# SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

| | |
|---|---|
| **Reporting year** | 2022 |
| **Project Title:** | AMOC hysteresis in the EC-Earth model |
| **Computer Project Account:** | spitmec2 |
| **Principal Investigator(s):** | Virna Loana Meccia |
| **Affiliation:** | Institute of Atmospheric Sciences and Climate, National Research Council (ISAC-CNR), Italy. |
| **Name of ECMWF scientist(s) collaborating to the project** (if applicable) | - |
| **Start date of the project:** | 01-01-2021 |
| **Expected end date:** | 31-12-2022 |

## Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

| | | Previous year | | Current year | |
|---|---|---|---|---|---|
| | | Allocated | Used | Allocated | Used |
| **High Performance Computing Facility** | (units) | 9,500,000 | 9,500,000 | 9,500,000 | 0 |
| **Data storage capacity** | (Gbytes) | 22,500 | 22,500 | 45,000 | 22,500 |

## Summary of project objectives (10 lines max)

This special project (SP) has the main objectives of a) exploring the bi-stability of the Atlantic Meridional Overturning Circulation (AMOC) in the EC-Earth state-of-the-art climate model, and b) studying the climate impacts of a reduced AMOC in the same model. To face this topic, we perform experiments of water hosing in the North Atlantic. With this SP we aim to participate in a model inter-comparison project with EC-Earth to study the AMOC hysteresis. This project will contribute to a better understanding of the likelihood of AMOC collapse in the future.

## Summary of problems encountered (10 lines max)

We have run additional experiments with respect to the ones originally proposed. On the one hand, we ran a pre-industrial (*piControl*) experiment because we needed some outputs that were not available in the existing *piControl* run. On the other hand, we extended the original runs of the water hosing perturbation, and we ran an additional ensemble member. This was possible thanks to the collaboration with the SPITBELL special project.

## Summary of plans for the continuation of the project (10 lines max)

We plan to use the computing resources from the current year to perform simulations that will help us deepen the study of the climate impacts of a reduced AMOC, particularly in the Euro-Atlantic region. Taking advantage of the water hosing experiments already run, we will use 10-year SST from different mean AMOC index values as boundary conditions for AMIP experiments. The idea is to run 20 ensemble members of 10 years each for four different mean AMOC index values: 17, 14, 11 and 8 Sv. We will save daily outputs to study the impacts of a reduced AMOC on the blocking, weather regimes and extreme events in Europe.

## List of publications/reports from the project with complete references


- 2021. Bellomo K., V. Meccia, F. Fabiano, R. D'Agostino, P. Davini, J. v. Hardenberg and S. Corti. Weather impacts of an AMOC decline in the EC-Earth climate model. *TIPES General Assembly*, 7-11 June, 2021, online.
- 2021. Jackson L.C., R.A. Wood, K. Bellomo, G. Danabasoglu, A. Hu, J. Jungclaus, V. Meccia, O. Saenko, D. Swingedouw. AMOC tipping points in GCMs. *TIPES General Assembly*, 7-11 June, 2021, online.
- 2022. Bellomo K., Meccia V., D'Agostino R., Fabiano F., von Hardenberg J., and Corti S.: The climate impacts of an abrupt AMOC weakening on the European winters , EGU General Assembly 2022, EGU22-1023, https://doi.org/10.5194/egusphere-egu22-1023.
- 2022. Jackson L., Alastrue-De-Asenjo E., Bellomo K., Danabasoglu G., Hu A., Jungclaus J., Meccia V., Saenko O., Shao A., and Swingedouw,D.: AMOC thresholds in CMIP6 models: NAHosMIP, EGU General Assembly 2022, EGU22-2778, https://doi.org/10.5194/egusphere-egu22-2778.

## Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

### *a) EC-Earth as part of NAHosMIP*

The experiments ran so far within this SP are part of the North Atlantic Hosing Model Intercomparison Project (NAHosMIP), in which nine climate models participate. NAHosMIP aims to examine AMOC thresholds in CMIP6 models in the presence of freshwater forcing. We have used the CMIP6-generation EC-Earth version 3 in its standard resolution (T255 L91, ORCA1L75). The ocean component of EC-Earth, NEMO, was modified in order to account for idealized forcing of a freshwater flux (water hosing). The water hosing is then applied as an additional freshwater flux uniformly distributed over the region between 50°N in the Atlantic and the Bering Strait, as indicated in Fig. 1.

