2014 (October 21-24) FAMOS Abstracts

A.

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Pathways, variability and Modification of the Arctic Atlantic water in the model inter-comparison experiment

Distribution of the Atlantic Water (AW) in the Arctic Ocean has impact on ocean mixing, ocean dynamics, heat and salt budgets, as well as for nutrients and biology. We use an ensemble of five Ocean General Circulation models with passive "colour" tracers released during 1979-2010 to track the simulated inflow of the AW in the Arctic Ocean via the Fram Strait and the Barents Sea Opening and examine the spread of AW in the Arctic Ocean. The model differences in AW distribution, transit time of AW in the Fram Strait and Barents Sea branches and AW circulation in the Arctic Ocean are analysed. We identify model errors by comparing the simulations with observational data. The models demonstrate a realistic spread of the Fram Strait and Barents Sea modes of AW in the Arctic Ocean. The former occupies depth range of 200-700m and the latter has a maximum at ca. 1000m. Using Walin's watermass transformation diagnostics, we differentiate AW modification due to surface heat loss and freshening and interior mixing with ambient watermasses. We analyze interannual variability of the AW circulation and the mechanisms which drives it, including the role of bathymetric steering of the flow.

Predicting the Arctic Ocean Environment

Recent environmental changes in the Arctic have clearly demonstrated that climate change is faster and more vigorously in the Polar Regions than anywhere else. Significantly, change in the Arctic Ocean (AO) environment presents a variety of impacts, from ecological to social-economic and political. Mitigation of this change and adaptation to it requires detailed and robust environmental predictions. Here we present a detailed projection of ocean circulation and sea ice from the present until 2099, based on an eddy-permitting high-resolution global simulation of the NEMO ¼ degree ocean model. This is forced at the surface with HadGEM2-ES atmosphere model output from the UK MetOffice CMIP5/AR5 run for scenario RCP8.5. Between 2000-2009 and 2090-2099 the AO experiences a significant warming, with sea surface temperature increasing on average by about 4° C, particularly in the Barents and Kara Seas, and in the Greenland Sea and Hudson Bay. By the end of the simulation, Arctic sea ice has an average annual thickness of less than 10 cm in the central AO, and less than 0.5 m in the East-Siberian Sea and Canadian Archipelago, and disappears entirely during the Arctic summer. Analysis of the AO circulation reveals evidence of (i) the reversal of the Arctic boundary currents in the Canadian Basin, from a weak cyclonic current in 2040-2049 to a strong anti-cyclonic current in 2090-2099, and (ii) increased anti-cyclonic surface ocean circulation in the eastern part of the AO, while the surface circulation in the western Arctic becomes more cyclonic. We relate the shift in the circulation to changes in the winds and reduction of sea ice cover, which modify momentum transfer from atmosphere to the ocean. Our simulation suggests a potentially complex picture of future AO change, and highlights the importance of high resolution modelling in forecasting it.

A.
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Recirculation in the Fram Strait: Transport and dynamics based on observations and eddy-resolving modeling

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The Fram Strait is the main gateway for exchanging mass, heat and salt between the Atlantic and Arctic Oceans. In particular, the relatively warm and saline Atlantic Water (AW) within the northward-flowing West Spitsbergen Current (WSC) is assumed to be a major contributor to the Arctic Ocean heat budget. But not all AW reaching Fram Strait eventually enters the interior basins, with recent studies indicating that as much as 50% of the AW may recirculate at 79° N. This recirculation is recognized as westward transport shedding off the boundary current west of Spitsbergen, although little is known about its driving mechanisms.

Proposing that the interaction of mesoscale eddies with the mean flow plays an important role for the fate of the AW within the WSC, we present recent oceanic hindcast simulations at two different resolutions (a 4km pan-Arctic model and a nested 800 m regional setup, both based on ROMS) to study the Fram Strait recirculation pattern. Our models reproduce the major currents, showing westward flow of AW possibly associated with topographic features at 79° N and 80.5° N. Simulated current statistics at both resolutions compare well with observations from the AWI/NPI Fram Strait mooring array for the energetic boundary currents over the eastern and western continental slope. However, with an internal Rossby radius typically being in the range of 3-10km, the models show significant differences in reproducing the enhanced eddy kinetic energy observed in the central part of the Fram Strait. Comparing these two realizations of the circulation with each other and the observations allows us to decompose the different contributors to the recirculation transport and investigate the underlying processes controlling the advection of AW into the Arctic Ocean.

A.

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Sea level in the Arctic Ocean from ERS, Envisat and CryoSat-2 satellite radar altimeters

Basin-scale and regional sea level trends in the Arctic Ocean are examined using an 18-year time series of radar altimeter sea level estimates up to 82N. Since it was last surveyed the sea level in the western Arctic continued to rise, peaking in 2011 before levelling off, pointing to further accumulation of fresh water in the Beaufort Gyre. This convergence of fresh water is associated with a strengthening of the anti-cyclonic atmospheric circulation, particularly in the summer time. We also investigate how the changing state of the sea ice pack is influencing the atmosphere-ocean momentum exchange. As well as looking at long-term trends, the altimetry dataset allows us to examine the annual cycle of sea level in the western Arctic Ocean. This is compared with the annual cycles of liquid and solid fresh water in the region, incorporating state-of-the-art sea ice volume estimates from CryoSat-2.

A.

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Extreme Sea Level Oscillations in the Arctic Seas and their long-term changes

Igor Ashik

The conditions of the extreme (an annual maximum, a minimum and size) sea level oscillations on stations of the Russian Arctic seas is described in article. Spatial distribution of the parameters of extreme sea level oscillations is analyzed and their dependence on morphometry of the Arctic seas and their areas is shown. The estimation of the trends of annual maxima, minima and sizes sea level oscillations is executed and the existence of the long-term tendency to reduction of the values of annual maxima and sizes of sea level oscillations is shown. The hypothesis explaining marked regularity is offered.

A.

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Inter-annual and Shorter-Term Variability in Physical and Biological Characteristics across Barrow Canyon in August – September 2005-2013.

Carin Ashjian, Stephen Okkonen, Robert G. Campbell, Philip Alatalo

Physical and biological conditions across a 37 km transect of Barrow Canyon have been described for the past nine years as part of an ongoing program focusing on inter-annual variability and the formation of a bowhead whale feeding hotspot near Barrow. These repeated transects (at least two per year, separated in time by days-weeks) provide an opportunity to assess the inter-annual and shorter term (days-weeks) changes in hydrographic structure, ocean temperature, current velocity and transport, chlorophyll fluorescence, nutrients, and micro- and mesozooplankton community composition and abundance. Inter-annual variability in all properties was high and was associated with larger scale, meteorological forcing. Shorter-term variability could also be high but was strongly influenced by local wind forcing. The sustained sampling at this location provided critical measures of inter-annual variability that should permit detection of longer-term trends that are associated with ongoing climate change.

B.

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Arctic freshwater and heat fluxes: variability, and assessment

Paucity of measurements means that quantifying and evaluating the Arctic thermal and hydrological cycles is problematic. For example: atmospheric reanalyses are not well constrained by observations; for river runoff measurements, there are un-gauged flows to consider; and until the relatively recent advent of autonomous measurement systems, ocean measurements outside the summer melt season were rare. It has proved possible, however, to design a metric based on sea ice and ocean measurements which captures net surface fluxes (atmosphere-ocean and land-ocean, including sea ice) of freshwater and heat. A closed circuit is formed around the Arctic Ocean boundary by moored measurement systems and land, supplemented by remote-sensed and other measurements. Occasionally "patching" with coupled ice-ocean general circulation model (GCM) output is required; if so, the output water properties are validated and calibrated against climatology. This approach enables application of inverse modelling methods through the use of conservation constraints, and consequent generation of monthly-mean ocean (including sea ice) fluxes of freshwater and heat, and a draft version of a single annual cycle will be presented (2005-6). Availability of an objective metric permits subsequent intercomparison, and ultimately assessment, of the performance of GCMs and climate models in terms of Arctic ice and ocean surface fluxes. Illustrations will be given of the dependence of both surface (air-sea-ice) and ocean boundary fluxes from GCMs and their dependence both on model resolution and on surface forcing fields, and these in turn will be compared with an example of the same quantities calculated from a coupled climate model. These are steps towards (i) designing a viable Arctic Ocean boundary observation system, and (ii) quantification of Arctic fluxes.

B.

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Variability of Turbulent Heat Flux Estimates in the Nordic Seas

The magnitude and variations of air-sea heat fluxes at high latitudes are greatly dominated by surface turbulent processes. Intense surface cooling in the Nordic Seas (Greenland, Icelandic, Norwegian, Barents) can induce deep convection which is a key mechanism in driving the water mass formation and hence global ocean thermohaline circulation. Uncertainty and bias in turbulent heat flux estimates limit understanding of related physical processes and feedbacks at high latitudes. By using 3-hourly output from the Arctic System Reanalysis (ASR) interim version in which cyclone activity was captured more realistically, sensible and latent heat fluxes are calculated at 30 km spatial resolution for the 11 year period from 2000–2010. Spatio-temporal patterns and variability of turbulent heat fluxes are analyzed and compared with National Centers for Environmental Prediction-Climate Forecast System Reanalysis (NCEP-CFSR) and European Centre for Medium-Range Weather Forecasts Reanalysis (ERA)-Interim.

B.

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Using sea-ice deformation distributions to constrain sea-ice dynamic models

Calibration of sea-ice dynamic models against a certain set of parameters (e.g., air and ocean drag, ice strength in compression, ellipse ratio) is usually done by minimizing the error between simulated and observed sea-ice drift. Since the deformation fields resulting from the simulated drift are also sensitive to changes in those parameters, we explore the idea of adding the deformation distribution statistics to further constrain the model parameters. To do so, we compute the probability density functions (PDFs) for simulated strain rate invariants (divergence and maximum shear stress) and compare against those obtained with the 3-day gridded deformation products from the RADARSAT Geophysical Processor System (RGPS). We first investigate the effects of spatial resolution, convergence and different parameter values on the simulated PDFs. We find that, as the spatial resolution increases, the PDFs of simulated deformation fields are corresponding more and more to the RGPS PDFs, but there are still significant differences in the shape of the modeled and observed PDFs. These differences point out the need for an increased ice strength parameter (P*) or increased ice thickness over most of the Arctic to get a best fit with the RGPS data. Since these solutions might not be physical, we are looking instead at the role of the air and ocean drag parameters to set a force balance that would reconcile the deformation PDFs with the RGPS deformation PDFs, while keeping valid drift values. We are currently focusing our experiments with viscous-plastic models using the elliptical yield curve and normal flow rule of Hibler (1979), but oncoming results with other yield curves will also be investigated in the context of testing different rheological models to assess their physical validity.

B.

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On computing noise-free sea ice deformation fields from SAR-derived sea ice motion

We propose a method to compute nearly noise-free sea ice deformation fields from SAR-derived motion and present the results of its application to RGPS sea ice trajectories. The method is based on two steps. The first step consists in using a triangulation of the positions taken from the sea ice trajectories to define a mesh. The second step consists in applying a specific smoother on the deformation fields to reduce the artificial noise that arises along ice drift discontinuities. From the comparison between unfiltered and filtered fields, we estimate that the artificial noise causes an overestimation of about 60% of the accumulated opening and closing area. The artificial noise has also a strong impact on the statistical distribution of the deformation and on the scaling exponents estimated with multi-fractal analysis. The method proposed is applicable to other SAR derived drift data sets and has been used to produce a new sea ice deformation dataset.

B.

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Observations of Wind-Driven Processes in The Surface Layer Of The Marginal Ice Zone

As the Arctic transitions from a persistent multi-year ice pack to a seasonal pack dominated by first-year ice, the relative area and importance of the Marginal Ice Zone (MIZ) will continue to increase. The MIZ is subject to both ice and ocean dynamics and is typically considered the area with ice concentrations from 15% to 90\% surrounding the remaining permanent ice pack. The 2013 Marginal Ice Zone Processes Experiment (MIZOPEX) used a number of instruments on unmanned aircraft (UAS) and air-deployed micro-buoys (ADMB) to study processes in the MIZ. The buoys measure sub-surface temperatures to depths of 2 meters and include a small GPS module to track position. This study uses measurements from the ADMBs, supplemented by airborne surface temperature maps and reanalysis data to address the interactions between surface winds and the upper ocean in the MIZ. Comparisons of drift vectors (differential positions of the buoys) with interpolated NCEP reanalysis wind vectors show that surface currents are primarily driven by Ekman transport. High winds induce mixing, strongly positive surface temperature gradients are possible only at low wind speeds, and negative surface temperature gradients can be set up by moderate winds in the proximity of ice floes. The utility of SST as an estimate of upper ocean heat content is therefore highly dependent on wind conditions.

C.

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Convection changes in the Greenland Sea since the 1980s: Causes and consequences.

In the last three decades, deep convection ventilating the deep water masses below 2000 meters depth has come to a halt in the Greenland Sea. During this period, temperature and salinity in the deep Greenland Sea have strongly increased because advection of relatively warm and salty Arctic Ocean deep waters continued. The temperature between 2000 metres depth and the sea floor has risen by 0.3 °C in the last 30 years, which is ten times higher than the temperature increase in the global ocean on average, and salinity rose by 0.02. The necessary transports to explain the observed changes suggest an increase of Arctic Ocean deep water transport after the 1980s. The stop of deep convection in the last decades has been often related with a flattening of the Greenland Sea dome yielding minimum stratification in the center of a cyclonic gyre. However, the vertical descend of the interface between the upper and deep waters in the Greenland Sea both in the center of the gyre and at the rims shows that both a flattening and a deepening of the entire dome structure have occurred. The causes for both are different and are investigated in this work. The first is related with a lower cyclonicity driven by atmospheric forcing. The second is related with the generation and/or accumulation of lighter waters in the center of the Greenland Sea.

C.

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Numerical simulation and sensitivity analysis of subglacial meltwater plumes: implications for ocean-glacier coupling in Rink Isbrae, west Greenland

The rate of mass loss from the Greenland Ice Sheet quadrupled over the last two decades and may be due in part to changes in ocean heat transport to marine-terminating outlet glaciers. Meltwater commonly discharges at the grounding line in these outlet glacier fjords, generating a turbulent upwelling plume that separates from the glacier face when it reaches neutral density. This mechanism is the current paradigm for setting the magnitude of net heat transport in Greenland's glacial fjords. However, sufficient observations of meltwater plumes are not available to test the buoyancy-driven circulation hypothesis. Here, we use an ocean general circulation model (MITgcm) of the near-glacier field to investigate how plume water properties, terminal height, centerline velocity and volume transport depend on the initial conditions and numerical parameter choices in the model. These results are compared to a hydrodynamic mixing model (CORMIX), typically used in civil engineering applications. Experiments using stratification profiles from the continental shelf quantify the errors associated with using far-field observations to initialize near-glacier plume models. The plume-scale model results are then integrated with a 3-D fjord-scale model of the Rink Isbrae glacier/fjord system in west Greenland. We find that variability in the near-glacier plume structure can strongly control the resulting fjord-scale circulation. The fjord model is forced with wind and tides to examine how oceanic and atmospheric forcing influences net heat transport to the glacier.

C.

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Arctic weather and heat content of the Nordic Seas: CMIP5 historical simulations

While it is known that the Nordic Seas/Barents Sea region is subject to strong variability in heat storage on multi-year to decadal timescales it is unclear what the mechanism is that sustains this variability. In particular, it is unclear what the impact is of year-to-year variations in the frequency, location, and intensity of higher latitude winter storms. As a contribution to addressing these issues we examine surface meteorology and its relationship to the high latitude ocean as they appear in a suite of ensemble members from each of 14 CMIP5 coupled model historical simulations (spanning 1861–2005). The first part of this presentation reviews the simulated surface meteorology in comparison to observations. Both the seasonal and synoptic meteorology produced by these models span a wide parameter space. For example, features of the surface atmospheric pressure field such as the Polar High and the Icelandic Low vary in placement, magnitude, and intensity. Since the Icelandic Low is closely associated with atmospheric storm tracks and the North Atlantic Oscillation in sea level pressure we find variations in these as well. Shifts in the seasonal meteorology can be connected, in these simulations, to shifts in the frequency of synoptic Greenland atmospheric blocking events which guide storms into the eastern Arctic. The second part of the presentation discusses how the simulated ocean responds to this atmospheric variability. All models produce heat and salt content variability in the Nordic Seas area suggestive of the observed record. By constructing closed heat budgets for these models we are then able to determine the contributions of individual terms, and in particular the relative contribution of oceanic advection versus surface heat flux for each model. An important result is that the relative contribution of fluxes versus advection depends on each model's ability to represent the frequency and distribution of synoptic meteorological events.

