27th International Forum for Research into Ice Shelf Processes (FRISP)

Gregynog Hall, Powys, Wales

17-19 June 2013

PROGRAMME

Sunday 16th June

19:00 – Dinner

Monday 17th June

08:00 – Breakfast

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09:00 – Welcome and housekeeping

Oral Session 1 – Ice/Ocean Interaction in Climate Models

09:20 – Hartmut Helmer: Southern Ocean warming: Increase in basal melting and grounded ice loss
09:40 – Christian Rodehacke: Fully coupled ice sheet – earth system simulations: The Greenlandic ice sheet response and its interaction with the climate system under raising CO2
10:00 – Xylar Asay-Davies: Simulations of Antarctic ice shelves in the Parallel Ocean Program (POP)
10:20 – Marianne Bugelmayer: The effect of climate on icebergs - a model study

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10:40 – Break

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Oral Session 2 – Icebergs and Sea Ice

11:10 – Louise Biddle: Iceberg induced productivity in the northwest Weddell Sea
11:30 – Martin O'Leary: Bounding the strength of proglacial melange
11:50 – Alek Petty: Sea ice-ocean modelling of the Antarctic shelf seas
12:10 – Paul Holland: Antarctic sea ice trends from observation and model

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12:30 – Lunch

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Oral Session 3 – Amundsen Sea Sector

14:00 – Tae Wan Kim: Seasonal variation of warm circumpolar deep water in central Amundsen Sea
14:20 – Anna Wåhlin: Variability of warm deep water inflow in a submarine trough in the central Amundsen Sea
14:40 – Karen Assman: Shelf break processes and the variability of Circumpolar Deep Water Transport in the Amundsen Sea
15:00 – Adrian Jenkins: Inter-annual variability on the eastern Amundsen sea shelf: insights from observation and modelling

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15:20 – Break

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16:00 – Poster Session

Marius Arthun: Eddy-driven exchange between the open ocean and a sub-ice shelf cavity
Elin Darelius: Hydrography and Circulation in the Flichner Depression
Eleanor Darlington: Submarine glacial melt contributions inferred from development of sediment plumes, Kongsfjorden, Svalbard
Jan de Rydt: Geometrically controlled melt rates of Pine Island Glacier during early stages of its retreat
Michael Dinniman: The ACCIMA Project - Coupled Modelling of the High Southern Latitudes **&** What Determines the Differences in Basal Melt between Ice Shelves in the Amundsen Sea?
Tom Holt: Stange Ice Shelf: An assessment of its structure, dynamics and evolution
Ola Kalen: Observations of circulation of warm deep-water at the Amundsen Shelf edge
Bernd Kulessa: Siesmic properties of marine and meteoric ice in Larsen C Ice Shelf, Antarctic Peninsula
Benoit Legresy: Interaction of dense shelf water with the Mertz Glacier Tongue (1992-2007)
Christian Rodehacke: Fully coupled ice sheet–earth system simulations: The Greenlandic ice sheet response and its interaction with the climate system under raising CO2 concentrations
Deb Shoosmith: Variability of ocean heat transport and implications for melting beneath Dotson Ice Shelf, West Antarctica **&** Oceanographic Observations in the Bellingshausen Sea

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18:00 – Close

19:00 – Dinner
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Tuesday 18th June

08:00 – Breakfast

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Oral Session 4 – Weddell Sea Sector

09:00 – Martin Siegert: Late Holocene ice-flow reconfiguration in the Weddell sector of West Antarctica
09:20 – Alex Brisbourne: Seabed Topography beneath the Larsen C Ice Shelf from seismic soundings
09:40 – Mathias Rucker Van Caspel: Antarctic Bottom Water formation in the Larsen Ice Shelf area
10:00 – Mike Schröder: The LASSO Expedition 2013
10:20 – Svein Østerhus: TBC

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10:40 – Break

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Oral Session 5 – Regional Ice-Ocean Modelling

11:10 – Mike Dinniman: Sensitivity of Water Masses and Ice Shelf Basal Melt in the Ross Sea to Changes in the Winds and Atmospheric Temperatures
11:30 – Pierre Mathiot: Ocean/sea ice sensitivity to the presence of ice shelves in a regional model of Pine Island Bay
11:50 – Adam Candy: Towards an adaptive resolution multiscale model of Pine Island Glacier and ice shelf ocean cavity and its interaction with the ice sheet
12:10 – Tom Millgate: Effect of Basal Channels on Oceanic Ice-Shelf Melting

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12:30 – Lunch

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Oral Session 6 – Ice-Ocean Process Studies

14:00 – Craig Stewart: Recent observations of oceanographic conditions and basal melting of the Ross Ice Shelf
14:20 – Tore Hatterman: Parameterizing basal melting beneath the Fimbul Ice Shelf, Antarctica
14:40 – Jim Jordan: Modelling ice-ocean interaction in ice shelf crevasses
15:00 – Satoshi Kimura: Impacts of subglacial discharge on glacial melting
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15:20 – Break

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16:00 – Presentation of Field Plans
16:45 – FRISP Business

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18:00 – Close

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19:00 – Conference Dinner

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Wednesday 19th June

08:00 – Breakfast

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Oral Session 7 – Ice Shelf Structure

09:00 – Chris Borstad: Creep deformation and buttressing capacity of damaged ice shelves
09:20 – Daniela Jansen: Marine ice in Larsen C ice shelf and implications for ice dynamics
09:40 – Bryn Hubbard: Optical-televiewer-based investigations of the internal structure of ice shelves
10:00 – Mike Hambrey: Structure and Debris-Transfer Processes in the McMurdo Ice Shelf (Ross Embayment)

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10:20 Break

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Oral Session 8 – Remote Sensing

11:00 – Adrian Luckman: Melt extent, duration and ponding on iceshelves from Envisat ASAR
11:20 – Jamin Greenbaum: Cavity shape, continental shelf bathymetry, and surface elevation change measurements from 2003 to 2012 for the area around Totten Glacier, East Antarctica.
11:40 – Helen Fricker: Improved elevation change records for Antarctic ice shelves from satellite radar and laser altimetry, 1992-2012

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12:30 Lunch

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TALKS

In alphabetical order

Submitter: Dr. Xylar Asay-Davis

Title: Simulations of Antarctic ice shelves in the Parallel Ocean Program (POP)

Abstract: We present simulations of Antarctic ice shelves using a modified version of Los Alamos National Laboratory's POP ocean model that includes circulations in ice-shelf cavities. The geometry of the ice-shelf/ocean interface is represented using the partial-top cells, following the approach developed by Losch (2008) for the MITgcm. The model domain covers all Antarctic ice shelves that can be resolved at ~5 km resolution (0.1 degrees), as well as the full Southern Ocean up to 50 degrees south. We use Bedmap2 bathymetry and ice-draft data, and Core2 Normal Year atmospheric and sea-ice forcing fields. The simulations show warm Circumpolar Deep Water (CDW) upwelling into troughs along the continental shelf in the Amundsen and Bellingshausen Sea regions but not in other parts of Antarctica, consistent with observations. We show that melt rates are broadly consistent with observations. We expect that we can achieve further improvements by increasing vertical resolution, and by tuning model parameters such as salt and heat transfer coefficients, mean tidal velocity and surface roughness for individual ice shelves. Further, we show early progress toward coupling POP to the Community Ice Sheet Model (CISM), allowing advance and retreat of ice-shelf cavities in the ocean model.

Submitter: Dr Karen Assman

Title: Shelf break processes and the variability of Circumpolar Deep Water Transport in the Amundsen Sea

Abstract: The presence of warm Circumpolar Deep Water (CDW) intrusions on the Amundsen continental shelf has been linked to recent thinning of the outlet glaciers draining the West Antarctic ice sheet into the Amundsen Sea. CDW is sourced from within the Antarctic Circumpolar Current (ACC) situated well north of the glacial ice fronts. To be able to access the Amundsen Sea glaciers, CDW must first cross the continental shelf break where the deep ocean meets the shallower waters of the continental shelf. Here, we present data that shows how CDW moves along the continental slope and across the shelf break into the Amundsen Sea. On-shelf flow of CDW is enhanced where a subsea trough bisects the shelf edge. A previously unreported undercurrent is observed flowing eastward along the shelf edge and when this current encounters the trough mouth it circulates southward into the trough and toward the glaciers. Upwelling associated with this trough circulation appears to allow Lower CDW onto the shelf that would otherwise be blocked by the topography.

We use observations between 1994 and 2011 and a numerical model to investigate the variability of CDW transport within the trough. The location of the main CDW inflow into the trough varies between its eastern flank and centre, while the western part of the trough is filled by a re-circulation that commonly entrains cooler water originating further South on the shelf. Thermocline depth decreases between the early and late 2000s with an indication that the depth of the 1994 thermocline was similar to the later years. Mooring results show that the CDW layer cools and thins in summer and thickens and warms in winter. In addition to a deeper thermocline in summer, we observe a stronger presence of Lower CDW in the bottom of the trough. Heat flux onto the shelf appears to be controlled by current velocities rather than CDW temperature and the majority of the heat is carried onto the shelf by background flow rather than episodic events.

