Dynamic ice sheet-ocean interactions in the Energy Exascale Earth System Model (E3SM)

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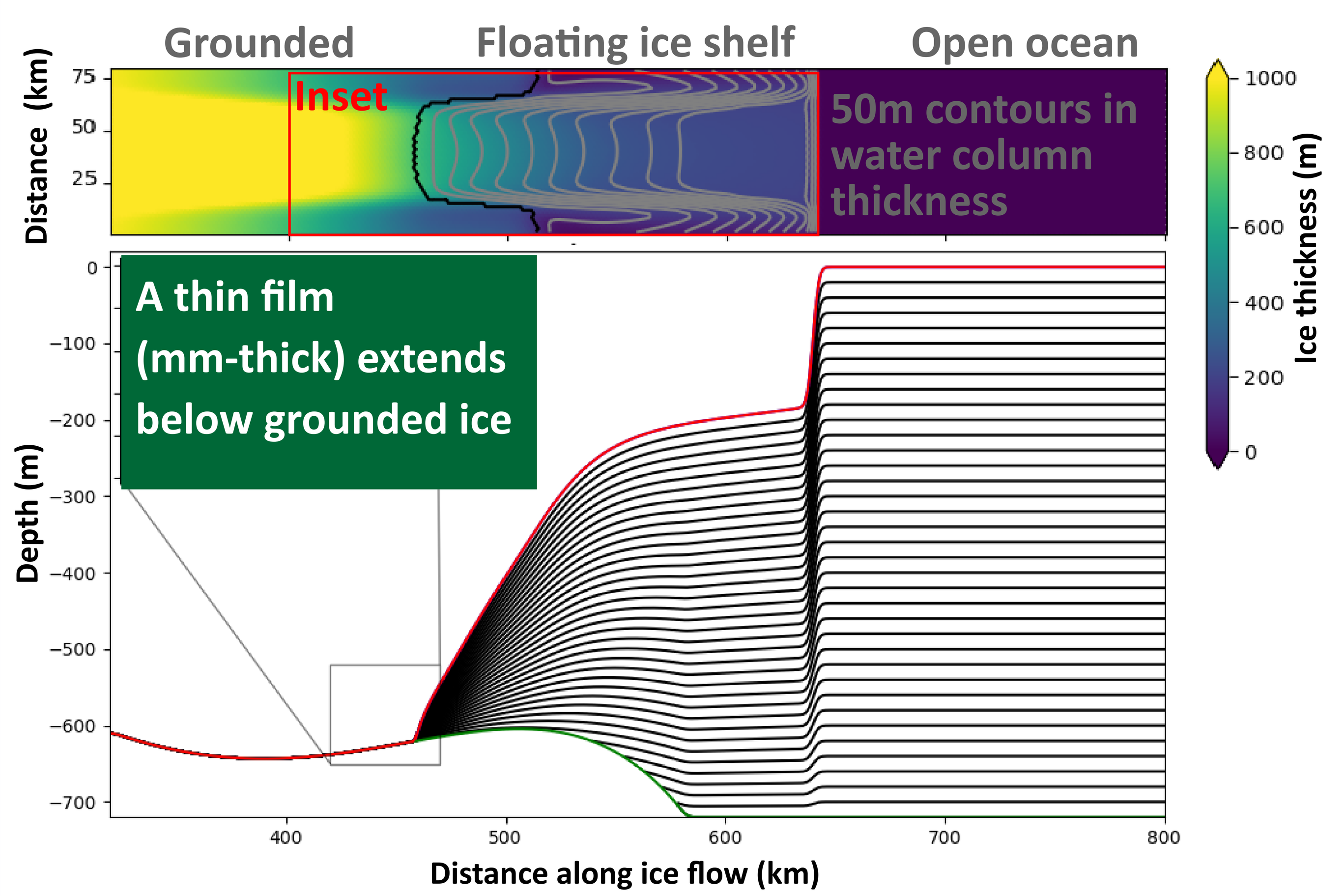
We report on progress in two aspects of ice sheet-ocean coupling. Frist, we use an idealized ice shelf-ocean configuration to explore the impact of including grounding zone processes in the ocean component of E3SM. Then, we show simulations in which ice-shelf melt fluxes are computed in the E3SM coupler.

