First results from coupling the Parallel Ice Sheet Model with the Modular Ocean Model via an Antarctic ice-shelf cavity module

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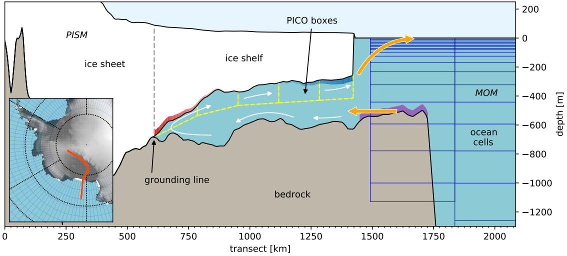

DFG-SCHWERPUNKTPROGRAMM 1158
ANTARKTISFORSCHUNG
mit vergleichenden Untersuchungen in arktischen Eisgebieten

work supported by DFG grant WI 4556/4-1

see also the paper (under review): https://doi.org/10.5194/gmd-2020-230

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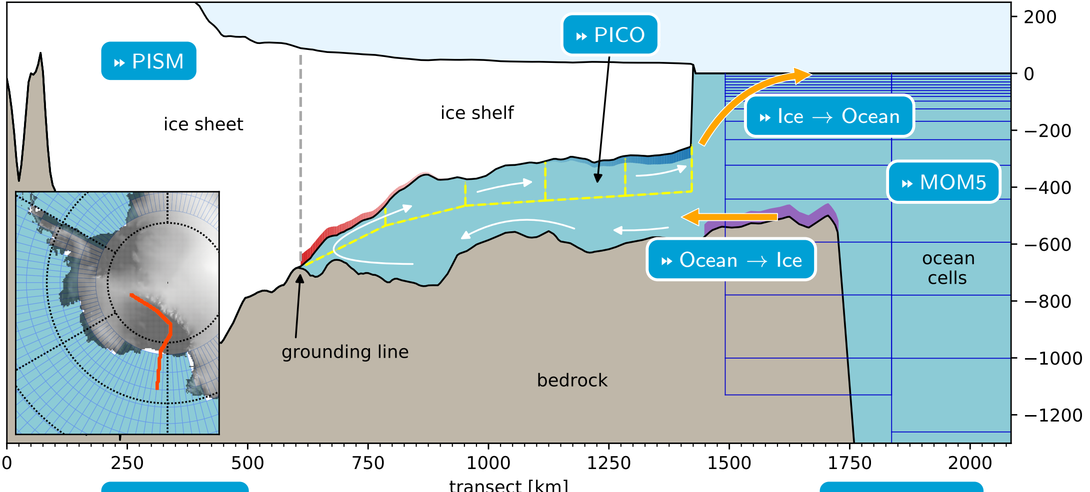
» Offline Coupling Framework

» Coupled run results ← click the buttons!



» Benchmark

» Conservation

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Parallel Ice Sheet Model (PISM) [1,8,2]

- 3d thermodynamically coupled model
- simulates ice sheets and ice shelves using a finite-difference discretisation
- regular cartesian grid projected on WGS84 ellipsoid [7]
- dynamic timestepping (CFL based): minutes to years
- typical resolution: 16x16 km, 80 vertical levels
- written in C++

Potsdam Ice-shelf Cavity mOdel (PICO) [6]

- parametrises the vertical overturning circulation in ice-shelf cavities
- calculates sub-shelf melt rates
- uses box approach underneath ice shelves from Olbers and Hellmer [5]
- input: ocean temperature and salinity (2d)
- implemented as submodule in PISM

more information: PISM website, PICO documentation

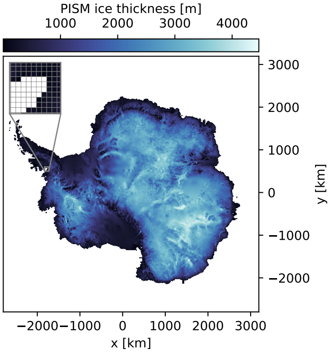

Figure 1: Antarctic ice sheet model by PISM on a 10km resolution as shown in the inset

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Modular Ocean Model v5 (MOM5)[4]