Submitter: Miss Louise Biddle

Title: Iceberg induced productivity in the northwest Weddell Sea

Abstract: In January and February 2012, three underwater gliders (Seagliders) were deployed from the RRS James Clark Ross in the northwest Weddell Sea to measure the ocean characteristics across the continental shelf and slope. At the same time, using satellite imagery, an iceberg (C19C; 39 km x 22 km x 0.9 km) was tracked along the continental slope. Ship-based temperature, salinity, dissolved oxygen and fluorescence measurements were taken in the same area to calibrate the Seaglider sensors and provide additional data nearby to the iceberg. Using this combination of high spatial and temporal resolution data from the Seagliders and location information from satellites, it was observed that the region the iceberg passed over displayed a pronounced biological response with elevated chlorophyll fluorescence and increased oxygen concentrations. However, this response was confined to water in the direct vicinity of the iceberg track and delayed by three days in the case of chlorophyll fluorescence, whilst the dissolved oxygen concentrations remained elevated for up to two weeks after the passage of the iceberg. These findings suggest that icebergs can have a significant impact on Antarctic continental shelf productivity rates, affecting carbon uptake rates in the region.

Submitter: Chris Borstad

Title: Creep deformation and buttressing capacity of damaged ice shelves

Abstract: The majority of the Antarctic ice sheet drains to the ocean through floating ice shelves, and many outlet glaciers in northern Greenland terminate with floating ice tongues. Most ice shelves are contained within embayments or run aground against ice rises, and these points of contact play a critical buttressing role for the neighboring grounded portions of the ice sheet. Ice shelves are currently thinning around most of Antarctica, and this thinning is believed to be reducing their buttressing capacity and allowing neighboring grounded ice to thin and accelerate. However, the diminished buttressing capacity of ice shelves could have as much to do with mechanical weakening of the ice as it thins and becomes more susceptible to fracture. Here, we present a framework for describing the creep deformation and buttressing capacity of ice shelves using continuum damage mechanics. We derive a new relation for the creep of an ice shelf, accounting for the role of fractures through a state damage variable. We apply this new theory to several Antarctic ice shelves, finding good spatial agreement between areas of inferred damage and observations of rifts and crevasses in satellite imagery. The Larsen C ice shelf appears stable at present compared to the damaged state of the neighboring Larsen B ice shelf prior to collapse, though the backstress provided by the Bawden ice rise appears to be a critical stabilizing factor for the northern part of the shelf. In contrast, the shear margins of the Pine Island Glacier ice shelf are highly damaged, akin to Larsen B before collapse, and the buttressing stress provided by the ice shelf declined between 1996 and 2007.

Submitter: Dr Alex Brisbourne

Title: Seabed Topography beneath the Larsen C Ice Shelf from seismic soundings

Abstract: Seismic reflection soundings of ice thickness and seabed topography were acquired on the Larsen C Ice Shelf in the austral summer of 2012-13. Over 100 sites at 3 to 5 km spacing along 10 lines were recorded, from the Churchill Peninsula in the north to the Joerg Peninsula in the south, and also towards the shelf edge. Sites were selected using a bathymetry model derived from the inversion of IceBridge gravity data, which indicated key regions where sub-shelf oceanic circulation may be restricted.

The seismic velocity profile in the upper 100m of firn and ice was derived from shallow refraction surveys at a number of locations. Measured sub-shelf water temperatures and an ice temperature-depth model were used to define the velocity profile through the remainder of the ice shelf. Seismic velocities in the water column were derived from previous CTD measurements. Uncertainties in ice and water cavity thickness are in general <10m.

The derived seismic bathymetry profiles indicate that a number of significant topographic features of the seabed, which could potentially inhibit oceanic circulation beneath the ice shelf and are present in the gravity inversion model, are not observed. The discrepancies between the gravity inversion results and the seismic bathymetry are attributed to the assumption of uniform geology in the inversion process and the sparsity of IceBridge flight lines. These results will be used to improve existing sub-shelf ocean circulation models.

Submitter: Dr Marianne Bugelmayer

Title: The effect of climate on icebergs - a model study

Abstract: Ice sheets play an important role in the climate system as they alter the atmospheric circulation due to their topography and high albedo as well as the ocean circulation due to their freshwater fluxes being released either as runoff or icebergs. Icebergs, in turn, affect the ocean circulation due to their melt water flux that is slowly released and due to their take up of latent heat. Their impact on the sea surface temperature, salinity and formation of sea ice has been investigated by different authors (eg. Jongma et al., 2009, 2013; Bigg et al., 1996; Gladstone et al., 2001; Martin and Adcroft, 2010) and found to be regionally significant. In the past ice-shelf break-ups have resulted in large discharges of icebergs and also recently there have been ice-shelf break-ups (Mueller et al., 2003) leading to enhanced calving events.

The presented study is focused on the effect of the atmosphere and the ocean, respectively, on the movement of icebergs and consequently on the impact of icebergs on climate. Moreover, we investigate the effect of the initial size distribution of the icebergs as this might have changed during past climates. These questions are addressed by using a version of the Earth System Model of Intermediate Complexity, *i*LOVECLIM, that includes a 3D dynamic – thermodynamic iceberg module (Jongma et al, 2009) 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 shelf model itself depends on the precipitation and temperature that is calculated by *i*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 distribution we are investigating.

By performing different sensitivity experiments with only the atmospheric (oceanic) forcing acting on the icebergs as well as using only small (big) icebergs, we find that smaller icebergs are transported further south than bigger ones. Further, our results reveal that the ocean currents are responsible for the spreading of the bergs further away from their calving sites. However, the effect of the atmospheric and the oceanic conditions, respectively, differ when being applied to different iceberg sizes. These findings can be used to better understand the sediment records of the ocean floor and the distribution of ice rafted debris contained as well as the changes in iceberg spreading across the North Atlantic due to different atmospheric patterns such as the North Atlantic Oscillation.

Submitter: Dr Adam Candy

Title: Towards an adaptive resolution multiscale model of Pine Island Glacier and ice shelf ocean cavity and its interaction with the ice sheet

Abstract: 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. It is estimated that West Antarctic ice streams contribute to 10% of the observed global sea rise (Dutrieux et al. 2013). A large contributor to this ice

loss is Pine Island Glacier (PIG), which has been thinning since 1992. Given the importance of ice shelf systems to future sea-level prediction, it is expected they will be included in model simulations used to inform the next IPCC report. Details of the processes driving the observed changes are not understood, which makes it difficult to infer parameterisations for these climate simulations that adequately capture the interaction and ultimately provide accurate predictions of future change.

Recent observational studies (Jenkins et al. 2010 and Dutrieux et al. 2013) have helped to constrain estimates of the melt behaviour underneath the shelf. Generally, however, observations are limited, due to the relatively inaccessible and inhospitable environment. A solid ice cover, up to many kilometres thick, bars access to the water column, so that observational data can only be obtained by inference from above, drilling holes through, or launching autonomous vehicles beneath the ice. This is further exacerbated by the fact that results of these recent studies have implied a significant proportion of the melting (~80%) occurs in networks of sub-kilometre scale basal channels close to the grounding line, some of the most inaccessible parts of sub-ice shelf ocean cavities.

Accurately representing these small-scale processes in conventional ocean models is a huge challenge even in focused regional studies, and will not be possible in global coupled climate simulations in the near future. Dutrieux et al. 2013 highlight that, 'Possibly the most important implication of this work concerns the modelling of sub-ice shelf cavities' and in response, we present the development of a new model of PIG that is capable of resolving the range of scales necessary to evaluate the melt distribution and forming processes that dominate. This is built on the Fluidity-ICOM model (Piggott et al. 2008) that simulates non-hydrostatic dynamics on meshes that, like the model of Timmermann et al. 2012, can be unstructured. In this case, in all three dimensions and use an anisotropic adaptive-in-time resolution to optimise the mesh and calculation in response to evolving solution dynamics. The parameterisation of melting in this model has been validated in idealised cavity domains (Kimura et al. 2013) and a validation is underway for the dynamic treatment of the ice-ocean interface (Candy et al. 2013). The model is not limited to a vertical coordinate system, which enables it to accurately represent ice sheet fronts, and small shallow features.

We will discuss the development of this model of PIG; including the cavity domain, conforming to appropriately filtered boundaries generated from data collected during the BAS Autosub 2009 expedition, and the simulation of non-hydrostatic dynamics to date. This model has the potential to capture the high spatial variation seen in melt rates in the small-scale channels, and hence provide valuable insights into the physical processes driving the observed large melting and modulation of ice-ocean interactions at kilometre scales.

