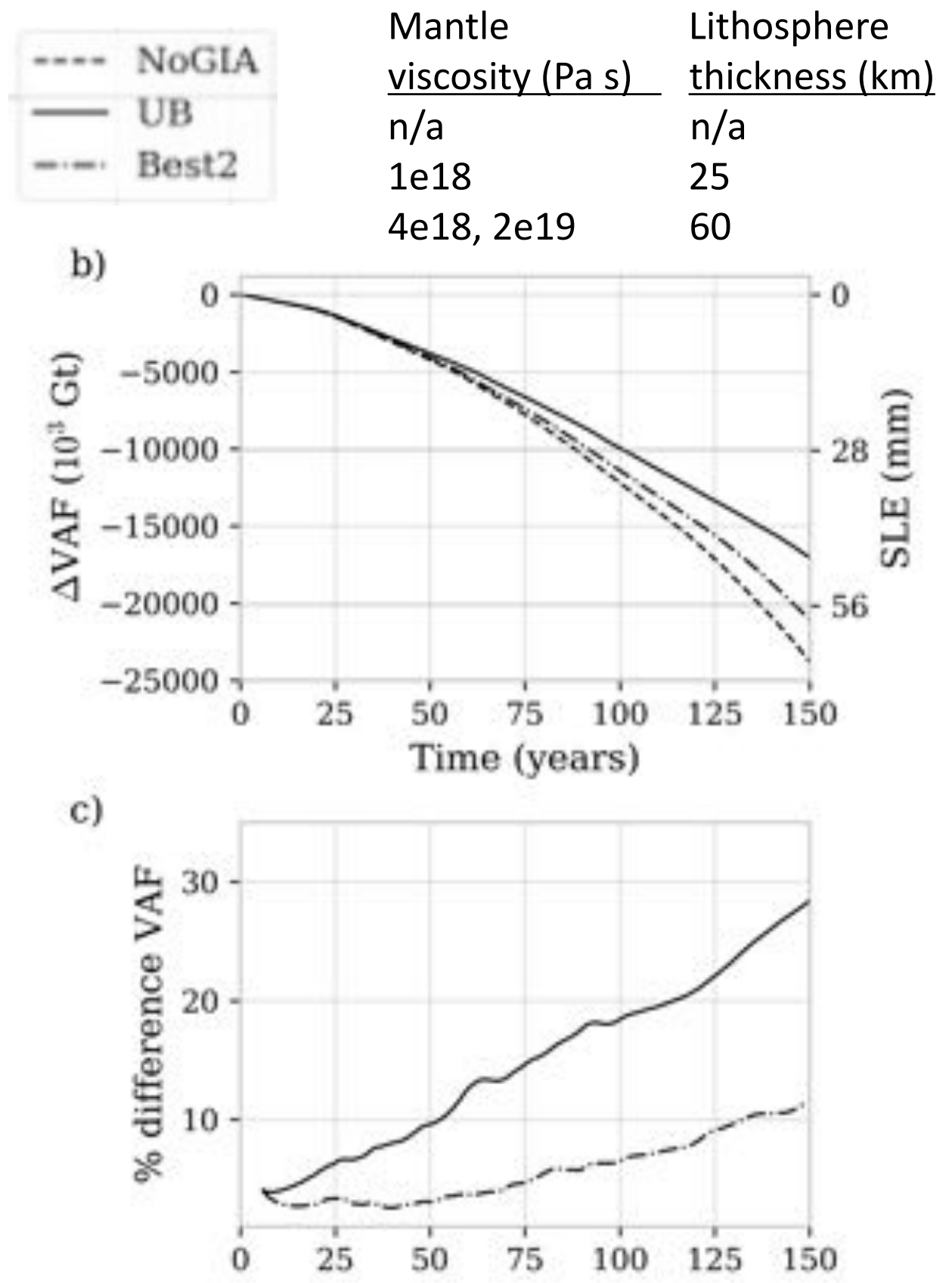
Probabilistic Sea-Level Projections from Ice Sheet and Earth System Models 2: Ice Sheet and Earth System Model Coupling

Solid Earth Coupling

Goals: Assess impact of accounting for interactions between ice sheets and solid earth for future retreat of important glaciers in Antarctica

Results at Pine Island Glacier using BISICLES

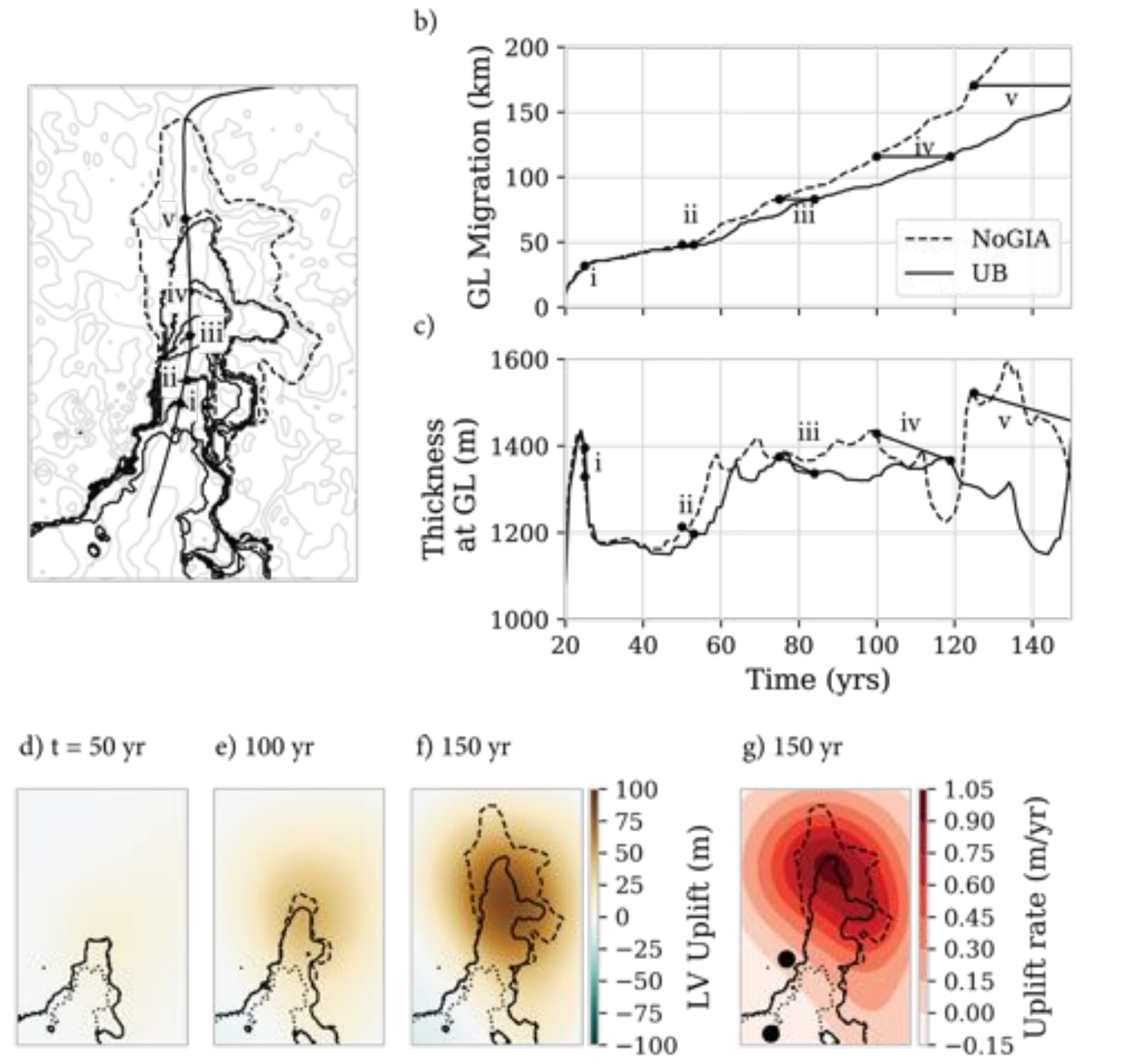
Including GIA reduces mass lost over 150 years by as much as 30%. **Below:** b) Change in total VAF. c) Percentage difference VAF between models with GIA and without.



