REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE: Italy

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Project Title: HICE - Exploring the potential of high-resolution in climate-ice sheet coupling

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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.)	2025	
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]	13,000,000	39,000,000	
Accumulated data storage (total archive volume)[2]	[GB]	2,500	20,000	

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

[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.

Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

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Extended abstract

Abstract

Earth's cryosphere, including the Greenland (GrIS) and Antarctic (AIS) ice sheets, will continue evolving in response to present-day climate change for centuries ahead, severely impacting global sea level. Recently, GrIS and AIS have experienced substantial ice loss, accelerated in the last two decades. Future projections, particularly from the Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6) initiative, suggest continued GrIS mass loss across all emissions scenarios, with significant uncertainty stemming from ice-sheet models, climate model forcings, and ocean-ice sheet interactions. AIS projections also show a wide range of potential contributions to sea level rise, highlighting the complexity of accurately modelling its dynamics.

ISIMIP6 relies on offline coupling of climate and ice sheet models, but fully coupled Earth System Models (ESMs) are needed for better representation of ice sheet-climate interactions. Some models have achieved two-way coupling with GrIS, but coupling AIS remains challenging due to complex ice-ocean interactions.

This project aims to contribute to the development and testing of a high-resolution version of the EC-Earth4 model, incorporating two-way interactions with both GrIS and AIS through the Parallel Ice Sheet Model (PISM). The project will involve tuning and testing the coupled model, followed by a simulation from 1950 to 2050 to assess the impact of resolution on ice sheet dynamics, potentially offering improved insights into future cryosphere changes and their climate impacts.

Introduction

Earth's cryosphere constitutes a slow component of the climate system, responding to a change in global mean temperature on multi-centennial to millennial timescales. Nevertheless, understanding the cryosphere's evolution is paramount to predict significant impacts in the long-term future of the planet, the most relevant being its contribution to global sea level rise. One of the most alarming signals of present-day climate change is represented by the mass loss from the Greenland (GrIS) and Antarctic (AIS) ice sheets. GrIS has lost about 5000 Gt of ice between 1992 and 2020, experiencing a decreasing trend from 1980 onwards, with a drastic acceleration after 2000 (Fox-Kemper et al., 2021). In the same period, AIS lost about 2700 Gt of ice, mostly from the West Antarctic ice sheet (WAIS).

The processes driving GrIS and AIS evolution are different. GrIS mass loss is mostly driven by a negative surface mass balance (SMB) and subsequent runoff of the meltwater, while the ice sheet-ocean interaction is of secondary importance and is expected to contribute less in the future as the ice sheet retreats inland. On the other hand, the AIS features a generally positive SMB, primarily due to increased precipitation over the continent, while the main contribution to the mass loss is due to direct ice discharge to the ocean and sub-shelf melting, both driven by the interaction of the ice sheet with warmer oceanic waters (Fox-Kemper et al., 2021; Fyke et al., 2018).

Future evolution of the GrIS and AIS has been studied under a variety of approaches. The main effort is represented by the ISMIP6 initiative (Nowicki et al., 2016; 2020), which applies atmospheric and oceanic forcing obtained from future projections in the CMIP6 ensemble to a set of stand-alone dynamical ice sheet models. Results from ISMIP6 show that

GrIS will continue to lose mass this century under all emissions scenarios, with estimates for the SSP5-8.5 scenario ranging from 0.08 to 0.25 m of equivalent sea level rise (SLE) (Payne et al., 2021). According to Goelzer et al. (2020), multiple error sources explain the significant spread in the ISMIP6 ensemble, which is attributed to the specific ice-sheet model used (40%), the uncertainty in the forcing from climate models (40%) and the limited knowledge of the ocean-ice sheet interaction (20%). Regarding Antarctica, estimates of the ice sheet contribution to sea level rise in response to the RCP8.5 scenario forcing during 2015-2100 vary between -0.08 and 0.3 m SLE, according to ISMIP6 (Seroussi et al., 2020). The large spread of the AIS contribution to sea level rise - and the uncertainty even in its sign - highlight the challenge in representing AIS dynamics.

The multi-model comparison in ISMIP6 is performed using an offline coupling of climate and ice sheet models. However, Fyke et al. (2018) highlighted the need to address the ice sheet problem using fully coupled Earth System models, that allow the full representation of the two-way interaction between the ice sheets and the model climate, and therefore, for example, to consider the impact of the ice sheet elevation and albedo on the atmospheric circulation and the effect of the meltwater on the coastal waters and ocean dynamics. Moreover, the poor representation of ice sheets in current climate models has been shown to affect future projections of the climate for the next centuries (e.g. Fabiano et al., 2024).