Submitter: Mr Michael Dinniman

Title: Sensitivity of Water Masses and Ice Shelf Basal Melt in the Ross Sea to Changes in the Winds and Atmospheric Temperatures

Abstract: The Ross Sea is one of the few locations along the Antarctic margins where Antarctic Bottom Water (AABW) is exported to the World Ocean and thus the formation on the Ross Sea continental shelf of cold and saline Shelf Water (SW), a precursor to AABW, has consequences for the Global Thermohaline Circulation. Meanwhile, transport of relatively warm, nutrient-rich Circumpolar Deep Water (CDW) onto the continental shelf has important consequences for physical and biological processes in the Ross Sea. 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 formation of SW, transport of CDW onto the shelf, vertical mixing of CDW and its transformation into Modified CDW (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 over the past three decades. Increases in the winds combined with spatially uniform decreases in the air temperatures led to realistic increases in sea-ice concentrations. Stronger winds and cooler air temperatures both led to increases in the quantity of CDW advected onto the continental shelf and increases in the vertical mixing of MCDW into the upper water column. The increased winds worked against the cooler air temperatures in changing the basal melt rate of the RIS and the slight change (a 4% increase) in the basal melt makes it difficult to distinguish the dominant forcing factor.

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 air temperatures would reduce the MCDW that gets to the upper shelf waters, although this could be balanced out by changes in the winds. Results from simulations forced with winds and air temperatures from the SRES A1B scenario simulations from the MPI ECHAM5 model show lower transport of CDW onto the continental shelf and decreased mixing of MCDW into the upper waters for 2046-2050 when 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 by 2046-2050 (6% increase) and 2096-2100 (9% increase).

There has also been an observed freshening of the Ross Sea over the last 50 years and it has been proposed that this is a signature of increased meltwater advected from the Amundsen Sea. A simplistic freshening of the water advected into the model domain for the 2046-2050 and 2096-2100 simulations did not have a significant effect on the modeled sea-ice extent or CDW transport onto the shelf. However, the freshening reduces the MCDW that is mixed into the upper waters over the shelf, increases the basal melt rate of the RIS for 2046-2050 (10% increase compared to the 2046-2050 simulation with no freshening, 17% increase compared to the end of the 20th century) and 2096-2100 (12%/22% increase) and leads to a major reduction in the volume of SW produced.

Submitter: Prof Helen Fricker

Title: Improved elevation change records for Antarctic ice shelves from satellite radar and laser altimetry, 1992-2012

Abstract: We have been working to increase accuracy, resolution and record length of satellite radar and laser altimetry over ice shelves to provide an improved data set of elevation change for studies linking ice-shelf change to oceanic- and atmospheric-forcing variability. Here, we report our recent findings, focusing on the large Filchner-Ronne and Ross ice shelves.

(i) **Satellite radar altimetry:** We use improved procedures to integrate data from multiple satellite radar altimeter missions (ERS-1, ERS-2, and Envisat) to derive reliable long-term (~20 years) continuous records of surface elevation changes for most of Antarctica's ice shelf area. There is considerable variability in the elevation change signal on the ice shelves both in space and time, with large interannual variability that masks the long-term trend when data from only a few years are considered.

(ii) **Satellite laser altimetry:** We have developed a new method that uses InSAR-based velocity fields to account for ice advection between overpasses of the ICESat laser altimeter. This allows us to monitor elevation changes in a "Lagrangian" reference frame, i.e., following specific locations on the ice shelf as they move seaward. The Lagrangian approach reduces the noise level of the derived elevation changes and reveals clearer spatial patterns that can be transferred into basal melt/accretion rates after accounting for ice shelf strain, surface accumulation, firn air content and hydrostatic compensation. For the largest ice shelves, we find that basal melt rates are highest around the grounding lines and near the ice shelf fronts, in agreement with oceanographic models. The maps show significant basal accretion over the central parts of the Filchner-Ronne Ice Shelf, and much less basal accretion on the Ross Ice Shelf, consistent with previous studies. Although both these ice shelves are relatively stable at present, the differences in their spatial structure of basal mass balance and temporal response of dh/dt (from radar) implies potential for distinct responses to large-scale changes in ocean state.

Submitter: Mr Jamin Greenbaum

Title: Cavity shape, continental shelf bathymetry, and surface elevation change measurements from 2003 to 2012 for the area around Totten Glacier, East Antarctica.

Abstract: The Totten Glacier has the largest outflow of any Glacier in East Antarctica and flux across the grounding line indicates net mass loss in spite of 40 years of heavy snowfall. Accordingly, Totten Glacier has been the focus of geophysical studies over the last several years. In particular, the international, collaborative ICECAP Project has acquired over 10,000 line-kilometres of aerogeophysical data in the vicinity of the glacier, from well upstream of the grounding line to well seaward of the glacier terminus over the ocean. Several flights in 2010 and 2012 were focussed on continuing

the line series of surface elevation change conducted by the ICESAT mission that was terminated in 2009. Several other flights were flown in a regular grid pattern over the glacier and the floating ice tongue to map the subglacial context for the observed elevation change and to determine the broad scale bathymetry beneath the ice tongue using airborne gravimetry. In 2012 the gravimetry experiment was expanded with the acquisition of an advanced, three-axis stabilized GT-1A gravimeter with improved resolution and higher production rates under challenging flight envelopes (including draped flying). With the GT-1A gravimeter installed, 5-km spaced survey lines were extended from the lower reaches of the cavity to about 100km seaward of the terminus to infer the location and approximate depth of potential warm water pathways from the deep continental shelf to the deep cavity. The time series of elevation change from 2003 to 2012 will be presented in the context of the new bathymetry beneath and seaward of Totten Glacier.

Submitter: Prof Michael Hambrey

Title: Structure and Debris-Transfer Processes in the McMurdo Ice Shelf (Ross Embayment)

Abstract: The southern McMurdo Ice Shelf is an offshoot of the much larger Ross Ice Shelf, pinned by various volcanic islands and peninsulas. Its southern reaches are unusual in exposing bare marine ice, along with marine organisms such as shells, sponges, corals and fish, as well as sediment. The aim of this project is to evaluate the dynamics, structure and ice/sediment accretionary characteristics of this ice shelf, and to determine the mode of formation of ice-shelf moraines. Using a combination of ice structural mapping, sedimentology of surface debris and moraines, isotopic studies and radar profiling, we characterize ice and debris facies. The ice comprise three main facies, two of which are marine and one is meteoritic, derived from an accumulation zone up-flow. Ground-penetrating radar data show a series of inclined reflectors, representing accretion layering at the base. With net ablation at the surface, these layers move upwards through the ice mass along with organisms and sediment. The surface sediment forms parallel to this layering and includes both local volcanic and far-travelled (Transantarctic Mountains) debris, the latter evidently accreted when the ice shelf touched down on a bed originally laid down during Late Glacial Maximum expansion. The ice and sediment layering is locally folded and thrust-faulted, with the proportion of debris increasing towards the southern margin where it impinges on Minna Bluff. Here, extensive ice-cored moraines are developed, the internal structure of which reflects the layered structure of the ice shelf. A conceptual model is developed to demonstrate the sequential development of the ice shelf over time, particularly its structural and sedimentological evolution.

Submitter: Mr Tore Hatterman

Title: Parameterizing basal melting beneath the Fimbul Ice Shelf, Antarctica

Abstract: Basal melting below the ice shelves along the Eastern Weddell Sea coast is strongly influenced by the dynamics of the adjacent coastal current / Antarctic Slope Front system which separates the Warm Deep Water of the deep Southern Ocean from the colder waters at the coast. Oceanic heat fluxes towards the ice in this region have long been subject to uncertainty, and results from large-scale climate models are not in agreement with sub-ice shelf observations. Analysis based on a regional high-resolution ice shelf-ocean model of the Fimbul ice shelf—the largest ice shelf in this sector of Antarctica—show that basal melt rates are controlled by a complex interplay of coastal processes that regulate the access of different water masses beneath the ice. We find that the depth of the coastal thermocline relative to the shelf break, as well as the current strength beneath the ice, are the main factors controlling the oceanic heat supply. In addition, the melting response to variations in model forcing is strongly modulated by the spatial distribution of ice shelf thickness, i.e. by the horizontal area of ice in contact with ocean waters at different depths. From these findings we derive a simple parameterization for basal melting, based on the one-dimensional plume model presented by Jenkins (1991), which is modified to incorporate the characteristic ice shelf geometry of the Fimbul Ice Shelf. The parameterized melt rates from this augmented plume model—and the predicted distribution of melt rates with depth—correspond well to the numerical model results, accurately capturing the response to variations in forcing within the studied parameter space. This indicates that the amount of melting is largely independent from the details of the cavity circulation, which is not explicitly represented within the parameterization. Instead, our results suggest that the glacial mass loss is largely determined by the ice shelf geometry and together with a handful of parameters characterizing the coastal circulation. The challenge remains, however, to properly determine these parameters which are presently not well constrained within large-scale and global models. A next step would be to test this parameterization also for other ice shelves.