	Mantle viscosity (Pa s)	Lithosphere thickness (km)
NoGIA	n/a	n/a
UB	1e18	25
Best2	4e18, 2e19	60

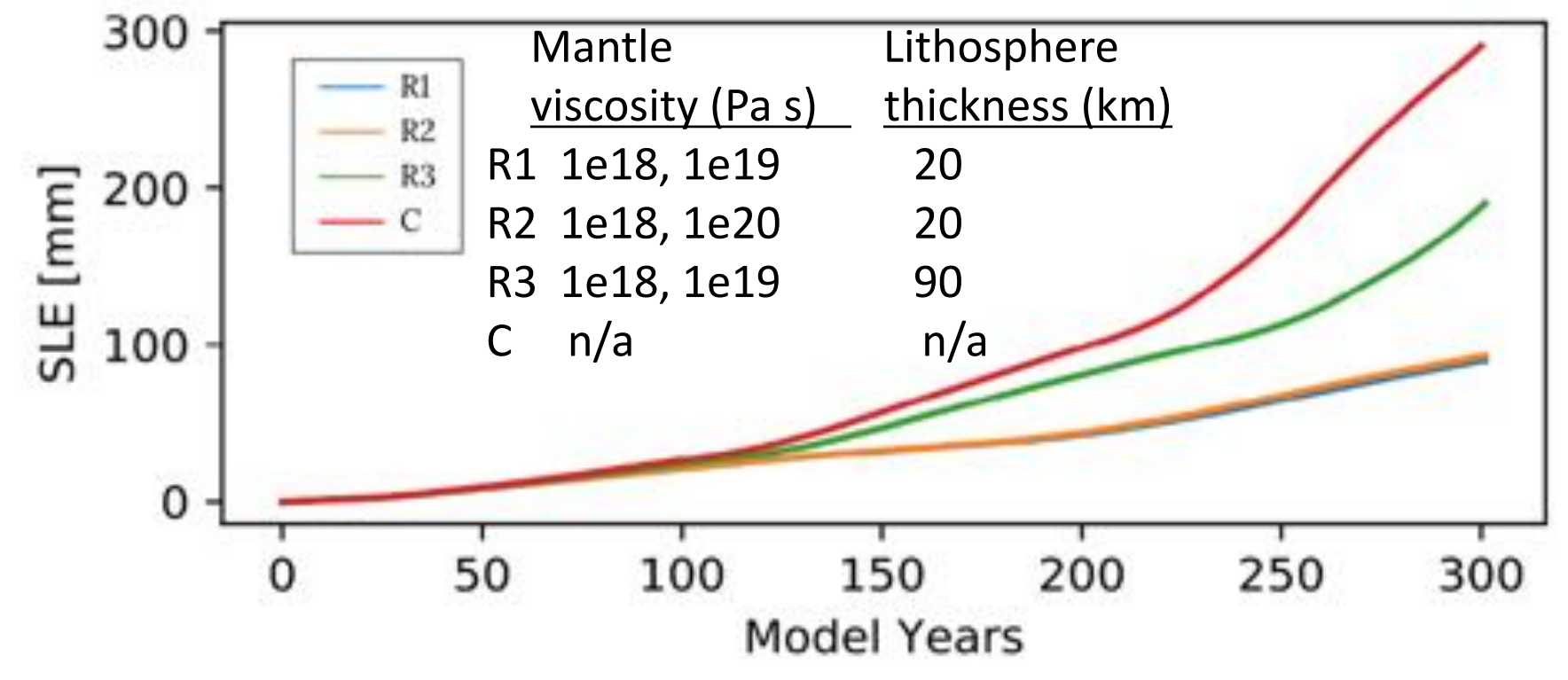
Mechanism of GIA stabilization

Below: a-c) grounding line retreat for uncoupled and UB (1E18, 20 km) simulations. Uplift decreases the thickness at the grounding line, stabilizing retreat.
d-g) Uplift and uplift rate. GPS locations (dots) miss the highly localized uplift.