C.

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Laboratory Experiments Investigating the Influence of Multiple Subglacial Discharges on Submarine Melting of Greenland's Glaciers

Idealized laboratory experiments investigate the ice-ocean boundary dynamics near a vertical 'glacier' (i.e. no floating ice tongue) in a two-layer stratified fluid, similar to Sermilik Fjord where Helheim Glacier terminates. In summer, the discharge of surface runoff at the base of the glacier (subglacial discharge) causes the circulation near the glacier to be much more vigorous and is associated with a larger melt rate than in winter. In the laboratory, the effect of multiple subglacial discharges is simulated by introducing fresh water at melting temperatures from two sources at the base of the ice block representing the glacier. Two buoyant plumes of cold melt water and subglacial discharge water entrain ambient waters, rise vertically and interact. The results suggest that the distance between the two subglacial discharges influences the amount of submarine melting and the final location of the melt water within the interior of the water column. Hence, the distribution and number of sources of subglacial discharge may play an important role in glacial melt rates and the fiord stratification and circulation.

C.

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Anomalous warming of the Barents Sea in summer 2013

In the summer of 2013 the pattern of ocean warming in the western Arctic that has persisted for the recent decades shifted to the eastern side, with the Barents Sea in particular exhibiting a dramatic 3°C warm anomaly. This seasonal anomaly is the largest since satellite SST observations have been collected. The placement of the Barents Sea downstream from the Atlantic Ocean and close to the latitude of the atmospheric front separating polar and midlatitude air masses makes this Sea particularly sensitive to variations in both oceanographic and meteorological conditions.

C.

Close Sally

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Large scale patterns of Arctic sea ice variability and links to climatic forcing

In this study, we examine the large-scale spatial and temporal patterns of Arctic sea ice variability, employing observational data (SSMI/S) and output from two data-assimilating models (PIOMAS and NEMO-LIM2). The timing of the onset of the recent tendency to rapid ice loss is analyzed, and found to be strongly regionally dependent, suggesting the need for caution in Arctic-wide studies. Patterns of ice thickness variability are described using EOF analysis, and the links between ice thickness and SIC variability are also studied. Consistency between the model responses indicates certain robust features; this is particularly true of the primary EOF modes, which, considered in combination with SVD analyses of the co-variability between sea ice and atmospheric forcing, suggest a coherent response to the Arctic Oscillation.

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The ocean's response to spring and summer melting

The response of the upper ocean to changing surface forcing is investigated using observations of temperature, salinity, and velocity from spring and summer 2014 taken as part of ONR's Marginal Ice Zone initiative in the Canada Basin. Changes in near-surface ocean currents and turbulent fluxes as well as inertial motions, internal waves, and subsurface eddies are investigated as ice cover thinned and broke apart. Thinning of the ice cover was associated with accelerating ice speeds, decreasing ice-ocean drag, changes to Ekman currents within the mixed layer, and increased turbulent fluxes of heat and salt. Inertial motions in the ice cover and the ocean below increased throughout the summer with more energetic inertial motions observed to increasingly deeper depths as the ice cover deteriorated. Stratification at the winter mixed layer base weakened likely due to increased mixing and internal wave activity. These observations imply that a more energetic ocean environment will continue to emerge as ice cover thins and shrinks in area on decadal timescales.

C.

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Arctic Outflow West Of Greenland: Nine Years Of Volume And Freshwater Transports From Observations In Davis Strait

Recent Arctic changes suggest alterations in the export of freshwater from the Arctic to the North Atlantic, with conceivable impacts on the Atlantic Meridional Overturning circulation. Approximately 50% of the Arctic outflow exits west of Greenland, traveling through the Canadian Arctic Archipelago (CAA) and into Baffin Bay before crossing Davis Strait. The CAA outflow contributes over 50% of the net southward freshwater outflow through Davis Strait. The remainder is deeper outflow from Baffin Bay, flow from the West Greenland Current and runoff from West Greenland and CAA glaciers.

Since September 2004, an observational program in Davis Strait has quantified volume and freshwater transport variability. The year-round program includes velocity, temperature and salinity measurements from 15 moorings spanning the full width (330 km) of the strait accompanied by autonomous Seagliders surveys (average profile separation = 4 km) and autumn ship-based hydrographic sections. Over the shallow Baffin Island and West Greenland shelves, moored instrumentation provides temperature and salinity measurements near the ice-ocean interface. From 2004-2013, the average net volume and liquid freshwater transports are -1.6 ± 0.2 Sv, -94 ± 7 mSv, respectively (salinity referenced to 34.8 and negative indicates southward transport); sea ice contributes an additional -10 ± 1 mSv. Over this period, volume and liquid freshwater transports show significant interannual variability and no clear trends, but a comparison with reanalyzed 1987-90 data indicate a roughly 40% decrease in net southward liquid volume transport and a corresponding an almost 30% decrease in freshwater transport. Connections between the Arctic are also captured, e.g., a unique yearlong Davis Strait freshening event starting September 2009 that was likely driven by an earlier freshening (January 2009 – April/May 2010) in the Canadian Arctic. The Davis Strait autumn 2009 salinity minimum was fresher (by about 0.2), lasted longer, and spanned a greater distance across the strait than in other years.

D.

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A Maxwell-elasto-brittle rheology for sea ice modeling

In recent years, statistical analysis of available ice buoy drift and RGPS data have revealed the strong heterogeneity and intermittency of Arctic ice pack deformation and thereby demonstrated that the viscous-plastic (VP) rheology widely used in climate and operational models does not simulate adequately the mechanical behavior of sea ice. A new rheological framework named ''elasto-brittle" (EB) has therefore been developed as an alternative to the VP model, which combines the linear elasticity of a continuum solid, a Mohr-Coulomb criterion for brittle failure and a progressive damage mechanism for the elastic modulus that allows for long-range interactions inside the pack. Recent implementation of this rheology into 3-days stand-alone realistic simulations of the Arctic ice pack without advection reproduced the strong localization of damage and agreed well with the deformation fields estimated from RGPS data. In the context of longer-term simulations of ice conditions and coupling to an ocean component, a suitable rheological framework should however distinguish between the permanent and recoverable (elastic) deformations in order to estimate the adequate ice drift velocities from the computed deformations, i.e., allow the passage from small to large deformations.
To achieve this, a viscous relaxation term is added in the elastic constitutive relationship of the EB model together with an ''apparent'' viscosity that evolves according to the local thickness, concentration and damage of the ice, much like the elastic modulus. The coupling between the level of damaging and both mechanical parameters is such that within an undamaged ice plate the viscosity is infinitely large and deformations are strictly elastic, while along highly damaged zones such as leads the elastic modulus vanishes and most of the constrain is dissipated through permanent deformations. In this augmented Maxwell-EB model the irreversible and recoverable deformations are solved for simultaneously, hence ice drift velocities are defined naturally. This new rheological framework is presented along with preliminary results of numerical experiments over domains with idealized geometries.

D.

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The Effect of Increased Background Mixing on the Stability of the Cold Halocline and the Diffusive Heat Flux in the Eurasian Basin.

Within the Eurasian Basin of the Arctic Ocean, the cold and fresh surface layer is separated from the warm and salty Atlantic derived waters beneath by the cold halocline. The cold halocline is characterised by the coincidence of near freezing point temperatures with a large salinity gradient, and consequently is a region of strong stratification. As a result, the direct interaction between the two layers from surface generated mixing is limited, and the heat contained within the Atlantic Water can only reach the surface layer, and thus the sea ice, through the dissipation of internal wave energy or double diffusive processes. Current estimates of the internal wave energy in the Arctic suggest that it is an order of magnitude lower than low latitude estimates, and the upward diffusive heat flux is not sufficient for oceanic heat to adversely affect the sea ice cover. However, as sea ice continues to decline in the Arctic, there is evidence to suggest that the internal wave energy may be enhanced due to an increase in wind driven inertial motions. Using a simple 1D model of the Eurasian Basin we investigate how an increase in the internal wave energy may affect the structure of the cold halocline, and how a change in the diffusive heat flux and the extent to which the two layers are directly isolated from each other may affect the sea ice cover at the surface.

D.

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Changes in Arctic marine dimethylsulfide with sea ice loss

Dimethylsulfide (DMS) is a climate-relevant trace gas originating from phytoplankton and ice algae. Its influence on climate could be most significant where there are low aerosol concentrations, such as in the Arctic in summer. Many of the changes taking place as the Arctic warms, including increased river discharge and coastal erosion, and expansion of the seasonal ice zone, could influence DMS emissions through the coupling between DMS biogeochemical cycling and the marine microbial food web. Recent observations and modeling suggest an increase in DMS emissions correlating with the widening seasonal ice zone. Observations of the DMS oxidation products over land support this view. Within this context, we present modeling results suggesting a northward shift in DMS production with decreasing sea ice extent and increased DMS emissions where sea ice reduction in most prevalent.

D.

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Finding the source regions of sea ice melting in the marginal ice zone

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Each fall, new sea ice floes are formed and drift under the action of surface wind and water relative movement. Some of these floes will drift over short distances and melt during the next summer, while some will survive and become multi-year ice. One of the goals of this project is to use back trajectories to locate the source regions and drifting paths towards peripheral seas where the ice melts. The idea behind this is that, if thick ice is advected in one peripheral sea, it is less likely to melt the following summer than if the ice floe was thinner. Therefore, determining the source region, which is a proxy for ice thickness, becomes really important. The completion of this work will yield a better understanding of the strength and/or limitation of global climate models predictions of the future ice edge position in view of complex ice dynamics.

D.

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Aerial Surveys of the Beaufort Sea Seasonal Ice Zone in 2012-2014

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Seasonal Ice Zone Reconnaissance Surveys (SIZRS) of the Beaufort Sea aboard U.S. Coast Guard Arctic Domain Awareness flights were made monthly from May 2012 to October 2012, June 2013 to August 2013, and June 2014 to October 2014. In 2012, sea ice extent reached a record minimum and the SIZRS sampling ranged from complete ice cover to open water; in addition to its large spatial coverage, the SIZRS program extends temporal coverage of the seasonal ice zone (SIZ) beyond the traditional season for ship-based observations, and is a good set of measurements for model validation and climatological comparison. The SIZ, where ice melts and reforms annually, encompasses the marginal ice zone (MIZ). Thus SIZRS tracks interannual MIZ conditions, providing a regional context for smaller-scale MIZ processes.

Observations with Air eXpendable CTDs (AXCTDs) reveal two near-surface warm layers: a locally-formed surface seasonal mixed layer and a layer of Pacific origin at 50-60m. Temperatures in the latter differ from the freezing point by up to 2°C more than climatologies. To distinguish vertical processes of mixed layer formation from Pacific advection, vertical heat and salt fluxes are quantified using a 1-D Price-Weller-Pinkel (PWP) model adapted for ice-covered seas. This PWP simulates mixing processes in the top 100m of the ocean. Surface forcing fluxes are taken from the Marginal Ice Zone Modeling and Assimilation System MIZMAS. Comparison of SIZRS observations with PWP output shows that the ocean behaves one-dimensionally above the Pacific layer of the Beaufort Gyre.

Despite agreement with the MIZMAS-forced PWP, SIZRS observations remain fresher to 100m than do outputs from MIZMAS and ECCO.2. The shapes of seasonal cycles in SIZRS salinity and temperature agree with MIZMAS and ECCO.2 model outputs despite differences in the values of each. However, the seasonal change of surface albedo is not high enough resolution to accurately drive the PWP. Use of ice albedo observations to scale shortwave radiation and salt fluxes improves agreement between observations and PWP outputs. Sensitivity analyses suggest that these are the two most impactful surface parameters on PWP output and that better knowledge of their seasonal changes – as well as better characterization of horizontal Pacific inflow – is imperative for future modeling.

D.

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The Role and Variability of Ocean Heat Content in the Arctic Ocean: 1948-2009

The observed rate of sea ice cover decline in the Arctic for the past decades is faster than those projected by the recent Coupled Model Intercomparison Project (CMIP5). I hypothesize that a critical source of energy in the Arctic Ocean, heat content accumulating below the surface mixed layer and above the halocline, has been increasing in magnitude and area and may be contributing to the recent decline in the ice cover. Consistent with observations, model results from a subset of the Regional Arctic System Model (RASM) indicate that heat has been stored between the mixed layer and the halocline and that it has increased during the period of 1948 to 2009. Ongoing analyses show that the total amount and rate of increase of heat content has been largest in the western Arctic and there is a causal relationship between the accumulation of heat content and the reduction of sea ice volume. Future studies involving new observations of physical processes and feedbacks in the western Arctic Ocean and higher resolution and coupled climate models with improved representation of such processes and feedbacks are needed to advance understanding, realistic modeling, and improved prediction of the Arctic System and its variability and change.

D.

Ding, Yanni

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Atmosphere-Ocean-Sea ice interaction on Arctic Ocean in CMIP5 simulations

The Arctic sea ice is extremely sensitive to the green-house-gas warming with a positive feedback with both surface heat fluxes and heat transports. The melting of sea ice at the Barents Sea Opening brings more warm water inflow into the Barents Sea, which causes more severe sea ice decline. Therefore, understanding interactions among the atmosphere, ocean and sea ice are critical to predicting the Arctic warming trend correctly. In this study, we examine the air-sea-ice interactions in fourteen CMIP5 models. We compare the mean state of temperature and salinity distribution among these models. The upper layer temperature distribution in the Arctic Basin is pretty uniform among models, while the salinity distribution is closely linked with the strength of the Beaufort Gyre and the corresponding Polar High. More fresh water is concentrated at the Beaufort Gyre when there is a strong Polar High.

The seasonal cycle of ocean heat content, sea ice, atmospheric flux, oceanic advection, and the controlling factors are also discussed in this study. The mean state of volume and heat transport through the Fram Strait and the Barents Sea Opening shows large biases among models, which seems correlated with the sea ice distribution. Most models exhibit similar seasonal cycle of volume transport, with more inflow in winter than in summer. The Arctic warming is found in all fourteen models; however, the relative contributions of sea water warming and sea ice melting in each model varies among models. In addition, we examine the relative importance of atmospheric heating and heat transport in determining the Arctic warming.

D.

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Impact of Declining Sea Ice on Wind Generated Near-Inertial Internal Waves and Implications for Mixing and Vertical Heat Flux

Using Ice-Tethered Profiler data from 2005 to 2012 in the Canada Basin, we quantify an increase in internal wave amplitudes linked to seasonal and interannual decreases in sea-ice cover. While mixing due to breaking internal waves in the Arctic Ocean has historically been at least an order of magnitude below that in other oceans, the impact of an increase in the average amplitude of wind generated near-inertial internal waves on mixing is unknown. One of the largest uncertainties in determining how an increasingly energetic internal wave field will affect the Arctic Ocean is the behaviour of internal waves as they propagate through the unique double-diffusive staircase stratification within the relatively warm Atlantic Water layer. Using an analytical numerical model, wave amplitude and stability with depth are determined for a changing internal wave field based on observations. Rapid variations with depth in the stratification associated with the double-diffusive staircase are shown to impact internal wave stability and thus the associated mixing and vertical heat flux.

D.

