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	2025
Project Title:	Sampling AMOC tipping events with a rare event algorithm with a low resolution version of state of the art model
Computer Project Account:	spitcini
Principal Investigator(s):	Matteo Cini
Affiliation:	Università degli Studi di Torino, ISAC-CNR
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Giuseppe Zappa (ISAC-CNR), Susanna Corti (ISAC-CNR), Francesco Ragone (University of Leicester).
Start date of the project:	1/01/2025
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)			**23.500.000**	**2.522.254**
Data storage capacity	(Gbytes)			55,000	1.801

Summary of project objectives (10 lines max)

This study investigates the Atlantic Meridional Overturning Circulation (AMOC) collapse in large ensemble simulations using an intermediate complexity climate model (PlaSIM coupled to LSG, T21). Indeed, growing evidences suggest that the probabilistic approach is the best framework to define a safe-operating space for the AMOC tipping (Mehling et al. 2023, Romanou et al., 2023) . Given the high computational costs of performing large ensemble simulations to estimate an accurate probability, we apply here rare-event techniques to sample efficiently those events and obtain an improved accuracy in the estimate.

Summary of problems encountered (10 lines max)

The primary technical challenge arises from managing the large number of output files produced by the climate model during ensemble simulations. Despite the relatively modest total data size (hundreds of GB), the scratch filesystem's file-count limits are quickly exceeded. This poses difficulties for storing and archiving results during parallel simulations, even when disk space is technically sufficient.

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

So far we have successfully performed simulations of 256 trajectories with the Trajectory-Adaptive Multilevel Splitting (TAMS) algorithm (see Summary of results). We are currently deciding whether to continue applying the methodology on the same model to improve statistical accuracy estimates and to extract physical insights from this model, or to move already to a more complex climate models

List of publications/reports from the project with complete references

A paper is already at the internal review phase, will be submitted soon.

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

Thanks to the computational resources provided, we successfully applied the Trajectory-Adaptive Multilevel Splitting (TAMS) algorithm to several large ensemble simulations (256 members) using the intermediate-complexity climate model PlaSIM-LSG. The TAMS algorithm works by iteratively eliminating the worst performing trajectories (based on the AMOC index) and resampling them from ones with lower AMOC index. This process biases the ensemble toward lower AMOC states, potentially reaching a collapse. Once the TAMS converges—i.e., all trajectories reach a predefined AMOC threshold—the algorithm yields an estimate of the probability of reaching such a threshold in an unbiased simulation.

We conducted two main types of simulations:

1. Equilibrium simulations at constant CO_2 concentrations (500 ppm and 600 ppm) over 150 years. These simulations indicate that the probability of an AMOC collapse is significantly different from zero over the 150-year period, depending on the CO_2 level.
2. Scenario-based simulations following SSP emission trajectories up to the year 2200. Results suggest that while an AMOC collapse is unlikely within the 21st century, it becomes increasingly probable by 2150 under high-emission scenarios.

It is important to note that PlaSIM-LSG does not include the freshwater flux from Greenland meltwater, which tends to stabilize the AMOC-on state. Including this effect would likely increase the estimated collapse probabilities. Overall, these findings emphasize the value of probabilistic approaches and rare-event sampling algorithms for assessing the stability of the AMOC and understanding its tipping dynamics.

References

Mehling, O., Börner, R., & Lucarini, V. (2023). Limits to predictability of the asymptotic state of the Atlantic Meridional Overturning Circulation in a conceptual climate model. *Physica D: Nonlinear Phenomena*, *459*, 134043. https://doi.org/10.1016/j.physd.2023.134043

Romanou, A., Rind, D., Jonas, J., Miller, R., Kelley, M., Russell, G., Orbe, C., Nazarenko, L., Latto, R., & Schmidt, G. A. (2023). Stochastic Bifurcation of the North Atlantic Circulation under a Midrange Future Climate Scenario with the NASA-GISS ModelE. *Journal of Climate*, *36*(18), 6141–6161. https://doi.org/10.1175/JCLI-D-22-0536.1