Submitter: Dr Hartmut Hellmer

Title: Southern Ocean warming: Increase in basal melting and grounded ice loss

Abstract: We apply a global finite element sea ice/ice shelf/ocean model (FESOM) to the Antarctic marginal seas to analyze projections of ice shelf basal melting in a warmer climate. The model is forced with the atmospheric output from two climate models: (1) the Hadley Centre Climate Model (HadCM3) and (2) Max Planck Institute's ECHAM5/MPI-OM. Results from their 20th-century simulations are used to evaluate the modeled present-day ocean state. Sea-ice coverage is largely realistic in both simulations. Modeled ice shelf basal melt rates compare well with observations in both cases, but are consistently smaller for ECHAM5/MPI-OM. Projections for future ice shelf basal melting are computed using atmospheric output for IPCC scenarios E1 and A1B. While trends in sea ice coverage, ocean heat content, and ice shelf basal melting are small in simulations forced with ECHAM5 data, a substantial shift towards a warmer regime is found in experiments forced with HadCM3 output. A strong sensitivity of basal melting to increased ocean temperatures is found for the ice shelves in the Amundsen Sea. For the cold-water ice shelves in the Ross and Weddell Seas,

decreasing convection on the continental shelf in the HadCM3 scenarios leads to an erosion of the continental slope front and to warm water of open ocean origin entering the continental shelf. As this water reaches deep into the Filchner-Ronne Ice Shelf (FRIS) cavity, basal melting increases by a factor of three to six compared to the present value of about 100 Gt/yr. Highest melt rates at the deep FRIS grounding line causes a retreat of > 200km, equivalent to an land ice loss of 110 Gt/yr.

Submitter: Dr Paul Holland

Title: Antarctic sea ice trends from observation and model

Abstract: Unlike the rapid sea-ice losses reported in the Arctic, satellite observations show an overall increase in Antarctic sea ice concentration over recent decades. Satellite tracking also reveals significant trends in Antarctic ice drift, which, in most sectors, can be linked to local winds. We observationally quantify dynamic and thermodynamic processes in the internal ice pack and show that wind-driven changes in ice advection are the dominant driver of ice-concentration trends around much of West Antarctica, whereas wind-driven thermodynamic changes dominate elsewhere. Observations of trends in Antarctic ice thickness, and hence ice volume, do not currently exist, so a model of the Southern Ocean and its ice is used to assess the magnitude and origin of recent trends in ice thickness. The model successfully reproduces existing observations of mean ice concentration, thickness, and drift, and decadal trends in ice concentration and drift, imparting confidence in the hindcasted trends in ice thickness. The model suggests that Antarctic sea ice volume has increased overall as a result of both thickening and areal expansion. Ice-thickness changes near the ice edge are in the same sense as observed concentration changes, with increasing concentration corresponding to increased thickness. Ice thickness increases are also found in the inner pack in the Amundsen and Weddell seas, where the model suggests that observed ice drift trends directed towards the coast have caused dynamical thickening in autumn and winter. Modelled changes are predominantly dynamic in origin in the Pacific sector and thermodynamic elsewhere, in agreement with the observations. The ice trends imply large changes in the surface stress that drives the Antarctic ocean gyres, and in the fluxes of heat and salt responsible for the production of Antarctic bottom and intermediate waters.

Submitter: Professor Bryn Hubbard

Title: Optical-televiewer-based investigations of the internal structure of ice shelves

Abstract: Digital optical televiewing (OPTV) recovers geometrically accurate, complete (i.e., laterally and vertically continuous), orientated, colour logs of borehole walls. The technique can be applied both to electro-mechanically-drilled boreholes, from which ice core has been recovered, and to hot-water-drilled boreholes, yielding no core but allowing for more boreholes to be drilled with equipment that is lightweight

and transportable. Since 2008, OPTV has been used to log several boreholes, up to 120 m long, drilled into or through the Roi Baudouin Ice Shelf, Antarctica. Here, we summarize the results of these investigations, focusing on the potential of the technique to address a wide variety of ice shelf physical properties and processes. These applications include: (i) material facies identification and stratigraphy; (ii) annual layer stratigraphy and derivation of age-depth scales; (iii) identification, characterization and dating of surface melt events extending back in time for several tens to hundreds of years; (iv) proxy-based calculation of along-borehole snow and firn densification, and (v) calculation of rates of vertical compaction and velocity by comparison of repeat OPTV logs.

Submitter: Dr Daniela Jansen

Title: Marine ice in Larsen C ice shelf and implications for ice dynamics

Abstract: Marine ice bodies have been found in several Antarctic ice shelves, but little is known about their detailed geometry, rate of accretion, or influence on ice dynamics. They mostly form in the lee of peninsulas, which separate the ice shelves' feeding glaciers or inlets. Melt water generated at the grounding line of ice shelves can rise in the gaps between ice shelf inlets, which leads to frazil ice formation due to the pressure dependence of the freezing temperature of water. The deposition and consolidation of the frazil ice platelets finally forms a marine ice body in the suture zone.

Here we show results from a field survey investigating marine ice in a suture zone downstream of the Joerg Peninsula in the southern part of the Larsen C Shelf, Antarctic Peninsula. We present ground penetrating radar data which delineate the boundaries between the meteoric and marine ice bodies, quantify meteoric ice thickness and, in combination with GPS data and assuming hydrostatic equilibrium, also the thickness of the marine ice. We show that the Joerg Peninsula suture zone contains marine ice of significant thickness, which increases along-flow from ~140 m to 180 m over the 20 km surveyed area.

We tested the impact of this marine ice on ice shelf dynamics by modeling the suture zone within an ice flow model. Marine ice appears to be more rigid than meteoric ice in laboratory tests, but the rheology of ice is very much dependent on its temperature. Due to the low thermal conductivity of ice, the temperature of marine ice bodies stays close to the pressure melting point for long time periods. Thus, we implemented the suture zone within the numerical model as an area of warm and soft ice. The flow rate factor for suture zone ice is calculated using the vertically averaged temperature of the ice column. The results, which replicate observed surface velocities and strain rates, show that the warmer and thus softer ice of the suture zone serves to channel shear deformation, thereby providing a flexible coupling between neighboring flow units

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Submitter: Dr Adrian Jenkins

Title: Inter-annual variability on the eastern Amundsen sea shelf: insights from observation and modelling

Abstract: The part of the West Antarctic Ice Sheet that drains into the Amundsen Sea is currently thinning at such a rate that it contributes nearly 10% of the observed rise in global mean sea level. Acceleration of the outlet glaciers appears to be caused by thinning at their downstream ends, where the ice goes afloat, indicating that the changes are probably being forced from the ocean. Observations made since the mid-1990s on the Amundsen Sea continental shelf have revealed that the deep troughs, carved by previous glacial advances, are flooded by almost unmodified Circumpolar Deep Water (CDW) with temperatures around 3-4°C above the freezing point, and that this water mass drives rapid melting of the floating ice. This talk summarises the results from recent observational and modelling studies that have looked at the temporal variability in melting that is associated with changes in CDW properties on the inner shelf. Anomalously cold conditions observed on the inner continental shelf in early 2012 appear to be associcated with anomalous atmospheric forcing that can be linked to conditions in the central tropical Pacific Ocean. An earlier suggestion of a physical link between wind forcing and CDW inflow at the shelf edge, that could potentially provide an explanation for the observations, is re-examined using the results of a high-resolution regional ice-ocean model.

Submitter: Mr Jim Jordan

Title: Modelling ice-ocean interaction in ice shelf crevasses

Abstract: Ocean freezing within ice shelf basal crevasses could potentially act as a stabilising influence on ice shelves, however ice-ocean interaction and ocean dynamics within these crevasses are as yet poorly understood. To this end, a model of an ice shelf basal crevasse has been developed using Fluidity-ICOM, a finite element ocean model using an unstructured mesh. A model of frazil ice formation and deposition has been incorporated into Fluidity-ICOM to better represent the freezing process. In this talk I will present modelled results for an idealised, two-dimensional ice-shelf basal crevasse.

Submitter: Dr Tae Wan Kim

Title: Seasonal variation of warm circumpolar deep water in central Amundsen Sea

Abstract: The spatial and temporal variation of circumpolar deep water (CDW) was measured from the two intensive oceanographic surveys and one mooring during two years. The observed vertical distribution of temperature and salinity from 67˚ S to front of Dotson ice shelf shows the latitudinal variation of CDW. The relatively warm and salty CDW transports toward the ice shelves, it was became cold and fresh by interacting with AASW. Especially, the isohaline and isotherm was rise with southward. And, the strong seasonal variation of warm layer thickness of CDW found from the two years observed temperature and salinity data in central Amundsen Sea. The warm layer thickness increased during austral spring and summer and decreased during austral autumn and winter. The amplitude of warm layer thickness was approximately 60 m. To identify the effects of wind and sea ice concentration on the seasonal variation of the thickness of CDW in the Amundsen Sea, the Ekman pumping velocity was calculated using ERA interim wind data and satellite observed sea ice concentration. The Ekman pumping velocity at Amundsen Sea continental slope shows the strong seasonal variation due to the seasonal variation of sea ice concentration and latitudinal change of local wind pattern. At the Amundsen Sea continental slope, the Ekman pumping velocity increased under the influence of latitudinal decreasing of wind velocity during austral summer season. During austral winter season, the Ekman pumping velocity decreasing due to the reducing of wind effect by sea ice extend at Amundsen Sea continental slope. Such as seasonal variation of Ekman pumping velocity was produce the upwelling of CDW and influence to the seasonal variation of warm layer thickness of CDW.