Idealized geometry of an ice stream and shelf (ISOMIP+)



Methods

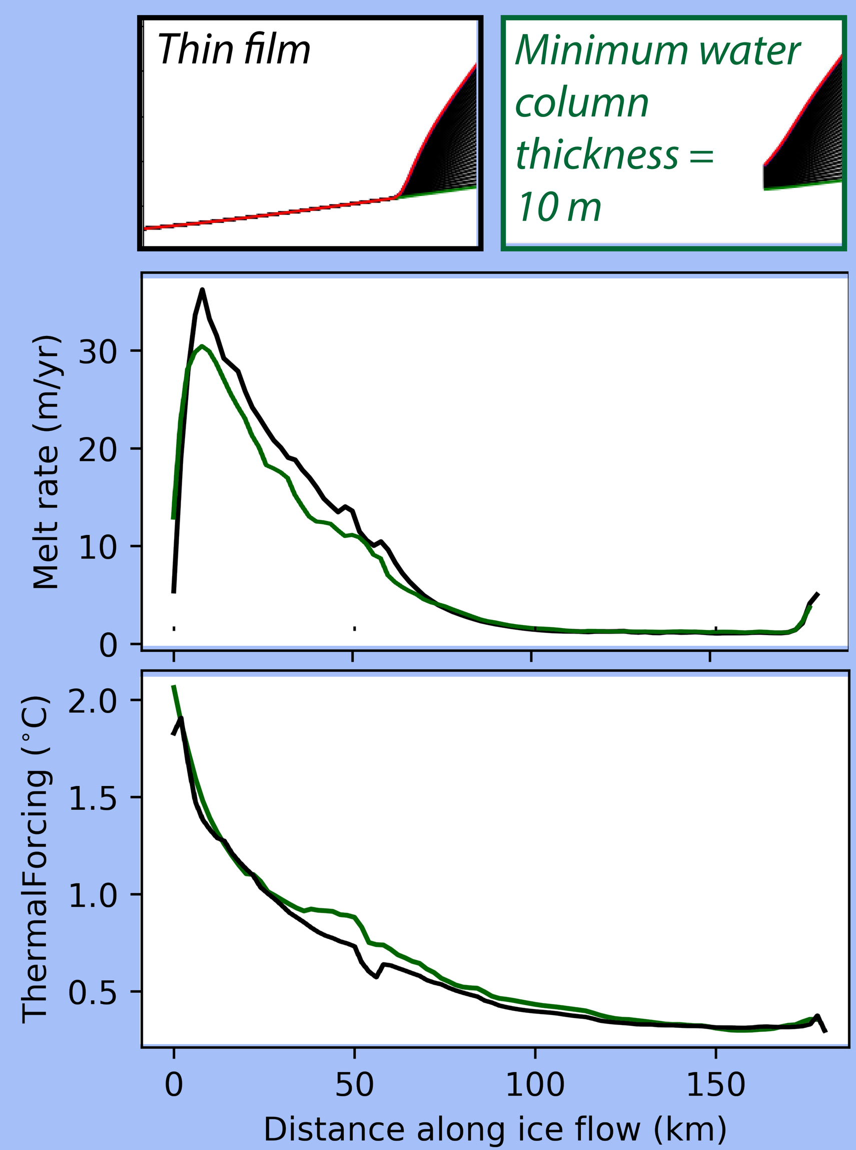
Suite of simulations with E3SM's ocean component, MPAS-Ocean

- Typical global ocean: 12 km horiz. res. in ice-shelf cavities
- This ISOMIP+ configuration: 2 km horiz. res.

