Book of Abstracts

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The iSTAR project – progress and future plans

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iSTAR is a directed research program, funded by the Natural Environment Research Council, UK, with the main goal of improving our understanding the dynamics of ice sheet stability, and in turn improving our predictions for future mass loss rates and sea-level rise. To achieve this goal, the program has two main components, investigating ocean forcing on the West Antarctic Ice Sheet, specifically in the Amundsen Sea, and the ice sheet response to this forcing. An array of oceanographic moorings was deployed from RV Araon in Feb.-Mar. 2012 to investigate the flow of CDW onto the continental shelf and southward toward Pine Island Glacier. We present a summary of the work undertaken this season and plans for the next 2 years.

Albrecht, T.

Fracture-induced softening for large-scale ice dynamics

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Shearing and expansive ice flow can result in fractures, which are carried with the flow downstream forming bandlike structures. Those fractured zones affect the ice flow in the entire ice shelf, its stability and hence its buttressing effect on the upstream tributaries. We account for fracture processes by introducing a two-dimensional fracture density field in the large-scale prognostic Potsdam Parallel Ice Sheet Model (PISM-PIK) and define first-order criteria and rates for the initiation, growth and healing of fractures depending on the prevailing stress regime. The fracture density field provides a continuum mechanics approach of incorporating the macro-scopic effect of fracture mechanics by determining a local softening factor, which reduces effective ice viscosity. Accordingly, flow simulations yield much more realistic flow patterns with large across-flow velocity gradients in fracture-weakened regions. This model framework is expandable to grounded ice streams as well as climate-induced enhanced fracturing. It further gives rise to an enhanced fracture-based calving model.

Anker, Paul G. D. **The BAS ice shelf hot water drill: current design and drilling methods**

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The 2011-12 Antarctic field season saw the first use of a new British Antarctic Survey ice shelf hot water drill system on Larsen C and George VI ice shelves. In total, five holes at three locations were successfully drilled through almost 400 m of ice to provide access to the underlying ocean, including the first access beneath Larsen C Ice Shelf. Whilst the drilling methodology has remained relatively unchanged over the last 20 years, this latest design eliminates or reduces past equipment failure modes and exploits developments in control systems and three phase power supply. The simple modular design allowed for rapid assembly and commissioning of the system, which proved highly reliable, requiring minimal supervision once the appropriate drilling parameters were set. The three phase petrol generator enabled the use of more compact motors and control systems, reducing the demands on field logistics. An acoustic housing for the generator also provided much quieter working conditions. A number of novel solutions to various operational sub-ice shelf profiling and mooring deployment issues were successfully employed through the hot water drilled access holes to aid the positioning, recovery and deployment of instruments. These solutions include a catch for accurate positioning of mooring cables with respect to ice base and a cable deployed tool to release profiling instrumentation trapped against the ice base. Also, a drill nozzle with a highly flexible 1 m diameter brush was used to enlarge the hole only at the ice shelf base, facilitating through ice shelf turbulence profiler deployments and preventing profiling instruments from becoming trapped at the ice base.

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Assmann, K.M. **Variability of shelf inflow characteristics – observations and modelling in the Amundsen Sea**

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Oceanographic research in the Antarctic marginal shelf seas has traditionally been focused on their outflow that ventilates the global abyssal ocean as deep and bottom waters. As the observational data base has grown sufficiently to identify interannual changes in the outflow products, attributing the causes behind those changes to local shelf processes and the source water masses entering the shelves has gathered importance. Observational and modeling studies in the Ross Sea indicate that the recent freshening in the dense shelf waters there are caused by upstream changes in the freshwater fluxes that counteract an apparent increase in local sea ice formation.

The interest in shelf inflow variability has also increased in marginal seas where deep and bottom water production does not occur, like the Amundsen and Bellingshausen Seas. While interest in the Bellingshausen Sea is also motivated by biological production, the main reason for this is that oceanic heat transport has been identified as a critical control on the mass balance of the West Antarctic Ice Sheet. Circumpolar Deep Water (CDW) with temperatures several degrees above the freezing point has been observed in the ice shelf cavities within the Amundsen Sea embayment. In view of the recent thinning observed in the glaciers terminating in the Amundsen Sea embayment, it is crucial to identify changes in the CDW transport onto the shelf and the mechanisms controlling it.

In this talk we will concentrate on the Amundsen Sea shelf break where CDW transport onto the continental shelf appears to occur principally within several glacial troughs that intersect the shelf break. Until recent years the Amundsen Sea has been a region sparse in oceanographic data due to its heavy sea ice cover. A submarine trough at the central Amundsen Sea shelf break offers the most complete set of observations to identify inter-annual changes in on-shelf CDW transport over the past 15 years and we will therefore focus our analysis here. The available data in the trough now includes two full occupations in 2003 and 2006 and scattered stations between 1994 and 2009. We use these observations supplemented by model results to assess the effect of changes in circulation and water mass composition on the on-shelf heat transport in this region and discuss processes that might account for these changes.

Bromwich, David

The ACCIMA Project – Coupled Modeling of the High Southern Latitudes

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The Atmosphere-ocean Coupling Causing Ice Shelf Melt in Antarctica (ACCIMA) collaborative project combines a team of researchers at The Ohio State University (OSU), New York University (NYU), and Old Dominion University (ODU) to model the multi-disciplinary processes impacting the Antarctic Ice Sheet. Understanding the mass balance of the Antarctic Ice Sheet is critical for projecting global sea-level change. The Antarctic Ice Sheet also responds to climate phenomena with signatures on the decadal time scale, such as the El Niño-Southern Oscillation, the Southern Annular Mode, and the Pacific Decadal Oscillation. Important mesoscale phenomena in the atmosphere and ocean deliver heat to the bottom of the floating Antarctic ice shelves, such as those in the Amundsen Sea embayment. Therefore, a mesoscale approach is required to treat the system processes that melt Antarctic ice shelves.

To better understand the physical processes of ice, ocean and atmosphere underlying Antarctic change, we select as the primary tool for the project a coupled modeling system including the Polar-optimized Weather Research and Forecasting model (Polar WRF) for the atmosphere, the Regional Ocean Modeling System (ROMS) for the ocean, and the Los Alamos sea ice model (CICE) for sea ice. A thermodynamic ice shelf model that is already part of ROMS is included. Upon project completion we will assess the feasibility of further advancing this regional modeling effort. If our downscaled hindcast and forecast regional model simulations are evaluated to be an improvement over coarse-resolution modeling, we would in the future propose to include an interactive ice sheet into our coupled system so as to freely evolve the ice sheet and thereby make quantitative projections of sea level change.

Work on the coupled modeling system is still underway. However, retrospective decadal simulations have been started for separate atmosphere and ocean-sea ice-ice shelf models at 10 km resolution on a common model grid that covers the continent and extends out over the entire Southern Ocean up to at least the Subantarctic Front and some preliminary results (including estimated ice shelf basal melt rates) will be shown.

Bügelmeyer, M.

From ice-shelf to icebergs: impact of cryosphere – ocean interaction in a coupled climate model of intermediate complexity

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The influence of icebergs on the climate system is well known. On the one hand they act as a source of fresh water and on the other hand icebergs are a sink of latent heat. As a consequence icebergs clearly affect the ocean stratification and the formation of sea ice. The influence of icebergs on the climate system is especially important during so – called Heinrich events, which were periods with huge armadas of icebergs during the glacial climate. So far, icebergs have mostly been parameterised in global climate models as freshwater and heat fluxes. More recently, an iceberg module was used to generate bergs at specific locations. In this study a version of the Earth System Model of Intermediate Complexity, LOVECLIM, that includes a 3D dynamic – thermodynamic iceberg module (Jongma et al, 2008) is coupled to the Grenoble model for ice shelves and land ice (GRISLI, Ritz et al, 1997; 2001). Therefore, the icebergs are generated according to the amount of mass loss at the calving sites of GRISLI. The ice-sheet / ice-shelf model itself depends on the precipitation and temperature that is calculated by LOVECLIM. The calving rate of GRISLI is given back to the dynamic iceberg module in the form of an ice volume flux. The volume flux is taken to generate icebergs according to the size and mass distribution of Bigg et al. (1997). These bergs are then released at the same locations as the calving took place. In the present study we analyse the effect of moving icebergs on sea surface temperature, salinity and convection in comparison to an experiment where the ice volume that is lost by calving is given to the ocean directly as a freshwater flux at the calving site. Moreover, the influence of the start position and the initial size of the icebergs on their tracks and on their lifespan is investigated. At present we focus our study on the northern Hemisphere (Greenland ice-sheet). All experiments are done under preindustrial forcing.

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Candy, Adam S.

Modelling of the Sub-Ice-Shelf Ocean Cavity and its Interaction with the Ice Sheet

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Quantitative prediction of future sea-level is currently limited because we lack an understanding of how the mass balance of the Earth's great ice sheets respond to and influence the climate. Understanding the behaviour of the ocean beneath an ice shelf and its interaction with the sheet above presents a great scientific challenge. A solid ice cover, in many places kilometres thick, bars access to the water column, so that observational data can only be obtained by drilling holes through, or launching autono-mous vehicles beneath, the ice. In the absence of a comprehen-sive observational database, numerical modelling can be a key tool to advancing our understanding of the sub-ice-shelf regime.

While we have a reasonable understanding of the overall ocean circulation and basic sensitivities, there remain critical processes that are difficult or impossible to represent in current operational models. Resolving these features adequately within a domain that includes the entire ice shelf and continental shelf to the north can be difficult with a structured horizontal resolution. It is currently impossible to adequately represent the key grounding line region, where the water column thickness reduces to zero, with a structured vertical grid. In addition, fronts and pycnoclines, the ice front geometry, shelf basal irregularities and modelling surface pressure all prove difficult in current approaches.

The Fluidity-ICOM model (Piggott et al. 2008) simulates non-hydrostatic dynamics on meshes that can be unstructured in all three dimensions and uses anisotropic adaptive resolution which optimises the mesh and calculation in response to evolving solution dynamics. These features give it the potential flexibility required to tackle the challenges outlined above and the opportunity to develop a model that can improve understanding of the physical processes occurring under ice shelves, and their interaction with the ice sheet.

The approaches taken to develop a multi-scale model of ice shelf ocean cavity dynamics will be presented; including a discussion of the dynamical adjustment of the ice-ocean interface, the parameterisation of meltrate over this boundary, and the strategies required to model non-hydrostatic dynamics in domains typical in this regime. The larger of the ice shelf ocean cavities of Antarctica lie in domains with very small aspect ratios, on the order of $1{:}10^3$. Elements of the mesh can typically have a similar acute anisotropic form, with aspect ratios of the order of $1{:}10^3$, up to $1{:}10^4$ in some parts of the domain. This anisotropy necessitates a careful treatment and the strategy developed will be described.

Verification of this modelling approach is underway with a comparison to the idealised modelling study of Holland et al. 2008. Results of this work will be summerised at this meeting in Kimura et al. 2012. Together, in combination with this presentation, progress towards an application of this approach to multi-scale modelling of more realistic ice shelf ocean cavity systems will be demonstrated. This is in preparation for future validation of the model with data collected by the autonomous submarine Autosub, which was recently deployed under the Pine Island Glacier (Jenkins et al. 2010).

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Christmann, J.

