Book of abstracts for the IICWG-DA-11 workshop

Topical sessions:

DA	Sea ice data assimilation (methods and results)
OBS	Sea ice observations and uncertainties
MOD	Sea ice model parameterizations and coupling to ocean and atmosphere models
VER	Verification approaches for sea ice analyses and forecasts
R2O	Recent research to sea ice operation transfer—Automated prediction systems

Note: If several authors are referenced in the abstract, then the presenter name is underlined.

TALKS (T)

Day 1: Tuesday, March 21, 2023

T1 - Towards drift-aware products for sea ice freeboard and thickness, retrieved from satellite altimetry

Robert Ricker (NORCE, Norway)

Sea ice thickness is a crucial parameters for the ice mass balance, the heat exchange between ocean and atmosphere and for the polar climate system. Within the European Space Agency (ESA) Climate Change Initiative (CCI) project, it is aimed to produce a consistent sea ice thickness time series across different satellite altimetry missions (ERS, Envisat, CryoSat-2, Sentinel-3). To provide monthly maps of ice freeboard and thickness, daily trajectories are averaged spatially, while each trajectory only represents the ice thickness in the moment of the satellite overflight. However, sea ice thickness within a certain region is highly variable being affected by sea drift (advection and deformation) over one month. Therefore, we suggest to analyse the impact of sea ice motion on the monthly products of the ESA CCI ice freeboard and thickness timeseries using a set of ice motion products. Here we will show first results of this impact analysis. Moreover, we will present an approach to correct sea ice thickness trajectories for ice motion, to retrieve daily drift-aware sea ice products using satellite altimetry measurements in conjunction with ice motion and concentration data.

T2 - Sea ice thickness and volume evolution over the past 30 years

Marion Bocquet (LEGOS, France)

Sea ice is a key witness and driver of climate change. Although sea ice extent evolution is widely studied and well identified, sea ice thickness evolution over the past 30 years remains poorly known. Nevertheless thickness is a mandatory variable to fully understand the past, present and future evolution of sea ice. Despite improvements in sea ice thickness estimation from altimetry during the past few years thanks to SAR and laser altimetry, former radar altimetry missions such as Envisat and especially ERS-1 and ERS-2 have remained under exploited so far. ERS-2 arctic sea ice thickness has been recently retrieved thanks to a machine learning approach aiming at calibrating ERS-2 and Envisat over CryoSat-2. We are now able to extend the time series from ERS-1 for both polar oceans allowing to a propose a 30 years-long sea ice thickness and volume time series. Estimates are combined with uncertainties derived from a Monte Carlo methodology. Study shows that Arctic sea ice is melting by 118 km^3/year from 1994 with a 99% significance while Antarctic sea ice evolution has no significant trends but a clear change in 2016. For both hemispheres prominent regional changes have been identified with a strong heterogeneity of trends across regions. Finally, comparisons between observations and models show increasing negative bias while going back in time.

T3 - Year-round satellite sea ice thickness for the Arctic and its potential for seasonal forecasting

Jack Landy (UiT The Arctic University of Norway)

Pan-Arctic sea ice thickness has been monitored by the European Space Agency SAR altimeter CryoSat-2 since 2010. However, sea ice thickness observations are so far restricted to Arctic winter months (Oct-Apr) because conventional processing techniques fail to work when meltwater ponds accumulate at the ice surface during summer months. Here we will present a new method for generating valid sea ice thickness observations in Arctic summer months (May-Sept) over the ten-year period between 2011 and 2020. We overcome existing data processing challenges using deep learning methods for radar waveform classification and numerical modelling of the radar altimeter signal over melting sea ice to correct for ranging biases. The summer freeboards are stitched together with an existing time series of winter freeboard observations, before they are converted to thickness by accounting for the ice density and the residual snow load accumulated on the ice. We find that derived sea ice thickness observations capture the spatial and temporal patterns of ice growth and melt from airborne measurements on AWI campaigns and from the BGEP moorings, respectively. By analyzing the lagged correlations between time series of sea ice volume and extent, we will demonstrate how summer sea ice thickness observations can potentially benefit seasonal forecasts of ice extent at lead times up to 10 months.

T4 - Assimilation of ice thickness observations at ECCC

Mark Buehner (Environment and Climate Change Canada)

A new sea ice thickness analysis system is being developed at Environment and Climate Change Canada. It is based on a similar approach as the ice concentration analysis system used operationally for both weather and ice-ocean prediction applications. The 3D-Var assimilation algorithm combines multiple sources of observational data with a background state obtained from the previous analysis. In addition, a separate algorithm is used to produce uncertainty estimates of the analysis. As part of this work, several aspects of the ice thickness analysis system have been investigated, including the use of the new Lognormal Altimeter Retracker Model (LARM) algorithm versus the Centre for Polar Observation and Modelling (CPOM) product as a source of winter ice thickness information from CryoSat-2 data. Also investigated are the sensitivity to the assimilation time window length, the source of snow depth information, and the relative error variances for L-band passive microwave and altimeter thickness observations.

T5 - Improving the Met Office's Forecast Ocean Assimilation Model (FOAM) with the assimilation of satellite-derived sea-ice thickness data from CryoSat-2 and SMOS in the Arctic

Davi Mignac Carneiro (Met Office, UK)

Derived from two complementary satellites, CryoSat-2 and Soil Moisture and Ocean Salinity (SMOS), sea-ice thickness (SIT) data are assimilated into the Met Office's global ocean-sea ice forecasting system, FOAM, using a 3D-Var assimilation scheme, NEMOVAR. CryoSat-2 along-track SITs, which are converted from freeboard measurements using the model snow depth, and a daily, gridded SMOS SIT product are used in the assimilation to constrain the Arctic sea ice thickness. When using only CryoSat-2 assimilation, SIT forecast fields within the ice pack are greatly improved with respect to independent airborne measurements. However, the positive impacts of CryoSat-2 assimilation in thick ice regions are counteracted by a SIT overestimation in areas of thin ice, due to biased freeboard measurements there. Adding the SMOS assimilation results in much thinner SITs in those regions, which performs better than the control when compared to SIT objective analyses and mooring measurements in the Beaufort and Barents Seas. Furthermore, SMOS assimilation enhances the short-term predictive skill of the marginal sea ice concentration relative to the control. This is translated into a consistent retreat of the sea-ice covered areas in the 5-day forecasts during March 2017, which is in better agreement with independent ice edge products. This work successfully demonstrates improvements in FOAM sea ice when SIT observations from both CryoSat-2 and SMOS are assimilated, representing an important step towards the operational implementation of SIT assimilation within Met Office forecasting systems. Reference: Mignac, D., Martin, M.,Fiedler, E., Blockley, E. & Fournier, N. (2022) Improving the Met Office's Forecast Ocean Assimilation Model (FOAM) with the assimilation of satellite-derived sea-ice thickness data from CryoSat-2 and SMOS in the Arctic. Quarterly Journal of the Royal Meteorological Society, 1–24. Available from: https://doi.org/10.1002/qj.4252.

T6 - A satellite era reanalysis of the Arctic sea ice cover utilising year-round observations of sea ice thickness

Nicholas Williams (NERSC, Norway)

In the last decade, there has been significant undertaking to produce new observations of the Arctic sea ice cover, with improved spatiotemporal coverage, allowing researchers to better understand the state of the Arctic sea ice system in new detail. In this work we use the recently developed sea ice data assimilation system, CICE-PDAF, to reanalyse the Arctic sea ice cover over the satellite era. We assimilate (in various combinations) several sea ice observations, including a year-round sea ice thickness product and a sub-grid scale sea ice thickness distribution product, alongside observations of sea ice concentration. The assimilation of year-round sea ice thickness provides substantial improvements to the modelled sea ice thickness in comparison to independent observations. The assimilation also has significant consequences on the modelled distribution of the ice thickness across the Arctic, particularly in regions of multi-year ice, and reduces regional model biases.

T7 - Modelling the evolution of Arctic multiyear sea ice over 2000-2018

Heather Regan (NERSC, Norway)

Multiyear sea ice (MYI) cover in the Arctic has been monitored for decades using increasingly sophisticated remote sensing techniques, and these have documented a significant decline in MYI over time. However, such techniques are unable to differentiate between the processes affecting the evolution of the MYI. Further, estimating the thickness, and thus the volume of MYI remains challenging. Here we use the neXtSIM sea ice model, coupled to the ocean component of NEMO, to investigate the changes to MYI over the period 2000-2018. We exploit the Lagrangian framework of the sea ice model to introduce a new method of tracking MYI area and volume, which is based on identifying MYI during freeze onset each autumn. The model is found to successfully reproduce the spatial distribution and evolution of observed MYI extent. We discuss the balance of the processes (melt, ridging, export, and replenishment) linked to the general decline in MYI cover. The model suggests that rather than one process dominating the losses, there is an episodic imbalance between the different sources and sinks of MYI. We identify those key to the significant observed declines of 2007 and 2012; while melt and replenishment are important in 2012, sea ice dynamics play a significant role in 2007. Notably, the model suggests that convergence of the ice, through ridging, can result in large reductions of MYI area without a corresponding loss of MYI volume. This highlights the benefit of using models alongside satellite observations to aid interpretation of the observed MYI evolution in the Arctic. Based on the MYI tracking method here, we demonstrate how MYI is now implemented in the neXtSIM-F forecasting platform.

T8 - Sea ice assimilation within ECMWF's next generation ocean and sea ice reanalysis, and beyond

Phil Browne (ECMWF)

The next operational sea ice model to be used at ECMWF for reanalysis and NWP required major data assimilation (DA) developments. The fundamental difference between the old sea ice model (LIM2) and the next model (SI3) is the change from a single category model to one of multi-categories.

In this talk we will present the work we have done to allow variational DA with the multi-category model and describe the many scientific and pragmatic choices we have made along the way.

Along with the challenges of the new multi-category model come opportunities. We will touch on future planned developments to fully support multi-category sea ice within the DA system, which amongst other things will allow to assimilate thickness (equiv. freeboard/altimeter profile) observations without needing to further extend the variational control vector.

T9 - Assimilation of sea-ice remotely-sensed observations for global ocean analysis/Reanalysis

Andrea Cipollone (Euro-Mediterranean Center on Climate Change, CMCC) – online

Despite the first sea-ice thickness observations from satellites dating back to 2000s, multivariate assimilation strategies for sea-ice variables are still in an early stage, due to the highly non-gaussian distributions of related uncertainties and the low accuracy of such measurements especially during the summer season.

To better constrain such variables, a 3dvar variational scheme (called OceanVar), employed in the routinely production of global/regional ocean Reanalysis and forecasts, has been recently extended to ingest sea-ice concentration and thickness via Gaussian anamorphous operator. This operator is used to covary thickness and concentration by transforming the probability density function of sea-ice variables into Gaussian ones.

We present the comparison among several sensitivity experiments that were performed assimilating different observation datasets and using different DA configurations at 1/4° global resolution. Specifically, we assess the impact of ingesting different SIT products, such as SMOS and CryoSat-2 data or the merged product CS2SMOS in a bivariate framework.

We show that the role assimilation of SIC generates a mild improvement in the spatial representation of SIT with respect to a free run. The spatial error reduces sharply only once CRYOSAT-2 data are assimilated jointly with SIC data. In the present set up, all the experiments generally tend to overestimate the sea-ice volume in the case SMOS data are not assimilated. Moreover, the intermittent availability of thickness data along the year, leads to potential discontinuities in the integrated quantities that require a dedicated tuning. Validation against independent mooring data will be also presented.

The proposed approach is suitable to be used for covarying ocean/sea-ice variables in future coupled ocean/sea-ice DA.

T10 - Deep learning for surrogate modelling of neXtSIM

Charlotte Durand (CEREA, ENPC)

A novel generation of sea-ice models with Elasto-Brittle rheologies can represent the drift and deformation of sea-ice with an unprecedented resolution and accuracy. As those models are computationally heavy, we investigate supervised deep learning techniques for surrogate modelling of large-scale, Arctic-wide, neXtSIM Lagrangian simulations. A successful approach will allow us to speed-up sea-ice simulations, and on the basis of the gained knowledge, we can build subgrid-scale parameterizations for neXtSIM. Faster sea-ice simulations additionally permit larger ensembles to better represent the discrete-continuous behaviour of sea ice and its dynamics, especially for data assimilation.

We adapt two different types of convolutional neural network architectures, namely U-Nets and ResNets, to emulate the sea-ice thickness for twelve hours. In our case, the U-Net learns to beneficially use information at multiple scales and correctly predict the advection of thickness given multiple atmospheric forcings. In general, cycling the neural network performs 18 % better than a persistence forecast on a daily timescale, and this gain prevails on monthly timescales with improvements of up to 40 %. Stacking multiple timesteps in the input and output reduces the error by 11 % on a monthly timescale. This suggests an emerging potential of recurrent neural networks like long-short-term memory architectures to model temporal dependencies in sea ice. In the end, this can facilitate the correct representation of small-scale events like linear kinematic features and the dynamics in the marginal ice zone. As a conclusion, our promising results demonstrate a way towards surrogate modelling of Arctic-wide simulations.

T11 - Sensitivity Analysis and Machine Learning of a Sea Ice Melt Pond Parametrisation

Simon Driscoll (University of Reading, UK)

Sea ice plays an essential role in global ocean circulation and in regulating Earth's climate and weather. Melt ponds that form on the ice have a profound impact on the Arctic's climate, and their evolution is one of the main factors affecting sea-ice albedo and hence the polar climate system. Parametrisations of these physical processes are based on a number of assumptions and can include many uncertain parameters that have a substantial effect on the simulated evolution of the melt ponds. Several studies have highlighted the potential for machine learning based parametrisation schemes, and machine learning has shown remarkable success in representing subgrid-scale processes and other parametrisations of Global Circulation Models. Here we seek to understand and characterise the sensitivity of a 1D thermodynamics sea ice model to its melt pond parametrisation and see if machine learning can learn and replace this parametrisation.

Using the state-of-the-art sea ice column physics model, Icepack, we first conduct a global sensitivity sensitivity analysis of all its melt pond parameters. We focus our analysis on the effect of these parameter values on the simulated ice area fraction, ice thickness, effective pond area and total albedo. Results from the sensitivity analysis indicate that parameters controlling the amount of melt water allowed to run off to the ocean plays the most substantial effect on sea ice evolution, as well as meltwater added to melt ponds earlier in the melting season.

