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	2024
Project Title:	Mechanisms and impacts of an abrupt decline in the Atlantic Meridional Overturning Circulation (AMOC) strength
Computer Project Account:	spitbell
Principal Investigator(s):	Katinka Bellomo
Affiliation:	[1]National Research Council of Italy, Institute of Atmospheric Sciences and Climate (CNR-ISAC), Turin, Italy [2]Department of Environment, Land and Infrastructure Engineering, Polytechnic University of Turin, Turin, Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	spitmehl
Start date of the project:	01/01/2023
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)	10,000,000	10,000,000	10,000,000	2,000,000
Data storage capacity	(Gbytes)	18,000	18,000	50,000	41,000

Summary of project objectives (10 lines max)

The aim of this project is to use the EC-Earth3 general circulation model to investigate mechanisms of precipitation change associated with changes in the strength of the AMOC, with or without the influence of increasing concentrations of greenhouse gases. This is a continuation of a past project titled 'Impacts of the AMOC decline on European climate'. To address this question, 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. In the second year of this project, we implemented a new version of the water hosing setup. Instead of reducing the strength of the AMOC, we increased its strength while also imposing an external forcing of 4xCO2. We ran a small ensemble of 3 members and we managed to publish one paper analyzing the output of these runs in Geophysical Research Letters.

Summary of problems encountered (10 lines max)

We didn't encounter specific problems. We noticed that the output of the model requires larger storage space than expected, which is delaying some of the runs that we intended to perform. We also found that writing data on tape requires more time than we expected.

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

We plan to continue the analysis of the state-dependence of AMOC impacts on temperature and precipitation increasing the ensemble members of the runs that were published in Geophysical Research Letters. In addition, we want to test whether changing regions of hosing or external radiative forcings affects our results. We also plan to change resolution to see if the water hosing depends on the resolution of the model.

List of publications/reports from the project with complete references

Publications:

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

Presentations:

Poster: "Multi-model evidence of future tropical Atlantic precipitation change modulated by AMOC decline". American Geophysical Union Fall meeting, December 11-15 2023, San Francisco, CA (USA).

Oral: "Influence of the Atlantic Meridional Overturning Circulation on future climate change impacts", WCRP open science conference, October 23-27, 2023, Kigali, Rwanda.

Oral: "The influence of a weakened AMOC on weather regimes, blocking, and extreme events in idealized climate model experiments", August 9-11, AMV and Tropical Basins Interactions workshop, ICTP, Trieste, Italy.

Oral: "Impacts of an AMOC slowdown of future climate change", IUGG 28th General Assembly, Berlin, July 11-20 2023, Berlin, Germany.

Summary of results

The results described herein are based on the main findings reported in Bellomo and Mehling (2024) (full citation provided above).

We compared model experiments carried out with coupled climate model EC-Earth3, which participates in CMIP6, with our own experiments carried out on ATOS using the same model. EC-Earth3 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 has 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 analyzed the control climate from the preindustrial control experiment from the CMIP6 archive, which is 500 years long. We then investigated the impacts of greenhouse gas forcing by analyzing the abrupt-4×CO2 experiment, also taken from the CMIP6 archive. The 4×CO2 experiment is initialized from the preindustrial experiment and is forced with a fixed CO2 concentration of four times the preindustrial level for 150 years. In addition, we carried out two types of experiments on ATOS: the first one is a classical “water hosing” experiment. The water hosing experiment is integrated for 140 years 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 for an additional 70 years. The second type of experiment is identical to the abrupt-4×CO2, including initial conditions, but we artificially kept the AMOC strength at values comparable to the preindustrial. In this experiment, 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×CO2 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×CO2 + 0.4 Sv”, “4×CO2 + 0.5 Sv”, and “4×CO2 + 0.6 Sv.” We refer to the ensemble mean of these three ensemble members as the “fixed AMOC” experiment in the summary of the main results below.

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).

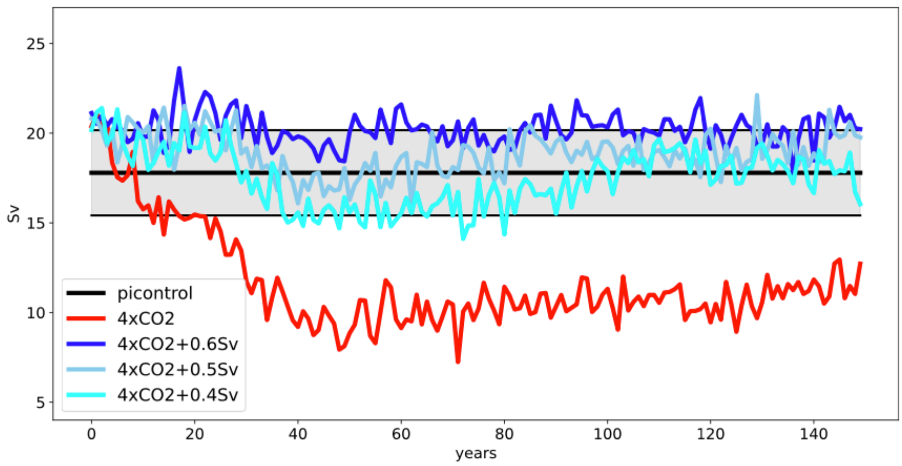

Fig. 1 (adapted from Bellomo and Mehling, 2024): *AMOC index at 26.5°N. The timeseries are calculated as the annual mean maximum of the mass overturning streamfunction in the Atlantic* *sector below 500 m. The picontrol is represented as the long-term mean (thick black line) and the gray band spans plus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