Simulation of Calving Events and Calving Rates at Antarctic Ice Shelves

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For a better understanding of the influence of environmental parameters on calving processes, the nature and frequency of calving events are investigated from a fracture mechanical perspective. In the past two predominant approaches to model ice were applied: on long time scales ice is modeled as a viscous fluid and on short time scales as an elastic solid. As a first approach, linear elastic fracture mechanics can be applied because failure processes occur at a very short time scale. For simplification the ice shelf is modeled as a two dimensional block loaded by gravity, water pressure at the ice front and buoyancy forces at the bottom of the ice shelf. The computations are done with the Finite Element program COMSOL. In an initial simulation, the stresses in the ice shelf are computed with a linear elastic material behavior. It is found out that after the decay of the boundary disturbance, a stationary behavior of the computed parameters is reached. The simulations indicate that the position of the maximum tensile stress and therefore the most probable location for a calving event is at a distance of about two-thirds of the ice thickness away from the ice front. In order to observe the frequency of the calving event, the creep behavior of ice has to be included in the simulation. One aim of the work is to combine both approaches in a viscoelastic model, which leads to more realistic results. With this approach, the influence of the stress field and the flow velocities of the remaining ice shelf after a calving event are computed. Additionally, the time period until the system reaches the critical state again is simulated and compared to the flow distance in this time period.

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De Rydt, Jan

Modeling ice-ocean interactions beneath Pine Island Glacier ice shelf at various stages of its grounding line retreat

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Observations and ocean models have shown that the heat content of deep waters in Pine Island Bay, West Antarctica, has increased over the past decades, and that warm saline waters reach the grounding line of the Pine Island Ice Shelf (PIIS). The enhanced thermal forcing has been observed to coincide with an increase in average basal melt rates of the PIIS from about 20m/yr in 1994 to more than 30m/yr in 2009 [Jacobs et al., 2011]. At the same time, Pine Island glacier has continued its retreat from a submarine ridge [Jenkins et al., 2010], opening up a subglacial cavity which might further enhance basal melting processes through increased flow circulation. However, the interplay between the effects of increasing temperature and changing cavity geometry is poorly understood, and their relative impact on the thinning of the PIIS is unknown. To provide more insight into this issue, we use a high-resolution, Eddy-resolving ocean model for Pine

Island Bay, supplemented by a proper representation of ice-ocean interactions. The steady-state dynamics and melt rates for different geometric configurations of the cavity are investigated. As a reference case, we analyze the 2009 configuration, for which a substantial amount of remote sensing, CTD and Autosub data is available for model initialization and validation. Subsequently we present cases that correspond to the 1970s no-cavity scenario when Pine Island Glacier was still grounded on its subglacial ridge, and the 1990s scenario when the glacier had initiated its retreat. For all cases we investigate melt rates and ocean circulation patterns, as well as their sensitivity to changes in ocean temperature.

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Dinniman, Michael

Sensitivity of Modified Circumpolar Deep Water in the Ross Sea to Changes in the Winds and Atmospheric Temperatures

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Transport of relatively warm, nutrient-rich Modified Circumpolar Deep Water (MCDW) onto the Ross Sea continental shelf has important consequences for physical and biological processes. Strengthening of the cold southerly winds over the Ross Sea is thought to be one of the causes for the observed increases in sea-ice extent in this area and may have significant effects on other aspects of the circulation. A high resolution (5 km) regional ocean/sea-ice/ice shelf model of the Ross Sea is used to examine the effects of changes in the winds on the transport of MCDW onto the shelf, vertical mixing of MCDW and basal melt of the Ross Ice Shelf (RIS). Simple increases in the wind speed with no other atmospheric changes actually reduced the sea-ice, opposite of what has been observed. Increases in the winds combined with spatially uniform decreases in the air temperature led to realistic increases in sea-ice concentrations. Stronger winds and cooler air temperatures both led to increases in the quantity of MCDW advected onto the continental shelf and increases in the vertical mixing of MCDW into the upper water column, possibly increasing nutrient transport into the euphotic zone. The increased winds worked against the cooler air temperatures in changing the basal melt rate of the RIS and the slight change (4% increase) in the basal melt makes it difficult to tell from these experiments which effect dominates.

AR4 future scenario simulations typically show atmospheric warming and changes in wind speed (increases and decreases) and direction over the Ross Sea. One would expect from the idealized forcing simulations that warmer temperatures would reduce the MCDW that gets to the upper shelf waters, although this could be balanced out by changes in the winds. Preliminary results from simulations forced with winds and air temperatures from the SRES A1B scenario simulations from the MPI ECHAM5 model do show lower transport of MCDW onto the continental shelf and decreased mixing of MCDW into the upper waters for 2046-2050 compared to the end of the 20th century. The MCDW concentrations on the shelf are about the same for 2096-2100 compared to the end of the 20th century, although many other aspects of the circulation are different. The basal melt rate of the RIS increased slightly for 2046-2050 (6% increase) and 2096-2100 (9% increase) compared to the end of the 20th century.

Dutrieux, Pierre

Detailed basal topography of the floating portion of Pine Island Glacier, West Antarctica

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In January 2009 the underside of Pine Island glacier's floating ice shelf, in West Antarctica, was imaged along three 30 km tracks using an upward-looking multi-beam echo-sounder mounted on an autonomous underwater vehicle. At 4-m resolution with a 300-m wide swath, these observations reveal with unprecedented detail the presence of channels oriented along and across the direction of ice flow. Many of these channels are characterized by basal crevasses above their apex and successive 200-500 m wide, 10-20m high terraces on their flanks. A near coincident, high resolution airborne radar survey confirm the widespread nature of these features. The oceanographic and glaciological conditions of Pine Island glacier are discussed to shed light on the processes leading to their formation and maintenance. For comparison, observations of terraces in a different setting, but in a similar oceanographic context in Greenland are also presented.

Gladstone, R. M.

Calibrated prediction of Pine Island Glacier retreat during the 21st and 22nd centuries with a coupled flowline model

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A flowline ice sheet model is coupled to a box model for cavity circulation and configured for the Pine Island Glacier. An ensemble of 5000 simulations are carried out from 1900 to 2200 with varying inputs and parameters, forced by ocean temperatures predicted by a regional ocean model under the A1B ‘business as usual’ emissions scenario. Comparison is made against recent observations to provide a calibrated prediction in the form of a 95% confidence set. Predictions are for monotonic (apart from some small scale fluctuations in a minority of cases) retreat of the grounding line over the next 200 years with huge uncertainty in the rate of retreat. Full collapse of the main trunk of the PIG during the 22nd century remains a possibility.

Graham, Alastair

First sea-floor observations beneath Pine Island Ice Shelfand implications for its history

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Ice shelves are emerging as critical features in the debate on West Antarctic ice-sheet change and sea-level rise, because they limit ice-discharge and are sensitive to change in the surrounding ocean. The Pine Island Glacier ice shelf has been thinning rapidly since at least the early 1990s, while its grounded trunk has undergone acceleration and retreat. Although the ice shelf front has remained stable for the past six decades, ancient periods of ice-shelf collapse have been inferred from relict seabed features (‘corrugations’), preserved 340 km from the glacier, in Pine Island Trough. In this talk, we report the first high-resolution bathymetry gathered by an autonomous underwater vehicle, operating beneath the ice shelf, that provides evidence of recent and long-term change. Corrugated ridges and ploughmarks, mapped on a prominent sub-ice shelf ridge, closely resemble those observed offshore, interpreted previously as the result of iceberg grounding. The same interpretation here would indicate a significantly reduced ice shelf extent within the last 10 kyrs, implying that current glacier retreat is not without precedent. The alternative interpretation, that corrugations were not formed in open-water, would challenge ice-shelf collapse events interpreted from the geological record, and reveal new detail of another bed-forming process occurring at glacier margins. Observations of corrugations forming in nature are now urgently needed to understand the significance of contemporary changes in Pine Island Glacier and its ice shelf.

Greenbaum, Jamin

Seafloor shapes of the floating portion of Totten Glacier and Moscow University Ice Shelf, East Antarctica

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3. *Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart*
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New aerogeophysical data were acquired over coastal targets in East Antarctica during the 2011/2012 season of the international collaborative ICECAP project, as part of NASA’s Operation Ice Bridge. Data types include multi-frequency ice sounding radar, spot and scanning laser altimetry, magnetics,

and dual-instrument airborne gravimetry. The Totten Glacier and nearby Moscow University Ice Shelf were prime targets, resulting in 5 km x 5 km and 10 km x 10 km coverage, respectively, when combined with data acquired during the 2010/2011 field season. Recent studies using independent, space-based platforms indicate accelerating mass loss in the region surrounding Totten Glacier and Moscow University Ice Shelf during the last two decades (Zwally et al., 2005; Rignot et al., 2008; Chen et al., 2009; Pritchard et al., 2009) so these new data provide the sub-glacial context for those estimates and extend the record of surface elevation change begun using satellite radar and laser altimetry. Ocean forcing is a leading hypothesis for the observed changes (Rignot and Jacobs, 2002; Pritchard et al., 2009) and circulation modeling has shown that knowledge of sub-shelf seafloor bathymetry is critical to estimate sub-ice melt and freeze rates (MacAyeal, 1984; Thoma et al., 2005; 2008) which are needed to test whether the ocean is responsible for the observed surface changes. New gravity-derived bathymetry will be presented for the floating portion of the Totten Glacier and sample profiles of the Moscow University Ice Shelf will be shown. Uncertainty in water column thickness derived from sediment distribution models will also be discussed.

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Ha, H. K.

Intrusion of Circumpolar Deep Water over the continental shelf in the central Amundsen Sea

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3. *Korea Ocean Research and Development Institute;*
4. *British Antarctic Survey (BAS)*

The Amundsen Sea sector is the most rapidly changing region of the Antarctic ice sheets. It has been claimed that the rapid retreat of the glaciers (or ice sheets) is primarily related to the intrusion of warm Circumpolar Deep Water (CDW) which acts as an oceanic heat source. The Amundsen shelf troughs were suspected to be main conduits supplying warm CDW onto the continental shelf, eroding the underside of the ice sheets and glaciers.

Despite the critical role of CDW in the continental shelf of the Amundsen Sea, vital information is still lacking concerning the spatial-temporal variability of CDW. This is mainly because the Amundsen Sea is remotely located and the harsh weather and sea conditions limit the access to its inner shelf. This pronounced lack of data hinders the evaluation and prediction of physical processes and associated biogeochemical processes in the Amundsen Sea.

Using the icebreaker R/V Araon, three institutes (KOPRI, UGOT and BAS) launched a resource-sharing program for monitoring the distribution of CDW and associated rapid melting of glaciers in the Amundsen Shelf. During the 2012 Amundsen Sea cruise, 52 CTD stations were visited, and a total of 6 moorings were successfully recovered and 15 moorings were newly deployed at the shelf break, troughs and ice shelf front. During the presentation, preliminary data and results archived during the 2012 Araon cruise will be presented in terms of CDW intrusion and its synoptic circulation on the Amundsen shelf. The mechanism of external forcings (e.g., wind) controlling the inflow or outflow of CDW will be also discussed.

Hamilton, Gordon

Seasonal variations in terminus position of outlet glaciers in Greenland: insights from 10 years of near-daily remote sensing observations

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Climate Change Institute, University of Maine

Many of Greenland's marine-terminating outlet glaciers have undergone rapid retreat in the last decade, accompanied by accelerated flow speeds and dynamic thinning. Superimposed on this secular pattern of retreat, these glaciers undergo seasonal variations in terminus position, corresponding

roughly to wintertime advance and summertime retreat. This rough characterization obscures some important details of the timing of each phase. We compiled near-daily time series of terminus position for five of Greenland's largest outlet glaciers (Daugaard Jensen, Kangerdlugssuaq and Helheim glaciers in East Greenland, and Jakobshavn and Rink isbraes in West Greenland) using MODIS satellite imagery. There are spatial differences in the timing of the onset/completion of seasonal retreat among all the glaciers in our study, as well as temporal variability in terminus behavior for individual glaciers from year to year. We examine if this spatial and temporal variability is linked to external environmental controls such as above-freezing air temperatures, warm SSTs or strong offshore winds, but find no simple relationship. Instead, we hypothesize that terminus geometry (ice thickness, subglacial topography, fjord bathymetry) exerts an important control on the response of marine-terminating glaciers to external forcing. Models for predicting outlet glacier response to climate change need to include this complex interaction between geometry and environmental forcing.

