Assessing melt season characterizes in the Community Earth System Model Large Ensemble

Climate models in CMIP3 and CMIP5 show a large spread in their simulated Arctic sea ice cover, with large mean biases of the sea ice cover in many models. Among other factors, this could be a result of too short simulated melt season lengths. However, there are multiple possible definitions for the day of sea ice melt and freeze onset in climate models, and none of them exactly correspond to the brightness-temperature based melt and freeze onset definitions used for satellite retrievals. This makes the comparison of climate model output to satellite data challenging, as different definitions can bracket the satellite derived melt season dates. To assess the influence of various melt and freeze onset definitions, we compare data from the Community Earth System Model Large Ensemble (available for 1920-2100) to passive microwave-derived melt onset/freeze updates (available for 1979-2013). Melt onset definitions for the Large Ensemble are derived from thermodynamic volume tendency, snowmelt, and change in snow thickness, while freeze up definitions are derived from thermodynamic volume tendency, frazil ice growth, and congelation ice growth. By determining which definitions for melt and freeze onset produce results most similar to satellite data, we will have a fuller picture of any changes in model processes necessary to accurately represent the length of the melt season. By improving our understanding of different melt season definitions and the influence of internal variability in models compared to satellite data, this analysis will also be useful in assessing the upcoming CMIP6 simulations for melt season biases.
We present results from the model tracer release experiment in the two 4 km-resolution models, NEMO and HYCOM. The experiment is designed to examine North Atlantic water (NAW) inflow in the Arctic Ocean in the models with the “eddying” capability and investigate the role of the eddy dynamics on the NAW spread and trough the Barents Sea and Arctic Ocean interior. The NAW tracers have been released within the principal known pathways: across the Greenland-Scotland Ridge, in the eastern Fram Strait and in the western Barents Sea and tracked off-line for the period 2000-2015 using the 5-day averaged model velocity fields. The model results show that downstream from Fram Strait NAW is advected eastwards along the Siberian continental shelf slopes within the Arctic Circumpolar Boundary Current (ACBC) but also extends from the shelf slopes into the Nansen and Amundsen basins interior, with the eddy transport being a principal mechanism for the spread. We investigate cascading of the dense northern Barents Sea water into the deep Arctic Ocean, another mechanism to transport the modified NAW into the deep Arctic Ocean. From comparing the eddying runs with the companion runs at a lower non-eddying resolution, we assert the differences in the NAW model dynamics at low and high resolutions and argue for a need in the eddy resolving simulations to accurately represent the NAW.
Recent Improvements in the U.S. Navy’s Ice Modeling Using Blended CryoSat-2/SMOS Ice Thickness

The U.S. Navy’s Arctic Cap Nowcast/Forecast System (ACNFS) is composed of the Community Ice CodE (CICE) coupled to the HYbrid Community Ocean Model (HYCOM). The system assimilates ocean and ice observations including ice concentration from the Advanced Microwave Scanning Radiometer 2 (AMSR2), Special Sensor Microwave Imager Sounder (SSMIS) and ice edge data from the National Ice Center’s Interactive Multisensor Snow and Ice Mapping System (IMS). In this study, we perform a series of experiments in which the ACNFS is initialized with a blended ice thickness field from CryoSat-2 and the Soil Moisture and Ocean Salinity (SMOS) Missions. CryoSat-2 produces a sea ice thickness product which is more accurate for thicknesses greater than 0.5 m while SMOS ice thickness is best for thicknesses less than 0.5 m. The experiments begin in March 2014 and continue through September 2015. ACNFS ice thickness is compared against NASA IceBridge, WHOI Upward Looking Sonar, and Cold Region Research Engineering Laboratory (CRREL) ice mass balance buoy data. Preliminary results show significantly reduced ice thickness biases using this blended technique.
Variability in Circulation and Hydrographic Structures in the Denmark Strait

Authors: Almansi M., T. Haine, R. Gelderloos, M. Magaldi, D. Mastropole

Results from a 12 month (from September 2007 to September 2008) high-resolution numerical simulation of the Irminger and Iceland Seas and adjacent Greenland shelf are presented. The model domain has been extended with respect to a previous version of this model to include the whole Iceland Sea in the north as well as Cape Farewell in the southwest. Moreover, surface runoff and solid ice discharge from the Greenland Ice Sheet are now an integral part of the model forcing. Our analysis focuses on the Latrabjarg hydrographic section across Denmark Strait. The model density at this section shows good agreement with a composite of hydrographic sections over a 20-year period. Temperature and salinity structures in our model are also similar to the structures identified from observations, although the model temperature values are slightly lower and the salinity values slightly higher. These biases can be due to interannual variability, as previous studies showed evidence of cooling of the overflow and increased salinity in the modeled period. Furthermore, we compared the size, location and hydrographic properties of weakly stratified ‘boluses’ of dense water found in our model simulation with in situ observations of these features. Our analysis has been performed following the process explained in Mastropole et al. (submitted). Estimating the true annual average hydrographic section we found that mean fields obtained using the uneven observational sampling process are consistent.

References:
Armitage, Tom: University College London, t.armitage@ucl.ac.uk

Arctic Ocean geostrophic circulation and eddy kinetic energy 2003-2014

We present a 12-year record of geostrophic currents in the ice-covered and ice-free Arctic Ocean derived from Envisat and CryoSat-2 radar altimetry and examine their seasonal to decadal variability. Geostrophic currents across the Arctic Ocean increased in the late 2000s and, in particular, the Beaufort gyre circulation accelerated significantly in autumn 2007. At this time, the Beaufort Sea saw strong and persistent anticyclonic atmospheric circulation anomalies, a record low sea ice extent and an associated dramatic loss of multiyear sea ice, and a consequently thinner and more mobile autumn ice pack. These factors combined to bring about high ocean surface stress, strong Ekman convergence, and anomalously strong geostrophic current speeds in the south-eastern Beaufort Sea in the period 2003 to 2014. Current speeds in the south-eastern Beaufort Sea remained higher until 2011, after which they decreased to speeds representative of the period 2003-2006. Meanwhile, there was an almost three-fold increase in the westward current at the western periphery of the Beaufort gyre between 2003 and 2014. This likely played a more important role in advecting old ice from the southern Beaufort Sea to the Siberian shelf seas where it is more easily melted in summer compared to ice that is re-circulated in the Beaufort gyre. The southward current through Fram Start increased between 2003 and 2012 before slowing somewhat by the end of the time period. Seasonal fields of eddy kinetic energy, calculated from the geostrophic current speed variance, reveal high eddy activity congruent with the Chukchi plateau and Northwind Ridge formations. Both the Beaufort gyre circulation and the southward current through Fram Strait are strongest in autumn and winter, modulated by the seasonal strength of the Beaufort Sea high and Icelandic low pressure systems. Our results point to a variable and changing role of ocean currents in the coupled sea ice-ocean momentum balance.
On Anomalous Ocean Heat Transport toward the Arctic and Associated Climate Predictability

It is commonly understood that the potential for skillful climate prediction resides in the ocean. The observed poleward propagation of ocean temperature anomalies in the North Atlantic Ocean has in particular been suggested as a primary source for predictability. Here the propagation and drivers of ocean heat anomalies with the Atlantic thermohaline circulation’s northernmost limb and their interaction with the atmosphere and Arctic sea ice cover are assessed from observations and a multi-century climate model simulation. We show that variations in ocean temperature in the high latitude North Atlantic and Nordic Seas are reflected in the climate of Northern Europe as well as in winter Arctic sea ice extent. Rooted in the persistent poleward propagation of heat anomalies we show that the winter Arctic sea ice extent can be skillfully predicted with a forecast horizon of ten years.
The relationship between double-diffusive intrusions and staircases in the Arctic Ocean

The origin of double-diffusive staircases in the Arctic Ocean is investigated for the particular background setting in which both temperature and salinity increase with depth. Motivated by observations that show the co-existence of interleaving thermohaline intrusions and double-diffusive staircases, a linear stability analysis is performed on the governing equations to determine the conditions under which staircases form. It is shown that a double-diffusive staircase can result from interleaving motions if the observed bulk vertical density ratio is below a critical vertical density ratio estimated for particular lateral and vertical background temperature and salinity gradients. Vertical temperature and salinity gradients dominate over horizontal gradients in determining whether staircases form. Theoretical predictions for conditions under which a staircase is the end result of a perturbation (or alternatively, intrusions) are consistent with Arctic Ocean observations that show a range of staircase and intrusion structures.
Splitting of Atlantic water transport towards the Arctic Ocean into the Fram Strait and Barents Sea Branches - mechanisms and consequences

The heat content in the Arctic Ocean is to a large extent determined by oceanic advection from the south. During the last two decades the extraordinary warm Atlantic water (AW) has been reported to progress from the North Atlantic into the Arctic Ocean. On their way northward warm anomalies can further modified by a reduced/increased heat loss in the Nordic Seas and variable strength of oceanic advection. But the ultimate fate of warm anomalies of Atlantic origin depends strongly on their two possible pathways towards the Arctic Ocean. When AW passes through the shallow Barents Sea, nearly all its heat is lost due to atmospheric cooling and AW loses its signature. In the deep Fram Strait AW preserves its warm core as its upper part becomes transformed into a less saline and colder surface layer. A significant warming and strongly variable transport was observed in two recent decades in the AW inflow through Fram Strait, which carries between 26 and 50 TW of heat into the Arctic Ocean. While the oceanic heat influx to the Barents Sea is of a similar order, the heat leaving it through the northern exit into the Arctic Ocean is negligible.

The relative strength of two Atlantic water branches through Fram Strait and the Barents Sea governs the oceanic heat transport into the Arctic Ocean. The AW flow in the Barents Sea Branch is controlled by the strength of atmospheric low over the northern Barents Sea while AW transport in the Fram Strait Branch is mainly forced by the large-scale low-pressure system over the eastern Norwegian and Greenland seas. Long-term moored observations in the Barents Sea Opening and the northern Fram Strait reveal that AW transport in both branches vary with the opposite phase on the inter-annual time scale. In the periods of weaker Atlantic water flow in the shelf break current the increased transport in the Barents Sea Branch can also further weaken the Fram Strait Branch. The anomalously warm AW inflow in the Fram Strait Branch has a strong impact on sea ice conditions in the southern Nansen Basin, while positive transport anomalies in the Barents Sea Branch increase availability of oceanic heat in the Barents Sea and subsequently influence its sea ice cover. Here we present the results of the Polish-Norwegian project PAVE, focused on variability of the Atlantic Water inflow through Fram Strait and the Barents Sea, and mechanisms that govern the AW split between both branches.
Blanchard-Wrigglesworth, Edward: University of Washington, ed@atmos.washington.edu

Stability of polar atmospheric teleconnections in dynamical models

Recent observational studies have shown various patterns of atmospheric teleconnection of seasonal circulation anomalies between the poles and regions further afield, ranging from the sub-polar and mid-latitude regions to the tropics. These atmospheric teleconnection patterns have been evoked as links to explain observed co-variability between various surface climate variables in different regions, such as Arctic sea ice and tropical Pacific SSTs or northern hemisphere winter conditions, yet their study is constrained by the limited duration of the observational record, particularly in the high latitudes. In this work we assess the presence and stability of regimes of atmospheric teleconnection patterns that originate both in the poles and tropics in long control runs of dynamical models and in the CESM Large Ensemble. We find a rich spectrum of variability in the strength of teleconnection patterns, with decadal periods of strong Arctic – tropical teleconnections interspersed with decadal periods of weak or no teleconnections, while southern hemisphere – tropical teleconnections tend to be more robust. Furthermore, teleconnection patterns only stabilize when centennial or longer time-periods are used for their calculation. To the extent that such behavior is realistic, we discuss the implications our results have for the use of statistical models in seasonal forecasts and in the detection and attribution of observed changes in co-variability.
The impact of initialization & data assimilation on sea ice forecasts within the Met Office's coupled seasonal prediction system.

Seasonal predictions at the Met Office are made using the GloSea5 coupled forecasting system which is run daily out to 210 days using the NEMO ocean and CICE sea ice models at 1/4 degree global resolution. The ocean and sea ice components of GloSea are initialised using analysis fields from the FOAM ocean-sea ice analysis and forecast system. Satellite and in-situ observations of temperature, salinity, sea level anomaly and sea ice concentration are assimilated by FOAM using the NEMOVAR 3D-Var data assimilation scheme.

Here we present details recent work focussed on understanding initialisation shock and factors affecting sea ice forecast skill in GloSea performed using initialised coupled forecasts. A number of structural differences and inconsistencies between the coupled GloSea and forced FOAM models are identified and their impacts assessed. Details of experiments designed to better understand the impact of assumptions made within the sea ice data assimilation are also presented. The sensitivity of coupled model forecasts to the initialisation of quantities that are currently not assimilated within FOAM such as sea ice thickness and snow depth is also explored. In particular, results from recent trials that assimilate sea ice thickness data derived from satellite altimetry (CryoSat-2) will be provided.
Do viscous-plastic sea-ice models need more shear strength?

High resolution sea-ice dynamic models offer the potential to study the ability of sea-ice rheologies to reproduce satellite-derived deformation fields. Recent studies have confirmed that the viscous-plastic (VP) models with an elliptical yield curve are able to reproduce similar spatial scaling of deformations as what is obtained with the RADARSAT Geophysical Processor System (RGPS) satellite observations. On the other hand, the elliptical VP model doesn't reproduce the large shear and divergence deformations found in the RGPS observations. Here, we explore the sensitivity of the VP model's deformation fields with an elliptical yield curve to changes in the ice compressive and shear strengths to understand what sets the modeled deformation distributions. It appears that the ellipse aspect ratio 'e' (ratio of compressive to shear strength) ultimately controls the deformation distributions properties. We show that a larger ratio of shear to divergence (smaller 'e') is needed to achieve the large shear and divergence deformations that are found in satellite observations. We also further investigate the effects of adding isotropic tensile strength on the deformation fields. It is not clear yet if the elliptical rheology can be calibrated to simultaneously yield accurate drift, mass, and deformation fields, but understanding how the modeled deformations fields respond to changes in mechanical strength can help us understand sea ice's plastic behavior and further improve new proposed rheologies.
Sea ice age as a predictor for the minimum sea ice extent

The present project considers the use of sea ice age as a predictor for minimum sea ice extent on a pan-Arctic scale, following a method proposed by Russian scientists A.J. Nikolaeva and N.P. Sesterikov in the late 60’s. Sea ice concentration observations and velocity products are used. Starting from September sea ice conditions, a forward Lagrangian method is employed to track the ice displacement until the end of May. Every month, newly formed ice is identified. New ice forms as polynyas, resulting from coastal divergence, freeze-up during winter. Age is defined as the number of months prior to the end of May at which the freeze-up occurs. A map is obtained at the end of the tracking period, showing regions of October-formed ice, November-formed ice, and so on. To first-order, older ice is assumed thicker and more likely to survive the melt season than younger ice. Nikolaeva and Sesterikov, in a regional study for the Laptev sea, found that sea ice formed after February 1st had usually melted by the end of August. February-formed ice can grow to a thickness of ~1 to ~1.5m, which is in the same range as the amount of melting during the summer. One of the goals of this project is to re-evaluate, for modern sea ice conditions, the freeze-up threshold for which sea ice is likely to survive the summer, and use it as a minimum extent predictor. Another objective is to assess the differences between Arctic peripheral seas. The skill is expected to be good for seas whose sea ice dynamics are dominated by coastal divergence (e.g.: Laptev), and is expected to be less for seas where both divergence and convergence are important (e.g.: Beaufort).
Summer enhancement of Arctic sea-ice volume anomalies in the September-ice zone

Due to its persistence on seasonal timescales, Arctic sea-ice thickness (SIT) is a potential source of predictability for summer sea-ice extent (SIE). New satellite observations of SIT represent an opportunity to harness this potential predictability via improved thickness initialization in seasonal forecast systems. In this work, the evolution of Arctic sea-ice volume anomalies is studied using a 700-year control integration and a suite of initialized ensemble forecasts from a fully-coupled global climate model. Our analysis is focused on the September sea-ice zone, as this is the region where thickness anomalies have the potential to impact the SIE minimum. The primary finding of this work is that, in addition to a general decay with time, sea-ice volume anomalies display a summer enhancement, in which anomalies tend to grow between the months of May and July. This summer enhancement is relatively symmetric for positive and negative volume anomalies and peaks in July regardless of the initial month. Analysis of the surface energy budget reveals that the summer volume anomaly enhancement is driven by a positive feedback between the SIT state and the surface albedo. The SIT state affects surface albedo through changes in the melt onset date, snow coverage, ice-thickness distribution, and sea-ice concentration field, yielding an anomaly in the total absorbed shortwave radiation between May and August, which enhances the existing SIT anomaly. This phenomenon highlights the crucial importance of accurate SIT initialization and representation of ice-albedo feedback processes in seasonal forecast systems.
Variability of the Arctic ocean/sea ice system in SODA3

We present results from a new version of the SODA ocean reanalysis, version 3. The model is a 1/4degx1/4degx50 level version of GFDL MOM5, similar to the ocean component of the CM2.5 coupled model. In the Arctic the grid is tripolar so that the grid spacing at Fram Strait, for example, is a few km. Nearsurface vertical resolution is 10m. Active sea ice is provided by GFDL SISv1. Assimilated observations include those contained in the hydrographic archives of the World Ocean Database 2013 augmented by in situ and satellite SST. Surface forcing for two separate 36-year experiments spanning 1980-2015 (SODA3.3 and SODA3.4) is provided by the NASA MERRA2 and the ECMWF ERA-int reanalyses. The analyses are being saved at native resolution as well as remapped onto a uniform 1/2degx1/2degx50 level grid at 5dy intervals and have also been remapped onto isopycnal surfaces. All of this should be publicly available by the time of this presentation. The first part of the presentation will cover comparisons to the transport estimates at the straits, comparisons of the seasonal cycle of ocean and sea ice variables to other climatologies such as PHC3.0, and to the ITP records, much of which has not yet been included in WOD 2013. The second part of the presentation will examine interannual variability of water masses as they appear in SODA3, and the differences in the variability due to the choice of different meteorological forcings.
Arctic Ice algae distribution as function of large scale sea ice variables

One of the most pronounced impacts of climate change is the declining sea ice cover in the Arctic Ocean, which has implications for sea-ice associated ecosystems that are strongly dependent on carbon produced by ice algae. In order to understand these ecosystems there is a need to understand the interaction between the physical and biological components of sea ice. Our current understanding of Arctic sea ice algae is based on observations with limited spatial coverage. Therefore, we aim to model the spatial distribution of ice-algae on a basin scale. Current sea-ice-ocean models do allow the representation of sea-ice variability on a scale of few km. Large scale characteristics of sea ice such as age, deformation, and snow cover, do affect the small scale ice properties, such as salinity, porosity, light transmission. The latter directly affect the sea ice algae content, but to what extent is not yet well understood. In this work we present a new parameterization for the sea-ice algae content developed with the aim to model the algae content and variability based on large scale sea-ice characteristics. Particular attention is given to ridges, since they represent a potential algae growth site. The distinction between ridges-associated algae and level ice-associated algae is the novelty of such work. The developed parameterization is tuned with data collected during a ship-based campaign to the Eastern Central Arctic in summer 2012. Sea-ice thickness and under-ice spectral surveys over different sea ice regimes were conducted with a Surface and Under Ice Trawl (SUIT) and a Remote Operated Vehicle (ROV). In addition, ice cores were extracted at several sites for chl a analysis. We use a coupled sea-ice-ocean model (MITgcm) with a spatial scale of ~25 km and we show here the results for the temporal evolution of algae content in sea ice over the year 2012, with distinction between ridges-associated algae and level ice-associated algae.
Castellani, Giulia: Alfred Wegener Institute (AWI), giulia.castellani@awi.de