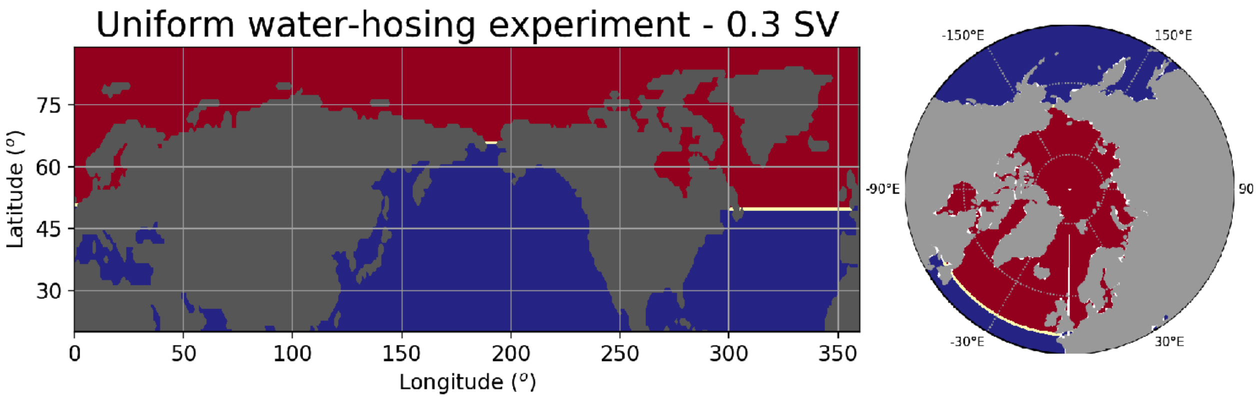


*Figure 1: Area in red indicates the region in which the freshwater flux anomaly is applied for a total water hosing of 0.3 SV of intensity.*

After 20 years and after 50 years of water hosing forcing, the perturbation is interrupted to leave the system freely adjust to its new equilibrium. Preliminary results from the nine models are shown in Fig. 2, taken from Jackson et al. (in preparation). The AMOC weakens in all models from the freshening, but once the freshening ceases, the AMOC recovers in some models, and in others, it stays weakened. In our particular case with EC-Earth, the AMOC recovers, even if the water hosing is stopped after 100 years (not shown). Therefore, EC-Earth is resilient to the freshwater perturbation intended to reduce the AMOC. However, some models show a threshold where the AMOC does not recover after stopping the perturbation. In experiments where AMOC does not recover after hosing, the AMOC has the weakest absolute values initially when hosing is stopped. There appears to be a threshold of about 7 Sv from below the AMOC does not recover.

Led by Laura Jackson from the MetOffice, we are still investigating the feedback mechanisms in each model to understand why the models respond differently. One paper presenting the experiments and one paper analysing the different model responses are in preparation.