We then perform simulations of the Icepack model forced by hourly data from NCEP's CFSV2 dataset and assess if neural networks can learn and emulate the level-ice melt pond parametrisation of the Icepack model. Neural networks demonstrate the ability to learn and predict output given by the level-ice melt pond parametrisation, and furthermore do not suffer from drift or instability when used in the Icepack model replacing the melt pond parametrisation itself. With uncertainty around the precise values of many sea ice parameters, our work opens the possibility of, for example, applying hybrid data assimilation and machine learning techniques that have been used to incorporate direct data to infer unresolved scale parametrisations, in sea ice models, and extending emulations to all major column/1D thermodynamic sea ice processes.

T12 - Fusion of satellite SAR and passive microwave radiometer observations for automatic sea ice mapping using convolutional neural networks

Tore Wulf (Danish Meteorological Institute)

Manual sea ice charting from multi-sensor satellite data analysis has for many years been the primary method at the National Ice Services for producing sea ice information in the Arctic. Ice charters primarily use satellite-borne synthetic aperture radar (SAR) imagery due to the high spatial resolution and the capability to image the surface through clouds and in polar darkness. Auxiliary satellite observations, including optical imagery and passive microwave radiometer (PMR) observations, are used when available and advantageous.

Here, we present the DMI-ASIP model; a carefully designed Convolutional Neural Network (CNN) that fuses high resolution Sentinel-1 SAR imagery and PMR observations from AMSR-2 to generate high resolution maps of sea ice in Greenland and Antarctic (and soon Pan-Arctic) waters. The DMI-ASIP

model has been trained on a vast dataset containing ice charts produced manually at the Greenland and Canadian ice services co-located with Sentinel-1 SAR imagery and AMSR-2 observations. The DMI-ASIP model is trained as a multi-tasking CNN to generate maps of several sea ice parameters simultaneously; sea ice concentration, stage of development and floe size.
Current development of the DMI-ASIP model focuses on the inclusion of other C-band SAR missions, such as the Radarsat Constellation Mission, as well as on the preparation of the launch of the Copernicus Expansion Missions, such as CIMR and ROSE-L.

Day 2: Wednesday, March 22, 2023

T13 - Sea Ice Age Climate Data Record

Anton Korosov (NERSC, Norway)

The SICCI sea ice age algorithm previously developed by us (Korosov et al., 2018) has several advantages over the classical NSIDC ice age algorithm as it produces continuous fields of fractions of ice of different age. That allows to compute sea ice age as a more accurate weighted average of the fractions, and increases the accuracy of the Multi-Year Ice (MYI) area estimation.
The ice age algorithm was further improved by using a Lagrangian triangular mesh instead of a Eulerian advection scheme. The mesh moves together with sea ice drift, which reduces the diffusion of fractions of ice of older age. The mesh is re-meshed in order to keep the area and the perimeter of the elements in a predefined range. Contribution to the new elements of the re-meshed mesh from the original elements is computed as area weighted average, and the weights are saved at each advection step. That allows to do the computationally expensive advection of the mesh only once and then reuse the weights and indexing of the elements for advecting any sea ice property almost instantaneously.
The new sea ice age algorithm was applied to the newly released climate data record of sea ice drift (OSI-455) from the Ocean and Sea Ice Satellite Application Facility (OSI SAF) and a data record of sea ice age from 1995 to 2020 was produced. Analysis of individual fractions of ice age distinctly show two regime shifts in the Arctic sea ice. First, there is a gradual replacement of MYI by first-year ice (FYI) observed in the period from 2000 to 2010. Second, there is a sudden drop in the replenishment of 6-year old ice in 2017.

T14 - A Climate Record of Wave-Affected Marginal Ice Zone in the Atlantic Arctic based on CryoSat-2

Shiming Xu (Tsinghua University, China)

Marginal Ice Zone (MIZ) is a region of extensive interactions between the polar atmosphere, ocean, and sea ice. Waves and swells develop over the open ocean and propagate into the ice edge, breaking the ice into smaller floes and modifying the bottom of the atmosphere and the surface ocean. Given the ongoing climate change in polar regions, wave-affected MIZ is of particular importance, which is also a focus of the ongoing effort of the community for better defining and observing MIZs. We introduce a new climate record for wintertime wave-affected MIZ based on CryoSat-2, covering the Atlantic Arctic during the winter months since 2010. The retrieval method is based on the delay-Doppler radar altimetry over sea ice, and in particular, the waveform stack parameters of CryoSat-2. Large MIZs can reach over 300km into the ice pack, as observed by CS2. No statistically significant change of the wave-affected MIZ is found since 2010, however, large inter-annual and intra-seasonal variability is present. We relate the wave-affected MIZ to both wave/swell conditions and sea ice parameters. Especially, the new dataset sheds light on the swell attenuation in the MIZ, which: (1) contains systematic coverage of the various sea ice conditions, and (2) is consistent with various Arctic and Antarctic in-situ measurements. Related issues, including altimetric representation for MIZ, as well as extensions to the dataset are also discussed.

T15 - Sea-ice mechanical weakening by ocean currents and winds: Observations and statistics

Sascha Willmes (University Trier, Germany)

Based on a novel sea-ice lead climatology for the Arctic derived from thermal-infrared satellite imagery we identify drivers of wintertime sea-ice dynamics by looking at associated processes in the ocean and atmosphere. We find that overall spatial patterns in lead occurrences show a significant signature of ocean bathymetry and associated surface currents and eddy kinetic energies (FESOM model). Especially over the shelf and at water depths above 500 meters, ocean floor topography seems to significantly influence the stability of the overlying sea ice. In the temporal domain of the Arctic wintertime sea-ice variability we find the divergence of the wind field (ERA5 reanalysis and C15 model data) to have the largest impact on the question where and when the sea ice becomes prone to weakening and break-up. We here present results from our comparison of sea-ice lead observations and potential drivers in the atmosphere and ocean. Implications for sea-ice modelling and predictions are discussed.

T16 - Advancements in Ice Products from SAR for Analysis and Model Utilization

Sean Helfrich (NOAA, US)

Use of remote sensing for ice monitoring is essential for mapping, analysis, modeling, and forecasting in the remote polar environments. However, frequent cloud cover and long dark seasons limit the use of optical and infrared imagery for ice monitoring and passive microwave have limited resolutions and have issues with water attenuation of the signal using the melt season and along the marginal ice zone. It is for these reasons that synthetic aperture radar (SAR) is the most preferred data source for ice remote sensing. While SAR imagery has been applied for many years by ice services, SAR ice Level 2 and Level 3 products have only recently been considered at a quality and availability to be integrated into ice analyses and model data assimilation. Recent expansion of SAR coverage, reduced latency, and new algorithms have made the This presentation with demonstrate NOAA's (National Oceanic and Atmospheric Administration) recent advancements in the use of SAR for hemispheric and high-resolution ice motions, ice extent, ice concentrations, and ice thickness. This will also cover the blending of SAR with other sensors to utilities the strengths and offset the weaknesses of each data source. The intent of these new products is to improve the initialization of ice analyses for ice charting and for model assimilation. This will serve to reduce uncertainty, provide quicker ice analysis production, improve forecast guidance, improve model dynamics, and provide higher spatial resolution. These SAR products could fill many of the current observational gaps in ice observations and forecasting. While SAR and Blended SAR ice products are advancing in technical maturity, it will be important to resolve challenges in integration with ice chart analysis and model assimilation to ensure the products are used to their full potential to correct issues with the current ice charts and models.

T17 - Effects of damage on the scaling laws of viscous-plastic sea ice

Antoine Savard (McGill University, US)

Sea ice deformations occur along well-defined lines of deformation called linear kinematic features (LKFs), which exhibit complex laws like spatiotemporal scaling. The complexity of these interactions is undeniable, and a desirable sea ice model should represent LKFs adequately since various processes affecting heat, salt, and moisture exchange between the ocean and the atmosphere occur along these LKFs. This multifractal property of LKFs can be seen in observations and models. However, fine-scale LKFs happen at high resolution (0-2 km), and high-resolution models are costly to run, hence the importance of parametrizing these sub-grid phenomena. Different models are more or less in agreement with the observations, and one model, the Maxwell-Elasto-Brittle model (MEB), claims to reproduce the observed spatiotemporal scaling laws better than the standard viscous-plastic model (VP). One reason could be the presence of an ice damage parametrization in the MEB model that has no equivalent in the VP model. Therefore, we include a suitable damage parametrization with advection in the VP model to disentangle the effect of rheology from the effects of damage on the scaling laws. Results show that the deformation statistics in the VP model are influenced by the inclusion of damage in the model. The inclusion of this damage parametrization gives scaling exponents in agreement with the commonly accepted values computed from the RGPS observations, hinting that damage parametrizations play a crucial role in sea ice models.

T18 - A coupled ice-ocean framework to investigate the impact of sea-ice deformation in the winter *sea-ice mass balance in the Arctic*

Guillaume Boutin (NERSC, Norway)

Sea ice is a key component of the earth's climate system as it modulates the energy exchanges and associated feedback processes at the air-sea interface in polar regions. These exchanges strongly depend on openings in the sea-ice cover, which are associated with fine-scale sea-ice deformations, but the importance of these processes remains poorly understood as most numerical models struggle to represent these deformations without using very costly horizontal resolutions (~1km). Here, we present results from a 12km resolution ocean--sea-ice coupled model, involving the ocean component of NEMO and the sea ice model neXtSIM. This is the first coupled model that uses a brittle rheology to represent the mechanical behaviour of sea ice. Using this rheology enables the reproduction of the observed characteristics and complexity of fine-scale sea ice deformations with little dependency on the mesh resolution.

We investigate the sea ice mass balance of the model for the period 2000-2018. After a careful evaluation of the modelled sea ice against available observations (extent, drift, volume, deformations, etc.), we assess the relative contribution of dynamical vs. thermodynamic processes to the sea-ice mass balance in the Arctic Basin. We find a good agreement with ice volume changes estimated from the ESA CCI sea-ice thickness dataset in the winter, demonstrating the ability of brittle rheologies to produce a reasonable sea ice mass balance over long periods. Using the unique capability of the model to reproduce sea-ice deformations, we estimate the contribution of leads and polynyas to winter ice production. We find this contribution to add up from 25% to 35% of the total ice growth in pack ice in winter, showing a significant increase over the 18 years covered by the model simulation. This coupled framework opens new opportunities to understand and quantify the interplay between small-scale sea-ice dynamics and ocean properties that cannot be inferred from satellite observations.

T19 - A new brittle rheology and numerical framework for large-scale sea-ice models

Einar Örn Ólason (NERSC, Norway)

We present a new brittle rheology and its implementation into the neXtSIM model and neXtSIM-F forecasting platform. The new rheology, which we refer to as the brittle Bingham-Maxwell rheology (BBM), is based on a Bingham-Maxwell constitutive model and the Maxwell-Elasto-Brittle (MEB) rheology. The primary motivation for developing BBM was to address the unrealistic thickening of the ice seen in the previous implementation of MEB in neXtSIM. We show that by using BBM we get good long-term thickness evolution over several decades, contrary to our results with MEB. Using BBM, the neXtSIM-F forecasting platform also simulates thickness evolution and drift that compares well with satellite observations. We then show that the simulated deformation fields and statistics compare very well with those observed from satellites. Finally, we explore the role of model resolution in simulating deformation statistics.

T20 - Sea-ice deformation derived from the RADARSAT Constellation Mission and Sentinel-1 SAR Imagery at 24- and 72-hr intervals from 2017 to 2021

Amélie Bouchat (McGill University, US)

Sea-ice deformation features are a key component of the Arctic sea-ice dynamics that can be used to evaluate the performance of sea-ice models against observations across multiple spatial and temporal scales. High-resolution sea-ice deformation products are also in demand for navigation purposes, such as routing and ice pressure risk assessments. We present a new pan-Arctic sea-ice deformation dataset derived from the RADARSAT Constellation Mission (RCM) and Sentinel-1 (S1) SAR imagery for November to April 2017/2018 to 2020/2021. Deformation estimates are derived from contour integrals of ice motion obtained by the triangulation of tracked points in successive SAR images by the Environment and Climate Change Canada automated sea ice tracking system (ECCC-ASITS). The resulting deformation estimates have a temporal resolution ranging from 12 hours to 7 days, with a mean spatial resolution of ~7-10 km. The spatial coverage of the combined RCM+S1 product depends largely on the temporal resolution of the deformation estimates, but the whole Arctic Ocean (including the Canadian Arctic Archipelago, Baffin Bay, and Hudson Bay) is generally covered. We explore the limitations of the deformation dataset at 24- and 72-hr temporal resolution as a basis for sea-ice model evaluation using spatio-temporal scaling analyses, including an analysis of the deformation rate error. We show that checkered patterns of deformation features are visible when the sampled deformation rates are lower than the deformation rate error, which depends on the resolution of the deformation estimates but is ultimately controlled by the tracking error (200 m). Nevertheless, the extended spatial coverage and higher temporal resolution of this new deformation dataset provides an interesting opportunity to further investigate regional and seasonal variability of sea-ice deformation statistics across scales.

T21 - The RADARSAT Constellation Mission data assimilation in ECCC ice prediction system

Alexander Komarov (Environment and Climate Change Canada)

Data assimilation component of the Regional Ice-Ocean Prediction System (RIOPS) at Environment and Climate Change Canada's (ECCC) currently relies on multiple data sources such as active microwave ASCAT, passive microwave SSMIS and AMSR2, as well as Canadian Ice Service (CIS) ice charts manually produced from synthetic aperture radar (SAR) images. However, ASCAT, AMSR2 and SSMIS data have a low spatial resolution (~20-50 km), and spatiotemporal coverage of CIS charts is limited. The launch of the three-satellite RADARSAT Constellation Mission (RCM) in 2019 dramatically increased spatial and temporal coverage of SAR data, particularly over the Arctic region. We extracted ice concentration information from more than 65,000 RCM images over a 12-months time period between August 2020 and July 2021, and conducted data assimilation experiments with and without including SAR retrievals. Verification of resulting ice analyses against CIS Image Analyses, CIS Regional Charts, National Ice Center (NIC) Charts, and the Interactive Multisensor Snow and Ice Mapping System (IMS) was conducted. Our findings suggest that assimilation of RCM retrievals in ECCC ice analysis system leads to more accurate ice concentration analyses, particularly in the situations where the CIS ice charts are not available (e.g., the Eurasian Arctic) and where the high spatial resolution is important (e.g., near land and over inland lakes).

