Local processes determine global sea level rise

Ice sheet–ice shelf–ocean interaction in the marginal seas of the Southern Ocean

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Kurzgefasst

- coupled ocean–sea ice–ice shelf–ice sheet modelling
- investigation of tipping points
- marginal seas in the center of our research

Ice shelf basal melting has been shown to be an important component in the southern hemisphere's ice mass budget and its variability. In order to explore mechanisms of ice-ocean interaction and the potential of substantial changes in ice-shelf basal mass loss in a warmer climate, we use the global Finite Element Sea ice–ice shelf–Ocean Model FESOM (Timmermann et al., 2012) with a high resolution in the Antarctic marginal seas. Simulations are performed with prescribed cavity geometries and with a dynamic ice shelf as part of a coupled ocean–ice shelf–ice sheet model. Next to the implications for the Antarctic ice sheet mass budget (which is relevant to global sea level), we are interested in the effects of an increased meltwater input for Southern Ocean hydrography and the formation and properties of Antarctic Bottom Water (AABW), one of the driving components of the ocean's global thermohaline circulation. Another focus of our work is the investigation of tippings points in the Antarctic climate system.

A key achievement of the past year is the successful implementation of a new coupled ocean–ice shelf–ice sheet model (FESOM-PISM; Timmermann and Albrecht, 2020) with an explicit representation of variable cavity geometry and grounding line dynamics. This was achieved in close collaboration with Dr. Torsten Albrecht (Potsdam Institut for Climate Impact Research, PIK) and supported by funding from the DFG SPP "Antarktisforschung". Similar to the Regional Antarctic and Global Ocean (RAnGO) model (Timmermann and Goeller, 2017), the coupled system is based on a global FESOM implementation with a mesh that uses hybrid vertical coordinates and is substantially refined in the marginal seas of the Southern Ocean. The Antarctic cryosphere is now represented by a regional setup of the Parallel Ice Sheet Model PISM, comprising Filchner-Ronne Ice Shelf (FRIS) and the grounded ice in its catchment area up to the ice divides. At the base of FRIS, melt rates and boundary layer temperatures from FESOM are applied. PISM returns ice thickness, temperature near the ice base, and the position of the grounding line. Dynamic FESOM mesh modification and several other aspects of the RAnGO coupler have been adopted to the new system. The ice-sheet model is run on a horizontal grid with 1 km resolution to ensure an appropriate representation of grounding line processes. Enhancement factors for the approximation of the stress balance, as often used in coarse-resolution ice sheet models, become obsolete at such high resolution.

The Antarctic ice sheet evolves on timescales that are longer than the dominant timescales of climate variability. As it is thus never in equilibrium, the ice-sheet model component requires a high-resolution spin-up procedure that provides a realistic configuration of the present-day Antarctic Ice Sheet and at the same time accounts for the long-term drift as a delayed response to the climate conditions during the last glacial cycles. The distributed architecture of the RAnGO coupling interface allows us to perform spin-up and coupled integration of the ice sheet model on the same server (not at HLRN), thus avoiding unnecessary porting of the PISM code, and at the same time benefit from the very robust and computationally efficient FESOM installation at HLRN. Overhead arising from file transfer between the two computers amounts to about 0.2 % of total runtime and can therefore safely be regarded negligible.

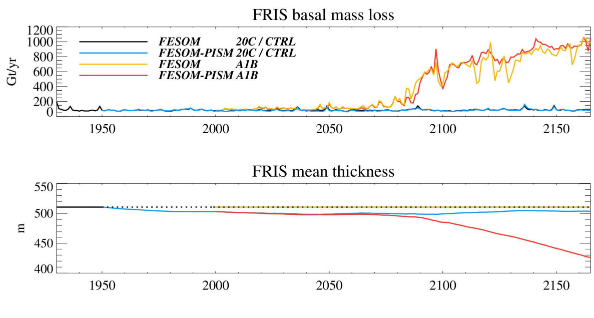

***Abbildung 1:** Top: Simulated basal melt rates for Filchner Ronne Ice Shelf in uncoupled FESOM experiments (black and yellow lines) and with the coupled FESOM-PISM model (blue and red lines). Bottom: Mean thickness of FRIS in the coupled control experiment with 20th-century climate (blue line) and the coupled model projection for the A1B scenario (red line).*

Similar to previous studies with uncoupled ocean-ice shelf models (e.g. Timmermann and Hellmer, 2013) and with the coupled RAnGO model (Timmermann and Goeller, 2017), a regime shift from cold to warm water on the continental shelf off Filchner-

Ronne Ice Shelf leads to an increase of ice shelf basal melt rates by a factor of 6 after 2070 (Fig. 1, top). Note that the melt-rate increase in FESOM-PISM is slightly stronger than in fixed-geometry FESOM.

