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	2025
Project Title:	HICE - Exploring the potential of high-resolution in climate-ice sheet coupling
Computer Project Account:	spitfabi
Principal Investigator(s):	Federico Fabiano (ccff) Paolo Davini (ccpd), Valerio Lembo, Virna Meccia (ccvm), Susanna Corti, Christian Rodehacke
Affiliation:	CNR-ISAC
Name of ECMWF scientist(s) collaborating to the project (if applicable)	…… ……
Start date of the project:	01/01/2025
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)	13 000 000	7 280 000	25 000 000	1 044 000
Data storage capacity	(Gbytes)	2 500	~2 000	20 000	~3 000

Summary of project objectives (10 lines max)

The final objective of the project is to perform a historical and near-future climate simulation with the EC-Earth4 Earth System Model, including land-ice components over Greenland and Antarctica. Intermediate goals include the testing and tuning of the land-ice component to achieve a realistic representation of the inter-component feedbacks.

Summary of problems encountered (10 lines max)

The EC-Earth4 model version to be used for CMIP7 is still under development and some delay was encountered in that respect, which has partially affected the original timeline of the project. Most of the work performed so far has been dedicated to the testing of the coupled model, with a focus on the high latitudes.

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

The development of the CMIP7 version of EC-Earth4 is close to completion. About 2 months are needed to obtain the final tuning of the ESM version. After that, we expect to run the main simulation in the autumn, in October and November.

List of publications/reports from the project with complete references

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Summary of results

The work performed so far on the HPC was aimed at testing and tuning the EC-Earth4 coupled global General Circulation Model (GCM) with a focus on the ice sheet integration for the development of the ESM version of the model. The primary objective is to couple the PISM ice sheet model with EC-Earth4's main components (OpenIFS cy48 for the atmosphere and NEMO for the ocean) to enable dynamic modeling of Greenland and Antarctic ice sheets, including Antarctic ice shelf representation through the PICO submodule.

Model Development Status

The PISM ice sheet model has been successfully implemented as the 'ismm' component within EC-Earth4 and has been technically validated for both Greenland and Antarctic configurations. However, before the production runs can start, some time is needed to perform the tuning and spinup of the ice sheet component (particularly challenging for Antarctica), across multiple model resolutions (ULR, SR, HR configurations).

Testing and Tuning Activities

Work is underway on the ECMWF HPC2020 platform to test and tune the various model configurations. We report the current model status in Table 1, with a summary of the current status of the development and tuning.

Configuration	Resolution	Status	Notes
EC-Earth4-FAST (ULR)	TL63-ORCA2	Tuning ongoing	warm bias overall
EC-Earth4 (SR)	TL255-eORCA1	Tuning ongoing	general climate ok, warm SO bias, cold NA bias
EC-Earth4-HR	TL399-ORCA025	Development	untuned

Table 1. Current status of the development of the three EC-Earth4 configurations.

Tuning activities have been conducted across EC-Earth4 versions from v4.1.0 through v4.1.7 in both atmosphere-only and coupled atmosphere-ocean configurations (ice sheet coupling not yet integrated in tested versions).
In the following we focus specifically on the SR version, especially targeting the polar regions and sea-ice diagnostics relevant to Ice Sheet modeling. Indeed, to ensure a proper coupling of the Ice Sheet components the biases in the polar regions have to be reduced as much as possible.

Present-Day Climate Tuning (Standard Resolution)

We briefly summarize here the current state of the tuning for the standard resolution in present-day. The 2 metre temperature map and the sea-ice diagnostics have been performed through AQUA (https://aqua-diagnostics.readthedocs.io/en/latest/introduction.html).

The new tuned experiment (Figure 1) shows promising improvements:
- The global cold bias observed in previous versions is reduced but persists at approximately 0.5 K below observations;
- Energy imbalance remains near zero;
- Southern Ocean bias is strongly reduced, though regional SST remains approximately 2 K warmer than observations;

