SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	NEMO4 sensitivity experiments
Computer Project Account:	Spitmecc
Start Year - End Year:	2022 - 2023
Principal Investigator(s)	Virna Loana Meccia
Affiliation/Address:	Institute of Atmospheric Sciences and Climate, National Research Council (ISAC-CNR), Italy.
Other Researchers (Name/Affiliation):	-

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

In this special project (SP), it was proposed to perform sensitivity experiments with NEMO4 to different parameters, focusing on the different vertical mixing parameterizations. The original proposal aimed at helping design the tuning experiments with EC-Earth4. EC-Earth4 is the new version of the EC-Earth climate model currently under development and it will participate in the next phase of the Coupled Model Intercomparison Project, CMIP7.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

During the first year of this SP, we ran a set of standalone ocean experiments with NEMO4.2 and eORCA1 grid. The simulations consisted of sensitivity experiments to the vertical eddy viscosity and diffusivity coefficients for temperature and salinity. The aim was to evaluate the model sensitivity in reproducing the strength and low-frequency variability of the Atlantic Meridional Overturning Circulation (AMOC). However, the initial AMOC strength is lost in the first years, for almost all the experiments. Therefore, there is a need to test other default parameters apart from the vertical mixing parameterizations set in the *namelist* to obtain realistic values of the AMOC. It was planned to collaborate on this with the NEMO consortium but at the moment of the second year of this SP, there was no clue of the parameters to change in order to get a stable AMOC strength.

Due to the problem described above, it was decided to change the original plan for the second year. In this case, we continued the topic of research of the previous SP regarding the AMOC hysteresis in the EC-Earth model. We therefore took advantage of the modifications of the code in EC-Earth3 to allow for water-hosing experiments to continue investigating the climate impacts of a reduced AMOC under different background climates.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The experience with the application and submission has been straightforward. Besides, the staff at ECMWF kindly helped assist with any problems.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

The results are divided into two topics regarding the two-year duration of this SP:

1) *Sensitivity experiments to the vertical mixing in NEMO4*

During the first year of the project, we explored different parameterizations of the vertical mixing in NEMO4. They included the Turbulent Kinetic Energy (TKE) closure with different turbulent length scales (*tke0*, *tke1*, *tke2*, *tke3*, *tke4*); the Richarson number-dependent (*ric1*), and the non-penetrative Convective algorithm (*npcT*).

The AMOC index, defined as the maximum meridional streamfunction in the Atlantic at 26.5°N and between 30°N and 40°N in the depth range of 500 and 2000 meters was computed using CDFTOOL (Fig. 1).

