SPECIAL PROJECT FINAL REPORT

Project Title:	Mechanisms and impacts of an abrupt decline in the Atlantic Meridional Overturning Circulation (AMOC) strength
Computer Project Account:	spitbell
Start Year - End Year :	2023 - 2025
Principal Investigator(s)	Katinka Bellomo
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Other Researchers (Name/Affiliation):	Oliver Mehling, Utrecht University Andrea Vito Vacca, Polytechnic University of Turin

Summary of project objectives

The aim of this project was to use the EC-Earth3 general circulation model to investigate mechanisms of global climate change associated with changes in the strength of the AMOC, with or without the influence of increasing concentrations of greenhouse gases. This was a continuation of a past special project titled "Impacts of the AMOC decline on European climate". We proposed to run ad-hoc model experiments in which we artificially modify the strength of the AMOC by modifying a virtual salinity flux in the North Atlantic, following the protocol outlined in NAHosMIP. However, instead of reducing the strength of the AMOC, we increased its strength ("dehosing") while also imposing an external forcing of 4xCO_2. We ran a small ensemble of runs with different strengths of dehosing and extended the runs to analyze the impacts of AMOC decline on natural modes of internal climate variability.

Summary of problems encountered

We didn't encounter any specific problems. We noticed that the output of the model requires larger storage space than expected, which has delayed some of the runs that we intended to perform because we ran out of storage. We also found that writing data on tape and retrieving it from there is not as straightforward as we hoped, and required more time than we expected.

Experience with the Special Project framework

The framework worked very smoothly overall. It would be great if other members of a research group were able to share storage space allowance instead of only computing time. That would make the workflow of a research unit much more streamlined. Also writing and retrieving from tape could be made a bit easier, especially by creating commands that allow moving multiple folders together.

Summary of results

We carried out model experiments on ATOS using the EC-Earth3 model, which includes the IFS cy36r4 atmospheric model, the land-surface scheme H-TESSEL, the NEMO 3.6 ocean model and the LIM3 sea-ice component. The OASIS3-MCT version 3.0 coupler exchanges fields between the components. In all of the experiments, EC-Earth3 was integrated with a horizontal resolution of ~80 km (T255) for the atmosphere and ~100 km (1°) for the ocean, with a grid refinement to 1/3° in the tropical ocean. The vertical levels are 91 for the atmosphere and 75 for the ocean.

We investigated background climate state dependence comparing the impacts of an AMOC decline in preindustrial and 4xCO_2 forced climates. The preindustrial background climate has external forcing fixed at preindustrial levels, hence all of the climate variability is internally driven. The 4×CO_2 experiment is initialized from the preindustrial experiment and is forced with a fixed CO_2 concentration of four times the preindustrial level for 150 years. We carried out two types of experiments on ATOS: the first one is a classical "water hosing" experiment. The water hosing experiment is integrated adding a uniform negative virtual salinity flux equivalent to − 0.3 Sv poleward of 50°N in the Atlantic and Arctic Oceans. Then, the hosing is halted and the model is left to freely evolve. The second type of experiment is identical to the abrupt-4×CO_2, including initial conditions, but we artificially kept the AMOC strength at values comparable to the preindustrial, which we will refer to as the "dehosing". In this setup, we also added a uniform virtual salinity flux poleward of 50°N in the Atlantic and Arctic Oceans, but we applied a positive virtual salinity flux to counterbalance the weakening of the AMOC induced by the 4×CO_2 forcing. We ran three ensemble members, which are identical in the setup and initial conditions but differ in the amount of the virtual salinity flux. The three ensemble members are run with the following positive salinity flux anomalies: "4×CO_2 + 0.4 Sv", "4×CO_2 + 0.5 Sv", and "4×CO_2 + 0.6 Sv." Collectively, we refer to these experiments as "fixed AMOC" results. In addition to the results reported in the summary of results from 2024, we extended these three experiments for additional 300 years each (wrt fig. 1), which allows us to investigate impacts of modes of coupled climate variability in addition to the mean state changes.

