REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE:	Denmark
Principal Investigator[1]:	Christian Rodehacke
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Project Title:	LiquidIce: Dual hemispheric ice sheets in EC-Earth

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.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2026**	**2027**	**2028**
High Performance Computing Facility	[SBU]	17,000,000	20,000,00	20,000,00
Accumulated data storage (total archive volume)[2]	[GB]	20TB	45TB	55TB

EWC resources required for project year:		**2026**	**2027**	**2028**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

[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.

Principal Investigator: Christian Rodehacke

Project Title: LiquidIce: Dual hemispheric ice sheets in EC-Earth

Extended abstract

Summary

Within the framework of the European project LiquidIce, DMI will develop a model system comprising EC-Earth (Version 4) and the Parallel Ice Sheet Model (PISM). This system will include the two-way coupling between the classical climate components, such as the atmosphere and ocean, on one side, and the Greenland and Antarctic ice sheets at both poles. As part of this challenging task, a novel aspect of similar work will be the enhancement of the representation of the surface mass balance (SMB), which determines the growth and, potentially, decay of ice sheets. The SMB model CISSEMBEL (Copenhagen Ice Snow Surface Energy and Mass Balance modEL) will interact directly with the atmosphere OpenIFS.

Once the system has been developed and tested, we aim to perform future climate simulations covering the following centuries, adhering to the Ice Sheet Modelling Intercomparison Project (ISMIP) protocol, which is currently under development.

Background

Ice sheets are often regarded as a passive component in climate model systems. Hence, their evolution is disregarded, which also neglects the consequences of evolving ice sheets on the climate. For instance, Madsen (Madsen, 2022a) has demonstrated that integrating an interacting ice sheet into a former EC-Earth version has dampened the warming in the Arctic region. Additionally, the sea level contribution from disintegrating ice sheets is underrepresented in common climate simulations. To gain a better understanding of these consequences, it is necessary to include ice sheets in state-of-the-art Earth system models. It will allow a better

Surface Mass Balance (SMB)

Since the total mass balance of the Greenland ice sheet is predominantly controlled by processes at the atmosphere-ice sheet interface, a realistic description of the surface mass balance is crucial. Therefore, we will explore CISSEMBEL (Copenhagen Ice Snow Surface Energy and Mass Balance modEL). CISSEMBEL, a multi-layer snow model applied across the Greenland ice sheet (Madsen, 2022), unifies independent approaches into a single, modular model. It utilizes the downscaling capabilities of Kapsch (2021) and Vizcaino (2015), the sophisticated physical description of snow/firn processes (Langen 2015), and a collection of albedo parameterization schemes (CISSEMBEL albedo documentation). CISSEMBEL is published open-source and is well-documented (see CISSEMBEL documentation, which can be fetch from https://gitlab.com/crodehacke/CISSEMBEL). A paper describing the model and its capabilities is under preparation.

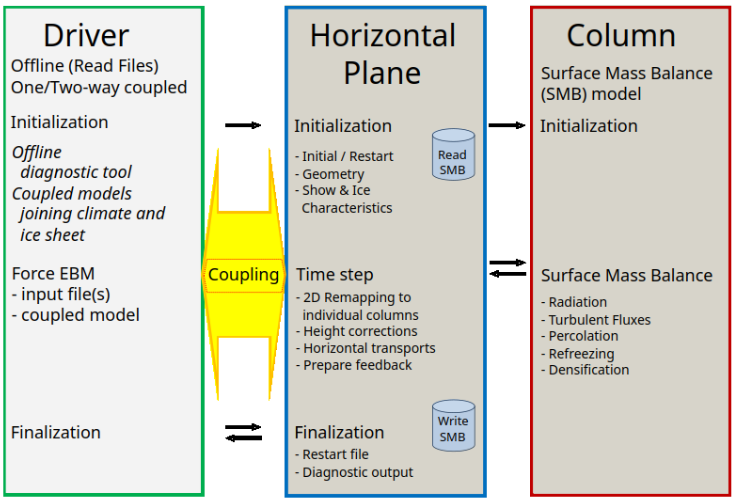

Figure 1 Code structure of the surface mass balance (SMB) model CISSEMBEL. The modular Fortran 2008 code is organized in three columns named "Driver", "Horizontal Plane", and "Column". Note: The driver can be replaced by a driving atmospheric model, such as OpenIFS as part of EC-Earth.