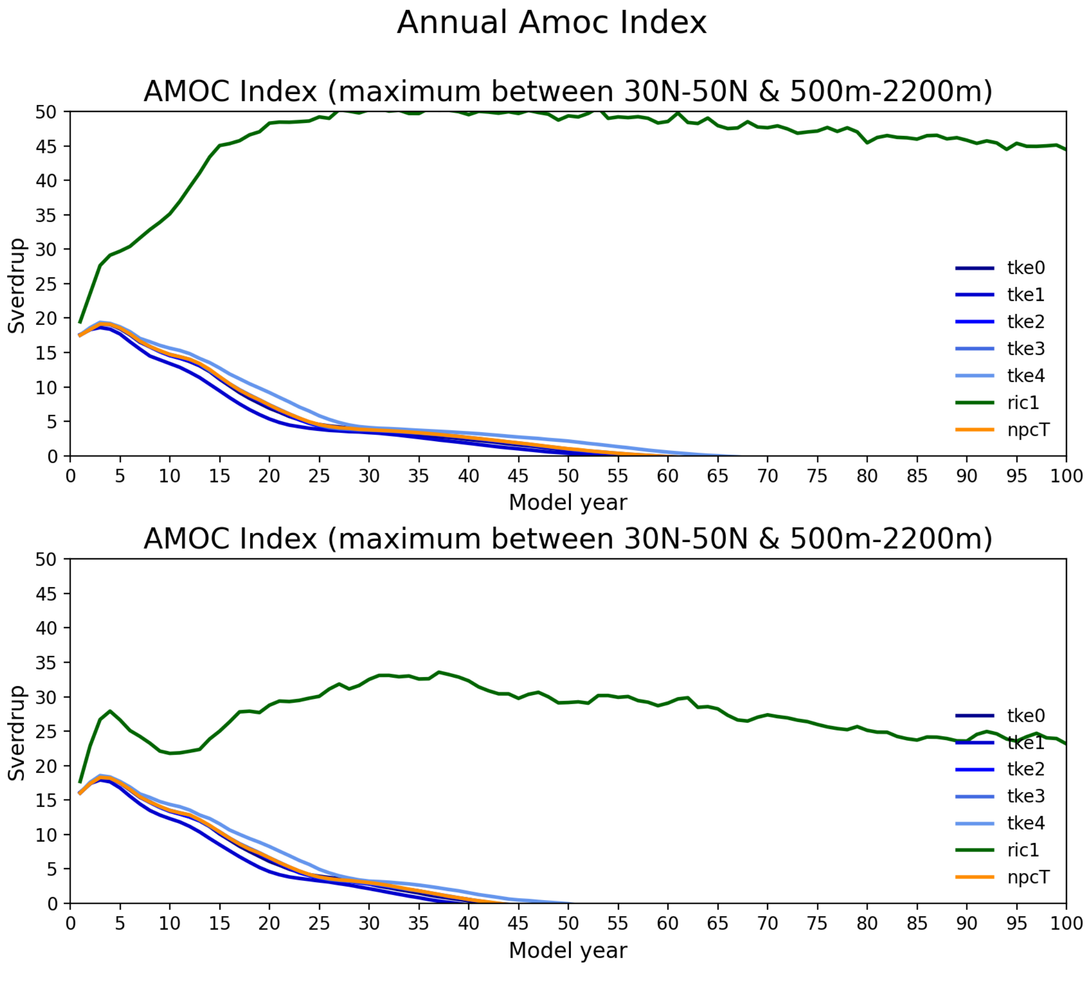

Figure 1: AMOC index at 26.5°N (upper panel) and between 30°N and 50°N in the depth range of 500-2000 meters for the first 100 years of simulation and the seven experiments.

As anticipated above, the strength of the AMOC is lost in the first 40 years of simulation in almost all the experiments. The only exception is the experiment with the Richarson number dependent parameterization. More simulations are needed to explore how to get reliable values of the AMOC strength, changing the default values of some parameters from the namelist. At the moment, we are waiting for the release of an updated namelist to continue with this project.

2) *Sensitivity experiments to water hosing under different background climates*

The second year of this SP was used to perform experiments of water hosing under different background climates. The water hosing experiments consist of a virtual surface freshwater release in the North Atlantic and the Arctic. The intensity of the hosing is 0.3 Sv and the freshwater perturbation is uniformly distributed over the region between 50°N in the Atlantic and the Bering Strait. This yields a freshening of the upper levels stabilizing the water column and inhibiting the deep convection. As a result, the AMOC reduces. We have already performed this experiment under a pre-industrial climate (*piControl*) in a previous special project that finished last year (spitmec2). The new experiments performed in the second year of this SP consist of 150 years of water hosing under the *abrupt-4xCO2* scenario and 100 years of water hosing under *abrupt-stabilization* climates representative of the years 2025 and 2050.

For the *abrupt-4xCO2* experiment, we used as a background climate the ensemble r8i1p1f1 from the CMIP6. For the *abrupt-stabilization* climates of the years 2025 and 2050, we used as a background climate, the conditions obtained by forcing the model with the fixed conditions of 2025 and 2050, respectively (Fabiano et al., 2024). Each simulation follows a sudden stabilization of the external forcing at the level specified by CMIP6 for the SSP5-8.5 scenario. Details on these simulations together with a preliminary analysis of them are published in Fabiano et al. (2024).

The results regarding the Atlantic meridional streamfunction and the timeseries of the AMOC index (maximum AMOC at 26.5°N) are shown in Figs. 2 and 3, respectively. In Fig. 2, the mean meridional streamfunction of the last 50 years of simulation is plotted. The first column shows the results from the original experiments, that is, without applying water hosing, whereas the middle column shows the results of the water hosing experiments. The third column shows the difference between both experiments for the last 50 years of simulation. The timeseries of the AMOC index are plotted in Fig. 3, in blue for the original experiments and in red for the water hosing runs. Applying water hosing reduces the AMOC strength, but the rate of reduction depends on the background climate. For instance, the maximum reduction of about 8 Sv (from 16 to 8 Sv; Fig. 3) occurs under the pre-industrial climate (*piControl*), and the minimum AMOC reduction of 5 Sv (from 11 to 6 Sv; Fig. 3) occurs under the *abrupt-4xCO2* scenario. A very similar rate of reduction (from 15 to 5 Sv) occurs in the experiments under *abrupt-stabilization* climates representative of 2025 and 2050.