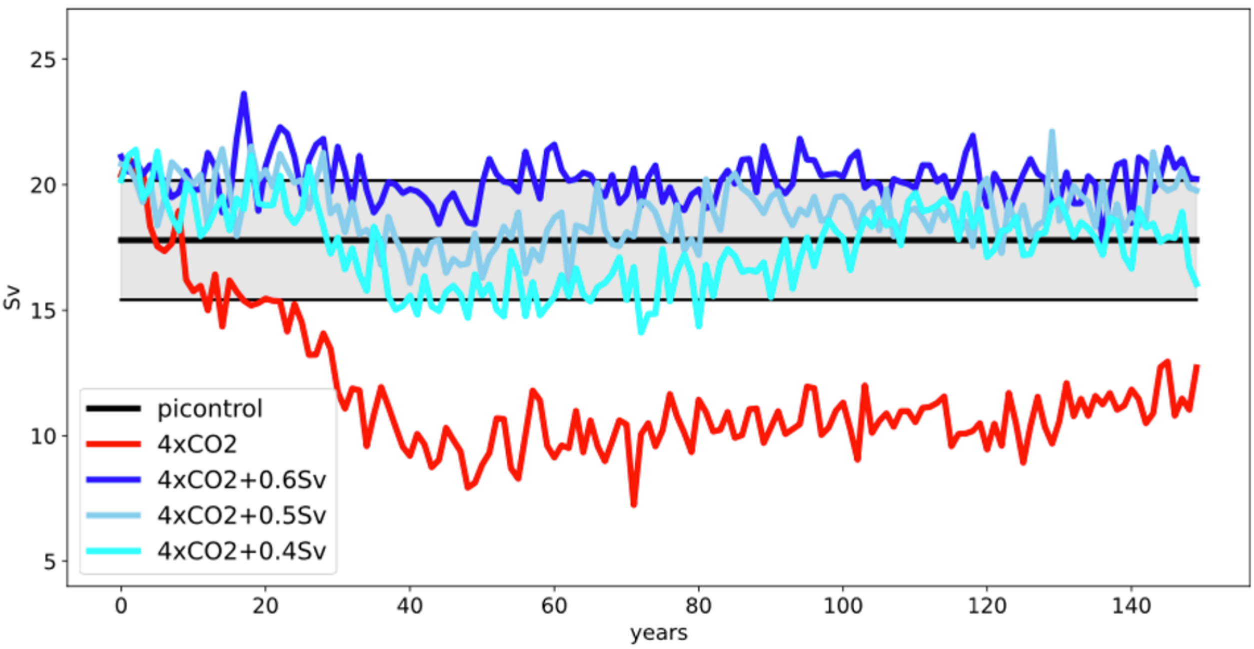

Fig. 1 (adapted from Bellomo and Mehling, 2024): *AMOC index at 26.5°N. The timeseries are calculated as the annual mean maximum of the mass overturning streamfunction in the Atlantic sector below 500 m. The picontrol is represented as the long-term mean (thick black line) and the gray band spans plus and minus 1.5 standard deviations for an estimate of internal variability. The other curves are colored according to the legend.*

As expected, our experimental design of the "fixed AMOC" experiment, restores the AMOC strength at approximately the same level as in the preindustrial simulation (fig. 1), which allows us to investigate the impacts of an AMOC weakening (4xCO2 experiment) relative to greenhouse gas forcing (4xCO2 minus fixed AMOC experiment).

For what concerns impacts on the mean state, our results show that an AMOC weakening in the preindustrial climate activates the polar sea-ice albedo feedback, which amplifies cooling effects. This also alters precipitation patterns worldwide, meaning that in a warmer climate an AMOC shutdown could have less severe impacts than previously thought (Bellomo and Mehling 2024).

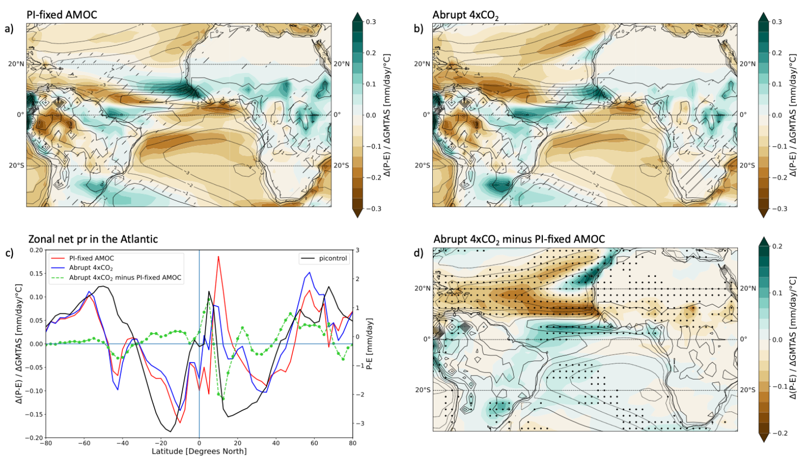

Fig. 2 (adapted from Cerato et al., 2025): *Precipitation impacts in 4xCO2 experiments: (a) the AMOC is fixed at preindustrial levels (fig. 1); (b) the AMOC is allowed to slow down due to the 4xCO2 forcing; (c) zonal mean average in the Atlantic basin showing shifts in the ITCZ; (d) difference between panel (b) and (a).*

Moreover, in Cerato et al. (2025) we investigated the precipitation impacts in the 4xCO2 experiments with and without an AMOC decline (fig. 2). We found that, an AMOC decline leads to a southward shift in the tropical Atlantic ITCZ, which is absent in the fixed AMOC experiment. The moisture budget analysis further revealed that an AMOC decline overlaps with 4xCO2 forcing, leading to dynamic readjustments in the meridional oceanic and heat transports. These effect appear to be present albeit much smaller for the global mean ITCZ, and overall underscore the importance in narrowing down the inter-model uncertainty in AMOC decline (Bellomo et al. 2021) in future climate projections.

