in the melt season when the sun is lower over the horizon. A temperature index model driven by the 1995-2008 time series and calibrated using post-2008 glacier mass balance measurements shows large interannual variability, with 5 out of 6 years between 2003 and 2008 being the most negative mass balance years of the entire 1995-2011 period. 2008 in particular was the most negative year, with almost no net accumulation over the entire glacier. This matches observation at Freya Glacier on Clavering Island, ca. 40 km SW of A.P. Olsen (WGMS, 2011). The most positive mass balance year was 1999.

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Altimetry-determined Mass Balance of the northern Antarctic Peninsula

We have combined satellite stereo-image digital elevation model (DEM) differencing and along-track elevation changes derived from Ice, Cloud and land Elevation Satellite (ICESat) data to measure ice mass loss for the Antarctic Peninsula north of 66°S between 2001-2010, focusing on the ICESat period of operation (2003-2009). DEM differencing is used to estimate ice-covered areas below 1000m. For higher elevaitons and for glacier basins without DEM differencing coverage, we used cross-track adjusted repeat-track analysis of ICESat profiles using a regional DEM. Ice mass loss for the study region over this period averages 28.8 ± 5 Gt a^{-1}. The dominant areas of mass loss are glacier trunks affected by eastern Antarctic Peninsula ice shelf retreats in the past 25 years, with 10 formerly ice-shelf-buttressed glaciers accounting for 66% of the loss (out of 33 catchment basins overall). However, low rates of elevation loss pervade the entire study region, for high elevation areas, major islands, and most of the western glacier trunks. Rapid accumulation increases over the past few decades are apparently compensated by a combination of increased firn densification (not a mass change signal) and still-ongoing effects of decades- to centuries-old western coast ice retreats.

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Assessing recent mass changes of Greenland's glaciers and icecaps - challenges and results

The melt water of the glaciers and ice caps (GIC) on Greenland could potentially make a substantial contribution to global sea-level rise during this century. An important baseline information is a detailed glacier inventory. The glaciology group at the University of Zurich compiled an inventory from more than 70 Landsat scenes (mostly acquired between 1999 and 2002) using semi-automated glacier mapping techniques. The GIMP digital elevation model (DEM) was used to derive drainage divides from watershed analysis and topographic attributes for each glacier entity. A major challenge was the application of a consistent strategy to separate the local GIC from the ice sheet. To serve the requirements of different communities, we have assigned three connectivity levels (CL) for the local GIC with the ice sheet (CL0, CL1, CL2; i.e. no, weak, and strong connection) to clearly, but still flexibly, distinguish the local glaciers and ice caps (GIC) from the ice sheet and its outlet glaciers. In total glaciers larger than 0.05 km^2 cover an area of 130,076 ± 4032 km^2, or 89,720 ± 2781 km^2 without the CL2 GIC. The latter value is about 50% higher than the mean value of more recent previous estimates. This inventory enabled us to determine the GIC's mass changes based on space-borne laser altimetry (ICESat GLAS) data. The accuracy of the altimetry measurements of about ±0.5 m even over rough surfaces like glaciers and the small footprint of ~70m makes the data ideal to assess elevation changes. A major challenge with ICESat data is the sparse density of the tracks (the tracks are separated horizontally by ~30 km in southern and ~10 km in northern Greenland), and the fact that the repeat tracks can be several hundred metres apart. A further challenge is the volume to mass conversion. We extrapolated the dh values based on the glacier hypsometry and applied corrections for firn compaction and a density model that are based on climatic conditions for the conversion from volume to mass changes. The Greenland GIC which are clearly separable from the ice-sheet lost 30.1 ± 9.4 Gt a^{-1} or 0.08 ± 0.026 mm a^{-1} sea-level equivalent (SLE) between 2003 and 2008. When considering all GIC (including the Geikie Plateau) the loss is 46.8 ± 13.4 Gt a^{-1} (0.12 ± 0.038 mm a^{-1} SLE). This is a significant fraction (about 20%) of the reported overall mass loss of Greenland (including the ice sheet) and up to 10% of the estimated contribution from the world's GIC to global sea-level rise. The mass loss of the GIC per area unit is about 2.5 times higher than for the ice sheet, and marine-terminating glaciers account for about half of the mass loss. This loss was highest in the south-eastern sector and lowest in the northern sector of Greenland.

