Project: **1138**

Project title: **Impact of sea ice parameterizations on polar predictions**

Principal investigator: **Helge Goessling**

Report period: **2020-01-01 to 2020-12-31**

As detailed in the project proposal, the project “Impact of sea ice parameterizations on polar predictions” has been subdivided into two parallel subprojects. The first subproject (**SP1**) deals with the impact of the sea-ice model complexity on the performances of an unstructured-mesh sea-ice and ocean model. The second subproject (**SP2**) aims to formulate sea-ice predictions at various timescales with a fully coupled climate model equipped with data assimilation capabilities. As we detail below, both subprojects were successful in addressing the scientific questions formulated in the proposal.

1. **SP1**

This subproject has the double purpose of testing a new formulation of the new sea-ice component of the unstructured FESOM2 sea-ice and ocean model, and of assessing the impact of the improved sea-ice description on the model performance in uncoupled sea-ice/ocean simulations. More specifically, we have equipped the unstructured global sea-ice and ocean model FESOM2 with a set of physical parameterizations derived from the single-column sea-ice model Icepack. The simple 0-layer sea-ice and snow thermodynamics have been replaced with a set of multi-layer parameterizations that take the enthalpy and salinity of the ice into account. The new system can simulate prognostic thickness and floe-size distributions (also jointly), accounting for sea-ice ridging and for processes regulating the break-up and healing of sea-ice floes. A sophisticated delta Eddington multi scattering solar radiation parameterization and three prognostic melt-pond schemes are also available. The implementation of Icepack in FESOM2 has been designed to maintain the modular architecture of Icepack, which allows to easily vary the complexity of the sea-ice description.

To compare fairly eventual improvements or drawbacks associated with the changing model complexity, we optimized a subset of the parameter space of each tested model configuration by applying a Green's function optimization technique. The results indicate that a complex model formulation leads to a better agreement between modelled and the observed sea-ice concentration and snow thickness, while differences are smaller for sea-ice thickness and drift speed. However, the choice of the atmospheric forcing also impacts the agreement between simulations and observations, with NCEP-CFSR/CFSv2 being particularly beneficial for the simulated sea-ice concentration and ERA5 for sea-ice drift speed. Furthermore, the results indicate that the parameter calibration can better compensate for differences among atmospheric forcings and for model deficiencies in a simpler model setting (where sea-ice has no heat capacity) compared to more energy consistent formulations with a prognostic ice thickness distribution.

The previous findings are summarized in Fig. 1, which shows the mismatch between six model configurations and the observations at different stages of the parameter optimization process. The model performance is measured by a quadratic cost function, computed separately for different observation types. Lower cost function values indicate better agreement with observations and therefore satisfactory model performance.

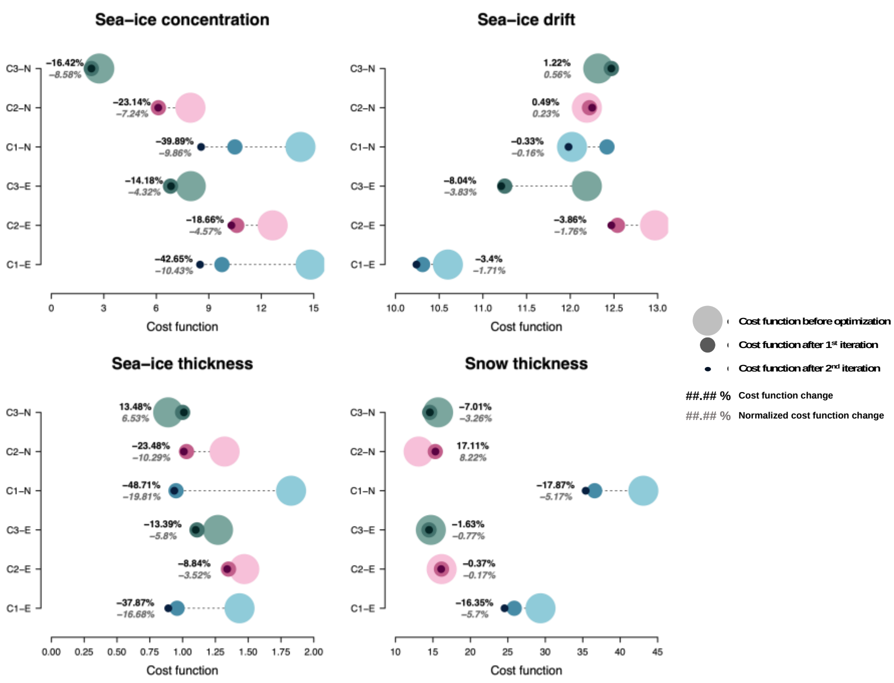

Figure 1. Cost function values for the period 2002–2015 at the three stages of the Green's function parameter optimization (x-axis). The cost function measures the average mismatch between the state of six model configurations (y-axis) and four observational products in the Arctic region: sea-ice concentration, drift, thickness, and snow thickness. The suffixes “-E” and “-N” indicate the employment of the ERA5 and NCEP atmospheric reanalysis used to force the three model setups C1, C2, and C3, respectively. The percentages in black font indicate the cost function change induced by the optimization. The percentages in grey font refer to the normalized cost function change.

