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	2025
Project Title:	Impacts of an AMOC collapse on atmospheric circulation in the Euro-Atlantic area
Computer Project Account:	andrea.vacca@polito.it (spitvacc)
Principal Investigator(s):	Andrea Vito Vacca
Affiliation:	Politecnico di Torino, Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Oliver Mehling, Katinka Bellomo
Start date of the project:	1/01/2024
Expected end date:	31/12/2025

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)	*72,000,000*	*47,000,000*	*72,000,000*	*3,000,000*
Data storage capacity	(Gbytes)	*180,000*	*100,000*	*180,000*	*500*

Summary of project objectives (10 lines max)

The aim of this project is to perform ad-hoc model experiments with EC-Earth3 state-of-art general circulation model to investigate the atmospheric response to the AMOC slowdown at different timescales, from sub-seasonal to multi-decadal. To this end, we analyse the atmospheric circulation and variability in a set of climate experiments where:

- The AMOC is artifically weakened imposing positive freshwater salinity anomalies (Water-Hosing experiments).
- The AMOC is artifically streghtened imposing negative freshwater salinity anomalies (Fixed-AMOC experiments).
- Sea Surface temperature (SST) is artificially modified to simulate the response of the surface ocean to the AMOC decline (AMIP experiments).

Summary of problems encountered (10 lines max)

As a complement to the above simulations, we planned to carry out "Mechanical Decoupling" experiments during the past year. These are climate simulations in which wind stress on the ocean is prescribed, and thus the effect of ocean-atmosphere feedbacks is removed (Larson et al., 2024). The objective was to assess the impact of the feedbacks on the AMOC decline and SST evolution in the North Atlantic, which in turn impacts on the atmospheric circulation. However, we encountered several technical problems in implementing this protocol in the EC-Earth3 code, which forced us to abandon these experiments for the time being.

In addition, with regard to the Water-Hosing and Fixed-AMOC experiments, we encountered several problems with the post-processing of the data with the easy2cmor software (https://github.com/EC-Earth/ece2cmor3), which we have since solved.

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

The majority of the climate experiments will be carried out from August until December 2025. In particular, we plan to run:

- An ensemble of atmosphere-only experiments in which we prescribe SST anomalies to reproduce the NAWH (North Atlantic Warming Hole), a typical response pattern related to the AMOC decline (Gervais et al., 2019). We will simulate different types of anomaly patterns and different background climates.

- A long high-forcing Water-Hosing experiment (~1000 years) similar to van Westen et al., 2024, with the aim of assessing whether in EC-Earth3 the AMOC can reach a tipping point.

- A simulation for the TIPMIP - Tipping Point Modelling Intercomparison Project. Specifically, we will perform an additional Water-Hosing experiment where we simulate a freshwater release in the Arctic Ocean comparable to the Laurentide-type release, which is estimated to have occurred around 8.2k years ago (Lochte et al. 2019).

List of publications/reports from the project with complete references

Vacca, A.V., Bellomo, K., Fabiano, F. et al. On the role of AMOC weakening in shaping wintertime Euro-Atlantic atmospheric circulation. Clim Dyn 63, 273 (2025). https://doi.org/10.1007/s00382-025-07747-z

Summary of results

We performed a series of fixed-AMOC experiments with EC-Earth3. In these experiments, we added a uniform positive virtual salt flux in the subpolar North Atlantic and the Arctic Ocean that stabilises the AMOC in opposition to weakening following abrupt-4xCO2, following the protocol described in Bellomo & Mehling 2024. These experiments are used to isolate the impact of AMOC on the atmosphere in a climate change context at different time scales, from sub-seasonal to multi-decadal. For the analysis of the impact of AMOC on multi-decadal variability, we extended three previously conducted Fixed-AMOC simulations, which spanned the period 1850-2000, to the year 2200.