T22 - Resolution Enhanced Sea Ice Concentration from Passive Microwave

Jozef Jan Rusin (Norwegian Meteorological Institute)

Sea ice concentration (SIC) is an essential climate variable, it is used to indicate high latitude and global climate change, it is an important boundary condition for atmospheric and coupled climate models and is also used to initialise and correct sea ice forecasting models. Passive Microwave Radiometers (PMW) have provided this key information with daily imaging since the 1970s and are the backbone of sea ice monitoring in the Arctic and Antarctic.

To derive SIC these satellites apply a selection of frequencies and polarizations. Common algorithms either use a combination of 19/37 GHz frequencies (i.e. Comiso Bootstrap and NASA team) or purely 90GHz (i.e. ASI). Algorithms based on 19/37 GHz provide accurate SIC measurements but produce a coarse SIC field (~25km when using the AMSR2 instrument). 90GHz algorithms offer a much higher spatial resolution (~5km when using the AMSR2 satellite) but will also result in larger SIC uncertainties when compared to 19/37 GHz products.

This research, undertaken for the Norwegian-funded Sustainable Development of the Arctic Ocean (SUDARCO) and Sea Ice Retrievals and data Assimilation in NOrway (SIRANO) projects, applies the Resolution Enhanced (RE) algorithm to produce a new 5km AMSR2 SIC product in the Barents Sea and Arctic Ocean for the sea ice community. The RE algorithm was first implemented by ESA CCI+ to produce a 12.5km SIC Climate Data Record from the SSMIS satellite. The novelty of this RE algorithm is that it uses the 90GHz SIC to sharpen and enhance sea ice details such as the ice edge in the coarser 19/37 GHz product, with the aim of getting the benefits from both types of algorithms (high resolution and low measurement error).
This research tunes this algorithm further and applies it only to the AMSR2 satellite enabling the production of a new 5km SIC product. This product retains information from the coarse but accurate 19/37 GHz but is now at a much higher spatial resolution. Validation of this product is undertaken using high resolution multispectral data from Landsat-8 as well as known 0% and 100% tie-points using the Round Robin Data Package Phase 2 dataset. Additional comparisons against other operational SIC products; N90LIN, SICCI3LF and ASI will be presented to better understand the technical capabilities of this new product.

T23 - Data assimilation of SIC satellite observations in the Barents Sea region

Marina Durán Moro (Norwegian Meteorological Institute)

Operational forecasting systems assimilate daily average maps of sea-ice concentration (SIC) data from microwave radiometers on a daily or weekly basis in order to improve the accuracy of the forecasts. However, temporal and spatial averaging of the SIC data entails several drawbacks: (i) the spatial resolution of the original product is blurred (specially critical on periods with strong sub-daily sea-ice movement); (ii) the sub-daily frequency of passive microwave observations in the Arctic is not used, providing less temporal resolution in the data assimilation (DA) analysis and therefore, in the forecast; (iii) the observation uncertainties are much more difficult to specify on the daily averaged satellite products than on the individual swaths. Within the SIRANO (Sea Ice Retrievals and data Assimilation in NOrway) project, we investigate how the challenges listed above could be avoided by assimilating directly sea-ice information from the individual orbits (Level-2 information). As a first approach, we explore the performance of assimilating Level-3 data (individual swaths in the model grid) versus Level-4 data (daily average maps). To do so, we use a coupled ROMS/CICE regional configuration of the Barents Sea (2.5 km grid) together with the Ensemble Kalman Filter (EnKF) DA system. Two weeks of simulations with DA every second day are run. First results show that the assimilation of the SIC individual swaths (asynchronous run) provides a significantly better correction of the model fields compared to the assimilation of daily means (synchronous run). The mean absolute difference between model and observation SIC fields (daily means) is computed for every day during the 2 weeks period. At the end of this period, the free run shows a reduction of this difference by 10%, the synchronous run by 39% and the asynchronous one by 48%.

T24 - Impact of coupling complexity within the ECMWF forecast systems

Sarah Keeley (ECMWF)

The current operational ECMWF forecast systems are coupled to a dynamic-thermodynamic single category sea ice model, LIM2. Constraints due to the initialisation of the atmosphere and ocean model components separately mean that the only the sea ice fraction is coupled between the atmospheric surface scheme and the sea ice model. In this study we present the impact of enhanced thermodynamic coupling, exchanging surface temperatures and albedo and the impact that this has on the sea ice and atmospheric evolution. We also present results making use of NEMO4-SI3 ocean and sea.

Day 3: Thursday, March 23, 2023

T25 - Assessment of sea ice simulations in an operational model system for the North and Baltic Sea

Xin Li (German Federal Maritime and Hydrographic Agency, BSH) – online

For more than 30 years, the German Federal Maritime and Hydrographic Agency (BSH) has been providing the operational forecasting service, including sea ice forecasts for the North and Baltic Sea. The service is based on its 3D baroclinic circulation model HBM (HIROMB-BOOS Model), which is further coupled to the parallel data assimilation framework (PDAF, https://pdaf.awi.de). The HBM-PDAF system uses the Local Error Subspace Kalman Transform Filter (LESKTF) algorithm. Currently, sea surface temperature (SST), sea ice concentration (SIC) and sea ice thickness (SIT) can be assimilated in the model system. Assimilation experiments are conducted using different coupling regimes and different satellite data. The assimilation results are assessed with respect to the weak- and strong-coupled influences of the physical and sea ice observations onto the coupled model state. Furthermore, the experiments are performed using satellite data from CMEMS or from BSH satellite data service. The influences of using different SST satellite products on the sea ice forecasts will be discussed.

T26 - An ensemble prediction system for the ocean state and sea ice cover in the Barents Sea

Johannes Röhrs (Norwegian Meteorological Institute)

An operational ocean and sea ice forecast model, Barents-2.5km, is implemented at MET Norway for short-term forecasting of the ocean's state at the coast off Northern Norway, the Barents Sea, and waters around Svalbard. Primary forecast parameters are the extent of the ice cover, sea surface temperature (SST), and ocean currents. The model is also an substantial input for drift modeling of pollutants, ice berg, and in search-and-rescue pertinent applications in the Arctic domain. Barents-2.5km has recently been upgraded to include an Ensemble Prediction System with 24 daily realizations of the model state. Sea ice cover, SST and in-situ hydrography are constrained through a Ensemble-Kalman filter (EnKF) data assimilation scheme executed in daily forecast cycles with lead time up to 66 hours. While the ocean circulation is not directly constrained by assimilation of ocean currents, the model ensemble represents the given uncertainty in the short-term current field by retaining the current state for each member throughout forecast cycles. We present here a model validation in terms of sea ice concentration, SST and in-situ hydrography, the performance of the ensemble to represent the models uncertainty, and the performance of the EnKF to constrain the model state. Finally, a discussion of forecast skill for selected variables, and an assessment of the ensemble's capability to reflect uncertainties in sea ice cover is provided.

T27 - Progress of the Arctic sea ice forecast at the Danish Meteorological Institute

Till Andreas Soya Rasmussen (Danish Meteorological Institute)

The sea ice forecast at the Danish Meteorological Institute has recently been through an update, which includes an increased resolution and new versions of the ocean and sea ice models. These upgrades include melt ponds, introduction of the mushy layer thermodynamics and a change in the infrastructure of the models and how these communicate with each other. The model covers the entire Arctic; however, the main focus is on the sea ice forecast around Greenland. As part of the upgrade, a validation of the sea ice edge of the forecast around Greenland has been carried out. This includes validation towards passive microwave data, ice charts and a novel CNN algorithm that utilizes passive microwave and SAR data. Results of the latter indicate that it will be beneficial to use the CNN product in the assimilation; therefore the first steps to integrate this data set in the model will be discussed.

In addition this presentation will discuss the performance of the model both in terms of how it represents the physics and how to improve the utilization of the hardware available for the simulations. The latter will focus on a study of the EVP dynamics.

T28 - A multi-model comparison of September Arctic sea ice seasonal prediction skill

Mitch Bushuk (NOAA Geophysical Fluid Dynamics Laboratory)

Many earlier studies have documented individual prediction systems that skillfully forecast September sea ice extent (SIE) 1-3 months in advance, however, these studies are difficult to compare due to the different skill metrics used and time periods considered. These published skill estimates are also generally higher than the prediction skill revealed by retrospective analyses of real-time predictions submitted to the Sea Ice Outlook (SIO) over the period 2008-2021. In order to directly compare prediction skill across systems and resolve this apparent discrepancy with SIO skill, SIO Contributors have assembled a novel multi-model dataset of retrospective seasonal predictions of September Arctic sea ice. The dataset includes predictions from 17 statistical models and 17 dynamical models, spanning a minimum period of 2001-2020, with SIO initialization dates of June 1, July 1, August 1, and September 1.
We find that most statistical and dynamical models skillfully predict detrended Pan-Arctic SIE, and that detrended anomaly correlation coefficients of 0.5, 0.7, 0.8, and 0.9, respectively, could be expected at SIO lead times. Regional SIE predictions are found to be generally less skillful than Pan-Arctic predictions, and show comparatively better performance in the Alaskan and Siberian regions than the Canadian and Atlantic sectors. The skill of dynamical and statistical models is generally comparable for Pan-Arctic SIE, whereas dynamical models perform better for regional predictions. We find that models struggle to predict extreme sea ice years, such as 1996, 2007, and 2012, however they do skillfully capture some portion of these anomalies. Overall, this analysis shows that skillful operational predictions of September SIE are likely possible at least three months in advance. The SIO Community anticipates this new retrospective prediction dataset will provide future opportunities to understand mechanisms of prediction skill, the importance of model formulation, and sources of forecast error.

T29 - Data Assimilation for Lagrangian Sea Ice Models

Christopher K Jones (RENCI, University of North Carolina)

The Lagrangian sea ice model neXtSIM is solved on an evolving mesh with remeshing when the distortion of the mesh geometry exceeds certain prescribed tolerance. The evolving mesh presents a particular challenge to standard DA schemes. This work addresses these issues in making a state-of-the-art Ensemble Kalman Filter interface with the Lagrangian model. Experiments with SIC and SIT observational data show an improvement in forecast skill over a direct insertion method. Also discussed will be a new approach in which the assimilation step is carried out directly on the mesh without projection onto a reference grid. This is explored in a 1-dimensional prototype model. The research presented involves joint work with Sukun Cheng, Yumeng Chen, Ali Aydogdu, Laurent Bertino, Alberto Carrassi, Pierre Rampal, and Christian Sampson.

T30 - Predicting Lagrangian trajectories for drifting objects in the Marginal Ice Zone

Graig Sutherland (Environment and Climate Change Canada)

Understanding the drift of objects and material in the Marginal Ice Zone (MIZ) is of increasing importance as human activities increase in polar regions. Due to the remote nature of these regions, emergency response will depend strongly on drift prediction using data provided by environmental prediction systems. Predicting drift in the MIZ is complicated by the presence of wind, sea ice and waves all impacting the local dynamics. Currently, there is no consensus on a preferred drift model in the MIZ, which is most likely due to a lack of reliable observations of drift in the MIZ. Presented here are trajectories from four drifters placed at various ice concentrations north of Svalbard during September 2018. These trajectories are compared with drift estimates from two environmental prediction systems. A new drift model is designed to reduce sensitivity to predicted ice concentration developed which significantly reduces the trajectory errors for both environmental prediction systems and is less sensitive to uncertainties in predicted ice concentration. A new drift model is developed to reduce sensitivity to the uncertainty in predicted ice concentration and to include parameterized effects from surface waves in both the ocean and ice. This model significantly reduces the predicted trajectory error across a broad range of ice concentrations.

T31 - Deformation forecasts from the Sea Ice Drift Forecast Experiment (SIDFEx)

Valentin Ludwig (Alfred Wegener Institute, Germany)

We assess the capability of a variety of sea-ice models to predict the deformation of an array of buoys at different spatial scales and lead times up to ten days. We know that the models have skill at predicting locations of single buoys, but expanding this analysis to an array of buoys is something novel, the current state of which we will be presenting here. The forecasts stem from the Sea Ice Drift Experiment (SIDFEx). In the framework of SIDFEx, we have been collecting more than 200,000 forecasts for trajectories of single sea-ice buoys in the Arctic and Antarctic since 2017. SIDFEx is a community effort originating from the Year Of Polar Prediction. Forecasts are provided by various forecast centres and collected and archived by the Alfred Wegener Institute (AWI). AWI provides a dedicated software package and an interactive online platform for analysing the forecasts. Their lead times range from daily to seasonal scales. SIDFEx forecasts have been used for operational support before and during the MOSAiC and Endurance22 campaigns.

T32 - Fully automated navigation support for vessels in the Arctic: An application and validation example of ice type mapping during the CIRFA cruise 2022

Johannes Lohse (UiT The Arctic University of Norway)

Near real-time information about sea ice conditions and icebergs is crucial for navigational support and to ensure the safety of vessels in the Arctic. At present, such information is most commonly transferred to the mariners in the form of manually produced sea ice charts. In some cases, also the original SAR imagery, which is the main data source for ice chart production, can be transferred. However, the correct interpretation of SAR imagery over sea ice requires extensive training and experience, and the manual production of ice charts is a subjective and time-consuming process. This makes automation of sea ice mapping from SAR data a desirable goal. While there has been considerable progress in the scientific field of (semi-)automated sea ice classification over the past years, the transfer of this research into operations is not straightforward. Fully automated products must be thoroughly tested and validated in-situ, before they can be implemented into an operational workflow. Since the ice services usually work on a tight time schedule in order to provide their operational ice chart products, they often lack the time and manpower for such testing. Many research projects, on the other hand, do not have the necessary long-term funding and planning security to bridge the gap between research and operations in sea ice charting. In this study, we take a step towards bridging this gap, using the “CIRFA cruise 2022” as an example for application and validation of fully automated navigation support.

In April and May 2022, the “Center for Integrated Remote Sensing and Forecasting for Arctic Operations” (CIRFA) conducted a research cruise on the Norwegian icebreaker RV Kronprins Haakon (KPH). The vessel left from Longyearbyen, Svalbard, on April 21st and spent approximately three weeks in the Belgica Bank area outside the north-east Greenland coast. The main goal of the cruise was to provide in-situ observations for the validation of information and forecast products resulting from the CIRFA work. Even for an ice-breaking vessel, the sea ice situation around Belgica Bank can be challenging at this time of the year, consisting of both level and heavily deformed landfast ice close to the Greenland coast, as well as drift ice at various stages of development further east.

