Coupled ocean—ice shelf—ice sheet projections for the Weddell Sea Basin, Antarctica

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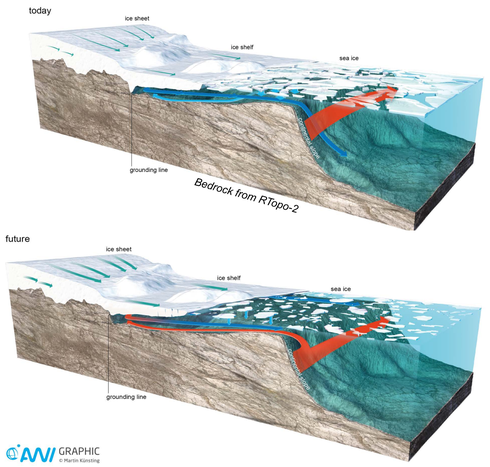
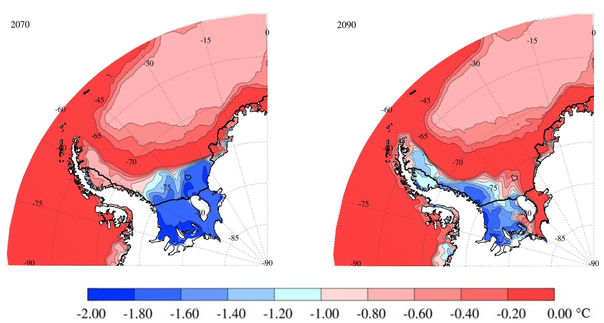
Overview

A coupled ice sheet – ice shelf – ocean model with an explicit representation of a variable Filchner-Ronne Ice Shelf (FRIS) cavity has been developed, based on a global implementation of the Finite Element Sea ice Ocean Model (FESOM) and a regional setup of the Parallel Ice Sheet Model (PISM). At the base of the FRIS, melt rates and boundary layer temperatures from FESOM are applied. PISM returns ice thickness, ice temperatures and the position of the grounding line. Building on the Timmermann & Goeller (2017) infrastructure, we run FESOM with a hybrid vertical coordinate and a horizontal mesh that adjusts to the varying cavity geometry. The ice sheet model uses a horizontal grid with 1 km resolution for an appropriate representation of grounding line processes. Enhancement factors for the approximation of the stress balance become obsolete at such high resolution. Ice stream flow is well captured by polythermal coupling of the ice flow and a Mohr-Coulomb yield stress criterion that accounts for properties of the till material and the effective pressure on the saturated till. We present results from model runs with a 20th-century climate forcing and projections until the end of the 22nd century.



Sections along Filchner Trough illustrate the reduced sea ice-formation, potentially causing an inflow of Modified Warm Deep Water, a thinning of the ice shelf near the grounding line, and a speedup of grounded ice flow towards the ocean

Simulated ocean bottom temperature in A1B scenario



Simulated bottom temperature for 2070 and 2090 in the FESOM-PISM A1B experiment.

The inflow of Modified Warm Deep Water (MWDW) leads to a rapid increase of basal melt rates (see panel on top right of this poster)

FESOM - PISM

FESOM

Finite element
Sea ice – ice shelf – ocean model

Timmermann et al., 2012

- domain: global
- horizontal resolution: 1.9 – 250 km
- dynamic-thermodynamic sea ice model
- 3-equation model of ice shelf-ocean interaction
- projections: atmospheric forcing from HadCM3 for IPCC scenario A1B

- **coupling:** ice shelf thickness and grounding line position from PISM (updated once per year)