Hattermann, Tore

Ocean circulation and basal melting below the Fimbul Ice Shelf, Antarctica

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The mechanisms by which oceanic heat is delivered to Antarctic ice shelves are a major source of uncertainty when assessing the response of the Antarctic ice sheet to climate change. The Fimbul Ice Shelf is situated at the prime meridian and is the sixth largest ice shelf in Antarctica. The regional oceanography in the vicinity of the Fimbul seems to be typical for ice shelves along the the Eastern Weddell Sea. A narrow continental shelf lies between the glaciated coast and relatively warm Circumpolar Deep Water (CDW), and estimates of melting along this coast vary widely from study to study depending on how effective CDW comes in direct contact with the ice shelves here. Since 2010 extensive oceanographic and glaciological fieldwork of the Fimbul region has been accomplished, which has greatly improved our understanding of ice-shelf-ocean interaction in this region of Antarctica. The observations show cold cavity waters, with average

temperatures of less than 0.1 °C above the surface freezing point. This suggests that basal melt rates are mostly controlled by the by depression of the surface freezing-point with pressure, and are thus higher in deep areas close to the grounding-line.

There are however two main intrusions of warmer water to the cavity: (1) “eddy-like” bursts of Modified CDW enter the cavity at depth during some months; and (2) a seasonal inflow of warm and relatively fresh summer surface water flushes parts of the ice base from late February to May. We show model simulations of currents and melting using the Regional Ocean Modeling System (ROMS). The model uses cyclic east-west boundary conditions including a relaxation towards observed hydrography, and reanalysis winds at the surface. The simulations reproduce an inflow at the eastern sill, and an outflow of Ice Shelf Water in the surface layers in the west. Mixing across the deepest sill is driven by eddies that propagate westward with the coastal current, similar to what is seen at the sub-ice-shelf moorings. The basal melting appears to be directly linked to both the solar forcing at the surface and coastal oceanographic processes that controls the transport of deep ocean heat to the continental shelf.

Hellmer, H. H.

The 21st-century Weddell Sea hosing experiment

Hartmut H. Hellmer & Ralph Timmermann

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Simulations with the circumpolar coupled ice-ocean model (BRIOS) forced with the A1B atmospheric output of the Hadley Centre climate model HadCM3 revealed a sudden (within a decade) increase of Filchner-Ronne Ice Shelf (FRIS) basal melting from 0.2 m/yr (82 Gt/yr) to almost 4 m/yr (1600 Gt/yr) in the late 21st century, due to a redirection of the coastal current in the southeastern Weddell Sea. The enhanced freshwater input of 51 mSv ($1x10^3$ m^3/s) represents more than an order of magnitude increase relative to the FRIS melt flux calculated for present day conditions (Hellmer, 2004). In this talk we discuss the manifold consequences such freshwater 'hosing' has for Weddell Sea's ice conditions and hydrology with special emphasis on the shelf water characteristics and related deep and bottom water formation.

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Herraiz-Borreguero, Laura

Sub-Amery Ice Shelf circulation: new results from borehole observations

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The presence of ice shelves affects the rate at which ice sheets discharge grounded ice into the ocean and, consequently, indirectly affecting the rate of sea level rise. The seasonal variability of the circulation and water properties beneath the Amery Ice Shelf (AIS) are investigated using data from an instrumented mooring deployed through borehole AM1 in 2002, about 100 km from the calving front of the AIS. Data recorded from a second mooring deployed through borehole AM4 in 2006, about 170 km from the calving front along the same flow line as AM1, is also used as a reference. The mooring has three temperature and salinity recorders at different depths (441, 582 and 743 dbar from mean sea level) in the ocean cavity. Conductivity-Temperature-Depth profiles, measured at the time of the borehole drilling, are also used.

At AM1, a mixed layer, dominated by Ice Shelf Water (ISW), occupies the top 50 m (or more) of the water column in February, and reaches its maximum thickness (~ 156 m) during the end of July. High Salinity Shelf Water (HSSW), produced by sea ice formation off the front of the AIS, reaches site AM1 in August at intermediate and bottom depths. HSSW and ISW co-exist at intermediate depths, suggesting that the flow of HSSW is intermittent compared to the bottom flow. Observations suggest that marine ice forms continuously from the end of December to August. In August, the temperature at the mixed layer is above its *in situ* freezing point coinciding with the arrival of the relatively warm HSSW, likely depressing the formation of marine ice. The strong seasonal cycle in the water properties of the ocean cavity suggest that (at least) the outer 100 km of the AIS responds quickly to external ocean variability. We argue that the advection of HSSW disrupts the main “ice pump” (buoyancy driven) circulation under the AIS, allowing the formation of local “ice pump" cells. These local cells promote the sporadic (or scattered/isolated) formation of marine ice.

Heuzé, Céline

A comparison of global coupled climate models around Antarctica

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2. *School of Mathematics, University of East Anglia;*
3. *Hadley MetOffice Centre*

The Southern Ocean plays an important role in regulating the Earth's climate, hence its accurate representation in climate models is essential for predicting future climate change. Comparison of climate models has been facilitated by the Coupled Model Intercomparison Project Phase 5 (CMIP5), which provides a new set of coordinated model experiments in support of the next Intergovernmental Panel on Climate Change's Assessment Report (IPCC AR5). The Argo Project tremendously increases the data coverage in remote regions such as the Southern Ocean and provides an important new dataset for evaluating climate models. Simulations of salinity and potential temperature of the Southern Ocean for the period 1985-2005 from fourteen CMIP5 climate models and the high-resolution HiGEM are compared to new climatologies constructed from Argo and CTD/XBT datasets. For both salinity and temperature, we based the comparison of four main tests: Taylor diagrams (variance ratio, correlation and standard deviation difference), zonal means of particular layers (salinity minimum, salinity maximum and temperature minimum), value of the bottom layer and volumes of water in a certain range of temperatures (below 0°C, between 0°C and 2°C, 2°C and 4°C, and 4°C and 6°C). Given those criteria, we find that the majority of the climate models perform reasonably well, with however big discrepancies from one test to another. Apart from three models, they all have a correlation of more than 60% for the salinity; for the temperature, the correlation with the climatology is higher than 80% for both summer and winter. On the contrary, the zonal mean depth of the salinity minimum layer indicates that most models produce a surface fresh layer north of the ACC whereas the climatology does not. Here we discuss possible causes of the different model behaviours, including their resolution and model physics.

Heywood, Karen

Observations of processes on the Antarctic continental shelf and slope, and future plans in Pine Island Bay

Karen Heywood
School of Environmental Sciences, Univ. of East Anglia, UK

Our goal is to better understand the transport of ocean heat toward ice shelves. Here I will present two observational projects in the Weddell Sea looking at physical processes that determine exchange across the Antarctic continental shelf break. As part of the multinational SASSI project, we deployed

a moored array on the Antarctic continental shelf and slope in front of the Riiser-Larsen Ice Shelf, in the southeastern Weddell Sea (~18°W). The array encompasses the Antarctic Slope Front, marking the boundary between cold, fresh shelf waters influenced by melting of the Antarctic Ice Sheet and warmer, saltier waters influenced by the inflow of waters originating in the Antarctic Circumpolar Current. Two hydrographic sections revealed northeastward undercurrents trapped against the steepest part of the slope, associated with an onshore upward sloping of isopycnals. The moored time series suggest that coastally trapped waves may be the mechanism setting up these undercurrents.
Ocean gliders were deployed in the northwest Weddell Sea during the GENTOO project during the austral summer 2011-2012. Multiple cross shelf glider sections, occupied simultaneously by 3 Seagliders, measured temperature, salinity, dissolved oxygen, and depth-averaged current in the upper 1000 m along sections across the Antarctic continental shelf and slope into the Weddell Sea. They reveal intrusions crossing the continental shelf break onto the shelf. GENTOO demonstrates the capability of ocean gliders to play a key role in a future polar ocean observing system, resolving temporal evolution and variability over a broader spatial scale than a mooring. We conclude by mentioning plans for future observations and modelling in the region of Pine Island Bay.

Hindmarsh, R.

An Observationally-Validated Theory of Viscous Flow Dynamics at the Ice-Shelf Calving-Front

Hindmarsh, Richard , *British Antarctic Survey*

An analytical theory is developed for ice flow velocity in a boundary layer couplet at the calving front. The theory has simple quantitative characteristics that relate ice front velocity to thickness, strain rate and shelf width, matching one set of empirically derived relationships (Alley and others, 2008) and implying that these relationships predict ice velocity rather than calving rate. The two boundary layers are where longitudinal and transverse flow fields change from the interior flow to patterns consistent with the calving-front stress condition. Numerical simulations confirm the analytical theory. The quantitative predictions of the theory have low sensitivity to unmeasured parameters and to shelf plan aspect ratio, while its robustness arises from its dependence on the scale invariance of the governing equations. The theory provides insights into calving, the stability of ice-shelf calving fronts, the stability of the grounding line of laterally resisted ice streams, and also suggests that the calving front is an instructive dynamical analogue to the grounding line.

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Holland, David

Near-continuous monitoring of Antarctic ice shelf and sub-ice shelf ocean temperatures

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During the Austral spring of 2011, two instrumented boreholes were completed through the McMurdo Ice Shelf (MIS) at Windless Bight to test rapid drilling and continuous monitoring methods. The boreholes were drilled using an approach combining ice coring for the upper portion of the borehole, with a new hot-point method for the final penetration through the ice-ocean interface. Each borehole was drilled through 190 m of ice to the ocean using two-person drilling team. The core drilling provided a 130mm diameter open borehole that remained dry through the drilling period. A hot point drill was used to penetrate into the ocean, and provided a 40 mm diameter borehole. The boreholes were instrumented with distributed temperature sensing (DTS) fiber-optic cables temperature measurements within the ~190m thick ice shelf and into the ocean below. The boreholes were also instrumented with traditional thermistors both in the ice shelf and in the ocean column and pressure transducers all attached to the armored DTS cables. Borehole BH1 is instrumented with fiber optic temperature sensing cable through the ice shelf and extending 30m into the ocean below. BH2, located 40 north of BH1, was used to test measurements to depths of 800m and also to demonstrate the potential for multiple independent installations through the same borehole. BH2 is completed with one DTS cable extending 600m below the ice/ocean interface, a logging pressure transducer and thermister located 450m below the ice/ocean interface and four additional logging thermistors. Temperature measurements are made every 1 meter along each optical fiber. The measurements are repeated hourly through the summer, and 4 times per day in winter months to conserve power. Data are transmitted off site via satellite link. After 3 months of operation (February 2012) there has been warming trend (~0.5 ^{o}C) in the upper ocean column that began in late December, consistent with previous measurements in the vicinity.