Submitter: Mr Satoshi Kimura

Title: Impacts of subglacial discharge on glacial melting

Abstract: The glacial fjords provide an important interface between the terrestrial ice and ocean. Surface meltwater on the Greenland Ice Sheet percolates down to the bed rock through moulins and enters the ocean from the bottom of glaciers, forming upwelling plumes in front of the glacier calving face. The dynamics at the ice front in fjords are significantly influenced by the buoyancy of freshwater discharge at the bottom of the glacier. We employ a finite-element, fully-unstructured-mesh ocean model, Fluidity-ICOM in an idealized domain. The geometric flexibility of employing the fully-unstructured-mesh offers several advantages over previous approaches. The model can allocate fine resolution near the ice front and decrease the resolution in all three directions toward the open boundary and represent melting or freezing on ice-ocean interfaces oriented in any direction. Our main goal is to assess the impacts of the volume flux and channel size of subglacial discharge on glacier melting. The circulation is dominated by a buoyant jet that ascends along the ice face. As the plume reaches near the surface, the plume detaches from the ice face and forms the surface layer that flows toward the open ocean. Below this surface layer, the ambient water flows toward the ice face as return flow. The melt rate of glacier is proportional to the volume flux of subglacial discharge. Given the same volume flux, the larger channel is more effective in melting the glacier.

Submitter: Dr Adrian Luckman

Title: Melt extent, duration and ponding on iceshelves from Envisat ASAR

Abstract: Melt extent and duration on ice shelves is on the increase (Tedesco et al., 2009). It is important to know where densification is occurring because it complicates the interpretation of altimeter measurement of ice shelf thinning (Holland et al., 2011). Melt also has implications for ice shelf flow and fracture because of the potential transfer of heat energy into the ice through meltwater percolation and refreezing (Vaughan, 2008). Where melt is great enough to cause ponding there may be risk of hydrofracture, a process previously associated with ice-shelf collapse.
Surface melt may be monitored by spaceborne microwave instruments because they are very sensitive to melt/freeze transitions (e.g. Kunz and Long, 2006). Scatterometers have provided daily data at low spatial resolution while Synthetic Aperture Radars provide much higher spatial resolution, but normally lack the required temporal resolution for melt monitoring. Here we use the Wide-Swath-Mode of Envisat ASAR which provides data every 2 or 3 days from 2006 to 2012 but gives a spatial resolution of 150m, which is unprecedented for surface melt studies. Melt is assumed to occur where the backscatter falls beyond a threshold below the winter mean value.
Using this technique we investigate the pattern of melt over a number of Antarctic ice shelves. We highlight new and potentially important patterns of melt driven by foehn wind events on Larsen C Ice Shelf and compare these to meteorological modelling of the foehn process. We demonstrate that melt ponding is becoming an annual feature of Larsen C ice shelf and conclude that Wide-Swath-Mode SAR data is well suited to monitoring ice shelf melt processes.

Submitter: Dr. Pierre Mathiot

Title: Ocean/sea ice sensitivity to the presence of ice shelves in a regional model of Pine Island Bay.

Abstract: Antarctica's fresh water flux due to basal melting of ice shelves reaches 20 mSv. It is known to be the third source of fresh water in Antarctica after surface precipitation and iceberg melting. In many climate models, this fresh water flux is not included or parametrised. This could lead to large uncertainties and errors in ocean and sea ice properties around Antarctica.

An ice shelf cavity module is developed and validated in the coupled ocean/sea ice model NEMO. Performance of the ice shelf cavity module is assessed through comparison with other models in a well-defined, idealized configuration (ISOMIP). Afterwards, this model is used in a regional configuration of Pine Island Bay. Simulations with and without melting ice shelves are carried out in order to evaluate the sensitivity of the ocean to the presence of ice shelves. Our experiment with ice shelves shows large changes in ocean dynamics such as the generation of a barotropic circulation and an overturning circulation on the continental shelf. The water mass properties are also modified. The thermocline is deeper and weaker due to an increase of the vertical mixing between the Modified Circumpolar Deep Water and the Antarctic

Surface Water along the ice shelf fronts. Consequences are a warming of the surface water and a decrease in sea ice thickness and concentration.

Submitter: Mr Thomas Millgate

Title: Effect of Basal Channels on Oceanic Ice-Shelf Melting

Abstract: Prominent basal channels have been found on ice-shelves undergoing strong oceanic melting in both Greenland and Antarctica. The question as to their importance to the stability of these ice shelves remains open; with proposed impacts including an increase in mechanical instability and a reduction in basal melting, leading to an increase in ice-shelf stability. One such channelized ice-shelf is Petermann Glacier, which 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 an understanding of the impact of it's four deep along shelf channels is paramount to understanding the stability of the ice shelf. We have applied a three-dimensional ocean model to the cavity beneath a, idealised, Petermann-style ice shelf containing channels running along the length of the ice shelf. Here we discuss findings detailing the effect of such basal channels on ocean flow and ice-ocean interactions.

Submitter: Dr Martin O'Leary

Title: Bounding the strength of proglacial melange

Abstract: It has been widely noted that the behaviour of many ocean-terminating glaciers appears to be controlled by pro-glacial melange, a mixture of icebergs and sea ice that seasonally fills fjords, behaving somewhat like a granular ice shelf. Changes in both glacier flow velocity and calving regime have been linked to qualitative variations in the melange. However, the properties of the melange itself which lead to these changes have received little attention, and no predictive model exists for these effects.

We use SAR imagery of the melange at Jakobshavn Isbrae, obtained during the ERS-2 3-day campaign from March to July 2011 to derive velocities via intensity tracking. By combining these velocities with contemporaneous thickness measurements from Operation IceBridge, we are able to analyse the flow of the melange, and the consequences for its mechanical behaviour. We find that the velocity of the melange is spatially uniform, with near-zero strain rates, indicating plug-like flow. Any shearing at the margins occurs over distance scales too small to be resolved by our imagery. These observations are inconsistent with the existence of significant viscous stresses within the melange, and thus with drag at the fjord walls acting as a source of mechanical resistance.

At the time of major calving events, we observe translation of the melange by up to a kilometre over a period of less than 3 days, with some accompanying extension of the

melange. In the aftermath, melange movement is slowed, and compression is observed as the melange consolidates in its new position. As time passes, this compression lessens, and the melange flow accelerates until the speed of the melange matches the speed of the glacier front . This cycle is repeated several times prior to the eventual breakup of the melange. We also observe clear evidence of compression of the melange as it is forced into the fjord wall by a former tributary of the glacier, which now exists as a separate ice front. We hypothesise that resistance to compression is the source of any force

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Submitter: Mr Alek Petty

Title: Sea ice-ocean modelling of the Antarctic shelf seas

Abstract: 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. To investigate the cause of this bimodal distribution, a simple mixed layer model has been incorporated into the Los Alamos sea ice climate model component CICE. This study builds on the idealised modelling work of Petty et al. [2013] which demonstrated that regional differences in the atmosphere and specifically air temperature can explain this bimodal distribution in the shelf seas. Through the use of a more sophisticated thermodynamic/dynamic sea ice model, we can more accurately represent the buoyancy fluxes into the ocean and extend our domain to the entire Southern Ocean. Preliminary results show that the salt flux from sea ice growth/melt dominate the annual mixed layer cycle over the continental shelf. The sea ice mass balance within each of the shelf seas further highlights the contrasting dynamic/thermodynamic bimodal response of the shelf seas, with a high ice production and export in the Weddell and Ross seas. A statistical analysis has also been undertaken to demonstrate the covariance and correlation between specific atmospheric and shelf sea variables.

Submitter: Dr Christian Rodehacke

Title: Fully coupled ice sheet–earth system simulations: The Greenlandic ice sheet response and its interaction with the climate system under raising CO2 concentrations

Abstract: The observed distinct warming in the Arctic and the northward flow of tropical water masses seems to drive enhanced melting of the Greenland ice sheet, which both adds more fresh water into the ambient ocean. Ongoing accelerating ice loss would stabilize the water column and threatens deep water formation. In a multi-modell ensemble additionally released fresh water (hosing experiments of 105 m3/s) seems to show escalating oceanic warming at some major fjord mouths, indicating a positive feedback by melting. With fully coupled ice sheet-earth system models we approach questions about Greenland changes under ongoing raising CO2 forcing and how it

influences the climate system and oceanic conditions. We have performed idealized future projections with two independent two-way coupled ice sheet-earth system models based on both earth system models (ESM) MPI-ESM and EC-Earth.