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The (lack of) consensus in modeling marine biogeochemistry in the Arctic

The main goal of this presentation is to compare different approaches used to simulate similar marine biogeochemical processes and evaluate the consequences of their differences focusing on three interrelated topics: marine stoichiometry, limitation of primary production and spatial resolution in ice algal models. The diversity of approaches used to simulate similar processes results from the lack of generally accepted theories and laws in Ecology and it is reflected in the usage of different state variables for the same ecosystem and different formulations for the same processes. Possibly, one of the main challenges in Marine Ecosystem Modeling is to update the structure and function of current models to integrate the most recent findings from experimental studies. This is important not only to make the best possible usage of empirical results but also to feedback those, using models as a test of the concepts put forward by experimentalists and, therefore, reinforcing the feedbacks between experimentation and modeling. The different approaches were selected among those more commonly reported in the literature in the so called "NPZ " and "NPZD type models" and also in more recent approaches that explicitly simulate marine stoichiometry, decoupling different biogeochemical cycles ("ERSEM type models").

D.

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Relation between the Large-Scale Atmospheric Variability and Ocean Circulation in the Nordic Seas

D.S. Dukhovskoy, M.A. Bourassa, and A. Proshutinsky

The large-scale atmospheric variability and its impact on the ocean circulation in the Nordic (Greenland, Norwegian, and Iceland) Seas are analyzed. The winter mean atmospheric circulation over the region is dominated by strong cyclonic winds. Analysis of the ocean surface wind fields over the Nordic Seas estimated from wind measurements by the NASA Quik Scatterometer (QuikSCAT) demonstrates substantial interannual variability of cyclonic wind stress. Large-scale variability in the surface winds impacts ocean circulation through several mechanisms, such as Ekman pumping and Ekman transport resulting in upwelling in the central Greenland Sea, downwelling along the coasts, generation of coastal waves, modification of coastal and open ocean currents, etc. Our particular interest is impact of the large-scale cyclonic winds on the East Greenland Current. It is speculated that besides direct impact through the northerly winds along eastern Greenland coast, cyclonic winds affect the East Greenland Current by modifying the Sverdrup balance. In this presentation, climatology and statistics of the ocean surface wind fields over the Nordic Seas derived from the NASA QuikSCAT and Cross-Calibrated Multi-Platform surface wind data (CCMP) is presented. Ocean response to the large-scale atmospheric variability is analyzed from numerical experiments with the fully coupled 1/12° resolution HYbrid Coordinate Ocean Model (HYCOM) and CICE sea ice model of the Arctic Ocean.

Freshwater pathways in the Nordic Seas from the Greenland Freshwater Experiment

D.S. Dukhovskoy, A. Proshutinsky, and M.-L. Timmermans

The objective of this experiment is to investigate the role of Greenland freshwater fluxes in the Nordic Seas. Recent studies demonstrate accelerating Greenland melting rate and associated with it increasing freshwater fluxes to the surrounding seas over the last decade. The cumulative Greenland freshwater flux anomaly since mid-1990s is a third of the magnitude of the Great Salinity Anomaly. It is hypothesized that the Greenland freshwater can impact open-ocean deep convection processes in the interior Nordic and Irminger seas. However, the actual pathways of freshwater from the East Greenland coast to the convection regions are not well known. To address these questions the 0.08-degree Hybrid Coordinate Ocean Model (HYCOM) coupled with the Los Alamos sea ice model (CICE) is used. An experiment with passive tracers seeded at the river runoff locations along the Greenland coast is integrated for several years to track Greenland freshwater in the basin. Additionally, an experiment with Lagrangian floats is performed to highlight the role of larger-scale versus smaller-scale processes in freshwater transport over the region.

D.

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Updates on ice-ocean coupling in the Canadian CONCEPTS 1/12th degree regional modelling system

Under the CONCEPTS program, Canada developed a high resolution ice-ocean model based on NEMO-CICE for the Arctic and North Atlantic regions for operational oceanography purposes. Following the 2 last year presentations, we will focus this year on the different additions made to the system for improving the ice re ice mass embedding and dynamic ice embedding. We also discussed the resolution-dependence of the results.

F.

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Interannual variability in contemporaneous measurements of Arctic snow and sea ice thickness from airborne altimetry

The NASA Operation IceBridge mission was initiated in 2009 to collect airborne remote sensing measurements with the goal of bridging the gap between NASA's ICESat mission and the upcoming ICESat-2 mission, scheduled for launch in 2017. IceBridge uses multi-instrumented aircraft to monitor the Arctic and Southern Oceans and provides new and unique data that describes the topography, morphology and snow cover of the sea ice pack across basin scales. Here we present the latest results from the IceBridge mission paying particular attention to advances in the measurement of snow depth on Arctic sea ice. We investigate interannual variability in the winter snow and sea ice packs of the Arctic Ocean. We present the regional trends in thickness derived from six years of IceBridge retrievals between 2009 and 2014, contrasting observations of the multi-year ice pack with seasonal ice zones.

F.

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A new parameterisation of frazil and grease ice formation in a climate sea ice models

Harold Heorton, Alexander Wilchinsky, Daniel Feltham

An idealized model describing frazil ice formation in the ocean mixed layer beneath a lead in the sea ice cover is developed and incorporated into the sea ice climate model CICE. The frazil ice model assumes a steady state formation of single size frazil ice crystals. The crystals are uniformly distributed under the lead over the mixed layer depth and the lead width. The basic processes affecting the frazil ice mass balance is the rate of frazil ice formation due to the heat loss from the open water to the atmosphere, advection of heat and frazil ice volume into the lead from the water under sea ice, and precipitation of frazil ice crystals to the ocean surface and formation of grease ice. The grease ice is pushed against one of the lead edges by wind and water drag keeping the lead open. The frazil ice model is incorporated into CICE and used to simulate the sea ice state in the Arctic Basin and Southern Ocean.
In contrast to the original frazil ice treatment in CICE which produces sea ice with only around 10% frazil ice fraction, the new model produces of order of 50% of frazil-derived sea ice, which corresponds better to observations. While the original model can be re-tuned in order to produce a similar average fraction of frazil ice by having a frazil collection thickness of 30 cm in the Antarctic and 5 cm in the Arctic, the new model's collection thickness is dynamically calculated, allowing for a larger collection thickness in large leads whereas the old model assumes it to be equal for wide and narrow leads. The new model keeps leads open for a longer period thus increasing the period of frazil ice formation. This is particularly important in the central Arctic where the new model's increased frazil ice production results in sea ice 0.5 m thicker than in the old model.

The impact of refreezing melt ponds on Arctic sea ice thinning

Daniela Flocco, Daniel Feltham, David Schroeder, Michel Tsamados:

The presence of melt ponds over the sea ice cover in the Arctic has a profound impact on the surface albedo inducing a positive feedback leading to sea ice thinning. At the end of summer the melt ponds, covering a large fraction of the sea ice, start freezing and get trapped between the sea ice beneath and a thin surface layer of ice. The pond water stores latent heat that is released as they freeze. Ponds trapped under a layer of refrozen ice have been observed in the Arctic and our model results, confirmed by observations, show that the latent heat stored in the ice due to their presence slows the basal sea ice growth for over a month after a sea ice lid appears on their surface. In this work, we study the ice/water temperature profile in the trapped pond system and its evolution until the pond freezes and show the impact of the presence of a trapped pond on sea ice growth. We have carried out this study by developing a three layer, one-dimensional model of temperature and salinity evolution to study the refreezing process. We show some preliminary results obtained by including this new process in the CICE model and in particular, the impact that the increased pond salinity and the refrozen pond persistence have on the sea ice basal growth.

September Arctic sea ice minimum predicted by spring melt pond fraction

G.

David Schroeder, Daniel Feltham, Daniela Flocco, and Michel Tsamados

The area of Arctic September sea ice has diminished from about 7 million km2 in the 1990s to less than 5 million km2 in 5 of the last 7 years with a record minimum of 3.6 million km2 in 2012. The strength of this decrease is greater than expected by the scientific community, the reasons for this are not fully understood, and its simulation is an on-going challenge for existing climate models. With growing Arctic marine activity there is an urgent demand for forecasting Arctic summer sea ice. Previous attempts at seasonal forecasts of ice extent were of limited skill. However, here we show that the Arctic sea ice minimum can be accurately forecasted from melt pond area in spring. We developed a physical based melt pond model suitable for forecasting the evolution of melt ponds and incorporated this model into the Los Alamos sea ice model CICE. We find a strong correlation between the simulated spring pond fraction and the observed September sea ice extent for the period 1979 to 2013. This is explained by a positive feedback mechanism: more ponds reduce the albedo; a lower albedo causes more melting; more melting increases pond fraction. Our results help explain the acceleration of Arctic sea ice decrease during the last decade. We are able to predict the observed September ice area with a similar degree of skill as the observed ice extent. The choice of the applied SSM/I algorithm (NASA Team or bootstrap) does not materially affect our results. The inclusion of our new melt pond model promises to improve the skill of future forecast and climate models in Arctic regions and beyond.

G.

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A simple model of Nares Strait throughflow

The Canadian Arctic Archipelago is one of the two major oceanic gateways between the Arctic and the Atlantic Ocean. If has been estimated that the flow through this region currently accounts for about half of the freshwater transport between these two oceanic basins, its importance potentially increasing with increased melting of sea ice. However, factors such as its complex morphology, harsh meteorological conditions, the remote location and an almost continuous presence of sea ice form a hindrance to understanding the dynamics that force the flow through this region. In contrast to previous efforts which all used realistic model configurations, the approach in this study is one of a simple straight channel representing Nares Strait in a 3D primitive equation model. This enables us to disentangle different factors acting to drive or reduce the throughflow, or alter its cross-strait structure.

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The PPP Year of Polar Prediction

The WWRP Polar Prediction Project (PPP) is a decadal effort to promote cooperative international research enabling development of improved weather and environmental prediction services for the Polar Regions, on time scales from hourly to seasonal. The Year of Polar Prediction (YOPP) is one of PPP's flagship activities planned for the period from 2013 to 2022, with a particular focus on 2018. The YOPP mission is to enable a significant improvement in environmental prediction capabilities for the Polar Regions and beyond, by coordinating a period of intensive observing, modelling, verification, user-engagement and education activities. An intense coordination and collaboration between PPP/YOPP and FAMOS would be a major contribution to the overall success of YOPP. The talk is a general introduction to PPP/YOPP and is meant to set the stage for vivid discussions among the communities.

G.

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Sensitivity of the Arctic-North Atlantic numerical model to the mixed layer parameterization

E.Golubeva and D.Yakshina

The sensitivity of a regional model of the Arctic and North Atlantic to the parameterizations of convective processes in the upper mixed layer was investigated. Numerical experiments carried out for the time interval 1948-2011 have shown that model results can be very sensitive to the mixed layer parameterization. The intensification of mixing in the upper layer may lead to the disappearance of fresh water in the Beaufort Sea, reduce the thickness of the Atlantic water layer and change the Arctic Ocean circulation in the model results. On the other hand, the restriction of the ocean upper layer mixing in the numerical models leads to reducing of heat loss in the Atlantic layer and excessive heat accumulation in the Arctic waters.

G.

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Baffin Bay transports and budgets from a suite of numerical modelling experiments

Baffin Bay is a small water body between the Canadian Arctic and Greenland. It receives warm salty inflows from the sub-polar North Atlantic and cold and fresh Arctic waters, which it then transports south to the rest of the Atlantic. This study is based on five different numerical model experiments, using different resolutions and configurations, for the years 1962 to 2010. We perform a budget study examining the transports and storage components, and their variability, in the different simulations.

H.

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Measurement of suspended particulate matter under sea ice using ADCP and LISST

Ice-camp measurement has been conducted to investigate the dynamic behavior of suspended particulate matters (SPM) under the sea ice in the Chukchi Sea. Main objectives are (1) to report the role of summer sea ice in releasing SPM into the water column, and (2) to estimate the vertical and temporal variation in size and settling flux of SPM under sea ice using novel holographic and acoustic techniques. Mooring observation of hydrography, hydrodynamics and suspended particles distribution under a drifting sea ice revealed the mixing and entrainment pattern in the upper mixed layer of the marginal ice zone. The ice floe where the mooring system was installed drifted as near-inertial motion with approximately 12-h cycle. Due to the high melt rates of the sea ice during the summertime, a large amount of particulate matters embedded in the sea ice were released into the underlying water column. SPM concentration under the sea ice fluctuated in the range of 60–100 mg l-1 during the mooring period. Results suggest that combined effects of the increase in insolation, ice algal production, and the decrease in ice and snow cover and multi-year sea ice extent could create favorable conditions for enhancing the concentration and flux of SPM during the summer season. During the presentation, the preliminary data collected from 2014 summer ice camp study (ONR-MIZ) will be also presented.

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Anisotropic Internal Thermal Stress in Landfast Sea Ice from the Canadian Arctic Archipelago

An Internal Ice Stress Buoy (ISB) was deployed near the center of a multiyear floe in the Viscount Melville Sound of the Canadian Arctic Archipelago on October 10, 2010. The buoy measured internal sea-ice stresses, Global Positioning System coordinates, air temperature, internal ice temperature at the sensor depth, and stresses orientation with respect to Magnetic North Pole for nearly 10 month between October 10, 2010 and August 17, 2011. The position record indicates that the landfast season was nearly 5 month from January 18 to June 22. The thermally-induced stresses (ranging from -85 to 77 kPa) dominant the internal stress record with a few dynamic stress events associated with floe interactions ~50 kPa). Intriguingly, the thermally induced stresses are isotropic before the landfast ice onset and are anisotropic during the landfast ice season, contrary to what is generally assumed in the analysis of ISB data. We consider two possible causes to explain anisotropy in thermal stresses: preferred c-axis alignment in the ice crystal with surface ocean current in coastal water leading to different material properties along and normal to the c-axis, and land confinement in the north-south direction associated with the nearby coastline. The stress orientation indicates that the effect of land confinement dominants over the effect of the c-axis alignment (if at all present). We conclude the anisotropic thermal stresses during the landfast season are explained by the land confinement rather than the c-axis alignment. The stress record also show an interesting shift between thermal stress and the diurnal cycle of temperature when melt start around the sensor from a negative correlation between stress and temperature before the onset of melt (cooling leads to positive tensile stress in the ice) to a positive correlation after melt onset when the local freezing of water around the seawater during the night load to negative compressive stresses. Results from a 1.5D anisotropic thermal stress model suggests a value of the Young's modulus of the multiyear ice is equal to 0.3 GPa, and a viscous creep time relaxation of 15 days in general agreement with observation. To the best of the authors' knowledge, this is the first time that anisotropic thermal stresses have been reported in sea ice.

H.

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Origin and fate of the AW anomalies in the Arctic from tracer experiments

The variability of the properties of the Atlantic Water in the Fram Strait Branch (FSB) and the Barents Sea Branch (BSB) is analyzed in idealized tracer experiments over the period 1979-2012.Temperature anomalies in the AW boundary current are shown to develop as a result of complex interactions between mixing and advective processes. In the FSB, the variability of the temperature downstream of St Anna Trough is mainly driven by advection of anomalies from the Nordic Seas. The main changes in T and S properties of the FSB occuring eastward of St Anna Trough are analyzed and the relative contributions of the Fram Strait and the BSO sources to the FSB properties is evaluated.

H.

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Effects of Sea ice surface roughness on remotely sensed thickness values

When making remote measurements of sea ice/snow thickness from the air, it is often assumed that the surface conditions are flat and smooth. However, this is often not the case, as ridging will cause very rough surface with "boulders" and ridges. This surface roughness can affect the way signals sent by remote sensors are returned back to the sensor. In this talk remote measurements of sea ice and snow thickness made from airborne instruments are compared to those made in situ on sea ice located near Barrow, AK.

H.

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Arctic summer sea ice decline in CMIP5

Paul Hezel, University of Bergen

I will present analysis of the CMIP5 Arctic sea ice from two studies. The first looks at the response of the sea ice to the changes in forcing in the Extended RCP2.6 scenario, and the beginning of recovery in response to the change in forcing. The second involves an understanding of the recent observed trend in sea ice from the perspective of a Rapid Ice Loss Event (RILE). We show that linear trends from a RILE in CMIP5 over predict the decline of the sea ice compared to the evolution of the ensemble members themselves. It is more likely that the Arctic sea ice returns to a decline consistent with the anthropogenically forced trend in the following 1--2 decades. We anticipate, therefore, that the decline in the observed Arctic summer sea ice extent will be more moderate in the coming 10-20 years, having identified a RILE in the observations from 2002-2009.