Sea-ice drag as function of deformation and ice cover: Effects on simulated sea ice and ocean circulation in the Arctic

Many state-of-the-art coupled sea ice-ocean models use atmospheric and oceanic drag coefficients that are at best a function of the atmospheric stability but otherwise constant in time and space. Since observations of turbulent fluxes imply high variability of drag coefficients, constant drag coefficients might lead to an incorrect representation of the ice-air and ice-ocean momentum exchange. We compare two model runs, one with constant drag coefficients and one with drag coefficients varying as function of ice concentration and deformation. The main sea ice parameters, that are ice concentration, thickness and drift, are affected. In particular, the ice moves faster with variable drag coefficients and this leads to a stronger Beaufort Gyre and to a stronger Transpolar Drift Stream. Large changes in thickness are seen in the Lincoln Sea, from where more ice is removed and exported through the Fram Strait due to higher atmospheric drag coefficients, leading also to a larger export of sea ice. The ocean is also affected by the implementation of variable drag coefficients. The mixed layer is deeper and the stream function shows a clearer anticyclonic pattern in the Beaufort Sea. The stronger Beaufort Gyre increases the downwelling in the central Beaufort Sea which leads to a depression of the 34 isohaline. Effects reach the Atlantic Water with slower anticyclonic circulation in the Makarov and Nansen Basins.
Spatial and temporal variability of internal waves and their effect on mixing in the Canadian Arctic

Mixing in the Arctic Ocean is integral to understanding a variety of physical processes such as the transport of mass, heat, salt and biogeochemical tracers, sea ice melt, and the large-scale circulation. In particular, there has recently been great interest in quantifying the energy available in mesoscale, submesoscale and wave-scale motions that may ultimately drive turbulent mixing. While a comprehensive survey of the spatial and temporal variability of the energy spectra of the circulation across the Canadian Arctic has not yet been done, there exists a wealth of finescale vertical density profiles collected from Arctic expeditions over the last two decades that makes this endeavour possible. We aim to use this data to examine observed strain profiles in the region and map the potential energies that characterize the internal wave field as a function of space and time. The driving forces behind these patterns are investigated to assess the links to bathymetry, tidal energy, and wind forcing. The energy spectra will further be used to estimate vertical diffusivity rates. Our work is still in its very preliminary stages, and as such we invite feedback on our project plans and early results. We believe the large scope of the analysis, involving over 4200 CTD profiles spanning 15 years and distributed throughout the Canadian Arctic, provides the opportunity for an improved understanding of the internal wave field energetics and mixing patterns that exist in the region. Further, the large scope promises greater insight into the underpinning mechanisms that drive spatial and temporal variability.
Mooring and Ice-Tethered Profiler observations from the last decade are used to investigate horizontal stirring and eddy diffusivity in the Arctic Ocean. A decade of mooring observations from the BGOS program are used to estimate a representative depth profile of horizontal eddy diffusivity at 100 km horizontal scales for the Beaufort Gyre and Canada Basin. Eddy diffusivity decays with depth in the upper 300 m, and is spatially variable with elevated values near the basin boundaries. Ice-Tethered Profilers show signals of horizontal stirring on a range of scales from 1-100 km and over a broader region of the Arctic Ocean. The Canadian and Eurasian basins are compared, as well as data near and away from the basin boundaries. Horizontal stirring in the Arctic Ocean is active on a range of horizontal scales. These investigations into horizontal stirring and eddy diffusivity advance our understanding of key processes and parameters important to numerical modeling efforts.
Systematic improvements in Arctic atmospheric reanalyses: Progress and prospects

In May 2015, the Inter-agency Arctic Research Policy Committee (IARPC) organized a panel appointed by NOAA and NASA with a focus on Arctic atmospheric reanalyses. The charge was to:

• Evaluate the state, utilization, limitations and potential utility of the current Arctic reanalyses;
• Inventory and assess the currently planned operational and experimental observations of the Arctic system to improve reanalyses;
• Examine reanalyses products and forecast models for potential improvement; and
• Assess the potential utility of YOPP and CMIP6 as focal points to facilitate progress.

Here, I briefly summarize the results presented in the white paper on Systematic Improvements of Reanalyses in the Arctic (SIRTA). Reanalyses are retrospective, gridded depictions of the atmosphere that are generated through a statistical adjustment of a prior, short-term numerical forecast to observations. The Arctic region is particularly challenging for reanalyses because of issues with both the limited available observing network and with short-term numerical forecasts. With the presence of a frozen ocean surface, the Arctic has a paucity of in situ observations. Additionally, both infrared and microwave satellite sensors have difficulty in profiling the lower atmosphere over snow- and ice-covered surfaces, and geostationary satellites do not cover the high latitudes. Because of the reliance on a limited observing system, abrupt changes in its coverage can produce artificial discontinuities in reanalysis time series. Numerical forecast models have difficulty with Arctic physical processes. This is especially true of the treatment of moisture, including clouds and precipitation. Varied surface properties over the polar ocean, glaciated land surfaces, and non-glaciated terrestrial zones are also difficult to represent. Nevertheless reanalyses continue to be used for Arctic research – in spite of known shortcoming – because of their consistent format in time and space, and because the information they provide cannot be easily obtained from other sources. I briefly review the composition of the Arctic observing system, current areas of development for atmospheric reanalyses, and identified areas for potential improvement.
Dansereau, Véronique: CNRS, France, veronique.dansereau@univ-grenoble-alpes.fr

A Maxwell-Elasto-Brittle model for the drift and deformation of sea ice

In recent years, the viscous hypothesis and other underlying physical assumptions of the viscous-plastic (VP) rheology widely used in current climate and operational models have been revisited and found to be inconsistent with the observed mechanical behaviour of sea ice. Other studies have suggested that while the VP model can represent the mean global drift of sea ice with a certain level of accuracy, it fails at reproducing some key observed properties of sea ice deformation. Other studies have suggested that while the VP model can represent the mean global drift of sea ice with a certain level of accuracy, it fails at reproducing some key observed properties of sea ice deformation. We developed a new mechanical model, named Maxwell-Elasto-Brittle, as an alternative to the VP rheology in the view of accurately reproducing the drift and deformation of the ice cover in continuum sea ice models. The model builds on a damage mechanics framework used for ice and rocks. A viscous-like relaxation term is added to a linear-elastic constitutive relationship together with an effective viscosity that evolves with the local level of damage of the material, like its elastic modulus. This framework allows the internal stress to dissipate in large, permanent deformations along faults, or leads, once the material is highly damaged, while reproducing the small deformations associated with the fracturing process and retaining the memory of elastic deformations over relatively low damage areas. A healing mechanism counterbalances the effects of damaging over large time scales.

Idealized simulations have confirmed that the Maxwell-EB model reproduces the important characteristics of sea ice mechanics revealed by the analyses of available ice buoy and satellite data: the anisotropy of the deformation, the strain localization and intermittency, as well as the associated scaling laws. Sensitivity analyses have shown that the model, with few independent variables, can represent a large range of mechanical behaviours, with both the persistence of creeping leads and the activation of new leads with different shapes and orientations.

Realistic simulations will be presented. Simulations of the flow of ice through Nares Strait will demonstrate that the model reproduces the formation of stable ice bridges as well as the stoppage of the flow, a common phenomenon within numerous channels of the Arctic. In agreement with observations, the propagation of damage along narrow arch-like kinematic features, the discontinuities in the velocity field across these features, defining floes, and the eventual opening of polynyas downstream of the Strait are all represented.
Real-Time Observations and Thermodynamic Sea-Ice Modelling from the Cambridge Bay Observatory

In 2012, Ocean Networks Canada installed a cabled ocean observatory in Cambridge Bay, Nunavut. The shallow water system includes a shore-based weather station and in-water sensors to monitor the coastal marine conditions in 6-8m of water. Servicing of the observatory each summer has resulted in a near continuous record of the marine conditions over 4 years. The data include standard meteorological measurements (air temperature, wind speed and direction, and solar radiation), and near bottom measurements of seawater temperature, salinity, dissolved Oxygen, and ice draft thickness. A thermodynamic sea-ice model has been developed to test various sea-ice thermodynamic formulations forced by the real-time observations and weather forecasts. The goals are to enhance the model’s skill to better predict the dates of both freeze-up and break-up. These critical periods often limit safe transportation on the ice and in the marine environment and are likely to evolve dramatically under the influence of climate change.
Area changes and the influence factors of Terra Nova Bay Polynya from 2004 to 2015

Terra Nova Bay Polynya (TNBP) plays an important role in mass circulation between ocean and atmospheric. The distribution of sea ice in TNB directly influences the area of the polynya. According to this, we observed the area changes of TNBP in winter from 2004 to 2015 using AMSR-E and AMSR2 data. Here we extracted the area extent and defined the open water time by using the sea ice concentration data and by estimating the junction with the north of Drygalski Ice Tongue and the south of Cape Washington. The results show that, in the early years (2004-2010), TNBP tends to be more expansive and violate; however, it gradually becomes relatively stable and the mean area also decreases in the late years(2011-2015). The area of TNBP has a distinct seasonal nature, which is significantly decreased from June to September, along with the temperature becoming lower. The maximum area is nearly 8800 km², which usually appears in the primary and end growth of sea ice, like early March and late November. The minimum area is 0 km², which means TNBP can be completely covered by the thick sea ice(sea ice concentration over than 70%). Meanwhile, the surrounding glaciers, such as Priestley Glacier and Reeves Glacier, strengthen the katabatic from the Antarctic inland, which result to the frequent fluctuations of area during the whole observing time. The three major influence factors are the strong katabatic wind from the glaciers, the blocking function on the sea ice from the south by Drygalski Ice tongue and the generated new sea ice under lower temperature. We also analysis the relationship between area changes of TNBP and the meteorological data from the nearby automatic weather stations, such as temperature and wind speed data. In the future, my work will be focused on the ice production and heat flux in Terra Nova Bay, which is aiming at optimizing the heat flux result by the estimation of ice production.
**Circulation and mixing in the deep Canada Basin**

The deep and bottom waters in the Canada Basin exhibit a complex and slowly evolving temperature and salinity structure, influenced by geothermal heating from below, and lateral and vertical diffusive fluxes from above. In the bottom ~1000m of the water column, properties are actively mixed by rotationally controlled thermal convective plumes driven by geothermal heating. Above the bottom water, a series of double-diffusive layers form at the base of a 500-1000m thick layer of cooler water inflowing from the Eurasian Basin. Unlike the bottom layer, which has previously been shown to warm at a rate consistent with geothermal heating, warming of these inflowing waters is consistent with increased downward heat flux from the Atlantic Water above; in particular, fluxes from the Barents Sea Branch of the Atlantic Water, which penetrates the Canada Basin as double-diffusive intrusions. The fundamental physical processes driving the temporal and spatial evolution of deep water masses are investigated using geophysical theory constrained by repeat hydrographic measurements from the Canada Basin between 2003 and 2015. Inferred vertical fluxes and large-scale lateral circulation are used to estimate diffusivity of heat and salt, and provide a comprehensive view of the dynamics of this considerable portion of the Arctic Ocean water column.
Duarte, Pedro: Norwegian Polar Institute, Pedro.Duarte@npolar.no

Sea ice thermo-, halo-dynamics and biogeochemistry during the Norwegian Young Sea Ice cruise (N-ICE2015) in the Arctic Ocean: empirical and modeling results at small spatial and temporal scales


The sea ice cover north of Svalbard (80-83°N), was studied from January to June 2015, during the N-ICE2015 expedition. The main goal was to improve the understanding of the energy budget of the Arctic Ocean, the sea ice mass balance and the seasonal dynamics of the ice-associated ecosystem under the new ice regime, dominated by first-year ice. The atmosphere, the sea water and four different ice floes were monitored, including different types of ice: multiyear, first year ice and a refrozen lead. Among other things, observations included: a meteorological station, oceanographic measurements, ice and snow coring, sampling by scuba divers, usage of a remote operated vehicle and of sensors deployed underneath the ice. Several physical, chemical and biological variables were measured in the atmosphere, the sea ice and the sea water, including: air temperature, relative humidity and wind speed, incident and under-ice short and longwave radiation, snow and ice thickness, seawater and sea-ice temperature and salinity, organic particulates, nutrient and chlorophyll concentrations, and abundance of ice algae and ice fauna. Sea ice cores were cut in 10 cm sections. Therefore, sampled variables were vertically resolved in the ice. Data was used to force the Los Alamos Sea Ice Model (CICE) and evaluate its capacity to reproduce the physical and biogeochemical changes observed in some of the ice types monitored during the cruise, over time scales of ~1 month. The 1D vertical version of CICE was used, coupling thermodynamic with vertically resolved biogeochemical processes. Various model setups were tested, including different halodynamic schemes, different sea surface forcing setups, based on heat fluxes across the mixed layer, and different biogeochemical submodels, by using CICE biogeochemistry or coupling CICE with the ecosystem modelling software EcoDynamo. Model results were used to close the ice energy and nitrogen budgets and to get insight into the most critical aspects to properly forecast sea ice halo- thermo- and biogeochemical dynamics. The ultimate goal of this study is to contribute with improved parameterizations of pan-arctic coupled physical-biogeochemical models.
Progress report on Greenland Freshwater experiments

Accelerating melting of the Greenland Ice Sheet leads to the increasing freshwater flux into the North Atlantic. It has been hypothesized that the surplus Greenland freshwater can spread and accumulate in the sub-Arctic seas influencing thermohaline processes there and through this impacting the climate in the region. In order to evaluate the influence of Greenland freshwater on thermohaline processes in the sub-Arctic seas, the pathways of Greenland freshwater need to be determined. In order to investigate the fate, pathways, and propagation rate of Greenland freshwater in the sub-Arctic seas, several numerical experiments using a passive tracer to track the spreading of Greenland freshwater have been conducted as a part of the Forum for Arctic Ocean Modeling and Observational Synthesis (FAMOS) effort. Three groups participating in the FAMOS project have run ocean-ice models with passive tracers released at the Greenland freshwater sources. The models used in the first set of experiments are from the Florida State University (AO-HYCOM), the University of Alberta (NEMO-LIM2), and the Institute of Computational Mathematics and Mathematical Geophysics (ICMMG). The simulations had different model forcing, spatial resolutions, vertical grid, and configurations. The only coordinated forcing was the Greenland freshwater flux data. In the model experiments, Greenland freshwater was tracked by a passive tracer released at the locations of Greenland freshwater sources. Results of the first set of experiments have demonstrated that Greenland freshwater propagates and accumulates in the sub-Arctic seas, although the models disagree on the amount of tracer propagation into the convective regions. Mechanisms of freshwater advection into the interior part of the convective sites have not been explained in the first set of experiments. Other questions that need further understanding are 1) What is the residence time of Greenland freshwater? 2) What is the vertical propagation of Greenland freshwater? 3) What is the influence of Greenland freshwater on the air-sea heat fluxes? 4) How well are the physical mechanisms involved in propagation and mixing of Greenland freshwater represented in the numerical models with different spatial resolution, vertical grid, and configuration. These and other questions have motivated the continuation of the Greenland freshwater coordinated experiments. The following modeling groups participate in the second set of the experiments: FSU (AO-HYCOM), the University of Alberta (NEMO-LIM2), ICMMG (ICMMG model), Southampton NOC (NEMO), LANL (POP/CICE). The description of the model experiment setup and status update from the modeling groups are provided.
Dukhovskoy, Dmitry Florida State University, ddukovskoy@fsu.edu

Comparison of the ocean surface vector winds from atmospheric reanalyses and scatterometer-based wind products over the North Atlantic

D.S. Dukhovskoy¹, M.A. Bourassa¹, J. Steffen¹, G. N. Petersen²

¹Florida State University, Tallahassee, USA
²Icelandic Meteorological Office

Ocean surface vector wind fields from reanalysis data sets and scatterometer-derived gridded products are analyzed over the subpolar North Atlantic for the time period from 2000 through 2009. The data sets include the reanalysis data of the National Center for Environmental Prediction Reanalysis 2 (NCEPR2), Climate Forecast System Reanalysis (CFSR), Arctic System Reanalysis (ASR) and satellite wind products Cross-Calibrated Multi-Platform (CCCMP) wind product version 1.1 and recently released version 2.0, and QuikSCAT. The goal of the study is to assess discrepancies across the wind vector fields in the data sets and demonstrate possible implication of these differences for ocean modeling. Large- and mesoscale characteristics of winds are compared at interannual, seasonal, and synoptic time scales. Cyclone tracking methodology is developed and applied to the wind fields to compare cyclone characteristics in the data sets. In general, the agreement among the wind data sets is better for longer time scales and larger spatial scales. The discrepancies start showing off for synoptic time scales and mesoscales. Both versions of CCCMP, ASR, and CFSR show the closest overall agreement with each other. Additionally, the wind vectors are evaluated against observations recorded at the Iceland Meteorological buoy deployed in the central Iceland Sea. The CCCMP wind fields have the best agreement with the Iceland buoy observations. Overall, the largest biases are found in the NCEPR2 winds. Numerical sensitivity experiments are conducted with a coupled ice-ocean model forced by different wind fields. The model experiments demonstrate noticeable differences in the net surface heat fluxes during storms. In the experiment forced by NCEPR2 winds, there are substantial discrepancies in thermohaline structure and wind-driven Sverdrup transport compared to the other experiments.
**Ellingsen, Ingrid**: SINTEF Fisheries and Aquaculture AS, Norway, Ingrid.Ellingsen@sintef.no

**Nutrient fluxes in the Arctic Ocean**

The Arctic Ocean (AO) will likely become ice-free in summer within the next two decades. This will change light conditions for primary production. Parts of the AO where primary production is presently light limited will be constrained also by nutrient availability in the future. It is therefore of interest to study horizontal and vertical transports of nutrients in the AO and to assess the relative importance of the different nutrient sources. We have used the coupled system SINMOD to quantify import and export of nutrients. Results are compared with estimates based on analysis of observational data. Vertical transport and mixing of nutrients in the Arctic are also quantified and the relative importance of the different processes is assessed.
Copepod biogeography in a changing Arctic environment

The Arctic marine environments have been undergoing dramatic changes in the past three decades, especially in terms of sea ice loss and ocean warming, which may modify the phenology of marine plankton and cause chain reactions to upper trophic levels. We seek to understand how the biogeographic distribution of an important endemic copepod species, Calanus glacialis, may respond to the decadal trend and inter-annual variability in sea ice, ocean temperature, and its phytoplankton prey (food). An Arctic copepod individual-based model that is coupled to an ice-ocean-ecosystem model is used to simulate temperature- and food-dependent life history development for C. glacialis annually from 1980 to 2014. The annual percentages of successfully diapausing C. glacialis individuals in the transitional zones between relatively lower latitude Arctic shelf seas and central Arctic basins dramatically increase over the 35-year period with a linear trend of +20% per decade. The increasing trend in C. glacialis diapausers can be largely explained by the lengthening growth season (during which food is available) and shortening critical development time (for C. glacialis maturing from the first feeding stage N3 to the diapausing stage C4). The changing life history development of C. glacialis can be linked to large scale processes, particularly diminishing sea ice and warming upper ocean temperature, and may have potential consequences to the entire Arctic shelf/slope marine ecosystem.
Fewings, Melanie, University of Connecticut, melanie.fewings@uconn.edu

Conditional Averaging of Satellite Ocean Vector Winds: An Analysis Technique with Potential for Use in the Arctic

Melanie R. Fewings and Kayla Flynn, Department of Marine Sciences, University of Connecticut

Libe Washburn and Christopher Gotschalk, Marine Science Institute and Department of Geography, University of California, Santa Barbara

Clive E. Dorman, Scripps Institution of Oceanography, University of California, San Diego

We present a successful case of the use of conditional averaging of satellite and reanalysis data to 1) reveal spatial coherence in synoptic wind fluctuations, 2) deduce the relevant atmospheric pressure forcing patterns, and 3) reveal the resulting sea-surface temperature anomalies and associated heat balance. The example presented here is for California, but is presented as a conversation piece to identify potential collaborators for future application of these methods in the Arctic.