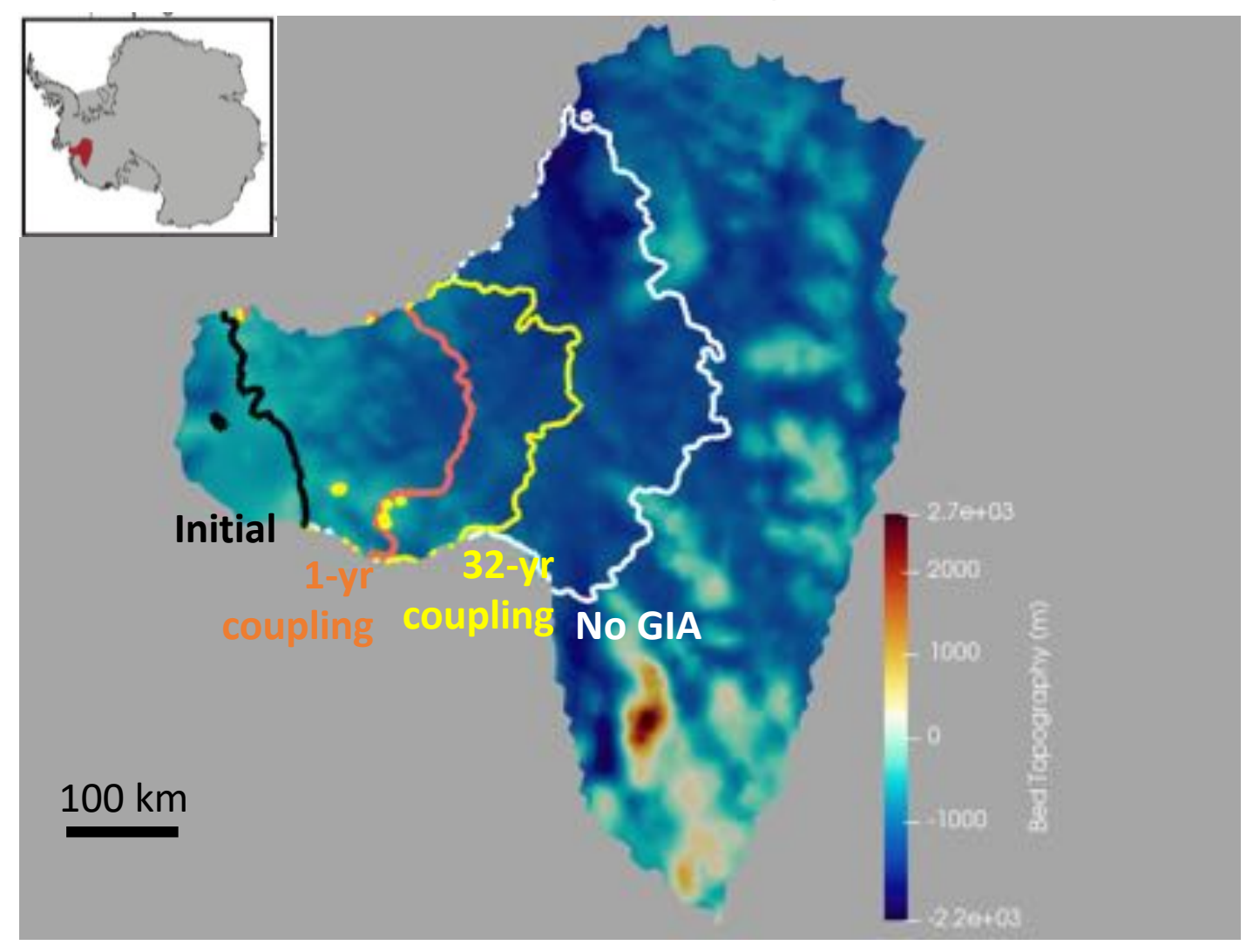
Results at Thwaites Glacier using MALI

Including GIA reduces mass lost over 150 years by 10-30% **Right:** Cumulative sea level rise equivalent with GIA and without. Uncertainties in solid earth parameters contribute to large uncertainty in sea-level rise projections.



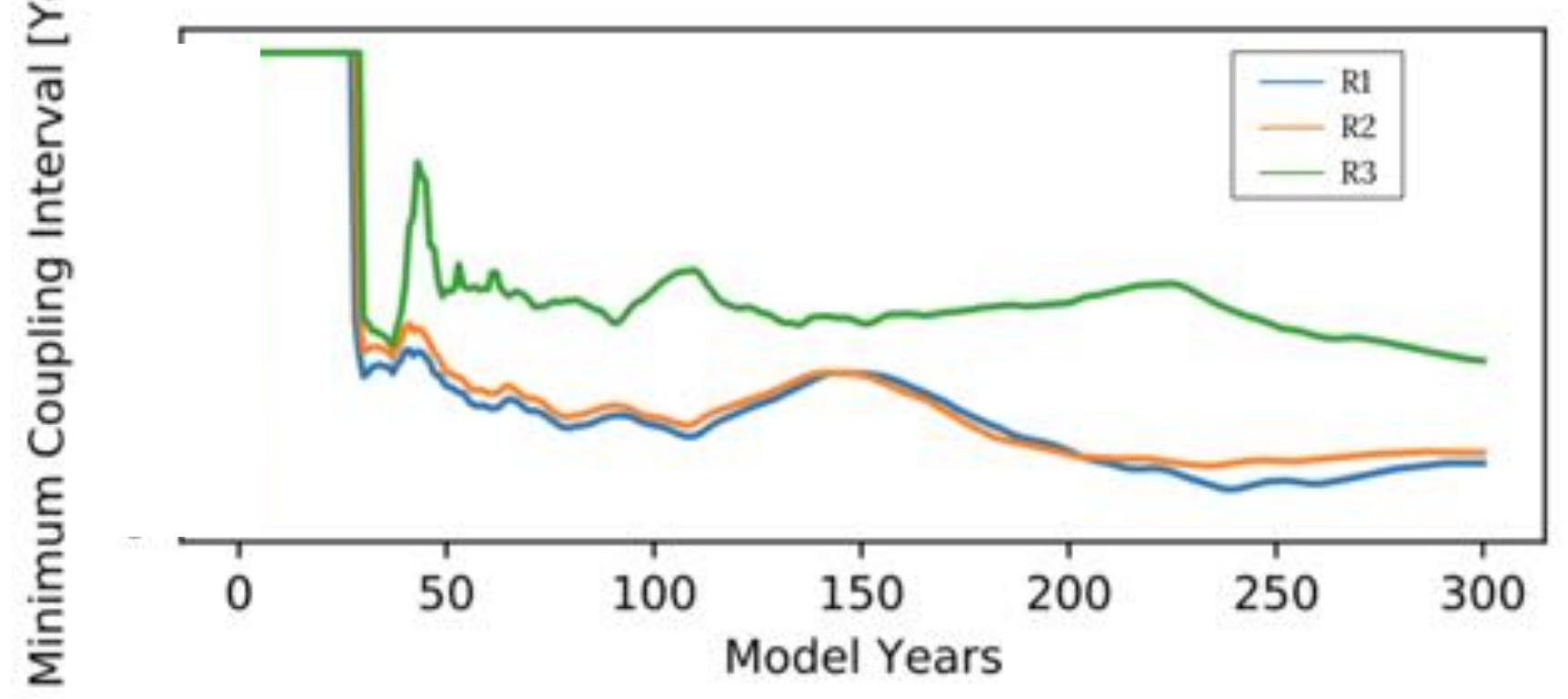
	Mantle viscosity (Pa s)	Lithosphere thickness (km)
R1	1e18, 1e19	20
R2	1e18, 1e20	20
R3	1e18, 1e19	90
C	n/a	n/a

Importance of GIA coupling timescale



Above: Grounding line position for Thwaites Glacier after 300 years using the MALI model coupled to GIA model. Insufficiently frequent coupling leads to large inaccuracy.