Before the cruise, UiT and the Norwegian Ice Service set up a fully automated Sentinel-1 (S1) ice type classification algorithm (Lohse et al., 2020) on the IT infrastructure of the Norwegian Ice Service. The algorithm was re-trained specifically for the area, using overlapping S1 and optical (Sentinel-2) data from the weeks previous to the cruise. During the expedition, all incoming S1 data covering the area of interest was automatically processed, classified, compressed, and geo-coded at different spatial resolutions. The resulting geotiff files were uploaded to an FTP server, which could be accessed from KPH. Depending on the available internet connection, the most suitable resolution and file size of classification products could be accessed and downloaded on board. Classification results were usually available within several hours after image acquisition, which is currently considered near-real-time for sea ice charting and navigation. In combination with complementary satellite imagery (for example Radarsat-2,ICEYE, Sentinel-2), the ice type maps were used to assist in route planning and navigation of KPH. Furthermore, having classification results immediately available in the field allows for easier and better targeted validation of the results, using visual observations, manual photographs, shipboard cameras, and imagery from drones. In this presentation, we will outline the technical details of the data processing and transfer and show how the satellite products can be used for navigation and route planning on board. We will also show preliminary results of the validation of classification results.

T33 - Pan-Arctic Sea Ice-Atmosphere Drag Coefficients Derived from ICESat-2 Topography Data

Alexander Mchedlishvili (Institute of Environmental Physics, University of Bremen, Germany)

The effect that sea ice topography has on the momentum transfer between ice and atmosphere is not fully quantified due to the limitations of current measurement techniques, which is problematic since the Arctic Ocean is a highly dynamic environment and sea ice roughness, and therefore the associated momentum transfer, varies with respect to both time and space. We present a method to better estimate pan-Arctic momentum transfer via an parameterization which links sea ice-atmosphere 10-m neutral form drag coefficients with surface feature height and spacing. While localized airborne studies have successfully used this parameterization, satellite remote sensing was generally deemed unsuitable due to its relatively low resolution. Here we attempt to measure these sea ice surface feature parameters using the Cloud and land Elevation Satellite-2 (ICESat-2) which, though it cannot resolve as well airborne surveys, has an along-track spatial resolution that is unprecedented in satellite altimetry. Pan-Arctic drag coefficient assessments are expected to improve coupled atmosphere-sea ice models and better quantify the interplay between the two mediums; leading to a better understanding of the climate system.

T34 - High-resolution winter Arctic sea ice profiling with NASA's ICESat-2

Alek Petty (University of Maryland/NASA GSFC) – online

National Aeronautics and Space Administration's (NASA's) Ice, Cloud, and land Elevation Satellite 2 (ICESat-2) mission continues to generate reliable, very high-resolution estimates of surface height/type (the ATL07 product) and freeboard (the ATL10 product) across the Arctic and Southern Oceans since data collection started in October 2018.

In addition to the official ICESat-2 sea ice products (height and freeboard), estimates of winter sea ice thickness across the entire Arctic Ocean have also been generated by combining ATL10 freeboards with snow depth and density estimates from the NASA Eulerian Snow on Sea Ice Model (NESOSIM) (Petty et al., 2020). The winter Arctic thickness data have been recently validated against upward looking sonar draft measurements from moorings deployed in the Beaufort Sea and show good agreement with various CryoSat-2 derived products. The winter Arctic sea ice thickness data showed a strong decline in the 2020/21 winter compared to the previous two winters. In addition to thickness, work is on-going to generate reliable estimates of IS-2 lead fraction and chord length towards a joint floe-size/thickness distribution.

In this presentation we aim to give an overview of the current state of knowledge regarding these various ICESat-2 sea ice datasets, with an extra focus on summarizing recent validations of these data and uncertainty estimates relevant to sea ice data assimilation efforts.

T35 - The OceanMAPS v4 sea-ice forecast demonstration project mk 2

Stewart Allen (Bureau of Meteorology, Australia)

The Ocean Model, Analysis and Prediction System version 4 (OceanMAPS v4) upgrade, currently planned for late 2023, will see the operational implementation of a fully global ocean and sea-ice short-range forecast capability. The advances of this system include a new fully global ocean and sea-ice model and an ensemble Kalman Filter hybrid ocean and sea-ice data assimilation system. The model is based on ACCESS-OM2-01, which was developed through a national partnership, COSIMA.

A key focus of the system is the production of a sea-ice analysis and forecasts for the southern high-latitudes. Hindcasts of Antarctic sea ice for the austral 2021-2022 summer season were produced, which provided valuable insights into the system's performance and in developing new sea-ice forecast products. The system has continued running through the Austral winter and will be used to produce experimental forecasts for the next summer season.

This presentation will describe the background and development of the model. Statistics of the model's sea-ice performance during the hindcast period through to present date will be presented. Lastly there will be a discussion of planned future improvements ahead of the system's operational implementation.

T36 - Subseasonal Arctic Sea ice predictions in a UFS-based System

Yanyun Liu (ERT Inc @ NOAA/NCEP/CPC) – online

In support of NOAA's sea ice forecasts in week 3-4 time-range, the Climate Prediction Center (CPC) has been using an experimental sea ice prediction system, CFSm5, for weekly Arctic sea ice predictions. The CFSm5 was developed based on the Climate Forecast System (CFS) with the MOM5 as oceanic component. CFSm5 sea ice forecasts initialized from the CPC sea ice system (CSIS) showed improvements over the operational CFS. In 2021, CPC started to prepare a transition from the use of CFSm5 to a new FV3-based Unified Forecast System (UFS) prototype 5. This coupled UFS S2S model consists of the new FV3 atmospheric component, MOM6 oceanic component and CICE6 sea ice component. In this work, we evaluate the Arctic sea ice forecast skill in the UFS system for the melt and freeze-up seasons and investigate impacts of cloud related parameters for an improved representation of sea ice in the coupled system. Analysis of the retrospective 45-day forecasts spanning 2012-2020 show the prediction skill of multi-week Arctic sea ice is generally (a) comparable or better than CFSm5 especially for the freeze-up seasons, and (b) better than the operational CFSv2 hindcasts. The skill comparisons of CFSm5, CFSv2, UFS and Multi-Model Ensemble (MME) hindcasts are presented. To further explore skill improvement of Arctic sea ice prediction, we also examined factors potentially influencing the sea ice predictions, including the role of initial sea surface temperature.

POSTERS (P)

P1 - Recent development of the Combined Optimal Interpolation and Nudging method in assimilating the AMSR2 sea ice concentration (SIC) in SHAPS

Keguang Wang (Norwegian Meteorological Institute)

We report the recent development of the Combined Optimal Interpolation and Nudging (COIN) method in assimilating the AMSR2 sea ice concentration (SIC) in the Super High-resolution Arctic ocean and sea ice Prediction System (SHAPS) in the Norwegian Meteorological Institute. SHAPS is a developing high-resolution (3-5 km) pan-Arctic coupled ocean and sea ice prediction system based on the Hybrid Coordinate Ocean Model (HYCOM Version 2.2.98) and the Los Alamos multi-category sea ice model (CICE Version 5.1.2), with the COIN method for data assimilation. In this study, the focus is on the COIN assimilation of the AMSR2 SIC, which is designed to update the model SIC in every time step such that the analysis will eventually reach the optimal estimate. The SIC innovation (model minus observation) is designed to be proportionally distributed to the multiple sea ice categories. A twin experiment is performed with and without the COIN assimilation for the period 1 January 2021 to 30 April 2022. The results show that the assimilation greatly improves the simulated sea ice concentration, extent, area, thickness and volume, as well as the sea surface temperature (SST) and salinity (SSS). The results are also compared with the CMEMS operational analyses from TOPAZ4, NEMO and neXtSIM which use ensemble Kalman filter (EnKF), three-dimensional variational (3DVar) and optimal interpolation (OI) as the assimilation methods, evaluated against the observed AMSR2 SIC and the Norwegian Ice Service ice charts.

P2 - Observation impact on the multi-variate state and parameter estimation of Maxwell-Elasto-Brittle rheology model

Yumeng Chen (University of Reading, UK)

Data assimilation (DA) combines observations with model forecasts to improve the trajectory and/or the parameters of numerical models. Recently, DA shows flourishing applications for the Arctic sea-ice, thanks primarily to the increasing satellite observations. Together with better observations, sea-ice models have undergone a substantial change of paradigm.

The recently developed sea ice model, neXtSIM, uses a novel Maxwell-Elasto-Brittle (MEB) rheology treating the sea ice as elastic and viscous materials. For long-term climate simulations, neXtSIM_DG adopting discontinuous Galerkin method on Eulerian grids is under development. Climate simulations are hugely dependent on the model parameters and external forcing. To improve climate prediction, we use DA to estimate the model parameters based on physical observations of the sea ice. As a first step, we investigate the state and parameter estimations for the sea ice model using a pure rheological MEB model without any parameterization and thermodynamics. Using idealised experiments, we focus on the impact of observations on different model quantities and parameters in a multivariate setup. Our experiments show that assimilating sea ice concentration, thickness and drift data can lead to improved sea ice state estimation and complex interplay between sea ice quantities. However, the forecast error can be severely affected by the external forcing, which reduces the benefits of DA beyond few hours after the analysis. Our experiments also show some success in estimating some key model parameters, such as the air drag coefficient. Even though further investigation will be needed using an operational sea ice model, our results demonstrate the feasibility of observation-informed parameter estimation in the sea ice model and show possible caveats in sea ice DA.

P3 - Assimilating observations of deformation to improve short-term ensemble forecasts of sea ice features

Yue Ying, Anton Korosov, Laurent Bertino (NERSC)

Sea ice features such as open leads and ridges at kilometer scale are important information for the safety of sea navigation. However, short-term prediction of ice features is still challenging despite recent advancements in sea ice modeling and observation techniques. In this talk, we present some preliminary results from data assimilation experiments using deformation observations to improve sea ice feature prediction skill at day-to-day time scales. An ensemble of next generation sea ice model (neXtSIM) simulations are used to provide prior information. The boundary conditions of the stand-alone sea ice model are provided by the ERA5 atmospheric and TOPAZ4 ocean reanalyses. After the spin-up period, the ensemble developed a multivariate flow-dependent error covariance, the ensemble Kalman filter (EnKF) is used to assimilate deformation of ice drifts obtained from synthetic-aperture radar (SAR) satellite images to update neXtSIM ice drift and concentrations. Error reduction in the observed and unobserved model state variables are diagnosed with both spatial-average and feature-based metrics. Observation impact is evaluated in both the analysis and ensemble forecast up to a one-week lead time. We will discuss issues in assimilating nonlinear features, especially due to large position mismatches between the simulated and observed ice leads, and discuss potential remedies from using the EnKF in a multiscale framework.

P4 - Insights of the coupling between sea ice and atmosphere by assimilation of sea ice thickness from CS2SMOS

Jiping Xie (NERSC)

The sea ice thickness (SIT) is an essential climate variable representing how the sea ice volume varied under global warming. However, the role of sea ice thickness has been underrated in forecasting Arctic sea ice due to the significant bias of the simulated SIT without direct constraint because of the lack of direct observations.

In recent years, the satellite-based SIT combined from Cryosat2 and SMOS has been assimilated into different ice-ocean coupled model systems and shows a common feature: the previous deviations of SIT in the Arctic have been dominantly corrected. In this study, based on the two parallel assimilation runs in TOPAZ4 during 2014-2017, we investigate the differences incurred from the additional assimilation of the SIT observations. Comparing the autocorrelations of SIC and SIT, respectively, the SIT variability shows a much longer timescale (100 days). The analysis highlights the dynamics between the SIT and the key variables from the atmospheric forcing through the singular value decomposition (SVD), which improves understanding of the coupling responses between sea ice and the atmosphere.

P5 - NorCPM's new seasonal prediction skill in regional Arctic sea ice

Yiguo Wang (NERSC)

The Norwegian Climate Prediction Model (NorCPM) is developed at the Bjerknes Center for Climate Research (BCCR) in Norway. NorCPM combines the Norwegian Earth System Model (NorESM) and the EnKF for the purpose of climate predictions and long-term climate reanalyses. Recently, we have revised the scheme of sea ice concentration assimilation in NorCPM. Compared to the previous scheme, there is no longer degradation in ocean heat content at the middle latitude. It is likely due to the fact that the implementation of the assimilation of sea ice concentration in the previous scheme strongly reduces the influence of SST data near ice-covered regions and thus influences ocean circulation. We noticed that the new regional sea ice prediction skill verified over 2002-2020 is higher than the old one verified over 1985-2010. It can be caused by the revised scheme, modulation of variability or improved accuracy of other datasets (e.g., ARGO floats). We implemented the assimilation of sea ice thickness in NorCPM. The error of ice thickness is constrained to about 1 m during the ESA CCI period and 0.6 m during the

C2SMOS period. We will also present the benefit of ice thickness assimilation on seasonal sea ice prediction.

P6 - Improve short-term sea ice predictability using deformation observations

Anton Korosov (NERSC)

Short-term sea ice predictability is challenging despite recent advancements in sea ice modelling and new observations of sea ice deformation, that capture small-scale features (open leads and ridges) at kilometre scale. A new method for assimilation of satellite-derived sea ice deformation into the neXt-generation Sea Ice Model (neXtSIM) is presented. Ice deformation provided by the Copernicus Marine Service is computed from sea ice drift derived from Synthetic Aperture Radar at a high spatio-temporal resolution. We show that high values of ice deformation can be interpreted as reduced ice concentration and increased ice damage - scalar variables of neXtSIM. This proof-of-concept assimilation scheme uses a data insertion approach and forecasting with one member. We obtain statistics of assimilation impact over a long test period with many realisations starting from different initial times. Assimilation and forecasting experiments are run on synthetic and real observations in January 2021 and show increased accuracy of deformation prediction for the first 2 -- 3 days. It is demonstrated that neXtSIM is also capable of extrapolating the assimilated information in space - gaps in spatially discontinuous satellite observations of deformation are filled with a realistic pattern of ice cracks, confirmed by later satellite observations. Limitations and usefulness of the proposed assimilation approach are discussed in a context of ensemble forecasts. Pathways to estimate intrinsic predictability of sea ice deformation are proposed.

P7 - Improving sea-ice representation through data assimilation in a global NEMO model

Aliette Chenal (MOI, France)

Sea-ice is a crucial element in our climate system, and it is very sensitive to climate change. Sea-ice volume is a key indicator of the sea-ice evolution in both hemispheres, but it is very challenging to estimate precisely: combining information from both observations and models through data assimilation can be a mean to a better understanding of the past and current sea-ice state.

For more than a decade, Mercator Ocean International develops global real time operational systems and produces Global Ocean Reanalysis. Based on the NEMO (Nucleus for European Modelling of the Ocean) modelling platform, observations are assimilated by a reduced-order Kalman filter. In-situ temperature and salinity profiles, altimetric data, sea surface temperature, and sea-ice concentration are jointly assimilated to constrain the ocean and sea-ice model. The ocean model is coupled to a multicategories ice model.