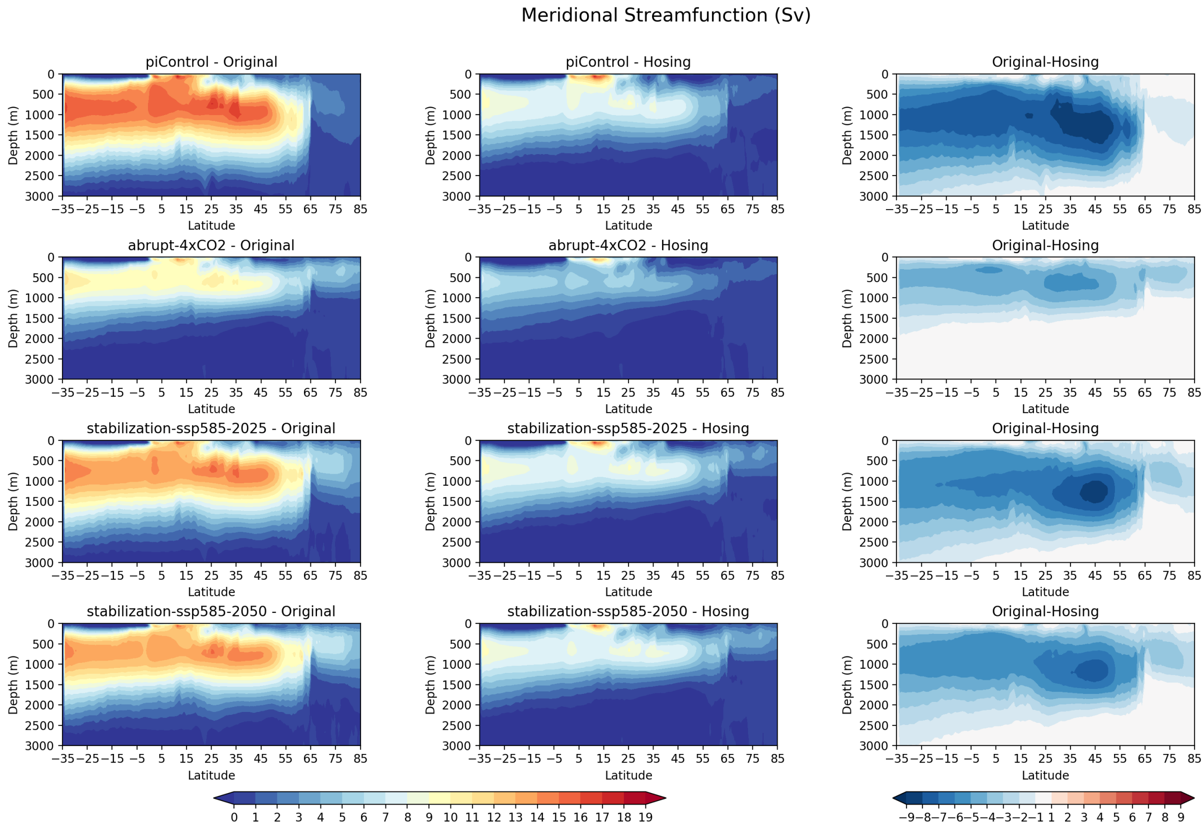

Figure 2: Mean Atlantic meridional streamfunctions of the last 50 years of simulations for the original experiments (left column), the experiments in which the water hosing is applied (middle column) and the difference between the two (right column).