Ice-shelf cavity evolves with prescribed land ice pressure field

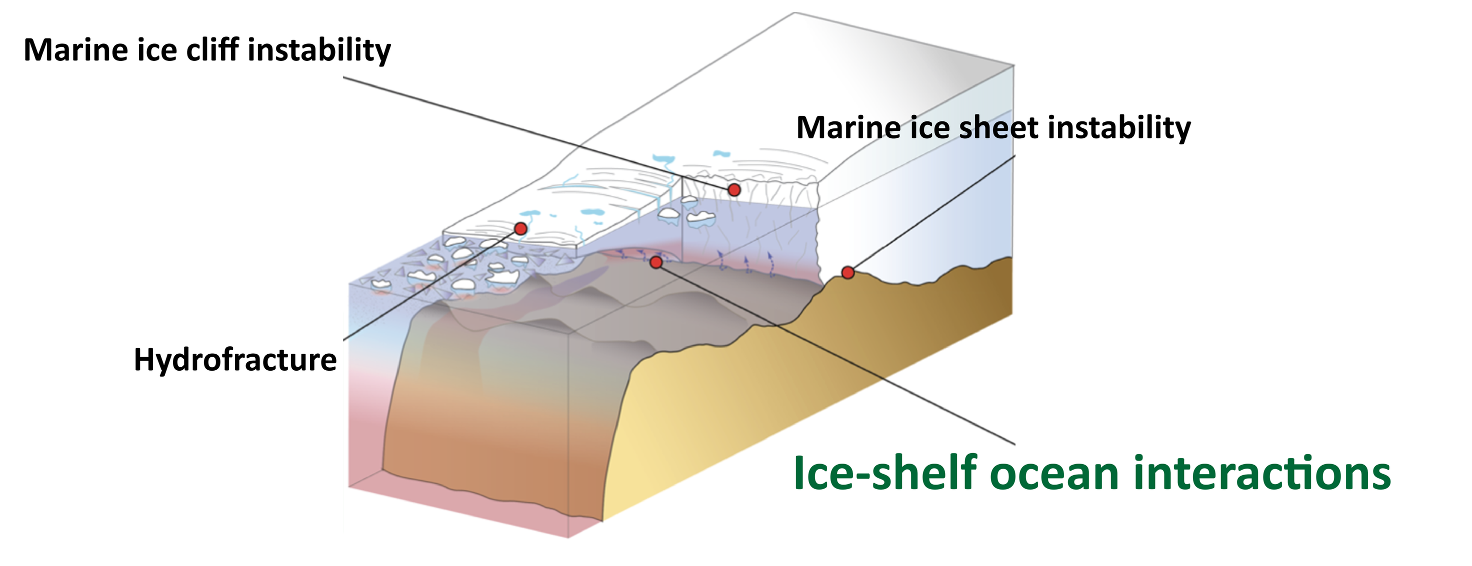
Dynamic grounding line migration with thin film wetting-and-drying algorithm

Resolving the grounding zone affects local thermal forcing and widespread melt rates (through friction velocity).