We'll present the building blocks of our fully coupled systems, which includes a physical based calculation of the ice sheet's surface mass balance and ice sheet-ocean interaction in some cases; The ESM instead receives fresh water fluxes, and some runs are subject to orographic changes as well, for instance. Since the behavior of an ice sheet in the near future is controlled by both the external forcing and by its initial conditions, we have performed Latin Hyper Cube (LHC) simulations with the ice sheet model over more than one glacial-interglacial cycle utilizing standard techniques to obtain a reasonable initial state for the MPI-ESM system. In contrast to commonly used strategies, our coupled ice sheet inherits the memory of a glacial cycle simulations obtain from ESM fields. Furthermore we do neither apply flux corrections nor utilize anomaly coupling.

Under different CO2 forcing scenarios —for example, raising CO2 by 1%/year until four times the per-industrial concentration (4xCO2) has reached, abrupt raise to 4xCO2 —the response of the coupled system is analyzed. For instance, an abrupt CO2 forcing leads to an immediate response of the Greenlandic ice sheet. The surface mass balance turns strongly negative within a couple of years, causing skyrocketing melting rates and sea level rise. The contribution of the ocean-ice sheet interaction decreases instead, because the ice sheets retreats from the coast and is therefore less susceptible to an eroding ocean. The additionally released fresh water and the heat both have the potential to stifle the meridional overturning circulation (MOC) and therefore the oceanic heat transport towards the north. Sensitivity experiments indicate that the additional fresh water has a negligible influence on the MOC initially. However on longer time scales the additional fresh water damps a recovery of the MOC, while the mass loss rate of the ice sheet is slightly reduced.

For the study we have used two state-of-the-art CMIP5 earth system models which are both coupled to the
Parallel Ice Sheet Model (PISM) covering Greenland. One setup use the MPI-ESM that comprises the atmosphere model ECHAM6 (T63L47), the vegetation model JSBACH and the ocean biogeochemical model MPIOM / HAMOCC
(GR15L40, nominal horizontal resolution of 1.5°with one pole over Greenland), where PISM has a horizontal resolution of 10 km. The other setup uses EC-Earth with the atmosphere model IFS (T159L62) and the ocean model-sea ice model NEMO / LIM (TP10L42, nominal horizontal resolution of 1°with three pols), where PISM has a horizontal resolution of 20 km.

Submitter: MSc Mathias Rücker van Caspel

Title: Antarctic Bottom Water formation in the Larsen Ice Shelf area

Abstract: The dense water that flows out from Weddell Sea originates more than 50%

of the Antarctic Bottom Water (AABW) and is therefore an important part of the Meridional Overturning Circulation. Several studies focused on the contribution of the Ronne-Filchner Ice Shelf region for this dense water production, i.e. Weddell Sea Deep Water (WSDW) and Weddell Sea Bottom Water (WSBW), but the contribution of the Larsen Ice Shelf (LIS) area for this process is still unclear. Measurements made during Polarstern cruise ANT XXIX-3 add relevant evidence for the importance of this source. During the cruise three quasi-synoptic sections were made crossing the northwestern Weddell Sea slope. This unique dataset shows that dense water is present on the shelf at the southern line, 65o S, but is absent further north. In addition to that, a comparison of a station around 1800m depth indicates that the thickness of the WSDW layer increases about 50% from south to north. This increase is due to the downslope flow of the dense shelf water observed in a deep channel connected to the LIS.
WSDW is the main precursor of AABW since the spreading of WSBW is restricted by the bathymetry and this enhances the importance of the LIS area for renewal of the AABW and the global ocean circulation.

Submitter: Dr. Michael Schröder

Title: The LASSO Expedition 2013

Abstract: A short description of the German POLARSTERN expediton (ANT29/3, LASSO)to the Larsen shelf in summer 2013.

Submitter: Prof Martin Siegert

Title: Late Holocene ice-flow reconfiguration in the Weddell sector of West Antarctica

Abstract: Here we discuss late Holocene ice sheet and grounding-line changes to the Weddell Sea sector of West Antarctica. Internal radio-echo layering within the Bungenstock Ice Rise, which comprises very slow-flowing ice separating the fast-flowing Institute and Möller ice streams, reveals ice deformed by former enhanced flow, overlain by ice deposited during the current slow flow regime. The ice-rise surface is traversed by surface lineations explicable as diffuse ice-flow generated stripes, which thus capture ice velocity direction immediately prior to the creation of the ice-rise. The arrangement of internal layers can be explained by adjustment to the flow path of the Institute Ice Stream, during either a phase of ice sheet retreat not longer than ~4000 years ago or by wholesale expansion of the grounding-line from an already retreated situation not sooner than ~400 years ago. Some combination of these events, involving uplift of the ice rise bed during ice stream retreat and reorganisation, is also possible. Whichever the case, the implication is that the ice sheet upstream of the Bungenstock Ice Rise, which currently grounds over a >1.5 km deep basin has been, and therefore may be, susceptible to significant change.

Submitter: Mr Craig Stewart

Title: Recent observations of oceanographic conditions and basal melting of the Ross Ice Shelf

Abstract: In January 2011 an oceanographic mooring was deployed beneath the northern Ross Ice Shelf approximately 7km from the ice front. This mooring has now provided a two year record of water temperature, currents and ice shelf basal melt rates from upward looking sonar (ULS). During the 2012-13 season additional basal melt rate measurements were made near the ice front using a phase-sensitive Radio Echo Sounder. Here we show some preliminary observations.

While mean flow at the mooring site is to the north west (i.e. an outflow oblique to the icefront), repeated southward intrusions during summer carry relatively warm Antarctic Surface Water (AASW) to the mooring site. These intrusions match the timing of maximum melt rates observed by the ULS at the mooring suggesting that the AASW drives this summer melting. Radar melt-rate transects show summer melt rates increase rapidly towards the ice front reaching > 10 cm/day. These rates are approximately an order of magnitude greater than estimated annual averages, suggesting that summer melt dominates the annual signal in this region.

Submitter: Dr Anna Wåhlin

Title: Variability of warm deep water inflow in a submarine trough in the central Amundsen Sea

Abstract: The ice shelves in the Amundsen Sea are thinning rapidly, and the main reason for their decline appears to be warm ocean currents circulating below the ice shelves and melting these from below. Ocean currents transport warm dense water onto the shelf, channeled by bathymetric troughs leading to the deep inner basins. A hydrographic mooring equipped with an upward-looking ADCP has been placed in one of these troughs on the Central Amundsen Shelf. The two years (2010-2011) of mooring data are here used to characterize the inflow of warm deep water to the deep shelf basins. During both years the warm layer thickness and temperature peaked in austral fall. The along-trough velocity is dominated by strong fluctuations that do not vary in the vertical. These fluctuations are correlated with the local wind, with eastward wind over the shelf and shelf-break giving flow towards the ice shelves. In addition there is a persistent flow of dense lower Circumpolar Deep Water (CDW) towards the ice shelves in the bottom layer. This bottom-intensified flow appears to be driven by buoyancy forces rather than the shelf-break wind. The years of 2010 and 2011 were characterized by a comparatively stationary Amundsen Sea Low, and hence there were no strong eastward winds during winter that could drive an upwelling of warm water along the shelf break. Regardless of this, there was a persistent flow of lower CDW in the bottom layer during the two years. The average heat transport towards the ice shelves in the trough was estimated from the mooring data to be 0.95 TW.

A suggested future collaborative work with focus on better quantification of the heat flux from the ocean to the glaciers in the region will be presented and discussed. The focus of this work will be on hydrographic transects in the unexplored areas further west, and subsurface moorings in the main paths of the deep water and the meltwater. Climate scale oscillations in the heat transport, dominated presumably by the Southern Annular Mode, requires up to decadal time series.

POSTERS

In alphabetical order

Submitter: Dr Marius Arthun

Title: Eddy-driven exchange between the open ocean and a sub-ice shelf cavity

Abstract: The exchange between the open ocean and sub-ice shelf cavities is important to both water mass transformations and basal melt. Here we use a high resolution (500 m) numerical model to investigate to which degree eddies produced by frontal instability at the edge of a polynya are capable of transporting dense High Salinity Shelf Water (HSSW) underneath the ice shelf. The applied surface buoyancy flux and ice shelf geometry is based on Ronne Ice Shelf in the southern Weddell Sea, an area of intense wintertime sea ice production and where a flow of HSSW into the cavity has been observed. Results show that eddies are able to enter the cavity at the south-western corner of the polynya where an anticyclonic rim current intersects the ice shelf front. The size and time scale of simulated eddies are in agreement with observations close to the Ronne Ice Front. The properties and strength of the inflow are sensitive to the prescribed total ice production, flushing the ice shelf cavity at a rate of 0.2-0.4*10^6 m^3s^{-1} depending on polynya size and magnitude of surface buoyancy flux. Eddy-driven HSSW transport into the cavity is reduced by about 50% if the model grid resolution is decreased to 2-5 km and eddies are not properly resolved.