H.

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The Influence of High Frequency Atmospheric Forcing on the Circulation and Deep Convection of the Labrador Sea

The influence of high frequency atmospheric forcing on the circulation of the North Atlantic Ocean was investigated by comparing simulations of a coupled ocean-ice model with hourly atmospheric data to simulations in which the high frequency forcing was filtered from the air temperature and wind fields. In the absence of high frequency atmospheric forcing we found that the strength of the AMOC and sub polar gyres decreased by 25%. Moreover, high frequency forcing was shown to contribute the oscillatory behavior of the AMOC and sub polar gyre strengths. In the Labrador Sea, the eddy kinetic energy decreased by 75% and the average maximum mixed layer depth decreased by between 20% and 110% depending on the climatology. In particular, high frequency forcing was found to a have a greater impact on mixed layer deepening in moderate to warm years whereas in relatively cold years the temperatures alone were enough to facilitate deep convection.

H.

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Challenges in coupled ocean-shelf modelling in the Arctic and North Atlantic context

Modelling the connection between shallow continental shelves and the open ocean remains one of the grand challenges in Earth System modelling today. This is especially pressing in the Arctic Ocean where a range of dynamically complex processes on its broad shelves and at the shelf-break mediate the transport of heat, freshwater and carbon, as well as affecting dense water formation and sea ice, with important consequences for the Earth System as a whole. Examples include barotropic and baroclinic tides, cascades, and boundary currents and the consequent Ekman drain. In this contribution we explore these processes and the challenges of accurately modelling them in the Arctic context of widely varying stratification, steep slopes, small Rossby Radii and sea ice. We draw on the experience with the NEMO model system in regional model applications of the Arctic and North Atlantic. NEMO is now well established both as a global ocean and a shelf sea model, so it is timely to consider how the two can best be merged. As a precursor to this, regional model have been developed for the Northern North Atlantic (Holt et al., 2014) at 1/12o and Arctic (Luneva et al.) at 1/4^{o}. Both are based on the corresponding global meshes and include tidal forcing, a vertical turbulence model that can accommodate multiple boundary layers (the GLS model) and a hybrid vertical coordinate system that transitions between geopotential levels in the open ocean and terrain following coordinates on shelf.

H.

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Modelling Ocean Surface Waves in Polar Regions

Lucia Hosekova (1), Stefanie Rynders (2), Yevgeny Aksenov (1), Andrew Coward (1), Laurent Bertino (3), Timothy Williams (3), Daniel Feltham (4) and George A. Nurser (1)

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(3) Nansen Environmental Remote Sensing Center, Bergen, Norway
(4) Centre for Polar Observations and Modelling, University of Reading, Reading, UK

In the Polar Oceans, the surface ocean waves break up sea ice cover and create the Marginal Ice Zone (MIZ), the buffer area between the sea-ice free ocean and pack ice. The MIZ, observed in both the Arctic and Southern Oceans, is characterized by a highly fragmented sea ice cover and can be several tens of kilometers wide in the Arctic Ocean and several hundreds of kilometers wide in the Antarctic. The MIZ is the area of the ocean where the waves, sea ice and surface ocean interact through multiple complex feedbacks and is undergoing a dramatic change due to sea ice retreat. However, none of the present-day climate models account for these processes. We present a model development which implements surface ocean wave effects in the global Ocean General Circulation Model NEMO, coupled to the CICE sea ice model. Our implementation includes wave attenuation in the MIZ and sea ice fragmentation and generates a floe size distribution which can be fed into CICE. This allows for better simulations of sea ice rheology and thermodynamics in the MIZ. We will present initial results from a one-year run of the wave-ice interaction module in NEMO using the ORCA2 configuration, and discuss their potential for further analyses of impact on the ocean, sea ice and surface ocean waves. The study contributes to the EU FP7 project ‘Ships and Waves Reaching Polar Regions (SWARP)’, aimed at developing techniques for sea ice and waves modelling and forecasting in the MIZ in the Arctic.

H.

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Atlantic water transports to the Arctic from hindcast simulations

Houssais, M.-N., C. Herbaut, A.-C. Blaizot and S. Close

Based on hindcast simulations, we examine the AW transports to the Arctic Ocean through the two main openings, the Fram Strait and the Barents Sea. We determine to which extent the interannual variability of the transports can be explained by wind-driven dynamics. Heat fluxes anomalies associated with the Barents Sea Opening inflow are shown to precede winter sea ice anomalies in the northern Barents Sea with a lag of up to one year when temperature anomalies are involved. The origin and fate of the AW temperature anomalies in the Arctic Ocean are consistent with information gained from idealized tracer experiments.

I.

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Intercomparison of Arctic Ocean hydrography, heat and salt fluxes in IPCC type global coupled ocean/sea-ice models using CORE-II forcing

We analyzed performance of 14 different global ocean-ice coupled simulations in the Arctic Ocean. All these models have comparable spatial resolution (approx. 1 degree) and they all used the same CORE-II interannual atmospheric forcing. The basic features of the temperature and salinity fields and associated biases in the Arctic Ocean are examined. Ten years after Holloway et al (2007) study, state-of-the-art global climate models still suffer from deepening of the Atlantic Inflow Water (AIW). Warm bias models (NCAR-POP, GFDL-MOM, GFDL-MOM0.25, FSU-HYCOM) have very strong AIW and week water mass conversion in the Barents and the Kara Seas. On the other hand, cold bias models (GFDL-GOLD, CNRM-ORCA, NORESM-BERGEN) have excessive amount of cold water convection on the west shelves of the Arctic Ocean and they have weak AIW. We also describe time series of heat and volume transports at the Fram Strait and the Barents Sea Opening. All models underestimate the observation based northward and southward transports, typically by a factor of two or more. Results also indicate that some models have negative southward heat transports (MRI-DATA,MRI-FREE, POP, AWI-FESOM) at the Fram Strait. The exported temperature across the Fram Strait is above 0 Celsius in these models. The other models have positive southward heat transport with the mean southward temperature below 0 Celsius (cold-biased models).

I.

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Estimation of Arctic Sea Ice Freeboard and Thickness Using CryoSat-2

Sanggyun Lee and Jungho Im

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Arctic sea ice is one of the significant components of the global climate system as it plays a significant role in driving global ocean circulation, provides a continuous insulating layer at air-sea interface, and reflects a large portion of the incoming solar radiation in Polar Regions. Sea ice extent has constantly declined since 1980s. Its area was the lowest ever recorded on 16 September 2012 since the satellite record began in 1979. Arctic sea ice thickness has also been diminishing along with the decreasing sea ice extent. Because extent and thickness, two main characteristics of sea ice, are important indicators of the polar response to on-going climate change, there has been a great effort to quantify them using various approaches. Sea ice thickness has been measured with numerous field techniques such as surface drilling and deploying buoys. These techniques provide sparse and discontinuous data in spatiotemporal domain. Space-borne radar and laser altimeters can overcome these limitations and have been used to estimate sea ice thickness.
In this study, Arctic sea ice freeboard and thickness were estimated using CryoSat-2 SAR and SARIn mode data that have sea ice surface height relative to the reference ellipsoid WGS84. In order to estimate sea ice thickness, freeboard, elevation difference between the top of sea ice surface should be calculated. Freeboard can be estimated with lead detection technique. A machine learning based lead detection method was proposed. CryoSat-2 profiles such as pulse peakiness, backscatter sigma-0, stack standard deviation, skewness and kurtosis were examined to distinguish leads from sea ice. Near-real time cloud-free MODIS images as CryoSat-2 data were used to extract lead reference data. Two rule-based machine learning approaches--See5.0 and random forest--were evaluated for lead analysis. Using the freeboard height calculated from the lead analysis, sea ice thickness was finally estimated using the Archimedes' buoyancy principle with density of sea ice, sea water and snow and the height of freeboard. Freeboard and thickness were validated with ESA airborne Ku-band interferometric radar and Airborne Electromagnetic (AEM).

I.

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Baroclinic instability and the mesoscale eddy field in the Arctic Ocean: a model study

Baroclinic instability and mesoscale eddy advection is likely responsible for much of the heat and freshwater exchanges between the boundary currents and interior basins of the Arctic Ocean. Here we study the Arctic Ocean mesoscale eddy field in a 10-year long hindcast simulation conducted with the ROMS primitive equation model at 4 km horizontal resolution. First we compare the model mesoscale flow statistics to equivalent statistics obtained from real observations. Then we relate characteristics of the fully-developed macroturbulent field (eddy kinetic energies, eddy length scales) to the predictions from linear stability calculations. The stability calculations tell us whether time and length scales from the Eady model of baroclinic instability are useful approximations, or whether more complex models need to be considered.

J.

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Modeling arctic sea ice biogeochemistry throughout the ice interior

Traditional modeling approaches to arctic sea ice ecosystems have focused on land fast, bottom-ice layer communities. Observations suggest that, indeed, highest concentrations and production rates in the Arctic occur at the ice-ocean interface in the porous ice "skeletal" layer or in sub-ice algal mats. This is largely believed to be a result of sea ice physics; salinity, temperature, and brine dynamics establish the microstructural properties of sea ice and create an environment with the necessary features to support algal blooms. Sympagic microorganisms, however, have been found throughout the ice interior, in surface meltponds and the ice freeboard. Again, physical processes, such as snow accumulation, melt and surface flooding, play an important role in establishing interior and surface algal communities. Recent advancements in modeling ice halodynamics have allowed for the development of vertically resolved sea ice algal models, which do not establish a priori the "type" or location of the algal community. Here we present preliminary results of arctic algal production using the Los Alamos sea ice model (CICE) with a vertically resolved ice-algal component. Incorporating multiphase dynamics in CICE has given us an important tool for global and predictive applications in which both the sea ice physical and biogeochemical properties are evolving.

J.

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Evaluating CICE5 model with long term observations of snow, ice and biological data off Barrow

The community sea ice model CICE 5.0 by Los Alamos National Lab consists of various improvements of the snow and sea ice thermodynamics and the addition of ice algal model capability. A 1-D CICE model was configured to run with atmospheric forcing at Barrow and validated with long term observations of snow depth, ice thickness, profiles of temperature and salinity. The ice algal model output is also compared with observations after the physical model validation. Precipitation seems to cause most uncertainty of the model due to its strong influence on snow depth and thus on ice thickness. The sea ice mass balance data includes some high frequency variations of snow depth, possibly due to wind drift. The current model can reproduce the low frequency changes of snow depth, and fortunately this discrepancy did not lead to significant errors in the modeled ice thickness.

K.

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The problems and possibilities in identifying the evolution of the Winter Mixed Layer during melt season from the ITP observations

The surface layer of the Arctic Ocean is seasonally modified by the melting and freezing of sea ice. During winter the haline convection triggered by ice formation homogenizes the surface layer while in summer seasonal ice melt increases the near surface stability by forming a summer halocline. The established stratification enables the base of the Winter Mixed Layer to remain nearly intact throughout the melt season. Consequently, in autumn, a temperature minimum indicating the depth of the previous winter convection can be identified below the summer halocline. With the year-round observations on temperature and salinity that the Ice-Tethered Profilers have provided during the past ten years (2004-2013) from the Canada Basin, it is possible to determine whether the properties of the temperature minimum found from the summertime observations indeed corresponds, and if so, to what extent, to the properties of the previous Winter Mixed Layer. However, unexpectedly large differences emerged. While the depth of WML averaged to 32 m in spring, in autumn the temperature minimum was found at the average depth of 45 m. In addition to the deepening, the temperature minimum had a temperature 0.2 C and salinity nearly 2 higher than the Winter Mixed Layer. Part of the deepening is assumed to result from downwelling driven by Ekman-convergence. The increase in temperature and salinity is presumably a consequence of entrainment from below. In addition, the change in properties of the underlying water along the drift track of ice and ITPs have to be taken into account.

K.

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Numerical Experiment of Tidal Effect on the Arctic Ocean Using an Ice-Coupled Ocean Model

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We investigate the tidal effects on the oceanic state and sea-ice distribution of the Arctic Ocean using an ice-coupled Ocean General Circulation Model (OGCM). The OGCM used in this study is the Regional Ocean Modeling System (ROMS) version 3.4, which is a three dimensional, s-coordinate, primitive equation ocean model with a free surface. The model covers the Arctic Ocean with the adjacent seas including Norwegian Sea, Greenland Sea and Hudson bay. The horizontal grid size ranges from 23 to 30 km. A total of 50 s-coordinate levels are adopted along the vertical direction with enhanced resolution near the surface.

A set of 12-hourly atmospheric fields obtained from ERA (European center of medium range weather forecasting Re-Analysis)-Interim during the period from 1980 to 2013 is used to calculate heat and salt fluxes as well as wind stress at the sea surface. Temperature, salinity, flow and sea surface elevation from SODA (Simple Ocean Data Assimilation) Global 1/2°data are used to set the heat, salt, and volume fluxes through boundaries. Four major tidal forcing (M_2, S_2, K_1, O_1) are included along the open boundaries based on TPXO7.

To initialize the model, the model was spun up for 10 years with monthly mean atmospheric fields. During the spin-up mode, temperature and salinity were restored toward monthly climatology of the PHC (Polar science center Hydrographic Climatology, [Steele et al., 2001]) with a relaxation scale of 30 days. After spinning up model, we conducted a hindcast simulation from January 1, 1980 to the end of 2013 with a 12-hourly atmospheric forcing.

L.

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Year-long, daily-scale bio-optical observations under perennial ice cover in the Arctic Ocean

Sensors for chlorophyll fluorescence, optical scattering, CDOM fluorescence, and incident solar radiation were integrated into eight Ice-Tethered Profilers (ITPs) and deployed in perennially ice-covered regions of the Arctic Ocean between 2011 and 2013. These bio-optically equipped ITPs have generated unique long-term time series of irradiance, algal biomass, particulate scattering, and organic matter concentrations in the top 800m under Arctic sea ice, with profiles conducted daily or better. Two of these systems operated for an entire year, capturing the entire annual trends in these bio-optical properties in the central Arctic Ocean and Beaufort Sea respectively. These time series reveal the basic seasonal trends in bio-optical distributions in these perennially ice-covered regions, and the high-resolution temporal profiling enables a more accurate assessment of the timing and magnitude of intermittent events down to the time scale of one to several days. These bio-optical observations were used to determine the timing and duration of the under-ice algal growing season, the subsequent export of particulate organic matter later in the season, and the occurrence of intermittent perturbations in both the central Arctic Ocean and the Beaufort Sea.

L.

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Investigating Arctic subsurface primary production in a model: where, when, how much, and does it matter for satellite primary production estimates

Density nitrate relationships and lateral advection timescales indicate that Arctic primary production is fuelled by vertical nitrate fluxes. Net drawdown of surface nitrate throughout the growing season results in migration of production maxima subsurface. Limited in situ measurements indicate that subsurface production maxima may account for up 30-40% of total annual production.

A General Circulation Model with a chlorophyll-a field that is in good agreement with in situ observations, is used to extend these spatially-limited observations and investigate subsurface production magnitude and distribution across the Arctic.

Subsurface production is found to contribute significantly to total annual production, up to 60% in certain locations. It's contribution is largest in areas where surface nitrate is depleted earlier in the growing season. These areas correspond to places where winter nitrate recharging is lower due to winter ice cover, yet ice is thin enough (or absent) in summer to allow significant production rates at depth.

Subsurface production that occurs without a surface expression is neglected by satellite estimates of primary production. Cross-correlations between surface and depth-integrated model primary production are weak across the ice-covered Arctic. They are weakest in areas where the proportion of production that is subsurface is highest (Lomonsov Ridge area and Beaufort Sea). Correlations are generally high (>0.8) in areas where ice cover is less than 10%, implying that satellite algorithms neglect of subsurface production does not currently introduce substantial errors, but an increase in the extent of the marginal ice zone may increase these errors.

L.