Holland, Paul

Wind-driven trends in Antarctic sea ice motion

Paul Holland[1], Ron Kwok[2]

1. *British Antarctic Survey, UK;*
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In contrast to the dramatic decline in Arctic sea ice, the Antarctic sea ice cover has experienced a slight areal increase in recent decades. Climate models fail to reproduce this trend, severely limiting confidence in their predictions of future ice behaviour. The small overall increase is the sum of much larger opposing trends in different sectors, but it is unclear which processes control this behaviour, with to regional studies linking the trends changes in atmospheric temperature or wind stress, precipitation, ocean temperature, and atmosphere or ocean feedbacks. In this study we present a 19-year dataset of satellite-tracked sea ice motion, revealing large and significant decadal trends in Antarctic sea ice flow that in most sectors are caused by trends in the local winds. The data allow us to quantify dynamic and thermodynamic ice processes, showing that wind-driven changes in ice advection are the dominant driver of ice concentration trends around much of West Antarctica. This implies that a faithful representation of wind changes is crucial to a successful model prediction of Antarctic ice trends. The discovery of ice motion trends also implies large changes in the surface stress that drives the Antarctic ocean gyres and the fluxes of heat and salt responsible for the production of Antarctic bottom and intermediate waters.

Humbert, Angelika

Calving at Pine Island Glacier

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4. *DLR IMF, Oberpfaffenhofen, Germany*
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At Pine Island Glacier, a marine based outlet glacier of the West Antarctic Ice Sheet, a rift formed in fall 2011, indicating an upcoming calving event. Calving is among the major unknowns in glaciology and hence, this calving event will be studied in a multi-disciplinary approach. In October 2011 a new 24km long rift has formed and propagated to a length of 28km in the subsequent weeks. Since then an area of about 750km^2 is suspected to calve off in the near future.
We will present the temporal evolution of this well surveyed calving event using high resolution radar imagery obtained by

the TerraSAR-X. This includes rift length and width, as well as the changes in the flow velocities estimated using speckle tracking. We compare this calving event with those in the years 2001 and 2007 using Radarsat and ERS data. Apparent changes in the shear margin in the past decade as a result of ungrounding of a former ice rise are presented. The decline of the formerly dome-like grounded spot has contributed to a widening of the shear margin and the formation of a heterogeneous ice mélange. This changes the lateral stress boundary condition that the floating extension of the glacier experiences.
Furthermore, we incorporate this rift into a flow modeling as a softened zone and compute the increase of flow speeds and compare this to speckle tracking velocities based on TerraSAR-X data. Additionally, these information are then incorporated into a fracture mechanical model of the crack and will be presented in a separate contribution.

Jakobsson, Martin

Huge ice shelves in the Arctic Ocean: a recurrent feature during glacial periods?

Martin Jakobsson

Department of Geological Sciences, Stockholm University

In 1996 the Lomonosov Ridge was mapped between about 85-88° N with a chirp subbottom profiler during the *Arctic Ocean 96* expedition with Swedish icebreaker *Oden* (Jakobsson, 1999). The chirp sonar profiles revealed extensive glacial erosion of the Lomonosov Ridge crest down to approximately 1000 m present water depth. A few years earlier, Vogt et al. (1994) had reported deep iceberg scours on the Yermak Plateau north of Svalbard. These first evidences of deep ice grounding in the Arctic Ocean were revealed a bit more than two decades after the hypothesis of a continuous floating ice shelf covering the Arctic Ocean was raised by glaciologist John Hainsworth Mercer in a publication (Mercer, 1970). The hypothesis of an Arctic Ocean ice shelf was subsequently discussed in the scientific literature. In its most extreme form, a 1000 m thick ice shelf covering the entire Arctic Ocean during the Last Glacial Maximum was postulated (Grosswald and Hughes, 1988).

Since icebreakers and submarines begun operating and map more frequently in the central Arctic Ocean over the last two decades, much more evidences of deep-draft ice erosion in the central Arctic Ocean have shed the light, e.g. on the central Lomonosov Ridge, Chukchi Borderland, Morris Jesup Rise, and the Yermak Plateau (e.g. Polyak et al., 2001; Jakobsson et al., 2008; 2010; Polyak et al.2007). In this presentation our current knowledge about extensions and timings of large ice shelves in the Arctic Ocean will be reviewed and discussed.

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Jendersie, Stefan

Circulation in the RIS cavity: a boundary condition experiment with ROMS.

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2. *National Institute of Water and Atmospheric Research, Wellington, New Zealand;*
3. *University of New South Wales at the Australian Defence Force Academy, Canberra, Australia*

Sea ice formation in McMurdo Sound is dominated by interaction with the ocean[1,2], with currents importing water masses that have been modified and produced beneath the Ross Ice Shelf (RIS) and in the Ross Sea Polynya[1,3],.
The Regional Ocean Modeling System (ROMS), a free surface, terrain-following, primitive equation model, is used to numerically model the circulation of the Ross Sea. The domain stretches from the RIS cavity at its southern boundary, and incorporates parts of the Antarctic Circumpolar Current as a northern boundary. The aim is to recursively adjust lateral boundary conditions in order to resemble the large scale circulation of the open parts of the Ross Sea to produce

behavior that agrees with observations and previous models. Special attention is given to water mass production on the continental shelf and exchange processes at the slope. The objective is to move solution-constraining boundaries as far away as possible from the region of interest; that is the ocean underneath the RIS. By allowing the circulation within the cavity to evolve without forcing exchange at the ice shelf front, ice-ocean interaction at the base of the RIS and polynya evolution in the Ross Sea provide boundary properties for a nested high resolution ocean model of McMurdo Sound.

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Jenkins, Adrian

A simple parameterisation of melting near the grounding lines of ice shelves and tidewater glaciers

Adrian Jenkins

British Antarctic Survey, Natural Environment Research Council, Cambridge, UK

Both the Antarctic and Greenland ice sheets are experiencing rapid change, at least in part as a result of acceleration of some of their larger, marine-terminating outlet glaciers. It is generally assumed that the accelerations have been driven by the ocean, probably through changes in the submarine melt rate. However, the processes that drive melting, particularly in the region close to the grounding line are difficult to observer and quantify. The rapid flow of the outlet glaciers is almost always associated with an active sub-glacial hydrological system, so in the key regions where the glaciers either discharge into ice shelves or terminate in fjords there will be a flow of freshwater draining across the grounding line from the glacier bed. The input of freshwater to the ocean provides a source of buoyancy and drives convective motion alongside the ice-ocean interface.
This process is modelled using the theory of buoyant plumes that has previously been applied to the study of the larger-scale circulation beneath ice shelves. The plume grows through entrainment of ocean waters, and the heat brought into the plume as a result drives melting at the ice-ocean interface. The equations are non-dimensionalised using scales appropriate for the region where the sub-glacial drainage, rather than the subsequent addition of meltwater,

supplies the majority of the buoyancy forcing. It is found that the melt rate within this region can be approximated reasonably well by a simple expression that is linear in ocean temperature, has a cube root dependence on the flux of sub-glacial meltwater, and a more complex dependency on the slope of the ice-ocean interface. The model is used to investigate variability in melting induced by changes in both ocean temperature and sub-glacial discharge for a number of realistic examples of ice shelves and tidewater glaciers. The results show how warming ocean waters and increasing sub-glacial drainage both generate increases in melting near the grounding line. The model is particularly appropriate for the study of melting at the quasi-vertical calving face of a tidewater glacier, where conventional ocean models struggle to capture the appropriate scales and fundamentally non-hydrostatic dynamics.

Johnson, Helen

Where the ice meets the ocean: Ocean circulation and properties in Petermann Fjord, Greenland

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2. *College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon*
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4. *Institute of Ocean Science, Department of Fisheries & Oceans, Sidney BC, Canada*

Changes in the mass balance of the Greenland ice sheet have important implications for global sea level, and for freshwater input to the high-latitude ocean. The Petermann glacier is one of four major outlet glaciers in Greenland that are grounded below sea level, and one of only two such glaciers retaining a substantial floating ice shelf, via which the ice sheet interacts directly with the ocean. Located in the northwest, the approximately 70 km long, 20 km wide ice shelf drains about 6% of the Greenland ice sheet. Radar and satellite observations suggest the ice shelf is in approximately steady state and that ocean driven basal melting is responsible for about 80% of losses in the ice shelf mass balance. Here we report findings from opportunistic ocean sampling efforts in the Petermann Fjord in August 2003, 2007 & 2009. Our goal is to establish the circulation within the fjord, the heat available to melt the ice, and the fate of the resulting freshwater. The sensitivity of the ice shelf to changing forcing in the region will be discussed, and the case made for a targeted observational and modelling study.

Jordan, James

Ocean Stabilisation of Larsen Ice Shelf

James Jordan[1,2], Paul Holland[1], Adrian Jenkins[1], Matthew Piggott[2]

1. *British Antarctic Survey*
2. *Imperial College London*

Many ice shelves on the Antarctic Peninsula have disintegrated over the last 50 years and the largest that remains, Larsen C Ice Shelf (LCIS), is thinning. These changes have been largely attributed to the rapid atmospheric warming of the region and increased basal melting of the ice shelf. However, a recent study [Holland et al., 2009] shows the presence of marine ice in rifts on the LCIS, which is believed to act as a stabilising force by “healing” rifts and preventing further fractures through the formation of marine ice bands. While the broad explanation of marine ice formation is well understood, ice formation and ocean flow within a rift cavity is not. The Imperial College Ocean Model (ICOM) has been used to investigate ocean dynamics and ice formation within an idealised 2D rift cavity for a range of water temperatures and flow speeds. A number of flow regimes were identified depending upon the initial conditions.

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Jullion, Loic

Recent decadal-scale freshening of the Antarctic Bottom Water exported from the Weddell Sea

Jullion, Loïc; Naveira Garabato, Alberto; Meredith, Mike; Holland, Paul; Courtois, Peggy; King, Brian.

On the Antarctic continental shelf, the intricate interplay between the ocean, the atmosphere and the cryosphere, leading to the formation of Antarctic Bottom Water (AABW), makes the water mass potentially very sensitive to the significant climatic changes observed in Antarctica. The recent observations of a rapid freshening of the AABW in the Indian and Pacific sectors of the Southern Ocean and a widespread warming in the Atlantic highlight this sensitivity. The driving mechanisms of this variability are still an open question. Here, we will report the first observational evidence of a recent decadal-scale freshening of the AABW exported from the Weddell Sea, based on the analysis of 17 occupations (1993 - 2011) of the SR1b hydrographic section in eastern Drake Passage. We will present evidence suggesting that the breaking of the Larsen B ice shelf and changes in the atmospheric conditions near the Antarctic Peninsula linked to the Southern Annular Mode are the most likely causes of the observed freshening. Recent inter-decadal changes in the

SAM have been linked to greenhouse gas emissions and ozone depletion, raising the possibility of a partially anthropogenic cause for the observed AABW freshening.

Kalén, Ola

Remote and local meteorological forcing of warm deep water inflows on the Amundsen Shelf

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2. *Earth and Space Research, Seattle*

Thinning and acceleration of the West Antarctic Ice Sheet has been attributed to basal melting induced by intrusions of relatively warm, salty water across the shelf. Hydrographic measurements on the Amundsen Shelf show instantaneous 0.2 - 0.4 Sv southward flows of warm deep water in cross-shelf troughs. We examine possible impacts of meteorological forcing on this southward flow. Temperature, salinity and velocity profiles measured for one year in the westernmost deep channel are compared with reanalysis and satellite-derived time series of the wind and atmospheric pressure fields in the West Antarctic sector. Both the baroclinic component of the trough inflow and the near-bottom temperature appear to be positively correlated with local along-shelf winds. In otherwords, eastward winds along the shelf break induce a baroclinic inflow of warm water. However, the remote wind field response is oppositely directed such that westward winds far offshelf are associated with baroclinic inflow of warm water on the shelf. The results are compared to the outcome of a numerical model for Antarctic Shelf regions. The barotropic current component is analyzed using satellite-derived OSCAR data.

