SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	High-resolution ocean reconstructions for initializing decadal climate predictions
Computer Project Account:	spesiccf
Start Year - End Year :	2022-2022
Principal Investigator(s)	Etienne Tourigny
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The following should cover the entire project duration.

Summary of project objectives

The overall objective of this 1-year project was to improve the predictive skill of the Decadal Climate Prediction (DCP) system produced with EC-Earth3.3 in its high-resolution (HR). After a dedicated tuning exercise of EC-Earth3-HR (spesiccf-2020), the specific goal of this project was to improve the initialization method of the DCP system, by producing new in-house ocean reconstructions. We developed a refined strategy to make the most of the ocean and atmosphere HR reanalyses from ECMWF (ORAS5 and ERA5) avoiding the non-stationary bias reported in the North Atlantic for the ECMWF seasonal forecast system SEAS5, arising from problems in the ORAS5 subsurface fields (Tietsche et al., 2020). The oceanic initial conditions of the EC-Earth3.3-HR DCP system are now provided by the HR ocean-only simulations that we produced thanks to this project.

Summary of problems encountered

We encountered several technical issues delaying the production of the oceanic reconstructions. We produced a first member that was thoroughly validated, which allowed us to realise that the routine dedicated to save the initial conditions (IC) from the ocean-only experiment was outdated on the ECMWF Cray XC40 HPC, generating IC files which were not readable by the coupled version of the model used to make the predictions. We also noticed that the atmospheric forcing fields from the ERA5 reanalysis applied were not correct as the precipitation forcing only included rain, instead of the total precipitation (snow + rain). This difference in the rainfall forcing has an impact in particular in the deep-convection regions where salinity errors associated with the incomplete freshwater fluxes can induce errors in deep convection (see paragraph *Summary of results* for more details).

Experience with the Special Project framework

The overall experience with the Special Project framework is very positive. This specific project was run on the cca machine, before its decommission. Because of questions of reproducibility of the model's simulation results, we had to finalize the production of all the members of this in-house oceanic reconstruction on this machine. Due to technical issues that we encountered (described in the "Summary of problems encountered" section above), we used more computing resources than initially expected. After these technical issues, we did some optimisation to slightly lower the consumption of cores per simulated year (CPSY) of our simulations, but this was still insufficient to fully complete all the members of the reconstruction we needed. We therefore requested additional resources (5 M SBU) and the procedure for this request was easy and facilitated by our contacts with the Special Projects manager. The (positive) response was quick which enabled us to complete the simulations we needed on time and in good conditions.

Summary of results

We produced the ocean initial conditions of our EC-Earth3 DCP system at high resolution. We applied the new framework as described in the paragraph *Summary of project objectives* to avoid the non-stationary bias reported in the North Atlantic for the ECMWF seasonal forecast system SEAS5, arising from problems in the ORAS5 subsurface fields (Tietsche et al., 2020). This new protocol is the result of extensive testing with the standard resolution configuration, as described in the request for this project. We used HR ocean-sea ice-only simulations with NEMO3.6-LIM3, driven by ERA5 surface atmospheric forcings and assimilating sea temperature and salinity at the surface from the ORAS5 ocean reanalysis and 3D ocean temperature and salinity below the mixed layer from the EN4 (v4.2.2) ocean reanalysis. The atmospheric variables used to force the ocean are air temperature at 10m, latent and sensible heat fluxes, specific humidity, precipitation (including rain and snow) and surface winds at 10m.

We produced five different members of this HR ocean-sea ice only simulation (historical reconstructions), covering the period 1959-2021. The ensemble members have been generated by applying infinitesimal perturbations to the atmospheric forcings from ERA5 (following the method of Massonet et al., 2015) and by using 5 different ocean initial conditions, corresponding to December 31st restarts from the last five years of a HR NEMO3.6-LIM3 spin-up. The atmospheric forcing variables perturbed are temperature at 10m and the sensible and latent heat fluxes. The ocean-only spin-up has been run with constant 1959 ERA5 forcing and assimilation of 1959 ocean observations (again from ORAS5 at the surface and EN4-v4.2.2 at the subsurface), and covered a total period of 30 years to allow for the model to equilibrate.

This new updated 5-members ocean reconstruction can be compared to the first ocean reconstruction that was done using only the rain as atmospheric forcing rather than all precipitation (rain and snow), the preliminary version of the ERA5 back extension (from 1959-1978) and an older version of EN4.2.1 for the subsurface nudging. This first reconstruction was also affected by the error in the routine used to save the initial conditions used for the decadal and seasonal hindcasts (see paragraph *Summary of problems encountered*).