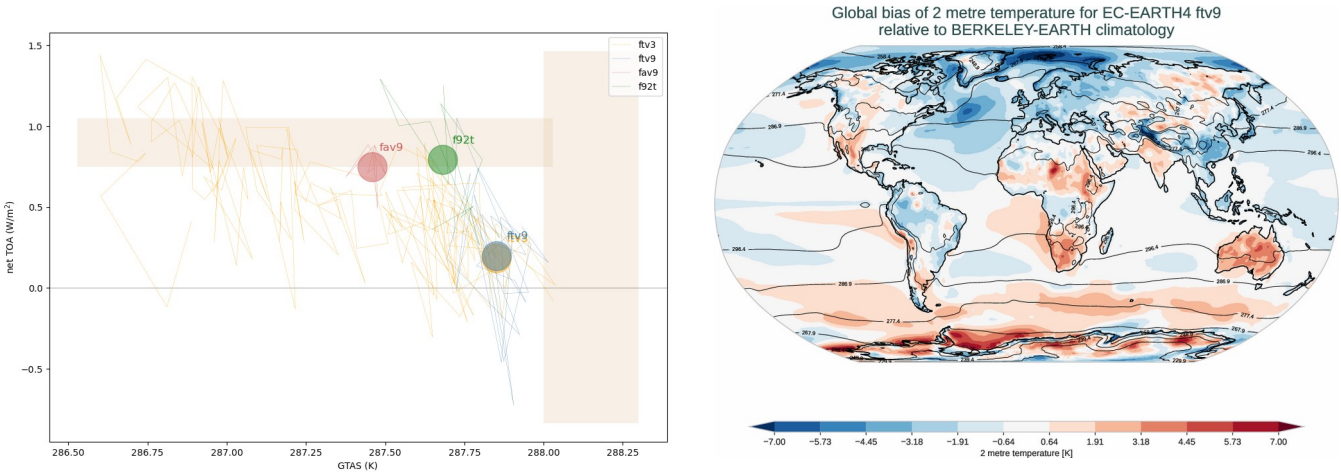

Figure 1. Left panel: gregory plot showing the status of the coupled tuning (SR, v 4.1.5); the best tuned run is ftv9, which however still shows a 0.5 K cold bias and a 0.6 W/m2 bias in net TOA. Right panel: spatial bias, showing the cold North-Atlantic and the warm Southern Ocean biases.

Regarding the sea-ice diagnostics (shown in Figure 2 below):
- Arctic Sea Ice: areal extent within acceptable range; however, ice volume is excessive, likely linked to the persistent global cold bias and requiring further investigation;

- Antarctic Sea Ice: extent is too low relative to observations, likely associated with regional SST biases and potentially ice/snow albedo; this underestimation has implications for ice sheet-ocean coupling, particularly for ice shelf stability.