- 3d Ocean General Circulation Model
- includes the Sea Ice Simulator (SIS)[9]
- uses the Flexible Modeling System (FMS) coupler
- example setup: global coarse grid[3]
  longitude: 120 cells (3°)
  latitude: 80 cells ($0.6^\circ - 3^\circ$)
- 28 vertical layers (rescaled pressure coordinate p*)
- 8h timestep
- written in Fortran

more information: MOM5 website

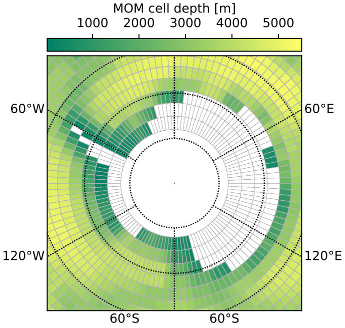

Figure 2: Stereographic South Pole projection of the MOM grid. Land cells are white and the grid is not defined below 78°S.

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Offline Coupling Framework

- running both models in alternating order for *coupling time step*
- exchange of variables between the model runs
  - temperature, salinity (ocean $\rightarrow$ ice)
  - mass & energy flux (ice $\rightarrow$ ocean)
- inter-model processing of variables in between

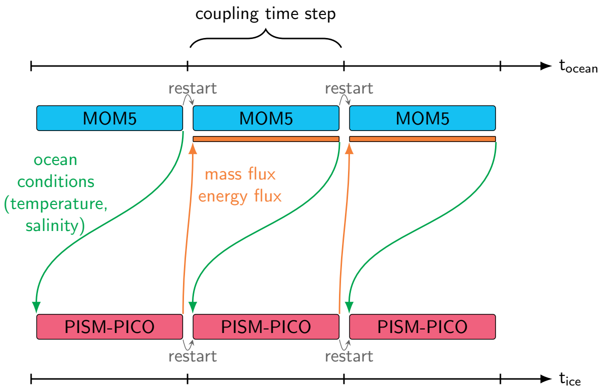

Figure 3: Alternation of ocean and ice sheet model execution. Regridding between the different grids, conversion of units and adaptation of dimensions is required in between.

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Processing MOM → PISM
making use of PICO basins based on Antarctic drainage systems by Zwally et al. [10]

- bilinear regridding of 3d ocean variables (temperature, salt) to cartesian PISM grid
- filling of missing data per basin: average of defined gridcells at the edge to empty grid points
- vertical interpolation per basin to PICO input depth

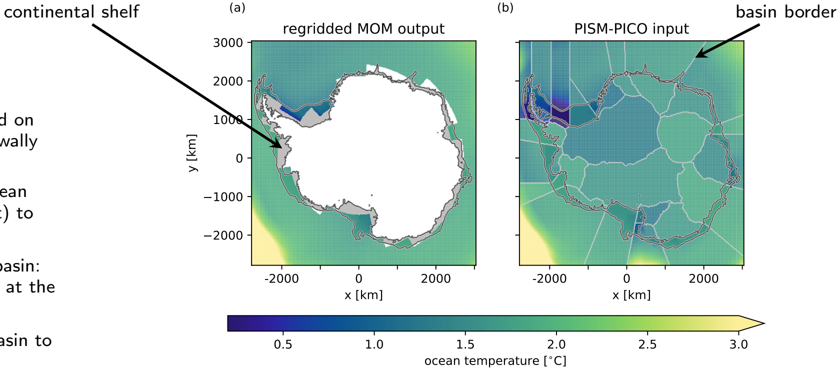

Figure 4: After regridding ocean variables to the ice grid, missing values are filled with edge averages of each basin. This ensures appropriate values for all areas of the continental shelf which is used for input in PICO.

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Processing PISM → MOM

- can't use regular remapping due to lack of grid overlapping
- mapping of southernmost MOM grid cells to PISM basins
- mass flux $= m_s + m_b + m_c$
- energy flux $= L \cdot (m_b + m_c)$

m_s	surface mass flux
m_b	basal mass fluxes
m_c	calving mass fluxes
L	latent heat of fusion $= 3.34 \cdot 10^5\,\mathrm{J/kg}$

