Danmarks Meteorologiske Institut

DMI Report 22-21
Coupling of ice- and climate models

Final scientific report of the 2021 National Centre for Climate Research Work Package 2.2.1, Kobling af is- og klimamodeller

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1. Scientific summary

Short description

This work package aims at developing and running a fully coupled global climate model including ice sheets. The envisioned model system comprises both continental-scale ice sheets (Greenland and Antarctica) and a dedicated representation of surface mass balance processes at a higher horizontal scale.

The work package develops the technical coupling of EC-Earth3 (Döscher et al. 2021) and the PISM ice sheet model (www.pism.io, Büeler and Brown 2009). The initialization of the ice sheet model for Greenland and Antarctica has been a focus point, as a reasonable initial state of the ice sheet is needed for the coupled model experiments. For Greenland, the EC-Earth surface mass balance has been assessed, as it plays a key role in the coupling, and the perspectives of including the *Copenhagen Ice Snow Surface Energy and Mass Balance modEL* (CISSEMBEL, Rodehacke (2021)) for downscaling the surface mass balance (SMB) in the fully coupled model has been explored.

Overall results

- Initialization experiments of the Greenland and Antarctic ice sheets have been performed and reasonable starting points for the ice sheets in coupled experiments have been prepared. The ice sheet model is run at 5 / 8 km resolution for Greenland / Antarctica.
- First coupled model runs have been performed for Greenland for 4xCO2 conditions. Two model experiments were performed, a) the ice sheet model was forced directly with the SMB calculated inside EC-Earth, and b) the EC-Earth SMB was downscaled using the CISSEMBEL before forcing the ice sheet model. These experiments were used to evaluate the influence of the SMB downscaling.
- Our results clearly indicate that the SMB from CISSEMBEL is more realistic and in better agreement with other estimates. However, in the 2-way coupled system, a tighter coupling needs to be established between EC-Earth and CISSEMBEL with exchange of fields during the model run. Most importantly, the surface melt calculated in CISSEMBEL must be consistent with the freshwater that passed to the ocean module at the atmosphere-ocean coupling time step. EC-

- A number of model developments have been initiated since the test experiments:
    - Coupling framework includes Greenland as well as Antarctica
    - New drainage basins have been designed to achieve a more realistic distribution of freshwater to the ocean
    - A 2-way coupling between EC-Earth and the CISSEMBEL is being implemented with exchange of fields during the model run. This is still work-in-progress.

Next steps

The integration of the CISSEMBEL in the coupled model system will be finalized, the fully coupled model system will be initialized and a new set of experiments will be run for pre-industrial and 4xCO2 conditions. A manuscript documenting the coupled model system and the preindustrial control experiment will be prepared for submission to Geoscientific Model Developments.

The EC-Earth model developments will be uploaded to the EC-Earth Development Portal and shared with the EC-Earth Consortium members.

The coupled model system will be used to study the interactions between the Greenland Ice sheet and the climate system, e.g.:

- Impact of melt water from the Greenland ice sheet to ocean circulation in the North Atlantic (AMOC) and the Arctic (stratification and Arctic-MOC).
- Ocean induced calving and its impact on the rate of Greenland Ice sheet mass loss
- Global warming rate and stability of the Greenland Ice sheet

2. Scientific publication

The analysis of the surface energy balance for Greenland and the first coupled experiments with EC-Earth3-GrIS were documented in the master thesis by Lindpointner (2021). These first experiments resulted in some additional model developments as described above. Experiments with the updated code will be performed and a detailed description of the improved model system and an analysis of the control experiment will be given in a manuscript which will be prepared for submission to GMD in 2022.

A manuscript analyzing the results from the first coupled experiments with the initial version of the model system was resubmitted t Climate Dynamics in December 2021 (Madsen et al. 2022) and accepted for publication.

Furthermore, the consortium paper on EC-Earth3 (Döscher et al. 2021) includes a general description of the coupling of EC-Earth3 to the ice sheet model component for the Greenland Ice Sheet.

Büeler E and Brown J (2009) Shallow shelf approximation as a "sliding law" in a thermodynamically coupled ice sheet model, J Geophys Res 114, F03008, doi:10.1029/2008JF001179

Döscher R, Acosta M, Alessandri A, Anthoni P, Arneth A, Arsouze T, Bergmann T, Bernadello R, Bousetta S, Caron L-P, Carver G, Castrillo M, Catalano F, Cvijanovic I, Davini P, Dekker E, Doblas-Reyes FJ, Docquier D, Echevarria P, Fladrich U, Fuentes-Franco R, Gröger M, v Hardenberg J, Hieronymus J, Karami MP, Keskinen J-P, Koenigk T, Makkonen R, Massonnet F, Ménégoz M, Miller PA, Moreno-Chamarro E, Nieradzik L, van Noije T, Nolan P, O'Donnell D, Ollinaho P, van den Oord G, Ortega P, Prims OT, Ramos A, Reerink T, Rousset C, Ruprich-Robert Y, Le Sager P, Schmith T, Schrödner R, Serva F, Sicardi V, Sloth Madsen M, Smith B, Tian T, Tourigny E, Uotila P, Vancoppenolle M, Wang S, Wårlind D, Willén U, Wyser K, Yang S, Yepes-Arbós X, and Zhang Q (2021): The EC-Earth3 Earth System Model for the Climate Model Intercomparison Project 6, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2020-441.

Lindpointner L (2021) Master Thesis: Incorporating a dynamical Greenland Ice sheet into a Global Climate Model System.

Madsen MS, Yang S, Adalgeirsdottir G, Svendsen SH, Rodehacke CB, Ringgaard IM (2022). The role of an interactive Greenland ice sheet in the coupled climate-ice sheet model EC-Earth-PISM, Clim. Dyn. https://doi.org/10.1007/s00382-022-06184-6.

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