Near Pt. Conception at the central/southern California border, in summer the prevailing upwelling-favorable winds episodically weaken. These wind relaxations cause oceanic flow reversals within ~20 km of the coast of central California, allowing warm water to flow poleward against the prevailing California Current. These warm flows affect larval transport and the thermal environment of intertidal species.

We used QuikSCAT satellite vector wind stress to study ~65 wind relaxations at Pt. Conception, California during summer 2000–2009. We identified the local wind relaxation times using NDBC buoys, and then the QuikSCAT wind stress fields allowed us to determine the offshore spatial extent of the wind anomalies for the first time. The wind relaxations near Pt. Conception extend ~600-1000 km offshore, similarly to the California-scale expansion fan that sets the scale of the prevailing winds. Using QuikSCAT wind anomalies and the North American Regional Reanalysis, we linked these central/southern California wind relaxations to a sequence of synoptic patterns already known to cause wind reversals off northern California and Oregon. The “northern” and “southern” wind relaxations turn out to be linked in an alternating pattern that affects the entire 1600-km West Coast of the continental United States. On average, the wind relaxes or reverses off Oregon 5–7 dy before the wind relaxes near Pt. Conception. Next, the upwelling-favorable wind intensifies along central California and Oregon over ~5 dy. Finally, the wind relaxes near Pt. Conception and the area of weakened winds extends to northern California over 3–5 dy. Using NARR atmospheric pressure anomalies, we linked this wind pattern to a previously described but rarer synoptic sequence involving mid-level ridging followed by offshore advection of the desert heat low.

Composited microwave satellite sea-surface temperature data indicate these wind relaxations also cause substantial sea-surface temperature anomalies up to ±1 degree C extending ~1000 km offshore. We calculated terms in a mixed-layer heat budget and found substantial differences between the air-sea heat flux during the northern vs. southern wind relaxations, due to differing responses of regional cloud cover during wind relaxation.
Frants, Marina: Naval Postgraduate School, mfrants@nps.edu

Coupling climate and biogeochemistry in the high-resolution Regional Arctic System Model

Arctic marine biogeochemistry (mBGC) is strongly coupled to and affected by the ocean and sea ice dynamics, yet coupled modeling of Arctic climate and biogeochemistry has been limited so far. This has been in part due to limited capabilities in representing sea ice mBGC, the upper ocean seasonal stratification, mesoscale processes and mixing as well as to computational requirements to represent such features and their realistic coupling. The Regional Arctic System Model (RASM) has been recently expanded with mBGC components both in the ocean and sea ice model components to address such limitations. In particular, the latest version of the Los Alamos National Laboratory sea ice model (CICE), the so called Column Package, including sophisticated representation of mBGC, has been implemented in RASM, in addition to the mBGC component addition in the Parallel Ocean Program (POP) of RASM.

We will summarize those mBGC additions in the sea ice and ocean components of RASM. Results from fully coupled simulations with ocean and sea ice components at 9-km horizontal resolution will discussed and compared against earlier results from the RASM simulations without the sea ice Column Package biogeochemistry. Water mass and nutrient distributions in the upper ocean will be presented and compared against observations and against several other coupled models. Finally, we will summarize near-term plans for RASM-mBGC simulations, including near eddy-resolving configurations of the ocean and sea ice components of RASM.
**Fujisaki-Manome, Ayumi: Climate & Space Sciences and Engineering, University of Michigan, ayumi.fujisaki@noaa.gov**

**Reconstructing Hydrographic Data and Salinity in the Chukchi and Eastern Siberian Seas: Simulation and Evaluation of Oceanic Analyses**

The recent international efforts of the Russian-American Long-term Census of the Arctic (RUSALCA) resulted in an increased accumulation of hydrographic data in the Chukchi and Eastern Siberian Seas, allowing us to evaluate existing oceanic analyses and new ice-ocean simulations in the model performance over the region. This study conducts ice-ocean coupled simulations for the entire Arctic Ocean using ICEPOM with 25 km horizontal resolution. ICEPOM is based on the Princeton Ocean Model and is coupled with an ice model, whose dynamic model employs the elastic-viscous-plastic rheology. The ice thermodynamics is based on the one-dimensional 0-layer model. These models are fully parallelized using the Message-Passing Interface. The results are compared with the hydrographic data from the RUSALCA cruises. We also examine selected oceanic analyses including the NCEP Climate Forecast System Reanalysis and the HYCOM 1/12° Global Analysis.
Seasonal variability in pathways and along-path transformation of warm water masses towards Kangerdlugssuaq Fjord

The pathways of warm (above 0°C) water masses towards Kangerdlugssuaq Fjord are investigated in a Lagrangian framework based on a one-year long Eulerian high-resolution simulation. Three regions of origin are identified based on water-mass identification near the fjord, accounting for water traveling in the Greenland coastal current system from the Arctic Ocean (AO), coming from the Irminger Basin (IB), and traveling along the Greenland shelf break or as deep water through Denmark Strait (DS). The top ca 200m of the water column near Kangerdlugssuaq Fjord is dominated by AO particles, warmed up by solar heating of the near-surface ocean layer in summer. Below about 200m, the warm water is a mixture of IB and DS water masses. A careful consideration of the particle trajectories and the heat and salt budgets determined that the contribution of IB particles is about 1/3 in summer and autumn and 1/2 in winter and spring, with the rest coming mainly through Denmark Strait. Importantly, temperature variations at the control sections have a negligible impact on temperature variations near the fjord; the seasonal variability is almost entirely controlled by the volume fractions of the source waters being mixed, not their properties. Successful monitoring of heat flux to the fjord therefore needs to take place close to the fjord, and cannot be inferred from upstream conditions. Moreover, our results suggest that global warming and multi-decadal variability in the gyre temperature also have a negligible effect on the heat flux compared to water-mass mixing.
Goessling, Helge: Alfred Wegener Institute, helge.goessling@awi.de

A probabilistic verification score for contours demonstrated with idealized ice-edge forecasts

We introduce a probabilistic verification score for ensemble-based forecasts of contours: the Spatial Probability Score (SPS). Defined as the spatial integral of local (Half) Brier Scores, the SPS can be considered the spatial analog of the Continuous Ranked Probability Score (CRPS). Applying the SPS to idealized seasonal ensemble forecasts of the Arctic sea-ice edge in a global coupled climate model, we demonstrate that the SPS responds properly to ensemble size, bias, and spread. When applied to individual forecasts or ensemble means (or quantiles), the SPS is reduced to the 'volume' of mismatch, in case of the ice edge corresponding to the Integrated Ice Edge Error (IIEE).
Golubeva, Elena: Institute of Computational Mathematics and Mathematical Geophysics SB RAS, elen@ommfao.sscc.ru

A comparison of vertical mixing parametrizations on the simulation of the ice and upper ocean state in the Arctic Ocean model

The upper Arctic Ocean (ice state, temperature, salinity and ocean current system) have been simulated by a 3-dimensional ice-ocean general circulation model using four different vertical mixing schemes. One scheme corresponds to the modified Richardson number dependent scheme; the other schemes are adapted from the General Ocean Turbulence Model (GOTM) package. The performances of the schemes in the Arctic Ocean model are evaluated under the same model configuration and boundary conditions using reanalysis data as the atmospheric forcing. Model and data comparisons are made for the mean state, annual cycle, and interannual variability.
Gonçalves-Araujo, Rafael: Alfred Wegener Institute, rafael.goncalves.araujo@awi.de

Using fluorescent dissolved organic matter to trace Arctic surface fresh water

Gonçalves-Araujo, Rafael, Granskog, Mats A., Bracher, Astrid, Azetsu-Scott, Kumiko, Dodd, Paul A., Stedmon, Colin A.

Climate change affects the Arctic environment with regards to permafrost thaw, changes in the riverine runoff and subsequent export of fresh water and terrestrial material to the Arctic Ocean. In this context, the Fram Strait represents a major pathway for export to the Atlantic basin. We assess the potential of visible wavelength dissolved organic matter fluorescence (VIS-FDOM) to trace the origin of Arctic outflow waters. Oceanographic surveys were performed in the Fram Strait, as well as on the east Greenland shelf (following the East Greenland Current), in late summer 2012 and 2013. Meteotropic (fmw), sea-ice melt (fism), Atlantic (faw) and Pacific (fpw) water fractions were determined and FDOM components were identified by PARAFAC modeling. In Fram Strait and east Greenland shelf, a robust correlation between VIS-FDOM and fmw was apparent, suggesting it as a reliable tracer of polar waters. However, variability was observed in the origin of polar waters, in relation to contribution of faw and fpw, between the sampled years. VIS-FDOM traced this variability, and distinguished between the origins of the halocline waters as originating in either the Eurasian or Canada basins. The findings presented highlight the potential of designing in situ DOM fluorometers to trace the freshwater origins and decipher water mass dynamics in the region.
The loss of Arctic sea ice is a conspicuous example of climate change. Climate models project ice-free conditions during summer this century under realistic emission scenarios, reflecting the increase in seasonality in ice cover. To quantify the increased seasonality in the Arctic-Subarctic sea ice system, we define a non-dimensional seasonality number for sea ice extent, area, and volume from satellite data and realistic coupled climate models. We show that the Arctic-Subarctic (northern hemisphere) sea ice now exhibits similar levels of seasonality to the Antarctic, which in a seasonal regime without significant change since satellite observations began in 1979. The realistic climate models suggest that this transition to the seasonal regime is being accompanied by a maximum in Arctic sea ice albedo feedback, which is the acceleration of sea ice retreat as more ocean surface is exposed and requires sea ice present during the sunlit months. Consistently, climate models predict that Arctic amplification of global warming, that is the enhanced warming in high northern latitudes compared to the global mean, is likely to peak in the 2010s, and decline thereafter.
The forces acting on sea ice in the Canadian Arctic Archipelago and preliminary results of estimated sea ice strength

We analyze the GPS data obtained via the Surface Velocity Profilers [SVP] deployed in the Canadian Arctic Archipelago from 2009 to 2013. The sea ice floe on which the SVP is deployed drifts in summer and becomes landfast in winter. In Viscount Melville Sound, the one-day averaged sea ice drift speed has strong positive correlation ($r = 0.74$ in October) with wind speed. We interpret that the dominant force in Viscount Melville Sound is the wind. As the season gets closer to winter, the drift speed decreases without decrease in associated wind speed, suggesting an increase in the average ice thickness. In M'Clintock Channel, however, the correlation between sea ice drift speed and wind speed is weak ($r < 0.35$). Stronger ocean currents and the higher proportion of thick ice in M'Clintock than in Viscount Melville Sound could be a source of weak correlation between ice drift and wind in M'Clintock Channel. To this end, we analyze the ocean currents from the ANHA NEMO simulation and the CIS ice chart. Additionally, we present preliminary results from our analysis of wind stress and mean ice thickness around the time of landfast onset to estimate the sea ice compressive strength ($p^*$).
Hebert, David: Naval Research Laboratory, david.hebert@nrlssc.navy.mil

Assimilating high resolution VIIRS sea ice concentration into the U.S. Navy Arctic Cap Nowcast/Forecast System (ACNFS)

The U.S. Navy's operational Arctic Cap Nowcast/Forecast System (ACNFS) is a data assimilative, two-way coupled ocean-sea ice modeling system designed to provide 7-day forecasts of arctic sea ice conditions. ACNFS is run at high horizontal resolution (3.5 km at the North Pole), and extends from the North Pole to 40°N. Currently, ACNFS assimilates ice concentrations observed from the passive microwave sensors Special Sensor Microwave Imager/Sounder (SSMI/S) and Advanced Microwave Scanning Radiometer 2 (AMSR2), along with the Interactive Multisensor Snow and Ice Mapping System (IMS) ice mask produced by the U.S. National Ice Center (NIC). SSMI/S and AMSR2 ice concentration observations are at relatively coarse horizontal resolutions, 25 km and 10 km respectively, compared to the ACNFS model resolution. While these data sources have been shown to improve ACNFS ice edge forecast skill, it is highly desired to have observations that are closer to the ACNFS horizontal resolution. Recently, very high resolution (750 m) ice concentration observations from NOAA’s Visible Infrared Imaging Radiometer Suite (VIIRS) has been made available in near real time. In contrast to SSMI/S and AMSR2 that can “see” through cloud cover, VIIRS cannot “see” through clouds and could pose a problem as a sole-source of ice concentration observations in an operational model like ACNFS. In this study we present preliminary results of assimilating VIIRS ice concentration into ACNFS along with SSMI/S and AMSR2 using the Navy Coupled Ocean Data Assimilation (NCODA). ACNFS ice concentration forecasts and ice edge location errors will be examined.
Interactions between sea ice floe size, ocean eddies, and sea ice melting

The distribution of floe sizes is known to influence the melting of the sea ice cover by leading to lateral melting when floes are smaller than about 30 meters. This ignores the potentially important feedbacks between sea ice floes and ocean circulation, specifically ocean eddies that mix heat between ice-covered and ice-free regions. We examine the interaction between mixed-layer eddies that form at the sides of floes using high-resolution GCM experiments, finding a sensitivity of sea ice melting to floe size on scales from 1-50 kilometers that leads to differences in the timing of elimination of sea ice from a climate model grid cell of several months.
Hunke, Elizabeth: Los Alamos National Laboratory, eclare@lanl.gov

Highlights from DOE's high-latitude ice modeling teams

The US Department of Energy has embarked on some exciting new projects with significant polar foci, involving development of next-generation ocean, land-ice, sea-ice and climate models. This talk will highlight DOE's current efforts and engage the audience in a discussion of what future research directions might entail.
Scaling properties of Arctic sea ice deformation in high-resolution viscous-plastic sea ice models

Many climate models use a viscous-plastic rheology to simulate sea ice dynamics. With this rheology, large scale velocity and thickness fields can be realistically simulated, but the representation of small scale deformation rates and Linear Kinematic Features (LKF) is thought to be inadequate. However, at high resolution (< 5 km) the rheology starts to produce lines of localised deformation rates. In this study we use results from a 1-km Pan-Arctic model to investigate the influence of these deformation features on the scaling properties of sea ice deformation. For evaluation the EGPS satellite data set of small-scale sea ice kinematics for the Central Arctic, the successor of the RGPS data set, is used.

The modelled sea ice deformation shows multi-fractal spatial scaling and, in this sense, agrees with the satellite data. In addition, the temporal coupling of the spatial scaling is reproduced. Furthermore, the regional and seasonal variations of spatial scaling properties and their dependence on the ice condition, that is, sea ice concentration and thickness, are in agreement with previous RGPS studies.
Iakshina, Dina: Institute of Computational Mathematics and Mathematical Geophysics, iakshina.dina@gmail.com

Study of the Atlantic Water Influence on the Arctic Sea Ice Cover State

Warm intermediate water of Atlantic origin is one of the sources of heat entering the Arctic Ocean. Even though it passes at quite great depths it is considered that heat flux coming from the Atlantic water could approach the bottom edge of the ice cover. The influence of Atlantic waters on the Arctic ice state is analyzed on the basis of numerical model of the ocean and sea ice, developed in ICMMG SB RAS, Novosibirsk, Russia. Numerical experiments were conducted for period 1948-2014 using the NCEP/NCAR reanalysis data as the atmospheric forcing. Numerical results show the significant reduction of Arctic summer sea ice extent during the past two decades. Analyzing numerical results, we found that the variability of the atmospheric circulation in the Arctic and North Atlantic results in noticeable change of the Atlantic water, entering the Arctic Ocean. The heat transfer from the Atlantic water to the atmosphere and sea ice in our model is most distinctly represented in the Barents Sea and to the west of Spitsbergen, where there is no ice even during the winter season. Numerical results show noticeable reduction in the sea ice thickness along the continental slope to the north of Barents Sea, where warm Atlantic water passes close to the surface and mixing processes facilitate the involvement of water and heat transfer to overlying layers. We try to evaluate the heat fluxes coming from the Atlantic waters to the bottom edge of the ice during different periods of atmospheric circulation and compare them to the atmospheric fluxes.
The study of seasonal variability of circulation and of heat, salt and fresh water budget in Arctic Ocean model

We present results of simulation of the seasonal variability of Arctic Ocean by the coupled ocean-ice model with 7-km resolution. The model is based on INMIO ocean general circulation model, developed in the Institute of Numerical Mathematics and P.P. Shirshov Institute of Oceanology, and CICE, the Los Alamos sea ice model. The model is driven with “normal” year forcing (Large and Yeager, 2004). Different mechanisms of interaction of the Arctic Ocean with North Atlantic and Pacific are analyzed. A high sensitivity of the Arctic Ocean circulation to variations of North Atlantic current being one of key factors of seasonal cycle of the Arctic Ocean currents, defines heat impact to Arctic Ocean thermohaline and sea-ice state. The seasonal variations of the Arctic Ocean sea-ice extent and total volume correlate with observed data. The water, heat and salt budget of Arctic Ocean is estimated based on model results. It's shown that they are in correlation with estimations based on observations. And finally, several experiments estimating sensitivity of the Arctic circulation to variations of North Atlantic water inflow are presented.
The Arctic4 coupled ocean-ice-ecosystem model

Paul Erik Isachsen et al.