These experiments were analyzed also in Vacca et al. (2025), in which we investigated the impacts of an AMOC decline on Weather Regimes (WRs) in the Euro-Atlantic sector, as part of a broader investigation of the response of WRs to future climate change in idealized IPCC ssps scenarios (fig. 3). We found that the increase in wintertime NAO+ is driven by the AMOC weakening in projections in all models in the CMIP6 archive. This result was corroborated by the ad-hoc experiments with EC-Earth3 described above that allowed us to separate the impacts due to CO2 from those due to an AMOC decline.

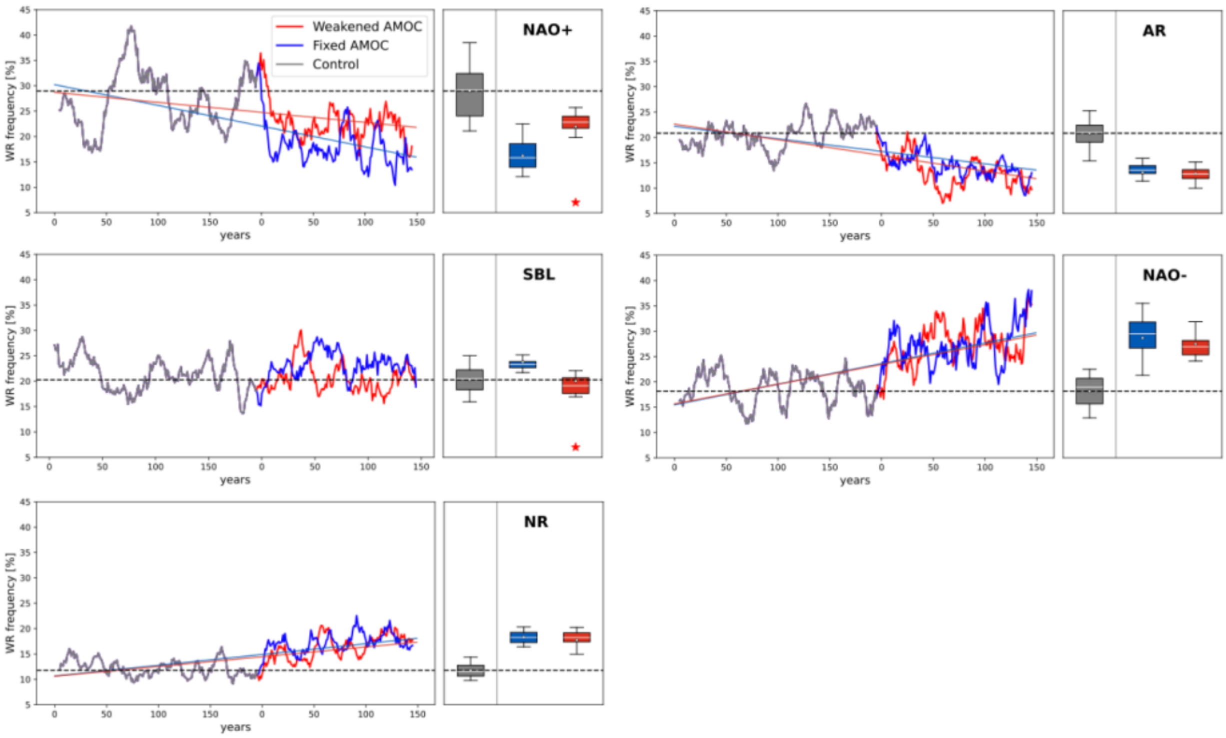

Fig. 3 (adapted from Vacca et al., 2025): *Wintertime weather regimes in the EC-Earth3 experiments, from top left to bottom left: North Atlantic Oscillation positive phase (NAO+), Atlantic Ridge (AR), Scandinavian Blocking (SBL), North Atlantic Oscillation negative phase (NAO-), No regime (NR).*

Other research efforts leveraging these experiments are currently in progress, in particular:

- Analysis of climate feedbacks and comparison with CESM2 experiments: collaboration with Lily Hahn from Scripps Institution of Oceanography, UCSD, USA
- Analysis of tropical heat transports: collaboration with Qiupeng Ren, Institute of Oceanography, Chinese Academy of Science
- Impacts on El Niño Southern Oscillation: Master's thesis supervised by Katinka Bellomo at the Polytechnic University of Turin

List of publications/reports from the project with complete references

Bellomo K. and O. Mehling, 2024: Impacts and state-dependence of AMOC weakening in a warming climate. Geophysical Research Letters, 51, e2023GL107624. *https://doi.org/10.1029/2023GL107624*

Cerato G., **K. Bellomo**, R. D'Agostino, J. von Hardenberg, 2025: Multi-model evidence of future tropical Atlantic precipitation change modulated by AMOC decline .J. Climate, 38, 3093–3107, *https://doi.org/10.1175/JCLI-D-24-0333.1.*

Vacca A., **K. Bellomo**, F. Fabiano, J. von Hardenberg, 2025: On the role of AMOC weakening in shaping wintertime Euro-Atlantic atmospheric circulation. *Climate Dynamics*, 63, 273 *https://doi.org/10.1007/s00382-025-07747-z*

Future plans

We plan to finish extending the runs until the end of 2025 and analyze the output for future publications. We have no plans to submit a special project to continue this analysis for the time being.