2. **SP2**

We begin this section by illustrating a major technical change that was made to our modelling infrastructure and that, in our view, was relevant for the project success. A new version of the "Seamless Sea Ice Prediction System" (SSIPS) has been formulated by abandoning the ECHAM6 atmospheric component of AWI-CM coupled model and substituting it with OpenIFS version 43r3. In total, 144 cores are now used for running one coupled model instance, with a dramatic reduction in computing costs compared to its ancestor, which used 480 cores. This speedup allowed us to substantially increased the ensemble size of our prediction system to 30, thus improving the value of our result. Furthermore, the resolution in the atmosphere model in the current configuration is even higher than before. The following observations are now assimilated into the SSIPS: sea ice concentration, sea ice thickness, sea ice velocity, 3D temperature, 3D salinity, and sea surface height. Still, no data constraints are applied in the atmospheric component as in the first version.

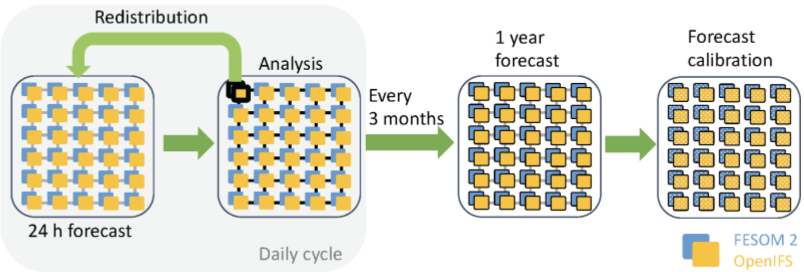

Figure 2. Schematic of the SSIPS. The ensemble has 30 members with FESOM2 and OpenIFS shown in blue and orange. Communications between each coupled model through the Message Passing Interface (MPI) are represented by staggered mesh in the background, which is emphasized by black colour when the communication is active.

A schematic of the SSIPS system is shown in Fig. 2. SSIPS conducts daily data assimilation starting from January 1st, 2003 to December 31th, 2019, providing a reanalysis product that covers almost two decades. The analysis results of sea surface temperature and sea surface salinity are shown in Fig. 3a, where a significant reduction of model errors is observed. As our scientific interest in terms of sea-ice prediction is mainly on the subseasonal-to-seasonal time scale and beyond, we performed four 1-year long forecast experiments per year. For each year, the system is initialized at the beginning of each season, (January 1st, April 1st, July 1st, and October 1st). Such experiments are carried out from 2003 to 2019. We evaluate forecast results from 2011 to 2019 only, while the previous years are used as a baseline for the calibration of the forecasts. Fig. 3b illustrates the performance of SSIPS in predicting the of the sea-ice edge position in comparison to a climatological benchmark forecast based on satellite observations.

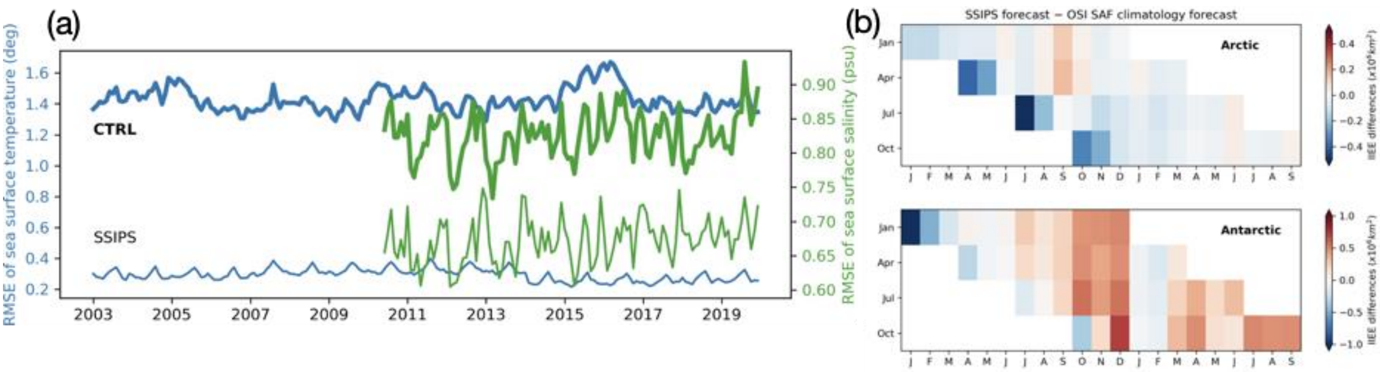

Figure 3. (a) RMSE of monthly mean sea surface temperature/salinity with respect to the OSTIA/SMOS observations. SSIPS results are shown by thin lines, while results from the control ensemble (CTRL) run without data assimilation are shown by thick lines. **(b)** Integrated ice-edge error (IIEE) differences of sea ice forecasts averaged over 2011–2019 against a climatological benchmark forecasts in the Arctic and the Antarctic. Blue colours indicate useful predictive skills while red colours indicate predictive skills worse than the observation-based benchmark.

3. **Final remarks**

As this computing project is in its first year, we do not have yet related peer-reviewed publications to present in this report. However, two manuscripts will be soon submitted to the "*Journal of Advances in Modeling Earth Systems"*.

A fraction of the computing resources granted during the first quarter of the project have not been used and therefore expired. We would like to mention that this has been in part due to the precarious situation that developed at the beginning of the coronavirus pandemic, which slowed down our work substantially in those months. We compensated for this by slightly reducing the number of planned simulations for the remaining quarters and by integrating the lost resources from different computing projects at DKRZ and from the AWI in-house HPC system. We believe to have managed the situation well and that the scientific outcome of the project was not impacted by this.