Assessment of required GIA coupling timescale: Results of convergence study of coupling interval between GIA model and MALI.



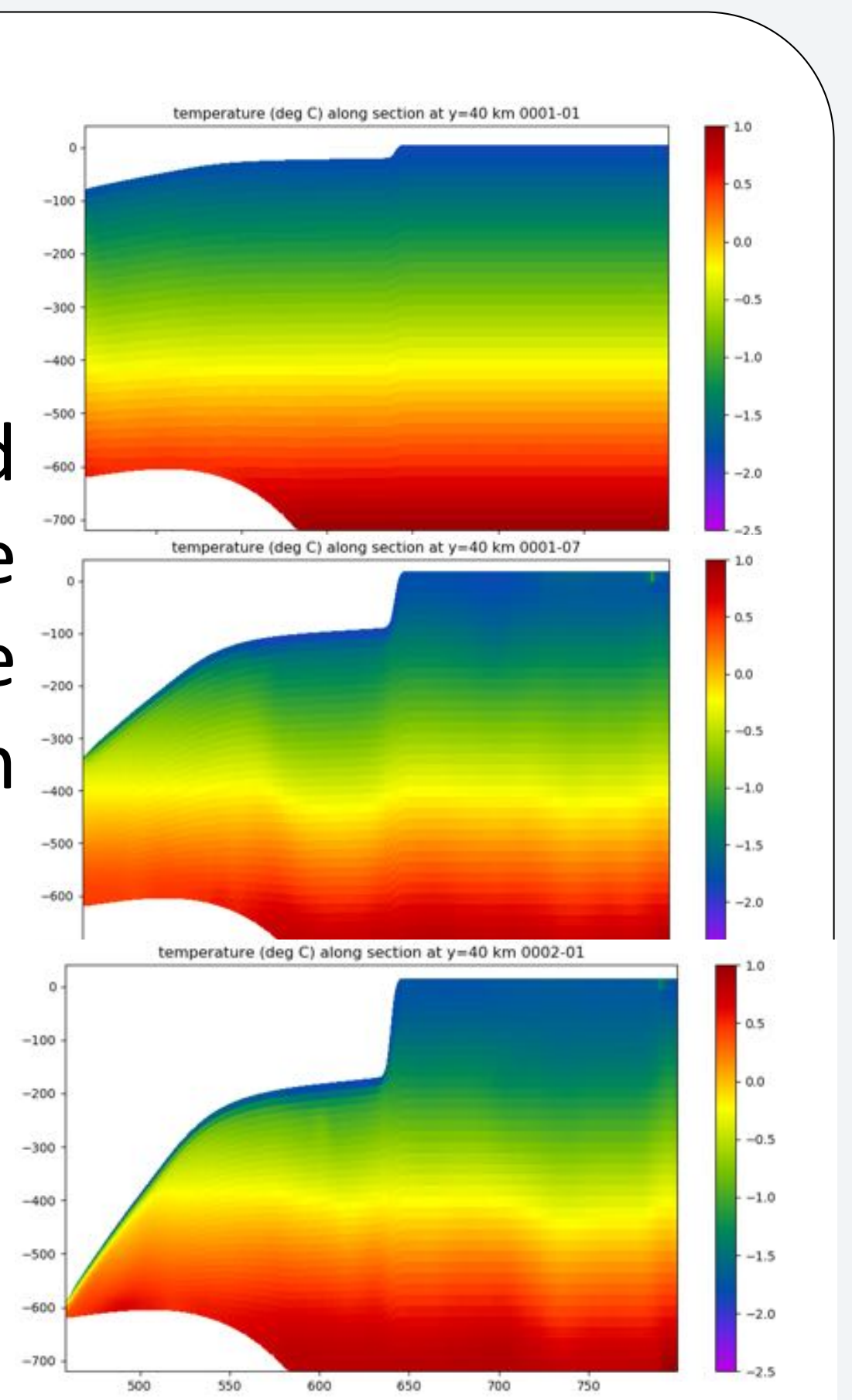
Above: The "minimum coupling interval" is defined as the coupling interval that permits <5% error in cumulative glacier mass loss relative to coupling every 1 year. Thickness of lithosphere has a strong control on the required coupling time-scale.

Future work: Directly compare results for BISICLES and MALI for a mesh including both Pine Island and Thwaites Glaciers (ongoing).

Ocean Coupling

Goals:

Currently, E3SM supports static shelves and fixed grounding lines. The improvements below are required to enable dynamic ice shelves, and include modification of fluxes, dynamic coupler fields, ocean algorithms, and standardized test cases.



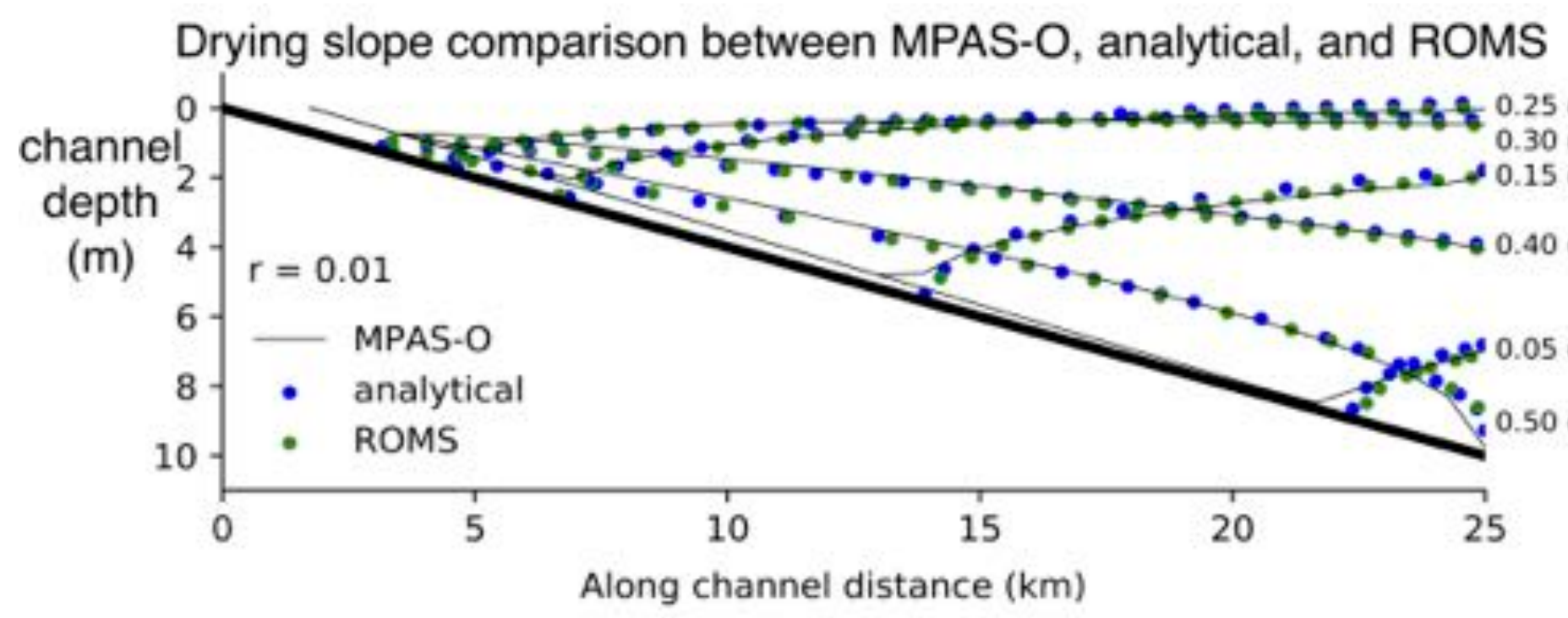
Above: A MISOMIP test case with a growing ice shelf but fixed grounding line