Submitter: Dr Elin Darelius

Title: Hydrography and Circulation in the Flichner Depression

Abstract: In January 2013 fieldwork was conducted in the Filchner Depression, Antarctica. In the Filchner Depression, cold Ice Shelf Water emerging from the Filchner Ice Shelf are flowing northward towards the shelf break. Meanwhile, seasonal intrusions of Modified Warm Deep Water are moving southward. A total of 116 stations, divided on six hydrographic sections - one on the western side, one across the Depression in front of the Filchner Front and four on the eastern slope - and four 12-h long time series where occupied, comprising temperature, salinity, pressure, oxygen (CTD) and velocity measurements (LADCP). In the time series, CTD-LADCP and VMP (Vertical Microstructure Profiler) casts were alternated.
Here we present preliminary results on water mass properties and transport from the six sections.

Submitter: Miss Eleanor Darlington

Title: Submarine glacial melt contributions inferred from development of sediment plumes, Kongsfjorden, Svalbard

Abstract: Submarine meltwater entering fjord systems from tidewater glaciers entrains large amounts of sediment, forming sediment plumes. These distinctive plumes can be utilised to monitor the seasonal evolution of meltwater entering the fjord, to further understand hydrological variability and ultimately glacial contributions to sea level rise.

Spectral measurements from a hand held device have been used to determine surface reflectance in Kongsfjorden. These have been calibrated to Total Suspended Solids values using filtered water samples. These *in-situ* data have been correlated with MODIS band 1 reflectance data, to enable sediment plumes to be identified and tracked remotely. This offers a method to remotely monitor meltwater inputs from Kronenbreen glacier for seasonal and multi-annual analysis.

Repeat oceanographic measurements of ocean conductivity, temperature and depth (CTD) were made in front of the calving face of Kronenbreen during the peak of the melt season in July 2012. These CTD data allow for the quantification of submarine melt at the calving face, from the determination of geostrophic flow velocities in Kongsfjorden.

This synergistic analysis not only progresses the understanding of tidewater glacier melt processes at the calving face, but also allows for upscaling to other high Arctic fjord systems, enabling increased accuracy when quantifying the freshwater inputs to the Arctic and surrounding Oceans.

Submitter: Dr Jan De Rydt

Title: Geometrically controlled melt rates of Pine Island Glacier during early stages of its retreat

Abstract: Observations beneath the floating section of Pine Island Glacier have revealed the presence of a subglacial ridge which rises up to 300m above the surrounding bathymetry. This topographic feature has likely served as a steady grounding line position until the early 1970s, whereas the present grounding line is situated approximately 30km further upstream, following an ongoing phase of rapid retreat. As a result, a large ocean cavity has formed behind the ridge, strongly controlling the ocean circulation beneath the ice shelf and modulating the ocean water properties that cause melting of the ice shelf in the vicinity of the grounding line. In order to understand how melt rates have changed during various phases of cavity formation, we use a high resolution ocean model to simulate the cavity circulation for a series of synthetic geometries. We show that the height of the ridge, as well as the gap between the ridge and the bottom of the ice shelf strongly control the inflow of warm bottom waters into the cavity, and hence influence the melt rates. Model results provide evidence for rapidly increasing melt rates at the onset of ice shelf thinning, but a weak change in melt rates once the gap between the ridge and the ice shelf has passed a threshold value of 150m. At present the gap is well over 150m, and our results suggest that observed variability in melt rates is primarily controlled by other factors such as the depth of the thermocline.

Submitter: Mr Michael Dinniman

Title: The ACCIMA Project - Coupled Modelling of the High Southern Latitudes

Abstract: 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. 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. While recent work in the climate modelling community has emphasized coupling of multiple components so as to achieve flexible, quantitative, multi-disciplinary tools to address the various critical climate questions, global models are not ideal to treat driving processes on the mesoscale. Consequently, we adopt a high-resolution regional climate approach to modelling the key coupled atmosphere-ocean-ice processes for the Antarctic Ice Sheet with an initial regional emphasis on the West Antarctic and Amundsen Sea.

The primary tool for the project will be a coupled modelling system including the Polar-optimized Weather Research and Forecasting model (Polar WRF) for the atmosphere, the Regional Ocean Modelling 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. Retrospective decadal simulations will be performed to understand recent past variability. Downscaled future projections for Antarctica will be driven by the global National Centre for Atmospheric Research (NCAR) Community Earth System Model (CESM or its equivalent). Upon project completion we will assess the feasibility of further advancing this regional modelling effort. If our downscaled hindcast and forecast regional model simulations are evaluated to be an improvement over coarse-resolution modelling, 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.

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Title: What Determines the Differences in Basal Melt between Ice Shelves in the Amundsen Sea?

Abstract: The Amundsen Sea features the fastest thinning ice shelves around Antarctica. We examine the hypothesis that ice shelf geometry is the main factor determining the differences between the steady basal melt rates of the individual ice shelves in this region. We employ a high-resolution (1.5km) 3-D ice shelf-ocean
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numerical model (ROMS) to simulate the steady basal melt rates of the Amundsen Sea sector. The model domain includes Cosgrove, Pine Island, Thwaites, Dotson and Getz ice shelves as well as parts of Crosson and Abbot ice shelves. The ocean and ice shelves are thermodynamically-coupled and the ice shelf geometry is assumed constant over the short period of time considered (5years). The model is compared to observations and the simulations reveal that ice shelf geometry can account for a significant fraction of the differences in basal melt rates.

Submitter: Dr Tom Holt

Title: Stange Ice Shelf: An assessment of its structure, dynamics and evolution

Abstract: Stange Ice Shelf (SIS) is situated on the Antarctic Peninsula, and is the most southern and westward ice-shelf system in the region. It is fed by glacier ice from three grounded locations thus making for a dynamically and structurally complex ice shelf. Here the evolution of SIS is documented through the analysis of several remote sensing datasets (Landsat, ERS-1/2, Envisat, ICESat) to highlight the responses to environmental changes that have been widely observed on other ice shelves on the Antarctic Peninsula. In total, SIS lost ~340 km^2 of ice over the period 1973-2011, with calving from its north ice front accounting for the majority of this change. ICESat GLAS measurements also reveal widespread negative elevation change across the ice shelf between 2003 and 2008, from which ice-shelf thinning is inferred. Structurally, SIS shows few changes, but a shift in dynamics towards the south ice front between 2001 and 2011 resulted in shear-induced rifts forming along its suture zone, thus making this region structurally weak and prone for further calving and retreat. We propose that SIS is currently stable; however, there is evidently a response to environmental changes reflected in its glaciological characteristics, and SIS should be monitored regularly in order to construct an improved understanding of ice-shelf dynamics to atmospheric and oceanic changes.

Submitter: Mr Ola Kalen

Title: Observations of circulation of warm deep-water at the Amundsen Shelf edge

Abstract: The observed thinning and acceleration of the West Antarctic glaciers emptying into the Amundsen Sea region has implications on global sea level rise. The primary driver in the thinning process is the advection of relatively warm circumpolar deep-water (CDW) melting the floating ice shelf from below. The dense CDW is topographically steered onto the shelf area via bathymetric channels by deep ocean currents. The spatial and temporal properties of inflow and outflow of deep-water in the shelf-break area are not fully understood, both due to the lack of in-situ measurements as well as ocean models being too coarse to resolve these dynamics. In this study we present time series observations from 2009 to 2011 of hydrographic properties from two moorings in a western and an eastern channel, both leading to the Amundsen Sea ice

shelf. Structure and variability of the time series of velocities and temperature are analyzed. The results suggest that there is a steady inflow of warm deep water in the eastern channel and an outflow in the western channel, which is slightly colder due to the heat loss to the melting of the ice shelf.

Submitter: Dr Bernd Kulessa

Title: Seismic properties of marine and meteoric ice in Larsen C Ice Shelf, Antarctic Peninsula

Abstract: We present initial estimates of the physical properties of meteoric and marine ice in Larsen C ice shelf, Antarctic Peninsula, as derived from common-midpoint (CMP) reflection-seismic datasets. The data were acquired during the 2008-09 austral summer in the south-eastern sector of the ice shelf, where the shelf is ~ 300 m thick with a firn-ice transition at a depth of ~ 45 m based on a density of 830 kg/m^3. We used Pentalite explosive charges deployed in shallow shot holes, and 48 vertical-component 100 Hz geophones. 24 of these phones were installed horizontally and transverse to the acquisition line, such that compressional (P), vertically-polarised shear (SV) and horizontally-polarised shear (SH) could be recorded. Seismic data were collected at two adjacent sites; a southernmost 'control site' (S-CMP) on a meteoric ice-flow unit derived from Mobile Oil inlet where marine ice is absent, and a marine-ice bearing flow unit to the north (N-CMP) that originates downflow of Joerg Peninsula.

