REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE:	Italy
Principal Investigator[1]:	Andrea Vito Vacca
Affiliation:	Politecnico di Torino & IUSS Pavia
Address:	Corso Duca degli Abruzzi 24 10129 Torino, Italy Palazzo del Broletto, Piazza della Vittoria, 15, 27100 Pavia PV
Other researchers:	Katinka Bellomo, Jost von Hardenberg, Oliver Mehling
Project Title:	Impacts of an AMOC collapse on atmospheric circulation in the Euro-Atlantic area

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** …………..	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2024	
Would you accept support for 1 year only, if necessary?	YES **X**	NO ☐

Computer resources required for project year:		**2024**	**2025**	**2026**
High Performance Computing Facility	[SBU]	72,000,000	144,000,000	-
Accumulated data storage (total archive volume)[2]	[GB]	180,000	360,000	-

EWC resources required for project year:		**2024**	**2025**	**2026**
Number of vCPUs	[#]	-	-	-
Total memory	[GB]	-	-	-
Storage	[GB]	-	-	-
Number of vGPUs[3]	[#]	-	-	-

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3] The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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Extended abstract

1. Background and motivation

The Atlantic Meridional Overturning Circulation (AMOC) is the Atlantic branch of the global thermohaline circulation, characterized by warm and salty water flowing northward in the upper layers and colder, deep waters flowing southward. Previous work based on paleoclimatic evidence and modelling studies highlight the importance of the AMOC in shaping the climate at the global scale (Bellomo et al., 2021; Clark et al., 2002; Jackson et al., 2015; Rahmstorf, 2002). In response to increased greenhouse gas concentration in the atmosphere, models robustly project a slowdown of the AMOC throughout the 21st century, although there is large uncertainty on the magnitude of this weakening (Srokosz & Bryden, 2015; Weijer et al., 2020). Moreover, there is an ongoing debate regarding the ability of models to realistically predict the abrupt collapse of the circulation, namely crossing a tipping point, with possible devastating societal impacts which, however, are still largely unknown (Liu et al., 2017; Orihuela-Pinto et al., 2022; Zhang et al., 2019). It is therefore of great interest to improve our understanding of the regional impacts of the AMOC slowdown/shutdown both from a scientific and societal standpoint.

In this project we aim to investigate atmospheric circulation changes over the Euro-Atlantic region associated with variations in the AMOC strength. Such changes are strictly connected with the occurrence of extreme weather conditions, which have significant impacts on socio-ecological systems (Fabiano et al., 2021; Faranda et al., 2023; Franzke, 2013; Horton et al., 2015).

The mechanisms governing the mid-latitudes atmospheric circulation changes with a warmer climate are the subject of a great ongoing debate. Future projections of climate change show a narrowing of the eddy-driven jet in the North Atlantic, with intensification and eastward elongation of the westerlies over Europe (Oudar et al., 2020; Peings et al., 2018). Further, the jet stream is influenced by the so called tug of war between Arctic Amplification and Upper Troposphere Warming (Barnes & Screen, 2015; Coumou et al., 2018; Fabiano et al., 2021). In this context, the role of the ocean is yet to be ruled out (Bellomo et al., 2023; Delworth et al., 2022). Previous work stressed on the importance of AMOC decline in future projections of climate change worldwide, highlighting that it is a source of enormous uncertainty especially when analysing the output of an ensemble of global climate models (Bellomo et al., 2021). In particular, our results (Vacca et al., in prep.) indicate that the AMOC decline plays a key role in the inter-model variability of future atmospheric circulation in the North Atlantic in climate model projections of the 21st archived in CMIP6.

In particular, our previous work analyzes the impacts of the inter-model spread in 21st century AMOC decline on projections of future jet stream and weather regimes. However, the relative roles of AMOC decline and greenhouse gas forcing on atmospheric circulation cannot be inferred from CMIP6 simulations. Hence, we intend to perform ad-hoc simulations with EC-Earth3 to better understand the role of AMOC in projected changes in Euro-Atlantic atmospheric circulation, disentangling the impacts associated with AMOC forcing from those related to other processes, such as increasing greenhouse gases concentration.

2. Proposed activities

2.1 Model

We plan to conduct model experiments using EC-Earth3, a cutting-edge global climate model developed by the Earth System Model (ESM) consortium that is actively participating in CMIP6 (Coupled Model Intercomparison Project Phase 6). EC-Earth3 consists of several components, including the atmospheric model ECMWF IFS cy36r4, the ocean model NEMO3.6 with the LIM3 sea ice component, the land surface scheme H-TESSEL, and the coupler OASIS3-MCT. Our proposed simulations for CMIP6 are based on the standard resolution of EC-Earth3, which utilizes a spectral truncation of TL255 with 91 vertical levels for the atmosphere, and an ORCA1 grid with 75 vertical levels for the ocean. This configuration corresponds to a horizontal resolution of approximately 80 km in the atmosphere and 100 km in the ocean, with a grid refinement to around 40 km in the tropical ocean. EC-Earth3 is already installed and used on the ATOS machine of ECMWF.