Ice shelf testing – In progress (right)

- MISOMIP test cases (designed by X. Asay-Davis) provide a framework for developing ice sheet-ocean coupling and for testing wetting-and-drying
- Dynamic land-ice forcing has recently been added to MPAS-Ocean, allowing ice shelves in MISOMIP to advance and retreat
- MISOMIP used to test new developments discussed below.

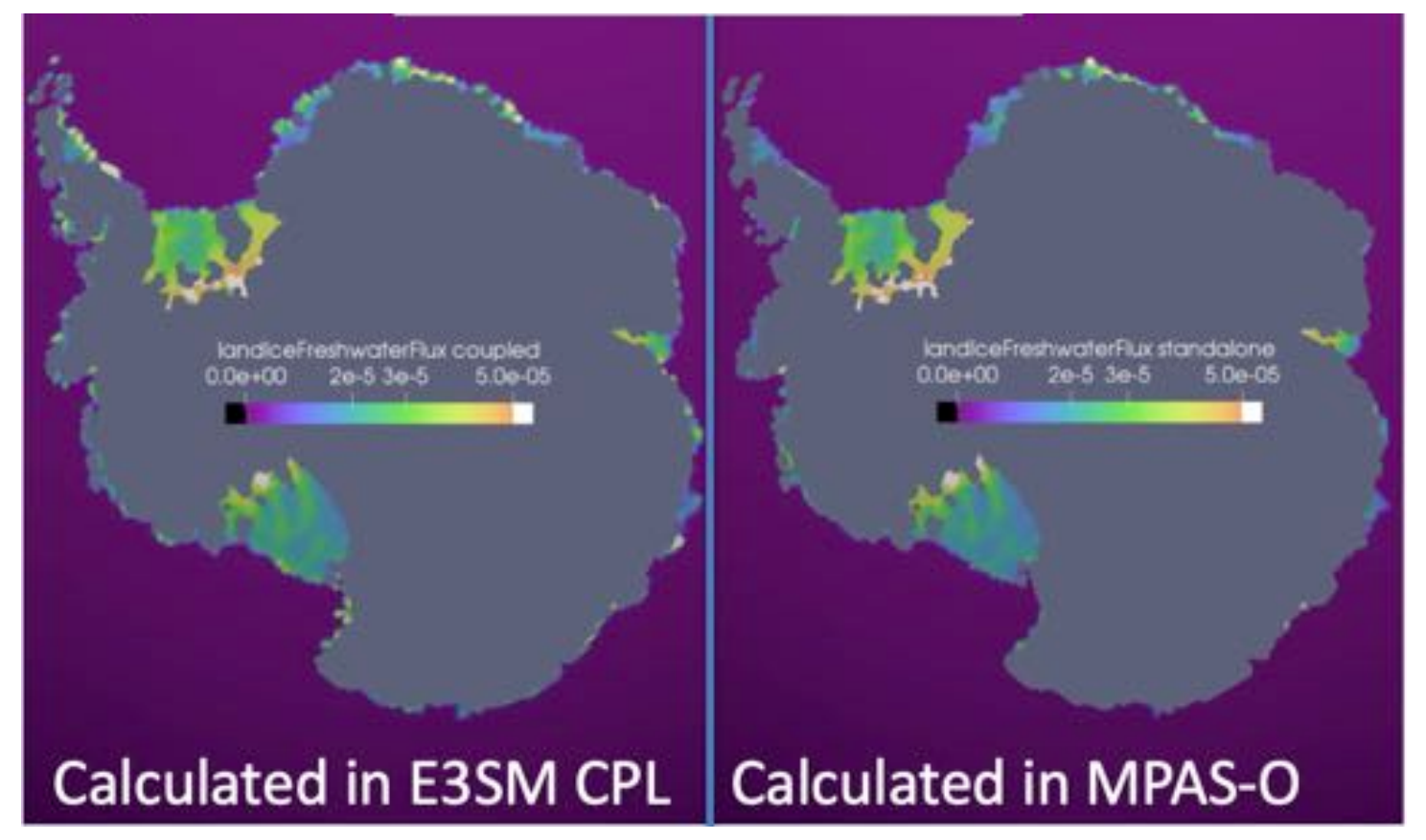
Wetting and Drying – In progress (right)

- Needed for moving grounding lines
- Preliminary implementation complete in Runge-Kutta-4 time stepping.
- Initial testing in coastal case matches analytic and ROMS solution.
- Next step is testing below ice shelves.



High-order pressure gradient – In progress

- Needed to prevent numerical instability from pressure gradient errors in thin, tilted ocean layers below ice shelves.
- **Short-term**, cheaper solution - nearing completion:
  - Semi-analytic pressure gradient with a new equation of state (Wright, 1997) nearing
- **Longer-term**, more expensive solution – in early stages:
  - Piecewise Parabolic Reconstruction (PPR) library by collaborator D. Engwirda has been linked into MPAS-Ocean and tested internally.
  - Algorithm design uses high-order vertical interpolation of temperature and salinity.
  - Code modification and testing is underway.

