Coupling the Parallel Ice Sheet Model (PISM) with the Modular Ocean Model v5 (MOM5) via an Antarctic Ice Shelf Cavity Model (PICO)

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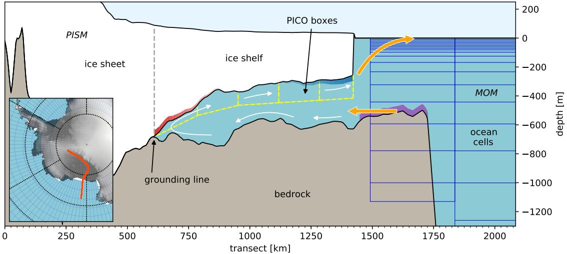

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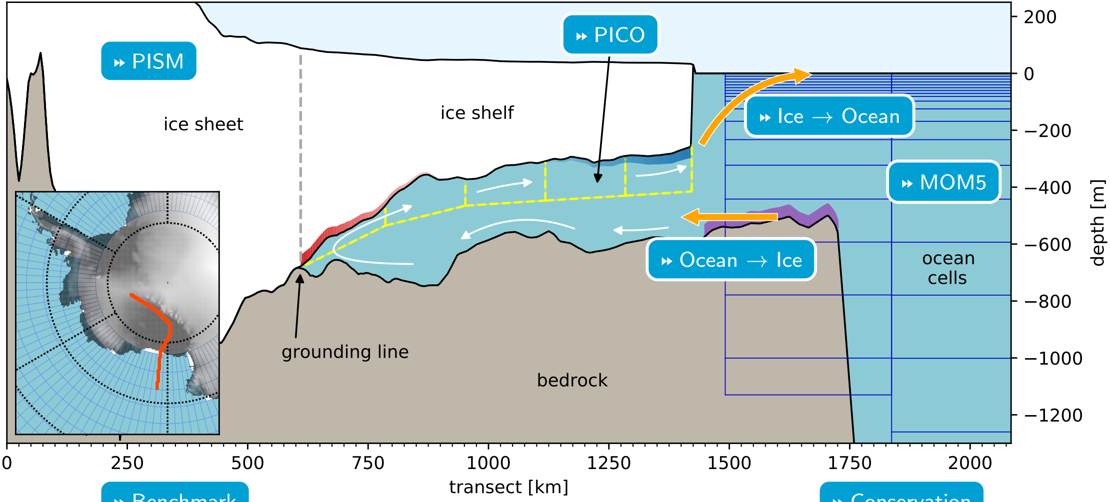
» Offline Coupling Framework



» Benchmark

» Conservation

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: 8x8km, 120 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

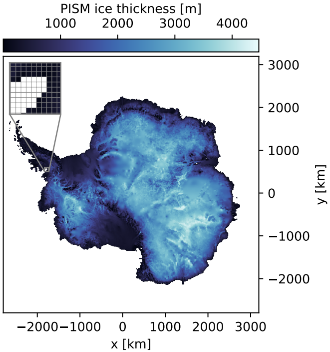


Figure 1: Antarctic ice sheet model by PISM on a 10km resolution as shown in the inset

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: coarse grid[3]
  longitude: 120 cells (3°)
  latitude: 80 cells (0.6° – 3°)
- 28 vertical layers (rescaled pressure coordinate p*)
- 8h timestep
- written in Fortran

more information: MOM5 website

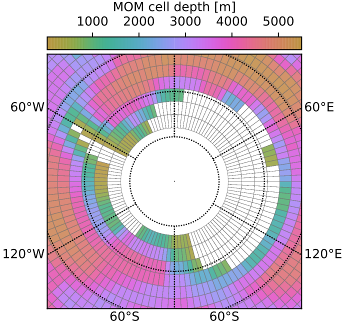


Figure 2: Stereographic South Pole projection of the MOM grid. Land cells are white and the grid is not defined below 78°S.

Offline Coupling Framework

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

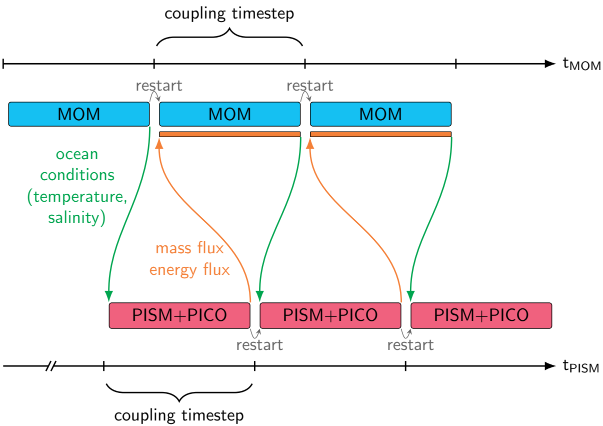


Figure 3: Alternation of ocean and ice sheet model execution. Regridding between the different grids, conversion of units and adaptation of dimensions is required in between.