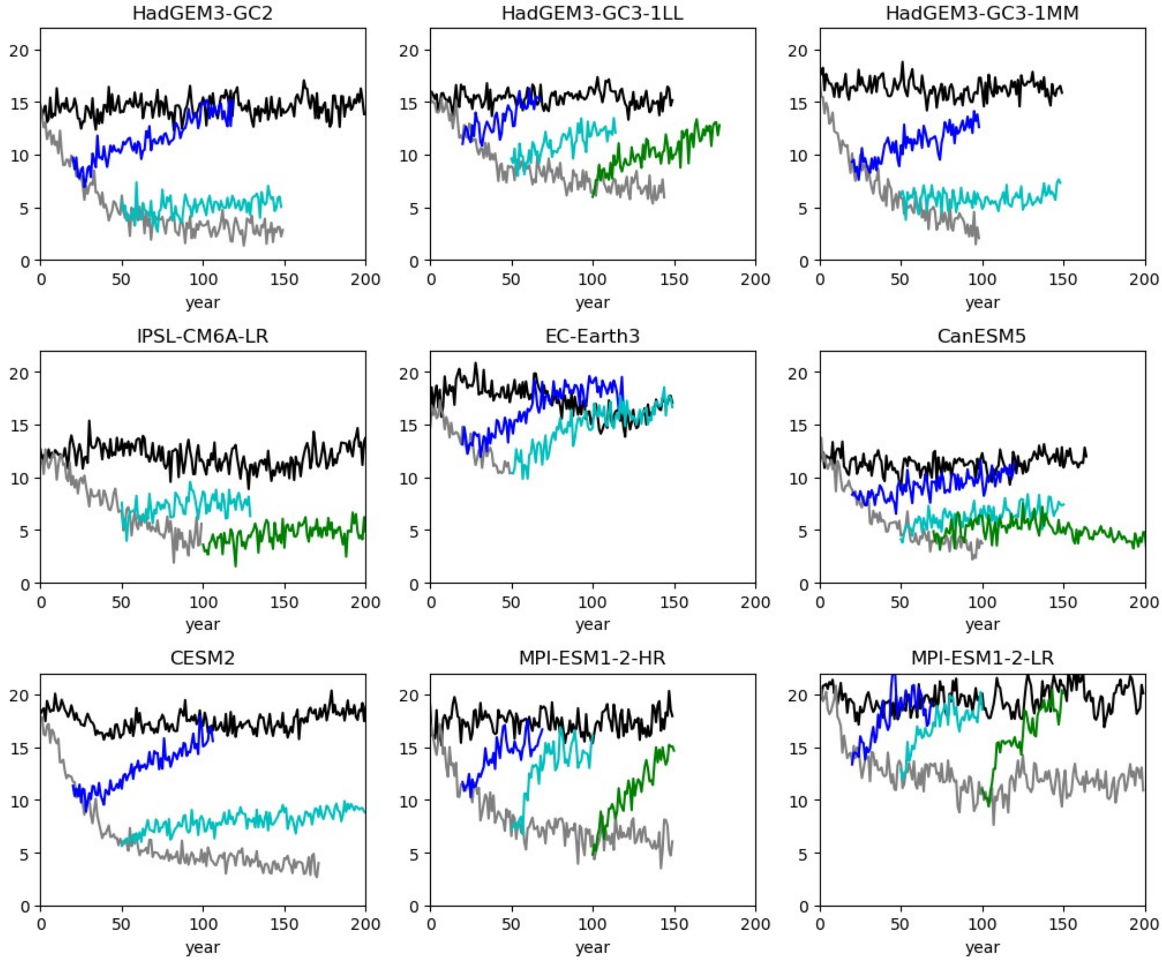


*Figure 2: Timeseries of the AMOC index for the different experiments and models participating in the NAHosMIP in which a uniform freshwater flux anomaly of 0.3 Sv is applied to the North Atlantic. The piControl runs are plotted in black, whereas the water hosing experiments are plotted in grey. Blue and cyan curves indicate the system response when the water hosing forcing is stopped after 20 and 50 years, respectively. From Jackson et al. (in preparation).*

***b) Climate impacts of a reduced AMOC on the Euro-Atlantic sector simulated by EC-Earth3***

We are further analysing the water hosing experiments with EC-Earth to investigate the impacts of an AMOC abrupt weakening on the winter climate variability focusing on the North Atlantic and Europe. Our preliminary results regarding the changes in the mean climate confirm the ones from previous studies. An overview of the annual mean impacts of a reduced AMOC is presented in Fig. 3, taken from Bellomo et al. (in preparation). For instance, due to the AMOC weakening and consequently a reduced meridional heat transport, the Earth cools, particularly in the northern hemisphere (NH; Fig. 3a), which experiences an average decrease in temperature of -2.09 °C. Some regions, such as the South Atlantic Ocean, even experience moderate warming. On the other hand, precipitation decreases over most of the NH (Fig. 3b), especially over the North Atlantic, and tropical precipitation exhibits a southward shift in the zonal mean annual mean Intertropical Convergence Zone (ITCZ) (Fig. 3d). The southward shift of the ITCZ corresponds to a southward shift of the Hadley cell (Fig 3c) in the annual mean. In the control simulation, the zero-crossing of the ascending branch of the annual mean Hadley cell at 700 hPa occurs at 4.5°N. In contrast, it shifts towards the southern hemisphere and occurs at 1°S in the water hosing experiment. These results evidence the important role of the ocean meridional heat transport due to the AMOC in regulating precipitation patterns.