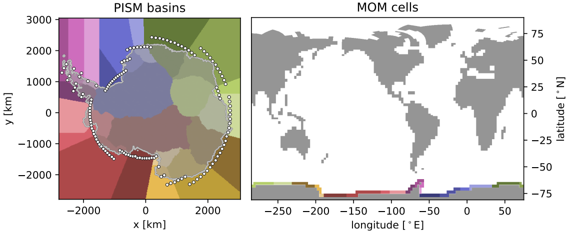

Figure 5: Mapping of PISM basins to southernmost MOM cells

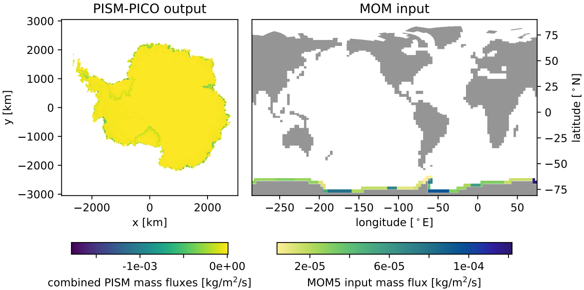

Figure 6: Redistribution of PISM mass fluxes to MOM5 ocean grid

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Coupled Benchmark

- 200 years run time
- coupling timesteps: 1, 10 years
- 32 CPU cores

conclusions:

- very little overhead during decadal coupling
- significant overhead during yearly coupling

  → PISM is designed for much longer integration times

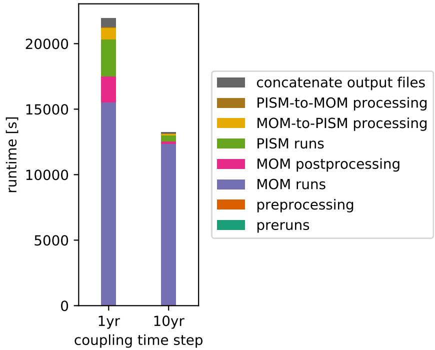

Figure 7: Aggregated run times of coupling framework components including pre-runs and pre-processing (insignificant), model execution times and inter-model processing. PISM run time in yearly coupling is about 8 times higher in decadal coupling.

Mass Conservation

examination of coupled mass PISM, MOM5 & SIS:

$$m_v = (m_o + m_{si} - m_{osi}^s - m_{osi}^d) + (m_{li} - m_{li}^s)$$

$$\frac{d}{dt} m_v = 0 Gt/a$$

m_o	mass ocean (MOM5)
m_{si}	mass sea ice (SIS)
m_{osi}^s	net mass: atm $\rightarrow$ ocean
m_{osi}^d	ocean model drift
m_{li}	mass land ice (PISM)
m_{li}^s	net mass: atm $\rightarrow$ land ice

Energy Conservation

examination of energy fluxes during remapping from ice to ocean grid (e_i, e_o)

- conservative to double machine precision:

$$\frac{\Sigma e_i - \Sigma e_o}{\Sigma e_i} = \mathcal{O}(10^{-16})$$

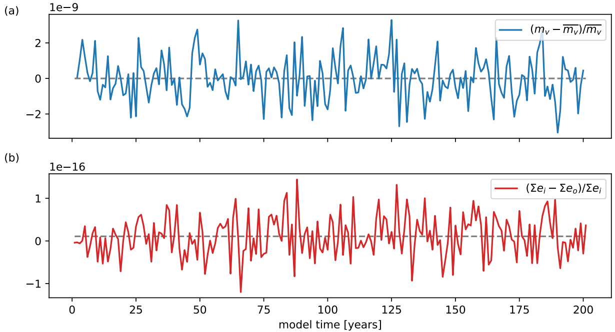

Figure 8: (a) Relative error of virtual coupled mass (excludes mass changes applied through surface fluxes and the internal model drift) (b) Relative error through remapping energy flux from ice to ocean grid

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Coupled runs for present-day conditions (4k years) [1/2]

standalone spin ups:

- ocean: 10k years (last 5k years with PISM mass & energy fluxes in Antarctica)
- ice: 210k years

coupled runs:

- 10 year coupl. time step
- ocean → ice variations:
  - average over coupling time step
  - annual mean time series forcing (ts) ⇒ like yearly coupling