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

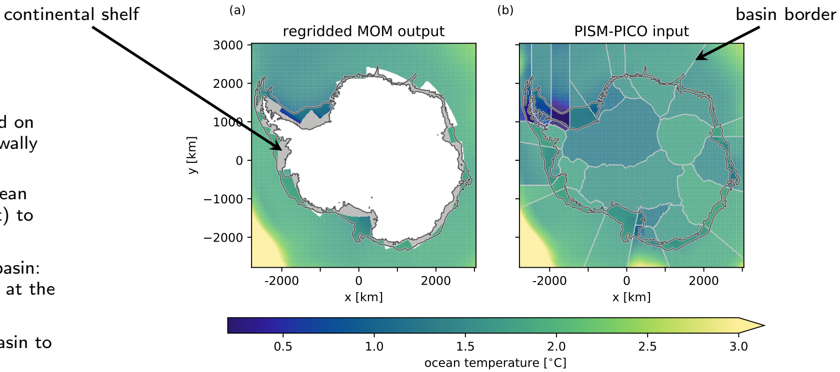


Figure 4: After regridding ocean variables to the ice grid, missing values are filled with edge averages of each basin. This ensures appropriate values for all areas of the continental shelf which is used for input in PICO.

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

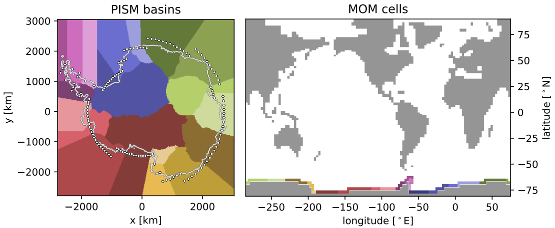
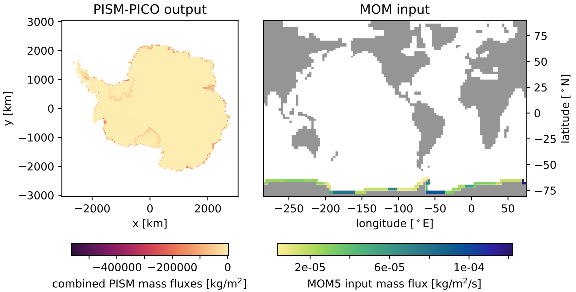


Figure 6: Redistribution of PISM mass fluxes to MOM5 ocean grid



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

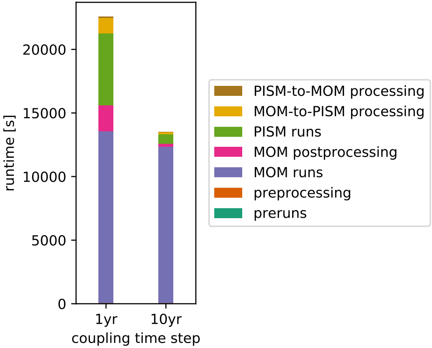


Figure 7: Aggregated run times of coupling framework components including pre-runs and pre-processing (insignificant), model execution times and inter-model processing. PISM run time in yearly coupling is about 8 times higher in decadal coupling.

Mass Conservation

examination of coupled mass PISM, MOM5 & SIS:

$$m_v = (m_o + m_{si} - smb_{osi} - d_{osi}) + (m_{li} - smb_{li})$$

$$\frac{d}{dt} m_v = \mathcal{O}(0)$$

m_o	mass MOM5 (ocean)
m_{si}	mass SIS (sea ice)
smb_{osi}	surface mass balance MOM5 & SIS
d_{osi}	model drift MOM5 & SIS
m_{li}	mass PISM (land ice)
smb_{li}	surface mass balance PISM

Energy Conservation

examination of energy fluxes during remapping from PISM to MOM5 grid

- conservative to double machine precision: $\mathcal{O}(10^{-16})$

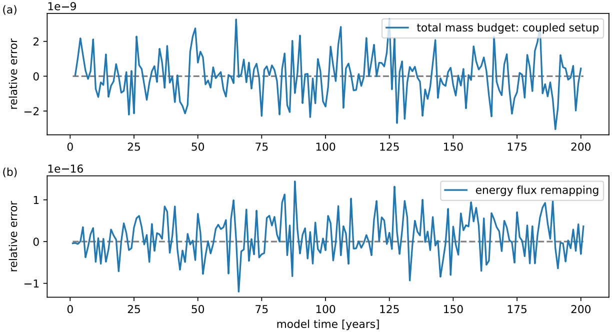


Figure 8: a) Relative change of coupled ice-ocean mass ($\frac{d}{dt} m_v / m_v$) is constant in order of 10^{-9}. b) Conservation error of energy flux remapping from ice to ocean grid is in the order of double machine precision

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