EMI R&D 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
……2026…….……

Project Title:
…Exploring the Stability of the Atlantic Meridional Overturning circulation in EC-Earth3-ESM Simulations: a contribution to the TIPMIP-OCEAN project (EStabAMOS)
……..……

Computer Project Account:
……sptilem2…….……

Principal Investigator(s):
…Valerio Lembo (ccvl)……..……

Affiliation:
CNR-ISAC……..……

Name of ECMWF scientist(s) collaborating to the project
(if applicable)
Alessio Bellucci (itab), Marco Buccellato (itmb), Matteo Cini (ita9727), Susanna Corti (mcb), Federico Fabiano (ccff), Virna Meccia (ccvm), Irene Trombini (ita4210)

Start date of the project:
…01/01/2026…….……

Expected end date:
…31/12/2026……

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)			40000000	34164334
Data storage capacity	(Gbytes)			40000	23569

Summary of project objectives (10 lines max)

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). In this context, 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. The EC-Earth modeling consortium has developed an improved version of the EC-Earth3 model, that is used in Earth System Model (ESM) configuration, that is hereby used to carry out part of the experiments envisaged within the TIPMIP-OCEAN protocol.

Summary of problems encountered (10 lines max)

The workflow to carry out EC-Earth-ESM-1 simulations had been previously designed on purpose for usage on ATOS machines (among other HPC options). Therefore, we found no difficulties in setting up the correct working environment. Some tests were carried out to find the most efficient distribution of nodes and cores across the different model's submodules. We focused on producing one run with TIPMIP-OCEAN's experiment A protocol (330 years). Some issues were found on the way the protocol was requesting the freshwater forcing to be included in the model. This led us to two iterations of the 330 years of simulations (about 14500000 SBU each): at first, the freshwater forcing was incorrectly accounted for twice, as water mass and virtual salinity flux, secondly, the depth of the freshwater forcing had to be changed in order to be applied only at the first vertical level of the NEMO ocean model.

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

The main set of simulations that the EC-Earth consortium has committed to provide for the TIPMIP-OCEAN Model Intercomparison is now completed. The next task will be producing a CF-compliant CMORized output for publication on the TIPMIP-dedicated ESGF node, currently maintained at DKRZ. Furthermore, we plan to carry out additional experiments with variants (either Tier 2 or phase 2 TIPMIP-OCEAN experiments) of the runs already produced. In particular, we plan to produce the Tier 2 Experiment A, with maximum 0.1 Sv freshwater forcing, and variants of the Experiment C with forcing larger than 0.3 Sv. Additionally, we are planning to use diagnostics to analyse key features of the climate system along the trajectory of the forcing. These analyses will be part of a EC-Earth-focused analysis paper led by Marion Devilliers (DMI) and a Multimodel Analysis paper led by Aixue Hu (NCAR).

List of publications/reports from the project with complete references

Swingedouw, D., Jackson, L., Hu, A., Romanou, A., Laureanti, N. C., Weijer, W., Loriani, S., Otto-Bliesner, B., Abe-Ouchi, A., Almeida, L., Bellucci, A., Börner, R., Danabasoglu, G., Dennis, D. P., Devilliers, M., Drijfhout, S., Donges, J., Fröb, F., Frölicher, T. L., Gastineau, G., Goelzer, H., Guo, C., Hofmann, U., Höse, A., Jones, C., Koenigk, T., Klose, A. K., Lembo, V., Licon-Salaiz, J., Mankoff, K., Meccia, V., Melnikova, I., Mehling, O., Menviel, L., Mignot, J., Robson, J. I., Schmidt, G. A., Smith, R., Sun, Y., Trombini, I., Willeit, M., Wood, R., Wu, F., Zhaohui, L., and Winkelmann, R.: TIPMIP-OCEAN experimental protocol phase 1: Tipping dynamics of the AMOC, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2026-1698, 2026

Summary of results

The project mainly focused on producing the official TIPMIP-OCEAN's run r3i1p1f1 with ECE-ESM1-2 model for experiment A. The protocol for experiment A is summarized as follows:

1. A CO_2 ramp-up branches from a pre-industrial simulation and runs for approximately 100 years at +X GtC/yr, using the same emission rate X as the TIPMIP-ESM protocol (Jones et al., 2026). The novelty here is the addition of a prescribed freshwater flux that increases

from 0 Sv in year 1 to +0.3 Sv by year ~100, or more precisely the same year at which the global warming stabilisation run begins in TIPMIP-ESM.