The Regional Ocean Modelling System (ROMS) has been set up for the Arctic Ocean and Nordic Seas at 4 km horizontal resolution. The model is hence eddy-permitting. An early version of this "Arctic4" model system was based on the existing ROMS ice code, but the ocean model has now been coupled to the Community Ice Code (CICE5) sea ice model using the Model Coupling Toolkit (MCT). The change of sea ice model introduces more suitable thermodynamics for long range simulations (ice thickness distribution, better vertical resolution in ice and snow, prognostic salt), but also alternative solvers and ice rheology that may be beneficial at eddy-permitting resolution. The SINMOD ecosystem module is implemented to run online with ROMS and coupled to the CICE biochemical module. Model resolution is an important factor for biochemistry, as earlier studies with SINMOD have shown an increase of about 14% of gross primary production when model resolution was increased from 20 km to 4 km. The eddy-permitting model system is now under testing. Current runs show that the seasonal cycle of ice production and melting is realistic and that the model contains a rich mesoscale eddy field. The biggest biases in the model at present are a too salty Arctic Ocean and too fresh Nordic Seas. Efforts now focus on identifying and tackling the sources of these biases.
Remote estimating methane emissions from submarine permafrost in the Arctic: methods and uncertainties

An overview of available methods for remote sensing of methane emission from the Arctic seafloor is presented. The main focus is on methods that exploit recent developments in sonar technology. These methods have the established capability to remotely provide acoustic images of strongly scattering objects, such as submarine gas bubbles, and to contour the areas of their significant concentration. However, for quantitative estimating such emissions, e.g. in terms of the methane mass flow, these methods require various additional measurements and calibration techniques, whose accuracy and related uncertainties have yet to be better understood. The primary goal of this presentation is to initiate discussion of these and related issues and, particularly, of what further developments are needed, including both acoustical and environmental research, to reduce such uncertainties and to provide reliable estimates of methane emission.
How predictable is the timing of a summer ice-free Arctic?

The Community Earth System Model Large Ensemble (CESM LE) provides an unprecedented opportunity to investigate the effect of internal variability on the simulation of the climate system. Internal variability in climate model simulations affects both the prediction uncertainty and the evaluation of model simulations against observations. For Arctic sea ice, the CESM LE shows that comparisons against observations need to be carefully designed, as internal variability has a large impact on sea ice over the observational period. We will present an assessment of all commonly used sea ice model metrics within the CESM LE, and show how strongly they are influenced by internal variability, in order to allow an informed interpretation of sea ice simulations from climate model simulations in the light of internal variability. For example, the CESM LE shows that trends of sea ice extent over the observational period are strongly affected by internal variability, so a “failure” to simulate the observed trend for 1979-2015 should not be used to discard the model. The CESM LE also shows that sea ice thickness fields are strongly influenced by internal variability, even for 5-10 year averages, complicating the comparison against the short satellite-derived sea ice thickness products, which span 5 years.
Janout, Markus: Alfred-Wegener-Institute, markus.janout@awi.de

On river water, Atlantic water upwelling and dense water formation in Vilkitsky Trough in the eastern Arctic from moorings and high-resolution CTD measurements

The Siberian Arctic is characterized by vast shallow shelves, complex and steep topography, and features important pathways for Siberian river water, which is important for Arctic sea ice and circulation. A recent high-resolution model study using NEMO showed that a large part of the Kara Sea freshwater exits into the northwestern Laptev Sea via Vilkitsky Strait in a seasonally and interannually variable surface-intensified current. The flow is guided along the Laptev Sea continental slope toward the western Arctic along the 250 km long, 300m deep Vilkitsky Trough. Data from this large submarine canyon are scarce and its importance for the eastern Arctic largely undocumented. In 2013 and 2014, enhanced efforts were invested in better understanding the northwest Laptev Sea shelf and Vilkitsky Trough, by employing some densely-spaced hydrographic cross-canyon and shelf transects complemented by oceanographic moorings. The measurements provide the first detailed observations from this dynamic area, and nicely confirm the modeled freshwater current propagating along the canyon edge. Furthermore, the deeper (>100m) waters in the central canyon largely consist of warmer Atlantic-derived waters, which are episodically advected toward the Laptev Sea shelf in response to wind-driven flow reversals. Finally, we observed the presence of polynya-formed near-freezing dense waters at a range of salinities between 34 and 35 along the canyon’s slope. These waters are exported to the Arctic Ocean in a swift (30 cm/s) along-canyon circulation, which emphasizes that Vilkitsky Trough is not only a pathway for Kara Sea freshwater but also an important conduit for cold dense waters that can affect isopycnal layers from the Arctic halocline through the Atlantic water layer and Arctic deep waters. This presentation will highlight the necessity of high-resolution CTD measurements and oceanographic moorings for capturing relevant processes that occur on small temporal and spatial scales such as narrow boundary currents, upwelling events and the formation and dispersion of polynya-formed dense waters.
Arctic ecosystem modeling using high resolution fully coupled RASM

Previous observational studies have found increasing primary production (PP) in response to declining sea ice cover in the Arctic Ocean. In this study, under-ice PP was assessed based on three coupled ice-ocean-ecosystem models participating in the Forum for Arctic Modeling and Observational Synthesis (FAMOS) project (published in JGR 2016) and a recent update with a high resolution fully coupled RASM run. All models showed good agreement with under-ice measurements of surface chlorophyll-a concentration and vertically integrated PP rates during the main under-ice production period, from mid-May to September. Further, modeled thirty-year (1980-2009) mean values and spatial patterns of sea ice concentration compared well with remote sensing data. Under-ice PP was higher in the Arctic shelf seas than in the Arctic Basin, but ratios of under-ice PP over total PP were spatially correlated with annual mean sea ice concentration, with higher ratios in higher ice concentration regions. Decreases in sea ice from 1980 to 2009 were correlated significantly with increases in total PP and decreases in the under-ice PP/total PP ratio for most of the Arctic, but nonsignificantly related to under-ice PP, especially in marginal ice zones. Total PP within the Arctic Circle increased at an annual rate of between 3.2 and 8.0 Tg C/year from 1980 to 2009. This increase in total PP was due mainly to a PP increase in open water, including increases in both open water area and PP rate per unit area, and therefore much stronger than the changes in under-ice PP. All models suggested that, on a pan-Arctic scale, the fraction of under-ice PP declined with declining sea ice cover over the last three decades.
Change in Arctic Ocean freshwater storage in response to a step change in wind forcing

We investigate how freshwater storage in the Arctic Ocean responds to a change in the Arctic Oscillation (AO), by examining the relationship between freshwater storage and sea-level pressure in an unperturbed control simulation of the high-resolution coupled climate model, HiGEM. We use the technique of Kostov et al. (2016) to extract the response of integrated freshwater content to a hypothetical step increase in the AO. We demonstrate that the freshwater content responds on a decadal timescale, consistent with our expectation that eddies set the timescale on which the Arctic Ocean adjusts to changes in surface forcing. Exploiting the relationship between freshwater and the AO, we attempt to predict the change in freshwater content under greenhouse gas forcing applied to the same model.
Seasonal prediction of sea ice extent using the Regional Arctic System Model (RASM) with bias correction

A requirement of the U.S. Navy Arctic Roadmap and Implementation Plan for the National Strategy for the Arctic Region is to advance modeling and prediction of the Arctic climate system. To address this requirement, the Regional Arctic System Model (RASM) has been developed and so far used for hindcast simulations and analyses. It has now also been adapted to generate sea ice forecasts. RASM is a fully coupled, limited-area pan-Arctic model that includes sophisticated atmospheric, oceanic, sea ice and land hydrology components. In this presentation we will summarize new work to use RASM for seasonal projections of the September 2016 sea ice extent minimum. We have adapted the model to use boundary conditions from Version 2 of the NCEP Coupled Forecast System (CFSv2) to generate forward RASM sea ice integrations. We have applied this adaption the 2016 Arctic summer sea ice season to create September sea ice forecasts initialized in June, July and August. The raw ice extent forecasts from RASM were bias corrected using a simple linear regression model based on the past 27 years of RASM hindcasts and NSIDC Merged SMMR and SSM/I sea ice concentration data. RASM ice extent residuals, carrying only information about interannual variability, were calculated after removing the average annual cycle of monthly sea ice extent for 1988-2014 and the interannual linear trend for 1996-2014. The respective observed average annual cycle of monthly sea ice extent and linear trend were added to the model residuals producing bias corrected projection. Trend-less biases between the observed sea ice extent and those from RASM for 1996-2014 were used to estimate projection uncertainties. We will assess the skill of the forecasts in terms of variance- and correlation-weighted skill scores of both concentration and thickness of the ice cover against passive microwave and CryoSat-2 data, respectively.
Mixing in mesoscale eddies in the western Arctic: internal waves and double diffusion

Turbulent mixing in the mesoscale/submesoscale eddies is thoroughly studied using many of in situ microstructure, ADCP and hydrographic profiles. Dominant mixing scheme differently works in various categories of eddies.

For example, in an anticyclonic cold-core eddy was dominated by near-inertial internal waves that were captured by negative vorticity core in the eddy and notably broke up near the base of vortex after propagating downward. This remarkable wave breaking can be accounted for by vertical variation of relative vorticity, resulting in a huge amount of turbulent kinetic energy. After increased chance of ice cover retreat, most of wind energy which comes into water could be absorbed and dissipate in those negative vorticity structures, instead of ubiquitously stirring up the internal water.

For another example, a warm submesoscale eddy encountered off the Barrow was where the double-diffusive interleavings are dominant in the frontal region between the core and rims. The interleavings are characterized by an umbrella-shaped layered convection, which contains alternate double-diffusive multilayers: salt finger and diffusive convection. The double diffusive layer could provide significant amount of vertical fluxes in heat and nutrient.

Those results are partially presented in our latest paper from JPO (Kawaguchi et al. 2016).
Oil Spills in the Arctic: Modelling Circulation Pathways in the Arctic Ocean

Due to the retreat of sea-ice in the Arctic Ocean, shipping in the area is predicted to increase, and, consequently, an Arctic oil spill is becoming more likely. Sparse infrastructure combined with a short operational season limits the amount of time available for a potential Arctic oil spill to be dealt with. This raises the chances of a clean-up operation being partially or fully unsuccessful, in which case the long-term fate of the unrecovered oil must be considered.

Biodegradation is inhibited by freezing temperatures, so there are two main possibilities for what could happen to spilled oil; some of it is likely to become entrained into the water column and follow ocean currents, and some of it will be encapsulated into sea-ice where it will follow the ice drift. It is the former case that we focus on here. In order to understand what will happen to this fraction of the oil, it is necessary to investigate the advective pathways which exist in the Arctic Ocean. A Lagrangian particle-tracking technique is employed to accomplish this.

We utilize 5-day mean output from NEMO (Nucleus for European Modelling of the Ocean) in ORCA0083-N06 configuration; a 1/12° resolution ocean model (which corresponds to a typical horizontal resolution of 3-5km in the Arctic), running with DRAKKAR DFS5 atmospheric forcing. At various locations of interest, we periodically release point particles into NEMO’s flow field and track their progress for two years. Particles are launched every year between 1990 and 2012, with releases taking place every 10 days from June to October in order to cover the full navigable season.

In this work, we assess the inter- and intra-annual variability in advective pathways in the Arctic. Changes in the sizes of circulation footprints, the routes that they follow, and the timescales associated with them are investigated, and physical causes for these variations are proposed. Blocking events are explored and linked to atmospheric forcing, thus enabling us to better predict the circulation patterns that are likely to be important for given atmospheric conditions.
IAOOS platforms, observing physical parameters at the atmosphere-snow-ice-ocean interface deployed as part of the N-ICE2015 campaign, provide new insights on winter conditions North of Svalbard. The three regions crossed during the drifts, the Nansen Basin, the Sofia Deep and the Svalbard northern continental slope had distinct hydrography and ice-ocean interaction. In the Nansen Basin the quiescent warm layer was capped by a stepped halocline (60 and 110 m) and a deep thermocline (110 m). Ice was forming and the winter mixed layer salinity was larger by ~0.1 g/kg than previously observed. Over the Svalbard continental slope, the Atlantic Water (AW) was very shallow (20 m from the surface) and extended offshore from the 500 m isobath by ~70 km, sank along the slope (40 m from the surface) and probably shedded eddies into the Sofia Deep. These characteristics may be primarily winter features. In the Sofia Deep, warm waters extended from 90 m downward and had different origin and modification history, resulting in a wide range of hydrographic characteristics. Sea-ice melt was widespread over the Svalbard continental slope and ocean-to-ice heat fluxes reached values of 400 Wm-2 (mean of ~150 Wm-2 over the continental slope). The intense sea-ice melt keeps Whalers Bay open in winter. Sea-ice melt events were associated with near 12-hour fluctuations in the mixed-layer temperature and salinity corresponding to the periodicity of tides and near-inertial waves potentially generated by winter storms, large barotropic tides over steep topography and geostrophic adjustments.
Drivers of freshwater distribution in the Arctic and Atlantic Oceans

Oceanic circulation plays an important role in setting the climate of the Arctic and the Northern Atlantic regions. Currents conveying large volumes of water masses at various depths transport heat and salt to great distances, forming a global circulation system. In the Atlantic, the Meridional Overturning Circulation (MOC) is driven by exchanges of heat, freshwater and momentum with the atmosphere. Previous modeling studies suggest that the stability of the MOC is sensitive to different climate scenarios due to the sensitivity of the deepwater formation, a crucial component of the circulation to perturbations of freshwater content. Global climate models predict significant temperature rise in the future with larger trends at higher latitudes, and an enhanced hydrological cycle. Both of these trends act against the MOC, decreasing its strength by reducing meridional air temperature differences and freshening of ocean waters in key high latitude areas. The observed increase of the strength of the North Atlantic Oscillation (NAO) in recent decades, a trend that is predicted by many climate models to persist in the future, however, acts as a driver of the MOC. This duel of the evolution of fresh water fluxes and the development of the NAO is most likely going to define the strength of the MOC in the future. We examine the effects of different NAO scenarios using the Modini-system, a partially coupled spin-up that allows prescription of wind stresses for the ocean in the otherwise fully coupled Earth System Model of the Max Planck Institute. In our work we describe the processes affecting the circulation in more detail. We present our first results by investigating the role different wind stress patterns play in shaping fresh water reservoirs and exchanges between different subregions of the Arctic and the Atlantic Ocean.
Kozlov, Igor: Russian State Hydrometeorological University, igor.eko@gmail.com

Internal solitary waves and submesoscale eddies in the ice-free Arctic Ocean observed from space

I. Kozlov, E. Zubkova, A. Atadzhanova, A. Zimin, D. Romanenkov, V. Kudryavtsev

High-frequency internal solitary waves (ISWs) and submesoscale eddies (SE) are important dynamical features significantly impacting the hydrology of the upper ocean. However, these dynamic processes still remain largely unexplored and poorly investigated in the Arctic Ocean. In this work taking the advantage of high resolution spaceborne synthetic aperture radar (SAR) data we present joint results of ISWs and SEs observations in the ice-free Arctic Ocean. Analysis of ISW observations is provided for the entire seasonally ice-free Eurasian Arctic basin, while the results of SEs observations cover the Barents and the Kara seas. The study is based on analysis of ENVISAT Advanced SAR images acquired during summer-autumn months in 2007-2011. More than 4000 cases of high-frequency ISWs and about 3400 surface manifestations of SEs were identified in about 3000 SAR images, and their main spatial and kinematic properties estimated. Detailed maps of ISWs and SEs observational frequency have helped to identify main hot-spots of their activity. Preliminary analysis shows that ISW hot-spots do not spatially correlate with those of submesoscale eddies. As found, ISWs are typically observed over the steep topography features and over the slopes, while SEs are typically found in the vicinity of various frontal zones.

This work is supported by RFBR grants 16-29-02106 mol_a_dk and 15-05-04639 A, and the Ministry of Education and Science of the Russian Federation President grant MK-5562.2016.5.
Kozlov, Igor: Russian State Hydrometeorological University, igor.eko@gmail.com

Surface currents, strong baroclinic tides and internal solitary waves in the Arctic Gibraltar (Kara Gates Strait)

I. Kozlov, E. Morozov, S. Shchuka, D. Frey

In this work we present joint results of in situ measurements, model calculations and spaceborne observations for the Kara Gates Strait, the region where large amplitude internal tidal waves were previously documented. In the Kara Gates internal tides are superimposed over a system of mean currents from the Barents to the Kara Sea that are well depicted in high-resolution satellite images. $M_2$ internal tidal wave is generated due to the interaction between the currents of the barotropic tide and bottom topography on the slopes of a ridge that crosses the strait from the Novaya Zemlya to the continent. The depths of the ridge crest are about 30-40 m. A permanent current of relatively warm water flows from the Barents Sea to the Kara Sea. While internal waves propagate in both directions from the ridge, in the Barents Sea internal waves are intensified by the opposite current from the Barents Sea to the Kara Sea. Model calculations show that internal bores followed by a packet of short-period internal solitary waves are found in both directions from the strait. Satellite images confirm the model results and show that packets of internal solitary waves propagate about 100-200 km to the both directions from the strait.

This work is supported by RSF grant 14-05-00095, RFBR grant 16-29-02106 mol_a_dk, and the Ministry of Education and Science of the Russian Federation, President grant MK-5562.2016.5.
Internal Variability in the Arctic Freshwater Budget

The Community Earth System Model (CESM) Large Ensemble (LE) with Community Atmospheric Model version 5 (CAM5) provides a means to study internal climate variability. Internal climate variability is a major contributor to uncertainty in climate projections, and also complicates the comparison of climate model results with observations. To investigate the role of internal variability in the Arctic freshwater (FW) budget, this study analyzes the output from the CESM large ensemble. The 40 climate model simulations in this ensemble use the same model and forcing, but were initiated with small perturbations in the atmospheric state in 1920. Simulation results from the CESM LE were examined to explore internal variability related to FW budget terms for the Arctic region during the 20th and 21st century. Freshwater fluxes are investigated with respect to time series trends, interannual variability, and ensemble spreads. We will show that individual FW budget terms have varying degrees of internal variability. For example, during the late 20th century the solid FW export through Fram Strait has the largest ensemble spread due to internal variability, which even impacts the mean Arctic FW budget over the observational period. Over the 21st century, as the Arctic sea ice cover continues to decline, the internal variability of the solid FW export decreases while the internal variability of the liquid FW export increases.
Thermohaline Circulation with Three Stable Regimes of Flow

The North Atlantic thermohaline circulation (THC) carries heat and salt toward the Arctic. This circulation is partly accommodated by buoyancy loss and is generally believed to be inhibited by northern freshwater input as indicated by the 'box-model' of Stommel (1961). The inferred freshwater-sensitivity of the THC, however, varies considerably between studies, both quantitatively and qualitatively. The northernmost branch of the Atlantic THC, which forms a double estuarine circulation in the Arctic Mediterranean, is one example where both buoyancy loss and buoyancy gain accommodate circulation. We have built on Stommel's original concept to examine the freshwater-sensitivity of a double estuarine circulation. Our model consists of three idealized basins, or boxes, connected by two coupled branches of circulation. The net inflow into the double estuary is found to be more sensitive to a change in the distribution of freshwater than to a change in the total freshwater input. Stommel's solutions for a single overturning appear as a limiting case when all freshwater feeds directly into the domain of dense water formation. In general, a double estuarine circulation is found to be more stable than a single overturning. A thermohaline 'collapse' requires a larger amount and more localized freshwater input into regions of buoyancy loss. For the Arctic Mediterranean, these findings imply that the Atlantic Inflow may be relatively insensitive to increased freshwater input. Complementing Stommel's thermal and haline flow regimes, the double estuarine circulation allows for a third: the throughflow regime. In this regime, a thermohaline circulation with warm poleward surface flow can be sustained without production of dense water; a decrease in high-latitude dense water formation does therefore not necessarily affect regional surface conditions as strongly as generally thought.
Upper Ocean Evolution Across the Beaufort Sea Marginal Ice Zone

The observed reduction of Arctic summertime sea ice extent and expansion of the marginal ice zone (MIZ) have profound impacts on the balance of processes controlling sea ice evolution, including the introduction of several positive feedback mechanisms that may act to accelerate melting. Examples of such feedbacks include increased upper ocean warming through absorption of solar radiation, elevated internal wave energy and mixing that may entrain heat stored in subsurface watermasses (e.g., the relatively warm Pacific Summer and Atlantic waters), and elevated surface wave energy that acts to deform and fracture sea ice. Spatial and temporal variability in ice properties and open water fraction impact these processes.

