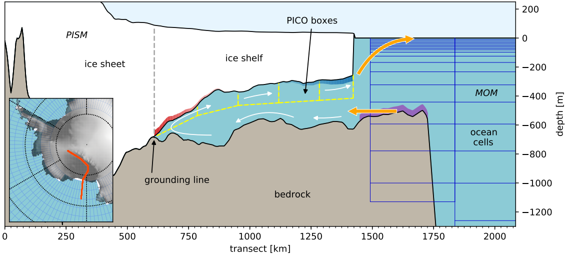
Coupling framework for simulating multi-millennial interactions of the Antarctic Ice Sheet and the global ocean

Moritz Kreuzer[a,b], Ronja Reese[a], Willem Huiskamp[a], Stefan Petri[a], Torsten Albrecht[a], Georg Feulner[a], Ricarda Winkelmann[a,b]

[a] Earth System Analysis, Potsdam Institute for Climate Impact Research, Potsdam, Germany
[b] Institute of Physics and Astronomy, University of Potsdam, Potsdam, Germany

kreuzer@pik-potsdam.de



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Motivation

Antarctic Bottom Water Formation

- influenced by Antarctic melt water
- part of global Thermohaline Circulation
- melt-water stratification feedback

goal:

- bidirectional ice-ocean coupling
- Antarctic Ice Sheet and global ocean
- multi-millennial time scales
- analyse feedbacks and tipping behaviour

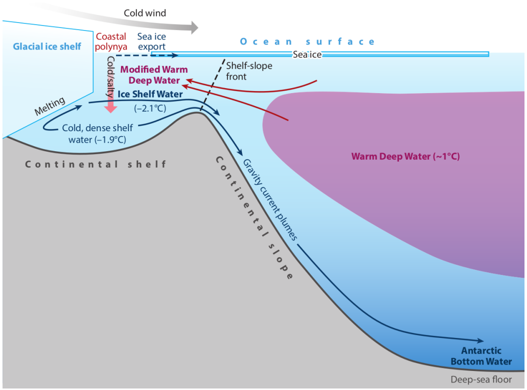

Figure 1: *Purkey et al. 2018*

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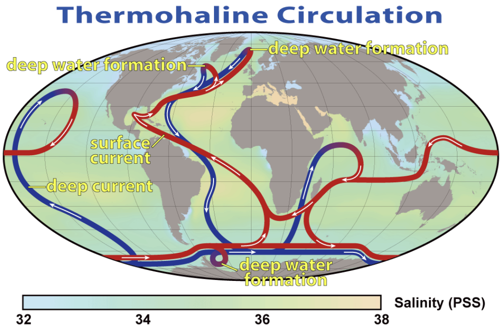

Figure 2: global THC, *Wikipedia (NASA)*

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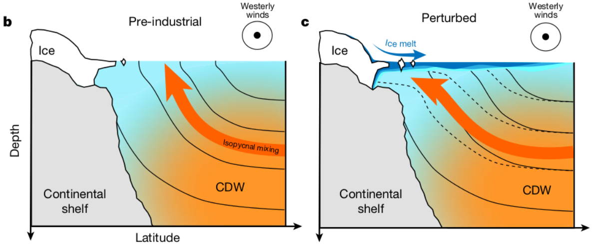

Figure 3: *Bronselaer et al. 2018*

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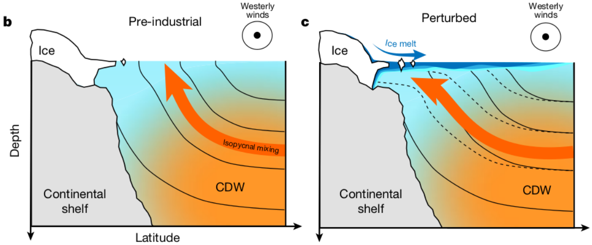

