<u>LATE</u> REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE: ……………………………………………………Italy…………………………………………….…

Principal Investigator[1]: …………Valerio Lembo (ccvl)…………………………………………………………

Affiliation: …………………CNR-ISAC…………………………………………………………………

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Project Title: Exploring the stability of the Atlantic Meridional Overturning Circulation in EC-Earth3-ESM simulations: a contribution to the TIPMIP-OCEAN project (EStabAMOS)...............................

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.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2025**	**2026**	**2027**
High Performance Computing Facility	[SBU]	0	34000000	34000000
Accumulated data storage (total archive volume)[2]	[GB]	0	40	80

EWC resources required for project year:		**2025**	**2026**	**2027**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

[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

Motivation

Abrupt climate changes and tipping points represent critical thresholds within the Earth's climate system, where small perturbations can trigger significant, often irreversible shifts in the climate state. Shifts as such have been theorized with analytical and statistical methods, predicted with models of different complexity, and also recorded in paleoclimatic records. Elucidating mechanisms connected with such abrupt changes is imperative for Earth System Models (ESMs) to accurately predict future climate change, including both external forcing and anthropogenic influences, and assess the resilience of human societies to abrupt transitions towards new climate states. While tipping points have been extensively studied in systems with constant or periodic forcing, analyzing paleoclimate and future climate scenarios involves the inclusion of a time-dependent forcing, that challenges our detection of the forced response as distinct from the internal variability of the system, which is in turn subject to the forcing in a presumably unknown way.

Model simulations in idealized settings have therefore attracted increasing attention, since they offer possibilities regarding the inference of mechanisms leading to critical transitions that are otherwise potentially hidden behind the interactions between a complex realistic forcing and the multi-scale internal variability of the system. Particularly suitable idealized settings are those involving linearly increasing forcings (hereafter "ramp-up or -down" experiments), abrupt changes and long stabilization runs.

The Tipping Points Intercomparison Project (TIPMIP; Winkelmann et al. 2025) is an international community-wide effort aimed at improving our understanding of critical tipping points through the lens of idealized and overshoot scenarios (i.e. scenarios in which a given climatic threshold, such as 1.5 or 2 degrees global warming level, namely GWL, is exceeded for a finite amount of time). The Project is an officially registered Model Intercomparison Project (MIP), and consists of several components, involving key domains of the climate system, such as ice sheets (TIPMIP-ICESHEET), permafrost (TIPMIP-PERMAFROST), oceans (TIPMIP-OCEAN) and biosphere (TIPMIP-BIOSPHERE). The scientific value of these experiments resides particularly in the opportunity to investigate overshoot runs, that have practical relevance to assess the implication of crossing the thresholds set during the Paris COP in 2015.

A particularly challenging endeavor is addressing the complex feedbacks and cascading effects (cfr. Wunderling et al. 2024; Meccia et al. 2025) related to the stability of the Atlantic Meridional Overturning Circulation (AMOC). Recent research raises concern that the AMOC, in particular, might be nearing or has already surpassed a tipping point (Ditlevesen and Ditlevesen, 2023; van Westen et al. 2024), also pointing out that the potential collapse of the AMOC might result from interaction between non-linear growth of perturbations due to internal variability (Cini et al. 2025). In this particular respect, the TIPMIP-OCEAN activity aims at addressing the response of AMOC to an idealized injection of freshwater (hereafter "hosing") inside given regions of the North Atlantic, reflecting the changes in salinity related to Arctic sea-ice and Greenland ice-sheet melting.With the aim of participating to TIPMIP-OCEAN, the community gathered by the EC-Earth modeling consortium has put decisive effort into the improvement of the third generation of the EC-Earth model (EC-Earth 3) after the Coupled Model Intercomparison Project, phase 6 (CMIP6) exercise included in the latest Assessment Report of the Intergovernmental Panel for Climate Change (IPCC). Improvements included, most notably, the addition of an interactive ice sheet model for Greenland, a meltwater emulator for Antarctica based on linear response functions, and, specifically for the ESM configuration, the CO2 box module, allowing for emission-driven simulations. That being said, a high priority has been set for the evaluation of model performances with the idealized freshwater scenarios defined in the TIPMIP-OCEAN protocol, exploiting the advantage of the recent improvements. Not secondarily, the consortium has framed these efforts under the umbrella of several large HEU-funded projects, such as OPTIMESM, TIPESM, LIQUIDICE, and in the context of other relevant intercomparison projects, e.g. SOFIAMIP, regarding freshwater hosing around the Antarctic continent.