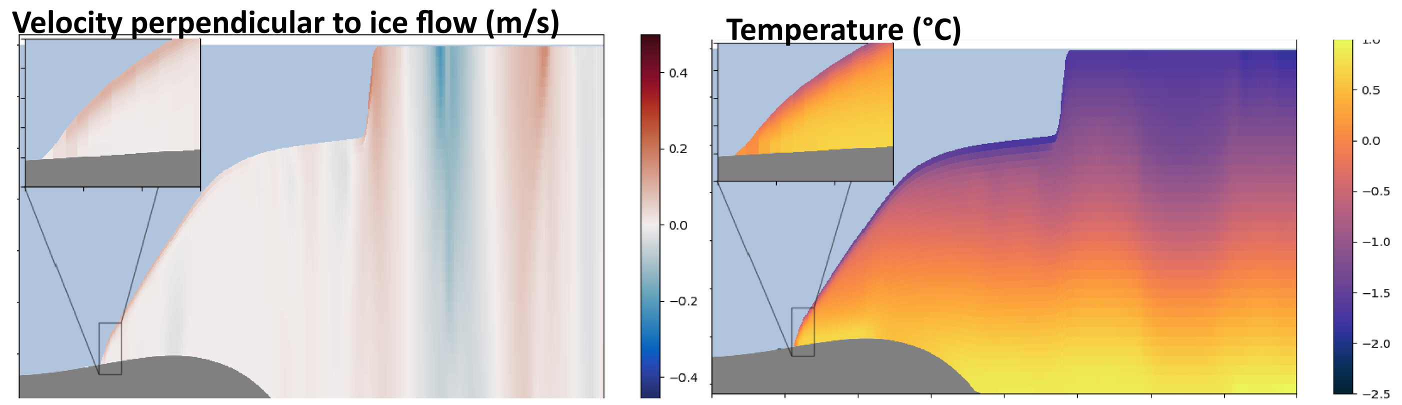


Melt rate peak near grounding line is amplified but thermal forcing is reduced close to the grounding line

Improving numerical representations of key processes relevant to sea-level projection:

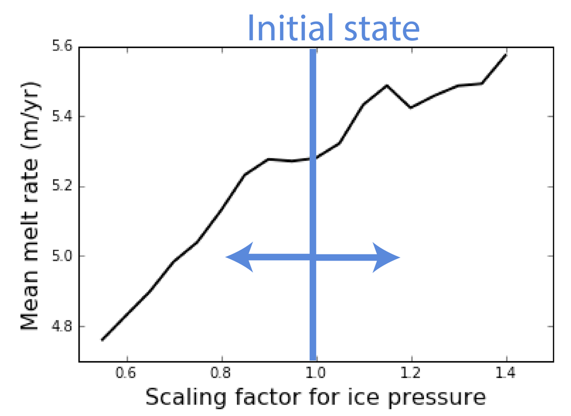


1 Simulated circulation in narrow ice shelf cavities



Simulations show the development of ice-shelf ocean boundary layer influences by Coriolis forces and buoyancy. We averaged ice-shelf ocean boundary variables over a 5-m vertical lengthscale for the 3-equation parameterization. This likely removes some of the benefit from enhanced vertical resolution in the grounding zone and enhances mixing there (inset).

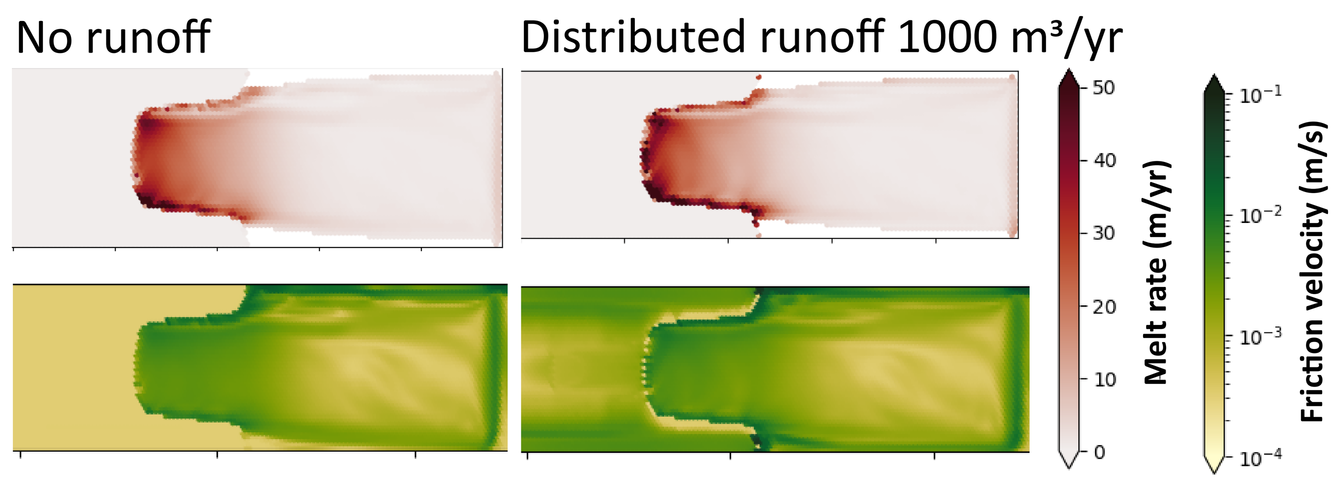
2 Ice shelf melt sensitivity to cavity geometry



We ran two simulations branched from the base case with decreasing or increasing land ice pressure at a constant rate of ±5%/year of the initial pressure field.