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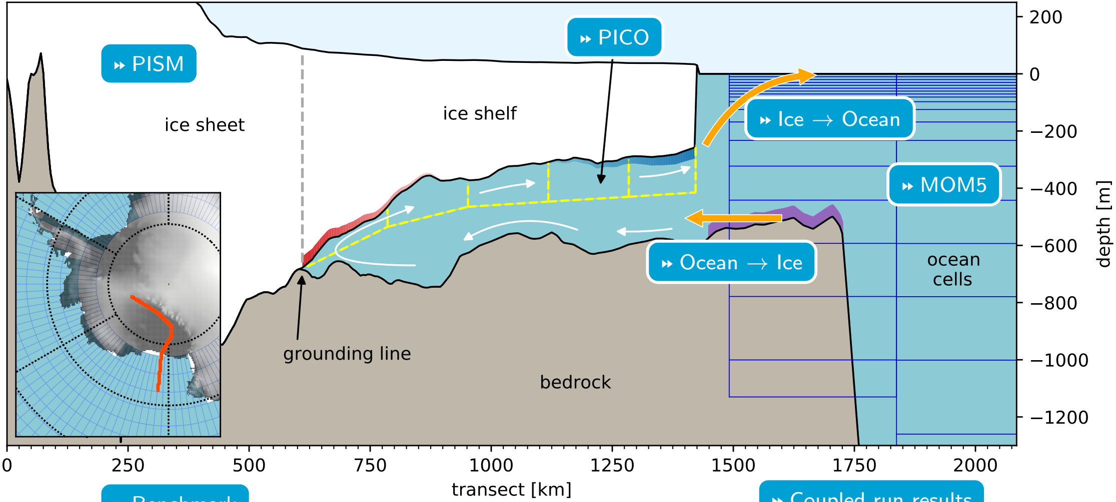
» Offline Coupling Framework



» Benchmark

» Coupled run results

ocean model MOM5

Modular Ocean Model v5 [5]

- 3d Ocean General Circulation Model
- includes Sea Ice model SIS [10]
- global coarse grid setup [4]:
  - longitude: 120 cells (3°)
  - latitude: 80 cells (0.6° − 3°)
  - vertical: 28 layers (rescaled pressure coordinate p*)
- 8h timestep
- prescribed atmospheric forcing

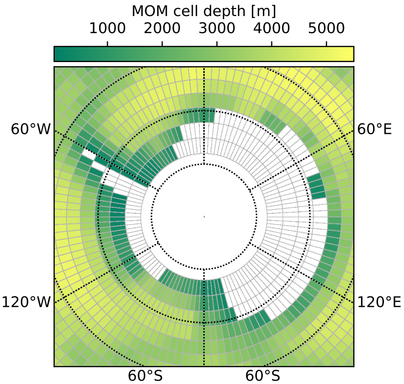


Figure 4: MOM grid in Stereographic South Pole projection

ice model PISM

Parallel Ice Sheet Model[2,9,3]

- 3d thermodynamically coupled model
- ice sheets and ice shelves (hybrid SIA & SSA formulation)
- regular cartesian grid (see inset)
- resolution: 16x16 km, 80 vertical levels
- dynamic timestepping (CFL based): minutes to years

Potsdam Ice-shelf Cavity mOdel (PICO)[8]

- parametrises the vertical overturning circulation in ice-shelf cavities
- calculates sub-shelf melt rates
- uses box approach underneath ice shelves from Olbers and Hellmer[6]
- input: ocean temperature and salinity (2d)
- submodule in PISM

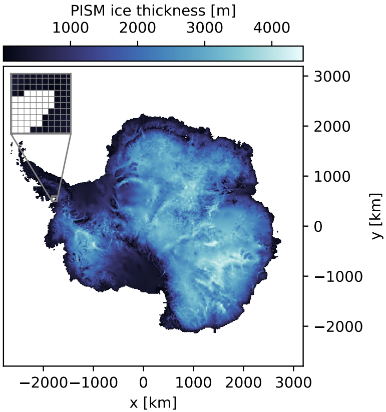


Figure 5: Antarctic PISM setup (10km grid)

Offline Coupling Framework

- alternating model execution: *coupling time step*
- exchange of variables between model runs
  - temperature, salinity, sea level
  - mass & energy flux
- inter-model processing of variables in between
- options:
  - sea level forcing
  - basal melt input depth
  - ocean tracer anomalies
  - ...