To investigate how upper ocean structure varies with changing ice cover, how the balance of processes shift as a function of ice fraction and distance from open water, and how these processes impact sea ice evolution, a network of autonomous platforms sampled the atmosphere-ice-ocean system in the Beaufort, beginning in spring, well before the start of melt, and ending with the autumn freeze-up. Four long-endurance autonomous Seagliders occupied sections that extended from open water, through the marginal ice zone, deep into the pack during summer 2014 in the Beaufort Sea. Gliders penetrated up to 200 km into the ice pack, under complete ice cover for up to 10 consecutive days. Sections reveal strong fronts where cold, ice-covered waters meet waters that have been exposed to solar warming, and O(10 km) scale eddies near the ice edge. In the pack, Pacific Summer Water and a deep chlorophyll maximum form distinct layers at roughly 60 m and 80 m, respectively, which become increasingly diffuse late in the season as they progress through the MIZ and into open water. Stratification just above the Pacific Summer Water rapidly weakens near the ice edge and temperature variance increases, likely due to mixing or energetic vertical exchange associated with strong lateral gradients at the MIZ. This presentation will discuss the evolution of the Arctic upper ocean over the summer to the start of freeze up and the relationship of its variability to sea ice extent and atmospheric forcing.
Modeling in Arctic primary production when models meet data

Primary production is the major source of energy for the Arctic Ocean (AO) ecosystem, as in all ecosystems. However, it is difficult to obtain a comprehensive picture of in situ primary production regime in the AO because of dramatic seasonal change and limited access due to sea ice conditions. Given the high heterogeneity of the AO with its marginal seas and the rapid change that the AO is undergoing, models are the best tool we have to simulate current conditions, reproduce historical observations, and project future conditions of net primary production (NPP) in the AO. Current projected changes in future climate and responses of the AO may indicate either i) an increase in NPP associated with enhanced light availability as a direct result of sea ice and snow cover loss as well as increased nutrient fluxes or ii) a decrease of NPP associated nutrient limitation with enhanced stratification and decreased light availability. Reliable models, such as biogeochemical ocean general circulation models (BOGCMs) and earth system models (ESMs), that estimate NPP are becoming increasingly available for the AO and can help us better understand how NPP is changing, and how such changes are impacting this marine ecosystem. On the contrary, sampling difficulties because of harsh environments in the AO and the resulting in situ data scarcity to validate simulations, further limited by the ongoing changes of the linked ocean-atmosphere-sea ice system (and ecosystem) has affected our ability to accurately simulate contemporary NPP variability in the AO and reduce the uncertainty of model projections. Although it is the increasing availability of in situ biogeochemical data in recent years, basin-wide, temporally-averaged climatological data are still used to evaluate model estimates.
Lei, Ji, ECCC, Canada, ji.lei@canada.ca

Evaluation of hindcasts simulations with the CONCEPTS regional ocean and sea-ice model covering three oceans around Canada

A new quarter degree regional ocean model configuration that includes the North Atlantic Ocean, the Arctic Ocean and the North Pacific Ocean has been established under the NEMO-CICE frame work of the Canadian Operational Network of Coupled Environmental Prediction Systems (CONCEPTS). A series of hindcasts (2004-2010) simulations has then been carried out to test the model’s sensitivity to various physical factors, including vertical resolution, tides, initial conditions, landfast ice, etc. The results are evaluated against in-situ observation, reanalysis data, and products from other models. The results of these runs will guide the future development of the operational Regional Ice-Ocean Prediction System (RIOPS) run at (Environment and Climate Change Canada) ECCC.
Li, Tian: Beijing Normal University, litiansky@foxmail.com

Monitoring the tabular icebergs C28A and C28B calved from the Mertz Ice Tongue using satellite remote sensing data

Icebergs play an important role in transferring freshwater to, and exchanging heat with the ocean. Its drifting process can modify ocean circulation and regional biodiversity. The dynamic mechanisms of iceberg drifting process have been extensively studied using remote sensing data but their mass loss due to calving and basal melt have not been fully investigated using radar remote sensing. This study analyzes the evolution process of two tabular icebergs (C28A and C28B), calved from iceberg C28 on April 2, 2010. The monitoring of the icebergs starts from the calving of C28 from the Mertz Ice Tongue in February 2010 and ends in April 2012 using continuously multi-source radar remotely sensed data. The evolution of the iceberg area and perimeter are monitored using ENVISAT ASAR images and the iceberg thickness is derived from CryoSat-2 data. The mass loss due to calving and basal melting of the icebergs is then estimated. We show that the area and thickness of the icebergs continuously decrease while drifting westwards under the effects of oceanic and atmospheric forces. The mass loss due to iceberg calving is about 131.34 Gt during the study period (greater in winter than in summer), with higher loss when the iceberg is floating in open water than when in the stranded state. The basal melting plays a more important role than calving in the iceberg mass loss, which is also found to be greater in winter than in summer. Submarine topography affects the different drifting routes of the icebergs. Our results reveal the complex interaction process between icebergs and their surrounding environment.
Li, Xinqing: Beijing Normal University, China, lixinqing0710@163.com

**Definition and analysis of the landfast ice around Antarctica from 2005 to 2011 with SAR images**

The landfast ice plays important role on the atmosphere, ocean and marine biology. In my study, ENVISAT ASAR images ranging from 2005 to 2011 are used to extract the more accurate edges of the landfast ice around Antarctica. A method based on gradient calculation is applied to define the edges of landfast ice. Then the edges will be delineated manually. There will be seven results through the research period, one result each year. On one hand, the results will be compared with the previous studies which were achieved with microwave radiometer or SAR images but not for whole Antarctica. On the other hand, the results will be used to do the inter-annual comparison and analysis to find the area where landfast ice extent change and the reasons which cause these changes.
Lique, Camille: Ifremer, France, camille.lique@ifremer.fr

Insight on the Arctic halocline formation from a Lagrangian model analysis

The Arctic halocline, characterized by the coincidence of a strong salinity gradient with cold temperatures, is present in most of the Arctic Ocean, and it plays a key role for the dynamics of this basin. It encompasses a large amount of freshwater, which has the potential to affect to the global thermohaline circulation when released to the North Atlantic. It also acts as a barrier between the sea ice pack at the surface and the warm Atlantic-origin water masses found in the intermediate layer of the Arctic Ocean. The mechanisms behind the formation of the Arctic halocline remain uncertain, although they are thought to be both advective and convective in nature. Observations have pointed out the Arctic shelves as a possible region for the halocline formation, through brine convection and haline convection occurring in this region during the ice formation periods.

Here we investigate the processes at play for the formation of the Arctic halocline and the timescale on which they operate using an original numerical method. A quantitative Lagrangian diagnostic is applied to the 3D outputs of a model historical hindcast performed with the global ocean/sea-ice high resolution DRAKKAR model (12 km resolution in the Arctic Ocean), in order to determine the regions and time periods where and when the halocline is formed. Our results emphasize the role of the Barents Sea and the Arctic shelves for the halocline formation. We also investigate the origin of the large seasonal and interannual variability in halocline formation, which is link to variations in sea ice conditions and atmospheric forcing.
Viscous-Plastic sea-ice solutions with Elastic-Viscous-Plastic sea-ice solvers

Most dynamic sea ice models for climate type simulations are based on the viscous-plastic (VP) rheology. The resulting stiff system of partial differential equations for ice velocity is either solved implicitly at great computational cost, or explicitly with added pseudo-elasticity (elastic-viscous-plastic, EVP). The more popular, because apparently faster EVP scheme has been found to create noisy solutions that do not converge to the VP rheology. A slight modification re-interprets EVP as a pseudotime VP solver and thus salvages the convergence to VP. In addition, the modification regularizes the EVP solutions so that they can be used in climate simulations at relatively low cost compared to efficient implicit methods. We present comparisons of two variants of the new EVP scheme with converged VP solution in Arctic. At coarse resolution (grid cell width of about 27km), the EVP solutions are very similar to the VP solutions. At higher resolution (4.5km), convergence of all schemes is more difficult to achieve and the solutions are obviously different.
Towards a merged sea ice concentration product at 1 km resolution from passive microwave and optical observations

Although it covers only about 1.5% of the Earth's surface, Arctic sea ice is a key element of the climate system with far-reaching impacts e.g. on mid-latitude weather conditions in Europe and Northern America. Further, various feedback loops make it a sensitive indicator of long-term climatic changes. The percentage of ice within a given area (sea ice concentration) is of special importance as it regulates the ocean/atmosphere exchange, determines primary production rates, is a main input variable for numerical models and provides valuable information about the safety of shipping routes. Since almost 40 years, passive microwave measurements have been used for monitoring sea ice in general and sea ice concentration in particular. Their capability to provide year-round daily measurements almost independently of the state of the atmosphere along with their good spatial coverage make them a powerful tool for sea ice concentration retrieval. However, they suffer from a coarse spatial resolution of today 5 kilometers at maximum. Optical measurements provide complementary error characteristics: While depending on daylight in the visible spectrum and cloud-free conditions in the whole optical spectrum, they come with spatial resolutions of up to 30 m for local coverage and 250 m to 4 km for daily Arctic-wide coverage. We present sea ice concentrations from optical data at a resolution of 1 km and their evaluation against a higher-resolution dataset. At a later stage, we plan a quantification of the uncertainties of passive microwaves and optical sea ice concentration measurements. They shall be used to develop a model which minimizes and produces for the first time a consistent product comprising passive microwave and optical sea ice concentrations at a resolution of 1 km. This unprecedented high resolution will, among other applications, be of importance for local and regional studies, forcing of high-resolution local models and for more accurate analysis of the local sea ice conditions for ships.
Effects of tides on Riverine and Glacial freshwater transport in the Arctic Ocean

In this study we use a novel pan-Arctic sea NENO-shelf ice-ocean coupled model, to examine the effects of tides, river runoff and vertical mixing schemes on sea ice and the mixing of water masses. Several 20-year long (1990-2010) simulations were performed: with explicitly resolved tides and without any tidal dynamics, with climatology river runoff, Dai et al., 2009 database and freshwater source from melting Greenland glaciers. The results have been compared with sea ice volume and concentration trends and temperature and salinity profiles from World Ocean Database. We compared the following characteristics: potential energy anomalies, depth of halocline, mixed layer depth, salinity at the subsurface layer.
Ma, Barry: University of Washington, APL, barry@apl.washington.edu

The variations and trends of vertical Ekman transport in the Arctic region

We examine the satellite data derived Ekman velocity from 1970 to 2014 in the Arctic. Two significant regions, the Canadian basin and Eurasian basin, are identified using the EOF and objective method. The seasonal to decadal variations and trends are described.
Manucharyan, Georgy: California Institute of Technology, USA, gmanuch@caltech.edu

The role of mesoscale eddies in the wind-driven Beaufort Gyre variability

A set of recent studies emphasized the role of mesoscale eddies in setting equilibrium halocline properties of the Ekman-driven Beaufort Gyre. However, its halocline varies significantly on interannual to decadal time scales and affects the freshwater content (FWC) of the entire Arctic Ocean. Here, we explore the role of eddies in the gyre variability subject to time-dependent and spatially inhomogeneous Ekman pumping. Following the Transformed Eulerian Mean framework, we develop a theory that links the FWC variability to the stability of the large scale gyre, defined as the inverse of its equilibration time. We verify our theory's agreement with eddy-resolving numerical simulations and demonstrate that the gyre stability is explicitly controlled by the mesoscale eddy diffusivity. The model suggests that a correct representation of the halocline dynamics requires the eddy diffusivity of 300±200 m²/s, which is lower than what is used in most low-resolution climate models.

We demonstrate that on seasonal time scales, FWC variability is explicitly governed by the Ekman pumping, whereas on interannual and longer time scales eddies provide an equally important contribution. In addition, only large-scale Ekman pumping patterns can significantly alter the FWC, with spatially localized perturbations being an order of magnitude less efficient. Incorporating the eddy effects, we introduce a FWC tendency diagnostic -- the Gyre Index -- that can be conveniently calculated using observations of surface stress and halocline slope only along the gyre boundaries. We demonstrate its strong predictive capabilities in the eddy-resolving model forced by stochastic winds and speculate that this index would be of use in interpreting FWC evolution in observations as well as in numerical models.
Marbouti, Marjan: University of Helsinki, marjan.marbouti@helsinki.fi

Deriving Sea ice information from Coastal radar data in X band and Satellite SAR imagery in C, and X bands, around Hailuoto island, during the ice formation and melting period

M. Marbout1, A. Gegiuc1, E. Rinne1

1Finnish Meteorological Institute, Marine Research, Erik Palménin aukio 1, 00560, Helsinki, Finland

Synthetic Aperture Radar (SAR) is one of the widely remote sensing data sources used in sea ice monitoring, analysis and shipping activities, and also one of the main sources of information used in the operational ice charting by the Finnish Ice Services. However, besides the coarse time span availability, the backscattered signal from SAR varies strongly with the frequency and the local ice conditions, and therefore cannot be used alone in any situation when the ice information is needed. Where available, coastal radars are used instead for real time sea ice monitoring having a similar operation principle, with only difference being in the incidence angle.

Here, we look into the retrieval of different ice information from radar data provided in X-band and several SAR data frames available in C, L and X bands, during the ice formation and melting period around Hailuoto island, in the Baltic Sea.
A coordinated set of Arctic Ocean modeling experiments are run under the auspices of the FAMOS project. Our aim is to compute and compare ‘Climate Response Functions’ (CRFs) — the transient response of key observable indicators such as seaice, freshwater content (FWC), fluxes across important Arctic gateways, among other metrics — to abrupt ‘step’ changes in forcing fields (i.e. winds, freshwater and heat sources) across a number of Arctic models. Convolutions of known or postulated time-series of these forcing fields with their respective CRFs then yields the (linear) response of these observables. Here, we illustrate the idea by showing results using a coarse-resolution, Arctic regional configuration of the MITgcm model. Sensitivity of the FWC of the Beaufort Gyre to step changes in the Beaufort High is documented and rationalized in terms of the resulting anomalous circulation and our understanding of key mixing and eddy processes. Convolutions of the CRF with the time-history of the Beaufort High, yields the predicted response and is used to interpret how the FWC has changed over time in recent decades. Finally we argue that a computation of Arctic CRFs across different ocean models, in the context of observed metrics, would provide an interesting comparison of the models.
Cascading off the West Greenland Shelf: A numerical perspective

When dense waters form and accumulate on the continental shelf, they eventually slide down the slope and reach intermediate and deep layers of the ocean. This process, known as cascading, plays an important role in ventilating the deep ocean. Among the numerous documented cases of cascading there are several that take place in high latitudes, where the heat loss and salinization from sea ice formation contribute to the production of a large volume of dense water. Although cascading was observed on the eastern Greenland shelf, an equivalent event at the western side was never reported. In this study, we analyze potential regions for shelf-basin exchange on the western Greenland shelf from a numerical perspective. The results from a 2002-2014 NEMO simulation show that cascading happens sporadically at Davis Strait. Each event starts around February and persists until the end of May. Between 2007 and 2013 no event was detected because the freshwater content in Davis Strait increased significantly, preventing the shelf water to reach a density which would allow it to flow near the bottom. The water that cascades from this part of west Greenland shelf goes, mostly, to the deep Baffin Bay, suggesting that those waters would take part on the formation of Baffin Bay Deep Water.
Masłowski, Wiesław: Naval Postgraduate School, maslowsk@nps.edu

Modeling the Arctic at increasing spatio-temporal resolution: results and challenges

Not available
Equilibration of the Beaufort Gyre by baroclinic eddies

Gianluca Meneghello, John Marshall and J-M Campin

The Arctic’s fresh water increase of the past thirty years is in large part concentrated in the Beaufort Gyre (see, e.g. Haine 2015). In order to better understand the main mechanisms behind this change, we build on previous theoretical models by Marshall, Karsten (2002) and Manucharyan (2015) in which the effect of the wind pumping down freshwater into the gyre is equilibrated by lateral 'bolus fluxes' by eddies. We identify key non-dimensionless parameters and review scaling laws governing the fresh water content of the gyre.