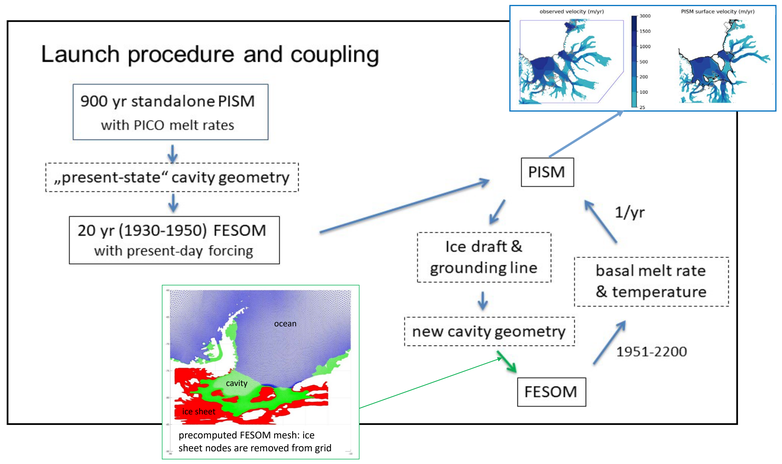
PISM

Parallel Ice Sheet Model

Winkelmann et al., 2011
Albrecht et al., 2020

- domain: FRIS + catchment area (2160 x 1800 km)
- horizontal resolution: 1 km
- vertical resolution: 401 sigma layers (3 m at base)
- ice dynamics: SIA-SSA hybrid
- basal friction interpolation at grounding line
- new BedMachine geometry, 900 yr spin-up
- annual-mean surface temperatures and accumulation rates from HadCM3/RACMO

- **coupling:** ice shelf basal melt rates and boundary layer temperatures from FESOM (annual mean, currently once per year)



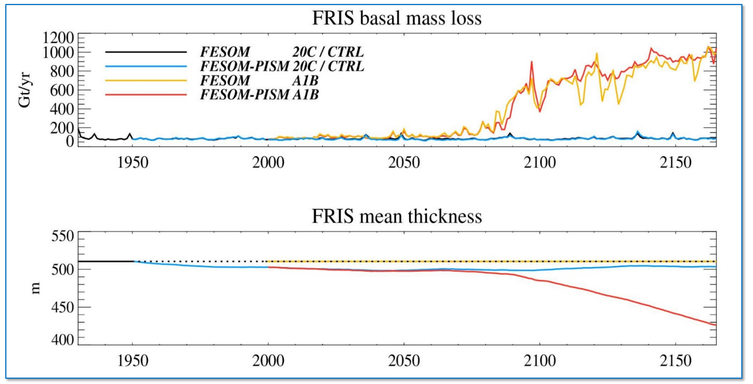
Experiments:

1.	FESOM-PISM 20C/A1B:	1950-2200	("A1B coupled projection")
2.	FESOM 20C/A1B:	1950-2200	("A1B fixed-geometry")
3.	FESOM-PISM 20C2:	2000-2200	present-day CTRL, with
4.	FESOM 20C2:	2000-2200	20th century forcing repeated

Total of 900 model years = 4.5 Mio CPU hours = 500 CPU years

The next generation:

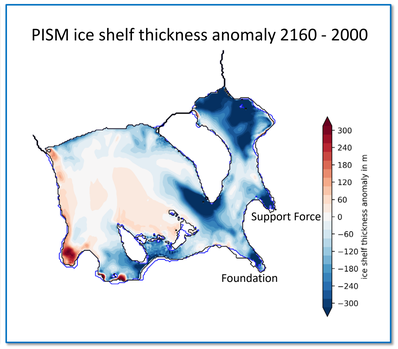
We are about to launch a suite of simulations with an **enhanced enthalpy coupling**. In these experiments, PISM will also provide the varying temperature within the ice to the computation of the heat flux between the ice-shelf boundary layer and the interior ice in the 3-equation system describing ice shelf-ocean interaction.
Next to the A1B sensitivity experiments forced with HadCM3/RACMO-A1B data, we will also produce coupled projections for the **SSP5-8.5 scenario** forced with atmosphere data from **CESM2/RACMO-2.3**.
A **pan-Antarctic** version of the model will be implemented in the TiPACCs project.



Time series of annual-mean basal melt rate and mean FRIS thickness in FESOM-PISM and for the 20th century (blue line) and the A1B scenario (red line), and the corresponding basal melt rates in standalone FESOM. The coupled A1B simulation has proceeded until the year 2165.

Main results for A1B scenario:

- Melt rates increase by a factor of 6 after 2070.
- Melt rate increase in FESOM-PISM is slightly stronger than in fixed-geometry FESOM.
- Mean thickness of FRIS reduces by 20% between 2060 and 2160.
- Strongest thinning near the grounding lines of Support Force and Foundation ice streams.



Summary

- Coupling of FESOM and high-resolution PISM works efficiently and can be expanded to pan-Antarctic Ice Sheet simulations.
- Coupled simulation for the A1B scenario suggests a contribution of 27 mm to sea level rise from the FRIS catchment area until 2165 (not shown here)
- Simulations with enhanced enthalpy coupling and with CESM2/RACMO-2.3 forcing for SSP5-8.5 are under way.

References

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