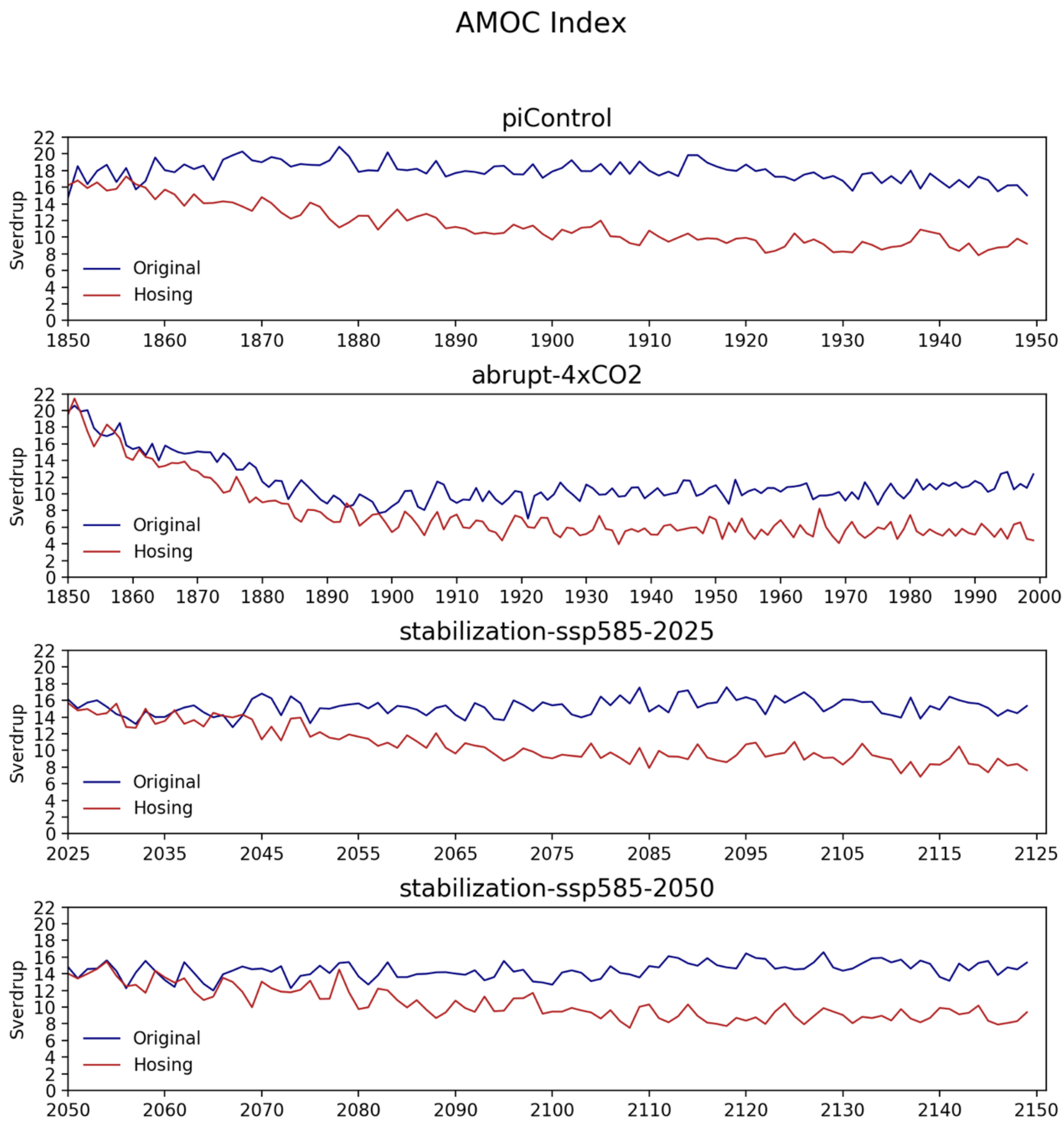

Figure 3: Timeseries of the AMOC index at 26°N for the set of original experiments (in blue) and water hosing experiments (in red).

To look at the climate impacts of a reduced AMOC under different background climates, the sea surface temperature and the sea ice cover averaged over the last 50 years of simulation are plotted in Figs. 4 and 5, respectively. The left columns show the values corresponding to the original experiments whereas the right columns show the differences between the experiments with water hosing and the original ones.

Under the pre-industrial climate, the reduction of the AMOC yields a cooling in the Labrador Sea (Fig. 4) with an increment in the sea ice cover (Fig. 5), and a warming in the Nordic seas (Fig. 4) with a reduction of the sea ice cover (Fig. 5). This pattern is partially repeated in the experiments under the *abrupt-stabilization* climate representative of 2025. In the other two experiments, that is, under the *abrupt-4xCO2* and under the *abrupt-stabilization* climate of 2050, the climate impacts of a reduced AMOC are slightly different with respect to the previous ones (Figs. 4 and 5). The reason for this can be that, under those more extreme scenarios, the sea ice cover in the original experiments is very much reduced. For instance, the Arctic was almost free of sea ice during the last years of the *abrupt-4xCO2* experiments, and therefore, applying water hosing leads to a recover of the sea ice (Fig. 5), with a cooling over the North Atlantic and the Arctic (Fig. 4).