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Influence of snow processes on sea ice: a model study

Sea ice, the result of seawater freezing at high latitudes, plays a key role in the global climate system. It is both a diagnostic and prognostic factor with regard to climate change. Besides, it is a platform for snow to accumulate on and, because this platform moves and deforms with ocean currents and winds, its snow cover is astoundingly heterogeneous. Snow processes on sea ice have crucial consequences in driving the evolution of sea ice, at a cascade of temporal and spatial scales. Although sea ice models have been developed for decades, the representation of snow in these models has remained under-addressed. This study is a contribution toward the improvement of the snow component in large-scale sea ice models. For the first time, a representation of snow physics of intermediate complexity was introduced in a model of this kind, providing the tools to assess the influence of snow on sea ice. Using those tools, we have shown in particular the importance of accounting for wind-driven snow processes and properties in models in order to realistically simulate the evolution of perennial sea ice. As such, this study opens the way for snow-related improvements in climate models and provides modelers with some guidance in achieving this task. As the better quantification of the impacts of snow processes on sea ice goes through the adequate constraining of their parameterization, extensive In Situ observations are required. This work also gives some directions for these future investigations.

L.

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Net Primary Productivity Algorithm Round Robin (PPARR) – Ocean Color-based Models for the Arctic Ocean

Yoonjoo Lee, Patricia Matrai, Marjorie Friederichs, and Vincent Saba

Autochthonous primary production is the major source of energy for the Arctic Ocean (AO) ecosystem, as in most ecosystems. Reproducing current patterns of AO net primary production (NPP) is essential to understand the physical and biogeochemical controls in the present and the future. The Primary Productivity Algorithm Round Robin activity (PPARR) provides a framework such that the skill and sensitivities of NPP estimated by ocean color-based models, coupled global/regional climate models, and earth system models can be assessed in the AO. We present here the first phase results from 30 ocean color-based models that estimate depth-integrated marine NPP with respect to a unique pan-Arctic data set (1998-2011) that includes in situ NPP, chlorophyll *a* concentration, mixed layer depth (MLD), euphotic zone depth (Zeu), and sea surface temperature (SST) as well as physical parameters derived from satellite observations, climatologies and/or re-analysis (MLD, EUZ, SST, photosynthetically available radiation – PAR, and bio-optical variables). Due to the difficult sampling conditions, most field data were collected in summer and south of 76^{o}N; this data set captures the change in AO conditions over the past 30 years. Twenty four cases with different sources of input variables were provided to all participating models; results will be presented for the two cases that used satellite-derived and in situ chlorophyll *a* data. The majority of the models overestimated mean integrated NPP when using satellite input variables. When in situ data were used as input variables, approx. half of the models overestimated integrated NPP. Four models showed a distribution of model results similar to the in situ data distribution, but not for the entire range of NPP data. Average model skill, determined by variability and mean difference between model estimates and observations, using root-mean square difference and bias, was very consistent for all models. Due to the inherent variability of the in situ data, chlorophyll *a* was the primary influence on ocean color-based model performance and data source (satellite vs. in situ) had the strongest effect. Model estimates better represented the mean NPP and its statistical distribution when in situ chlorophyll *a* data, rather than satellite chlorophyll *a* data, were used. Satellite algorithm improvement for these complex Arctic waters will likely increase the skill of ocean color models. Continual feedback, modification and improvement of the participating models and the resulting increase in model skill is the primary goal of the PPARR-5 AO exercise.

L.

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Air-sea interactions in the Barents Sea and Atlantic water layer in the central Arctic Ocean

The present study explores how the water temperature associated with the Atlantic Water Layer (AWL) might be modified under warming-induced conditions due to climate change. We performed simulations from 1970 to 2099 with a coupled ice-ocean model (CIOM) implemented for the Arctic Ocean. The surface fields to drive CIOM were provided by the Canadian Regional Climate Model (CRCM), in turn driven by the third-generation Canadian global climate model (CGCM3) outputs following the A1B climate change scenario. Compared to PHC data, CIOM is shown to reliably reproduce the AWL at 200-900m in the present climate, represented as 1990-2009. Under the A1B scenario (IPCC, 2007), there is a significant increase in the water volume transport into the central Arctic Ocean through Fram Strait, due to the weakened atmospheric high pressure system over the western Arctic and the intensified atmospheric low pressure system over the Nordic Seas. However, the water temperature associated with the AWL tends to decrease. The average temperature at 200-900m decreases from 0.63oC in 2030 to 0.45oC in 2060. In the vertical, the AWL slightly expands before the 2030s, but significantly shrinks after the 2050s, and by 2070-2099, our simulations suggest that there is no significant warm layer in the southern Beaufort Sea. Moreover, the temperature decrease after 2030 is mainly due to the enhanced air-sea interactions in the northeastern Barents Sea, where the loss of sea ice increases the heat loss from the Atlantic water and reduces the water temperature near the bottom of the northeastern Barents Sea. Therefore, there are significant decreases in the heat fluxes into the central Arctic Ocean from the Barents and Kara Seas, which offset the heat flux increase from Fram Strait and are responsible for the decreasing trend in the AWL water temperature.

L.

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The effects of tides on the water mass mixing and sea ice in the Arctic Ocean

We use a novel pan-Arctic sea ice-ocean coupled model: NEMO-LIM2, to examine the effects of tides on sea ice and the mixing of water masses. Two 30-year simulations were performed: one with explicitly resolved tides and the other without any tidal dynamics. We find that the tides are responsible for a ~15% ice reduction during the last 3 decades and also changes in the salinity distribution. At least three mechanisms of tidal interactions appear to be significant: (a) strong shear stresses generated by the baroclinic clockwise rotating component of tidal currents in the interior waters; (b) thicker subsurface ice-ocean and bottom boundary layers; and (c) intensification of vertical motions of isopycnals by ~50% through enhanced bottom Ekman pumping over rough bottom topography. In the latter, vertical mass fluxes lead to the entrainment of Warm Atlantic Waters with the colder and fresher surface waters, supporting the melting of the overlying ice.

M.

Martin, Torge (Polar Science Center and UW) and Lars H. Smedsrud

On modeling a variable lead closing parameter: Do we need to explicitly simulate grease ice in climate models?

The early stages of sea ice formation are often crudely parameterized in common basin-scale sea-ice ocean models. Energy lost from an ocean at the freezing point is instantly turned into solid sea ice. In reality, freezing begins with the formation of frazil ice that accumulates in a grease ice layer, which then solidifies over a couple of days. Most notably, grease ice does not significantly reduce the ocean-atmosphere heat flux, has a darker albedo than solid sea ice, and damps waves. In order to account for a slow refreezing of leads the sea ice model of Hibler (1979), which is a common precursor of modern sea ice models, comprises a constant lead closing parameter. This parameter determines the area that is covered by new ice volume forming in open water. Here, we study the impact of simulating a variable lead closing parameter, which depends on winds as well as currents and available grease ice volume, on Arctic sea ice volume and ocean heat loss in simulations with a regional set up of the MITgcm sea-ice ocean model. With increasing spatial resolution and thus shorter time steps and an Arctic ice pack trending towards a seasonal sea ice cover, grease ice may become an important player in models and reality.

Martin, Torge (Polar Science Center, UW) and Michel Tsamados, and Daniel Feltham

The effect of variable sea ice drag on optimal ice concentration for momentum transfer into the ocean

Recent rapid thinning and retreat of Arctic sea ice has created awareness for an associated adjustment of the climate system that will shape a “new” Arctic. One question raised is whether the diminishing sea ice cover enhances the momentum flux into the mostly quiescent Arctic Ocean. The common notion is that sea ice shields the ocean from interaction with the atmosphere and an ice-free ocean will receive more momentum. However, Martin et al. (2014, JGR) suggested that a loose ice cover can actually amplify momentum transfer and that there is an optimal ice concentration of about 80-90% at which the ocean surface stress is maximal. While this model study only considered a constant sea ice roughness in the calculation of the surface stress, Tsamados et al. (2014, JPO) recently implemented variable sea-ice drag coefficients into the sea ice model CICE. They showed in stand-alone sea ice simulations that varying sea ice roughness due to, amongst others, pressure ridges and floe edges significantly impacts sea ice motion likely with implications for the circulation of the ocean underneath. Here, we investigate the effect of variable sea ice drag on the concept of an optimal ice concentration for momentum transfer into the ocean in a collaborative effort using daily output from simulation with the CICE version of Tsamados et al. (2014).

M.

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Tackling the challenges of Modelling the *Calanus* complex in rapidly changing Arctic and sub-Arctic seas.

At a time when environmental research is challenged to keep up the pace of the ongoing changes in the Arctic, numerical models can speed up our understanding of the organization, functioning and the vulnerabilities of Arctic marine ecosystems. Major breakthrough will require innovative modelling techniques (e.g. evolutionary algorithms) and observation methods (e.g. *in situ* imaging of plankton and particles, individual-level data) but also to revisit carefully the basics of our approach, in line with the motivation of FAMOS and its AOIMP predecessor. We will present the example of the modelling of the *Calanus* complex, a community of three copepod congener species typical of the Arctic and its ancillary seas: *Calanus hyperboreus*, *C. glacialis* and *C. finmarchicus*. The model we developed is capable of simulating the complete life-cycle and highly specialized strategies (diapause, capital breeding, iteroparity, etc) of each species. We used this model to study whether the species-psecific phenologies observed in the sub-Arctic St-Lawrence estuary and the Arctic Amundsen Gulf are optimal responses to their environmental forcing, in the context of a changing environment. Alongside the presentation of the main results of the model, we will illustrate some common problems faced (paucity of reliable data for parameterization, difficulty to access the Arctic) and possible solutions.

M.

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Characterizing Energy Spectra in the Arctic Ocean Halocline

Energy transfer from the atmosphere into the upper Arctic Ocean is expected to become more efficient as seasonal sea-ice extent decreases and multiyear ice thins due to recent atmospheric warming. However, relatively little is known about how energy is transferred within the ocean by turbulent processes from large to small scales in the presence of ice and how these pathways might change in future. This study characterises horizontal variability under perennial and marginal sea-ice in the Eurasian Arctic Ocean. Historic high resolution CTD data collected along transects by a British submarine during summer 1996 allows a unique examination of horizontal variability and associated turbulence spectra within the Arctic Ocean halocline. Spectral analysis indicates that potential energy variance under perennial sea-ice is O(100) less than within the Marginal Ice Zone (MIZ). Nevertheless, the scaling and shape of spectra cannot be distinguished between the two environments suggesting similar dynamics and pathways for energy exchange. At length scales greater than the local baroclinic deformation radius (~ 8 km) to 50 km, energy spectra are generally consistent with interior quasi-geostrophic dynamics, with a k-3 scaling where k is wavenumber. At length scales below 8 km, spectra are flatter and more consistent with surface quasi-geostrophic dynamics. Findings indicate that upper ocean stratification may play an important role in altering routes of energy dissipation in the Arctic from those at mid latitudes.

M.

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Sensitivity of sea ice states to variable parameter space in the Regional Arctic System Model (RASM)

W. Maslowski, R. Osinski, A. Roberts

21st century projections of the magnitude of arctic climate change vary widely in the latest suite of global climate predictions. There are a number of reasons why global climate and Earth System models may not be able to simulate rapid change in the Arctic, which stem from a combination of coarse model resolution, inadequate parameterizations of sub-grid processes, and a limited knowledge of physical interactions. In addition, research using the Regional Arctic System Model (RASM) and other studies point to strong sensitivity of climate projections to multi-parameter space, varying within physically acceptable bounds.

To better understand model uncertainties in simulating variability and predicting seasonal to decadal change in Arctic climate we investigate sensitivity of simulated sea ice states to some model parameters controlling ice dynamics and coupling with the atmosphere and ocean. We use the ice-ocean components of the fully coupled Regional Arctic System Model (RASM), with atmospheric and land components replaced with reanalysis data. Our results suggest that many parameterizations of sub-grid physical processes currently used in climate models need to be optimized and we provide some suggestions on their fine-tuning required when increasing model spatial resolution. We also show that while sea ice extent in many simulations compares well with observations, the model total ice volume only agrees with the limited quantity of available measurements in a few specific cases. Hence, we conclude that the use of observed sea ice extent only to validate the skill of sea ice models is not a sufficient constraint.

M.

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Detection and attribution of Arctic sea ice change causes

Extensive observations of Arctic sea ice are available since the 1980s and suggest that Actic sea ice has been declining since then and that the rate of decline might be accelerating. The accelerated loss in Arctic sea ice is believed to go, at least partly, hand in hand with a rapid reduction of thick, multi-year sea ice. Other factors are changes in the sea ice dynamics and the atmospheric thermodynamics.
Climate models can be used to simulate expected response patterns of the climate system to different internal and external forcing. We use a standard optimal detection method where the observed changes of Arctic sea ice are expressed as a sum of scaled atmospheric response patterns, namely fingerprints, and internal climate variability. Our study involves the estimation of scaling factors using standard multivariate regression approaches.

M.

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Effects of enhanced Greenland melt on the hydrography of Baffin Bay and the water exchanges between the Arctic and Atlantic Ocean

by Laura Castro De La Guardia, Xianmin Hu, Paul G. Myers

The melting of Greenland's glaciers is predicted to increase as a result of temperature increases in the Northern Hemisphere. Here we examine the effects of increasing runoff from Greenland on the hydrography of Baffin Bay and on the total transport, heat and freshwater exchanges between the Arctic Ocean and Labrador Sea. Using a regional configuration of a coupled ocean/sea ice model (NEMO), we setup eight sensitivity experiments with enhanced runoff ranging from 158 to 1580 km^3/y and one control run with runoff <31.5km^3/y. We find that enhanced runoff leads to a freshening of the surface water, which increases dynamic heights and reduced the inflow of colder Arctic waters, strengthening the halocline and the West Greenland Current. This process also lifts the warm West Greenland Irminger Water so that it is found higher in the water column, which allows it to more easily penetrate onto the shelf and into the fjords of Greenland. Thus we identify a potential positive feedback between enhanced melt from Greenland into Baffin Bay and the provision of warm water to the coastal fjords of Greenland.

N.

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Progress and Assessment of the Arctic & sub-polar North Atlantic state estimate

An T. Nguyen, Patrick Heimbach , Rui Ponte , Ian Fenty

The Arctic Ocean and sub-polar North Atlantic are home to processes of great importance to the global climate system. These processes include the modulation of heat, moisture, and momentum fluxes between the atmosphere and ocean by sea ice, the ice albedo feedback which regulates the radiative budget, deep water formation in the Greenland and Labrador Seas which affect deep ocean circulation and energy transport, and a coupling between ocean heat and marine terminating glacier melt rates around the marginal Greenland ice sheet. To advance our understanding in this region, we produce an eddy-permitting Arctic and sub-polar North Atlantic state estimate (ASTE) for climate studies using the state estimation techniques developed within the framework of the ECCO consortium. Data constraints for the state estimate will include hydrographic profiles from Argo floats, ice-tethered profilers, a modern climatology, and moored arrays; sea ice observations such as concentration, thickness, and velocity; and the near-surface atmospheric state from several reanalyses. The estimation periods are from 1992--2001 and 2002--2011. Here we report progress in ASTE after 5 iterations and discuss preliminary results.

M.

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Arctic Ocean water masses under changing river runoff

Arctic air temperatures are rising, ocean heat flux and river runoff are increasing and summer sea ice cover is retreating. These changes will affect water mass transformations both inside the Arctic Ocean as well as further downstream in the North Atlantic. Here we investigate the effects of increasing river runoff – the largest freshwater source with a clear increasing trend – on the Arctic Ocean water mass properties. We perform perturbations tests with a 1-dimensional column model and a 3-dimensional coupled ocean – sea ice model. We find that the while the surface stratification becomes stronger with the increasing runoff, also the vertical temperature gradient increases below the surface mixed layer as the Atlantic water layer warms up and rises higher in the water column. As a result the net change in the vertical heat flux and the mean ice thickness remains small, in contrary to what would be expected from the stronger density stratification alone. We compare these results with future climate predictions and find reasonable agreement.