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Mapping of ice caps in Iceland with LiDAR

Airborne LiDAR mapping of the surface of glaciers and ice caps in Iceland was initiated during the International Polar Year 2007–2009 and essentially completed in the summer of 2012. The entire surface of each glacier/ice cap surveyed, yielding accurate maps of crevassed areas and other regions that are hard to access in ground-based surveys. The vertical accuracy of the surveys is better than 0.5 m and Digital Elevation Models (DEMs) with a resolution of 5x5m are produced. All glaciers in Iceland >10 km^2 in area have now been mapped with LiDAR, in total ~11 000 km^2 of ice-covered areas. The total surveyed area is >15 000 km^2, including proglacial areas and repeated mapping of some areas with rapid changes due to subglacial eruptions and emptying of subglacial water bodies. These new surface maps will serve as a benchmark for future evaluation of changes in the areal extent and volume of all major glaciers and ice caps in Iceland.

The publicly available DEMs are useful for glaciological and geological research, including studies of ice-volume changes, estimation of bias in mass-balance measurements, studies of jökulhlaups and subglacial lakes formed by subglacial geothermal areas, and for mapping of crevasses. The LiDAR mapping includes a 500–1000m wide ice-free buffer zone around the ice margins which contains many glacio-geomorphological features, and therefore the new DEMs have proved useful in geological investigations of proglacial areas. Comparison of the LiDAR DEMs with older maps confirms the rapid ongoing volume changes of the Icelandic ice caps which have been shown by mass-balance measurements since 1995/96. In some cases, ice- volume changes derived by comparing the LiDAR measurements with older DEMs are in good agreement with accumulated ice-volume changes derived from traditional mass-balance measurements, but in other cases such a comparison indicates substantial biases in the traditional mass-balance records.

Ongoing changes in glaciers in Iceland are changing design assumptions and operating conditions for various infrastructure in the country such as hydropower plants, power and communication lines, roads and bridges. Detailed monitoring and forecasting of the glacier changes is therefore of high priority in Iceland as well as in several neighbouring countries. Monitoring of the Icelandic glaciers is also a contribution to ongoing research on the effects of global warming on Arctic/Sub-Arctic ice caps and mountain glaciers worldwide. Planning of future resurveying of the glaciers with LiDAR or satellite observations is therefore an important task for planning of future glaciological research in Iceland.

Valentina R. Barletta

Mass changes estimates in glaciated regions with low-viscosity mantle: Patagonia, Iceland and the Antarctic Peninsula

Present-day mass changes in glaciated regions are causing large uplift rates. The latter is usually entirely attributed to the instantaneous elastic response of the Earth, which is certainly the largest contribution, but not the only one. The viscous mantle also adapts to the surface mass changes with a delayed response which, depending on the mantle viscosity, after some years can become an appreciable contribution to the total uplift rate. This contribution, known as Glacial Isostatic Adjustment (GIA), is usually solely related to the last ice age ended thousands of years ago However, recent evidences suggest a much faster Earth reaction in several glaciated areas (e.g. Patagonia, Iceland, Alaska, Antarctic Peninsula), which are very sensitive to climate change. This study investigates the viscous component in the uplift rate caused by present-day mass changes like the one detected in the last 10 years by the GRACE mission. We compute mass balance using the latest GRACE data release and we use this solution to show the role of fast Earth mantle flow triggered by very recent or even on-going ice variations. This local effect induces an uplift rate which is an important fraction of the total one. This implies that in those regions recent ice history must be accounted for when computing GIA correction and that a very tight coupling between ice dynamic and solid Earth modeling is necessary.