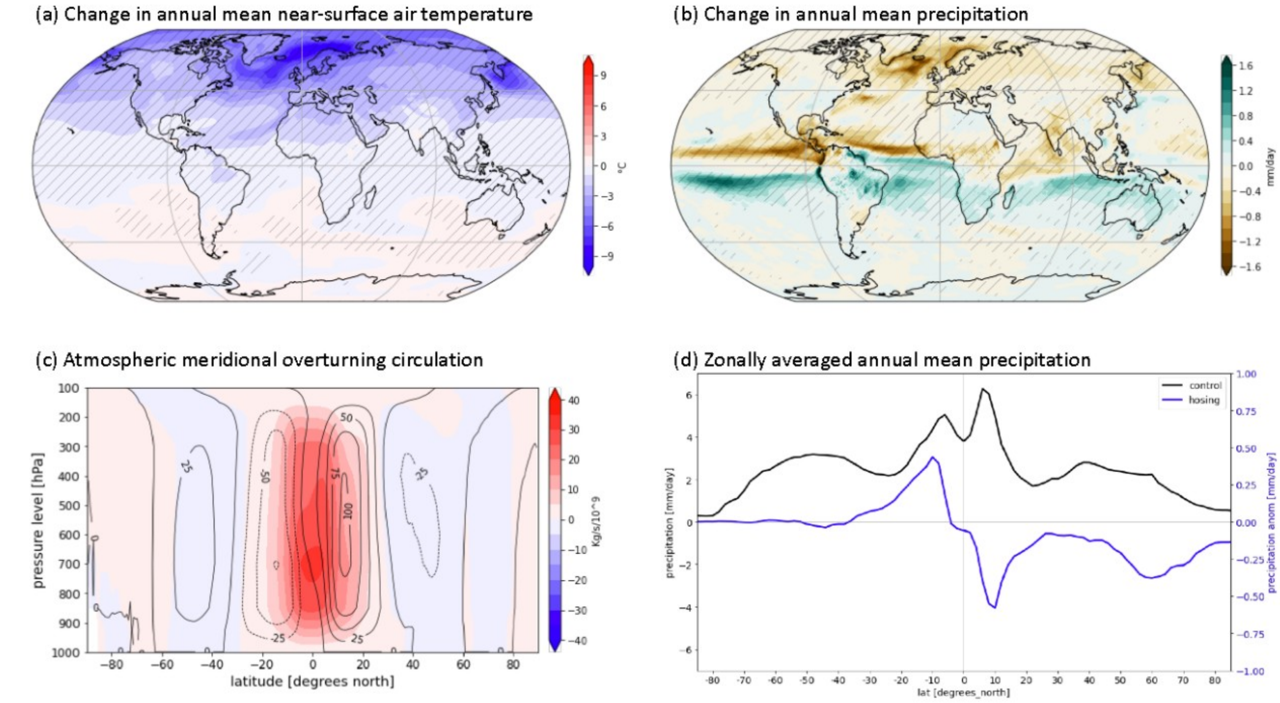


*Figure 3: Annual mean change in (a) near-surface air temperature; (b) precipitation; (c) atmospheric zonal mean meridional stream-function with the climatology superimposed in contours; and (d) zonal mean precipitation change for the climatology (black) and the water hosing anomaly (blue). Stippling in (a) and (b) indicates statistical significance.*

In addition, we have found an increase in the frequency and persistence of the positive phase of the North Atlantic Oscillation (NAO+) in winter by analysing the weather regimes. We are still investigating the impacts of a reduced AMOC in extreme precipitation events. A paper led by Katinka Bellomo from the Polytechnic University of Turin and the Institute of Atmospheric Sciences and Climate (ISAC-CNR) is in preparation.

***References***


- Bellomo K., Meccia V.L., D'Agostino R., Fabiano F., Larson S., von Hardenberg J. and Corti S. Climate impacts of a substantial weakening of the AMOC over the Euro-Atlantic region in the EC-Earth3 climate model. In preparation.
- Jackson L., Alastrue-De-Asenjo E., Bellomo K., Danabasoglu G., Hu A., Jungclaus J., Meccia V., Saenko O., Shao A., and Swingedouw,D. North Atlantic Hosing Model Intercomparison Project (NAHosMIP): overview. In preparation.