Developments are ongoing to prepare the future global 1/12° real time system. The currently sea-ice concentration product assimilated in the real time operational system at Mercator is the EUMETSAT OSI-SAF sea-ice concentration product (computed from DMSP/SSMIS brightness temperature measurements. We perform an OSE (Observing System Experiment) by assimilating EUMETSAT OSI-SAF sea-ice concentration product computed from AMSR-2 microwave measurements. This latter dataset is supposed to have at least three times the spatial resolution of that estimated from SSMIS. A validation protocol is in place to measure the impact of this OSE on marginal ice areas (ice edge) and coastal areas in the Arctic and Antarctic. When available, ice charts will be used in this validation. Different available satellite and in-situ observations are used for validation.

These experiments take place in a longer-term context of improving the sea ice cover representation and to prepare for the launches of Copernicus Sentinel expansion satellite missions.

P8 - Reconstruction of Arctic sea ice thickness (2000-2010) based on a hybrid machine learning and data assimilation approach

Léo Edel (NERSC)

In the Arctic, the sea ice thickness (SIT) remains one of the most challenging parameters to estimate and generally present temporal and spatial discontinuity which are a major difficulty for climate studies. Since 2010, the combined product CS2SMOS enables more accurate SIT retrievals that significantly decrease the SIT errors when assimilated in models (such as TOPAZ4). Can we extrapolate these benefits in the earlier period 2000-2010? In this study, we train a machine learning algorithm to learn the systematic SIT errors between two versions of TOPAZ4 (with and without CS2SMOS assimilation) in 2010-2020, in order to predict the SIT error and extrapolate the SIT prior to 2010. The ML algorithm relies on SIT coming from two versions of TOPAZ4, various oceanographic variables as well as atmospheric forcings (from ERA5). The ML model demonstrates its ability to correct a significant part of the SIT error. We will discuss the sensitivity of the method to the input variables and to different types of ML models. The long Arctic ML-reconstructed SIT record (2000-2022) is validated using in-situ data and earlier satellite data.

P9 - Collecting ground truth observations of the Marginal Ice Zone: recent deployments, data use, and outstanding questions

Jean Rabault (MET Norway)

In-situ observations are critical to provide the ground truth data needed to calibrate models and satellite processing algorithms. The Marginal Ice Zone (MIZ) has historically been relatively undersampled, especially since it is a very dynamic area where instrumentation lifetime is typically short - therefore, trajectories of instruments deployed there are often relatively short, and scientists may be reluctant to deploy expensive instruments there. In the last few years, low cost instrumentation has become increasingly available, and several deployments of sea ice trackers have taken place specifically in the MIZ. In this talk, I will i) quickly present the low cost instrumentation that has been developed at MetNo to measure sea ice drift and waves in ice, ii) provide an overview of the deployments performed in the last 5 years using these instruments and data collected, iii) present more specifically a couple of events where interesting dynamics are observed, iv) discuss how these data are made available to experts in need of ground truth data to calibrate their algorithms and models.

P10 - Linking scales of sea ice surface topography: evaluation of ICESat-2 measurements with coincident helicopter laser scanning during MOSAiC

Robert Ricker (NORCE)

Information about the sea ice surface topography and related deformation are crucial for studies of sea ice mass balance, sea ice modeling, and ship navigation through the ice pack. NASA's Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) has been on-orbit for nearly four years, sensing the sea ice surface topography with six laser beams capable of capturing individual features such as pressure ridges. To assess the capabilities and uncertainties of ICESat-2 products, coincident high-resolution measurements of the sea ice surface topography are required. During the year-long Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) Expedition in the Arctic Ocean, we successfully carried out a coincident underflight of ICESat-2 with a helicopter-based airborne laser scanner (ALS) achieving an overlap of more than 100 km. Despite the comparably short data set, the high resolution measurements on centimetre scales of the ALS can be used to evaluate the performance of ICESat-2 products. Our goal is to investigate how the sea ice surface roughness and topography is represented in different ICESat-2 products, and how sensitive ICESat-2 products are to leads and small cracks in the ice cover. Here we compare the ALS measurements with the ICESat-2's primary sea ice height product, ATL07, and the high-fidelity surface elevation product developed by the University of Maryland (UMD). By applying a ridge-detection algorithm, we find that 16 % (4 %) of the number of obstacles in the ALS data set are found using the strong (weak) center beam in ATL07. Significantly higher detection rates of 42 % (30 %)

are achieved when using the UMD product. Only one lead is indicated in ATL07 for the underflight, while the ALS reveals mostly small, narrow and only partly open cracks that appear to be overlooked by ATL07.

P11 - Quantifying the effect of snow-ice formation on SnowModel-LG product that is used in sea ice altimetry applications

Ioanna Merkouriadi (FMI)

This study quantified the effect of snow-ice formation on SnowModel-LG snow depth and density product. SnowModel-LG, is a snow modeling system adapted for snow depth and density reconstruction over sea ice for use in altimetry applications for sea ice thickness retrievals. We coupled SnowModel-LG with HIGHTSI, a 1-D sea ice thermodynamic model, to simulate snow-ice and thermal-ice growth. Pan-Arctic model simulations were performed over the period 1 August 1980 through 31 July 2021. We compared snow depth and density from the coupled product (SnowModel-LG_HS) to outputs from the SnowModel-LG only. In SnowModel-LG_HS, snow depth decreased (domain average: 18%), and snow density increased (2.3%). The differences were much larger in the Atlantic sector. Our simulations suggest that when snow-on-sea-ice models do not account for snow-ice formation, snow depth can be significantly overestimated. Sea ice thickness retrievals from CryoSat-2 were guided by SnowModel-LG_HS and were validated against Airborne Electromagnetic Measurements. SnowModel-LG_HS performance was highest when compared to other snow products.

P12 - Machine Learning for Sea Ice Challenge (AutoICE)

David Arthurs (PolarView)

The Norwegian Computing Center, the Danish Meteorological Institute (DMI), the Technical University of Denmark (DTU), Polar View, Nansen Environmental Remote Sensing Center (NERSC) and the European Space Agency (ESA), in collaboration with the International Ice Charting Working Group (IICWG), are hosting a machine learning challenge that brings together the AI, Earth Observation, sea ice charting communities.

The objective of the AutoICE challenge is to advance the state of the art for sea ice parameter retrieval from SAR data, thus improving the capacity to derive more robust and accurate automated sea ice maps. Challenge participants are tasked to build machine learning models using the provided training dataset and to submit their model results for each of three sea ice parameters: sea ice concentration, stage-of-development and floe size.

This talk will review the challenge results and the lessons learned for the sea ice charting community.

P13 - Extension of CCI sea ice climate time series with historical satellite data

Wiebke Margitta Kolbe and Rasmus T. Tonboe (DTU)

Arctic sea ice is an important climate indicator, because the effects of global climate change are amplified in the arctic. Current ESA CCI and EUMETSAT sea ice climate data records (CDRs) documenting this change are beginning with data from the Scanning Multichannel Microwave Radiometer onboard NASA's NIMBUS-7 satellite October 1978 . However, there are satellite missions from the early and mid 1970s which can be used for mapping sea ice and for extending the current CDRs. One example is the data of the Electrically Scanning Microwave Radiometer (ESMR) on board the NIMBUS 5 satellite, which was operating between 1972 and 1977. The data are available online at NASA Earth data archive (GES DISC) and a first reprocessing of the data using modern sea ice retrieval methods has been carried out as part of the ESA CCI+ program. Results show that while older satellite instruments have their limitations compared to modern multi-channel sensors, they still provide useful data for mapping sea ice extent and the distribution of sea ice type.

The work continues with a new PhD project building and running new methods to process historical satellite data in order to extend existing sea ice climate data records of sea ice extent into the past. The project is a part of the Danish National Centre for Climate Research (NCKF) at DMI and the research will provide insights into historical sea ice development and serve as an important sea ice extent reference from the 1970s, which can be used for input to climate models and re-analysis.

The aforementioned ESMR measured the horizontally polarized brightness temperature (TB) at 19.35 GHz for 78 different incidence angles from nadir to 63 degrees at the edges of the swath from December 1972 until May 1977 with some interruptions. With an impressive swath width of about 3100 km far beyond modern sensors ESMR provided full coverage of polar regions in half a day. The sea ice concentration is derived from the data using a single channel algorithm and modern processing steps including dynamical tie-points, regional noise reduction with a correction based on a radiative transfer model (RTM) and numerical weather prediction model data.

The first results show interesting sea ice features in the years 1972-1977. One such feature is the Maud Rise Polynya in Antarctica, while another is the formation of the new ice Odden in the Greenland Sea, an ice tongue which extends eastward from the East Greenland Current. Both features were much larger in extent in the mid-1970s than they are today, providing an important reference of the past.

Current work on the ESMR dataset includes re-calibration, further noise reduction and validation/ inter-comparison to other sea ice datasets during this period and further investigation of other historical satellite data from the 1970s for comparison and extending the current sea ice data record into the past.

P14 - Sea ice thickness from CryoSat2 freeboard assimilation

Imke Sievers (DMI)

Most sea ice thickness (SIT) assimilation products use CryoSat2 derived SIT. SIT is not directly measured by CryoSat2 though radar freeboard is. To derive SIT from radar freeboard, assumptions about snow thickness, sea ice density and snow density need to be made. All of these variables are poorly constrained due to a lack of comprehensive, timely, Arctic wide observations. For snow thickness a climatology or a snow model is used. For sea ice density a fixed value is applied depending on the ice type. The ice type is determined as either first year ice or multi year ice, derived from passive microwave measurements, even though it is well known that both ice types can exist within close proximity.

To improve the SIT derived from CryoSat2, an algorithm assimilating CryoSat2 radar freeboard was developed. The resulting assimilated radar freeboard is used to derive SIT based on model variables. The resulting SIT is compared to upward looking sonar measurements and MOSAiC sea ice thickness observations, and was found to be in an as good, or even better, of an agreements with the observations as classical derived CryoSat2 SIT products. We will present the method, first results and a discussion of the used model parameters and compare these to other sea ice thickness assimilation methods.

P15 - Combining automated sea-ice and iceberg observations

Jørgen Buus-Hinkler (DMI)

For high resolution sea ice charting and iceberg detection – applicable for navigation at sea – Synthetic Aperture Radar (SAR) satellite images are the main source of information. Ice analysts may also include observations from other space borne sensors such as Passive Microwave Radiometer (PMR) where sea ice and water usually are more easily distinguished. However, PMR is much coarser in spatial resolution than SAR and can therefore not be used “stand alone” for derivation of ice information detailed enough to be used for navigation at sea.

Within the ASIP/AI4Arctic projects deep Convolutional Neural Network (CNN) models are used to map sea-ice - here with SAR imagery from the ESA Sentinel-1 missions as primary input - as ""secondary input"" PMR data from JAXA's amsr2 is used along with information about the distance to the nearest coast. The ASIP/AI4Arctic CNN's were trained using ice charts as label data.

Since the launch of the Sentinel-1 SAR A & B satellites in 2014 and 2016 (respectively) the Danish Meteorological Institute DMI has used Sentinel-1 imagery to detect icebergs within the Greenland Waters. The DMI iceberg detection algorithm utilizes a Constant False Alarm Rate (CFAR) concept. Basically this means that if a given pixel (backscatter value) is very unlikely to be part of the background (i.e. open sea)

then this pixel will be classified as a target pixel. After the CFAR process all iceberg pixel clusters are vectorized to ""iceberg polygons"", which enables us to derive the final iceberg products available through the service provided by the Copernicus Sea Ice Thematic Assembly Centre (SI-TAC) at https://marine.copernicus.eu/.
Due to rugged structures in the sea ice (such as ridges and rubble fields) iceberg detection does not work reliably within sea ice infested areas and is thus only carried out in open water areas. Thus, to filter out sea-ice infested areas from the iceberg products sea-ice information a high spatial resolution is a necessity. DMI has recently with success applied CNN's trained with ASIP/AI4Arctic datasets to derive automated sea-ice maps at 80 meter spatial resolution. Since these CNN models use exactly the same Sentinel-1 SAR imagery as is used for DMI's iceberg detection there will be a perfect match both in space and time between the two products (i.e. sea-ice and icebergs). This means that the existing problems with ""false iceberg targets"" near the sea-ice-edge can be reduced dramatically by combining the two. Again, this means a significant quality improvement of our iceberg product. Furthermore, it opens the possibility to create automated ice charts holding high quality information on both sea-ice and icebergs (similar to the manual ice charts provided by national ice services).

P16 - Synoptic variability in satellite radar altimeter-derived sea ice thickness

Carmen Nab (University College London)

Satellite observations of sea ice freeboard are integral to the estimation of sea ice thickness. It is commonly assumed that radar pulses from satellite-mounted Ku-band altimeters penetrate through the snow and reflect from the snow-ice interface. We would therefore expect a negative correlation between snow accumulation and radar freeboard measurements, as increased snow loading weighs the ice floe down. In this study we produce daily-resolution radar freeboard products from the CryoSat-2 and Sentinel-3 altimeters via a recently developed optimal interpolation scheme. We find statistically significant ($p<0.05$) positive correlations between radar freeboard anomalies and modelled snow accumulation. This suggests that, in the period after snowfall, radar pulses are not penetrating through to the snow-ice interface as commonly assumed. Our results offer satellite-based evidence of winter Ku-band radar scattering above the snow-ice interface, violating a key assumption in sea ice thickness retrievals.

P17 - Incorporating sea ice into a nearshore wind wave transformation model (Hornsund, Svalbard)

Zuzanna Swirad (Department of Polar and Marine Research, Polish Academy of Sciences)

Three nested SWAN (Simulating Waves Nearshore) models that use global wind and wave models as boundary conditions successfully predict wind wave energy in coastal (~15 m depth) waters of central Hornsund fjord, Svalbard during ice-free days. However, when sea ice is present at the entrance to the fjord, the model set over-estimates wave height and under-estimates wave period. We present a framework that uses 1) available sea ice concentration products to improve the lowest-resolution SWAN model (Svalbard-scale) and 2) semi-automated classification of Sentinel-1A/B SAR data (2014-present) to improve medium- (Hornsund-scale) and highest- (northern bays of Hornsund) resolution SWAN models. Wave spectra and bulk parameters are compared to freely available in situ wave measurements (hourly since 2013). Accurate modelling of nearshore wave conditions will allow now-casting and scenario modelling of wave runup, flooding and coastal erosion which are critical for the safety of Polish Polar Station infrastructure.