Recently, a two-way coupling with GrIS has been implemented in some climate models (e.g. Muntjewerf et al., 2020; Madsen et al., 2022). The coupling of the Antarctic ice sheet is more challenging, due to the fundamental role played by ice-ocean interactions and small scale sub-shelf ocean cavities. Siahaan et al. (2022) presented the first ESM simulations considering interactive ice sheets at both poles, using the UKESM-ice model. Despite recent progress, the coupling of ice sheets inside Earth System models is still at a preliminary stage, primarily due to climate model biases in atmospheric/oceanic mean state (for example in the Southern ocean) and issues in representing high resolution features. Indeed, since ice-sheet models usually need a very high horizontal resolution to represent the dynamics of key features (e.g. outlet glaciers, ice shelves, ..), a relevant issue in the coupling of ice sheet models with climate models is represented by the model horizontal resolution (Vizcaino et al., 2014; Fyke et al., 2018).

Scientific project

The goal of this project is two-fold:

- to contribute to the development, tuning and testing of a high-resolution coupled version of the EC-Earth4 model that includes a two-way interaction with both Greenland and Antarctic ice sheets, represented through the Parallel Ice Sheet Model (PISM);
- to run an historical + near future (1950-2050) simulation with the high-resolution EC-Earth4-PISM model, assessing the impact of resolution on the representation of ice sheet dynamics.

EC-Earth4 is a state-of-the-art Earth System model, whose development by the EC-Earth consortium started in 2020 (see https://ec-earth.org/ec-earth/ec-earth4/). EC-Earth4 includes the atmospheric model OpenIFS (cy43r3), the ocean model NEMO (v 4.2.2) with the sea-ice component SI3 and the coupler OASIS3-MCT 5.2. We plan here to use the high resolution Tco319L91-eORCA025 model configuration, which features about 31 km horizontal resolution in the atmosphere (at the equator) and 0.25° resolution for the ocean model.

PISM is a land ice thermo-dynamical model used to simulate the evolution of glaciers and ice sheets, including the Earth's two large ice sheets in Greenland and Antarctica (Bueler and Brown, 2009; Winkelmann et al., 2011; https://www.pism.io). PISM incorporates various physical processes such as ice flow, basal sliding, calving, and subglacial hydrology, enabling a detailed and realistic modelling of ice sheet dynamics. PISM coupling for Greenland will follow the implementation already done for previous EC-Earth versions (Madsen et al., 2022). For Antarctica, the coupling will consider sub-shelf ice-ocean interactions through the Potsdam Ice-shelf Cavity mOdel (PICO) submodule (Kreuzer et al., 2021; Reese et al., 2018).

The coupling of EC-Earth4 with PISM is currently underway by the EC-Earth consortium. The first year of the project will be focussed on porting the developments to the high-resolution version, including tuning and testing. Tuning in particular represents a crucial step, since ice sheet models are very sensitive to climate model biases, especially in the Southern ocean, and will proceed during the second project year. Then, during the second year of the project, a coupled simulation including both ice sheets will be performed, extending from the recent past to the near future (1950-2050).

This simulation will represent a unique resource to study the added value of the high resolution in climate-ice sheet coupling in both hemispheres.

Justification of the computer resources requested

According to preliminary estimates, the high resolution version Tco319L91-eORCA025 of the EC-Earth4 model will require about 15000 core hours per simulated year (Y. Shuting, Special Project 2022 SPNLTUNE), corresponding to about 260,000 SBU per simulated year. PISM computational demand is much smaller and negligible compared to the atmospheric and oceanic components. Storage needed is estimated to be around 150 Gb/year, but can be reduced to about 50 Gb/year discarding daily output for the testing/tuning phase. We plan to use the testing/tuning resources partly during the first and partly at the beginning of the second project year.

Project year	Experiment	Model	Sim. years	SBU	storage (Gb)
Year 1	Testing/tuning	EC-Earth4-HR, EC-Earth4-HR-PISM	50	13,000,000	2,500
Year 2	Testing/tuning	EC-Earth4-HR-PISM	50	13,000,000	2,500
	Historical	EC-Earth4-HR-PISM	70 (1950-2020)	18,200,000	10,500
	Near future	EC-Earth4-HR-PISM	30 (2020-2050)	7,800,000	4,500

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