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Kimura, Satoshi

Multi-scale Modelling of the Ocean Beneath Ice Shelves

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2. *Earth Science and Engineering, Imperial College London, UK*

There have been many efforts to explicitly represent ice shelf cavities in ocean models. These ocean models employ isopycnic, terrain-following, or z coordinates. We will explore an alternate method by using the finite-element ocean model, Fluidity-ICOM, to represent an ice shelf. The Fluidity-ICOM model simulates non-hydrostatic dynamics on meshes that can be unstructured in all three dimensions. These features give us the flexibility to represent a smoothly varying ice base in the presence of a vertical ice front. We will investigate the response of ice shelf basal melting to variations in ocean temperature using an idealized ice shelf. Melting near the grounding line produces melt water that is lighter than the surrounding. As the melt water ascends along the base of the ice shelf, the kinetic energy of the flow is converted to melt the ice. A band of melting area is concentrated at the Western region due to the Coriolis force in the Southern Hemisphere. A verification of this modelling approach will be presented with a comparison to previous studies of the idealized ice shelf.

Progress towards an application of the model to more realistic ice shelf ocean cavity systems will be demonstrated. This is in preparation for future validation of the model with data collected by the autonomous submarine Autosub, which was recently deployed under the Pine Island Glacier.

Kirchner, Nina

Statistical modeling of a former Arctic Ocean ice shelf complex using Antarctic analogies

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3. *Department of Geological Sciences, Stockholm University;*
4. *NASA Goddard Space Flight Center, Greenbelt, MD*

Geophysical mapping and coring of the central Arctic Ocean seafloor provide evidence for repeated occurrence of ice sheet/ice shelf complexes during previous glacial periods. Several ridges and bathymetric highs shallower than ~1000 m present water depth show signs of erosion from deep drafting icebergs, and armadas of icebergs, originating from thick outlet

glaciers and ice shelves. The distribution of mapped glacigenic landforms and dating of cored sediments suggest that the largest former ice shelf complex was confined to the Amerasian sector of the Arctic Ocean during Marine Isotope Stage (MIS) 6. However, spatial extensions of ice shelves are not possible to fully reconstruct from occasional groundings on bathymetric highs. Therefore, we apply a statistical approach where former Arctic Ocean ice shelf configurations are predicted from relations between contemporary Antarctic ice shelves and their local physical environments. The analysis of the ice shelves calving fronts' thicknesses is critical when searching for the sources of deep-drafting icebergs. We employ Extreme Value Theory to address the potential sources of deep-draft icebergs; an approach previously not applied in modeling Arctic paleoglacial configurations. Predicted extreme values of ice shelf draft along the calving front of a hypothetical MIS 6 ice shelf complex in the Amerasian sector of the Arctic Ocean match observed deep-draft ice berg scours if the ice shelf complex is sufficiently large. Thereby, independent evidence is provided in favor of an extensive MIS 6 ice shelf complex, which hitherto was inferred from interpretation of geophysical and geological data only (Jakobsson et al. 2010; Kirchner et al. 2012).

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Le Brocq, Anne

Sub-ice-shelf channels indicative of a channelised subglacial hydrological system in Antarctica

Anne Le Brocq[1], Neil Ross[2], Jennifer Griggs[3], Rob Bingham[4], Hugh Corr[5], Fausto Ferraccioli[5], Adrian Jenkins[5], Tom Jordan[5], Tony Payne[3], Dave Rippin[6], Martin Siegert[2]

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2. *School of GeoSciences, University of Edinburgh;*
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4. *School of Geosciences, University of Aberdeen;*
5. *British Antarctic Survey, Cambridge;*
6. *Environment Department, University of York*

Meltwater generated beneath the Antarctic Ice Sheet exerts a strong influence on ice flow and ocean circulation. The subglacial water flow resulting from lake outburst events has been shown to correspond with a speed up in ice flow on the Byrd ice stream (Stearns et al., 2008) and plays a crucial role in a thermally driven ice flow internal feedback (Tulaczyk et al., 2000). Meltwater plumes beneath ice shelves cause large melt rates due to entrainment of warmer ocean water (Jenkins et al. 1991, Payne et al., 2007) and contribute to circulation in the sub-ice-shelf cavity. However, despite its importance, the nature of the subglacial hydrological regime remains as yet poorly characterised in Antarctica. Here we present the first direct evidence of large-scale meltwater channels beneath the Antarctic Ice Sheet extending as a plume under the ice shelf, melting huge sub-ice-shelf channels. We infer that the channels beneath the grounded ice sheet are only a few metres wide, however, once the meltwater exits the grounded ice sheet it forms a plume, entraining local, warmer ocean water and melts channels into the underside of the ice shelf of the order of 1 km wide by 250 m deep. The sub-ice-shelf channels show evidence of migration of drainage routes, recording the history of the subglacial drainage network. The existence of a channelised hydrological system has implications for the modelling and prediction of future behaviour of the ice sheet, but also has implications for the representation of freshwater input to sub-ice-shelf circulation and the stability of the ice shelf.

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Lee, Jae Hak

Two types of wind effect on the Circumpolar Deep Water inflow into the Amundsen Sea shelf

Jae Hak Lee[1], Chang-Su Hong[1], Ho Kyung Ha[2], Tae Wan Kim[2], Sang Hoon Lee[2]

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2. *Korea Polar Research Institute*

Though it has been believed that basal melting of the Amundsen Sea Ice Sheet is induced by intrusion of relatively warm Circumpolar Deep Water (CDW), direct field observation to support it is rare. During the austral summer season in 2010 and 2012, Korea Polar Research Institute conducted hydrographic surveys in the central Amundsen Sea shelf using the Korean IBRV ARAON. The data of CTD castings and year-long mooring current meters indicate that the near bottom penetration of CDW into the shelf area has temporal variability at multiple time scales ranging from sub-seasonal to inter-annual. Such variations in the intensity of CDW intrusion may be attributed to changes in regional wind forcing. We will present two types of conceptual model for wind effect on the CDW inflow.

Losch, Martin

Estimating Pine Island Ice Shelf melt rates from hydrography and an ocean circulation model

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2. *Massachussetts Institute of Technology;*
3. *NASA Jet Propulsion Laboratory;*
4. *British Antarctic Survey*

The fast flowing ice stream of the Pine Island Glacier (PIG) in West Antarctica feeds the Pine Island Ice Shelf (PIIS). Its flow acceleration, thinning and mass loss has been associated with changes in sub-ice shelf ocean circulation. Several recent field and remote sensing programs focused on the Pine Island Embayment and PIG to study the local circulation, water mass properties, as well as bathymetry and cavity geometry. Observations of water mass properties entering and leaving the ice-cavity of the PIIS, as well as observations within the cavity are used to estimate a horizontal map of basal melt rates for the PIIS. For this purpose a regional ocean general circulation model that includes ice-ocean interactions is fitted to observations using optimal estimation methods. Hence, the estimates combine on both observations and the dynamical information about the circulation underneath the ice-shelf as resolved by the numerical model. The control variables, that are adjusted during the estimation process, are initial conditions, open boundary conditions, vertical mixing parameters, and melt rates. Data coverage, but also the choice of bathymetry and melt-rate parameterization, affect the state estimate and the net melt rate.

Makinson, Keith

Modelling the seasonal ocean circulation and water mass distribution beneath Filchner-Ronne Ice Shelf

Keith Makinson[1], Paul R. Holland[1], Keith W. Nicholls[1], Adrian Jenkins[1], David M. Holland[2]

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2. *Courant Institute of Mathematical Sciences, New York University, New York, NY, USA*

Observations from beneath Filchner-Ronne Ice Shelf (FRIS) show the ocean cavity responding to seasonal water mass production over the southern Weddell Sea continental shelf, which results from the annual growth and decay of sea ice. Water masses entering the sub-ice shelf cavity are cooled and freshened before exiting as Ice Shelf Water (ISW), which ultimately flows down the continental slope, contributing to deep and bottom water production. Here we use a modified version of the Miami Isopycnic Coordinate Ocean circulation Model (MICOM) that includes tidal forcing, to investigate the seasonal propagation of shelf waters through the sub-ice shelf cavity. The primary inflow is associated with highest salinity water masses in Ronne Depression, with the model reproducing the key features of the observed seasonality. The strongly seasonal inflow which ranges from 0.4 Sv to 1.2 Sv, peaks during the second half of winter when ice front salinities are at their highest before declining as sea ice production diminishes. Beneath FRIS the inflow divides; one third containing the densest waters continues along the western side of the FRIS cavity, while the remaining less dense waters turn and flow to the southeast. Ultimately, both inflows pool and combine with older waters that recirculate within the deepest parts of the cavity. This pooling of water masses dampens the seasonality of the 0.6 Sv flow of ISW beneath eastern FRIS, to about ±15% before it exits the cavity and contributes to the continental shelf edge overflow.

Matsuoka, Kenny

ICE RISES: a new project to investigate evolution and roles of grounded ice in the ice shelf

Kenny Matsuoka[1], Denis Callens[2], Angela von Deschwanden[1], Svein-Erik Hamran[3], Elisabeth Isaksson[1], Jack Kohler[1], Kirsty Langley[4], and Frank Pattyn[2]

1. *Norwegian Polar Institute;*
2. *Université Libre de Bruxelles,*
3. *Norwegian Defence Research Establishment,*
4. *University of Oslo*

We started a new project “ICE RISES” to investigate grounded ice masses (ice rises), such as isles and promontories, in the vicinity of the Fimbul ice shelf, Dronning Maud Land (DML), East Antarctica. The DML coast is characterized by ice shelves extending over more than 1000 km, fed by outlet glaciers and punctuated by numerous ice rises. Mass balance of the upstream ice sheet largely depends on the dynamics of this inter-connected system at the coast. The close proximity of the DML ice shelf to the margin of the continental shelf could potentially allow relatively warm water from the abyssal

plains to circulate under the shelf, leading to enhanced sub-shelf melting. The DML coast and the upstream ice sheet are therefore intrinsically sensitive to changes in the ocean, as is roughly half of the present-day Antarctic coastline. During the 2011-12 field season, we investigated two ice rises (B and C in Figure 1) using geodetic GPS and ice-penetrating radar techniques. Summits of these ice rises are 200-300 m higher than the ice-shelf surface, and the grounded ice maintains its own local flow field. We present englacial structures imaged using radar, as well as the surface and bed topography of these ice rises and adjacent shelf ice. Our key findings, so far, include upward arches (Raymond Bumps) underneath the ice-rise summits, evidence of the stability of these ice rises over millennia, and downward arches near the grounding line, inferring large sub-shelf melting localized at the grounding line.