P18 - Moving the dominant scattering horizon in the Met Office's Forecast Ocean Assimilation Model (FOAM)

Carmen Nab (University College London)

Sea ice thickness (SIT) estimates derived from the Cryosat-2, Soil Moisture and Ocean Salinity (SMOS) and ICESat-2 satellites are assimilated into the Met Office's global ocean–sea ice forecasting system, FOAM, using a 3D-Var assimilation scheme, NEMOVAR. The CryoSat-2 and ICESat-2 along-track SIT estimates are converted from ice and total freeboard measurements, respectively, using the model snow depth and assimilated together with the daily, gridded SMOS SIT product to constrain the model SIT. It is commonly assumed that radar pulses from Cryosat-2 penetrate all the way through the snowpack, reflecting off the snow-ice interface. During the conversion of CryoSat-2 freeboard to SIT, the CryoSat-2 radar penetration depth (α) into the snowpack is calculated by normalising the difference between the CryoSat-2 and ICESat-2 freeboards. To set the limits of this normalisation procedure, we use the model snow depth as the maximum difference (full CryoSat-2 radar penetration of the snowpack, $\alpha = 1$) and a snow depth of 0 cm as the minimum difference (no radar penetration of the snowpack, $\alpha = 0$). We compare our model SIT results to in situ observations taken as part of the Beaufort Gyre Exploration Project (BGEP) and the MOSAiC expedition. This work evaluates for the first time the impacts of using a varying assumed penetration depth for CryoSat-2 on the SIT assimilation, as well as representing the first assimilation of ICESat-2 SIT data into a coupled ocean-sea ice system.

P19 - In-situ sea ice, iceberg and ocean drift observations in the Greenland Sea

Catherine Taelman (UiT The Arctic University of Norway)

We present a data set of in-situ sea ice, iceberg, and ocean drift observations collected by drifters in the Greenland sea in 2022. A total of 20 drifters were manufactured in-house at UiT following the open source OpenMetBuoy design (J. Rabault et al., 2022). The drifters were consecutively deployed during a research cruise organized by the Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA). The CIRFA cruise onboard the Research Vessel Kronprins Haakon went to the north-eastern coast of Greenland in the period April 22st - May 9th 2022. This area, located in Fram Strait, is characterized by complex and highly variable sea ice conditions and therefore of particular interest for the study of sea ice and iceberg drift.

Of the 20 drifters, 17 were deployed manually on sea ice, while the remaining 3 were deployed on icebergs by drones. The sea ice drifters collect a GPS position every 30 minutes and perform a wave motion measurement for a duration of 20 minutes every 3 hours. For the iceberg drifters a distinction was made between ‘grounded iceberg drifters’ and ‘floating iceberg drifters’. Their hardware design is identical, but the software differs. The grounded iceberg drifter (1 drifter) collects a GPS position every 12 hours, while the floating iceberg drifters (2 drifters) collect a GPS position every 30 minutes. The reasoning behind this different GPS sampling rate is that the grounded iceberg might only start moving weeks after drifter deployment, and hence a lower sampling rate is preferred in order to extend the battery lifetime as much as possible. None of the iceberg drifters has a wave sensor for wave measurements, due to weight restrictions related to the deployment by drone.

All drifters were deployed in Fram Strait at latitudes between N 78˚39.908' and N 78˚55.207’ and longitudes ranging from W 03˚04.532' to W 09˚15.630'. The sea ice drifters were deployed manually at walking distance from the ship. Auxiliary measurements of snow and ice properties were performed at the deployment sites: ice thickness, snow depth stake measurements, salinity of snow-ice interface samples, and snow-water equivalent. 11 sea ice drifters were deployed ‘in arrays’, meaning that 3 or 4 drifters were deployed close in space and time, i.e. within kilometers and hours from each other, respectively. This increases the chance of identifying multiple drifters within one satellite image, and allows to resolve small-scale differences in sea ice motion.

All sea ice drifters traveled southwards in the Greenland Sea, while the iceberg drifters remained in Fram Strait, two of them completely stationary. As the sea ice melts or breaks up, all sea ice drifters at some point end up in the water and become ocean drifters. This ice-to-water transition can be identified by analyzing the wave spectra recorded by the drifters. At the time of writing, 8 of the 20 drifters are still active and collecting ocean drift data.

The drift trajectories and accompanying wave motion data collected during this campaign form a comprehensive data set that can be used for various purposes. The data set can, for example, be used to validate the output of numerical and machine learning models, to study small-scale drift patterns, or to investigate wave propagation in different ice regimes. The data set has been cleaned and organized into ASCII files to facilitate the use of it. We plan to release the data open source in the near future.
In this work, we present in-situ observations of sea ice, iceberg, and ocean drift. We show the changes in the wave spectra and drift patterns during the transition of the drifters from sea ice to open water, and investigate the different stages of this transition. We then present a preliminary comparison of small-scale in-situ drift and large-scale drift derived from spatially overlapping satellite imagery for sea ice and icebergs.

P20 - Exploring Arctic Sea Ice Thickness Retrievals from Satellite Altimeters

Amy Swiggs (University of Leeds, UK)

Leads are narrow, dynamic openings within the sea ice pack. They are of vital importance for heat and moisture exchange between the atmosphere and the ocean, and their distribution and geometry can affect the movement and stability of the surrounding ice. Furthermore, leads are essential for providing safe shipping routes, with sea ice being hazardous to transiting ships. The identification of leads is also crucial for calculating sea ice freeboard from satellite altimetry because the correct discrimination of leads and floes allows the sea surface height to be determined, which is an essential component of sea ice freeboard and thickness calculation. Inaccurate discrimination of leads can therefore lead to systematic errors in estimates of sea ice thickness.
Here, we investigate changes in the density and distribution of leads in the Canadian Arctic Archipelago, with a focus on the Northwest Passage due to its strategic and economic interest as a shipping route. Leads and floes are discriminated in CryoSat-2 waveforms using measurements of their pulse peakiness and stack standard deviation, and in Landsat 8 thermal infrared imagery, using a classification of their heat anomalies. We then evaluate the agreement between these two independent estimates, and present the spatial and temporal trends in lead density in the Northwest Passage, thereby assessing how the ice pack is changing in a region of high economic interest. Our results reveal increases in lead density of ~10% in regions of the Northwest Passage since 2010, and we validate these results with over fifty near-coincident optical images.

P21 - Methodology for prediction of ice conditions based on SAR images and sea ice drift

Anna Telegina (UiT The Arctic University of Norway)

The main goal of the research is to provide short-term predictions (1-3 days) of sea ice conditions based on SAR images (and products of its analysis e.g., classified ice maps, ice charts) and ice drift forecasts from model simulations. In the poster I will talk about the effect of different ice regimes on reliability of ice drift retrieval. For this purpose, two different drift retrieval algorithms were applied to a set of images from different seasons (one implemented at CIRFA and one from NERSC). I also will discuss the experiment where retrieved drift fields are used for prediction of ice conditions based on SAR image and wrapping algorithm. That would be followed up by comparison of the results with consequent SAR image and addressing the problems encountered on the way.

P22 - Measuring uncertainty in sea ice edge across different observational datasets

Bimochan Niraula (AWI, Deutschland)

There are currently several observational sea ice concentration datasets, as well as analysis and process based datasets that provide similar records of sea ice concentration or presence. Prior studies have found that the use of distinct retrieval algorithms with the same radiometric measurements, or measurements from different instruments, results in differences in the sea ice concentration record among the datasets. Consequently, different sea ice edge position estimates can be expected from these products. Here, we analyze 5 observational and analysis datasets, and measure the mismatch between them pairwise in terms of Integrated Ice Edge Error (IIEE), with the highest IIEE between observations reaching 1.25 million square kms in the Arctic (for an ice extent of 7.58 million square kms) and 2.31 million square kms in the Antarctic (for an ice extent of 7.73 million square kms). We also suggest a novel approach for measuring the uncertainty in the observations using a probabilistic ensemble based on these datasets. Such a probabilistic observational dataset can also be very useful validating forecasts and analyses of sea ice edge. This study provides useful insights on the quality of single sea ice concentration estimates relative to the suite of products available, and delivers valuable feedback to observation providers aiming to improve their sea ice products.

P23 - Inter-analyst comparison of ice chart ice edges

Matilde Brandt Kreiner (DMI, Denmark)

The national ice services around the world produce Ice charts with the main purpose of supporting navigational safety. The ice charts are however also used for other purposes and within the research community, for example as reference data in quality assessments of satellite data derived ice products and as label data in training datasets for deep learning model applications. For such applications information about the uncertainty on the ice information provided in the ice chart e.g. on the ice edge location, is needed, but not available.

We have conducted a small exercise in collaboration with the DMI Greenland Ice Service to assess the uncertainty in the DMI ice chart ice edges. Five experienced DMI ice analysts have all produced sea ice charts based on five selected SAR scenes covering different locations along the Greenland coast, for making us able to assess the inter-analyst variability. For being able to also assess the intra-analyst variability, we asked three of the ice analysts to produce a second ice chart for three of the five locations, several months after the first ice charts were produced.

Two metrics where employed in order to quantify the offset between the ice edges at each location: the average ice edge displacement (DIE) and the integrated ice edge error average displacement (DIIEE). For the inter-analyst assessment both metrics show a mean of the average ice edge displacements for the five ice analysts in the order of 400-1500 meters. For the intra-analyst assessment, that included three of the five ice analysts, both metrics show a mean of the average ice edge displacements in the order of 300-1000 meters. The methodology and results will be explained in detail on the poster.

P24 - Sea Ice in a Climate Perspective and Monitored with Satellites

Signe Aaboe (MET Norway)

The Norwegian Meteorological Institute (MET Norway) has long experience in monitoring the sea ice from remote sensing and continuously works on improving the retrieval methods and the sea-ice product archive through several international projects like the EUMETSAT OSI SAF, ESA CCI, Copernicus services (CMEMS and C3S). This contribution intends to give an overview of all the different sea-ice climate data records (CDRs) produced at MET Norway. Today, these include the global sea-ice concentration, -drift, -edge, and the Northern Hemisphere sea-ice type (and an upcoming Southern Hemisphere sea-ice type). All CDRs come with uncertainty estimates and processing status flags. The CDRs are fixed in their time period and for most of the available records, they end in 2020. To fill the temporal gap towards today, most of the CDRs are supplemented with a corresponding Interim CDR (ICDR) which is updated on a daily basis and has a latency of typically a few days to a couple of weeks.

P25 - Patterns and mechanisms of low-frequency Arctic sea ice variability

Jakob Dörr (University of Bergen, Norway)

The Arctic sea ice cover is strongly influenced by internal variability at longer (decadal to multidecadal) time scales, which affects short-term trends and the timing of the first ice-free summer. Several modes of variability have been proposed, however, their origins and regional footprints in the observed record have not been fully assessed. The relative contribution of forced and unforced variability also remains uncertain. Here, we identify the dominant patterns of winter and summer decadal sea-ice variability and their underlying mechanisms in the satellite record using a novel technique called low-frequency component analysis (LFCA). These identified patterns explain large parts of the observed regional decadal variability and trends and help disentangle the role of forced and unforced changes in sea ice cover since 1979. In particular, we identify a pan-Arctic pattern connected to high geopotential height over the central Arctic that explains around a third of the accelerated decline in summer sea ice area between 2000 and 2012.

P26 - Sea ice thickness estimation based on X-band HH-polarized SAR imagery and background information

Juha Karvonen (FMI)

Sea ice thickness (SIT) estimates can be utilized by ice models (verification, data assimilation) by winter navigation and other offshore activities and also in climate modelling as time series. For the requirements of better temporal and spatial coverage of timely sea ice information over the Baltic Sea ice e.g. for Copernicus Marine Service (CMS) an algorithm to estimate Baltic Sea SIT based on X-band SAR data with a single polarization (HH) has been developed at FMI. The algorithm is based on SAR backscattering complemented by SAR texture measures and background information from a thermodynamic ice model and most recent daily ice chart. The algorithm provides SIT in a 500m grid. The proposed regression algorithm has been trained using in-situ SIT values measured by the Finnish and Swedish ice breakers during the winter season 2021-2022. X-band SAR data from Cosmo-SkyMed (CSK) and TerraSAR-X (TSX) have used in training and testing of the algorithm. Evaluation of the algorithm will be presented separately for CSK and TSX data, including examples of the SIT grids representing different stages of sea ice evolution during the winter provided by the algorithm. The first results indicate that the algorithm could be included as part of the CMS sea ice TAC Baltic Sea production to complement the current operational C-band SIT estimation algorithms. The algorithm will be applied in an operational test and evaluation mode during the winter season 2022-2023. There also exists a version of the algorithm without the ice chart input. This algorithm version is applicable over all the ice-covered sea areas with modeled ice thickness available to be used as a background data to make the SIT estimates quantitatively more accurate.

P27 - Rapid Ice Loss Events in the Arctic

Massonnet François (UCLouvain)

The Arctic is currently transitioning toward a new climatic state that will be characterized by seasonally sea-ice-free conditions almost every year from the 2050s, with widespread ecological, climatic, and societal consequences. There is growing evidence that the future summer sea ice retreat will not occur at a constant rate. Indeed, climate model simulations are suggestive of pronounced sub-decadal fluctuations on top of the long-term trend, leading to periods of relative stability followed by abrupt sea ice decline in hardly 3-5 years. A lot remains to be understood regarding the precursors, mechanisms, predictability, and impacts of these rapid events. In particular, it is unclear how close we might be to the next one. I will review the state of knowledge regarding these events, by stressing the need to bridge seasonal and multi-decadal sea ice prediction activities in a unified framework.

P28 - Melt ponds representation in Arctic and their influences on Arctic sea ice

Caixin Wang (MET Norway)

Melt ponds are a common feature on Arctic sea ice and cover up to 50-60% of the sea ice area. They are an accumulation of melt water on sea ice, mainly due to melting snow, and also due to melting of sea ice in later stages. The existence of melt ponds causes a decrease of the surface albedo approximately from 0.8 to 0.5 or even lower. The decreased surface albedo leads to more absorption of solar radiation by the ice and ocean, enhancing the upper ocean warming, sea ice melt and more primary production within and beneath the ice. Melt ponds thus play an important role in the Arctic climate system. With the thinning of the Arctic sea ice, melt ponds may become a reliable predictor for summer sea ice conditions.