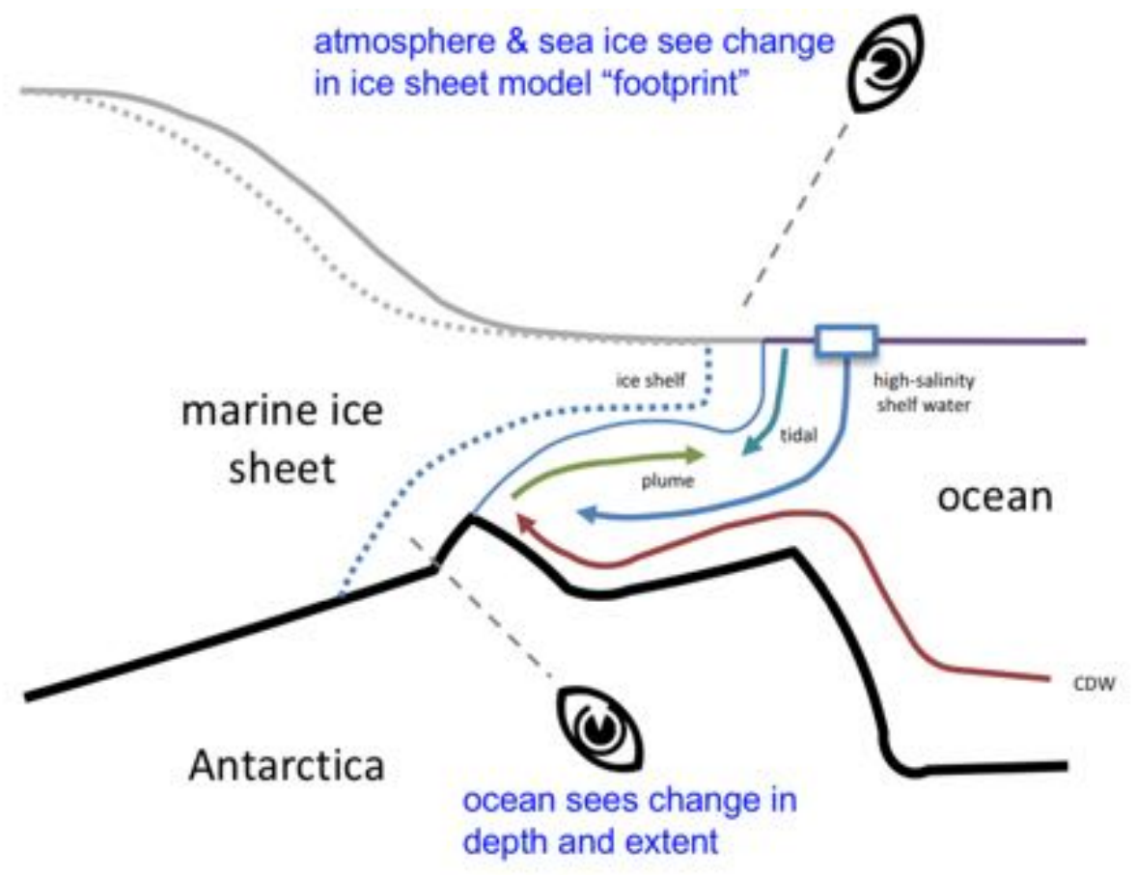


Ice Shelf Melt Fluxes – Complete (left)

- Previously calculated in MPAS-O; calculation and code moved to E3SM coupler
- On OCN coupling interval but GLC grid
- Ice shelf geometry and temperature from MALI
- First step to active ice sheets in E3SM

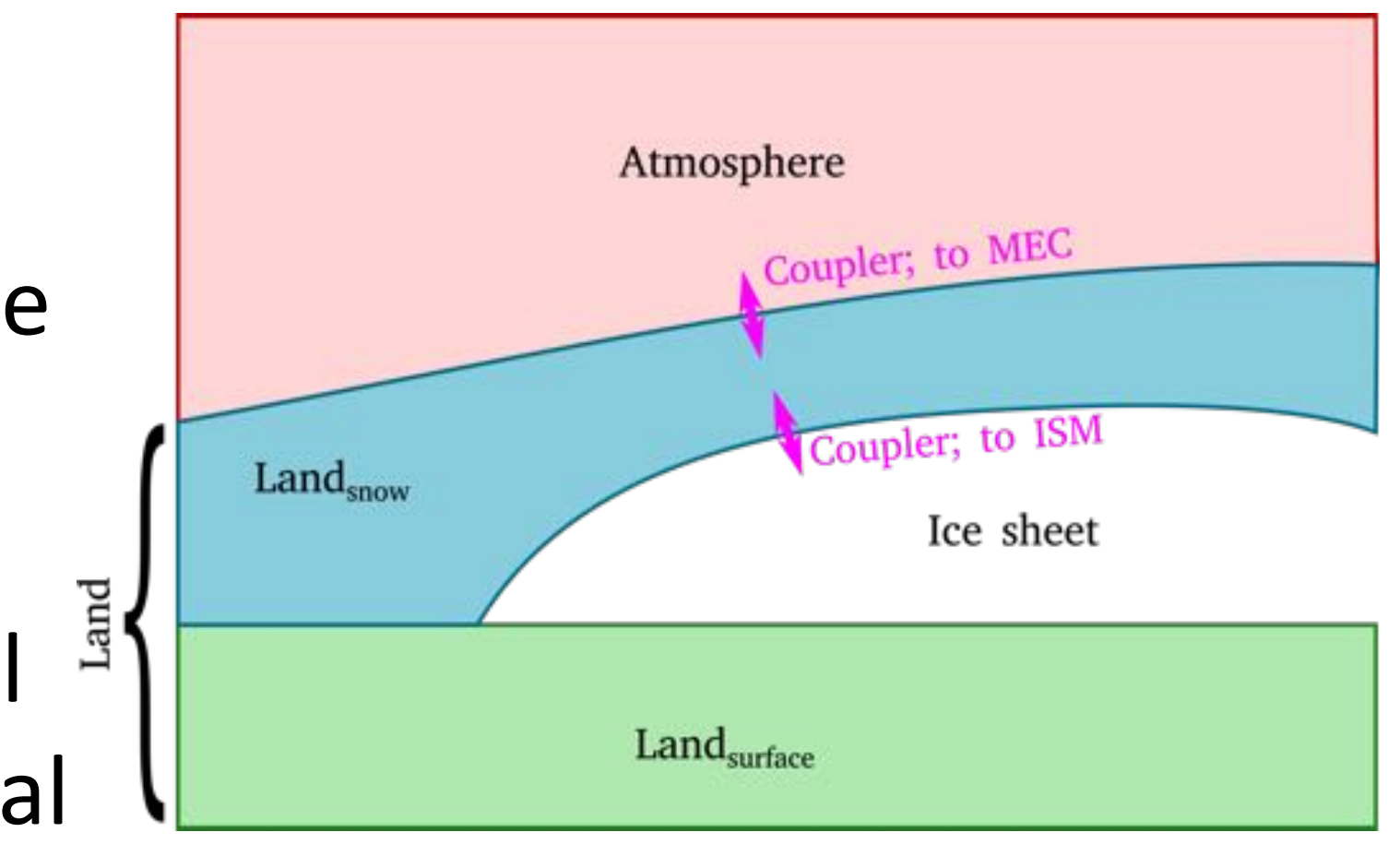
Dynamic component footprints – In progress (right)