CISSEMBEL is driven by atmospheric forcing data provided by the Driver part of the model (see Figure 1), which sends the data to the horizontal plane that handles all internal input/output operations, performs height corrections to account of height differences between the surface elevation in the forcing and the actual elevation of ice sheet model. Due to the height aspect ratio between the horizontal length and the vertical extent of the snow layers, the SMB is along the horizontal direction, as indicated by the Column.

CISSEMBEL can be run in two modes: Coupled to an atmosphere model or driven by read forcing fields. The offline mode enables the use of CISSEMBEL as a diagnostic tool and for developing parameterizations. CISSEMBEL's offline mode, in concert with its downscaling capabilities, provides Surface Mass Balances (SMBs) at various elevation classes (Sellevold 2019) that are consistent with the provided atmospheric forcing. For an evolving ice sheet, the updated SMB is obtained by computing the SMB on a given ice surface elevation, which is obtained via linear interpolation between two bracketing elevation levels. In addition, this offline state allows for finding parameter combinations that reproduce the observed estimates adequately for a given atmospheric forcing.

As part of this work, we will couple CISSMBEL directly with the atmospheric model OpenIFS. This coupling will occur via EC-Earth's coupler OASIS (Craig 2017). CISSEMBEL is a parallelized code offering the following parallelization techniques: OpenMP, Message Passing Interface (MPI), and hybrid mode (OpenMP+MPI). Current experiments in the offline state, where CISSEMBEL runs on one node of a standard HPC system (e.g., levante at the Deutsche Klimarechenzentrum (DKRZ) and DMI's HPC system boreas), show a good performance, making it implementable into EC-Earth.

Work

In this project, we propose the following steps. The coupling itself is script-based. After EC-Earth, including CISSEMBEL, has completed its simulations ("A", see Figure 2), input and forcing files are prepared, and subsequent batch jobs are started to perform ice sheet simulations for Greenland and Antarctica. Once those ice sheet simulations ("B", see Figure 2) have been completed, the ice sheet geometry and extent changes are used to modify the starting condition of the following EC-Earth simulation. During these simulations, the ice sheet model-based computed meltwater and iceberg mass releases are applied to close the mass budget and ensure proper coupling.

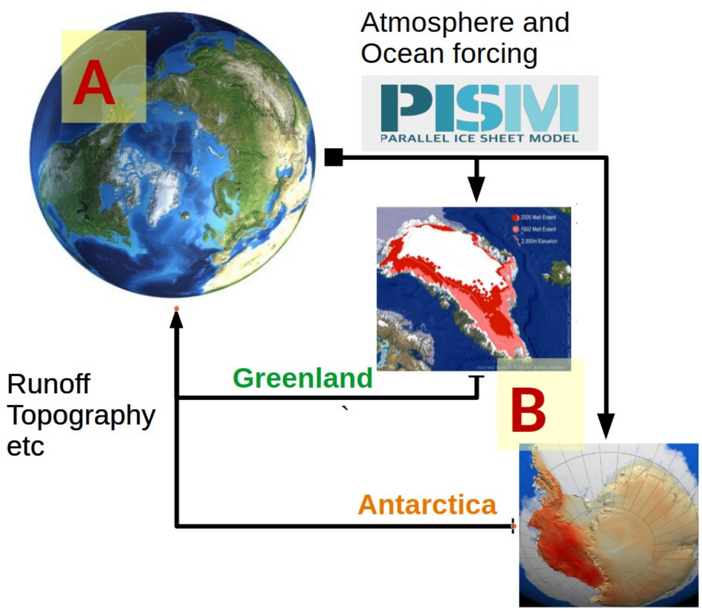

Figure 2 Skript-based coupling scheme between the Earth system model EC-Earth ("A") and two instances of the Parallel Ice Sheet Modell PISM ("B").