NorESM2 is the second generation of the coupled Earth system model (ESM) based on the Community Earth System Model (CESM2.1) developed by the Climate Center. We will investigate how the melt ponds are represented in NorESM2 through the melt ponds fraction (MPF) and the relative melt ponds fraction (RMPF). RMPF is the MPF divided by the sea ice concentration (SIC). The retrieved MPF from MODIS and MERIS, the ice age from NSIDC, and the SIC from MODIS and AMSR-E and AMSR2 (AMSR-E/2) over the years 2002-2011 are used. Our results show that melt ponds start to form in May, and further in June, reaching maximum in July, and then start to decrease with the freeze-up of melt ponds as simulated by NorESM2 or observed by MODIS and MERIS. Compared to MODIS and MERIS, melt ponds form later and freeze-up earlier in NorESM2. Thus, the area of MPF and RMPF in NorESM2 are lower in NorESM2 than in MODIS and MERIS. With the development of melt ponds in July and August, the MPF area in NorESM2 becomes closer to that in MODIS and MERIS, but the RMPF area in NorESM2 is much larger than in MODIS and MERIS. There are more melt ponds on FYI than on MYI as observed. But this is only true in May and June for NorESM2. For MODIS and MERIS, it is also true in May and June, and still valid in July regarding RMPF area, but becomes invalid in July regarding MPF area. From or after July, there are more melt ponds on MYI than on FYI whether in NorESM2, MODIS or MERIS. On average, there are more melt ponds in MODIS and MERIS, and less melt ponds in NorESM2 on FYI than on MYI. The reason that there are more melt ponds on MYI than on FYI in NorESM2 is because there are more MYI than FYI in the model. The MPF and RMPF are also closely investigated in four regions: south of 86.5oN and north of 80oN (North), south of 80oN: Pacific sector (150oE-120oW), Atlantic sector (30oW-60oE), and Laptev sector (60oE-150oE). The late development of melt ponds in May and June and what this means for the Arctic sea ice are discussed.

P29 - Wave impact on sea ice dynamics in the marginal ice zone using a coupled wave—sea-ice model

Guillaume Boutin (NERSC)

As sea ice extent decreases in the Arctic, surface ocean waves have more time and space to develop and grow, exposing the Marginal Ice Zone (MIZ) to more frequent and more energetic wave events. Waves can fragment the ice cover over tens of kilometres, and the prospect of increasing wave activity has brought a recent interest in their potential impact on the sea ice cover, which remains mostly unknown. Here, we introduce a new coupled framework involving the spectral wave model WAVEWATCH III and the sea ice model neXtSIM. neXtSIM can efficiently track and keep a memory of the level of damage of sea ice. We propose that the level of damage of sea ice increases when wave-induced fragmentation occurs. We use this coupled modelling system to investigate the potential impact of fragmentation on sea ice kinematics. To constrain the extent over which waves can impact the sea ice in our model, we evaluate the MIZ extent by comparing our model results to pan-Arctic wave-affected sea ice regions derived from ICESat-2 altimetry over the period December 2018 - May 2020. Using a definition of the MIZ based on the monthly maximum of the wave height, we suggest metrics to evaluate the model considering the sparse coverage of ICESat-2. The model produces MIZ extent comparable to observations, especially in winter, but underestimates the MIZ extent in autumn, which could be due to misrepresentation of wave growth in ice, overestimated sea ice concentration or the absence of other processes affecting floe size. We estimate the potential impact of wave-induced fragmentation on ice dynamics, which the model suggests is important at short time scales and for some regions of the Arctic, like the Barents Sea, as sea ice mobility increases in the aftermath of storm events.

P30 - Deep learning of subgrid-scale parametrisations for sea-ice models

Tobias Finn (ENPC, France)

Since small-scale processes are still unresolved in the newest generation of sea-ice models, their absence yields forecast errors and make sea-ice data assimilation difficult. To learn and parametrise such unresolved subgrid-scale processes, we propose to use deep neural networks in a hybrid modelling setup. We cast the parametrisation as model error correction – the network can also use the modelled dynamics as input. We tailor a convolutional network architecture for sea-ice modelling to make explicitly use of spatial correlations and anisotropy in the extracted features. Using a maximum likelihood approach, the network learns to parametrise processes for all prognostic model variables at the same time. Here, we train such a neural network to correct forecasts of a sea-ice model that depicts only sea-ice dynamics to fully-pledged neXtSIM simulations that also include thermodynamics. The neural network strongly reduces in independent datasets the forecast errors for all model variables. We additionally use explainable AI techniques to reveal which relations the neural network has learned. The network makes heavily use of the dynamics in the sea-ice model as input and has learned physical interpretable input-to-output relations. Furthermore, the parametrisation together with the geophysical forecast model are cycled to create continuously correct sea-ice forecast trajectories. In our tested cases, such corrected trajectories show improved dynamics and have a smaller forecast error than the original trajectories without parametrisation. Hence, we believe that such a model error correction with deep learning can facilitate data assimilation for sea-ice models. In conclusion, these results demonstrate that deep learning can parameterise previously unknown subgrid-scale processes in sea-ice models.

P31 - The sea-ice dynamics simulated by the Viscous-Plastic and Maxwell Elasto-Brittle models

Mathieu Plante (Environment and Climate Change Canada)

More than a decade ago, a brittle damage parameterization has been proposed to the sea-ice modelling community to represent the effect of smaller-scale fractures on the large scale sea-ice dynamics. Over the years, the brittle sea ice rheologies have seen many developments (e.g. the Maxwell Elasto-Brittle rheology, and recently the Bingham Maxwell rheology), and an increasing number of institutions are planning or considering its implementation within existing model frameworks. Meanwhile, the differences in simulated dynamical behaviour between brittle models and traditional Viscous-Plastic models are often not well understood.

Here, we use idealized numerical experiments to test the local-scale dynamics simulated by the VP and MEB models. In particular, we investigate the simulated dynamics with respect to 1. the different constitutive relationships ruling the solid dynamics prior to yielding, 2. the different material strengths (yield curve), and 3. the different relations ruling the deformations associated with yielding. We show that in the short term, using similar material strength parameters in both rheology results in similar yield behaviour. This suggests that the method of transition from the small to the large deformation regimes (e.g. by the use of a plastic law or a brittle parameterization) is not itself determining the spatial distribution of the deformations. Rather, it is the type of deformation simulated during and after yielding that directly affects the local scale processes and produces irreconcilable differences between the simulations in the longer-term. Determining which of the simulated behaviours are adequate remains difficult as the yielding constitutive relation at this scale has not yet been established.

P32 - Implementation of form drag scheme into NEMO sea ice model SI3

David Schroeder (University of Reading, UK)

The efficiency of air-sea momentum depends on top and bottom sea ice surface roughness which varies with ice types and conditions, but constants are applied in most climate models. Future sea ice reduction will entail an increase in efficiency of air-sea momentum transfer. A high physical process fidelity will be a requirement for realistic model predictions. Within the CANARI project (Climate change in the Arctic-North Atlantic Region and Impacts on the UK) the form drag scheme from the sea ice model CICE is implemented into SI3. Based on parameters of the ice cover such as ice concentration, size, and frequency of the sails and keels, freeboard and floe draft, and size of floes and melt pond fraction, the total form drag can be computed as a sum of form drag from sails and keels, form drag from floe edges, form drag from melt pond edges, and a reduced skin drag due to a sheltering effect. First simulations are presented discussing the impact on sea ice dynamics and mass balance separating the contributions from modified momentum and heat transfer.

P33 - Assessment of SMRT simulated microwave brightness temperatures over snow and sea ice in Arctic regions

Suman Singha, Fabrizio Baordo, André Emil Jensen, Gorm Dybkjær (Danish Meteorological Institute (DMI), Copenhagen, Denmark), Rasmus Tonboe (Technical University of Denmark (DTU), Copenhagen, Denmark)

Due to the very dynamic nature of sea ice, in the Polar regions, the sea ice surface properties are complex to simulate with large scale models to the extent where we can get an accurate representation of absorption, emission and scattering by snow and ice at microwave frequencies. As a consequence, it is challenging to build an observation operator capable of generating accurate simulations of brightness temperatures over the sea ice. Such simulations would be useful for sea ice model validation and data assimilation and atmospheric sounding. In the framework of the OSI SAF project, we are planning sensitivity studies to have a better understanding of snow and ice properties which can help to further developing forward modeling at microwave frequencies, i.e. building an observation operator for sea ice.

We use the in-house DMI HYCOM-CICE ocean sea ice coupled model (Skin Temperature, Ice Thickness and Snow Depth) to simulate brightness temperature through SMRT model (https://github.com/smrt-model). In our initial simulation we considered multiple unequally distributed layers of snow and sea ice. Models for some sea ice related input parameters such as snow salinity and density were developed from in-situ measurements and literature. After simulating brightness temperature at different frequency bands we compared those with the observed brightness temperatures from AMSR-2 level 1 observations (swath data). We will present our initial sensitivity studies based on tuning SMRT model parameters and different physical sea ice parameters.

P34 - Antarctic sea ice concentration and area patterns in CMIP5 and CMIP6

Ronald B. Souza (INPE, Brazil)

The sea ice is a complex component of the Earth System and considered a sensitive indicator of climate change. Here we evaluated the ability of twenty-two climate models from CMIP5 (1980-2005) and CMIP6 (1980-2014) to represent the spatial patterns of the Antarctic sea ice concentration and area with respect to satellite data. Additionally, we identified areas of improvement in sea ice concentration and area estimates between CMIP5 and CMIP6 and areas where systematic biases with respect to satellite data persist in the climate models studied here. The sea ice concentration model outputs presented large and systematic biases during February and September (periods of minimum and maximum sea ice concentration and area in the Southern Ocean), especially in the Weddell Sea, Amundsen Sea, Bellingshausen Sea and the Ross Sea. There is also a substantial inter-model spread in Antarctic sea ice area estimates across the climate models studied here. The relatively poor confidence of Antarctic sea ice estimates in both the CMIP5 and CMIP6 climate models is attributed to the complexity of the ocean-atmosphere-ice system in the southern hemisphere.

P35 - Ice-Free conditions and Polar Amplification under Paris Agreement thresholds using Climate Models

Fernanda Casagrande (INPE, Brazil)

One of the most visible signs of global warming is the fast change in the cryosphere for both, the North and South Hemispheres. The increase in Arctic temperatures has been almost twice as large as the global average in recent decades. This phenomenon known as the Arctic Amplification (AA) reflects several mutually supporting processes. The numerical climate simulations from Coupled Model Intercomparison Project phase 5 (CMIP5) and 6 (CMIP6) simulations are used here to investigate the effects of +1.5, 2, and 3.6 oC warming thresholds for sea ice changes in the Arctic and Antarctic. Our results show robust patterns of the near-surface temperature response to global warming at high latitudes. The year in which the medium of CMIP5 and CMIP6 models rise by 1.5 oC (2 oC) is 2024 (2042). The equivalent warming at northern high latitudes (southern high latitudes) for 1.5 oC global warming thresholds is nearly 3 oC (1.8 oC). For 3 oC of global warming level, the equivalent warming in the Arctic (Antarctic) region is close to 7 oC (3.5 oC). The ice-free conditions are found considering all warming thresholds for both Arctic and Antarctic, especially from the year 2030 and, the climate simulations show widespread between coupled models. Polar amplification and the rapid changes in sea ice cover suggest strong changes in ocean and atmospheric circulation with effects extending beyond the Polar Regions.

P36 - On the impact of sea ice forcing from CFOSAT on wave forecast in polar oceans

Aouf Lotfi (Meteo France)

Better description of ocean waves in the marginal ice zone is of crucial importance for the analysis of ocean mixing in upper layers and the understanding of the variations of key parameters such as temperature and salinity of the polar oceans. The CFOSAT mission provides with its wave scatterometer SWIM normalized radar cross section from 5 off-nadir beams with incidence of 2,4,6,8 and 10°. This signal products are able to retrieve sea ice information by using a maximum likelihood estimator derived from geophysical model functions. First validation of such sea ice concentration from SWIM are consistent with OSISAF products in both arctic and antarctic ocean regions. The objective of this work is to evaluate the impact of using sea ice products from CFOSAT on wave forecasting in marginal ice zones in the polar regions such as the Weddell Sea in Antarctica. Global Wave model MFWAM runs are implemented during 2020 and 2021 austral summer periods with sea ice forcing from CFOSAT. We also performed the assimilation of directional wave spectra in the model MFWAM in order to improve the estimate of integrated wave parameters, particularly in Southern Ocean where wind uncertainties increase. Validation of the impact of sea ice forcing is performed by comparing significant wave height in the marginal ice zone with those provided by Sentinel-3A and 3B altimeters that have orbit tracks adapted to the study areas.

In other respects, by using 1D ocean mixed layer model we analysed the impact of wave forcing in specific points where melt conditions are intensified in the weddell sea. Further comments and conclusions will be presented during the workshop.

P37 - SITool (v1.0) – a new evaluation tool for large-scale sea ice simulations: application to CMIP6 OMIP

Xia Lin (UCLouvain)

The Sea Ice Evaluation Tool (SITool) is a performance metrics and diagnostics tool developed to evaluate the skill of Arctic and Antarctic model reconstructions of sea ice concentration, extent, edge location, drift, thickness, and snow depth. It is a Python-based software and consists of well-documented functions used to derive various sea ice metrics and diagnostics. The SITool version 1.0 (v1.0) is introduced and documented, and is then used to evaluate the performance of global sea ice reconstructions from nine models that provided sea ice output under the experimental protocols of the Coupled Model Intercomparison Project phase 6 (CMIP6) Ocean Model Intercomparison Project with two different atmospheric forcing datasets: the Coordinated Ocean-ice Reference Experiments version 2 (CORE-II) and the updated Japanese 55-year atmospheric reanalysis (JRA55-do). Two sets of observational references for the sea ice concentration, thickness, snow depth, and ice drift are systematically used to reflect the impact of observational uncertainty on model performance. Based on available model outputs and observational references, the ice concentration, extent, and edge location during 1980–2007, as well as the ice thickness, snow depth, and ice drift during 2003–2007 are evaluated. In general, model biases are larger than observational uncertainties, and model performance is primarily consistent compared to different observational references. By changing the atmospheric forcing from CORE-II to JRA55-do reanalysis data, the overall performance (mean state, interannual variability, and trend) of the simulated sea ice areal properties in both hemispheres, as well as the mean ice thickness simulation in the Antarctic, the mean snow depth, and ice drift simulations in both hemispheres are improved. The simulated sea ice areal properties are also improved in the model with higher spatial resolution. For the cross-metric analysis, there is no link between the performance in one variable and the performance in another. SITool is an open-access version-controlled software that can run on a wide range of CMIP6-compliant sea ice outputs. The current version of SITool (v1.0) is primarily developed to evaluate atmosphere-forced simulations and it could be eventually extended to fully coupled models.