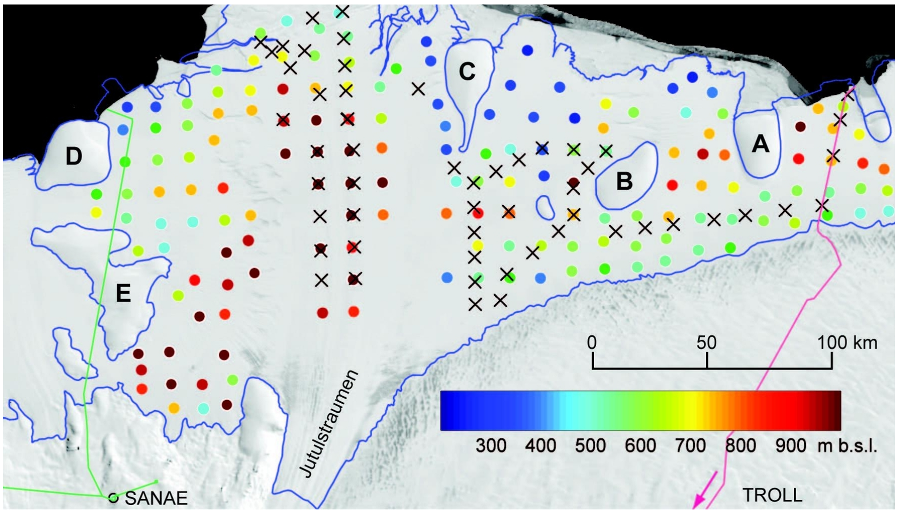

Figure 1: Ice rises proposed to study in this project (labeled **A**-**E**). See Figure 1b for the coverage of this map. Background is MODIS images [*Haran et al.*, 2005], and color of circles shows the elevation of seafloor in meters below sea level [*Nost*, 2004]. Cross markers show the sites of oceanographic and glaciological surveys for the ongoing NARE project “Fimbul top to bottom”. Blue curves: edge of the floating ice.

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Millgate, Thomas

The Effect of Basal Channels on Ocean Flow and Ice-Ocean Interactions

Thomas Millgate[1], Adrian Jenkins[1], Paul Holland[1], Helen Johnson[2]

1. *British Antarctic Survey;*
2. *University of Oxford*

Petermann Glacier in north–west Greenland has developed an extensive ice tongue which is constrained by the high vertical cliff faces of Petermann Fjord. It is one of the largest and most influential glaciers in northern Greenland in terms of ice discharge into the ocean and drainage area. The dominant term in the mass budget of Petermann Glacier is not iceberg formation, but basal melting (80%), so having a detailed understanding of the ice-ocean interactions beneath the ice shelf is paramount to gaining an enhanced understanding of the glacier's mass balance and its impact on that of the Greenland Ice Sheet. A notable feature of the glacier's floating tongue are four deep channels which run along its length, parallel to the ice flow direction. We have applied a three-dimensional ocean model to the cavity beneath a Petermann-style ice shelf containing channels running along the length of the ice shelf. Here we discuss some preliminary findings detailing the effect of such basal channels on ocean flow and ice-ocean interactions.

Nakayama, Y.

Spreading of the melt water plume from Pine Island Glacier

Yoshihiro Nakayama & Michael Schröder

Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

Previous studies showed that the ice shelves and glaciers are fringing the West Antarctic Ice Sheet (WAIS), especially in the Amundsen Sea due to high basal melting. This melting is caused by relatively warm Circumpolar Deep Water (CDW) that intrudes onto the continental shelf and cascades into the troughs underlying the floating extensions of WAIS.
In this study we have analyzed the data obtained from the RV Polarstern cruise 2010 in the Amundsen Sea. We present results on the intruding warm CDW onto the continental shelf, the observed melt rate and the pathway of the melt water outflow in the Amundsen Sea.

Naveira G., Alberto **Diagnosing the role of the Weddell Gyre in the global ocean circulation**

Naveira Garabato, Alberto; Jullion, Loïc; Bacon, Sheldon; Meredith, Mike; Brown, Peter; Venables, Hugh; Speer, Kevin; Baker, Dorothée; Watson, Andy; Sanders, Richard; Jenkins; William; Ballentine, Christopher

Bottom water formation in the Southern Ocean plays an important role in the lower cell of the Meridional Overturning Circulation and in marine biogeochemical cycling, by ventilating and cooling the ocean abyss and sequestering carbon and nutrients there. The lack of adequate observations has to date hindered the quantification of exchanges of mass and physical and biogeochemical tracers between the Weddell gyre and the global ocean.

The Antarctic Deep Water Rate of Export (ANDREX) project seeks to determine these exchanges through the analysis of the first systematic hydrographic and tracer survey along the gyre's outer rim. These measurements (including temperature, salinity, oxygen, nutrients, carbon system parameters, chlorofluorocarbons, sulphur hexafluoride, oxygen isotopes, noble gases and radiocarbon) are combined with velocity observations in an inverse model to obtain a self-consistent estimate of the physical and biogeochemical transports across the edge of the Weddell gyre and of the rate at which the deep ocean is ventilated from the region. Of particular interest to the analysis are the quantification of bottom water formation and the density profile of ventilation in the gyre, as well as an assessment of the region's role in biogeochemical cycling and anthropogenic carbon sequestration. In this presentation, we will discuss the initial results of the inverse model, focusing on the physical circulation and water mass transformations in the Weddell gyre as well as on the export of freshwater.

Nicholls, Keith **Ocean conditions beneath Larsen C Ice Shelf**

Keith Nicholls[1], Emily Venables[1], Keith Makinson[1], Paul Anker[1], James Smith[1]

1. *British Antarctic Survey, Natural Environment Research Council, Cambridge, U.K.*

Two sites on Larsen C Ice Shelf were occupied during December 2011, one in the south of the ice shelf, and one in the north. At both sites ~360-m deep hot-water drilled access holes were used to obtain Conductivity-Temperature-Depth (CTD) data from beneath the ice shelf. At the southern site, current meter data from the boundary layer at the ice shelf base were also obtained, together with a radar measurement of the basal melt rate.

At both sites, the temperature of the underlying water column was below the surface freezing point, and the temperature-salinity characteristics are consistent with a High Salinity Shelf Water source of maximum salinity 34.65. At the southern site, although the water column was cold, the 0.08°C thermal driving at the ice base and the 0.2-m s^{-1} rms water speed in the boundary layer resulted in a melt rate of around 2 m a^{-1}.
We describe the datasets that were obtained, show how they relate to the limited data available from the Larsen continental shelf seaward of the ice front, and speculate on sub-ice shelf circulation patterns that would be consistent with the observations.

Nilsson, Johan

Atlantic Water circulation and shelf ice in the Arctic Ocean

Johan Nilsson
Department of Meteorology, Stockholm University

Recent geophysical and geological data from the Arctic Ocean suggest that large shelf ice systems, reaching about a 1000 m below the sea surface, existed in the Marine Isotope Stage 6 (MIS 6, some 150 ka). These deep shelf ices, which should have been difficult sustain with a present-day distribution of warm Arctic Atlantic Water, are indicative of a very different circulation regime. In particular, the cold low-salinity upper layer appears to have extended significantly, displacing the warm Arctic Atlantic Water downward. The notion that the cold upper layer becomes deeper during glacial is supported by new Arctic Ocean temperature reconstructions from MIS 3. Here, possible physical mechanisms that can cause a glacial deepening of the Arctic Ocean stratification are discussed. One proposed explanation, based on a simple conceptual model, is that the stratifications change is a response to a reduction of the freshwater input to the Arctic Ocean. Other possibilities include changed flow paths of the topographically-steered Arctic Atlantic Water circulation due to sea level and wind changes. However, existing data and model studies are insufficient for identifying a dominant mechanism.

Petty, Alek

Impact of atmospheric forcing on Antarctic continental shelf water masses

Alek Petty[1], Daniel Feltham[1], Paul Holland[2]

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2. *BAS, Cambridge, UK*

The Antarctic continental shelf seas feature a bimodal distribution of water-mass temperature, with the Amundsen and Bellingshausen seas flooded by Circumpolar Deep Water that is several degrees Celsius warmer than the cold shelf

waters prevalent in the Weddell and Ross seas (*Orsi and Whitworth* [2005]). This bimodal distribution could be caused by differences in atmospheric forcing, ocean dynamics, ocean and ice feedbacks, or some combination of these factors. In this study a coupled sea ice-mixed layer model is developed to investigate the physical processes controlling this situation. Under regional atmospheric forcings and parameter choices the simulations demonstrate the Weddell Sea destratifying completely and forming cold shelf waters, while the Amundsen Sea mixed layer remains shallower, allowing a layer of deep warm water to persist. Applying the Weddell atmospheric forcings to the Amundsen Sea model destratifies the whole water column, and applying the Amundsen forcing to the Weddell setup produces shallow mixed layers. The simple model cannot rule out a governing role of ocean dynamics, but the results suggest that the difference in surface forcings alone is sufficient to account for the bimodal distribution in Antarctic continental shelf-sea temperature.

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Plate, Carolin

Creep stress driven fracture mechanical analysis of crack scenarios in Pine Island Glacier

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Previous studies of crack scenarios in ice shelves revealed the strong dependence of the stress intensity at the crack tip on the chosen boundary conditions. However, proper boundary conditions for linear elastic simulations of fracture scenarios are hard to determine. Therefore, a new approach links the viscous flow behavior and the resulting stresses to the linear elastic analysis via viscous volume forces, which trigger the shelf deformation and the consequent fracture process. This procedure allows considering larger shelf areas with spatially varying flow patterns. The numerical simulations are conducted using Finite Elements and the concept of configurational forces. This method is rather flexible and can account for inhomogeneous material properties volume forces and crack face loadings, e.g. due to additional water pressure. It is applied to a 2-dimensional geometry with various initial crack geometries. The method is validated using remote sensing data of past calving events at Pine Island Glacier.

Scherer, Reed

WISSARDs and GLiDERS: Integrated studies of the Whillans Ice Stream grounding zone and Ross Ice Shelf cavity

Reed Scherer[1], Ross Powell[1], Slawek Tulaczyk[2], John Priscu[3]
WSSARD Project members, GLiDERS Project Members

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The WISSARD (Whillans Ice Stream Subglacial Access Research Drilling) Project is a US National Science Foundation funded effort to analyze the deep subglacial environment of West Antarctica and the marine grounding zone of the Ross Ice Shelf, using a new hot water drill system and a suite of new borehole tools designed for clean access to subglacial lakes and the marine cavity proximal to the grounding zone. The program includes 19 Principle Investigators with varied expertise in geology, geochemistry, geophysics, glaciology, microbiology, micropaleontology, oceanography and modeling.

We will analyze the physical conditions and biota in a subglacial/submarine lake, the sea floor beneath the ice shelf, and subsurface sediment geometry and stratigraphy. Access to the bed is via a newly constructed hot water drill capable of both clean access for uncontaminated sampling of microbial communities, and boreholes with diameters up to 1m through up to 1000m of ice. A series of new tools have been developed, including shallow and intermediate depth (5m) coring, a suite of oceanographic and geochemical measurement and sampling tools, including long-term moorings, and robotic imaging of the sub-ice cavity.

LISSARD (Lake and Ice Stream Subglacial Access Research Drilling) is the component of WISSARD focusing on the subglacial lake and wetland system. Antarctic deployment for full field trials will begin in McMurdo Sound at the ANDRILL-McMurdo Ice Shelf site (Windless Bight) in November, 2012. Following these field trials, traverse to the Whillans Ice Stream and operations on Lake Whillans (LISSARD) will occur in January-February, 2013.

The marine cavity work, originally funded as part of WISSARD as RAGES (Robotics Access to Grounding-zones for Exploration and Science) has been postponed for budgetary and logistics reasons. A new proposal, GLiDERS (Grounding Line Dynamics and Environments of the Ross Shelf) will be submitted to resurrect and expand the marine cavity work, including physical oceanographic analysis and modeling and deployment of SIR, the large Sub-Ice ROV system designed for borehole deployment (80cm hole) and including multibeam and subbottom profiler systems, as well as extensive instrumentation for imaging, measurement and sampling strategies. Instrumentation for WISSARD and GLiDERS will, between abstract submission and the FRISP meeting, be field-tested in Lake Tahoe, California. Results of testing will be reported.