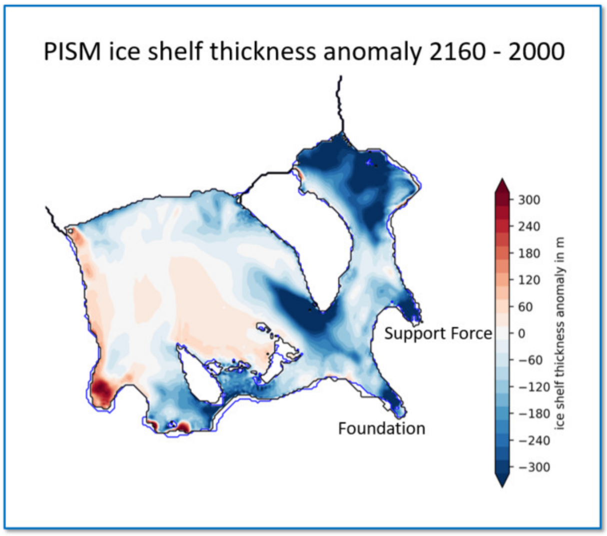

Abbildung 2: *FRIS thickness anomaly for 2160 relative to the year 2000 and the evolution of cavity geometry between these two years in the coupled FESOM-PISM model run with HadCM3-A1B atmosheric forcing. The coloured area represents the modelled ice shelf extent.*

In the FESOM-PISM coupled model projection, this leads to a thinning of FRIS by about 15 % (on spatial average) between 2060 and 2160 (Fig. 1, bottom). The strongest thinning occurs near the grounding lines of Support Force and Foundation ice streams (Fig. 2). While an evolution of the modelled cavity geometry can clearly be recognized, a retreat of the grounding line is limited by the steep bedrock topography below the ice streams. Even without a strong grounding-line retreat, reduced buttressing by thinner ice causes an increasing discharge of grounded ice into the ocean. The difference between the A1B projection (FESOM-PISM A1B) and the control run (FESOM-PISM 20C) contributes an equivalent of 27 mm to global sea level rise by 2165. These results are currently being prepared for publication.

Coupling of FESOM and high-resolution PISM works efficiently and shall now be expanded to pan-Antarctic Ice Sheet simulations in the next project phase. To contribute to the IPCC assessment of ongoing and future climate change, we also plan to run coupled ice sheet–ice shelf–ocean projections for the SSP5-8.5 szenario, forced with atmosphere output from CESM2/RACMO-2.3. This scenario extends until 2100.

Most of our studies so far have focused on the Weddell Sea. Within the EU Horizon 2020 project TiPACCs (Tipping Points in Antarctic Climate Components), we widen the focus and include the Ross Ice Shelf as well as ice shelves in the Amundsen Sea (e.g. Pine Island, Getz) in the investigation, which are examples of cold-water and warm-water ice shelves, respectively. For the Ross Ice Shelf, the project aims to determine why the "cold" state of the cavity is more stable than under FRIS, where the outer limits of this stability lie, and which atmospheric variable is most crucial in causing a tipping of the system. For the Amundsen Sea, we pose the questions whether the currently "warm" regime of the ice shelves are the result of a similar tipping point in the past, which conditions could may have been prevalent at that time, and whether a reversal to a "cold" state is possible. At a later stage, we will assess the impact of such a tipping point on the ice shelf's buttressing effect and determine whether it will trigger an unstable grounding-line retreat. Finally, the resulting consequences for the global sea level will be evaluated.

Weitere Informationen

[1] Hellmer, H.H, F. Kauker, R. Timmermann, and T. Hattermann: The Fate of the Southern Weddell Sea Continental Shelf in a Warming Climate, Journal of Climate, 30(12), 4337-4350, DOI: 10.1175/JCLI- D-16-0420.1 (2017).

[2] Timmermann, R. and S. Goeller: Response to Filchner-Ronne Ice Shelf cavity warming in a coupled ocean–ice sheet model. Part I: The ocean perspective, Ocean Sci. Discuss., https://doi.org/10.5194/os-2017-41 (2017).

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