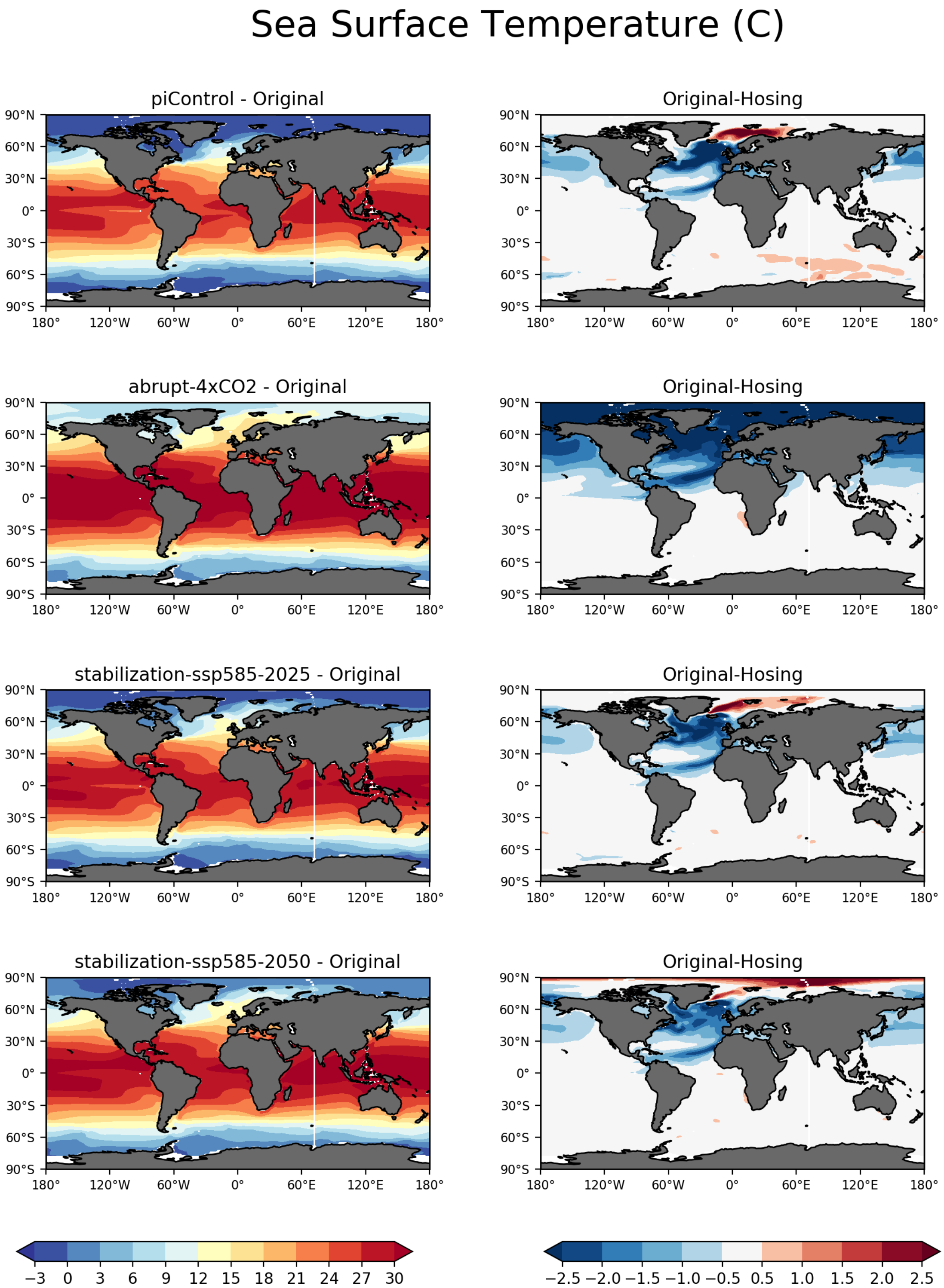

Figure 4: Sea surface temperature (°C) averaged over the last 50 years of simulations for the original experiments (left column), and the difference between the water hosing and the original experiments (right column).