Schröder, Michael

Forthcoming expeditions

Michael Schröder

Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

The German research icebreaker 'Polarstern' is finally scheduled until summer 2014. Within this time frame two cruise lags are discussed in more detail, which are of greater interest for the FRISP community. The focus of these two cruises are the Larsen shelf in front of the Larsen A, B, and C ice-shelves (20.01.13-19.03.13) and the Filchner trough region (20.12.2013-05.03.14). A detailed description of the scientific background, the station design and measuring techniques will be given. A discussion on international collaboration for these expeditions should follow.
There is also a need for ideas on the next 'Polarstern' cruise proposals for the upcoming application period 2014-2016.

Sinisalo, Anna

Spatial distribution of surface mass balance on Fimbul ice shelf (FIS), East Antarctica

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Mass balance of the Antarctic ice sheet is a major unknown in the prediction of the global sea level rise. A large part of the uncertainties in the total mass balance of the ice sheet arise from the uncertainties in the surface mass balance (SMB) due to lack of in-situ observations. In-situ observations of the SMB are also essential to reliably quantify the amount of basal melting from the recently observed lowering of sur-face of Antarctic ice shelves (Pritchard et al., 2012).

We show spatial variability of SMB over Fimbul iceshelf, the largest iceshelf in Dronning Maud Land, East Antarctica. We use a ground based radar calibrated with a set of shallow firn cores (Schlosser et al, 2012). Direct stake measurements of SMB over a 2 year time period between 2009 and 2011 give an insight to the very recent SMB. We use a volcanic deposition of the 1982 eruption of El Chichon volcano identified in the firn cores (Schlosser et al, 2012) as a time marker in our radar analysis, and present spatial distribution of SMB on FIS averaged over the last 26 years. We compare the results with the latest high-resolution results from an atmospheric climate model (Lenaerts et al, 2012), and present a new estimation of the SMB of the Fimbul iceshelf.

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Smedsrud, Lars H.

Fimbul Ice Shelf : New Observations

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The Fimbul ice shelf is fed by the fast flowing Jutulstraumen, one of the largest outlet glaciers of Dronning Maud Land, East Antarctica. Ice shelves along this coast are notable because they extend over large portions of the continental shelf. Beyond the continental shelf break Warm Deep Water circulates, and oceanographic models indicate that some of this warm water penetrates below the ice shelf resulting in basal melt of the ice.

We determine the spatial variability of the surface and the basal mass balances of the ice shelf with a ground-based phase sensitive radar, precise GPS and dated shallow firn cores. The melt estimates based on radar data are contrasted with the oceanographic observations of currents, salinity and temperature from the three boreholes in the ice shelf. Most of the water properties indicate that there is mainly one water mass with temperature close to -1.8 ºC and salinity around 34.3 in contact with the ice. This supports rather low basal melt rates estimated from remote sensing, and a steady state mass balance in this sector of Antarctica. There is a steady presence of Ice Shelf Water in the upper layers below the ice, and the flow seems to be controlled by a network of channels with quite narrow width.

Water slightly warmer than the freezing-point is found close to the bedrock and at times closer to the ice shelf base. This complex interplay of processes implies that no simple parameterization of basal melting related to deep coastal ocean temperatures exist, and suggest that high resolution modeling of the coastal processes is needed to estimate melt rates in a good way.

Smith, James

First sediment cores recovered from beneath Larsen C and George VI Ice Shelves

James Smith[1], Keith Nicholls[1], Keith Makinson[1], Emily Venables[1] , Paul Anker[1] , Dominic Hodgson

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To date, only a handful of studies have successfully recovered sediment samples from beneath Antarctic ice shelves with published data limited to just two short cores (0.47m & 1.44m) from beneath the Amery Ice Shelf, one 0.28m core from beneath the Novolazarskiy Ice Shelf and sediments recovered as part of major drilling efforts in the Ross Sea. The lack of data from these environments is surprising given their potential to reveal important information regarding ice shelf history (i.e., thinning and retreat), changes in ocean circulation through time, as well as much needed boundary information about sub-ice shelf sedimentation. The latter information is critical for determining periods of ice shelf presence and absence in the geological record.
Here we present a new dataset of sediment samples collected during the 2011/12 field season from two sites on the Larsen C Ice Shelf, one in the south and one in the north and one site on southern George VI Ice Shelf. Sediments were recovered using a simple hammer assisted gravity corer, which proved to be enormously effective and simple to deploy. In total, 11.60m of sediment was recovered with a maximum penetration of 2.90m. The access holes were drilled as part of a wider project looking at the turbulent boundary layer and melting beneath

ice shelves (see abstracts by K. Nicholls et al. and E. Venables et al.) and it is hoped that our new sedimentological dataset will provide a much needed long-term perspective on these recent observation.

Stewart, Craig

Oceanographic observations under the Ross Ice Shelf

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2. *National Institute of Water and Atmospheric Research, New Zealand*

In November 2010 an oceanographic mooring was deployed via hot water drill borehole into the sub-ice cavity of the Ross Ice Shelf east of Ross Island. The mooring contains current meters and temperature/salinity loggers at four depths through the water column. In addition, an upward looking acoustic altimeter is mounted below the ice to act as a basal melt sensor. Preliminary results from the first year of data are presented, including mean and seasonal variations in currents, temperature and salinity structure and basal melt rate.

St-Laurent, Pierre

Comparing the Oceanic Heat Transport to Antarctic Ice Shelves for Two Generic Continental Shelves

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Oceanic exchanges across the continental shelves of Antarctica play an important role in biological systems and the mass balance of ice sheets. We focus in this research on the ocean heat transport to two idealized ice shelves representative of the conditions encountered in Antarctica. The first domain is similar to the Bellingshausen Sea where warm shelf waters and a mean eastward flow prevail. The second domain mimics the Ross Sea with cold shelf waters and a westward mean flow along the shelf break. We examine the differences between these two scenarios by comparing process-oriented simulations conducted with a high-resolution (1km) 3-D ocean model (ROMS) coupled to a thermodynamically-active ice shelf. In both scenarios the cross-shelf exchanges of heat are initiated by corrugations at the bottom of the sea (troughs). Shelves with warm water exhibit relatively high basal melt rates (5m/yr) with the highest melt rates at the grounding line. Cold-water shelves have their basal melt determined by the pattern of onshore oceanic heat transport, which occurs on the eastern side of the troughs

regardless of the direction of the mean flow. The asymmetric response is explained by potential vorticity conservation and is compared to observational data recently acquired in the Ross and Bellingshausen seas. By assuming one large trough per 1000km of coastline, it is estimated that such flow-topography interaction provides 1GW of oceanic heat (relative to freezing point) per km of Antarctic coastline.

Straneo, Fiamma

Circulation and Impact of Arctic and Atlantic Waters on Greenland's Glaciers

Straneo, Fiamma
Dept. of Physical Oceanography - Woods Hole Oceanographic Institution

Increasing evidence suggests that ocean variability triggered the recent acceleration of glaciers in western and southeastern Greenland leading to a doubling of the ice sheet's contribution to sea level rise. This hypothesis is supported by the fact that the timing of the glaciers' acceleration coincided with the recent warming of the subpolar North Atlantic and by recent measurements showing that warm, salty waters of subtropical origin circulate rapidly through these fjords. Yet the processes regulating the inflow and variability of warm, salty waters inside Greenland's glacial fjords are complex and involve crossing shelves that are strongly influenced by cold, fresh waters of Arctic origin. Here, I will present recent measurements from one major glacial fjord in southeast Greenland and historical data, including a reconstruction of the shelf variability over the last 120 years, which indicate that the properties at the glaciers' margins and the glaciers' stability are affected both by Arctic and Atlantic variability on interannual to decadal time scales. These findings are then generalized to glaciers around Greenland using recent and historical measurements.

Sugiyama, Shin

Hot water drilling and subglacial measurements at the floating tongue of Langhovde Glacier, East Antarctica

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2. *Graduate School of Environmental Science, Hokkaido University*

Ice discharge from fast flowing ice streams and glaciers play a key role in the mass budget of Antarctic and Greenland ice sheets. Recent satellite observations show speed up and thinning of such glaciers and warming ocean is suspected as a trigger. Despite the importance of interaction between outlet glaciers and the ocean, direct observations at ice-water

interface are very few. Subshelf measurements in the vicinity of the grounding line are particularly crucial, because such data may indicate how far and how fast changes in the ocean spread into inner part of subshelf environment. In 2011/2012 austral summer season, we performed hot water drilling on the floating tongue of Langhovde Glacier, an outlet glacier in East Antarctica. Here, we report subshelf measurements carried out in boreholes drilled nearby the grounding line.

Langhovde Glacier is located at 69° 12' S, 39° 48' E, approximately 20 km south of a Japanese research station Syowa. The glacier discharges ice into Lützow-holm Bay through a 3-km-wide calving front at a rate of 130 m a^{-1}. The glacier surface is flat in the lower reaches, suggesting the ice is afloat within a few kilometers from the terminus. In January 2012, we set up a hot water drilling system at 2.5 and 3 km from the terminus to drill through the glacier. The hot water system had been developed for studies in other regions (Sugiyama and others, 2011), and was used for the first time in Antarctica. During a one-month field campaign, four boreholes were drilled to the glacier bottom and used for subglacial observations. According to borehole camera inspections, as well as other measurements described below, ice was underlain by a shallow saline water layer. Ice and water column thicknesses were 400 and 25 m at the first drilling site, and 430 and 10 m at the second site. According to the ice surface and bed elevations relative to the sea level, the drilling sites were situated within a several hundred meters from the grounding line.

A CTD profiler and current meter were lowered into the boreholes to measure subshelf water properties and current. Salinity and temperature were 34.15 PSU and -1.5°C, which are similar to the values reported for the ocean near the study site (Orsi and Whitworth, 2004). Subshelf water flows to a certain direction with a speed up to 3 cm s^{-1}. This speed is sufficient to transport water to the calving front within a few days. A borehole camera suspended in the boreholes captured several species of animals (probably a crustacean and fish) in the water and on the sea floor. The existence of a biome under >400 m thick glacier implies transportation of trophic resources and oxygen from open sea by the subshelf water current. After the borehole profiling, a pressure sensor was installed to measure subshelf water pressure. Temporal pressure variations were consistent with ocean tides as measured in the ocean near the calving front. The changes in the pressure were driving ice speed variations as previously observed on other floating and grounded ice in Antarctica (e.g. Anandakrishnan, and others, 2003).

Our borehole observations imply that subshelf environment in the vicinity of the grounding line is well connected to the ocean through a current system. Together with the tidally modulated ice dynamics, outlet glaciers are considered to be susceptible to changes in the ocean, even in the vicinity of the grounding line. We are expecting further information from several borehole sensors and GPSs, which are running over the winter until the 2012/2013 season.

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Thoma, M.