Using data from previous idealized rotating fluid experiments and new numerical experiments, we show that a single dimensionless parameter is sufficient to characterize the buoyancy anomaly over a wide range of values. Additionally, comparison with results for the Antarctic Circumpolar Current suggests that the same scaling holds in both cases. Finally, theoretical and numerical predictions are compared with observations.
Submesoscale dynamics under sea ice

Observations in the Arctic Ocean’s Canada Basin suggest that upper-ocean dynamics under sea ice might be significantly weaker than in the temperate oceans. In particular, observational evidence suggests that currents developing under sea ice present weak or absent submesoscale (order 1 km horizontal scale) dynamics, in contrast with mid-latitude oceans characterized by energetic dynamics at these scales. We present numerical model results of the upper ocean under sea ice, set in context with Arctic observations, to describe the submesoscale flow field and its evolution under multi-year sea ice. During the summer, ice melt generates a shallow mixing layer which isolates the surface from deeper, warmer and saltier waters. The upper ocean is strongly stratified and dominated by intense density fronts, however the resulting baroclinic activity is weak due to large ice-ocean stresses and thin mixed layers. During most of the winter season, mixed-layer deepening is associated with sea-ice growth and injection of brine. Convective brine plumes generate weak lateral density anomalies and balanced baroclinic flows. During both summer and winter, the submesoscale flow field is much less energetic than in the midlatitude, ice-free oceans. We diagnose and explore these dynamics, demonstrating the important implications for parameterizing the submesoscale flow field in GCMs in the Arctic, as well as to ocean-to-ice heat fluxes.
Potential predictability of Arctic sea-ice linear kinematic features in high-resolution ensemble simulations

Linear kinematic features (LKFs) in sea ice, potentially important for short-term forecasts and for climate simulations, emerge as viscous-plastic sea ice models are used at high resolution (~4.5 km). Here we analyze the short-range (up to 10 days) potential predictability of LKFs in Arctic sea ice using an ocean/sea-ice model with a grid point separation of 4.5 km. We analyze the sensitivity of predictability to idealized initial perturbations, mimicking the uncertainties in sea ice analyses, and to growing uncertainty of the atmospheric forcing caused by the chaotic nature of the atmosphere. For the latter we use different members of ECMWF ensemble forecasts to drive ocean/sea-ice forecasts. For our analysis, we diagnose LKFs occurrence and investigate different sea ice characteristics. We find that forcing uncertainty (due to limited atmospheric predictability) largely determines LKF predictability on the 10-day time scale. When it comes to metrics, we demonstrate that spatial correlation, although a useful metric to measure some aspects of deformation field similarity, fails to detect LKF similarity when LKFs are only slightly shifted in space. The Modified Hausdorff Distance (MHD) appears to be a more appropriate metric, but it can be misleading if the LKF density is very high, for example due to artificial LKFs caused by spurious small-scale perturbations of the sea-ice initial state.
Benefits of enhanced oceanic and atmospheric resolution for Arctic sea ice predictability

Rapid and dramatic changes that can have profound impacts on human activities and ecosystems have been observed in the Arctic over the past decades. As a result, there has been increased interest in better understanding the dynamical processes that drive not only the long-term variability but also the year-to-year variability of sea ice area and its seasonal predictability. Previous modeling studies have shown that predictability of summer sea ice area can be increased by the persistence of Central Arctic volume anomalies from one summer to the next (Blanchard et al. 2011, Tietsche et al. 2014, Day et al. 2014, Bushuk et al. 2014), whereas during winter, the ocean heat convergence is a key player in setting the location of the mean ice edge (Bitz et al. 2005). Such processes that play a key role in seasonal sea ice predictability are not well represented in most global coupled models partly because of the too coarse horizontal resolution in their atmospheric and oceanic components. For example, Kwok (2011) showed that most climate models do not properly simulate the blocking high over the Beaufort gyre, leading to a sea ice cover that is too thin and has a misplaced maximum. We analyze here control simulations from various global coupled models from GFDL and CNRM, which are eddy-resolving or eddy-permitting in the ocean, and have a 50 km resolution in the atmosphere. We assess the mean-state features that are improved with respect to classical coarse resolution global climate models and that are important for Arctic sea ice predictability. We highlight however a number of remaining biases and stress the need for an Arctic-oriented approach when tuning a model that is going to be used to assess Arctic sea ice predictability. This can be more easily done in a regional framework given the high-resolution that is needed to represent Arctic dynamics.
Warm and saline Atlantic Water originating in the North Atlantic enters the Arctic Ocean through the Fram Strait and is present below the Arctic Ocean sea ice in the deep part of the basin. Understanding the influence of Atlantic Water and ocean heat fluxes on the Arctic sea ice is important for determining causes of mean thickness change over time and the new Arctic seasonal ice cover. Here we present hydrographic and current observations collected between January and June 2015 on the Norwegian Young Sea Ice Cruise (N-ICE2015) in the region north of Svalbard. The observations are complimented with simulations from a global climate model and a one dimensional sea ice growth model.

Comparison with historical data shows that the new 2015 observations fill major gaps in existing climatologies, and help describing important processes linking changes in regional Atlantic Water heat transport and sea ice cover.

We find that Atlantic Water characteristics north of Svalbard are mainly controlled by the distance along the inflow path, and by changes in inflowing Atlantic Water temperature in the Fram Strait. Atlantic Water characteristics north of Svalbard are also largely affected by local sea ice growth and melting as well as tidal induced mixing on the shallow Yermak Plateau. Atlantic Water impact on ice growth during winter is studied using the column model showing that shallow and warm Atlantic Water efficiently reducing sea ice growth as expected. The impact on bottom melting is found throughout the year in the climate model simulations. The new thinner sea ice cover is likely more affected by Atlantic Water, and, we therefore expect a closer link between the Atlantic Water and the sea ice north of Svalbard in the future.
Shelf-Basin exchange in the Labrador Sea and Baffin Bay

Questions related to shelf-basin exchange, focussing on low salinity upper ocean waters, are considered for the Labrador Sea and Baffin Bay. A suite of high resolution numerical modelling simulations are used in conjunction with historical oceanographic observations. Analysis focusses on locations (and amount) of exchange, processes driving the exchange (e.g. storms, wind driven transport, eddies) and links to the melting of the Greenland Ice Sheet.
Investigation of the Dominant Processes controlling Volume, Heat, and Freshwater Transports through the Bering Strait

The 85-km wide Bering Strait serves as the only connection between the Pacific and Arctic oceans. Recent observations have shown increases in northward volume, heat and freshwater fluxes through this narrow and shallow strait, with implications for the prolongation of the ice-free season and enhancement of nutrient supply to the ecosystems in the Chukchi Sea. Further downstream the increased flux influences watermass transformations, heat and freshwater budgets, and stratification in the upper Arctic Ocean. Thus, quantifying the mechanisms that control the mean and variability of the flow through this vital gateway is important for understanding and predicting changes in the Arctic. Here, to identify these key mechanisms, we use 14 years of mooring observations from the Bering Strait and the non-linear inverse-modeling framework of the Arctic Sub-polar gyre sTate Estimate (ASTE). ASTE is a synthesis of the MITgcm coupled ocean-sea ice model with all available satellite and in-situ observations of sea ice and ocean, including hydrographic and mooring data from the Beaufort Sea and the major Arctic gateways (Fram, Bering, and Davis straits), and is developed using the estimation infrastructure of the ECCO consortium. In ASTE’s optimization mode, after 19 iterations, misfits to ITP hydrography and SSM/I ice concentration have reduced by 80% and 50% respectively. With ASTE as the baseline solution, we use the “adjoint” tool to compute the sensitivity of the model transports of volume and water properties at the Bering Strait to a set of control variables including ocean hydrography and atmospheric forcing. The partition of dominant sensitivities is connected to the data in two ways: the data serve as a guide to the interpretation of the controlling process while the model sensitivity can provide insights into processes which can be further tested with additional observations.
Arctic freshwater variability in the 21st century in a regionally coupled climate model

To investigate changes in the Arctic freshwater cycle in the 21st century, we use a regionally coupled climate model with high resolution in the Arctic, consisting of the global ocean-sea ice model MPIOM and the regional atmosphere model REMO. As external forcing we use global middle and high emission scenario experiments (RCP4.5 and RCP8.5) of the CMIP5 experiments. We are especially interested in the fate of liquid freshwater stored in the Arctic.
Arctic sea ice change from 1850 to present – where, when, how?

The Arctic sea ice cover has decreased dramatically in recent decades. The focus has typically been on the end of the melt season when decreasing trends are largest and the sea ice extent is at its minimum. However, decreasing sea ice trends in the Arctic Ocean are now significant for all months and in all regions. Examining satellite observations of sea ice concentration since 1979 and observed sea ice extent since 1850, we provide increased understanding of the ongoing observed changes by focusing on regional variability in winter and summer. We find that the Arctic Ocean sea ice cover has two distinct seasonal modes of variability throughout the observational record: The winter Arctic Ocean sea ice loss and variability take place in the Barents Sea, whereas change in summer is due to variations in the Beaufort, Chukchi, East Siberian and Laptev Seas. The recent winter sea ice loss, occurring in the Barents Sea, is driven by increased ocean heat transport, associated with internal climate variability. In contrast, the summer loss, causing new open-water areas in the Canadian and Russian Arctic, is largely due to increased surface atmospheric fluxes related to global warming.
Modeling Sea Ice Decline and Impacts on Coastal Processes

In the Arctic, the duration of sea ice-free conditions limits the time over which the most intense coastal processes occur. Rates of coastal bluff erosion are a function of the geometry and substrate of the coast, and of storm frequency, duration, magnitude, and wave field and setup.

Observations over the last 30 years showed dramatic decline of sea-ice coverage, and expansion of the open water season along the Beaufort Sea. Using a newly developed geomorphic bluff toppling model, we demonstrate that accelerated erosion occurs in response to longer open-water season. Another major controls in the model experiments are water temperature and water level setup due to storm events.

We compared predictions of the Community Climate Earth System Model – Large Ensemble with satellite observations over the period 1979-2014 and find that in most places the observations fall within the predicted range of open water days. Predictions show that the open water season will continue to expand through the 21st century.

We now further our coastal modeling, to better understand river and coastal interactions and so that they can be driven by the CCESM sea ice conditions. Coupled modeling is designed using the CSDMS –Community Surface Dynamics Modeling System interfaces and modeling framework.
Water mass transformations in the Arctic Ocean are studied using a recently developed salinity–temperature (S–T) framework. The framework allows the water mass transformations to be succinctly quantified by computing the surface and internal diffusive fluxes in S–T coordinates. This study shows how the method can be applied to a specific oceanic region, in this case the whole Arctic Ocean, by including the advective exchange of water masses across the boundaries of the region. Based on a simulation with a global ocean circulation model, we examine the importance of various parameterized mixing processes and surface fluxes for the transformation of water across isohaline and isothermal surfaces in the Arctic Ocean. The model-based results reveal a broadly realistic Arctic Ocean where the inflowing Atlantic and Pacific waters are primarily cooled and freshened before exiting back to the North Atlantic. In the model, the water mass transformation in the T-direction is primarily accomplished by the surface heat flux. However, the surface freshwater flux plays a minor role in the transformation of water toward lower salinities, which is mainly driven by a downgradient mixing of salt in the interior ocean. Near the freezing line, the seasonal melt and growth of sea ice influences the transformation pattern.
The Atlantic Water boundary current north of Svalbard

Atlantic Water (AW) carries a vast amount of heat and salt into the Arctic Ocean, circulating through the various basins via a system of boundary currents. This fundamentally influences the hydrographic structure of the Arctic and ventilates the lower halocline. Despite the importance of AW to the Arctic system, we presently don't know how much AW is transported in the boundary current system and how the water is transferred into the interior. Here we present results from a shipboard hydrographic/velocity survey carried out in September 2013 and from a year-long mooring array (2012-2013) used to study the AW current north of Svalbard, roughly 250 km to east of Fram Strait. The survey revealed that the current is O(40 km) wide, surface intensified, and meanders as it flows to the east. This is in line with its potential vorticity structure which suggests that the current is baroclinically unstable and should form the AW eddies that have been observed offshore of the boundary in this region. The transport of the current suggests that the two branches of AW exiting Fram Strait – the Yermak Plateau branch and continental slope branch – have combined into a single flow by 30oE. Only a small portion of AW enters the Kvitøya Trough where its T/S signature is quickly eroded. Using the mooring data we assess the mean properties of the current and the seasonal changes of the AW component.
Freshwater fluxes under landfast sea ice in Southeast Hudson Bay

Freshwater plays an important role in climate impacting on the ocean's vertical stability and ice-formation. Recent models showed that relatively small variations in freshwater amount flowing into the North Atlantic could cause large climate changes.

An ice-tethered mooring consisting of 9 conductivity and temperature (CT) sensors and acoustic Doppler current profiler (ADCP) was deployed during January-March 2014 in a narrow channel between Broomfield and O’Leary islands located in the south east tip of Belcher islands group in HB as a part of an oceanographic monitoring program in that region. CTD profiles at various locations from north to south around Belcher islands show increase of warmer and saltier water in bottom layer. Such layer preserved in the south due to presence of salinity/density stratification that prevented vertical mixing. The presence of fresher surface layer is caused by cyclonic circulation of river runoff water in Hudson Bay. The mooring recorded episode of surface under-ice warm water which might affect the thickness and formation of the land fast ice. Our analysis has goal to estimate freshwater fluxes and compare with modelled ones.
Land-fast ice is an important component of the Arctic system, capping the coastal Arctic waters for most of the year and exerting a large influence on ocean-atmosphere heat exchanges. Yet, the accurate representation of land-fast ice in most large-scale sea ice models remains a challenge, part due to the difficult (and sometimes non-physical) parameterization of ice fracture. In this study, a linear elastic model is developed to investigate the internal stresses induced by the wind on the land-fast ice, modeled as a 2D elastic plate. The model simulates ice fracture by the implementation of a damage coefficient which causes a local reduction in internal stress. This results in a cascade propagation of damage, simulating the fracture of a land-fast ice cover.

The modeled land-fast ice cover is able to produce ice arches (or ice bridges), but these formations are sensitive to the choice of failure criterion. The impact of the parametrised cohesion, tensile and compressive strength on the ice arches shape and stability is investigated. To estimate the large scale mechanical properties of land-fast ice, these results are compared to set of land-fast ice break up events and ice bridge formations observed in the Siberian Arctic and the Canadian Arctic Archipelago. These events are identified using brightness temperature imagery from the MODIS (Moderate Resolution Imaging Spectroradiometer) Terra and Aqua satellites, from which the position of the flaw lead is identifiable by the opening of polynyi adjacent to the land-fast ice. The model setting that best reproduce the scale of the observed break up events is used to provide an estimation of the strength of the ice relative to the wind forcing.
The study of the Arctic Ocean sensitivity to variations of solar radiation

Platov G., and V. Fedorov

The results of a set of numerical experiments to study a sensitivity of the Arctic ice-ocean system to variation of solar radiation will be presented. The aim is to understand how the aspects of Sun-Earth geometry and astronomy could affect sea ice and characteristics of the upper ocean. The intensity of solar radiation is the key factor driving the climate system and should be described most accurately. It depends on the distance between Sun and Earth, which varies seasonally because of ellipsoidal orbit, but it is not clear whether this variation is important comparing to other forcings. Non-sphericity of the Earth surface, precession of the Earth axis and interannual variations of Solar activity are also examined.
Proshutinsky, Andrey: Woods Hole Oceanographic Institution, aproshutinksy@whoi.edu

The Beaufort Gyre freshwater content (FWC) reaches absolute maximum in 2015

A. Proshutinsky, R. Krishfield, M-L. Timmermans, W. Williams, J. Toole, K. Shimada, D. Dukhovskoy, J. Yang, S. Nishino

Hydrographic surveys of the Arctic’s Ocean Beaufort Gyre (BG) region, year-round mooring observations and data from Ice-Tethered profilers are used to analyze the freshwater content, driving forces, sources and sinks of fresh water in the region. The liquid freshwater content in summer increased 5410 km$^3$ from 2003 to 2010, decreased a bit in 2011-2014, but in 2015 reached its absolute maximum of 22,600 km$^3$ or 5600 km$^3$ over climatology. Negative trend in sea ice freshwater content attesting to the ablation or removal of the older sea ice from the BG have been observed after 2007. It is concluded that since 2007, the fresh water flux to the ocean in summer from melting sea ice has not been compensated by ice growth in winter and served as a source of freshwater increase in the center of BG region forced for accumulation by strong convergence of Ekman transport under anticyclonic winds.
Provost, Christine: LOCEAN – CNRS, France, cp@locean-ipsl.upmc.fr

Observations of snow-ice formation in a thinner Arctic sea ice regime during the N-ICE2015 campaign: influence of basal ice melt and storms

Seven ice mass balance instruments deployed on different first-year and second-year ice floes, within a distance of 50 km near 83° N representing variable snow and ice conditions, documented the evolution of snow and ice conditions in the Arctic Ocean north of Svalbard in Jan-Mar 2015. Frequent profiles of temperature and thermal resistivity proxy were recorded to distinguish changes in snow depth and ice thickness with 2 cm vertical resolution. Four instruments documented snow-ice formation which was clearly detectable in the simultaneous changes in thermal resistivity proxy, increased temperature and heat propagation through the underlying ice. Snow-ice formation restored a positive freeboard after storm-induced break-up of snow-loaded floes and/or after loss of buoyancy due to basal ice melt. In the case of break-up, when the ice was cold and not permeable, the rapid snow-ice formation, probably due to lateral intrusion of seawater, led to snow-ice layers at the ocean freezing temperature (-1.88°C). After the storm the instruments registered basal sea-ice melt over warm Atlantic waters. Basal ablation reached 71 cm and ocean heat fluxes peaked at 400 Wm-2. The warm ice was permeable and the gradual snow-ice formation probably involved vertical intrusion of brines and led to colder snow-ice (-3°C). In both cases, the exothermic reaction warmed the underlying sea-ice. N-ICE2015 campaign provided the first documentation of significant snow-ice formation in the Arctic ice pack with a fraction of snow-ice to total ice thickness 28%. Snow-ice formation may become a more important process in a thinner-ice Arctic.
Sea ice cover in the Arctic has declined rapidly in recent decades. The much faster than projected retreat suggests that climate models may be missing some key processes, or that these processes are not accurately represented. The entrainment of heat from the mixed layer by small-scale turbulence is one such process. In the Canadian Basin of the Arctic Ocean, relatively warm Pacific Summer Water (PSW) resides at the base of the mixed layer. With an increasing influx of PSW, the upper ocean in the Canadian Basin has been getting warmer and fresher since the early 2000s. While studies show a correlation between sea ice reduction and an increase in PSW temperature, others argue that PSW intrusions in the Canadian Basin cannot affect sea ice thickness because the strongly-stratified halocline prevents heat from the PSW layer from being entrained into the mixed layer and up to the basal ice surface. In this study, we try to resolve this conundrum by simulating the turbulent entrainment of heat from the PSW layer to a moving basal ice surface using large eddy simulation (LES). The LES model is based on a high-fidelity spectral approach on horizontal planes, and includes a Lagrangian dynamic subgrid model that reduces the need for empirical inputs for subgrid-scale viscosities and diffusivities. This LES tool allows us to investigate physical processes in the mixed layer at a very fine scale. We focus our study on summer conditions, when ice is melting, and show for a range of ice-drift velocities, halocline temperatures, and halocline salinity gradients characteristic of the Canadian Basin how much heat can be entrained from the PSW layer to the sea ice. Our results can be used to improve parameterizations of vertical heat flux under sea ice in coarse-grid ocean and climate models.
Owing to the ice cover and strong stratification, both nutrients and light are scarce in the Arctic Ocean. Therefore the Arctic Ocean is regarded as fairly unproductive. However, spatial patterns in the limiting factors exist, and the continental shelves where nutrient-rich Pacific or Atlantic water flows into the Arctic are often seen as future hotspots for increases in primary production. Intense ice melt in summer around the margins of the ice pack leads to strong seasonal stratification which can trigger algal blooms, but also restricts nutrient supply from below and affects the transfer of near-inertial energy into the deep basins that drives nitracline turbulence.

Turbulent microstructure and high-resolution nitrate concentration data were collected in the Fram Strait-Barents shelf slope-western Nansen Basin area during 2012-2015 using ice drift camps, vessel-based surveys and a mooring, covering all seasons. Combining these with central Arctic Ocean data from the North Pole Environmental Observatory and the Beaufort Gyre Exploration Project, we are now increasingly able to quantify the nitrate supply to the photic zone both in the central Arctic (on average Redfield-equivalent to 1--2 gC/m², leading to a total export production of around 1.5--3 gC/m²) and the seasonal ice zone (0.3--0.7 mmol N/d/m² in the Atlantic sector during the summer months). Interestingly, given plausible trends in freshwater runoff and stratification from a climate model, end-of-century increases in the western Nansen Basin might be balanced by decreases in the rest of the central Arctic, leading to a negligible net change in nitrate supply over the deep basins. On the relatively productive shelves, fall and winter mixing accounts for the bulk of the net community production, although sea ice melt couples the annual nutrient budget to the light input via the seasonal pycnocline.