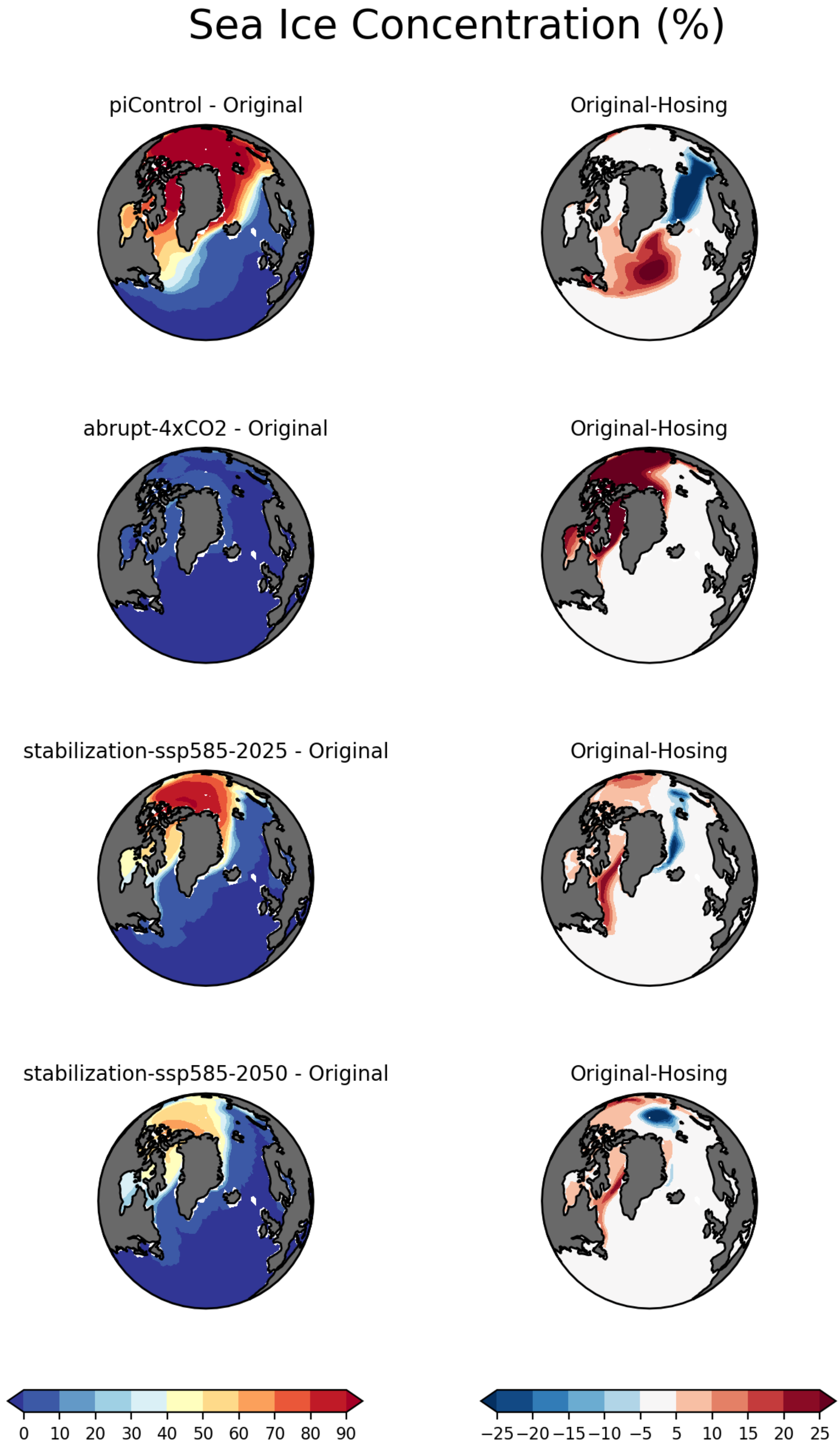

Figure 5: Sea ice cover (%) averaged over the last 50 years of simulations for the original experiments (left column), and the difference between the water hosing and the original experiments (right column).

We presented here the preliminary results of the simulations performed during the second year of this SP. More analysis is planned to focus on atmospheric variables as the response of the near-surface air temperature, precipitation and wind patterns.

References:

Fabiano F., P. Davini, V.L. Meccia, G. Zappa, A. Bellucci, V. Lembo, K. Bellomo and S. Corti. 2024. Multi-centennial evolution of the climate response and deep-ocean heat uptake in a set of abrupt stabilization scenarios with EC-Earth3. *Earth System Dynamics*, 15, 527–546. https://doi.org/10.5194/esd-15-527-2024. Previously in *Earth System Dynamics Discussions*.

List of publications/reports from the project with complete references

So far, there are no publications from this SP.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

We want to exploit the data produced during the second year of the project to deepen our knowledge of the implications of a weakened AMOC under different background climates. For the moment, we are not planning to run new experiments on this.