FINAL REPORT PROGRAM LEFE

Program LEFE/ GMMC	**ASSIM-ICE: assimilation of sea-ice observations in the NEMO model**	**Years 2016 – 2017**

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The general purpose of this project is to contribute to the evolution of the data assimilation system of Mercator Ocean. More specifically, this project was dedicated to improve data assimilation in the sea-ice component of the system, with the objective of reducing the uncertainties associated to the numerical simulations using satellite and in-situ sea-ice observations.

To reach this objective, several methods have been developed and explored during the project. In particular, we developed :

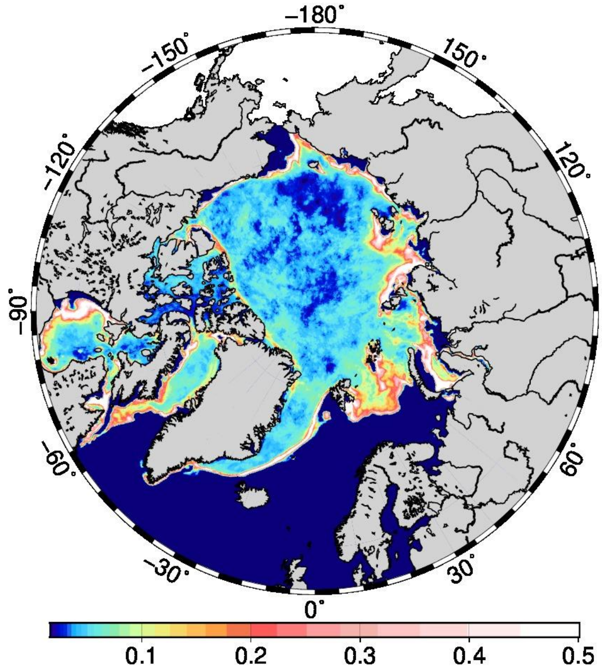
- Stochastic parameterizations to explicitly simulate uncertainties in the sea ice model. This was founded on the generic approach proposed in Brankart et al. (2015), and included uncertainties associated to ice strength, ice albedo and drag coefficients at the ice/ocean and ice/atmosphere interfaces.
- Anamorphosis transformation of the sea-ice variables to account for the non-Gaussian character of their probability distribution. Specific new developments were carried out to account for the non-Gaussianity of observation errors.
- Probabilistic scores, to evaluate the reliability and resolution of the ensemble results.

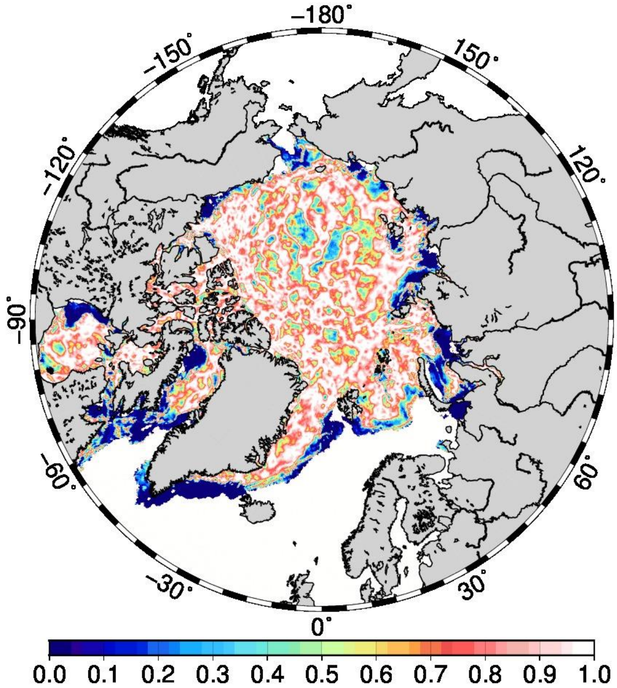
These methods were tested using two configurations of NEMO : first with ORCA2/LIM2 (global) at low resolution, and then with CREG4/LIM3 (Arctic and North Atlantiic) at a higher resolution. In both cases :

- Ensemble simulations were carried out, with explicit simulation of sea-ice uncertainties. These ensemble simulations are meant to describe the probability distribution of the response of sea-ice to modelling uncertainties. They illustrate the variety of the possible model solutions that can be produced by the model when uncertainty is explicity accounted for. The first figure below provides a possible measure of the ensemble spread as obtained with CREG4/LIM3.
- Observational updates have been performed to condition this prior ensemble to observations of sea-ice concentrations (in the context of twin experiments). These experiments demonstrated the need of the upgraded anamorphosis transformation to cope with the specificities of sea-ice data assimilation.
- Probabilistic scores have been systematically computed to evaluate the results and diagnose the improvements that are brought by the new schemes. The second figure below illustrates a possible measure of the information gain that is brought by data assimilation.

In summary, we found that these various developments were important because :

- the description of a complex nonlinear system cannot be complete without including an appropriate description of the uncertainties (which cannot be decoupled from the simulation of the mean state) ;
- the probability distribution of the sea-ice variables are essentially non-Gaussian (in particular because they are limited by bounds) ;
- the probability distribution of observation errors is non-Gaussian and asymmetric.





The left figure shows the difference between the 3rd and 1st quantiles of the ensemble for ice concentration on June 15, 2011. This figure illustrates the level of uncertainty that is obtained by the stochastic parameterizations that were introduced in the model. It can be observed in the figure that this uncertainty is larger along the ice edge, smaller in the interior of the ice pack, and equal to zero in the open ocean. In our data assimilation problem, a sufficient spread is necessary to make the probabilistic model consistent with observations and to make ensemble data assimilation possible.

The right figure shows the reduction of entropy that is obtained by assimilating observations of sea ice concentration (again on June 15, 2011). To compute entropy, we used the binary event defined by « being above or below the median of the prior ensemble ». From the figure, we see that most of the information gain is obtain along the ice edge, where most of the prior uncertainty is located. Where the model is already accurate, no much additional information is brought by the observation system.

Future of the project : This project was part of our contributions to the assimilation system of Mercator Ocean, which has been going on in other projects, as part of the CMEMS related activities.

Publications :

Brankart J.-M., Candille G., Garnier F., Calone C., Melet A., Bouttier P.-A., Brasseur P. and Verron, J., 2015 : A generic approach to explicit simulation of uncertainty in the NEMO ocean model. Geoscientific Model Development, 8, 1285-1297.

Zanna, L. , Brankart, J. M., Huber, M. , Leroux, S. , Penduff, T. and Williams, P. D., 2019: Uncertainty and Scale Interactions in Ocean Ensembles: From Seasonal Forecasts to Multi-Decadal Climate Predictions. Q J R Meteorol Soc. Accepted. doi:10.1002/qj.3397.

Germineaud C., Brankart J.-M., Brasseur P., 2019: An ensemble-based probabilistic score approach to compare observation scenarios: an application to biogeochemical-Argo deployments. Journal of Atmospheric and Oceanic Technology, en révision.