Grounding line migration rates are ~5 km/year because this ice stream has fairly high pressure gradients across the grounding line (strongly grounded).

3 With a thin film approach, subglacial runoff can flow across the grounding line

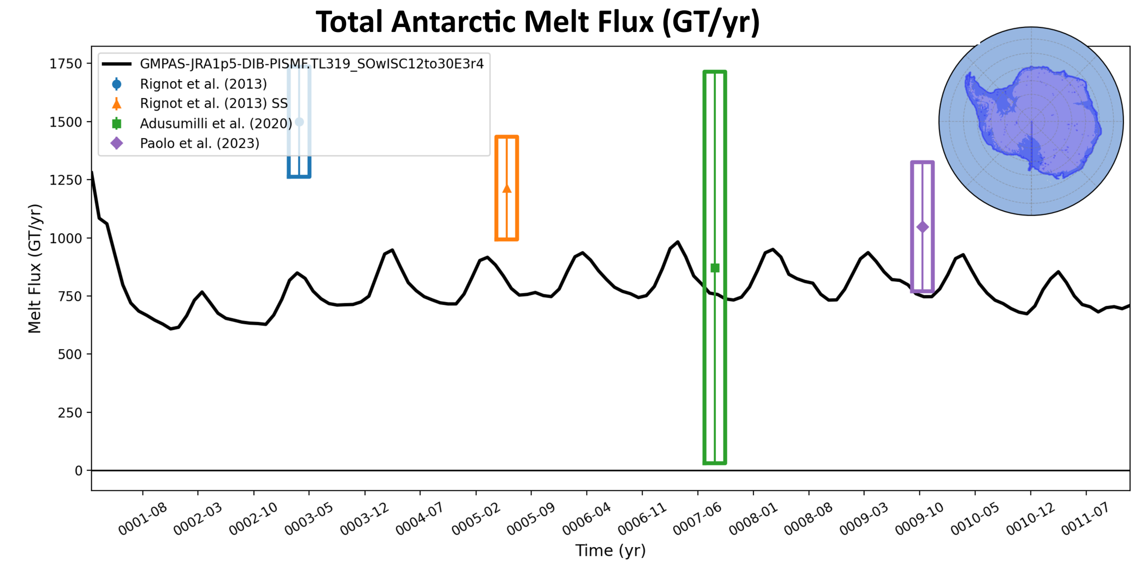


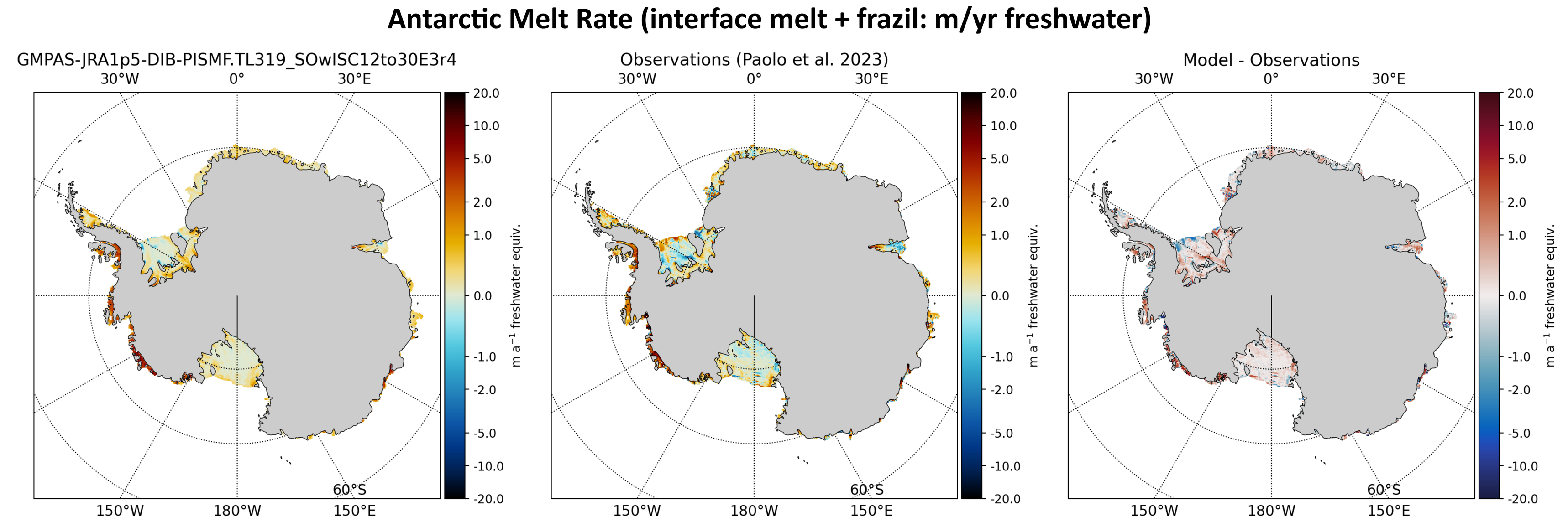