Greenland

The coupling to the atmosphere will be performed via CISSEMBEL. For the coupling to the ocean, we will utilize offshore coastal ocean hydrographic data to deduce ocean-driven ablation using the 3-equation model (Holland and Jenkins, 1999). For this setup, we will use a spin-up representing Greenland's contemporary state, which will be provided by efforts outside of the project.

Antarctica

The coupling to the atmosphere will also be performed via CISSEMBEL. However, we would require adjustments to some parameters to account for the differences in surface snow conditions between Greenland and Antarctica. For instance, snow is drier and rarely experiences large-scale melting events. The use of CISSEMBEL will enable us to account for potential large-scale melting events, already sporadically seen (). It has to be seen whether we may have to use a more straightforward approach, as the investigator has applied for AWI-ESM-PISM to account for biases in the climatological forcing, such as excessive air temperature and precipitation across the Antarctic continent.

Antarctica's mass loss is predominantly driven by ocean-driven processes: basal melting of floating ice shelves and the calving of icebergs. Hence, an ocean-ice sheet/ice shelf coupling is paramount for an adequate integration of the Antarctic ice sheet. Since the adaptation of the ice sheet geometry is not standard in ocean models, it is not uncommon to parameterise ocean-ice shelf interaction. Following the approach used by the yt principal investigator for the AWI-ESM-PISM model system, we will use the PICO submodel of the Parallel Ice Sheet Model (PISM) to determine the ocean-driven ice shelf basal melting rates.

Considered the model setup

Within the framework of the project, we aim to develop the system using EC-Earth4-LR and two separate PISM setups, as listed in Tables 2 and 3. This choice will be in line with the EC-Earth community, meaning if this community switches to another configuration, we may follow to create synergies with the community and to avoid costly double work

Table 1 lists the simulations required for this project.

Tabelle 1: Expected number of simulations and their duration in model years. Here, we report the duration of model years in the Earth System Model EC-Earth. We may consider using one EC-Earth model year to drive the ice sheet model PISM for several years, enabling faster convergence between the ice sheet state and the provided EC-Earth forcing.

Experiments	Duration (model years)	Comment
Development	500	It is an estimate
Test: EC-Earth PISM-Greenland-only	250	Focus: CISSEMBEL-OpenIFS coupling, Impact on AMOC and beyond
Test: EC-Earth PISM-Antarctica-only	300	Focus: NEMO-PICO coupling, Stability of ice shelves fringing the entire Antarctic continent.
Test: EC-Earth PISM	100	Combined test transitioning into the spin-up
Spin-up: EC-Earth PISM	550	Create a quasi-equilibrium
Baseline: EC-Earth PISM	650	1850-2500
1pctx4CO2: EC-Earth PISM	650	1850-2500; current standard ISMIP scenario; note the protocol is under discussion
Sum	3000	

Tabelle 2: EC-Earth setups under consideration. It will be decided in collaboration with the EC-Earth community. Our primary target setup is EC-Earth4-LR, while we consider EC-Earth4-ULR if we have sufficient time to enable participation from the Paleo-community or studies covering multi-millennia. Abbreviations: GrIS for the Greenland Ice Sheet and AIS for the Antarctic Ice Sheet.

Atmosphere		Ocean		GrIS	AIS	comment
Name	Resolution	Name	res			
OpenIFS	TL63	NEMO	ORCA2	1	1	EC-Earth4-ULR
OpenIFS	Tl159	NEMO	ORCA1	1	1	EC-Earth4- LR

Tabelle 3: Ice Sheet models and the covered domains. The proposed resolution is still under discussion, pending the availability of resources. Those resolutions are considered necessary.

Model	Domain	Resolution	Spin-up
PISM	Greenland	~5km	Multi-step equilibrium spin-up for multiple 10kyr—200kyr
PISM	Antarctica	~8km	Multi-step equilibrium spin-up for multiple 10kyr—300kyr

Bibliograpy

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