P38 - Initial Results from SAR-Based Validation of Sea Ice Drift Forecast Models

Martin Bathmann (DLR) and Stefan Wiehle, Anja Frost, Lasse Rabenstein, Gunnar Spreen

TOPAZ4 and neXtSIM sea ice drift forecast model data, provided in the CMEMS artic analysis and forecast products PHYS_002_001_a and PHY_ICE_002_011, is assessed using Sentinel-1 Synthetic Aperture Radar (SAR) image pairs. This work helps to improve the high-resolution forecast Predictive Ice Image (PRIIMA) (https://business.esa.int/projects/priima) application which generates multi-day forecasted SAR scenes. Results of PRIIMA form the basis for the calculation of possible ship routes in ice-infested waters, which are then made accessible for navigators in near real-time.

The true sea ice drift is derived from two successive Sentinel-1 scenes using phase correlation applied in a hierarchical resolution pyramid. The measured ice displacement vectors are compared to predicted drift trajectories derived from multi-day TOPAZ4 and neXtSIM forecasts available at acquisition time of the first SAR scene. Differences in sea ice drift direction and magnitude between models and actual SAR measurements are then analysed visually and statistically. A feature-based approach of data handling enables the comparison of drift data stored in vector format and model data stored in raster format. The analysis benefits from the high coordinate precision of vector models and a fine granularity of a grid spacing down to 500 m.

This initial study focuses on time differences of 1 to 3 days in two regions of interest (RIOs). The first ROI is located offshore close to Cape Morris Jesup at the transition between Lincoln and Wandel Sea. The second ROI is placed at open sea above Alpha Ridge near Ellesmere Island. A small initial sample of seven image pairs is analysed to test the approach, from which some preliminary conclusions can already be drawn: The root-mean-square separation distance between the end points of the measured drift vectors and the derived model trajectories (RMS separation distance) is around 4 to 5 km per day for both TOPAZ and neXtSIM. The RMS separation distance shows a high variability across the investigated image pairs. In the first ROI, a high RMS separation distance in the neXtSIM model was found near Cape Morris Jesup in the case of coastward drift or drift around the cape.

In future works, the conducted analysis will be extended to a one-year analysis in selected regions arctic wide, taking into consideration the influences of sea ice deformation, atmosphere and ocean.

P39 - Intrinsic and practical predictability of sea ice kinematic features estimated from neXtSIM ensemble forecasts

<u>Stephanie Leroux</u> (Institut de Géophysique de l'Environnement, Grenoble, France)

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Sea ice is rich with features such as open leads and ridges at kilometer scale, which are important information for sea navigators to ensure safety of operation. Recent advancements in sea ice modeling and observation techniques have improved sea ice prediction at seasonal scales. However, short-term sea ice forecasts remain challenging and there is a knowledge gap in sea ice predictability across scales. Estimation of the intrinsic and practical predictability limits provides useful guidance for further improvements of the short-term sea ice forecasting system.. In this study, we quantify the intrinsic and practical predictability of sea ice kinematic features on day-to-day timescales, based on ensemble forecast experiments using the neXt generation Sea Ice Model (neXtSIM). The intrinsic predictability is estimated from an ensemble forecast with very small initial and boundary condition perturbations representing the irreducible uncertainties in the system under a perfect-model assumption. The practical predictability of sea ice kinematic features is evaluated as a function of the amount of initial and boundary condition uncertainties and the difference between the intrinsic and practical predictability is identified as room for future improvements. The forecast skill is evaluated based on several diagnostic metrics such as the error spectrum and the maximum cross-correlation (MCC). We will also discuss some preliminary results regarding how the sea ice predictability estimates depend on the background atmospheric flow regimes.

P40 - Navy ESPC Sea Ice Assimilation: Present Capabilities and Planned Enhancements

Richard Allard (Naval Research Laboratory (NRL), USA)

The Navy Earth System Predictability Capability (Navy ESPC) is a global coupled forecast system that consists of the NAVy Global Environmental Model (NAVGEM) atmosphere model, the HYbrid Coordinate Ocean Model (HYCOM), the Community Ice CodE (CICE). This system has been developed to meet the U. S. Navy needs for high-resolution global environmental forecasts on timescales from days to months, and a unique aspect of the system is the eddy resolving ocean model at the ensemble and deterministic resolutions. Navy ESPC-E v1 (ensemble), consisting of weekly 45-day 16-member ensemble forecasts, became operational in August 2020. The ensemble system has a horizontal resolution of 3.5 km at the North Pole for both the ocean and ice components and is used by the U.S. National Ice Center to support efforts such as the McMurdo Resupply Mission (Ross Sea, February) and ICEX (Beaufort Sea). Navy ESPC-D v2 is coupled to the WAVEWATCH III wave model and has an ocean and ice component of 1.75 at the North Pole. ESPC-D v2 is scheduled for operational transition in late 2023. We will discuss the present sea ice model data assimilation scheme used in ESPC (both ensemble and deterministic) and future plans to assimilate CryoSat-2, SMOS, Sentinel 3A/B freeboard, VIIRS and MIZ/Ice edge data.

P41 - The COSI (Calibration of Sea-Ice forecasts) project

Cyril Palerme, Thomas Lavergne, Arne Melsom, Laurent Bertino, Julien Brajard, Malte Müller, Jozef Rusin (MET Norway)

In weather prediction, it is common practice to apply calibration techniques to forecasts produced by numerical models in order to improve their skill. This is in contrast with sea-ice prediction, where short-term forecasts are usually not calibrated. In the COSI project, we propose to develop calibration techniques using supervised machine learning algorithms in order to improve short-term (10 days) sea-ice concentration forecasts produced by the Copernicus Marine Service's (CMEMS) TOPAZ prediction system. Moreover, the probability that the sea-ice concentration exceeds 10 % and 20 % will be assessed in the calibrated forecasts in order to provide information to seafarers in agreement with the requirements from the International Code for Ships Operating in Polar Waters (International Maritime Organization, 2016). As a result of this project, calibrated forecasts will be available for demonstration from November 2023 and operationally in the CMEMS catalogue in 2025. Furthermore, an enhanced Pan-Arctic sea-ice concentration dataset will be created using observations from the Advanced Microwave Scanning Radiometer 2 (AMSR2) in COSI. This dataset will be used for training the machine learning models, and it is expected that its higher spatial resolution (5 km) will be advantageous for developing accurate calibration methods.

P42 - Developing a deep learning forecasting system for short term and high resolution prediction of sea ice concentration

Are Frode Kvanum, Cyril Palerme, Malte Müller, Jean Rabault (MET Norway)

Sea Ice forecasting systems based on machine learning have shown promising results for low resolution seasonal sea ice forecasting. This thesis aims to develop a machine learning model for image segmentation based on the U-Net architecture (supervised deep learning) which can predict Sea Ice Concentration on a 1km grid for short lead times (1 to 3 days). The data used to train the model include operational forecasts from a regional NWP developed by MET Norway (AROME-Arctic) which are upsampled from a 2.5-km grid onto a 1-km grid, as well as Ice Charts manually produced by MET Norway. Moreover, the developed model will be compared to relevant dynamical models as well as persistence to assess the quality of the resulting forecasts. The developed deep learning framework shows early promising results, indicating a potential to further develop a lightweight machine learning based model for operational use.

P43 - Sub-daily Antarctic sea-ice variability estimates using swath-based retrieval methods

Wayne de Jager (University of Cape Town, South Africa)

Satellite-derived sea-ice concentration measurements have traditionally been used to evaluate the impact of climate change on polar regions. However, concentration-based measurements of sea-ice variability do not allow the discrimination of the relative contributions made by thermodynamic and dynamic processes. This prompts the need to use sea-ice drift and type products and develop new methods to quantify changes in sea-ice properties that would indicate trends in the ice characteristics. A component of the sea-ice variability is driven by local weather events, and in some cases is the dominant driver of variability over larger-scale atmospheric features. Previous work by de Jager & Vichi (2022) has suggested that sea-ice vorticity (derived from low resolution sea-ice displacement vectors) may be a useful metric for quantifying dynamical features in Antarctic sea ice; specifically shorter term changes in the ice-interior driven by atmospheric storms. However, this study hypothesised that much of the rotational drift in the underlying sea-ice field was blurred as a result of the relatively large 48-hr temporal resolution of the drift product, therefore highlighting the necessity of measuring sea-ice properties at higher temporal frequencies. This study will therefore assess the usefulness of an overlapping swath-based method of sea-ice displacement retrieval recently made available by the EUMETSAT OSI-SAF. This swath-based method of retrieval allows for analysis of sea-ice variability at sub-daily timescales, which may be more suitable for measuring the effect of weather events on the sea-ice landscape than using daily averages of merged swaths. In situ data of sea-ice conditions were collected on board the SA Agulhas II research vessel in the Atlantic Sector in July, 2022, which will be compared to swath-based satellite estimates. Furthermore, the newly released 24-hr OSI-SAF drift product will also be compared. To complement these drift estimates, a modified swath-based ice-type retrieval method will be presented to add further context to any potential thermodynamic changes affecting the optical properties of the sea-ice surface.

P44 - Seasonal prediction of NorCPM in the regional Antarctic sea ice

Xiu YW (Sun Yat-sen University, China)

The Norwegian Climate Prediction Model (NorCPM) which combines the fully coupled Norwegian Earth System Model and the Ensemble Kalman Filter is a state-of-the-art climate prediction system. Previous studies have investigated its seasonal sea ice prediction skill in the Arctic. On the other hand, compared to the Arctic, seasonal Antarctic sea ice predictions have received relatively little attention. In this study, we assess the seasonal Antarctic sea ice prediction skill of NorCPM and the predictability of regional Antarctic sea ice (e.g., in the Weddell Sea and the Ross Sea). We utilise several sets of retrospective seasonal predictions initialised in January, April, July, and October in the period of 1985-2010. Each prediction set was initialised by weakly coupled data assimilation (updating the ocean state alone) when assimilating oceanic observations or strongly coupled data assimilation (jointly updating the sea ice and ocean states) when assimilating sea ice observations or both ocean and sea ice observations. The results will provide insights into the impact of ocean and sea ice initialisation on Antarctic sea ice prediction, which will help to understand the mechanisms of regional Antarctic sea ice predictability.

P45 - Polarimetric decomposition for an unsupervised ice separation approach using the CFAR method

Muhammad Amjad Iqbal (University POLITEHNICA of Bucharest, Romania)

This abstract discusses the use of Sentinel-1 polarimetric SAR data for water and ice separation using an automatic and unsupervised approach. Even though these are difficult environments in which floating ice can cause a large variability in normalized radar cross section, the constant false alarm rate (CFAR) provides the best empirical distribution for distinguishing between water and ice (floating ice). To begin, we propose extracting the complex coherence from the two polarization channels (VV and VH) and detecting ice in this domain. Water, as a smooth surface, has low values, whereas ice classes have higher values in general. A bimodal distribution can be used to represent this specific characteristic statistically. To accomplish this, we employ ensemble averaging by the mean of the box-car filter. We use the CFAR method to generate binary data to classify as water or ice after finding a suitable empirical distribution. We discriminate between classes using simple image processing and edge detectors. The method's performance was evaluated using a SAR data from a slightly dynamic water environment with dense ice. The physical soundness of the proposed rationale and the processing effectiveness are demonstrated by SAR data.

P46 - Evaluating the sea ice concentration retrievals considering different radiative transfer schemes for correcting the brightness temperatures from atmospheric contribution

Fabrizio Baordo (Danish Meteorological Institute (DMI), Copenhagen, Denmark), Thomas Lavergne (MET Norway), Suman Singha (DMI) and Atle Sørensen (MET Norway)

Algorithms for deriving sea ice concentration retrievals, based on satellite passive microwave observations, are generally characterized by a similar processing logic, although some diversity may be found, for instance, in the use of different sensor's channels/frequencies or in the way to identify the ocean and ice tie-points (the distinct signature of microwave brightness temperature over open water and closed-ice regions). These differences can surely impact on the estimate of sea ice concentration, however, it has been demonstrated that the accuracy of the retrievals can be improved when the brightness temperatures are corrected for atmospheric contribution by using a radiative transfer model. As a result, the radiative transfer and the atmospheric correction scheme play a fundamental role in the sea ice concentration algorithms. In this study, we would like to consider the OSI SAF sea ice concentration algorithm and evaluate the impact of using two different transfer radiative models: Wentz and Meissner and RTTOV. The two models adopt different surface and atmosphere fields from NWP and this also impacts on the atmospheric correction scheme. As a consequence, we would like also to analyze the impact of using different configurations to drive the radiative trasnfer calculations, for instance: NWP liquid water content on/off in Wentz and Meissner; RTTOV (absorption only) or RTTOV-SCATT (to enable scattering calculations).

P47 - Investigating the use of Convolutional Neural Networks for Automatic Sea Ice Concentration at MET-Norway

Frode Dinessen (MET Norway)

Automatic generating of high resolution Sea Ice Concentration (SIC) based only on SAR data is a challenging task due to ambiguities in the backscattering signal from different sea ice conditions. In addition, strong wind over open water may create a signature similar to sea ice.
Passive Microwave Radiometer (PMW) has for many years been used for automatic generation of sea ice concentration at a relatively good quality, but at a coarse resolution.

At MET-Norway we have developed a multisensor product that combines SIC derived from AMSR2 and Sentinel-1 data. The Sentinel-1 SIC is based on a bayesian classification approach to separate the data into ice and water pixels at a full 40m pixel resolution. After the separation of ice/water, concentration is calculated by estimating the area covered by ice within 1x1 km grid cells. The AMSR2 SIC product is produced from L1b brightness temperature (Tb) data using the 89 GHz channels and a processing chain similar to that successfully adopted for the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) service. The AMSR2 SIC product has a spatial resolution of ~3x5 km, upsampled to a 1x1km grid before it is merged with the Sentinel-1 product in an optimal interpolation approach. The multisensor product is produced as a daily product based on the latest available satellite data covering the European part of the Arctic.

Utilizing the Convolutional Neural Network (CNN) for combining SAR and PMW data for sea ice classification has become more and more popular and recent studies have shown good results. At MET-Norway we have implemented a U-net architecture where Sentinel-1 SAR and AMSR2 data are used as inputs. The network has been trained with sea ice concentrations estimates, retrieved from the manuale derived ice charts at MET.

Results from this study will be presented and compared against the current operational multisensor product.