Subglacial runoff is known to enhance melt rates near the grounding line. With our approach, subglacial runoff can be prescribed below the grounded ice sheet and mix with ocean waters before it crosses the grounding line.

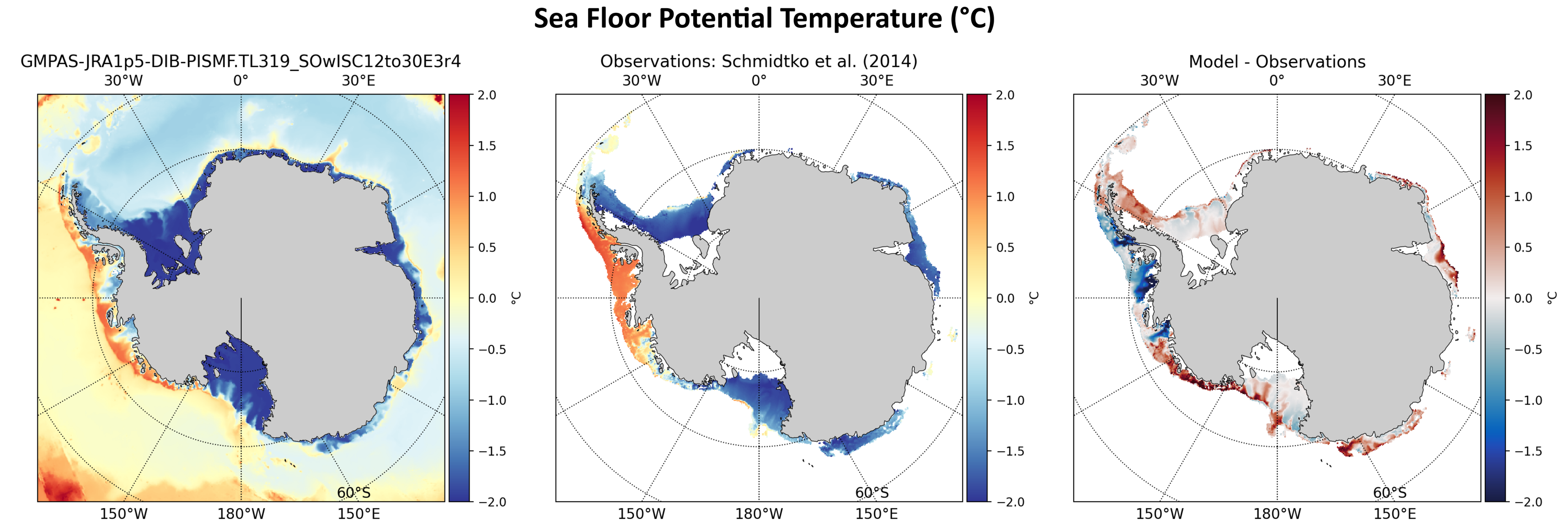
4 Global E3SM simulations with MALI topography

