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:

Tipping points of the Antarctic Ice Sheet in EC-Earth-PISM

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Computer Project Account:

spittrom

Principal Investigator(s):

Irene Trombini

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Affiliation:

University of Bologna

National Research Council, Institute of Atmospheric Sciences and Climate (CNR-ISAC)

Name of ECMWF scientist(s) collaborating to the project
(if applicable)

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Start date of the project:

……01.01.2024……

Expected end date:

……31.12.2026……

Computer resources allocated/used for the current year and the previous one
(if applicable)

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	21’500’000	20’667’642	23’100’000	1’163’157
Data storage capacity	(Gbytes)	32.250 GB	32.000 GB	105.750 GB	44.3 GB

Summary of project objectives (10 lines max)

The project aimed to investigate the tipping behavior of the West Antarctic Ice Sheet (WAIS) and East Antarctic Ice Sheet (EAIS), focusing on temperature thresholds and the potential for temporary overshoots without irreversible ice loss. It also sought to examine whether meltwater from Antarctic ice loss could trigger abrupt changes in the Antarctic Overturning Current, the Antarctic Circumpolar Current, and the Atlantic Meridional Overturning Circulation (AMOC), potentially leading to tipping cascades. Over time, the focus of the project shifted toward the latter goal and was reformulated to concentrate on experiments with prescribed hosing in the Southern Ocean. This shift allowed for a more detailed investigation of the impact of meltwater on the Southern Hemisphere climate and made use of an already existent model version. This work is conducted within the SOFIAMIP initiative, as detailed in the Summary of Results.

Summary of problems encountered (10 lines max)

- Availability of a working version of EC-Earth-FAST: As it is not yet available, the project was reformulated accordingly (see below).
- Definition of the protocol for SOFIAMIP experiments in EC-Earth3, especially concerning the handling of climatological runoff.
- Sharing and availability of initial conditions and freshwater forcing files for historical experiments (SOFIAMIP, Tier 2) experienced delays.
- Analysis: Direct downloading of CMIP6 data from ESGF nodes to ATOS is not possible, requiring local or alternative server downloads before uploading to ATOS, slowing the process.
- Cmorization: I installed on atos the latest version of the cmorizing tool ece2cmor3, but I then found out that was incompatible with the EC-Earth3 version used for SOFIAMIP experiments (r9409); therefore, I downgraded to a compatible earlier version and had to fix a number of problems arising from this downgrade.
- Difficulties in data sharing with other institutes contributing to SOFIAMIP.

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

Plans for continuing the project include completing the SOFIAMIP experiments and analyzing Tier 2 and Tier 3 simulations. Additionally, the hosing code will be ported to EC-Earth4, with the potential to run a subset of Southern Ocean hosing simulations. Since EC-Earth4 coupled with the Antarctic Ice Sheet model is still under development, these initial simulations will offer early insights into how the new model version responds to freshwater forcing.

List of publications/reports from the project with complete references

- Presentation of abstract at the upcoming Annual meeting of the European Meteorological Society (September 2025): *Impacts of Antarctic Meltwater under combined greenhouse and prescribed freshwaterforcing in EC-Earth3*, doi: https://doi.org/10.5194/ems2025-623

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.

In the first six months of the project (January to June 2024), I focused on familiarizing myself with the SPEEDY-NEMO and EC-Earth4 climate models, which I installed and configured on the machine, along with the script used to run EC-Earth in a coupled configuration with PISM. Christian Rodehacke from the Danish Meteorological Institute (DMI) kindly provided this script together with guidance on its use.

To gain experience with PISM, I installed and ran small standalone experiments for Antarctica, relying on a shared spin-up and guidance from Christian Rodehacke. However, after the EC-Earth community decided not to invest further in coupling PISM with EC-Earth3 for Antarctica—prioritizing its implementation in EC-Earth4, which is currently under development—I paused this activity. This decision was motivated by EC-Earth4's reduced warm bias in the Southern Ocean, which is highly relevant for my intended analysis. Consequently, I shifted my focus toward simpler EC-Earth3 simulations for the time being, also taking advantage of an existing and working model version.

I performed these simulations with prescribed hosing in the Southern Ocean, following the protocol defined in Swart et al. (2023) (https://doi.org/10.5194/gmd-16-7289-2023). Specifically, I used a modified CMIP6 version of the EC-Earth3 code developed by André Jueling (formerly at KNMI; documentation at https://github.com/AJueling/ECE3-FWF-workflow/blob/main/documentation/ECE3-FWF_workflow.md).
This version includes updates to the NEMO ocean module and a new subroutine, sbcfwf.F90, enabling freshwater input as surface runoff and optionally accounting for the latent heat of melting—an approximation for calving. The code also contains the isf.F90 ice shelf module (Mathiot et al., 2017), which I have not yet tested but is essential for some Tier 3 SOFIAMIP experiments.

A key objective of the project after this shift was to analyze the Tier 1 experiments previously completed by André Jueling but not fully analyzed. I focused my analysis on the response of Southern Hemisphere ocean circulation—such as the Antarctic Circumpolar Current and Weddell Gyre—to surface freshwater forcing. Additionally, I examined impacts on deep water formation and compared my results with those from other climate models. I conducted this analysis using Python notebooks on the Atos machine. Besides analyzing data, I managed data handling and took responsibility for sharing simulation outputs with the SOFIAMIP community.

In parallel, I ran Tier 2 simulations (hist-antwater-70-01, -03, -05, -92-11), along with the ssp585-ismip6-water and ssp126-ismip6-water scenarios, plus one Tier 3 simulation (antwater-lh). The historical simulations span 50 years, except for the shorter hist-antwater-92-11 (28 years), while the SSP scenario simulations cover 75 years. For detailed boundary conditions and hosing specifications, see Swart et al. (2023). I saved data at monthly resolution following the CMIP6 data request for monthly fields.

I restarted the historical runs from the CMIP6 EC-Earth3 run r4i1p1f1 provided by Paolo Davini, while SSP scenarios used standard initial conditions from the shared ece3data folder. I created ensemble members by perturbing atmospheric fields and, for the hist-antwater subset of simulations, by branching off from different years of the historical run. Since the reference historical run was executed on a different machine, this introduced some variability.

Several challenges emerged during the project, including some delays in finding initial conditions for 1970, identifying an error in a forcing file for one SSP585 simulation, and deciding on the best approach to combine climatological runoff with prescribed hosing. Due to delays in model setup and issues with the cmorization (see description in section above), only limited tests could be conducted before launching ensemble runs. For some simulations, it was later determined that a different runoff map would have been more appropriate. As a result, certain simulations will need to be repeated during the current year of the project.

In the second year, I set up Barakuda as a monitoring tool for the NEMO ocean component. This system automates diagnostics and provides near-real-time checks on simulation output, enabling closer oversight. I also performed further test runs to refine the runoff configuration. One properly configured Tier 2 simulation has been completed and cmorized. I plan to complete the remaining simulations scheduled for repetition by September 2025.

Separately from SOFIAMIP, I continued tracking EC-Earth community developments, focusing on EC-Earth4 and land-ice components. To stay current, I routinely pulled updates from the EC-Earth4 codebase and ran basic test simulations. I successfully compiled and executed the main EC-Earth4 version on the land-ice fork available at: https://git.smhi.se/dorothee.vallot/ecearth4.git.