Increases in Arctic marine primary production, both occasionally predicted and observed by remote sensing, are therefore most likely due to enhanced regeneration of available nutrients and thus not available to vertical export or harvest by higher trophic levels.
A new record low in Arctic sea-ice maximum winter extent has been observed in 2016 as a consequence of an anomalous warm winter. The high winter temperatures also lead to reduced thermodynamic growth rates and hence a thinner sea-ice cover in spring, which also has consequences for the following melt season. In addition to the summer conditions, it is crucial how thick and resistant the ice cover is in spring, at the end of the freezing period. Previous studies have shown that preconditioning through a thinned ice cover substantially contributed to the ice extent record minimum in September 2012. Finally, monitoring the sea-ice thickness is essential for the understanding of the rapid ongoing changes in the Arctic sea ice.

During the last years, significant progress has been made in retrieving sea-ice thickness from satellite observations, especially by radar altimetry. Altimeter range measurements provide surface elevations, which are referenced to the sea level to obtain freeboard that can be transformed into sea-ice thickness by assuming hydrostatic equilibrium. The current CryoSat-2 mission achieves great improvements in the along track resolution compared to previous radar altimeter missions like ERS or Envisat. The latitudinal coverage contains major parts of the Arctic marine ice fields where previous missions left a big data gap around the North Pole and especially over the multiyear ice zone north of Greenland. Moreover, radiometer measurements as from the SMOS satellite mission can be converted into ice thickness to complete observations over thin ice regimes. With these unique data sets, changes in sea-ice thickness can be investigated in the context of the rapid reduction of the Arctic sea-ice cover.

Here, we present how the Arctic-wide anomalous warm winter temperatures in 2016 have affected the thermodynamic ice growth and hence the sea-ice thickness in spring. We consider merged CryoSat-2 and SMOS ice thickness retrievals of the past six years to evaluate ice thickness and volume anomalies in 2016 with respect to previous years, also considering the role of first-year and multiyear ice. Finally, consequences of sea-ice thinning in the Arctic are discussed.
Ridenour, Natasha: University of Alberta, ridenour@ualberta.ca

Modelling freshwater dynamics and pathways in the Hudson Bay Complex using the ANHA4 configuration

The Hudson Bay Complex (HBC) receives between 850 to 1000 Km3 of river discharge per year which flows to the North Atlantic via Hudson Strait. As there are limited observations in this isolated region, the numerical ocean model, NEMO, combined with the ANHA4 configuration, is used to model freshwater dynamics and pathways associated with river discharge and sea ice melt. The present work establishes the freshwater budget and exchange in each component of the HBC, in addition to the main freshwater pathways. Quantitative estimates of regional eddy and Ekman transport of freshwater are also presented. Future work includes modelling freshwater eddies in the Hudson Strait outflow.
Quantifying the influence of atmospheric patterns and storms on the timing of fall freezeup

The amount of shear produced at the base of the mixed layer during Arctic storms is computed using a 1-D slab model forced by wind stress from the WRF-downscaled ERA Interim Reanalysis dataset. Shear at the bottom of the mixed layer plays a key role in mixed layer deepening, and is often dominated by long-lived inertial frequency oscillations of the mixed layer. Inertial current oscillations can be produced when the ratio of the storm horizontal scale to track speed equals the inertial period, i.e. $L/V = T$. We investigate whether or not the length scale and velocity of storms is appropriate to excite resonance of inertial motion in the Arctic. Mixed layer inertial currents forced by storms can propagate downward, important for mixing of heat from below. This can have consequences for freeze-up timing, which is currently poorly represented in operational prediction models.
State of the sea ice during N-ICE2015

The N-ICE2015 cruise, led by the Norwegian Polar Institute (NPI), was a drift experiment with the research vessel R/V Lance from January to June 2015. The ship started the drift at 83°14.45' N, 21°31.41' E in the region north of Svalbard. When she drifted free the ship was reinserted into the ice at similar latitude and the drift was repeated. In total 4 ice stations where installed during the 6 months; studying the complex ocean-sea ice-atmosphere system with an interdisciplinary approach.

During the N-ICE2015 cruise extensive ice thickness and snow depth measurements were performed during both winter and spring conditions. After the end of the N-ICE2015 cruise, the sea ice drifted south-west into the Fram Strait where the same sea ice pack was measured again in summer and autumn conditions during the NPI Fram Strait cruise in August and September 2015. To track the ice drift and to compliment the both field campaigns we use the ice and snow mass balance data from the autonomous buoys at the start of the N-ICE2015 cruise. Total ice and snow thickness was measured with ground-based and airborne electromagnetic instruments like EM31, GEM, and EM-bird; snow depth was measured with a magnaprobe. The comparison of the local datasets to regional scale measurements with the airborne EM-bird and the ice and snow mass balance buoys confirm that the local, smaller scale measurements on the ice stations are representative for the area. The ice mass balance data set can also be set into a temporal context by comparison to data from previous cruises in the same area. Snow and ice thickness measurements were performed on repeated transects to quantify the ice growth or decay as well as the snow accumulation and melt rate. Additionally, we collected large numbers of independent values on surveys to determine the general ice thickness distribution. For calibrating electromagnetic surveys, direct measurements were made regularly in drillholes. Simultaneously, also freeboard was measured, which is an important parameter for altimeter-derived ice thickness datasets like CyoSat-2.
The downward trend in Arctic sea ice extent is one of the most dramatic signals of climate change during recent decades. Comprehensive climate models have struggled to reproduce this, typically simulating a slower rate of sea ice retreat than has been observed. However, this bias has been substantially reduced in models participating in the most recent phase of the Coupled Model Intercomparison Project (CMIP5) compared with the previous generation of models (CMIP3). This improvement has been attributed to improved physics in the models. Here we examine simulations from CMIP3 and CMIP5 and find that simulated sea ice trends are strongly influenced by historical volcanic forcing, which was included in all of the CMIP5 models but in only about half of the CMIP3 models. The volcanic forcing causes temporary simulated cooling in the 1980s and 1990s, which contributes to raising the simulated 1979-2013 global-mean surface temperature trends to values substantially larger than observed. This warming bias is accompanied by an enhanced rate of Arctic sea ice retreat and hence a simulated sea ice trend that is closer to the observed value. We find that both generations of climate models simulate Arctic sea ice that is substantially less sensitive to global warming than has been observed. The results imply that the inclusion of volcanoes explains much of the difference in Arctic sea ice trends between CMIP3 and CMIP5.
Estimates of volume, heat and freshwater budgets for the Arctic Mediterranean and North Atlantic and their relation to the main physical processes: Insight from the EU-NACLIM observations

The EU NACLIM (North Atlantic Climate) project aims to understand the forcing of the North Atlantic circulation, and its importance for the climate of northwestern Europe. NACLIM comprises extensive modelling studies of the atmosphere, ocean and climate, but here mainly the oceanographic observations are presented. The core observation areas are the North Atlantic Subpolar Gyre and the Greenland-Scotland Ridge, separating the North Atlantic from the Arctic Mediterranean Sea. These are the areas, where the waters of the lower limb of the Atlantic Meridional Overturning Circulation (AMOC) are formed and sink into the deep North Atlantic to return southward, mainly in the Deep Western Boundary Current (DWBC). The exchanges across the Greenland-Scotland Ridge, both the northward flowing Atlantic water and the returning dense waters, have been monitored over decades, as have the circulation in the Subpolar gyre and the convection and mode water formation in the Labrador Sea. These studies are extended southward to the RAPID array located in the Subtropical gyre at 26oN to capture the AMOC further south, and northward into the Arctic Mediterranean Sea and the formation area of the densest water in the DWBC. In the Subtropical gyre the ocean circulation is mainly forced by the wind, while in the Subpolar gyre the atmospheric influence, in addition to wind forcing, also has a large thermodynamic component, changing the characteristics of the water masses and the density structure of the gyre. The importance of cooling and freshwater input increases in the Arctic Mediterranean Sea. Variability and a recent declining trend of the MOC strength have been observed in the Subtropical gyre at the RAPID array. By contrast, both the northward flow across the Greenland-Scotland Ridge and the overflows have remained steady during the observation periods. A warmer climate could reduce the cooling and the density increase in the Atlantic water. The sea ice extent and volume are presently declining and there is a possibility that not enough sea ice, formed elsewhere in the Arctic Ocean, is drifting over the Atlantic layer to create the low salinity upper layer in the Nansen Basin. Should this upper layer disappear, it could actually lead to more overflow water being produced.
Rynders, Stefanie: University of Southampton, S.Rynders@soton.ac.uk

Modelling dynamics of The Marginal Ice Zone

The Marginal Ice Zone (MIZ) in the Arctic has been expanding during the past three decades and is projected to become an ever more prevalent part of the ice covered seas. The need for better climate predictions, along with growing economic activity in the Polar Oceans, necessitates climate and forecasting models that can simulate thinner, fragmented sea ice with greater fidelity. Current models do not account for ocean waves in the MIZ; they neither simulate the effects of ice fragmentation, nor include sea ice rheology that represents both the thinner pack ice and MIZ. These processes affect the momentum transfer to the ocean and, ultimately, the state of the sea ice and ocean. We present results from a global ocean model NEMO (Nucleus for European Modelling of the Ocean) coupled to the Los Alamos sea ice model CICE. A novel, physically based rheological formulation for sea ice dynamics is used, accounting for ice floe collisions, while offering a seamless framework for pack ice and MIZ simulations. The effects of surface waves on ice fragmentation and ice motion, through wave pressure and the turbulent kinetic energy of ice floes are accounted for. We examine MIZ and basin scale sea ice and oceanic responses to the changes in ice dynamics. The results suggest that the effects of the newly included processes are mainly confined to the MIZ. However, with the current and future increases in summer Arctic MIZ, we argue that the effects of the combined sea ice rheology and ice fragmentation will be noticeable in large areas of the Arctic Ocean, affecting both sea ice and ocean. With this study we assert that for more accurate sea ice predictions in the changing Arctic models need to include MIZ dynamics and physics.
Cryosat-2 SAR altimeter sea ice thickness and freeboard retrieval validation and improvement with ocean model NEMO-LIM3 and other EO sources

The concentration of the study is on sea ice thickness and freeboard retrieved with Cryosat-2 SAR altimeter. The retrieved estimates will be coupled with sea ice thickness estimates from runs of ocean model NEMO-LIM3 and with some Earth observation sources. These coupled parameters will be used for validating the Cryosat-2 retrieved freeboards and for possible improvements.
Melting of the Greenland ice sheet has accelerated in the 21st century and this likely results in increasing shelfwater flow, but there are too few in situ observations to estimate this trend. However, along-track satellite altimeter data are available during August to November when there is no sea ice, and these data provide a way to estimate the trend in sea surface height (SSH) across the shelf and hence the trend in geostrophic shelf-averaged flow. Noise in the SSH estimates was reduced by averaging SSH along the shelf over several satellite tracks since gradients along shelf are much weaker than across-shelf. Calculations show that the East Greenland Coastal Current (EGCC) strengthens by 8.6 cm/s over the period 2003 to 2014 and this strengthening is consistent with an estimation of the observed melting rate in southeastern Greenland. The shelf flow trend in the inshore part of the West Greenland Current (WGC) is weaker and this is likely due to transport loss around Greenland's southern tip, as well as the offshore wind-driven Ekman transport along the southwestern Greenland coast and much smaller fresh water flux from the land.
Effect of resolution on Arctic Net Primary Production

Traditionally, Pan Arctic Ocean General Circulation Biogeochemical Models (OGCBMs) are run on relatively coarse grids due to computational limitations. The strong bio-physical coupling in the Arctic Ocean, however, means that in order to satisfactorily reproduce Arctic biology, a high accuracy of the physical processes, such as sea-ice melting and vertical mixing of water and tracers, is necessary. We know that increased horizontal resolution improves the representation of Arctic ocean currents and mixing in the Finite Element Sea-ice Ocean Model (FESOM), and here we take it a step further and look at the impact of resolution on the Arctic biogeochemistry using the biogeochemical model REcoM2 coupled to FESOM.

The model is run in a global 1-degree setup with the resolution being increased to 4.5 km (HIGH run) and 20 km (LOW run), respectively, north of 60 degrees north. Our results show that the total Arctic primary production is significantly higher in the the LOW resolution run compared to the HIGH run. The lower production is mainly due to differences in light availability; despite of relatively similar sea-ice distribution, the ice concentration is lower in the LOW resolution run in many areas, thereby letting a larger fraction of light through and allowing for a higher rate of under-ice production as compared to the high resolution run. This feature is especially prominent in the East Greenland Current and on the Siberian shelves in the LOW run. As light is the main limiting factor in the runs, dissolved inorganic nitrogen (DIN) is highest in the HIGH resolution run. In the high Arctic, vertical transport of nutrients is further increased in the HIGH resolution run due to higher vertical velocities relative to the LOW resolution run. The higher vertical transport is probably also responsible for the HIGH resolution run having the highest production rates in the Greenland Sea. Next steps include determination of the nitrogen budget for the Arctic and implementation of an improved algorithm for the penetration of light through the ice.
Schultz, Cristina: WHOI/MIT, cschultz@whoi.edu

High-Resolution Simulation of Sea Ice, circulation and biogeochemistry in the West Antarctic Peninsula (WAP)

Over the last decades, the West Antarctic Peninsula (WAP) has undergone physical and ecological changes at a rapid pace, with winter air temperatures warming up to 4.8 times the global average rate. The effects of this warming can be felt in the ecosystem; with changes in the chlorophyll patterns and a poleward shift of ice dependent species. These fluctuations are associated with the sea ice cover in the region, which influences the upper ocean mixed layer depth, heat exchanges and local circulation. Recent research has found a consistent trend of shortening in the sea ice season in the WAP, associated with changes in the wind pattern. The mechanisms behind these drastic climate changes are not fully understood and have been investigated by the Palmer-LTER (Long Term Ecological Research) over the last two decades. In this context, numerical modeling is a powerful tool, given the seasonal and sea ice constraints on data acquisition in the region. A high-resolution circulation model, coupled to a sea ice model and biogeochemistry, was implemented in the WAP to simulate the sea ice advance and retreat, and reproduce the annual cycle of sea ice, mixed layer depth and chlorophyll in different climate variability scenarios. The model used is MITgcm (general circulation model) coupled with REcoM-2 (Regulated Ecosystem Model, version 2). The general seasonal pattern of chlorophyll simulated is consistent with the observations, although the simulated surface concentration values are higher. Sensitivity analysis, therefore, are being conducted to identify the mechanisms behind this discrepancy.
A Basin-Wide Examination of the Arctic Ocean's Double-Diffusive Staircase

The Arctic Ocean stratification frequently exhibits a staircase structure above the Atlantic Water Layer (AWL) consisting of multiple mixed layers of O (1) m in thickness separated by sharp temperature/salinity interfaces. The double-diffusive staircase structure is characterized across the entire Arctic Ocean through a detailed analysis of Ice-Tethered Profiler (ITP) measurements between 2004 and 2013. Staircase properties are examined in relation to a vertical density ratio, $R_\rho$. It is shown that the Lomonosov Ridge serves as an approximate boundary between regions of low density ratio in the Eurasian Basin (EB) and higher density ratio in the Canadian Basin (CB). The diffusive staircase in the EB is characterized by fewer, thinner mixed layers than that in the CB. Margins of all basins are characterized by thin mixed layers. Using a 4/3-flux law, the distribution of vertical heat fluxes through the staircase is estimated to be O (0.1) Wm$^{-2}$ in the CB. In regions of the EB, it appears the 4/3-flux law is not appropriate. Heat fluxes computed using interface temperature gradients and molecular diffusivity are O (0.01) Wm$^{-2}$.
Squire, Vernon: University of Otago, Australia, vernon.squire@otago.ac.nz

**Recent developments in a phase-resolving model of wave ice interaction**

The US Office of Naval Research Departmental Research Initiative ‘Sea State and Boundary Layer Physics of the Emerging Arctic Ocean’ has triggered massively renewed activity targeted on understanding how ocean waves affect sea ice under the altered conditions that we are now observing in the summer Arctic. As part of this programme we have developed a new 3D phase resolving model of wave-ice interaction that incorporates 2D scattering from large numbers of ice floes, which I will discuss. Break up of sea ice and the resulting production of a floe size distribution will also be considered. The model will be compared with some early data, particularly in regard to how the directional distribution of wave energy changes as the waves propagate further into an ice field.
The Phenology of Arctic Ocean Surface Warming

In this work, we explore the seasonal relationships (i.e., the phenology) of sea ice retreat, ocean surface warming, and atmospheric heat fluxes in the Pacific Sector of the Arctic Ocean, using satellite and reanalysis data. We find that early ice retreat leads to warmer summertime ocean surface temperatures over the continental shelves and southern basins. This relationship is weaker in the Chukchi Sea (where ocean advection plays a large role) and in far northern latitudes (where atmospheric heat fluxes are weak). This result helps to explain the very different ocean warming responses found in two recent years with extreme ice retreat, 2007 and 2012. We also find that the timing of ice retreat impacts the date of maximum ocean surface warming, owing to a change in the ocean surface buoyancy and momentum forcing that occurs in early August that we term the Late Summer Transition. Our results indicate that in the near-term, earlier ice retreat is likely to cause enhanced ocean surface warming in much of the Arctic Ocean, although not in far northern areas, where earlier retreat for now still creates open water at a time of weak atmospheric heat fluxes.
Steiner, Nadja: Institute of Ocean Sciences, DFO Canada, nadja.steiner@canada.ca

**Progress in modelling biogeochemical processes in the Arctic**

The presentation will highlight recent progress in modelling and understanding biogeochemical processes in the Arctic marine ecosystem, including sea ice algae growth, carbon and sulphur cycling, stratification impacts on primary production. The presentation will also outline an approach to link biogeochemical model projections to higher trophic level changes and socioeconomic impacts.
Lessons learned from 500 sea ice forecasts submitted to the Sea Ice Outlook

A dramatic indicator of global climate change is the shrinking Arctic summer sea ice cover. Arctic sea ice loss has accelerated with the 9 lowest months of sea ice extent (SIE) occurring in the last 9 years, and the Arctic is expected to become ice-free during summer by about midcentury. This ice loss has profound consequences for activities in the Arctic, and there is an urgent need to predict the sea ice conditions in all seasons at the regional scale a few months in advance.