Moreover, we performed a series of Water-Hosing experiments (negative virtual salt flux in in the subpolar North Atlantic and the Arctic Ocean), with a protocol analogous to Bellomo et al., 2023, but with different background climates. In particular, we ran two Water Hosing members in a future SSP5-8.5 scenario and two Water Hosing members in addition to the abrupt-4xCO2 simulation.

The results regarding the impact of AMOC decline at sub-seasonal scale are described in Vacca et al., 2025. In the Figure 2 below we show that compared to the Fixed-AMOC experiment, the Weakened AMOC experiment (abrupt-4xCO2) features an increased frequency of the NAO+ Weather Regime, and decreased frequency in the Scandinavian Blocking Weather Regime, which is in agreement with the results of a multi-model analysis results (Vacca et al., 2025). Regarding the analysis of the impact of AMOC decline on multi-decadal scale and variability (e.g. NAO, ENSO), the experiment data have not yet been analysed to produce figures and plots.

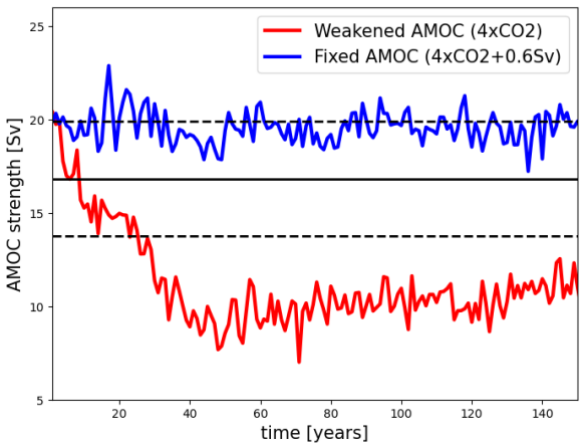

Figure1 (Figure S5 from Vacca et al., 2025): *AMOC strength in the Weakened and Fixed AMOC experiments (EC-Earth3). The time series represent the annual mean maximum of the mass overturning streamfunction in the Atlantic sector below 500 m at 26.5°N. The piControl is represented as the long-term mean (thick black line), while the band between the two dashed lines represents an estimate of the internal variability, computed as plus and minus 2 standard deviations from the long-term mean.*

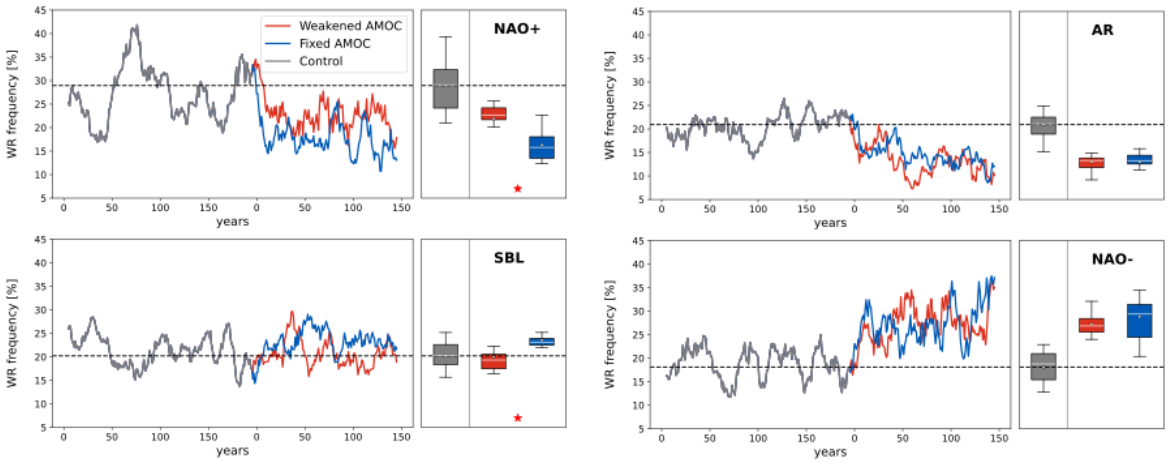

Figure 2 (Figure 10 from Vacca et al., 2025): *On the left hand side of each panel the time series of seasonal mean WRs' frequency in the Weakened and Fixed AMOC experiments. Grey lines indicate the last 200 years of the piControl experiment, while red and blue lines the 150-years Weakened and Fixed AMOC experiments, respectively. A 10-year running average smoothing is applied for better visualization. On the right side of each panel boxplots of 10-year mean frequencies in the experiments. Red stars indicate significance difference between the two distributions at the 95% confidence level (Welch two-tailed t-test).*