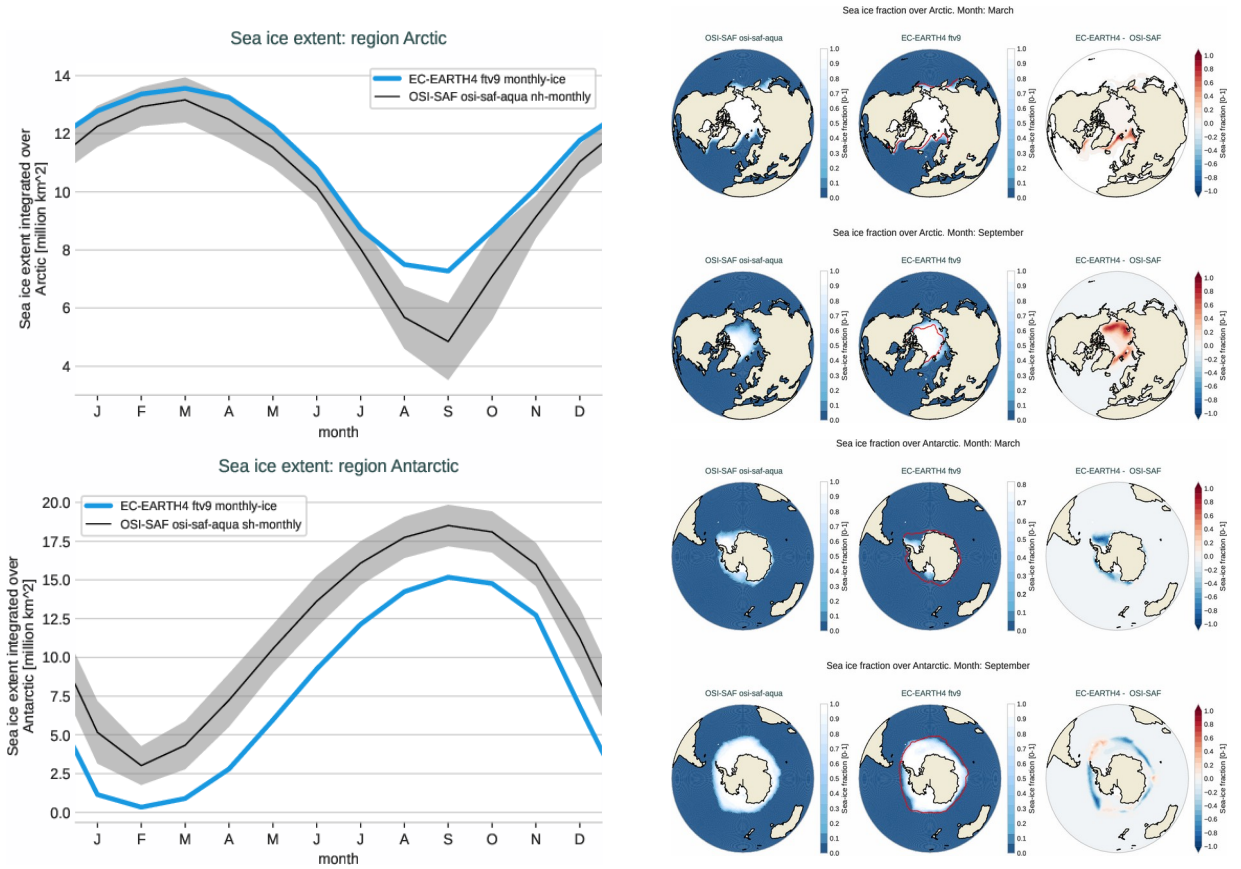

Figure 2. Left panel: sea-ice extent in present-day for Arctic (top) and Antarctic (bottom). Right panels: spatial maps of observed (left), simulated (centre) and bias (right) for summer (top) and winter (bottom) sea-ice concentration.

Pre-Industrial Climate (Figure 3)

- AMOC strength: slightly weak;
- Arctic sea-ice volume: excessive (consistent with present-day bias)
- Antarctic sea-ice extent: reasonable, though with delayed seasonality, suggesting timing issues in the ice thermodynamic cycle;

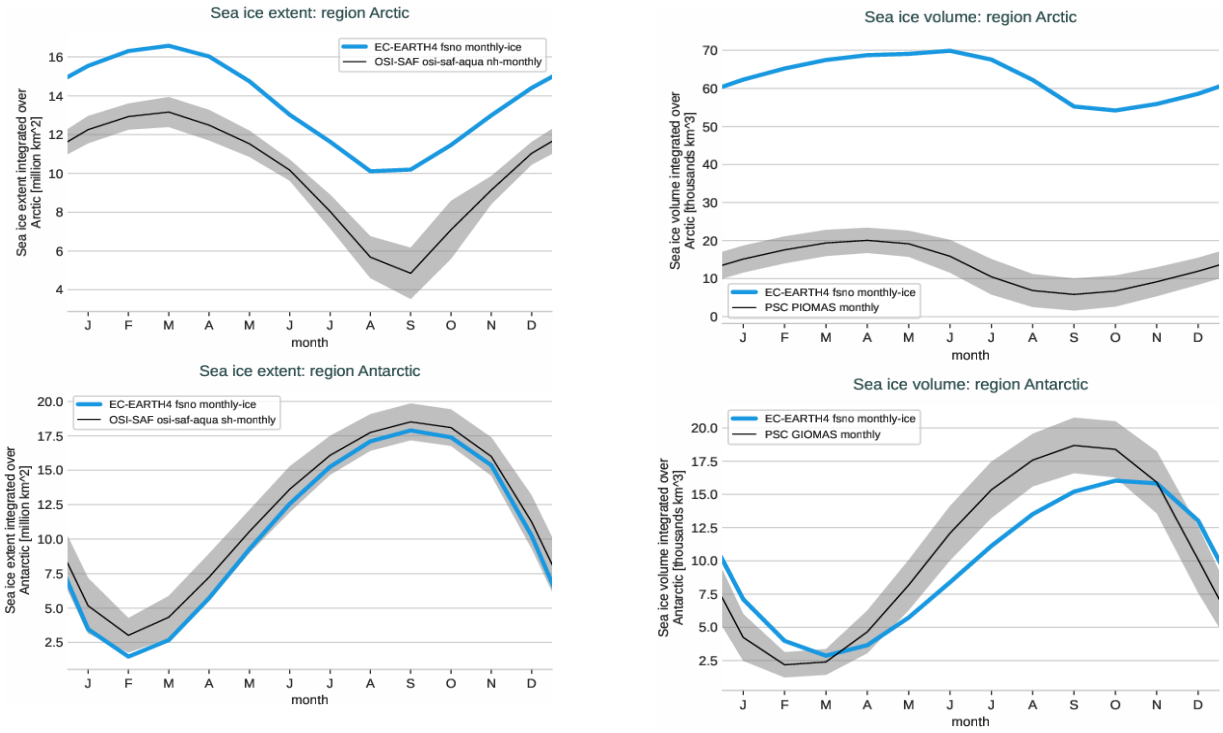

Figure 3. Sea-ice extent (left) and sea-ice volume (right) for Arctic (top) and Antarctic (bottom) in pre-industrial conditions.

Next Steps

1. Continue present-day tuning to reduce global cold bias and improve Southern Ocean representation;
2. Resolve Antarctic sea-ice extent underestimation through investigation of SST biases and ice/snow albedo;
3. Initiate ice sheet spinup procedures for Greenland and Antarctic configurations;
5. Progress toward coupled ice sheet simulations once tuning targets are met.