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Variability of the Arctic Ocean freshwater storage in a coupled climate model

The upper ocean gyres of the Arctic Ocean constitute a reservoir of freshwater. Accumulated liquid freshwater has exhibited a strong increase during the last decade, potentially linked to climate change. Sudden release of excess freshwater from the arctic may influence the sub-polar ocean circulation, the rate and properties of the North Atlantic deep water formation. Here we report variability of comparable magnitude in a free, multi-centennial pre-industrial control simulation with the coupled climate model EC-Earth. It is shown that the volume of liquid freshwater in the Arctic Ocean is largely unconstrained in the model, non Gaussian distributed and associated with a multi-decadal de-correlation time-scale. This may be explained by absorption of uncorrelated fluctuations in modelled exchanges with the neighboring ocean regions and, between liquid and solid phases. In contrast, the volume of sea-ice in the Arctic Ocean is highly constrained explained by a positive relation between the magnitude of storage and export. It is demonstrated that this coupling does not exist in the model for the storage of liquid freswhater controlled by multiple exchange systems. A simple approach is used to diagnose the changes in storage from the exchanges through individual ocean gateways. Multi-decadal variability in freshwater storage can be inferred from all exchange systems, though the largest amplitude is associated with the Fram Strait liquid FW export. Considering liquid and solid components independently reveals an important role of transfer between liquid and solid phases in forming the decadal to centennial variability in the liquid freshwater storage.

P.

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Analysis of the variability of the circulation in the Pacific Sector of the Arctic Ocean during 2003-2010 through the 4Dvar data assimilation

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(4) JAMSTEC, Japan

The climatological mean summer-fall circulations in the Pacific sector of Arctic Ocean were reconstructed by 4Dvar assimilation of observations available for the periods of (i) 1900-2006, (ii) cyclonic (1989-1997) and (iii) anticyclonic (1997-2006) states and (iv) for the period of the International Polar Year (2007-2009). Comparison of these climatological states with the 2008 July-October circulation reveals significant variations caused by drastic changes in model forcing — namely, wind forcing and sea ice conditions. The 2008 state was additionally validated with respect to independent velocity observations, which were not assimilated. The distribution of the SSH anoma- lies reveals reasonable correlation with gridded AVISO satellite altimetry anomaly, suggesting that the satellite along-track altimetry could be a valuable source of data for operational hindcast/forecast of the local circulation after its accurate re-tracking and validation.

Optimization of the high-frequency radar sites in the Bering Strait region

G.Panteleev, M.Yaremchuk, J. Stroh, P. Posey, D. Hebert

Monitoring surface currents by coastal high-frequency radars (HFRs) is a cost-effective observational technique with good prospects for further development. An important issue in improving the efficiency of HFR systems is optimization of radar positions on the coastline. Besides being constrained by environmental and logistic factors, such optimization has to account for prior knowledge of local circulation and the target quantities (such as transports through certain key sections) with respect to which the radar positions are to be optimized.

In the proposed methodology, prior information of the regional circulation isspecified by the solution of the 4d variational assimilation problem, where the available climatological data in the Bering Strait (BS) region are synthesized with dynamical constraints of a numerical model. The optimal HFR placement problem is solved by maximizing the reduction of a posteriori error in the mass, heat and salt (MHS) transports through the target sections in the region.It is shown that the MHS transports into the Arctic and their redistribution within the Chukchi Sea are best monitored by placing HFRs at Cape Prince of Wales and on the Little Diomede Island. Another equally efficient configuration involves placement of the second radar at Sinuk (Western Alaska) in place of Diomede. Computations show that 1) optimization of the HFR deployment yields a two-fold reduction of the transport errors; 2) error reduction provided by two HFRs is an order of magnitude better than the one obtained from three moorings permanently maintained in the region for the last five years. This result shows a significant advantage of BS monitoring by HFRs compared to more traditional technique of it in situ moored observations. The obtained results are validated by an extensive set of observing system simulation experiments.

Adjoint-Free Variational Data Assimilation into a Regional Models.

Gleb Panteleev, Max Yaremchuk

A variational data assimilation algorithm is developed for the ocean wave prediction model7 (WAM). The algorithm employs the adjoint-free technique and tested in a series of data8 assimilation experiments with synthetic observations in the South Chukchi Sea region from9 various platforms. The types of considered observations are directional spectra measured by stationary buoys, SWH observations by coastal high-frequency radars (HFRs) and satellite measurements of sea surface roughness. Numerical experiments demonstrate computational feasibility and robustness of the adjoint-free variational algorithm with the regional configuration of WAM. The largest improvement of the model forecast skill is provided by assimilating HFR data (the most numerous among the considered types). Assimilating observations of the wave spectrum from a moored platform provides only moderate improvement of the skill which disappears after 3 hours of running WAM in the forecast mode, whereas skill improvement provided by HFRs is shown to persist up to 9 hours. Space-borne observations, being the least numerous, do not have a significant impact on the forecast skill, but appear to have a noticeable effect when assimilated in combination with other types of data. In particular, when spectral data from a single mooring are used, the satellite data are found to be the most beneficial as a supplemental data type, suggesting the importance of spatial coverage of the domain by observations. Preliminary results of the application Adjoint-Free 4Dvar to NCOM and MIT GCM will be also discussed.

P.

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Analyses of Canadian CONCEPTS Regional 1/12-deg and ¼-deg simulations during 2003-2011

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Hindcasts of ocean and sea-ice variability in the North Atlantic and Arctic oceans during 2003-2011 are carried out with the Canadian CONCEPTS regional model, developed by the inter-departmental CONCEPTS program, based on the Nucleaus for European Modeling of the Ocean (NEMO) and CICE sea-ice models, with nominal spatial resolutions at 1/12-deg and ¼-deg in longitude/latitude. The high spatial resolution and high frequency atmospheric forcing is obtained from a re-forecast from the numerical weather forecasting system of the Canadian Meteorological Center. In this presentation, the model hindcast is validated using available ocean and sea-ice observations, and analyses of inter-annual variations sea surface height, circulation, and upper ocean mixed layer depth is performed. The relationship between variations of deep convection in Irminger Sea and surface winds around Greenland is explored.

P.

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Seasonal trends in sea ice dynamics and wind forcing over the Beaufort Sea

Both the ocean circulation and overlying sea ice cover of the Beaufort and Chukchi seas have experienced significant change in recent decades. We use sea ice drift estimates from satellite feature tracking (NSIDC/CERSAT) and wind forcing from atmospheric reanalysis products (NCEP-R2/ERA-I/JRA-55) to investigate the role of wind forcing and ice dynamics in driving these changes. An assessment of ice drift shows reasonable agreement across the different products, revealing interannual variability in the ice flux around the Beaufort Sea. However, clear uncertainties remain in determining the magnitude of these fluxes, especially in regions of low ice concentration. We find an increase in anti-cyclonic ice drift within the Beaufort Sea and an increase in ice export out of the southern Beaufort Sea (into the Chukchi Sea) across all seasons, despite the wind curl showing a similar trend in summer only. The strongest trend in ice drift curl appears to be in autumn, however recent years have seen a strong reduction in this anti-cyclonic drift, likely due to a combination of changes in the wind forcing and sea ice state. The implication of this finding is an enhanced response of the ocean circulation to shifts in atmospheric circulation compared to that experienced prior to 2000.

P.

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Arctic – GIN Sea Deep Water Passages in the FRAM Strait

Steve Piacsek, Pam Posey and David Hebert

Deep water (DW) fluxes of water-masses passing through the FRAM Strait have been investigated, using output from the ACNFS ice-ocean model of NRL, focusing on outflows produced by the contributions of various water masses, such as AODW (Arctic Ocean Deep Water,) EBDW (Eurasian Basin Deep Water) and NSDW (Norwegian Sea Deep Water). The computations were mostly carried out in the region (76N-81N, 20W – 20E), for the years 2005 – 2013 which included the two most ice-free years 2007 and 2012. EBDW was found to travel mostly in the 1500-2200m depth range; AODW in the 2200-bottom range, and some others defined as DW6 in Ref 1 below 2500m.

Ref. 1 Il Nuovo Cimento 31C, No.2, p.215, 2008.

P.

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Formation and break up of landfast ice in the Parry Channel, Canadian Arctic Archipelago

The time evolution of land-fast ice in the Canadian Arctic Archipelago (CAA) was investigated using imagery from the NASA MODIS Terra and Acqua satellites. Temperature brightness imagery is used to identify regions of open water, leads or polynya during the 2013-2014 Arctic winter. The extent of land-fast ice is determined by the presence of a stationary polynya, called flaw lead, typically found adjacent to the land-fast ice edge. The brightness temperature imagery is presented as a useful and accessible tool for the analysis of land-fast ice conditions.

We demonstrate that land-fast ice formation in the Parry Channel happens in stages of successive advances toward the Lancaster Sound. The break up of land-fast ice in the Parry Channel depends on the resistance of the ice bridges to the wind forcing. Links between the position of the flaw lead, the ice strength and the regional wind forcing are investigated. Ice charts from the National Ice Center are used to present the interannual variability of the CAA landfast ice, and compared to the inter-annual variability of the CAA landfast ice thickness provided by a multilayer sigma-coordinate thermodynamic sea ice model.

P.

Platov Gennady

Institute of Computational Mathematics and Mathematical Geophysics, Russia,

The coupled hydrodynamic system of Lena River delta and Laptev Sea shelf zone: problems of modeling and observational synthesis

Platov G., V. Shlychkov, E. Klimova and A. Krylova

A new model of hydrodynamic system consisting of the delta of the Lena River and the Laptev Sea shelf zone is described. Simulation of a complex fluvial system with many channels, watercourses and estuarine areas is based on the numerical solution of 1D Saint Venant equations for each segment of the river network and formulation of the coupling conditions for flows at branch points. During our test runs, an adopted scheme for interaction with the surrounding areas of the sea shelf implies the unilateral influence of delta water on the sea currents, ie river is the primary component in the considered system.

An assimilation technique based on the ensemble Kalman filtering is used to improve the model results. The idea is to use suboptimal algorithms in which the probability averaging is replaced by time-averaging, assuming random fields having temporal ergodicity.

The set of assimilated data is the Pathfinder NOAA/AVHRR archive of satellite observations for the summer 2008 period. The IPY data for the same period is used for comparison with numerical modeling.

The results of preliminary experiments to test the quality of the model and data assimilation procedure applied to the basin of the Laptev Sea in the vicinity of the Lena Delta will be discussed.

P.

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Eddies in the Western Arctic Halocline

Observations of velocity between 30 and 300 m depth in the western Arctic Ocean were used to detect eddies and determine their properties. Acoustic Doppler Current Profilers (ADCPs) were deployed below Ice Ocean Environmental Buoys (IOEBs) that were frozen into the pack ice and drifted within the Beaufort Gyre between 1992 and 1998. Eighty-one eddy encounters were identified during four deployments that totaled 44 months of buoy drift. Various eddy properties (e.g. depth, thickness, radius sense of rotation vorticity, strain, Rossby number) were estimated. Eddies were found predominantly in the upper halocline. Rotation speeds ranged from 10-35 cm s^{-1}, and radii were 2-8 km. Faster rotation was associated with larger radius and larger vertical extent. Rossby numbers near 1.0 indicated a cyclo-geostrophic balance. The sense of rotation was predominantly anticyclonic.

P.

Popova, Katya
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Modelling of the present and future Arctic Ocean Biogeochemistry

Due to anthropogenic climate change, the sea ice cover of the Arctic Ocean is undergoing an unexpectedly fast retreat. Can this retreat increase capacity of the Arctic Ocean to absorb atmospheric CO2 and can we accurately predict this change? In this work, the MEDUSA biogeochemical model, coupled to the global NEMO general circulation model, is run under a range of IPCC climate scenarios to seasonally ice-free Arctic Ocean. We analyse changes in the Arctic Ocean stratification, their impact on the efficiency of the biological pump and potential of the Arctic Ocean to absorb atmospheric CO2. Results indicate that climate feedbacks, and spatial heterogeneity thereof, play a strong role in the declines in pH and carbonate saturation seen in the Arctic. As a consequence, the predicted onset of undersaturation is highly variable regionally within the Arctic, occurring during the decade of 2000-2010 in the Siberian shelves and Canadian Arctic Archipelago, but as late as the 2080s in the Barents and Norwegian Seas. We conclude that, in order to make future projections of acidification and carbon saturation state in the Arctic, regional variability needs to be adequately resolved, with particular emphasis on reliable predictions of the rates of retreat of the sea-ice which are a major source of uncertainty.

P.

Posey, Pam
Naval Research Laboratory, USA

An Assessment of the Navy's Sea Ice Outlook Predictions for 2014

As conditions in the Arctic continue to change, the Naval Research Laboratory (NRL) has developed a capability to generate seasonal ice extent forecasts for the summer months. The Arctic Cap Nowcast/Forecast System (ACNFS), developed by the Oceanography Division of NRL, is run in forward mode without assimilation, to estimate the minimum ice extent for September 2014. The model is initialized with varying assimilative ACNFS analysis fields (May1, June 1, July 1, August 1 and September 1, 2014) and run forward using the archived Navy Operational Atmospheric Prediction System (NOGAPS) atmospheric forcing fields from 2004-2013. The ice extent for September, averaged across all ensemble members represents the projected minimum ice extent. These results are submitted to the Sea Ice Prediction Network (SIPN) Sea Ice Outlook project (http://www.arcus.org/sipn/sea-ice-outlook). The ACNFS is a 3.5 km coupled ice-ocean model that produces 7 day forecasts of the Arctic sea ice state in all ice covered areas in the northern hemisphere (poleward of 40°N). Along with the ACNFS minimum ice extent estimate, this year NRL has also run a simulation using the Global Ocean Forecast System (GOFS 3.1). GOFS 3.1 has the same resolution as ACNFS and produces 7 day forecasts for both the northern and southern hemispheres. ACNFS and GOFS 3.1 have similar major components: 1) ocean component - the HYbrid Coordinate Ocean Model (HYCOM), and 2) ice component - the Los Alamos National Laboratory Community Ice CodE (CICE). Both systems are coupled via the Earth System Modeling Framework (ESMF) and have the option of running in an assimilative cycle with the Navy's Coupled Ocean Data Assimilation (NCODA) system. The ACNFS is run operationally daily at the Naval Oceanographic Office (NAVOCEANO) where products are then automatically pushed to the National Ice Center. GOFS 3.1 is currently undergoing final validation with expected transition to NAVOCEANO by end of September 2014.

P.

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Causes and consequences of the Beaufort Gyre freshwater storage variability

A.Proshutinsky, R. Krishfield, M-L. Timmermans, J. Toole

The Beaufort Gyre (BG) system is a unique circulation component within the Arctic physical environmental system reflecting a set of specific atmospheric, sea-ice, and oceanic conditions that have significant interrelationships with the Arctic-wide as well as global climate systems. The BG, NSF funded observations have documented that in 2003-2013 the BG region accumulated more than 5000 km^3 of liquid freshwater (FW) relative to the climatology of the 1970s. Recent results suggest that the BG system may be entering a period of FW release which would be expected from previous climatological behavior and has the potential to cause a Great Salinity Anomaly in the North Atlantic. However, it is unclear whether a "tipping point" has been exceeded beyond which the FW will continue to accumulate and exceed anything observed in the past. The central idea of this presentation is to show how the BG system, with all its mechanisms and feedbacks, influences processes of FW accumulation and release, and is influenced by Arctic climate variability.

R.

Rabe, Benjamin
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Upper Arctic Ocean changes since the 1990s: freshwater, stratification and implications for biogeochemistry

Recent decades have shown substantial changes in the Arctic Ocean, yet observations are still relatively sparse compared to most other parts of the world's oceans. Results from numerical models still differ in the distribution of key variables, such as the pathways of liquid freshwater.
From salinity observed by a variety of platforms since 1992 we are able to show a substantial freshening in the upper Arctic Ocean impacting an increase in stratification between the mixed-layer and the lower halocline. Based on temperature and salinity profiles, we will present a first attempt at an objective analysis of mixed-layer depth changes during the recent two decades.
Although most of the freshwater volume increase occurred on the Amerasian side of the Arctic Ocean, the changes on the Eurasian side have strong implications not only for the stratification but also the vertical exchange of nutrients in the upper ocean.

R.