At global scale, some differences appear in the heat content in the first 300 m, as well as in the salinity field (Figure 1). These differences may come from the nudging to the new version of EN4 as well as a difference in the freshwater cycle due to the different atmospheric forcing from ERA5.

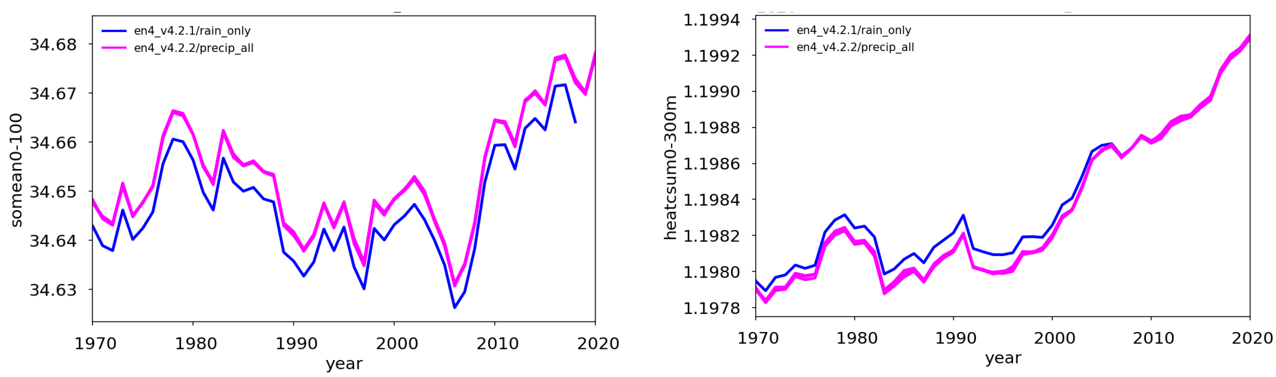

Figure 1: Timeseries of (left) the global salinity averaged in the 100 first meters (psu) and (right) the global heat content in the 300 first meters (10^{26} Joules). The blue lines correspond to the old reconstruction, the magenta lines to the analogous final corrected reconstruction.

Looking more precisely at the North Atlantic and Arctic ocean, there are some small differences in integrated variables such as the sea ice volume in the North Pole or the mixed layer depth in the Labrador Sea (Figure 2). Note that the differences, in particular for the sea ice volume, are somewhat more visible in the first years after initialisation, which can be linked with the updated version of ERA5 forcing before 1979.

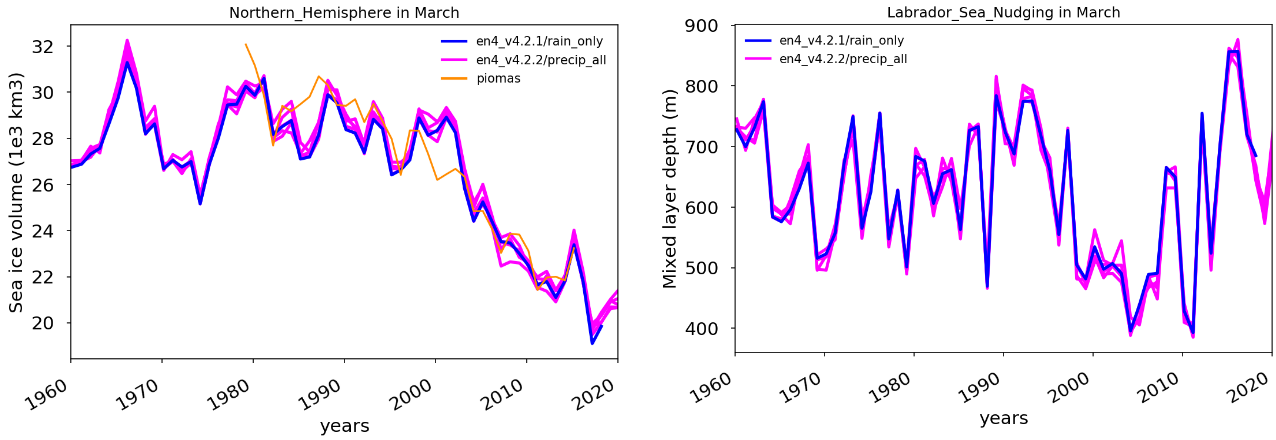

Figure 2: Timeseries of (left) the sea ice volume (1^3km^3) in the Arctic and (right) the mixed layer depth (m) in the Labrador Sea. Both timeseries show interannual variability in March monthly means, that is the month when deep convection is the most intense.