Studies show that predictability varies significantly by region and season and is driven by processes that differ from those that control pan-Arctic predictability. The challenges to making practical prediction stem from imperfect knowledge of sea ice processes, incomplete observations of the current and past sea ice state, structural errors in dynamic prediction systems and statistical methods, and deficiencies in metrics used to communicate predictions. These challenges are best overcome through collaboration, especially by sharing expertise, observations, data, and methods.
Sundfjord, Arild: Norwegian Polar Institute, arild.sundfjord@npolar.no

The slope current north of Svalbard; seasonality and forcing of Atlantic Water heat flux to the ice-ocean boundary layer

Data from moorings across and along the AW inflow north of Svalbard give new insight in the role of AW in the local sea ice heat budget. The boundary current is warmest and fastest in autumn and winter. At the same time, stratification is weak, and wind driven mixing is strong enough to produce vertical heat fluxes capable of keeping the upper slope area ice free well into winter, despite strong heat loss to the atmosphere. We investigate the relative importance of wind-driven versus tidal mixing, and discuss how upwelling and along-slope heat loss change the heat content of the boundary current as it flows eastwards.
Takeda, Hiroki: Tokyo Gakugei University, m151830m@st.u-gakugei.ac.jp

Turbulent mixing and heat balance within the surface mixed layer in the Pacific-side Arctic Ocean

In this study, turbulent mixing and heat balance in the surface mixed layer (SML) are argued in the Pacific-side Arctic Ocean. We collected a series of microstructure data set including dissipation of turbulent kinetic energy and thermal variance. Using RV Mirai, the observation was carried out for three weeks in September 2014 in the North Wind Abyssal Plain. Following the ship-based observation in summer, temporal change of SML was further explored by using “UpTempOs”, 60-m long drifting buoys with a thermistor chain.
Quantifying the impact of internal tide mixing on shelf-basin exchange in a numerical model of the Arctic Ocean

Shelf–basin exchange in the Arctic Ocean is impacted by a number of mixing processes in the region. The mixed layer depths and local ambient stratification can restrict the depth that the dense waters on the Arctic shelves can descend into the Arctic basin by decreasing the density gradient through entrainment. Lunar and solar tides in the Arctic can have a large impact on sea ice extent and salinity redistribution, which could impact the formation of dense water on the shelves through the movement of rejected brine from new sea ice formation. Tidal mixing within the water column and at the base of the sea ice cover can increase the heat flow from deeper water masses towards the surface.

A specific component of tidal mixing, which is not explicitly considered for its impact in the Arctic region and on shelf-basin exchange, is the enhanced mixing due to the breaking of internal tides. Internal tide mixing can be thought of as a transfer of energy from barotropic to baroclinic tides as flow moves over rough bottom topography which causes mixing from the overturning and breaking of these internal tides. In this study, the amount of energy that is put into the internal wave field from barotropic tides is estimated by the parameterization from Jayne and St Laurent (2002). The vertical dissipation profile and model implementation will be based on Melet et al. (2013).

The focus of this study will be to include an additional mixing parameterization for the breaking of internal tides and quantify the impact on shelf-basin dense water exchange in a numerical model. An Arctic and Northern Hemisphere Atlantic (ANHA) regional configuration of the Nucleus for European Modelling of the Ocean (NEMO) model in a ¼ degree resolution is used. The impact is evaluated by comparing the mass exchange of waters as a function of density class in the model outputs from two model simulations, one including the enhanced tidal mixing parameterization and a control run without the additional parameterization.
Seasonal ventilation of the Canada Basin halocline

Motivated by the persistence of the Canada Basin's warm upper halocline through all seasons, we examine the seasonal cycle in halocline ventilation. Observations and model results are analyzed to show how density outcrops in the Chukchi Sea migrate seasonally as surface buoyancy fluxes modify surface-water salinity and temperature. This migration of outcropping isopycnals is such that in winter, isopycnals bounding the warm water layer are effectively blocked from winter ventilation, while the cool, relatively salty and deeper layers of the halocline are ventilated. In this way, the warm waters of the Canada Basin halocline are isolated by stratification (both vertically and laterally) each winter.
Vertical Structure and Dynamics of the Beaufort Gyre Subsurface Layer from ADCP Observations

Daniel J. Torres, Richard Krishfield, Andrey Proshutinsky, Mary-Louise Timmermans

As part of the Beaufort Gyre Observing System (BGOS), several Acoustic Doppler Current Profilers (ADCPs) have been maintained at moorings in different locations in the Canada Basin since 2005 to measure upper ocean velocities and sea ice motion. The ADCP data have been analyzed to better understand relationships among different components of forcing driving the sea ice and upper ocean layer including: winds, tides, and horizontal and vertical density gradients in the ocean. Specific attention is paid to data processing and analysis to separate inertial and tidal motions in these regions in the vicinity of the critical latitudes. In addition, we describe the dynamic characteristics of halocline eddies and estimate their kinetic energy and their role in the total energy balance in this region. Ice-Tethered Profiler (ITP) data are used in conjunction with the ADCP measurements to identify relationships between T-S and vertical velocity structures in the mixed layer and deeper. Comparisons of mixed layer depth (MLD) determined from ITPs and ADCPs show MLD can be determined from ADCP data. We also describe the relationship between the seasonal cycle of ice thickness and sub-surface ocean velocity and its implication in a changing climate.
A Study of the Impact of Snow Cover and Melt Ponds in the Navy’s Arctic Cap Nowcast/Forecast System

The U.S. Navy’s Arctic Cap Nowcast/Forecast System (ACNFS) is a coupled ice-ocean modeling system consisting of the Community Ice CodE (CICE) and the HYbrid Coordinate Ocean Model (HYCOM) with atmospheric forcing from the Navy Global Environmental Model (NAVGEM). Observations of satellite-derived sea surface temperature, ice concentration and ice edge plus in situ data are assimilated via the Navy Coupled Ocean Data Assimilation System (NCODA). ACNFS has been running operationally at the Naval Oceanographic Office since 2013 to provide 7-day forecasts of ice thickness, concentration, drift, and lead opening rates to the National Ice Center. Optimum albedo parameterization within any ice-ocean modeling system is a critical factor for accurate sea ice thickness prediction. Surface albedo is relatively high where there is snow-covered, and uncovered ice and significantly lower where melted snow and ice occur in summer. Therefore, accurate snow depth and summer melt pond formation are required for proper thermodynamic flux balance at the ice surface. Within the operational ACNFS, snow deposition depends on monthly-varying snowfall rates which are derived from the Global Precipitation Climatology Project (GPCP) monthly-varying precipitation. In this study we compare snow depth and ice thickness from 2013-2015 ACNFS hindcasts with similarly-derived monthly snowfall rates and with daily snowfall rates derived from daily NAVGEM precipitation, both with and without a melt pond formulation, to available NASA Operation IceBridge and CRREL Ice Mass Balance Buoy data. The impact of climatological versus NAVGEM-derived snowfall and the presence of melt ponds on sea ice thickness are presented.
The mesoscale eddy field in the northern North Atlantic and its relationship to linear baroclinic instability

A 10-year long eddy-permitting ocean simulation is used to form an eddy census for the northern North Atlantic. Coherent vortices are extracted from daily-mean fields by a hybrid detection method that searches for closed surface geostrophic streamlines and negative Okubo-Weiss values. The calculations show that coherent vortices are largely responsible for the bulk of eddy kinetic energy in the Nordic Seas and the northern extremities of the North Atlantic. Boundary currents, following continental slopes, are the primary sources for most of the eddy field, but eddies are also advected into the deeper basins. Linear stability calculations done on the time-mean background model field suggest that baroclinic instability is a consistent source of the eddy field. The calculations also point to important deviations from Eady dynamics and, in particular, suggest that topographic slopes impact unstable growth significantly.
Tsubouchi, Takamasa: Alfred Wegener Institute, takamasa.tsubouchi@awi.de

**Observed seasonal to inter-annual variation of the Arctic Ocean heat and fresh water transports**

The Arctic Ocean has been accumulating fresh water (FW) over last decades [Rabe et al. 2014 GRL], which has a potential impact on deep water formation in the high latitude North Atlantic. In order to observe oceanic heat and FW exchanges between the Arctic and surrounding seas, five research groups in the world maintain the Arctic boundary mooring observation lines in Davis Strait, Fram Strait, Barents sea opening (BSO) and Bering Strait over many years.

Tsubouchi et al. [2012 JGR] is the first study to estimate a synoptic view of pan-Arctic heat and FW transports in summer 2005 using box inverse model. Followed by Tsubouchi et al. [2012], we have quantified an "observation based" full annual cycle of pan-Arctic boundary transports from September 2005 to September 2006. The oceanic transports are estimated based on 135 moored instruments across the pan-Arctic boundary. 12 months volume and salt conserved velocity fields are generated using box-inverse model. The obtained volume transports are reasonable both in magnitude and variation across the four Arctic gateways: -2.1±0.7 (Sv) in Davis Strait, -1.1±1.2 (Sv) in Fram Strait, 2.3±1.2 (Sv) in BSO and 0.7±0.7 (Sv) in Bering Strait. The associated oceanic and sea ice heat transports are 154±44 (TW) and 22±15 (TW), respectively. The associated oceanic and sea ice FW transports are 155±65 (mSv) and 48±32 (mSv), respectively.

Under the EU Marie Curie project, we aim to quantify multi-year monthly Arctic heat and FW budgets. The recently developed pan-Arctic approach will be applied to Arctic gateway data for the years 2004-2010. During the project, large amount of moored instrument data (c.a. 1,000 moored instruments from 230 mooring sites in total) will be analyzed. Preliminary results from the project will be also presented.
Wang, Qiang: Alfred Wegener Institute, qiang.wang@awi.de

Arctic Ocean and North Atlantic in a model with CORE forcing: An extension of the CORE-II exercise

The CORE-II (Coordinated Ocean-ice Reference Experiments Phase II) simulations provide a framework to evaluate ocean model performance and to study mechanisms of ocean phenomena and their variability. More than ten ocean sea ice models under this framework have been evaluated for the Arctic Ocean and the North Atlantic with respect to the mean state and variability. The performance and common issues in these ocean climate models were studied in a series of joint papers, however, the simulated linkage between the Arctic Ocean and North Atlantic has not been elucidated. In this presentation we will focus on this particular aspect with one of the models participating in the CORE-II project (FESOM, with 24 km horizontal resolution in the Arctic Ocean). The interaction between the two ocean basins and the sources of ocean variability in the model will be shown. For example, it is found that the interannual variability of Arctic freshwater exported through Davis Strait is driven more by the North Atlantic variability than the Arctic Ocean state, in this model setup. The model results might represent the status of current coarse resolution ocean climate models, and it remains to be seen how different the results will be if we increase the model resolution.
Winter ocean heat transport driven by subsurface shelf-break jet north of Chukchi Sea

Ocean heat transport is a possible important factor for recent sea ice decline, especially in the western Arctic Ocean. It has been indicated that vertical hydrographic profiles in the Canada Basin were characterized by three temperature maxima. The near-surface temperature maximum was the shallowest one arising from summer solar heat absorption and subsequent autumn Ekman downwelling. The subsurface temperature maximum reflected intrusion of Pacific summer water. The deepest maximum was located in the Atlantic layer. Substantial parts of upper ocean heat would eventually affect sea ice freezing/melting. However, spatial and temporal variabilities of these warm layers still remain uncertainties. In this study, a pan-Arctic sea ice-ocean modeling was performed to address wintertime transport of subsurface warm water. The horizontal grid size was approximately 5 km to resolve mesoscale eddies and narrow boundary currents. In the interannual experiments from 2001 to 2014, strong easterly winter winds in the southern part of the prevailed Beaufort High sometimes produced a westward shelf-break jet along the northern edge of Chukchi shelf. In this situation, lateral advection of shelf-origin water along jet streams is a key factor for subsurface warming around the Chukchi Borderland. Whereas a substantial part of subsurface heat in the shelf-break region was immediately released to atmosphere by wind-driven turbulent mixing, stronger stratification protected the warm layers against heat loss in some years.
Welker, Jeffrey: University of Alaska Anchorage, jimwelker@uaa.alaska.edu

Arctic and sub-Arctic water vapor and CO2/CH4 isotope cycles using in situ, real time measurements from the USCG Icebreaker Healy

A warming climate is resulting in sea ice loss that is impacting the Arctic marine water and carbon cycles. High-resolution measurements of the marine boundary layer water vapor, CO2 and CH4 isotopes are however; few and necessary if we are to fully understand the complex nuances of these cycles in the sub-Arctic and the Arctic marine systems, now, in the future and in the past. The water isotope values of δ18O, δ2H and deuterium excess, can provide a moisture source proxy that can serve as a tracer to help understand hydrological changes due to sea ice loss. And, the δ13C values of CO2 and CH4 can provide insight as to spatial and temporal variation in productivity and C source-sink relations and mechanisms. A modern understanding of the water and C isotope cycles are critical today as they provided a means by which we can fully resolve how sea ice changes in the past altered the water isotopes traits in ice cores. And, high temporal and spatial measurements of δ13CO2/δ13CH4 are necessary to elucidate productivity patterns and possible methane seep presence on the sea floor. Here we present the first isotope data linking a gradient of sea ice extents to oceanic in situ, continuous water vapor δ18O, δ2H and deuterium excess values and the δ13C of CO2 and CH4 along a 1200 mile transit from the Gulf of Alaska, through the Bering, Chukchi and Beaufort Seas aboard the USCG Healy. Initial loss of sea ice extent leads to deplete deuterium excess moisture sources, and then values progressively increase with further ice loss. Our new process-based interpretation explains that the most plausible explanation for past rapid (1-3 years) Greenland ice core changes in deuterium excess during warming is not abrupt atmospheric circulation shifts, but rather gradual loss of sea ice extent at northern latitude moisture sources. Our high resolution, continuous δ13C of CO2 measurements depict a very marked diurnal variation in ocean C source-sink dynamics that is along a range of 3-4 per mil and who’s variance from ice free to ice covered conditions is muted.
HiLAT: A new project for integrative studies of the high-latitude climate systems

HiLAT (High-Latitude Application and Testing of Global and Regional Climate Models) is a new Science Focus Area (SFA) of the Department of Energy. The project is a collaboration between climate scientists at Los Alamos (LANL) and Pacific Northwest (PNNL) National Laboratories. Its main thrusts are exploring impacts and feedbacks of changes in the cryosphere on 1) the regional high-latitude climate system, and 2) the global climate system through atmospheric and oceanic exchanges. In this presentation I will give an overview of the HiLAT project and our activities under this SFA.
Recirculation of Atlantic Water in Fram Strait: A high resolution modeling study

The West Spitsbergen Current transports warm and saline Atlantic Water northwards through Fram Strait towards the Arctic Ocean. At Fram Strait, a fraction of the Atlantic Water recirculates and travels southward as part of the East Greenland Current. The mechanism of the recirculation is still not fully understood, and in particular the role of eddies. Experiments with three configurations of the global Finite Element Sea ice Ocean Model differing in mesh resolution in the Fram Strait area (4.5 km, 2 km and 1 km horizontal resolution) are used to investigate the mechanism of Atlantic Water recirculation. The Rossby radius of deformation, an indication for the size of eddies, is relatively small in high latitudes (around 2-6 km in the Fram Strait); and thus only the simulation with 1 km horizontal resolution can be considered as eddy-resolving. Our results show that this resolution is at least necessary to correctly represent the observed temperature structure and eddy kinetic energy in the Fram Strait.
The challenge and benefit of using sea ice concentration satellite data products with uncertainty estimates in summer sea ice data assimilation

Data assimilation experiments that aim at improving summer ice concentration and thickness forecasts in the Arctic are carried out. The data assimilation system used is based on the MIT general circulation model (MITgcm) and a local singular evaluative interpolated Kalman (LSEIK) filter. The effect of using sea ice concentration satellite data products with appropriate uncertainty estimates is assessed by three different experiments using sea ice concentration data of the European Space Agency Sea Ice Climate Change Initiative (ESA SICCI) which are provided with a per-grid-cell physically based sea ice concentration uncertainty estimate. The first experiment uses the constant uncertainty, the second one imposes the provided SICCI uncertainty estimate, while the third experiment employs an elevated minimum uncertainty to account for a representation error. Using the observation uncertainties that are provided with the data improves the ensemble mean forecast of ice concentration compared to using constant data errors, but the thickness forecast, based on the sparsely available data, appears to be degraded. Further investigating this lack of positive impact on the sea ice thicknesses leads us to a fundamental mismatch between the satellite-based radiometric concentration and the modeled physical ice concentration in summer: the passive microwave sensors used for deriving the vast majority of the sea ice concentration satellite-based observations cannot distinguish ocean water (in leads) from melt water (in ponds). New data assimilation methodologies that fully account or mitigate this mismatch must be designed for successful assimilation of sea ice concentration satellite data in summer melt conditions. In our study, thickness forecasts can be slightly improved by adopting the pragmatic solution of raising the minimum observation uncertainty to inflate the data error and ensemble spread.
Estimate the potential of sea ice lead as a predictor for the seasonal Arctic sea ice extent

Affected by global warming, the arctic sea ice melt is accelerating. Under the influence of wind, ocean currents and basin terrain, polynia and lead occur. It is easy to discriminate a polynia in a remote sensing imagery because the scale of polynia is very large. The WMO define the sea ice lead as a “sea ice area that any crack or available for navigation” in 1985. Later researchers expand the definition of lead, describe it as “open water or thin ice area which has a linear character in pack ice”. As an main natural phenomenon in Arctic sea ice, it is necessary to do some research work with it. Lead is an important heat exchange window between warm humid ocean and cold dry air during winter time. With the formation and growth of sea ice, the heat exchange intensity gradually weaken. Sea ice lead also play an important role in navigation, sea ice drift, polar animal colony. Now high precision and high spatial resolution pan-Arctic lead product is still vacant. My work is to produce high quality lead product and estimate the potential of sea ice lead as a predictor for the seasonal Arctic sea ice extent.
Evolution of the eddy field in the Arctic Ocean's Canada Basin, 2005-2015

The eddy field across the Arctic Ocean's Canada Basin is analyzed using Ice-Tethered Profiler (ITP) and moored measurements of temperature, salinity and velocity spanning 2005 to 2015. ITPs encountered 243 eddies, 98% of which were anticyclones, with approximately 70% of these having anomalously cold cores. The spatially and temporally varying eddy field is analyzed accounting for sampling biases in the unevenly-distributed ITP data and caveats in detection methods. The highest concentration of eddies was found in the western and southern portions of the basin, close to topographic margins and boundaries of the Beaufort Gyre. The number of lower halocline eddies approximately doubled from 2005-2012 to 2013-2014. The increased eddy density suggests more active baroclinic instability of the Beaufort Gyre that releases available potential energy to balance the wind-energy input; this may stabilize the Gyre spin up and associated freshwater increase.
Arctic data in the World Ocean Database

The World Ocean Database (WOD) contains over 1.3 million oceanographic casts collected in the Arctic Ocean basin and its surrounding marginal seas. The data come from many submitters and countries, and were collected using a variety of instruments and platforms. These data, along with the derived products World Ocean Atlas (WOA) and the Arctic Regional Climatologies, are uniquely useful-- the data are presented in a standardized, easy to use format and include metadata and quality control information. This talk will discuss the strengths and limitations of WOD data and its derived products in the Arctic.