We found that the impacts of an AMOC weakening in a preindustrial control climate are much different from the impacts of an AMOC weakening in a warmer 4xCO2 climate (fig. 2).

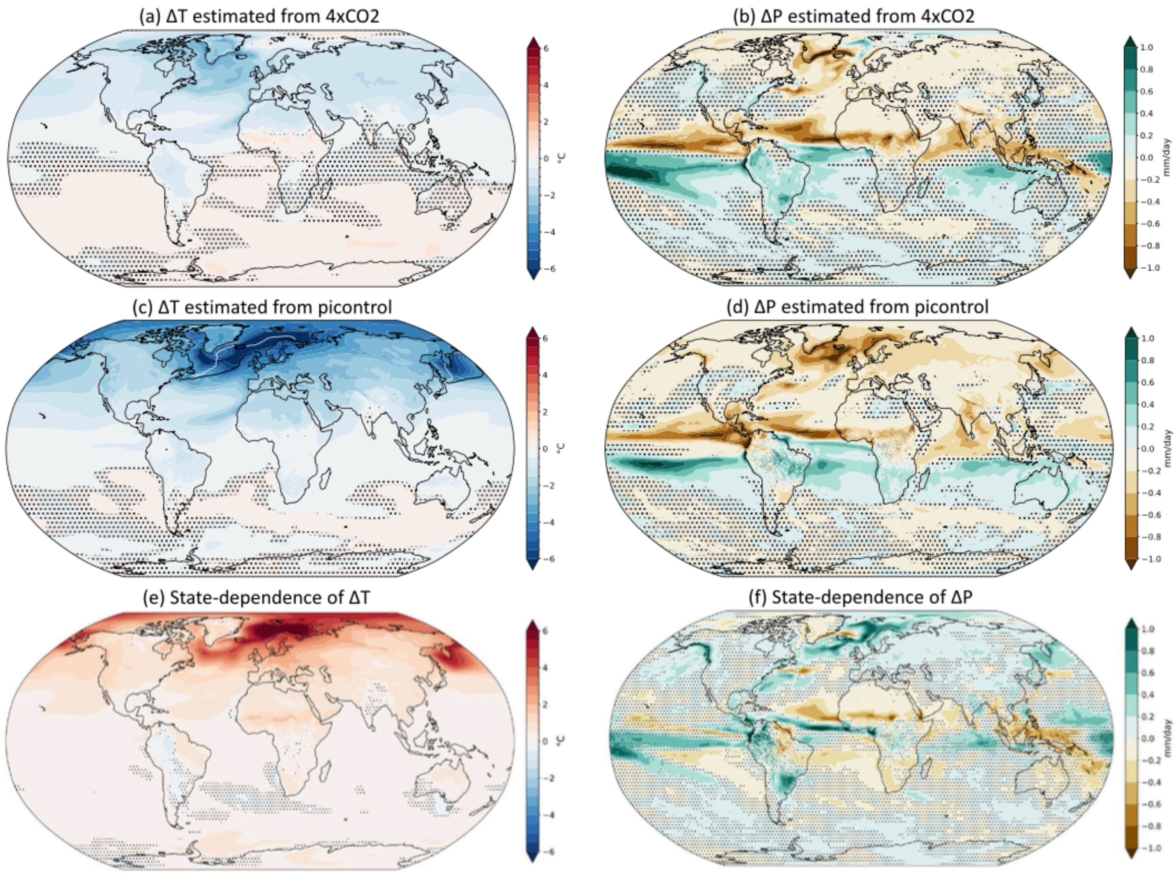

Fig. 2 (adapted from Bellomo and Mehling, 2024): Background state dependence of AMOC impacts. Left column: impact on temperature. Right column: impact on precipitation.

In our work, we demonstrated that AMOC impacts depend on the background climate state. Fig. 2 suggests that caution should be taken to quantify the impacts of AMOC decline under future climate change scenarios. Due to sea ice feedbacks (black and white lines in fig. 2c), water hosing experiments would overestimate the cooling due to a weakened AMOC in a 4×CO_2 climate. In addition, we found that water hosing experiments started from the preindustrial climate would also overestimate the drying in the Northern Hemisphere, and would not show an equatorial Pacific El Niño-like precipitation change in the EC-Earth3 model.