Interestingly, when computing the spatial differences in the Arctic region between the two reconstructions, some regions are more affected than others in particular for the months of March (see Figure 3).

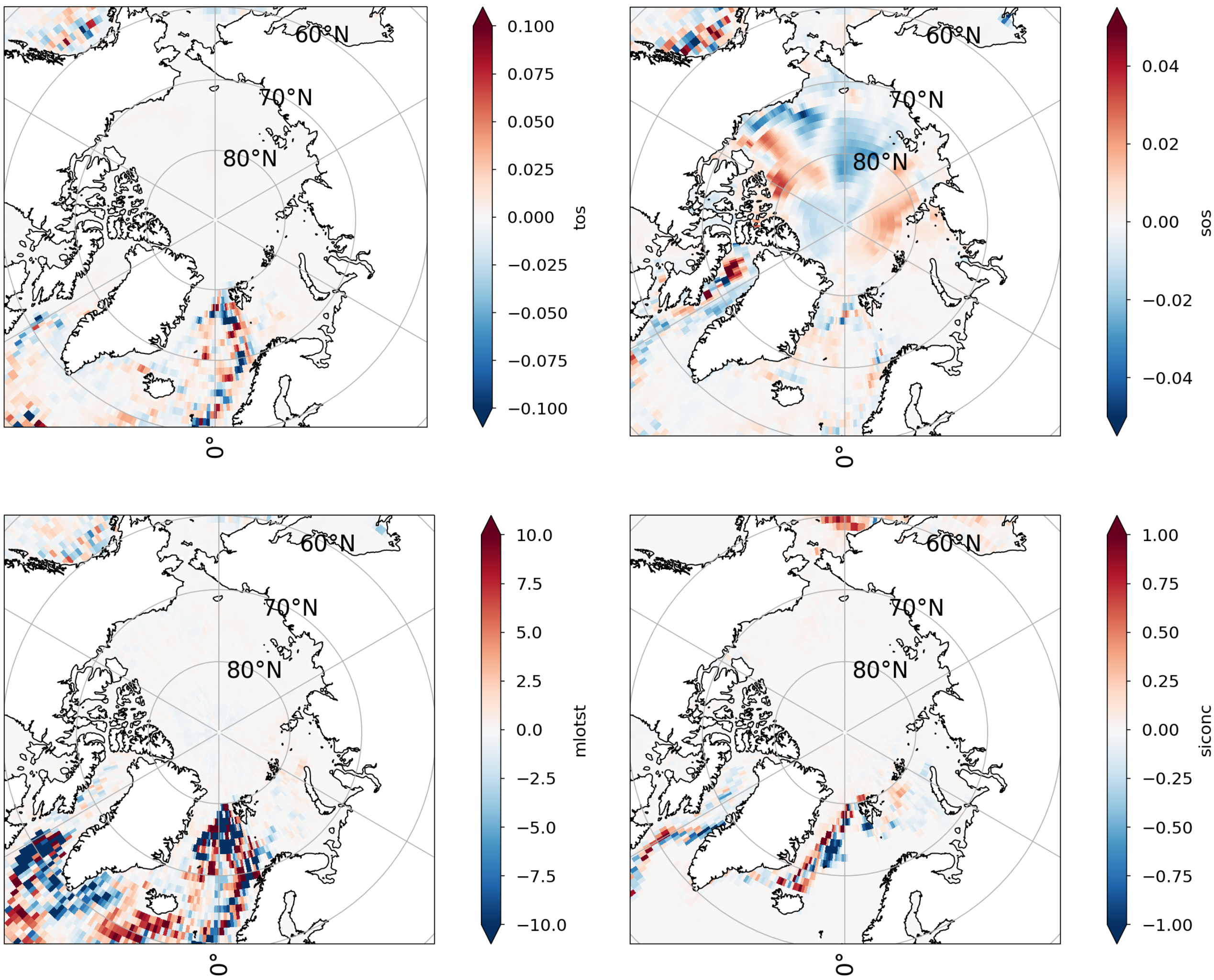

Figure 3: Differences between the two reconstructions for March averaged between 2000 and 2009 (when the timeseries in Figure 2 showed the largest discrepancies) for (Top left) the Sea Surface

Temperature (SST, indegrees Celcius), (Top right) the Sea Surface Salinity (SSS, in psu), (bottom left) the mixed layer depth (in m) and (bottom right) the sea ice concentration (in %.