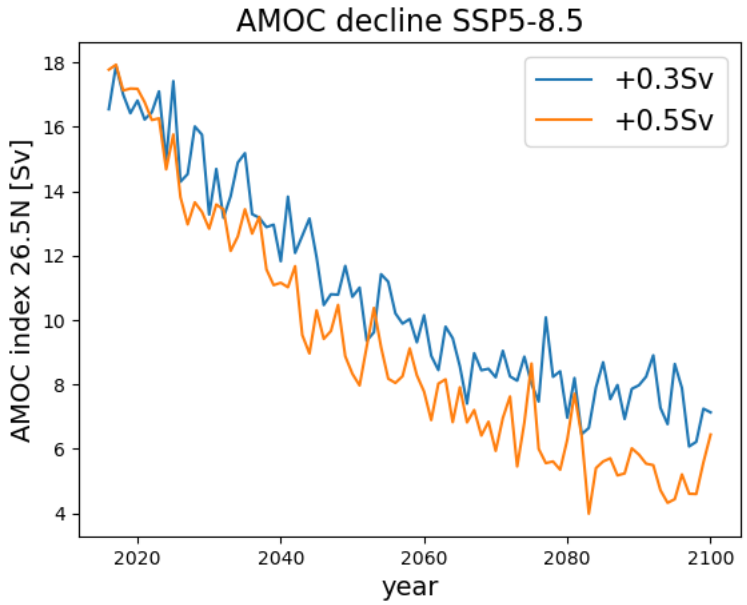

Figure 3: *AMOC strength in two Water Hosing experiments (EC-Earth3) under the SSP5-8.5 background climate. The time series represent the annual mean maximum of the mass overturning streamfunction in the Atlantic sector below 500 m at 26.5°N. The AMOC strength declines steadily reaching ~6Sv at the end of the century, declining by ~60%.*

Additional References

Larson, S. M., K. McMonigal, Y. Okumura, D. Amaya, A. Capotondi, K. Bellomo, I. R. Simpson, and A. C. Clement, 2024: Ocean Complexity Shapes Sea Surface Temperature Variability in a CESM2 Coupled Model Hierarchy. J. Climate, 37, 4931–4948, https://doi.org/10.1175/JCLI-D-23-0621.1.

Gervais, M., J. Shaman, and Y. Kushnir, 2019: Impacts of the North Atlantic Warming Hole in Future Climate Projections: Mean Atmospheric Circulation and the North Atlantic Jet. J. Climate, 32, 2673–2689, https://doi.org/10.1175/JCLI-D-18-0647.1.

Van Westen, R. M., Kliphuis, M., & Dijkstra, H. A. (2024). Physics-based early warning signal shows that AMOC is on tipping course. Science advances, 10(6), eadk1189.

Lochte, A. A., Schneider, R., Kienast, M., Repschläger, J., Blanz, T., Garbe-Schönberg, D., & Andersen, N. (2020). Surface and subsurface Labrador Shelf water mass conditions during the last 6000 years. Climate of the Past, 16(4), 1127-1143.

Bellomo, K., & Mehling, O. (2024). Impacts and state-dependence of AMOC weakening in a warming climate. Geophysical Research Letters, 51(10), e2023GL107624.

Bellomo, K., Meccia, V. L., D'Agostino, R., Fabiano, F., Larson, S. M., von Hardenberg, J., & Corti, S. (2023). Impacts of a weakened AMOC on precipitation over the Euro-Atlantic region in the EC-Earth3 climate model. Climate Dynamics, 61(7), 3397-3416.