EC-Earth3-ESM1

The consortium has been developing a modular ESM for over a decade (see Hazeleger et al. 2012 for a historical perspective). In its current version, an update of EC-Earth3 with the inclusion of new capabilities (i.e. EC-Earth v 3.3), the *model exists in different coupled configurations. Besides a pure physical core and a configuration in the form of a global climate model (GCM), the model is able to accommodate prescribed or interactively coupled dynamic vegetation, a dynamical Greenland Ice Sheet, and a closed carbon cycle (Figure 1). Also, a configuration with interactive aerosols and atmospheric chemistry is available, and GCM configurations have been established in different resolutions for the atmosphere and ocean.*

The atmosphere and land domains are currently covered by ECMWF's IFS cycle 36r4, the ocean is based on NEMO v3.6, whereas dynamic vegetation, land-use change and terrestrial biogeochemistry are covered by LPJ-Guess module (Nord et al. 2021). Aerosols and chemical processes in the atmosphere are described by TM5 (van Noije et al., 2014) and can be optionally turned on. The ice sheet model PISM (cfr. Madsen et al. 2022) is utilized to model the Greenland Ice Sheet (GrIS). Biogeochemical processes in the ocean are simulated by the PISCES model (Aumont et al. 2015).

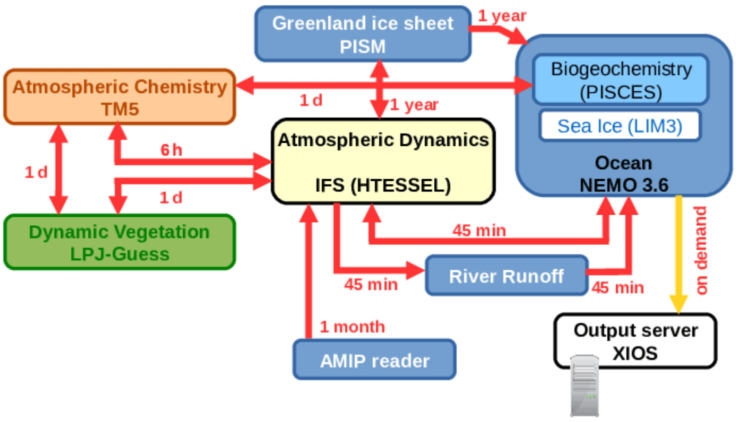

Figure 1: *EC-Earth3 model configuration (from Döscher et al. 2022). This scheme is not including the CO2 box model later introduced to account for the carbon cycle and replacing TM5 for the the EC-Earth3-ESM1 configuration.*

In the context of this project, the EC-Earth3-ESM1 configuration is put in place, featuring a CO2 box module to model the carbon cycle and allows for emission-driven scenarios, susbstituting the TM5 module. tripolar grid with a nominal 1 degree horizontal resolution and 1/3 refinement around the Tropics, coming with 75 vertical levels. The coupling frequency between the different components of the model are shown in Figure 1.

The freshwater forcing is applied in terms of either a virtual salinity flux applied between the surface and a depth of 50m around Greenland for experiments A1 and A2 (see below) or as a virtual constant salinity flux in the North Atlantic and Arctic oceans with volume compensation (see Jackson et al. 2023) for experiments C1 and C2.

Experimental design

The group is committed to run TIPMIP-OCEAN simulations following the latest available version of the experimental protocol (Swingedouw et al. 2025). A full set of Tier 1 and Tier 2 simulations for experiment A and C is planned. Details of the experimental protocol will be provided in a companion paper, that will be available in the course of 2026.

For experiment A1, a first leg (A1a) consisting of a ramp-up experiment with increasing CO2 emissions, calibrated to provide a 0.2 °C warming per decade, is carried out. Concomitantly, a ramp-up increase in freshwater hosing is applied in the region surrounding Greenland, as represented by panel c in Figure 2. The rate of freshwater is such that a 0.3 Sverdrup (Sv) increase in freshwater is reached on a time span of about 100 years, with the exact timing determined by the time a 30-years averaged 2°C GWL is reached in similar ramp-up simulations without hosing. This estimate is retrieved from simulations that have already contributed to the TIPMIP-ESM intercomparison (Jones et al. 2025) with the same version of the model. Thereafter, CO2 emissions are turned off for 50 years (A1b) so as to keep the GWL approximately stable, before starting a ramp-down experiment with linearly negative CO2 emissions and freshwater decrease (A1c), whose length is estimated similarly as to what done for the ramp-up leg. Finally, a stabilization leg (A1d) without hosing is performed for 100 years. Experiment A2 is branched off experiment A1 at year 150 and features a constant hosing at 0.3 Sv for additional 200 years. This is required in order to investigate the memory of the ramp-up in freshwater at timescales longer than the 50 years between A1a and A1c. A schematic representation of the time modulation of the GWL reflecting the ramp-up and -down emissions, and of the freshwater hosing, are displayed in Figures 2a and b from TIPMIP-OCEAN available protocol at the time of the SP request submission (Jackson et al. 2025).