Rimbay - A multi-physics 3D ice-sheet model for comprehensive applications: Model-description & examples

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Glaciers and ice caps are currently the largest cryospheric contributions to sea level rise. Modelling the dynamics and mass balance of the major ice sheets is therefore an important issue to investigate the current state and the future response of the cryosphere to changing environmental conditions, namely global warming. On the other hand, the Earth’s climate history is determined by the evolution of southern and northern hemisphere ice sheets which vary between glacial and interglacial extent during the last million years. For all these demands, a powerful high resolution multi-physics ice sheet model is needed. Based on the well-known and established ice sheet model by Pattyn (2003) we developed the Higher-Order/Full- Stokes physics thermomechanic ice model RIMBAY, in which we improved the original version in several aspects like a shallow-ice – shallow-shelf coupler and a full 3D grounding-line migration scheme based on the Schoof’s analytical approach. Further capabilities address the incorporation of basal hydrology as well as crustal adjustments by viscoelastic processes due to ice loads on long time scales. Different grid representations, a netdcf data-exchange interface, and plug-and-play GMT visualization tools make the RIMBAY package applicable to all conceivable tasks of ice-sheet modeling. Example model-setups and reference models cover almost any order of scales in time or space. Here, we present results from a variety of model projects investigating, e.g., the flow across subglacial lakes, ice-shelf-ocean interaction with grounding-line migration, and results from coupling RIMBAY to the earth system model COSMOS and to a viscoelastic isostatic adjustment model

Venables, Emily

Oceanic observations at the ice base: Microstructure and thermohaline staircases

Emily Venables[1], Keith Nicholls[1], Keith Makinson[1], Paul Anker[1], James Smith[1]

1. *British Antarctic Survey, Natural Environment Research Council, Cambridge, U.K.*

Understanding the physical oceanic processes that affect the heat supply to the base of the ice shelf is a fundamental requirement for accurate modeling of its melt rate. Observations of the ocean beneath George VI and Larsen C Ice Shelves were made between November 2011 and January 2012, with particular focus on the turbulent boundary layer. For the first time, a microstructure profiler was deployed through an ice shelf borehole in order to determine the dissipation rate of turbulent kinetic energy from direct measurements of horizontal shear and high resolution temperature and conductivity. Thermohaline staircase structures are apparent in both CTD and microstructure measurements made beneath George VI Ice Shelf. Mixed layers are *O*(4m) thick and have step increases of ~0.05°C. Such features are not apparent in similar measurements beneath Larsen C Ice Shelf. Results from the upper 30m of the water column are presented from both sites.

Warner, Roland

Distributed temperature sensing in the Amery Ice shelf and the sub ice shelf ocean

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Optical fibre cables for a distributed temperature sensing system have been installed through the Amery Ice Shelf and into the underlying ocean by the Australian AMISOR project. This was done at two hot water drilled boreholes during the austral summer of 2009-10.The cables extend beneath the ice shelf to near the ocean floor and permit the measurement of temperature profiles at metre scale resolution by detection of

Raman back-scattered laser light using a Sensornet Oryx system. We present results gathered to date and outline future prospects.

The temperature profiles provide a detailed record inside the ice shelf, and give insights into the vertical structure of the ice shelf in regions where the lower part of the ice column consists of accreted basal marine ice. The temperature records from the sub-ice ocean cavity show reasonable agreement with oceanographic instruments (Microcats) fixed on the same mooring, and provide a time series of temperature profiles through 300 metres of the water column.

Knowledge of the temperature regimes within the ice shelf and in the underlying ocean is important for the study of ice-ocean interactions, ice shelf mass budget and the dynamics of ice shelf flow. Measurements of ocean temperature profiles throughout the seasonal cycle should provide valuable insights into the sub-shelf ocean circulation, heat transport, and basal melting and freezing.

Wesche, Christine

Classification of calving fronts around Antarctica

Christine Wesche[1]

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Iceberg calving is the largest loss term in Antarctic mass balance. The iceberg areas vary from a few square meters (growler) to several hundred square kilometres (huge tabular icebergs or ice islands) and their shape (blocky, domed or tabular) depends on the morphology of their calving front. The Antarctic coastline has a length of about 18 000km and is characterized by a large spectrum of morphological properties. In contrast to the Greenland ice sheet, Antarctica is surrounded by a variety of large, medium and small sized ice shelves, besides of glacier tongues and parts without offshore floating ice masses.
With the aid of synthetic aperture radar (SAR) images all ice shelves and glacier tongues around Antarctica were mapped. The mosaic of the RADARSAT-1 Antarctica Mapping Project (RAMP) Antarctic Mapping Mission 1 (AMM) was used at a 100 m x 100 m image resolution and the ice shelves were extracted by using the grounding line of the MODIS Mosaic of Antarctica (MOA) Project and the RAMP1-AMM coastline. An automated detection of crevasses was used as a first calving front classification. On the basis of the orientation of the crevasses to one another and relative to the calving front, and the distance between them, an estimation of the dominant size of potentially calving icebergs was made. Other parameters (e.g. shape of the calving front itself, pinning points) were used

to make a clearer distinction between calving sites. The Antarctic coast is classified into several groups of calving sites e.g. no floating ice offshore (e.g. Mawson Coast), large ice shelf (e.g. Filcher-Ronne-Ice Shelf) or large glacier tongue (e.g. Mertz Glacier).
The resulting map of the classified calving fronts around Antarctica and their description will be used to achieve a detailed picture of crevasse formation and propagation within a co-operation with material scientists and ice shelf modelers.

Wilkens, Nina

Flow field sensitivities on the floating tongue of Pine Island Glacier on basal sliding and grid resolution

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2. *Alfred-Wegener-Institute, Bremerhaven, Germany*

A modeling study is performed to extend the understanding about the ice flow dynamics of Pine Island Glacier, West Antarctica. Pine Island Glacier is known to have accelerated, thinned and has experienced a significant grounding line retreat in the past decades. These ongoing processes are coinciding with a concentrated mass loss in the Amundsen Sea Embayment area, where the glacier is situated. A possible cause is found to be enhanced ocean melting from beneath the ice shelf, inducing ice shelf thinning and possible loss of contact to buttressing ice rises. Another factor is grounding line retreat, inducing loss of basal drag along an extensive ice plain. Also rifting and weakening of the shear margins induced by enhanced flow should be considered and can be seen as another positive feedback mechanism. An important factor at Pine Island Glacier is furthermore its potential instability due to a retrograde bed slope.

The model we use is a 3-D full-Stokes model set up with the commercial finite-element package COMSOL Multiphysics©. The non-Newtonian rheology of the ice is modeled using Glen’s flow law. At the base of the ice stream we apply a Weertman-type sliding law. We start with constraining basal sliding parameters, using information from other modeling studies and the misfit between observed and modeled flow fields. We test the sensitivity of the stresses and flow velocities in the floating tongue on the choice of the basal sliding parameters. Furthermore we test the effect of the mesh size in the vicinity of the grounding zone on the flow velocities in the floating part, aiming to find a resolution along the grounding line which guarantees grid-size independent velocities.

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Wåhlin, Anna

Circulation of warm deep water on the Amundsen Shelf: Variability and forcing mechanisms

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Two moorings have been placed on either side of a deep trough leading in to the deep shelf basin in the Western and Central Amundsen Shelf. The moorings measure current speed, temperature, salinity and oxygen content from about 300 m depth to the bottom (at ≈550 m depth), and the results are used to characterize the inflows of warm deep water, its variability, and connect the observed variability to meteorological forcing. An average flow of warm deep water towards the ice shelves was observed on the eastern side of the channel. The bottom water on the western side of the channel was colder and fresher than on the eastern side, but still warmer than the cold and fresh surface layer. The average flow direction in the deep water was away from the iceshelves on the western side. This indicates a net circulation of warm deep water where warm and salty CDW flows southward on the eastern side of the channel, and after interaction with the iceshelves flows northward steered by the topography on the western side of the channel. The flow in the trough is dominated by barotropic fluctuations that do not contribute to the on-shelf heat transport. Along-shelf wind at the shelf break is correlated to the barotropic fluctuations in the eastern part of the channel. This result agrees with previous model studies from the West Antarctic Peninsula and the Amundsen Sea. The flow also consists of a baroclinic part, where warm modified Lower Circumpolar Deep Water flows toward the coast in the lower layer. This part of the flow, as well as the net heat flux and the temperature field, is not correlated to the wind fields which contradicts the model results. The eastward winds at the shelf break were unusually weak at the time of the measurements, which may the reason for the discrepancy between the models and the observations.

Zhou, Qin

How the summer surface water is downwelling and spreading beneath the Fimbul Ice Shelf, Antarctica

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Surface water mass during summer along the Eastern Weddell Sea coast is characterized by fresh and warm water due to ice melt and onshore Ekman flux. Near the ice front/coast, the surface water is pumped downward by wind. When the downwelling depth exceeds ice shelf edge depth, some of the surface water is advected into the ice shelf cavity, which has significant effect on basal melting of ice shelves. From February to May of 2008, around 200 temperature and salinity profiles are collected by instrumented elephant seals near the sill of Fimbul Ice Shelf (FIS), where the ice shelf edge depth is around 200m. Data analysis clearly shows the surface fresh and warm water near the FIS is downwelling from February to April, with maximum downwelling depth more than 220m in March. Beneath the FIS, fresh and warm surface water has been observed in summer and autumn from under-ice oceanic mooring data during 2010-2012 (Hattermann, 2012). An idealized high-resolution regional ice-shelf model with idealized topography of the FIS is employed to study the process of summer surface water downwelling and spreading beneath the ice shelf. Our simulations are mainly focusing on wind and eddy effects due to their important roles in the process.

Årthun, M.

Seasonal hydrography and sea ice formation rates in the southern Weddell Sea

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The densest water mass in the World Ocean, Antarctic Bottom Water (AABW), is formed around the Antarctic continental margins. A major source for the precursors of AABW is the southern Weddell Sea continental shelf where high rates of sea ice formation and concurrent salinity increase during winter produces High Salinity Shelf Water (HSSW). Determination of sea ice formation rates in the Weddell Sea is thus important to constrain estimates of AABW production, in both observations and models.
Studies of the distribution and seasonal change in salinity below sea ice are limited due to the scarcity of wintertime

hydrography from the southern Weddell Sea. To elucidate the wintertime hydrography in the Weddell Sea 19 Weddell seals (*Leptonychotes-Weddelli*) were equipped with oceanographic sensors during February 2011. Here, we describe data from one of the seals that spent the following 8 months foraging in front of the Filchner Ice Shelf, yielding a unique time series of hydrography. The seasonal evolution of salinity is used to provide an estimate of sea ice formation rates in the south-eastern Weddell Sea.

Østerhus, Svein

Long term variations of the Ice Shelf Water in the Southern Weddell Sea

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Antarctic Bottom Water (AABW) occupies large portions of the deep ocean and is the densest water mass in the world because of its cold temperature. The source water of AABW originating from the Weddell Sea is the cold, low-salinity Weddell Sea Bottom Water (WSBW). The low temperature and salinity of the WSBW is because of the contribution of the Ice Shelf Water (ISW) that got its characteristics by sea ice formation over the continental shelf of the southwestern Weddell Sea and the circulation underneath the Filchner-Ronne Ice Shelf. Water circulating in the ice shelf cavity is cooled by the contact with the ice due to heat conduction through the ice and by melting of the ice shelf itself.

Any changes to the ISW properties might therefore result in changes of the AABW, and an increased understanding of variability within the ISW may help us understand the sensitivity of the AABW in the deep ocean

A great effort has been put into monitoring the ISW plume over a long time period in order to gain knowledge of its role in the climate system. This study is focusing on long-term variations of the ISW formed in the southern Weddell Sea and to investigate its sensitivity to external forcing. The main data being used is mooring data from a long-term monitoring site, named S2, located at the Filchner Sill. The first mooring was deployed in 1977, then again in 1985, 1987, 2003, 2009 and 2010-ongoing), all containing at least one year of data.

A proposal for long-term observations and results from the existing time series will be present.