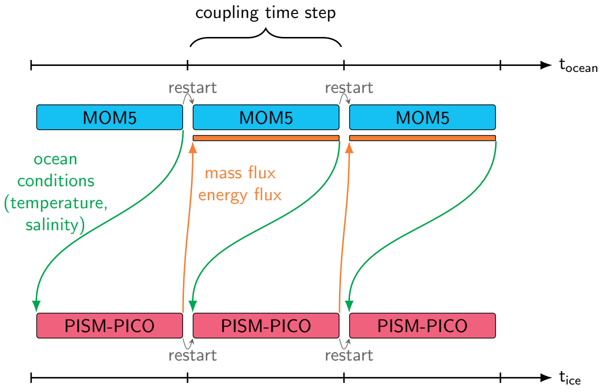


Figure 6: alternating execution of ocean and ice sheet model

Processing MOM → PISM

- bilinear regridding: 3d ocean output (temp., salt) → cartesian PISM grid
- filling missing data per basin: average of marginal cells
- vertical interpolation per basin to PICO input depth

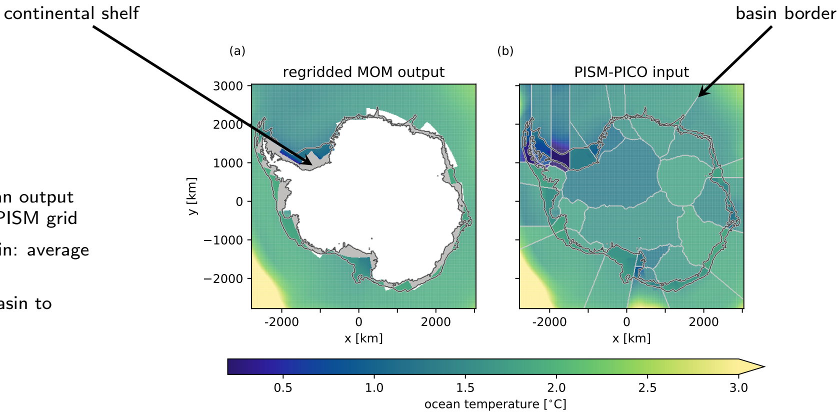


Figure 7: processing ocean output (T,S) for ice sheet input

Processing PISM $\rightarrow$ MOM

- no consistent 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 $= 3.34 \cdot 10^5\,\mathrm{J/kg}$

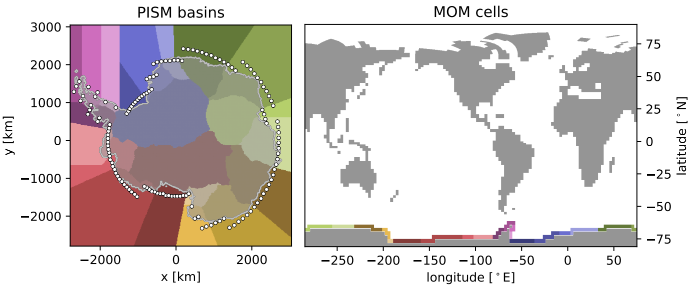


Figure 8: Mapping of PISM basins to southernmost MOM cells

Coupled Benchmark

test setup:

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

conclusions:

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

  $\rightarrow$ PISM is designed for much longer integration times

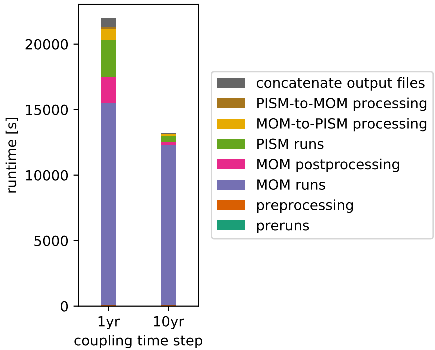


Figure 9: run time statistics

Coupled runs for present-day conditions [4k years]

standalone spin ups:

- ocean: 10k years
- ice: 210k years

coupled runs:

- coupl. time steps: 10yr, 1 yr
- ocean → ice forcing: anomalies

results:

- stable coupled system, no significant drift
- coupling adds ocean variability

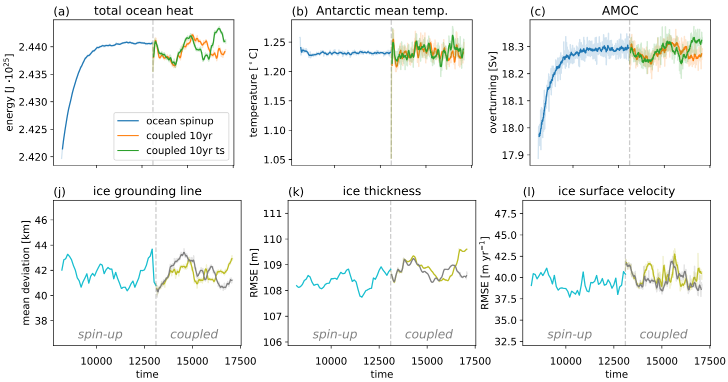


Figure 10: spin-up and coupled runs

Outlook: Forcing the coupled system

using different CMIP5 model output:

- pre-industrial (control run) [4ka]
- 1% CO_2 increase [135a]
- 1% CO_2 extension [4ka]

ocean surface forcing:

- T (air), wind, precipitation, radiation, pressure, humidity

ice surface forcing:

- T (air), precipitation

Figure 11: experiment outline

Questions

don't hesitate to contact us:

✉ **kreuzer@pik-potsdam.de**

or check our publication:

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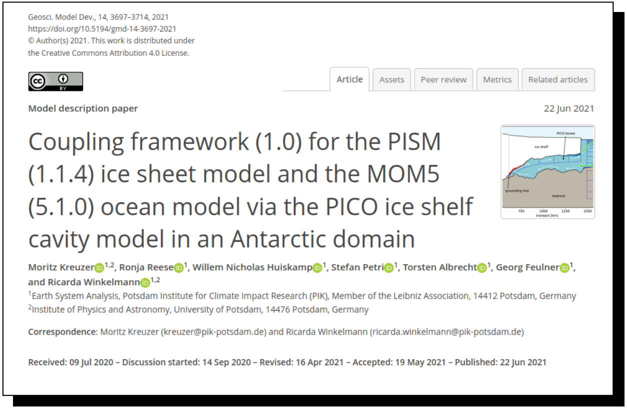
https://doi.org/10.5194/gmd-14-3697-2021



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Model description paper

22 Jun 2021

Coupling framework (1.0) for the PISM (1.1.4) ice sheet model and the MOM5 (5.1.0) ocean model via the PICO ice shelf cavity model in an Antarctic domain

Moritz Kreuzer[1,2], Ronja Reese[1], Willem Nicholas Huiskamp[1], Stefan Petri[1], Torsten Albrecht[1], Georg Feulner[1], and Ricarda Winkelmann[1,2]

[1]Earth System Analysis, Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, 14412 Potsdam, Germany

[2]Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany

Correspondence: Moritz Kreuzer (kreuzer@pik-potsdam.de) and Ricarda Winkelmann (ricarda.winkelmann@pik-potsdam.de)

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