For experiment C1, two legs are required. The first one (C1a) consists of a constant anomaly in freshwater hosing applied over a large mask comprising the Arctic ocean and parts of the North Atlantic, as displayed in Figure 2e. The anomaly amounts to 0.3 Sv, applied constantly for at least 50 years on top of an unperturbed pre-industrial (piControl) scenario. The freshwater anomaly is suddenly removed at year 50, and the model is run for additional 100 years. Tier 2 experiment (C2) is similar to C1, but instead of a piControl baseline, the freshwater hosing is applied to a stabilized 2°C GWL scenario. The time modulation of the freshwater forcing is displayed in Figure 2d.

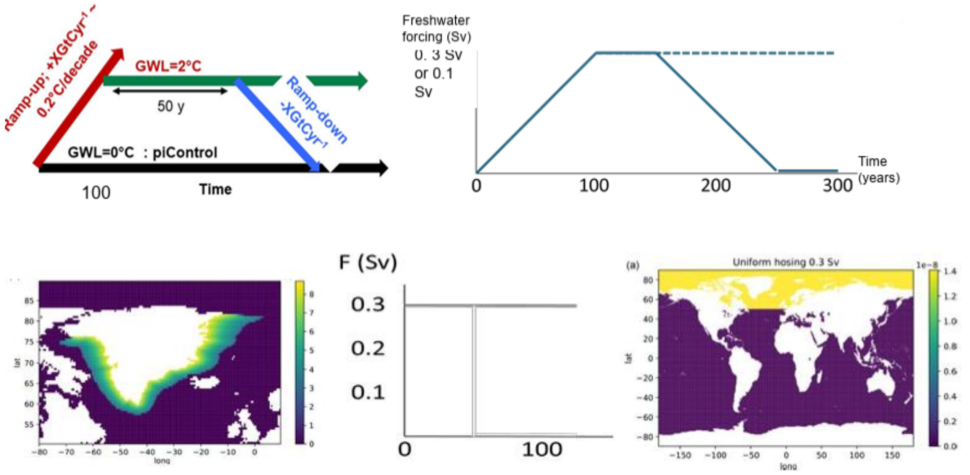

Figure 2: *time modulation of a) CO2 emissions for experiments A1 and A2, b) freshwater hosing for experiments A1 and A2, d) freshwater hosing for experiments C1 and C2 (they are the same, the two experiments differ in the background warming level, in one case pre-industrial, in the other case GWL2). Masks denoting where the hosing is applies in c) experiments A1 and A2, e) experiments C1 and C2. Adapted from Jackson et al. 2025*

Computational resources required for the experiment

EC-Earth3-ESM1 has been widely tested on ATOS machine in the context of the aforementioned projects, therefore we do not expect unforeseen configuration issues.hat the optimal configuration of nodes and cores would ensure a smooth and successful process along the production of the runs. According to test performed by partners of the EC-Earth consortium on the ATOS machine, this optimal configuration consists of 1173 cores on 10 computational nodes. At the mentioned T255L91-ORCA1L75 resolution, the model runs with 40000 SBU per year.

The required computational resources are therefore summarized per each experiment in Table 1. A total of 40'000'000 SBU is required, with a storage necessity of 50 TB (0.05 TB per year).

Experiment Name	***Notes***	***Total Years***	***Total SBU***	***Total Storage***
A1 a)	*An additional non-hosed ramp-down leg is required to know the exact number of* b) *years required in TIPMIP-ESM to reach 0°C GWL (about 100 years)*	*450 years*	*18000000*	
A2		*150 years*	*6000000*	
c) *C1*	*We* d) *do expect to run C1b (and C2b) for more than 50 years, in order to investigate long-term feedbacks (at least 150 years)*	*200 years* e)	*8000000*	
C2		*200 years*	*8000000*	

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