Very few differences appear in terms of sea surface temperature but the freshwater differences due to a different amount of total precipitation received as forcing have an impact in terms of spatial distribution of salinity, as expected in the Arctic where snowfals occur frequently. Taking into account the snow reduces the salinity in the surface in most of the Arctic region. This has an impact on the deep convection, which exhibits a slight decrease in strength in the sinking regions of the Labrador Sea and the Nordic Seas. East of Greenland, we also note a relative increase in winter sea ice cover.

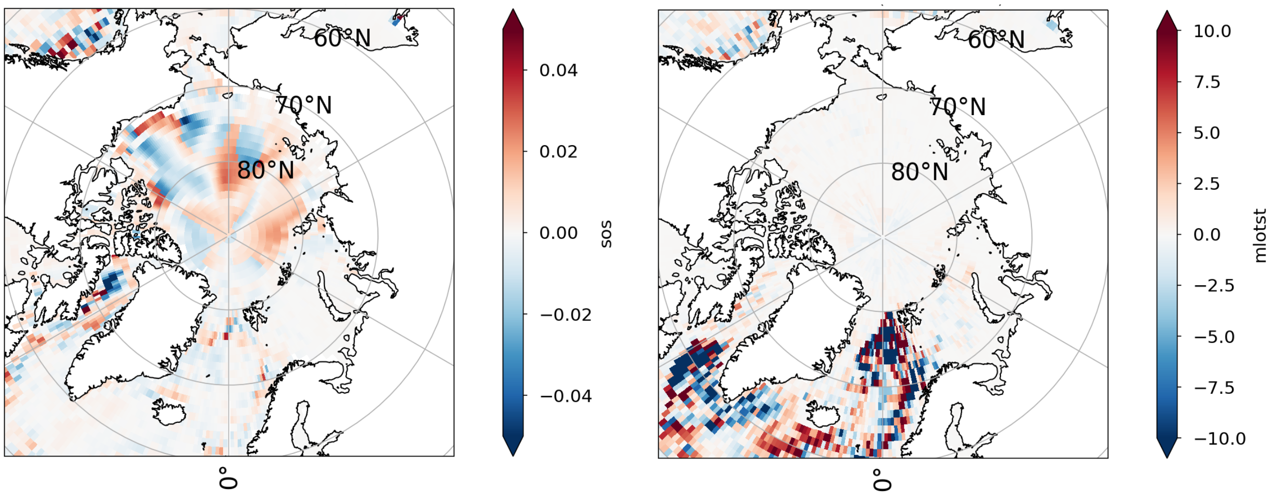

Figure 4: Difference between the absolute bias in the first and final reconstructions (|New recon. bias| - |Old recon. bias|) for sea surface salinity (left) and the mixed layer depth (right) in the months of March between 2000 and 2009. Blue color means that the new reconstruction has a reduced bias. The sea surface salinity bias is computed against EN4-v4.2.2. The mixed layer depth bias is computed against ORAS4 (as it is an independent reanalysis to the one assimilated in the reconstruction).

Overall, these differences due to the freshwater cycle in the Arctic have a different effect on the bias (derived by comparing each reconstruction with observations): while the bias in surface salinity is not reduced in the corrected reconstruction, the bias in the mixed layer depth is largely reduced in the regions of active deep convection.

List of publications/reports from the project with complete references

Deliverable 3.1 "Recommendations for the development of a new generation of climate forecast system", European Climate Prediction System (EUCP) HORIZON 2020 project, 2022. https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5e9807072&appId=PPGMS. Accessed on 30/06/2023.

Future plans

The HR reconstructions produced by this Special Project are being used to initialize the HR multi-year prediction system, which is currently in production on the BSC's Marenostrum4 supercomputer. We are producing two different sets of HR hindcasts:

- one set of hindcasts initialised in November each year, covering the period 1960-2021 with 15 members and 3 forecasted years,
- one set of hindcasts initialised in May each year, covering the period 1980-2021 with 15 members and 3 forecasted years.

These two sets of hindcasts are being used to initialize a multi-model ensemble of multi-years predictions at high resolution, which has been conceived to fill the gap between the current seasonal and decadal prediction systems. These multi-year hindcasts are currently in production and will contribute to the Horizon Europe project ASPECT.