- Required for dynamic ice shelf calving front
- Allows other model components to "see" change in ice sheet / shelf shape
- Working on porting progress under PISCEES



Atmosphere Coupling

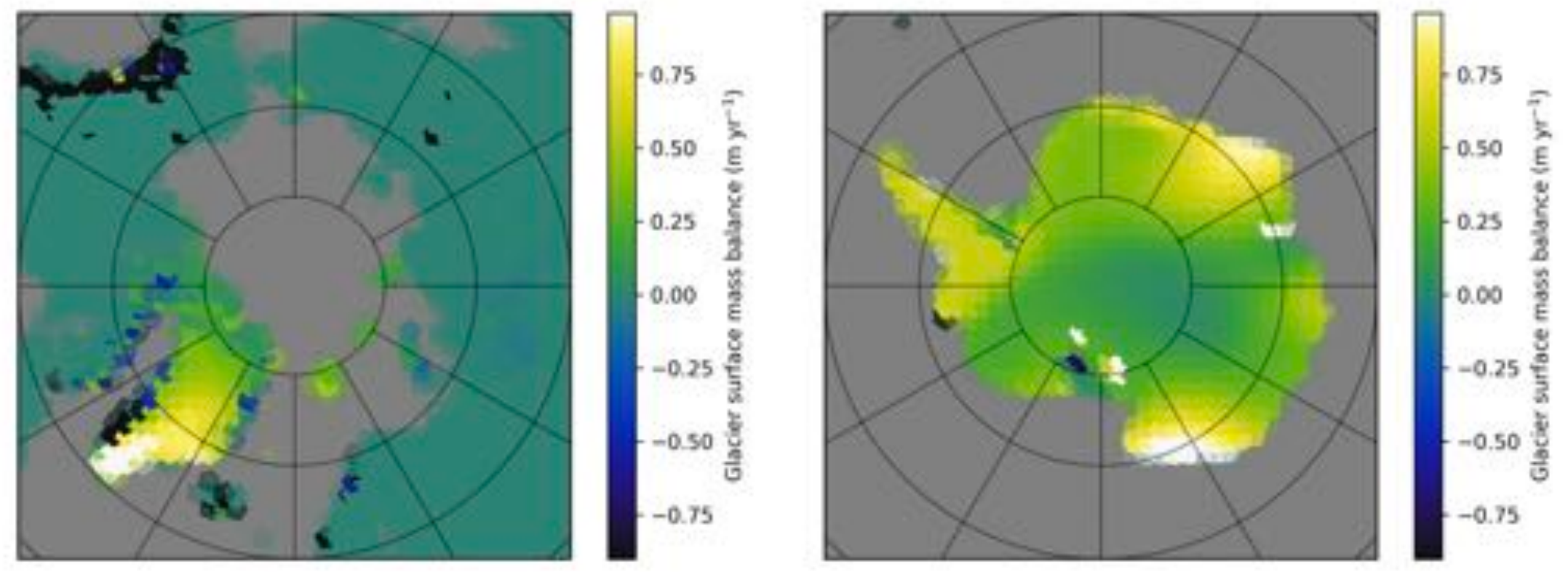
Goals:



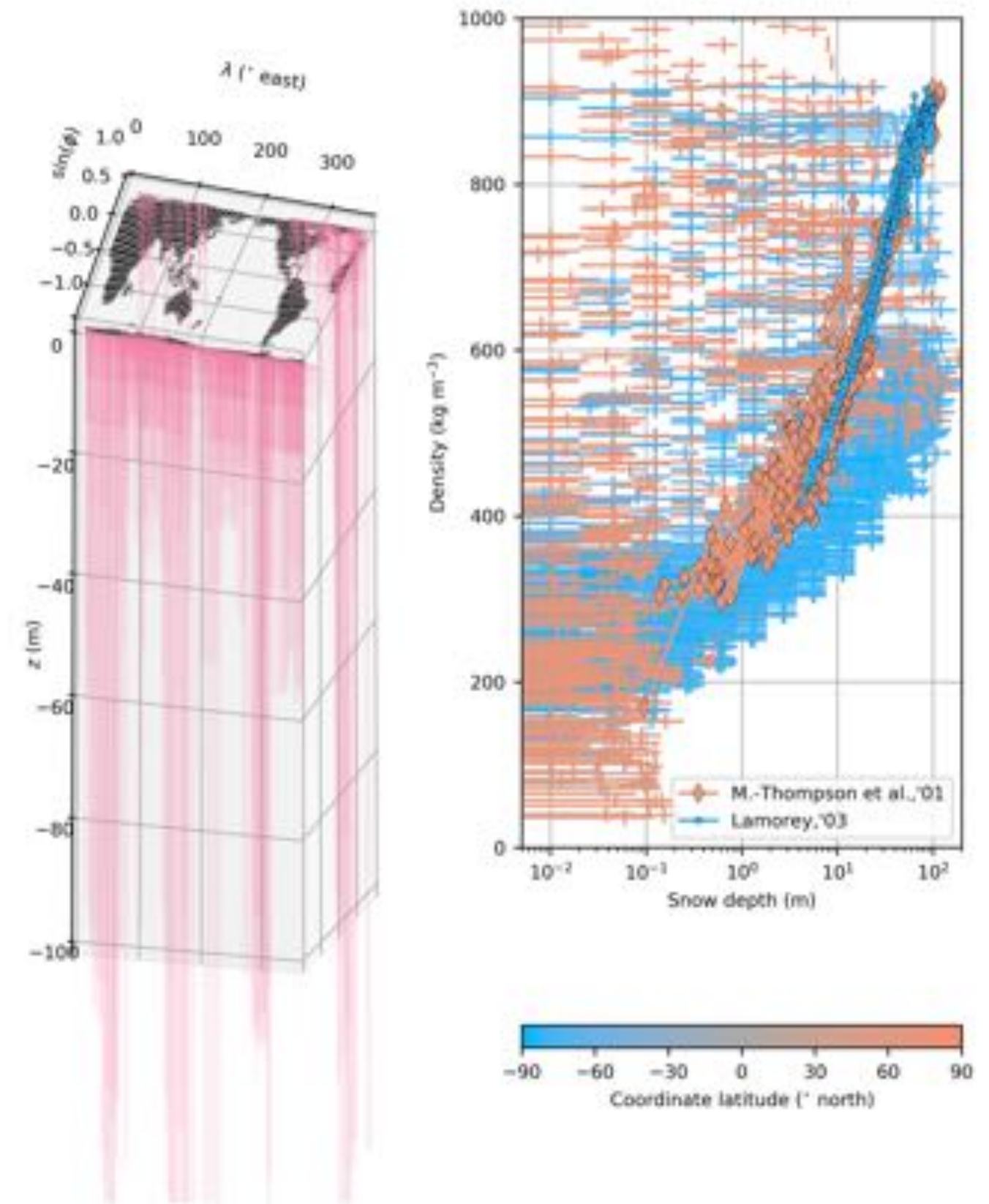
Ice sheet mass balance is strongly controlled by surface / atmosphere interactions. Surface mass balance (SMB) is the main source of mass gain (loss) for Antarctica (Greenland). E3SM suffers from (1) simplified snow model physics that don't accurately represent critical surface / atmosphere interactions and (2) grid resolutions that prevent accurate representation of steep SMB gradients along ice sheet margins. We are working to fix these problems in E3SM to improve the accuracy of the SMB that will eventually be received by coupled ice sheet models.