Rampal, Pierre
Nansen Center, Norway,

Towards a new sea ice model: neXtSIM

P. Rampal & S. Bouillon

With increasing temperatures in the Arctic is experiencing rapid and drastic changes in sea ice conditions, with innumerable consequences for the environment and human activities. In particular, the sea ice cover has thinned significantly over the last decades, becoming mainly seasonal and loosing part of its mechanical strength. These are likely to change the sea ice dynamical regime, with more frequent extreme sea ice break up events. A new sea ice model called neXtSIM is being developed including new physics in order to simulate these ongoing dynamical changes as well as their potential impacts on the ocean-sea ice-atmosphere system. In this talk we present an overview of this new model and show preliminary results from a stand-alone sea ice simulation over the Arctic.

R.

Record, Nicholas
Bigelow Laboratory for Ocean Sciences, USA

Predicting the biogeography of copepodid diapause

There is a need for predictive tools in order to prepare for and mitigate changes in the Arctic. Large copepods with a diapause strategy dominate the mesozooplankton biomass in Arctic Ocean and many Subarctic seas. Diapausing copepods convert pulsed blooms of primary production into an abundant and energy-rich lipid resource available to upper trophic levels for many months. The presence and dominance of diapausing copepods is a key determinant of the structure of the food web, supporting highly productive fisheries and critical marine mammal and seabird foraging grounds. This project has two objectives: (1) to produce a database and atlas of the biogeography and characteristics of diapause based on existing data sources, and (2) to synthesize the multiple diapause models available into a comprehensive model and forecasting tool that can predict the prevalence and characteristics of copepod diapause based on environmental information.

R.

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Modeling the distribution of the ballast water discharge in the Arctic Ocean

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Ballast is defined as any solid or liquid that is brought on board a vessel to increase the draft, change the trim, and regulate the stability or to maintain stress loads within acceptable limits. Since the introduction of steel hulled vessels, water has been used as ballast to stabilize vessels at sea. Ballast water is pumped-in to maintain safe operating conditions throughout a voyage.

While ballast water is essential for safe and efficient modern shipping operations, it may pose serious ecological, economic and health problems due to the multitude of marine species carried in ships' ballast water. There are thousands of aquatic species that may be carried in the ballast water tanks, including bacteria and other microbes, microalgae, and various life stages of aquatic plant and animal species. The transferred species may survive to establish a reproductive population in the host environment, becoming invasive, out-competing native species and multiplying into pest proportions.

Species are considered alien if they are not native to a given ecosystem. Alien species are considered to be invasive when their introduction causes, or is likely to cause, harm to the environment, the economy, or human health. The impacts of introduction and spread of alien invasive species depend on the origin of the organisms and the location of the point of discharge.

Using the oceanic model NAOSIM (North Atlantic/Arctic Ocean-Sea Ice Model) with a 9 km resolution, this study aims to model the distribution of the ballast water unloaded by vessels in the Arctic Ocean. It is expected with the results of this study to point out areas where the ballast water unload can be extremely harmful for the ecosystem and human health.

R.

Roberts, Andrew
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Intercomparison of isotropic and anisotropic sea ice mechanics in a high-resolution fully coupled climate model

We present the first results from simulations using anisotropic sea ice mechanics in the Regional Arctic System Model (RASM), and compare these results with an isotropic rheology currently used in many Earth System Models. RASM is a fully coupled pan-Arctic climate model that incorporates the same ocean, sea ice and coupling infrastructure as the Community Earth System Model, but is configured at a resolution of 1/12° for the ice-ocean models and 50 km for the atmosphere-land components, and resolves ice-ocean-atmosphere inertial feedbacks. The sea ice model in RASM has recently been upgraded to Version 5 of the Los Alamos Sea Ice Model (CICE5), which has the facility for either Elastic Viscous Plastic (EVP) sea ice mechanics (Hunke and Dukowicz, 1997), a revised EVP formulation (Bouillon et al. 2013) or an Elastic-Anisotropic-Plastic rheology (Tsamados et al. 2013). Our results show that there is a discernable difference in the thickness evolution between the first two of these model physics choices, but that their deformation characteristics remain similar. Despite thicker sea ice occurring across much of the Arctic Basin using Revised-EVP than for the original EVP formulation, the basin-wide ice drift is faster, which does not address a positive drift bias that has existed in RASM up to now. By contrast, the seasonal sea ice drift bias is reduced in RASM when using the anistropic sea ice rheology as compared to certain satellite drift products. There is a considerable difference, also, in the ice thickness and deformation fields using this rheology, which has fewer but more clearly defined linear kinematic features than both EVP variants.

R.

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Atlantic inflows, the Arctic Ocean volume and freshwater balances, and the Fram Strait branch contribution to the Arctic heat budget

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The inflows of Atlantic water from the Nordic Seas to the Arctic Ocean through Fram Strait and over the Barents Sea are examined based primarily on hydrographic observations from two cruises with RV Polarstern in 2007 and 2011. The contrast between the high salinity Atlantic water core in the Nansen Basin and the lower Atlantic water salinity combined with an underlying salinity minimum in the Amundsen Basin suggests that the Fram Strait branch mainly remains in the Nansen Basin, while the Barents Sea branch continues along the continental slope, enters the Amundsen Basin and provides most of the Atlantic water in the Makarov and Canada basins. To examine the consequences of such a circulation pattern for the Arctic Ocean heat balance recently published estimates of the in- and outflows of volume and liquid freshwater through the Barents Sea, Bering Strait and the Canadian Arctic Archipelago as well as river runoff, net precipitation and ice export are reviewed and added together. To achieve volume and freshwater balances net outflows through Fram Strait of 2.3 Sv and 100 mSv respectively are required, which is reasonably close to recently reported Fram Strait transport estimates. The net outflows are separated into two parts, upper layer transports, less dense than the entering Atlantic water, and lower layer transports, as dense as or denser than the Atlantic water. The largest net volume outflow occurs in the lower layer, 1.65 Sv, while the liquid freshwater is almost exclusively exported in the 0.64 Sv net outflow in upper layer, leading to unrealistically low salinities in the upper layer. Atlantic water transformed into less saline surface water through melting of sea ice north of Svalbard can supply the necessary higher salinity (halocline) water to the upper layer. 1.23 Sv of halocline water of salinity 34.2 must be added to obtain a more realistic salinity of 33.1, leading to a total export of 1.84 Sv upper layer water in the East Greenland Current. Existing observations of the net transports into and out of the Arctic Ocean through Fram Strait in different temperature classes are then used to estimate the heat loss of the Atlantic water entering through Fram Strait. About 10 TW are supplied to the atmosphere in addition to the loss of 24 TW occurring in connection with the formation of the halocline water. If the hypothesis that the Fram Strait branch remains in the Nansen Basin is true, it implies a heat loss between 5 and 15 Wm^2 in the Nansen Basin, depending upon how much heat is temporarily stored in the water column. This is high compared to the 2 Wm^2 commonly cited as the ocean heat flux to the atmosphere in the Arctic Ocean.

R.

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Implementation of a Combined Elastic-Viscous-Plastic and Collisional Sea Ice Rheology

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The importance of the Marginal Ice Zone (MIZ) is growing due to climate change and increases in human activities in the high latitudes. However there are fundamental shortcomings in the current representations of the MIZ in numerical sea ice-ocean models; sea ice models are constructed with the pack ice in mind and lack some specific MIZ processes. One of the aims of the Ships and Waves reaching the Polar Oceans (SWARP) project is to improve MIZ simulations with a view to improving operational models. One area to be improved is the sea ice rheology that is currently based on the Elactic-Viscous Plastis (EVP) rheology, suitable for near-continuous ice. It is argued that collisional rheologies, like Shen's rheology [1986], are more suitable for the MIZ, which behaves more like a granular material. The aim of the present study is to develop a combined rheology that is suitable for both regimes, combining the EVP and collisional effects on stress, following Feltham [2005]. Shen's collisional rheology is implemented in the CICE sea ice model and combined with the existing EVP formulation. This is coupled to a global NEMO ocean model at a 2-degree resolution and run with climatological forcing for ten years. The contribution of the collisional rheology is determined by the granular temperature, governed by the granular temperature equation. As a first stage granular temperature is kept constant having high values at low latitudes and an exponential decay to the poles. Preliminary results show effects in the pack ice interior, well beyond the sea ice edge.

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Mechanisms of landfast sea ice development in the southeastern Laptev Sea

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Accurate representation of landfast sea ice is found to be important for realistic simulations of Arctic sea ice concentration and thickness, ocean height and Arctic halocline stability. Todays coupled sea ice-ocean models are not capable of representing seasonal variability of landfast ice extent. To improve ice-ocean models and successfully incorporate landfast ice the mechanisms controlling seasonal fast ice development need to be further explored and thoroughly understood.

Here we present a study on fast ice development in the southeastern Laptev Sea. Detailed examination of SAR-based ice drift from October 2007 through January 2008 showed that several grounded ice features are formed offshore prior to fast ice expansion. These features play a key role in offshore advancement of the fast ice edge and serve as stabilizing points for surrounding pack ice as it becomes landfast and anchors for formation of ice arches at the fast ice edge.

The shape of fast ice edge from AARI operational sea ice charts 2000 - 2013 suggest that ice arching is an important mechanism defining position of fast ice edge at its maximal extent. Applying a simple thermodynamic ice growth model we estimate critical ice thickness required for formation of ice arches.

Further analysis of ice thickness data obtained from electromagnetic surveys indicates that grounded ridges may be a controlling factor for maximum fast ice extent in the region and their location can be inferred from the shape of the edge.

S.

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Freshwater changes and pathways in the Labrador Sea

Lena Schulze, Eleanor Frajka-William and Sheldon Bacon

The Labrador Sea is an important site for the formation of intermediate deep water due to its seasonally recurring dee convection. While the amount of heat lost to the atmosphere is an important factor to the strength of convection, changes in surface buoyancy, such as additional freshwater, are also critical and can lead to a supression of deep mixing [Dickson et al. 1988 and Gelderloos et al. 2012]. Additional freshwater from recent increase in Arctic ice melt, could therefore significantly impact the formation of deep water, if it were to reach the region of deep convection. Models disagree if, how and where this freshwater reaches the region or if it is simply advected south via the boundary currents (e.g. Weaver et al. 1994 and Myers, 2005).
An understanding of freshwater exchange between the basin and boundary domain is crucial in order to determine how increasing freshwater fluxes from the Arctic will influence deep convection patterns.
10-years of temperature and salinity from ARGO floats is used to determine interannual variability and changes in the freshwater budget in the basin. Furthermore, a Lagrangian particle tracking approach is used to determine key regions of exchange between the basin and boundary region.

S.

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Retarded responses of the oceanic Beaufort Gyre to winds and sea ice motions: Influences on variations of sea ice in the Pacific sector of the Arctic Ocean

The dominant sea ice type in the Arctic Ocean has been replaced by first-year ice from multi-year ice in the late 2000s. In this condition, growth of first-year ice in winter and resultant ice thickness at the melt onset are key preconditions on whether sea ice can survive or disappear during the following summer. The growth rate strongly depends on the upper ocean thermal condition. In the Pacific sector of the Arctic Ocean, the warm Pacific Summer Water (PSW), which is a major heat source affecting the sea ice growth in winter, is transported toward the central Arctic basin by the oceanic Beaufort Gyre (OBG) driven by winds and sea ice motions. The temporal variation of the OBG is related to the oceanic thermal condition in the basin, however, the response time scale of the OBG to the surface forcing has been still unclear. In the present study, we examine the relationship between the ocean dynamic height (ODH) near the Northwind Ridge as a proxy of the northward volume transport of the OBG and curls of winds and sea ice velocities, using multiple regression models that can explain relative contributions of past surface forcing to the current state of the OBG. As a result, the time scale of the retarded oceanic response in 2006-2012 was estimated to be about three years. The multiple regression model, using the satellite-derived sea ice motion data, successfully reconstructed the observed variations of ODH within the accuracy of about 0.2 dynamic cm, which corresponded to 2 % of the amplitude of the observed variations.

S.

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Atlantic inflow and sea ice in the Barents Sea and Arctic Ocean

Present global warming is amplified in the Arctic and accompanied by unprecedented sea ice decline. Located along the main pathway of Atlantic Water entering the Arctic, the Barents Sea is the site of coupled feedback processes that are important for creating variability in the entire Arctic air-ice-ocean system. As warm Atlantic Water flows through the Barents Sea, it loses heat to the Arctic atmosphere. Warm periods, like today, are associated with high northward heat transport, reduced Arctic sea ice cover, and high surface air temperatures. The cooling of the Atlantic inflow creates dense water sinking to great depths in the Arctic Basins. Recently, anomalously large ocean heat transport has reduced sea ice formation in the Barents Sea during winter. Atlantic Water has likely also caused loss of sea ice inside the Arctic Ocean north of Svalbard, and the missing Barents Sea winter ice makes up a large part of observed winter Arctic sea ice loss. Large air-ice-ocean variability is evident in proxy records of past climate conditions, suggesting that the Barents Sea has had an important role in Northern Hemisphere climate for, at least, the last 2500 years.

S.

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Arctic seasonal sea ice retreat: synchronicity, prediction, and dilation

We have investigated some details of seasonal sea ice retreat in the Beaufort Sea and beyond. We find that in the Beaufort Sea, areas with the strongest negative trends in the Date of ice Retreat (DOR) are also areas where ice has traditionally lasted the longest. This means that the DOR is becoming more spatially uniform across the region, which may have important implications for shipping and marine mammals. We also find a significant relationship between spring easterly winds and DOR, with several month lead times. Finally, we have found that throughout the Arctic Ocean, the position of the daily mean sea ice edge (15% concentration contour) is often "stalled" for several days, owing to light or southeastward (in the ice edge frame of reference) winds. After southeastward winds which dilate the ice pack, a change in wind direction frequently results in very rapid northward ice edge progression, owing to an enhanced ability to compress the loose ice pack.

S.

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International Arctic Research Center (IARC) / University of Alaska Fairbanks (UAF)

Sea-surface temperature and salinity product comparison against external in situ data in the Arctic Ocean

Sea-surface temperature and salinity (SST/S) in the Arctic Ocean (AO) from global satellite analyses and models which incorporate remotely-observed SST/S may be inaccurate in the AO due to lack of direct measurements for calibrating satellite observation and presence of sea ice. For this reason we are motivated to validate global SST satellite analyses and SST/S models by comparing product SST/S in the AO against oceanographic records during 2006–2013. The bulk of this pan-Arctic dataset was garnered as part of a NOAA-funded International Polar Year database, and contains over 30,000 hydrographical profiles. All SST satellite analyses considered favorably agree with high-latitude CTD in-situ data. Also, the US Navy Coupled Ocean Data Assimilation (NCODA) system using the Hybrid Ocean Coordinate Model (HYCOM) more accurately reflects the SST/S data than does the NASA Estimation of the Circulation and Climate of the Ocean version 2 (ECCO2) model.

T.

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Changing sea ice conditions in the Beaufort Sea – latest results from Ice Watch observations on the 2014 JOIS/BGEP cruise

The Beaufort Sea and its associated gyre is a region of great interest to polar oceanographers and sea ice scientists. Storage and release of freshwater by the gyre alters salinity across the Arctic Ocean and into the North Atlantic, and has the potential to impact the global thermohaline circulation. In addition, rotational surface currents have the effect of "recirculating" first year (FY) sea ice into the central Arctic, promoting multiyear (MY) ice growth. Since 2003, the Woods Hole Oceanographic Institution (WHOI) has run the Beaufort Gyre Exploration Project (BGEP) to investigate mechanisms driving variability in freshwater content of the region. The project combines data from shipboard measurements and a suite of in-situ instruments, as well as historical and model data, in order to generate a comprehensive picture of conditions in the Beaufort Sea. The Ice Watch project is run by International Arctic Research Centre (IARC) at the University of Alaska Fairbanks (UAF). Its goal is provide a central archive of standardised shipborne observations of sea ice. The annual Joint Ice Ocean Study (JOIS) cruise has been a major part of BGEP since its inception. Ice Watch observers have joined the cruise since 2006, providing an excellent record of round-the-clock sea ice conditions in the field.
Here we present a look at Ice Watch data gathered on the most recent JOIS cruise. These results give insight into the effect the 2014 melt season has had on sea ice conditions in the region. We examine the record of observations through the history of Ice Watch, assess the changes in regional sea ice conditions over the last 9 years and how this may impact the Beaufort Sea in the future.