2. A zero-emission run branches off phase (1) when GMSAT reaches 2 °C in TIPMIP-ESM. It starts at then end of phase 1, retaining the maximum (0.3 Sv) freshwater flux, and runs for 250 years with stable CO2 concentrations.
3. After 50 years of phase 2, a third branch starts with negative emissions set to −X GtC/yr negative slope towards pre-industrial conditions, with the length of the slope corresponding to the length of the ramp-down in the corresponding non-hosed TIPMIP-ESM run; analogously, the freshwater forcing is set to linearly decrease from 0.3 Sv to 0 Sv over the same period.
4. At the end of phase 3, both emissions and the freshwater flux are set to zero, and the run is extended for 100 years under external forcings equivalent to a preindustrial run.

The outputs of the run are still being analysed, together with other companion runs produced elsewhere on other HPC facilities. However, preliminary considerations suggest that in EC-Earth-ESM-1 the freshwater forcing has a role for the response of the Atlantic Meridional Overturning Circulation (AMOC). The comparison of non-hosed TIPMIP-ESM and a couple of hosed TIPMIP-OCEAN runs (see Figure 1) suggests that the minimum AMOC value achieved at the start of the ramp-down phase (phase 3) is considerably lower than in the non-hosed case. It is also worth noticing, but this is still under consideration, that AMOC recovers to a significantly lower value than the preindustrial value, suggesting a possible hysteresis.

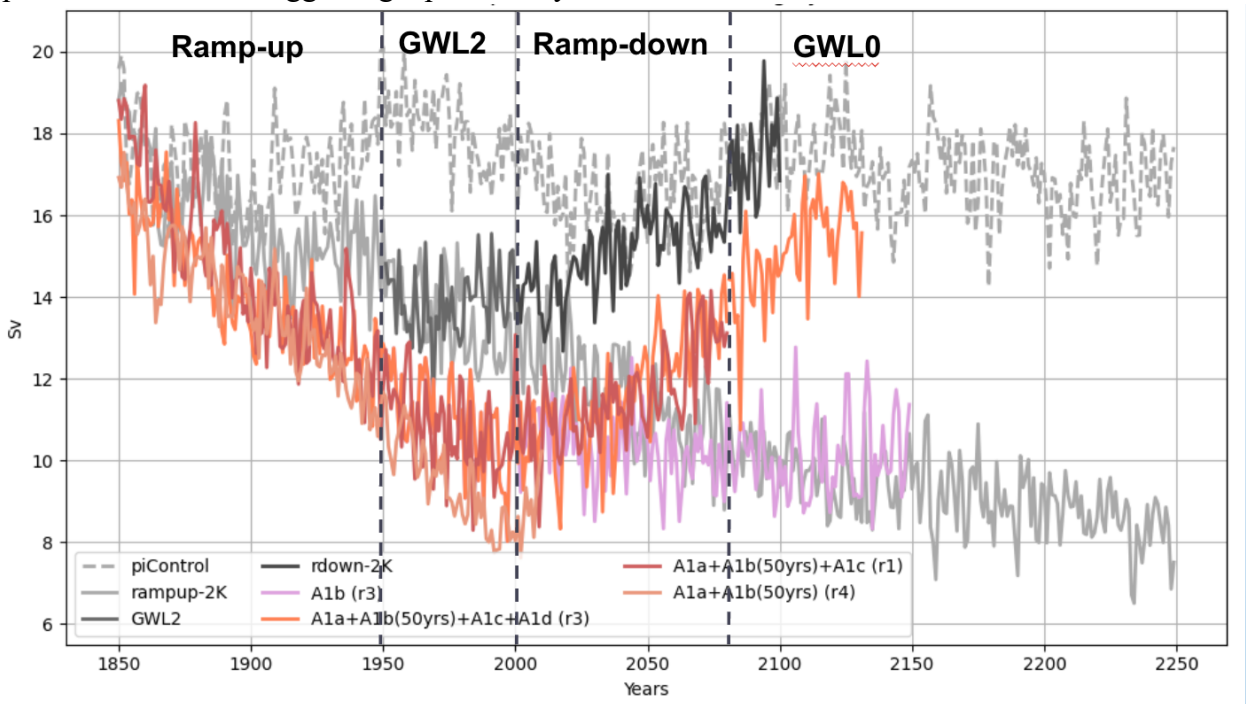

Figure 1: Time evolution of yearly mean AMOC for different EC-Earth-ESM-1 runs forced with experiment A protocol from TIPMIP-OCEAN (r1, r3, r4), compared to preindustrial AMOC evolution (grey, dashed) and non-hosed TIPMIP-ESM corresponding run (rampup-2K, GWL2, rdown-2K). Extension of phase 2 for run 3 (r3) is also shown (A1b, pink).