Snowpack model: Extend depth from ≈1m to ≈100m

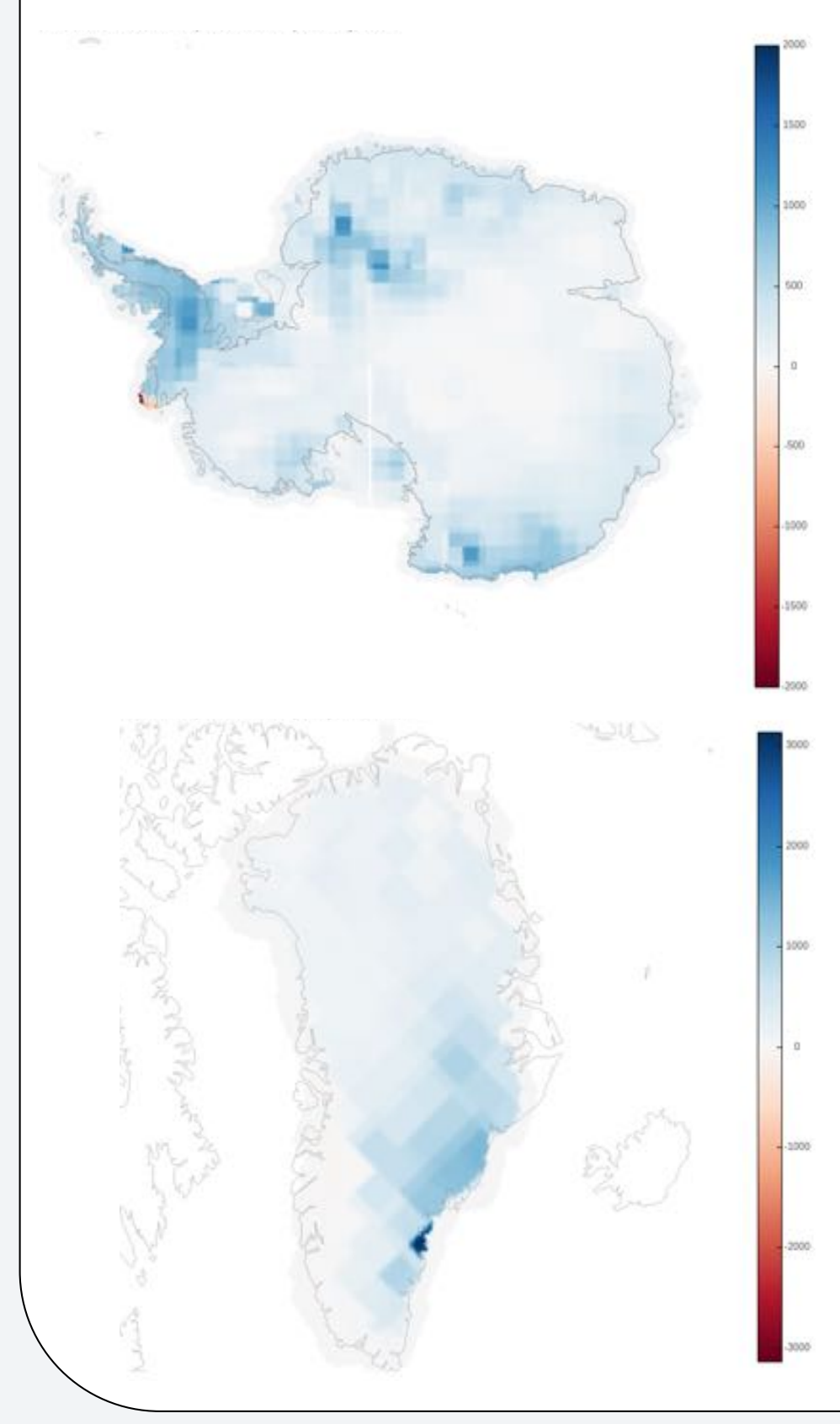
- observed snow/firn-to-ice transition is ≈100m or more
- melt water retention and refreezing requires 15 m min snowpack
- shallow snow model can expose bare ice directly to atmosphere too early, dramatically changing the surface energy budget and albedo feedback
- these changes require new model development, testing, and validation



Above: Early 20th century Arctic and Antarctic SMB calculated in E3SM's Land Model



Above: Firn depths and densities 100 years into a pre-industrial simulation, compared with observations from Antarctica (blue) and Greenland (brown)



SMB downscaling:

- E3SM downscales SMB to MALI using multiple elevation classes
  - initial testing (left) suffers from coarse grid imprinting
  - downscaling not yet available for new atmosphere grids
  - downscaling only for a single ice sheet at a time
- **In progress –** improved coupling
  - PR for support of new grids with combined AIS-GIS MALI mesh (calculate SMB for AIS and GIS *simultaneously*)
  - validation and testing of SMB (via MPAS-Analysis and LIVVkit)
- **Planned –** improved coupling
  - move MEC downscaling from cell level to ELM topo classes
  - improved downscaling computations and remove grid imprinting to better capture SMB gradients

Left: Mean surface mass balance (mm w.e.) from a 20-year cold-start run of E3SM (IGCLM45_MLI compset; new ne30_oECv3_aisgis grid) downscaled from ELM to the MALI mesh for Antarctica and Greenland.

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https://doe-prospect.github.io/