The seismic data are rich in reflection events, with different phases identifiable as primary and multiple P-waves, SV- and SH-waves, and also P to SV mode conversions. At S-CMP strong reflection events originate at the ice-shelf base at ~ 300 m depth, including a clear P-wave reflection at ~ 170 ms zero-offset travel-time and a P-S mode conversion at ~ 250 ms. Semblance and Dix-based analyses yield P-wave and S-wave velocities respectively of 3708 m/s and 1931 m/s for the meteoric ice at S-CMP, and the P-wave quality factor of meteoric ice (Q_P) is estimated at ~ 173 [-39, +70]. Model validation is provided by a good match between observed and modelled seismic CMP data, and by a reasonable estimate of the zero-offset reflection coefficient at the ice shelf base of ~ -0.46 +/- 0.13 compared to a theoretical value of -0.4. Assuming that meteoric ice has zero porosity and a density of 915 kg/m^3, we can estimate the bulk and shear moduli of meteoric ice respectively as 8.02 and 3.42 GPa, with a Poisson's ratio of 0.31.

Common-offset 50 MHz ground-penetrating radar (GPR) data are used to constrain the meteoric-marine ice boundary within the ice shelf where marine ice is present, or the base of the ice shelf where it is absent. In agreement with previous work we found that the high dielectric absorption of radar energy in marine ice did not allow detection of the ice-shelf base with GPR in the presence of marine ice. The meteoric-marine ice boundary is subject to pronounced thickness variations of several tens of metres over horizontal distances of a few hundred metres, presenting a particular challenge in seismic data analysis. Common-midpoint (CMP) GPR data are used to constrain the radar velocities within the ice shelf, thus facilitating depth conversion of the

common-offset GPR data. Since the meteoric-marine ice interface directly below N-CMP appears at ~ 240 m depth in the GPR data, we would expect a seismic P-wave reflector to appear at ~ 140 ms zero-offset travel time. Although multiple seismic energy returns appear at this time and later, the energy patterns are too complex to allow confident identification of a single seismic reflection event from the meteoric-marine ice boundary. We therefore conclude that the interface is acoustically diffuse, which concurs with previous measurements of the elastic modulus of the B15 ice core from Filchner-Ronne ice shelf in West Antarctica. Semblance analysis confirmed that akin to S-CMP, the ice-shelf base at N-CMP also appears at ~ 170 ms zero-offset travel time, albeit with a 10% lower root-mean-square P-wave velocity. Implementing a meteoric-marine ice transition at ~ 140 ms zero-offset travel time as suggested by the GPR data, Dix-based analysis yields an average P-wave velocity of 2162 m/s for the marine-ice layer at N-CMP. Below the P-wave reflector many seismic energy returns are apparent, although it is challenging to uniquely identify the P-S mode conversion at the ice-shelf base. We must therefore adopt an indirect route in estimating the S-wave velocity at N-CMP along with the appropriate elastic moduli of the marine ice layer.

Effective medium models are a common geophysical means of estimating the elastic properties of composite materials consisting of a phase mixture of solid grains and gas or fluid bearing pores, generally requiring specification of [i] the volume fractions of the various phases; [ii] the individual elastic moduli of these phases; and [iii] their geometrical arrangement. While the volume fractions and individual elastic moduli can often be estimated with reasonable certainty, their geometrical arrangement cannot and thus requires computation of upper and lower bounds of the elastic properties of the composite material. Here we apply the commonly-used *wider* 'Voight-Reuss-Hill' and *narrowest-possible* 'Hashin-Shtrikman' bounds to the marine ice in Larsen C ice shelf. We assume that marine ice consists of an ice fraction with the same elastic properties as meteoric ice and that it is fully-saturated with water that has respective bulk and shear moduli of 2.2 and 0 GPa. By further assuming that it has a density between 915 and 990 kg/m3, Hashin-Shtrikman bounds place the composite bulk and shear moduli of marine ice respectively between 2.87-5.58 GPa and < 1.97 GPa, with corresponding Voight-Reuss-Hill averages of 4.23 and 0.99. Using the average P-wave velocity of the marine-ice layer (2162 m/s), average marine-ice porosity is estimated at 28-68% from Hashin-Shtrikman bounds, and thus exceeds the average marine-ice porosity of 17 +/- 20% estimated at Amery ice shelf in East Antarctica. Using Hashin-Shtrikman bounds, the minimum porosity of 28% and the Voight-Reuss-Hill average of 0.99 of the shear modulus, we can estimate a maximum average S-wave velocity of the marine-ice layer of 1470 m/s. The layer's Poisson's ratio is respectively 0.07-0.5 or 0.31 from Hashin-Shtrikman or Voight-Reuss-Hill bounds.

In our analyses so far we have assumed isotropic and hyperbolic seismic wave propagation, and thus quote large uncertainty bounds. We are confident that more advanced seismic modelling with an undulating meteoric-marine ice interface and allowing for anisotropy will result in a refinement of our estimates of the (geo)physical properties of the Joerg-Peninsula derived marine-ice layer in the south-eastern sector of Larsen C ice shelf, and result in smaller uncertainty bounds. Our estimates of the physical properties of the meteoric and marine ices will ultimately be used to inform predictive models of the flow and fracture mechanics of Larsen C Ice Shelf.

Submitter: Dr Benoit LEGRESY

Title: Interaction of dense shelf water with the Mertz Glacier Tongue (1992-2007)

Abstract: Ocean observations around the Australian-Antarctic basin show the importance of coastal latent heat polynyas near the Mertz Glacier Tongue (MGT) to the formation of Dense Shelf Water (DSW) and associated Antarctic Bottom Water. The interaction between the glacial melt water from the ice sheet and the DSW is likely to be important by possibly freshening the exported DSW. Here, we use a regional ocean/ice shelf model to investigate the inter-annual variability in the production of DSW in the vicinity of the ice tongue and its interaction with the ice tongue. The MGT is simulated to melt at 11.4٢،4 Gt year-1, (area averaged of 1.9̊.4 m year-1), which represents a significant portion of the observed ice flux from the grounded ice sheet of 14-18 Gt year-1. About 26% of this melting comes from ice deeper than 900m. During periods of active polynya activity (defined by the observed air-ocean heat flux), high production rates of DSW lead to the melt rates becoming decreased to 1.2̥.4 m year-1. The melt rate peaks to 3.8̊.5 m year-1 for a short time during a period of sustained weak polynya activity, which is 3 times higher than during periods of active polynya activity. . The enhanced basal melting is due to the increased presence of relatively warmer water interacting with the base of the ice-shelf. This study highlights the need to understand how future climate change can impact coastal Antarctic air-sea fluxes.

Submitter: Dr Deb Shoosmith

Title: Variability of ocean heat transport and implications for melting beneath Dotson Ice Shelf, West Antarctica

Abstract: The ocean plays a key role in the process of mass loss from ice sheets through iceberg calving and basal melting. Given current concerns about the mass balance of the West Antarctic Ice Sheet, it is important that we understand this oceanographic impact. The Amundsen Sea, located in the eastern Pacific sector of the Southern Ocean (West Antarctica), is a region where the ice shelves are rapidly thinning. The widespread, coherent nature of the thinning, in a region where air temperatures are rarely above freezing, suggests a response to oceanic forcing. In the Amundsen Sea, the continental shelf is flooded by Circumpolar Deep Water (CDW), which is ~3°C warmer than the surface freezing point and is found only within the latitudinal band of the Antarctic Circumpolar Current around most of Antarctica. However, our knowledge of CDW transport under the Amundsen Sea ice shelves, where the high temperature can drive rapid basal melting, is limited by a sparsity of observations. To address this, in early 2006 and 2007 we conducted high resolution hydrographic surveys along the front of Dotson Ice Shelf. Studies using satellite data have indicated that Dotson Ice Shelf is thinning by about 3 m per year. Since the ice shelf is bounded by land, the CTD sections fully enclose the cavern of water beneath the ice, thus sampling both inflows and outflows. The purpose of this

study was to quantify the rate of melting beneath the ice shelf, and investigate the temporal variability of both the basal melting and the water mass properties at the ice shelf front.

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Title: Oceanographic Observations in the Bellingshausen Sea

Abstract: The Bellingshausen Sea, West Antarctica, experiences a variable and warming climate, and as a result, the sea ice and land ice cover in the region are declining. This poster provides an overview of cruise JR165 on RRS James Clark Ross in February – April 2007. The cruise set out to investigate the oceanographic regime of the Bellingshausen continental shelf, in particular the processes that introduce warm Circumpolar Deep Water (CDW) to the shelf, drive its circulation on the shelf and regulate the amount of heat it gives up to the overlying ice cover and atmosphere. To this end, we occupied a number of CTD sections that cross two major troughs on the Bellingshausen continental shelf, as well as further sections across the shelf break at the mouths of the troughs. These will allow us to track the progress of CDW along the shelf edge, onto the shelf and up to the floating ice shelves. A CTD section spanning the Bellingshausen Sea from Fletcher Peninsula to Charcot Island shows the predominance of CDW across the shelf and enables us to determine circulation and transports for the entire region. In addition, sections across the fronts of the Wilkins and George VI Ice Shelves will allow us to quantify heat and meltwater transports, giving an estimate of the rate of basal melting, and thus determine the oceanographic impact on these ice shelves.


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