T.

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Arctic sea ice thickness and volume 2010-2014 from CryoSat-2

Satellite records show a decline in Arctic sea ice extent over the past three decades with a record minimum in September 2012. Observations of thickness, and therefore volume trends, have been spatially and temporally sporadic, although results from the Pan-Arctic Ice-Ocean Modelling and Assimilation System (PIOMAS) suggest that this decline in extent has been accompanied by a reduction in volume. We use data from the European Space Agency CryoSat-2 (CS-2) mission to generate estimates of seasonal and inter-annual variations in Arctic sea ice thickness distribution and total volume between 2010 and 2014. We then investigate the factors driving these variations, considering both dynamic and thermodynamic influences on Arctic sea ice.

T.

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Mechanisms of Pacific Summer Water variability in the Arctic's Central Canada Basin

M.-L. Timmermans
A. Proshutinsky, E. Golubeva, J.M. Jackson, R. Krishfield, M. McCall, G. Platov, J. Toole, W. Williams

Pacific Water flows northward through Bering Strait and penetrates the Arctic Ocean halocline throughout the Canadian Basin sector of the Arctic. In summer, Pacific Summer Water (PSW) is modified by surface buoyancy fluxes and mixing as it crosses the shallow Chukchi Sea before entering the deep ocean. Measurements from Ice-Tethered Profilers, moorings and hydrographic surveys between 2003 and 2013 reveal spatial and temporal variability in the PSW component of the halocline in the Central Canada Basin with increasing trends in integrated heat and freshwater content, a consequence of PSW layer thickening as well as layer freshening and warming. It is shown here how properties in the Chukchi Sea in summer control the temperature-salinity properties of PSW in the interior by subduction at isopycnals that outcrop in the Chukchi Sea. Results of an ocean model, forced by idealized winds, provide support to the mechanism of surface ocean Ekman transport convergence maintaining PSW ventilation of the halocline.

T.

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OBSERVATIONS OF THE UPPER OCEAN FLOW FIELD AND SEA-ICE DYNAMICS IN THE BEAUFORT GYRE FROM 2005-2013 FROM MOORED INSTRUMENTATION

The Beaufort Gyre represents the largest freshwater reservoir in the Arctic Ocean, and is thought to be the source of large salinity anomalies that propagate through the sub-polar North Atlantic. As part of the Beaufort Gyre Observation System (BGOS), three bottom-tethered moorings have been maintained in the gyre since 2003. An acoustic Doppler current profiler (ADCP) has been maintained at mooring D (74˚ N, 140˚ W) since 2005 and at moorings A (75˚ N, 150˚ W) and B (78˚ N, 150˚ W) since 2010. Here we describe the upper ocean and sea-ice velocity structure and flow field over this time period. The sea-ice data come from a combination of ADCP data, upward looking sonar data, and various ice concentration products. We examine the velocity structure by separating the tidal, inertial, and lower frequency (eddy) components using various spectral analysis techniques. Mesoscale eddies detected in the near surface mixed layer are compared to those found below the halocline. The results suggest that mooring B is a particularly important site for assessing the energetics and dynamics of the Beaufort Gyre.

T.

Tremblay, Bruno
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Forecasting future sea ice conditions in the MIZ: a Langrangian approach

Significant changes in the Arctic Ocean ice extent have been observed in recent years, particularly at the end of the summer. Climate models that have a reasonable late 20th century Arctic climate, forecast ice-free summers in the Arctic before the end of this century. While these models agree on the decline of sea ice extent and the likelihood of a seasonal Arctic sea ice cover, the pattern of the sea ice loss and marginal ice zone locations predicted by different models varies widely. Narrowing the uncertainty implicit in these model disagreements is an important contribution to the accuracy of global climate projections. To this end we track the boundary between first and multi-year ice (i.e. the minimum September sea-ice edge position) using Lagrangian back and forward trajectories in both the instrumental record and GCMs participating in the IPCC-AR5. We use the trajectories to quantify the magnitude and interannual variability in the thermodynamic and dynamic (ice export) ice loss, the amount and geographical distribution of multiyear ice melt and first year promotion to second year ice. Results clearly highlight the importance of pre-conditioning (previous winter ice export) on the following summer minimum ice extent. Assessing whether climate models reproduce the correct dynamic of the MIZ can increase our confidence in climate forecast.

Tsamados, Michel

University College London

Processes controlling surface, bottom and lateral melt of Arctic sea ice in a state of the art sea ice model

Michel Tsamados, Daniel Feltham, Alek Petty, David Schroeder, Daniela Flocco

We present a modelling study of processes controlling the summer melt and disintegration of the Arctic sea ice cover. The NCEO/CPOM sea ice model is a branch of the Los Alamos community code CICE, version 5.0, that includes recently developed new physics of halodynamic, melt ponds, anisotropic rheology, and the impact of topography on air-ice and ice-ocean flux exchange coefficients (momentum, sensible heat, latent heat). The CPOM model is modified to include a prognostic mixed layer and a three equations boundary condition for the salt and heat flux at the ice ocean interface. The study focuses on the relative roles of lateral melt, basal melt and surface melt. Lateral melt is calculated based on a parameterized variable average floe perimeter and is modified to account for the observed power law floe size distribution. Basal melt is sensitive to the seasonal cycle of temperature, salinity and depth of the prognostic mixed layer as well as to the boundary condition at the ice-ocean interface. Surface melt utilises a model of melt ponds on sea ice and is also affected by the halodynamic in the ice interior. This study assesses the seasonal and inter-annual model response of the Arctic sea ice cover to prescribed atmospheric and oceanic forcing in a stand alone setting. Because it quantifies the relative importance of several new physical mechanisms in driving the summer melt of the sea ice this work will serve as a guide for future research priorities.

Tsukernik, Maria

Brown University, USA

The great Arctic cyclone of 2012: influences of the underlying surface

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The ‘Great Arctic cyclone’ was a dramatic synoptic system that developed over Siberia and tracked over the North pole toward the Canadian Archipelago in August 2012. The storm was extremely intense, its central pressure bottomed at 963 hPa – a new record for the satellite era for the summer Arctic storms. Several studies investigated how this storm might have contributed to the record-minimum sea ice extent in 2012. In this study we investigate how an exceptionally ice-free Arctic Ocean might have contributed to the development and the intensification of this synoptic system.

We utilize the Weather Research and Forecasting (WRF) model 3.5 and force it with ERA Interim Reanalysis that produces a reasonable representation of the ‘Great Arctic cyclone’. We perform a series of studies, changing the underlying sea ice surface from “realistic” to “ice-free” and to “fixed ice” settings. The cyclone barely developed in the "no ice" case, while the "fixed ice" case had a weaker development track than the “realistic” (control) run. This leads us to conclude that there is a sizeable effect of the underlying surface conditions on cyclone development, specifically the inhomogeneity between open water and sea ice.

W.

Waldemar Walczowski

Institute of Oceanology Polish Academy of Sciences

Changes of the West Spitsbergen Current properties and their climatic implications

Significant variability in the properties of the Atlantic Water carried by the West Spitsbergen Current has been observed by Institute of Oceanology PAS during the last eighteen summers. Changes in the Atlantic Water temperature, heat content and northward transport have a strong influence on the Arctic climate and ecosystem, sea ice extension and Svalbard glaciers. Part of the heat carried by the West Spitsbergen Current is released to the atmosphere, while the major share is transferred due advection and mixing processes to the the adjacent water masses.

Time series of temperature and salinity at 76°30’N reveal a presence of three 5-6 years long cycles. Horizontal distributions of properties and geostrophic velocities show phases of intensive transport into the Barents Sea and periods of increased northward volume and heat transports towards the Fram Strait.

In summer 2006 the highest Atlantic Water temperature in the Fram Strait was detected. The environmental effects of the northward propagating anomalous events of warm and saline water were clearly observed.

W.

Wassmann, Paul
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The productivity of the Arctic Ocean, now and in the future, as revealed by modelling

Based upon the SINMOD model and validation from the Barents Sea and adjacent regions the primary and secondary production in the entire Arctic Ocean is investigated. The hind cast investigation is then compared to projections until 2100 applying forcing of the model with IPCC A1B. It is shown that the productivity changes the most north of Svalbard and the Kara Sea, along the Siberian shelf break and the in the inner Chukchi Sea. Despite of the reduction of sea ice primary and secondary production does not increase much in the central Arctic Ocean and this is caused by increased vertical stability and nutrient limitation. Atlantic and probably also Pacific waters entering the Arctic Ocean transport a signature of global change into the inflow regions that provide increased stability and decreasing productivity which are not based upon local forcing, but are produced further south. The manner how ecosystem investigations accompanied with modelling work can be combined in a fruitful manner is described. It is shown that both approaches are complimentary and basically depend on each other when large systems are studied and questions of long-term changes are asked.

W.

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A Comparison of Melt Pond Evolution in the Beaufort and Chukchi Seas

Melt pond evolution on sea ice has been well-documented on multiyear and landfast sea ice in the Arctic, but estimates of melt pond evolution on drifting, first-year sea ice are sparse. Though landfast and drifting first-year sea ice have similar physical properties, they undergo different dynamic and thermodynamic processes, which results in different progressions of melt. Using 1-m resolution Literal Image Derived Products (LIDP) paired with in situ buoy data, we evaluated the melt pond evolution on drifting first-year and multiyear sea ice in the Beaufort and Chukchi seas during the 2009-2013 melt seasons. We characterized the sea ice surface into sea ice, young ice, melt pond, and open water fractions, and compared the results with those from the Surface Heat Budget of the Arctic Ocean (SHEBA) field campaign in 1998. Preliminary results show earlier melt onset, slower initial growth in melt pond fraction, and double the maximum melt pond fraction in the 2009-2013 period compared to the SHEBA results. Maximum melt pond fractions were reached one month after melt onset on drifting sea ice, in comparison to eight days on landfast ice. These results reveal differences in melt progression of drifting first-year, multiyear, and landfast sea ice in the Beaufort and Chukchi seas, and thus, may be useful for validating sea ice and climate models.

W.

Williams, James
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Marginal Ice Zone Buoy Forecasts: a Model Comparison

The Arctic Cap Nowcast Forecast System (ACNFS) and Global Ocean Forecast System 3.1 (GOFS) have the capability to represent past, present and future dynamic sea ice motion. These model velocities can be used to forecast the location of the MIZ buoy clusters after a period of time, given initial buoy positions. To assess the potential forecasting skill of these two systems, 24, 47 and 72 hour predictions are compared with the buoy tracks.

Y.

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Assimilating SMOS sea ice thickness into a coupled ice-ocean model using a local SEIK filter

The impact of assimilating sea ice thickness data derived from ESA's Soil Moisture and Ocean salinity (SMOS) satellite together with Special Sensor Microwave Imager/Sounder (SSMIS) sea ice concentration data of the National Snow and Ice Data Center (NSIDC) in a coupled sea ice-ocean model is examined. A period of three months from November 1st, 2011 to January 31st, 2012 is selected to assess the forecast skill of the assimilation system. 24h-forecasts and longer forecasts are based on the Massachusetts Institute of Technology general circulation model (MITgcm), and the assimilation is performed by a localized Singular Evolutive Interpolated Kalman (LSEIK) filter. For comparison, the assimilation is repeated only with the SSMIS sea ice concentrations. By running two different assimilation experiments, and comparing with the unassimilated model, independent! satellite derived data, and in-situ observation, it is shown that the SMOS ice thickness assimilation leads to substantially improved thickness forecasts. With SMOS thickness data, the sea ice concentration forecasts also agree better with observations, although this improvement is smaller.

Z.

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The Dispersal of Dense Water Formed in a Coastal Polynya on a Shallow Sloping Shelf

This study examines the dispersal of dense water formed in an idealized coastal polynya on a sloping shelf in the absence of ambient circulation and stratification. Both numerical and laboratory experiments reveal two separate bottom pathways for the dense water: an offshore plume moving downslope into deeper ambient water and a coastal current flowing in the direction of Kelvin Wave propagation. Scaling analysis shows that the velocity of the offshore plume is proportional not only to the reduced gravity, bottom slope, and inverse of the Coriolis parameter, but also to the ratio of the dense water depth to total water depth. The dense water coastal current is generated by the along-shelf baroclinic pressure gradient. Its dynamics can be separated into two stages: i) near the source region where viscous terms are negligible, its speed is proportional to the reduced gravity wave speed; ii) in the far field where bottom drag becomes important and balances the pressure gradient, the velocity is proportional to H_c[g'/(LC_d)]1/2 , where H_c is the water depth at the coast, g' the reduced gravity, C_d the quadratic bottom drag coefficient, and L the along-shelf span of the baroclinic pressure gradient. The velocity scalings are verified using numerical and laboratory sensitivity experiments. The numerical simulations suggest that only 3-23% of the dense water enters the coastal pathway, and the percentage depends highly on the ratio of the velocities of the offshore and coastal plumes. This makes the velocity ratio potentially useful for observational studies to assess the amount of dense water formed in coastal polynyas.

Z.

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Long-term Variability of the Canadian Arctic Archipelago Outflow and Its Impacts on the Arctic Basin-Scale Circulation

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A high-resolution, unstructured-grid, fully ice-current coupled Arctic Ocean Finite-Volume Community Ocean model (AO-FVCOM) was developed and used to hindcast the ice and ocean flow fields in the Arctic over the period 1978-2013. The model results were validated via direct transport measurements taken across Davis Strait over the period 2004-2010. Built on reasonable agreement between the model-predicted and observed volume transports, we have examined the physical mechanisms that control the seasonal and interannual variability of the Canadian Arctic Archipelago (CAA) outflow. Davis Strait is the gateway of the CAA outflow originating from the three main sources: Nares Strait, Lancaster Sound and Jones Sound. The interannual variability of the volume flux in Davis Strait was highly correlated and in the same phase with fluxes outflowing from Nares Strait, Lancaster Sound and Jones Sound, which is controlled not only by the along-strait sea surface height (SSH) gradient, but also by the cross-strait SSH gradient. The impact of the atmospherically driven basin-scale variability in the Arctic on the CAA outflow was also examined, which was approached by driving AO-FVCOM with three available large-scale atmospheric (CORE-v2, NCEP and ECMWF) plus high-resolution meso-scale MM5 wind fields, respectively. The results showed that the CAA flux is negatively correlated with the sea level pressure over the Arctic Basin. In addition to the basin-scale wind variability, the land-sea induced local wind in individual straits of the CAA could also influence the through-strait water transport. Davis Strait could be an indicator to evaluate the basin-scale responses of the Arctic to the atmospheric forcing, since the change of the flux through Davis Strait directly influenced the net flux through Fram Strait.

Z.

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Structure and Dynamics of the Mesoscale Eddy Field in the Arctic Ocean's Halocline

Ice-Tethered Profilers (ITP), deployed in the Arctic Ocean between 2004 and 2013, have provided detailed temperature and salinity measurements of an extensive collection of halocline eddies. 127 mesoscale eddies have been detected, 95% of which were anticyclones. The majority of the anticyclones had anomalously cold cores. These cold-core anticyclonic eddies were concentrated in the Beaufort Gyre region (Canadian water eddies) and the vicinity of Transpolar Drift Stream (Eurasian water eddies) although with some bias based on the distribution of ITP profiles. An Arctic-wide calculation of the first baroclinic Rossby deformation radius Rd has been made using ITP data coupled with climatology; Rd ~ 13 km in the Canadian water and ~ 8 km in the Eurasian water. The observed eddies are found to have comparable horizontal scales. Halocline eddies are in cyclogeostrophic balance and can be described by a Rankine Vortex with maximum azimuthal speeds between around 0.05 and 0.4 m/s. The relationship between radius and thickness for the eddies is consistent with adjustment to the ambient stratification. Eddies can be divided into four groups, each characterized by distinct core depths and core temperature and salinity properties, suggesting multiple source regions and enabling the assessment of various formation mechanisms.