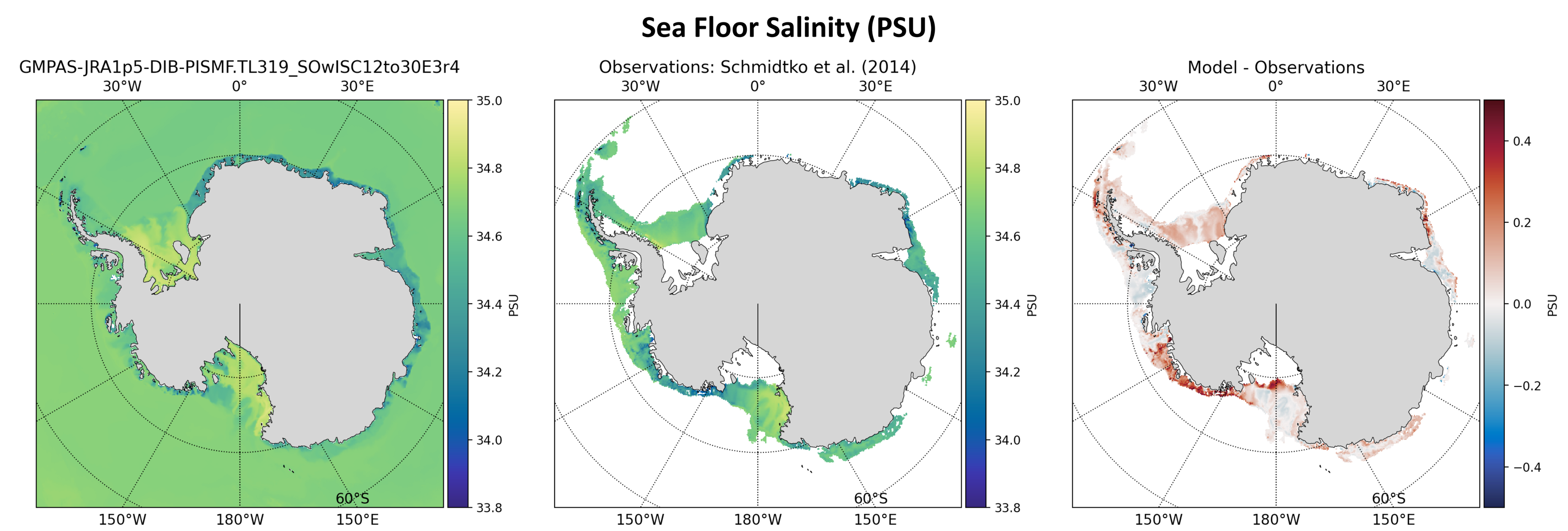
- Proof of concept
- Variable horiz. res; 12 km around Antarctica
- 11-year JRA1.5 forcing (1958-1968)
- Active ocean, sea ice and ice-shelf cavities
- Ice-shelf topography and Antarctic bathymetry from MALI initial condition
- Melt fluxes computed in MPAS-Ocean

- Simulations in progress:
  - melt fluxes computed in the E3SM coupler
  - land-ice pressure (i.e. ice topography) updated from MALI at each coupling step









Ongoing work

- Complete coupling in E3SM: ice pressure and draft from ice to ocean, melt rates from ocean to ice
- Algorithm can show some retreat inertia; further tuning needed
- Implementing wetting-and-drying on the barotropic time step of the split-explicit time integrator

References

ISOMIP+ configuration: Asay-Davis et al. 2016 GMD
E3SM v2.1 polar configuration: Comeau et al. 2022 JAMES
A similar wetting-and-drying algorithm: O'Dea et al. 2022 OM
Grounding line migration in an ocean model: Goldberg et al. 2018 OM
Coupled ice/ocean in an Earth System Model: Smith et al. 2021 JAMES
Melt sensitivity to subglacial runoff in ISOMIP+: Vaňková et al. 2024 TC

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