2.2 Simulations

To isolate changes in atmospheric circulation attributable to the AMOC decline, we plan to perform a series of idealized *reversed water hosing* experiments. This experimental design has proved his success in other studies, such as in (Delworth et al., 2022; Liu et al., 2020) that implemented it in different versions of a different (CESM2) global climate model.We will run the model following the CMIP6 protocol for the following ScenarioMIP and CMIP experiments: the business as usual ssp5-8.5 scenario which spans the years 2014-2100 starting from the historical experiment, and the idealized abrupt 4xCO2 experiment in which an abrupt quadrupling of CO2 is held fixed throughout the experiment which is started from the preindustrial control simulation. In these two experiments the AMOC steadily declines due to increased ocean stability caused by greenhouse gases. However, we will also add a positive salinity anomaly uniformly above 50°N over the North Atlantic and Arctic oceans that artificially strengthens deep water formation and therefore the AMOC. This way we will be able to compare experiments in which the AMOC weakens due to greenhouse gases with others in which we keep it fixed through the reversed hosing, allowing us to separate the effects of external forcings on atmospheric circulation from the effects of the AMOC decline.

The virtual salinity flux will be applied in the following terms:

$$F(t,j,i) = \frac{h(j,i)\, S_0(t,j,i)}{dz_0(j,i)}$$

where S_0 is the local salinity in the upper layer, dz_0 is the upper layer thickness, and h is the following:

$$h(j,i) = \frac{H}{\int_R dxdy}$$

The region where the reversed water hosing is implemented (specifically, the North Atlantic and the Arctic in our scenario) is denoted by the variables (j, i) belonging to the set R. For any other region, the value is 0. The salinity anomaly strength, denoted by H, is equal to 0.3 Sv (equivalent to 0.3x106 m3s-1). The variables dx and dy represent the zonal and meridional grid spacings, respectively. Consequently, we will apply a correction to the 3D salinity field in the remaining areas of the ocean, ensuring conservation of the total amount of salt. The equation below represents the quotient of the total removed flux divided by the total volume of the ocean.

$$\frac{\int h(j,i) S_0 (t,j,i) dxdy}{\int_{global} dxdydz}$$

As explained above, this experimental setup allows us to study a system in which CO2 concentration increases but AMOC is not weakened. Note that the 'canonical' (not reversed) water hosing setup has been implented already in EC-Earth3 but to address other research questions (Bellomo et al., 2023; Jackson et al., 2023).Our intention is to slightly adapt it to address our research goal. We will analyse the output data in terms of change in atmospheric circulation by comparing the results with the corresponding control simulations, in which the AMOC is weakened. In particular, we will employ metrics describing the change of the North Atlantic *storm track*, *jet stream* and *weather regimes* occurrence (Fabiano et al., 2021; Madonna et al., 2017; Shaw et al., 2016, Vacca et al. in prep.).

3. Justification of the computer resources requested

Runs on Atos HPCF have determined the most effective setup for the standard resolution of EC-Earth3 (TL255L91-ORCA1L75) requires the utilization of five nodes. These nodes consist of 490 cores for IFS, 148 cores for NEMO, one core each for the runoff mapper and the XIOS server. We estimate that employing the standard configuration of EC-Earth3 for one model year will consume approximately 20,000 SBU. Considering 6-hourly outputs for IFS and monthly outputs for NEMO, we anticipate a storage requirement of about 50 GB per model year, amounting to a total of 360 TB over the course of two years, evenly divided. To differentiate the forced signal from the internal variability of the system, each model experiment will be conducted with five ensemble members.

In summary, for the experiments performed within the project we request the following resources:

	Model configuration	**Experiments**	**Duration**	**Ensemble members**	**Total model years**
Year 1	Reversed water-hosing with 4xCO2	Control experiment	300 years	5	1500
		Reversed Water hosing and GHG	300 years	5	1500
		Extra (for testing)	100 years	1	100
				Total model years Year 1	3600
				SBU Year 1	**72,000,000**
				Storage after Year 1	**180TB**
Year 2	Reversed water-hosing with ssp5-8.5	Control experiment	300 years	5	1500

		Overshoot	300 years	5	1500
		Extra (for testing)	100 years	1	100
Total model years Year 2					3600
SBU Year 2					**72,000,000**
Storage after Year 2					**360TB**

4. References

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