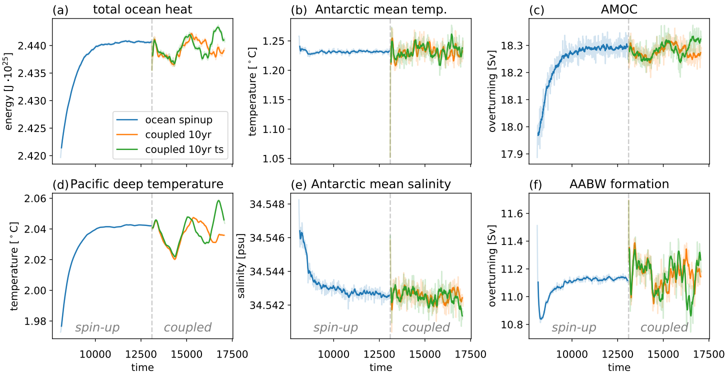

Figure 9: ocean spin-up and coupled

Coupled runs for present-day conditions (4k years) [2/2]

ocean anomaly approach:

- model ocean conditions too warm around Antarctica
- anomalies relative to spin-up applied to present day ice sheet ocean forcing

results:

- stable coupled system, no significant drift
- internal ice variability pattern observed in ocean heat, pacific deep temp, AMOC
- 10 year coupling time step (average vs. time series): no qualitative difference

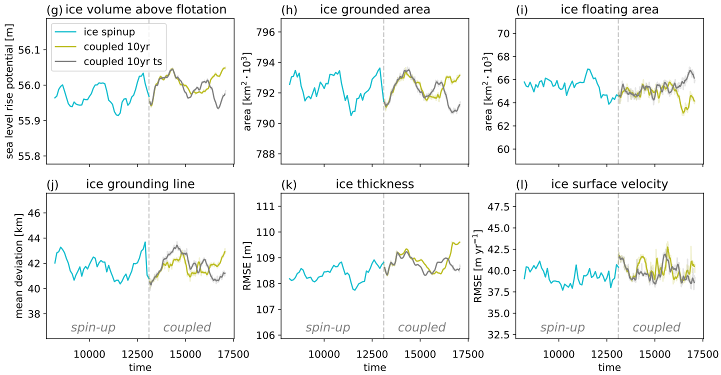

Figure 10: ice spin-up and coupled

Questions?

don't hesitate to contact us:

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or check our publication (under review at Geoscientific Model Development):
https://doi.org/10.5194/gmd-2020-230

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Abstract | Assets | Discussion | Metrics

Submitted as: model description paper 14 Sep 2020

Review status: a revised version of this preprint is currently under review for the journal GMD.

Coupling framework (1.0) for the ice sheet model PISM (1.1.1) and the ocean model MOM5 (5.1.0) via the ice-shelf cavity module PICO

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Received: 09 Jul 2020 – Accepted for review: 11 Sep 2020 – Discussion started: 14 Sep 2020

Abstract. The past and future evolution of the Antarctic Ice Sheet is largely controlled by interactions between the ocean and floating ice shelves. To investigate these interactions, coupled ocean and ice sheet model configurations are required. Previous modelling studies have mostly relied on high resolution configurations, limiting these studies to individual glaciers or regions over short time scales of decades to a few centuries. We present a framework to couple the dynamic ice sheet model PISM with the global ocean general circulation model MOM5 via the ice-shelf cavity module PICO. Since ice-shelf cavities are not resolved by MOM5, but parameterized with the box model PICO, the framework allows the ice sheet and ocean model to be run at resolution of 16 km and 3 degree, respectively. This approach makes the coupled configuration a useful tool for the analysis of interactions between the entire Antarctic Ice Sheet and the Earth system over time spans on the order of centuries to millennia. In this study we describe the technical implementation of this coupling framework: sub-shelf melting in the ice sheet model is calculated by PICO from modeled ocean temperatures and salinities at the depth of the continental shelf and, vice versa, the resulting mass and energy fluxes from the melting at the ice-ocean interface are transferred to the ocean model. Mass and energy fluxes are shown to be conserved to machine precision across the considered model domains. The implementation is computationally efficient as it introduces only minimal overhead. The framework deals with heterogeneous spatial grid geometries, varying grid resolutions and time scales between the ice and ocean model in a generic way, and can thus be adopted to a wide range of model setups.

How to cite. Kreuzer, M., Reese, R., Huiskamp, W. N., Petri, S., Albrecht, T., Feulner, G., and Winkelmann, R.: Coupling framework (1.0) for the ice sheet model PISM (1.1.1) and the ocean model MOM5 (5.1.0) via the ice-shelf cavity module PICO, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2020-230, in review, 2020.

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