Sensitivity of Ice-Ocean Coupling to Interactions with Subglacial Hydrology

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Motivation

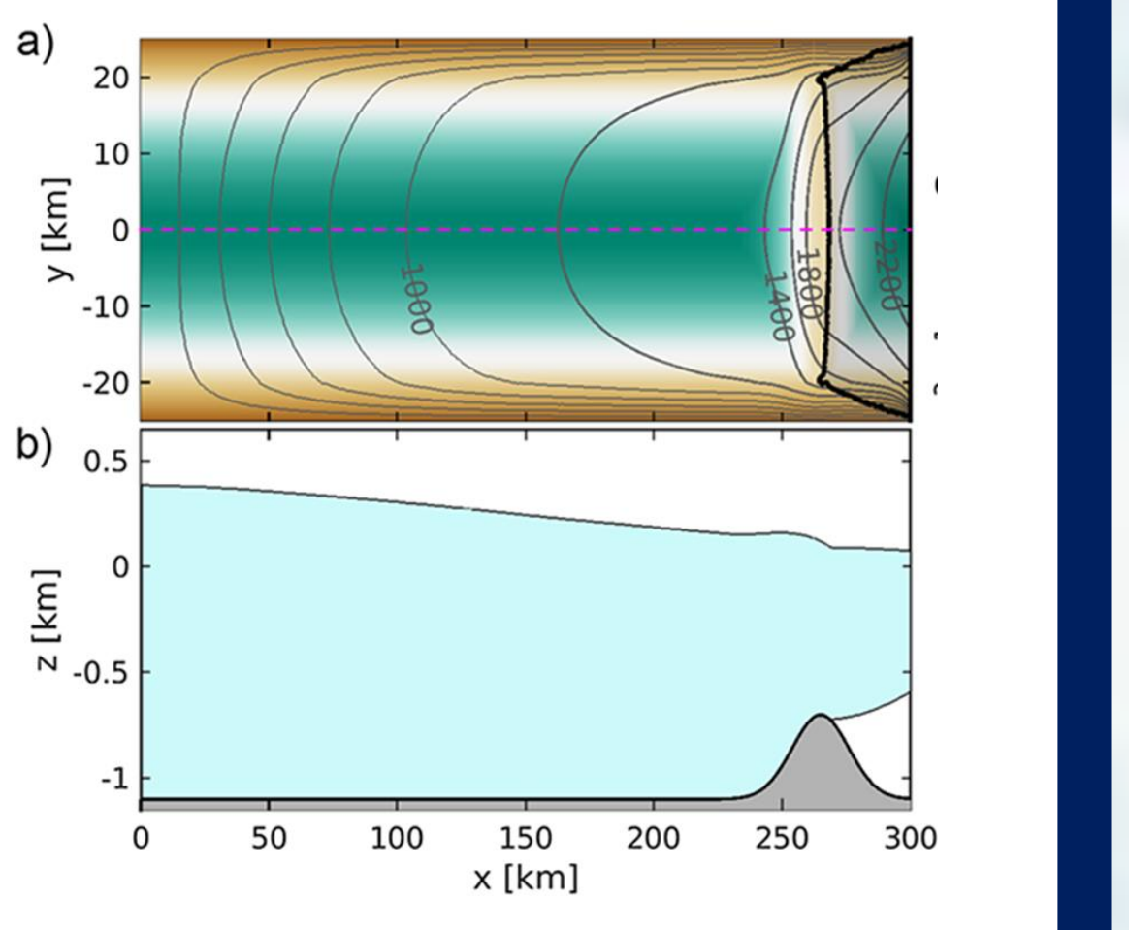
Correctly representing grounding line and calving-front dynamics is of fundamental importance in modeling marine ice sheets. One likely climate driver for marine ice-sheet instability is subshelf melting driven by warm(ing) ocean water intruding into subshelf cavities. Understanding and modeling this will require coupled ice sheet-ocean modeling.

Recent work by De Rydt and Gudmundsson (2016, DOI: 10.1002/2015JF003791) found that warm ocean water interacting with a pre-existing subglacial lake in an idealized ice-ocean coupled system could contribute to rapid grounding-line retreat far in excess of what was predicted using parameterized forcing applied to a standalone ice sheet model, demonstrating the need for the use of coupled models to better understand the dynamics of ice-ocean coupling in the context of grounding-line retreat.

Pine Island Glacier Test Problem

Bathymetry:

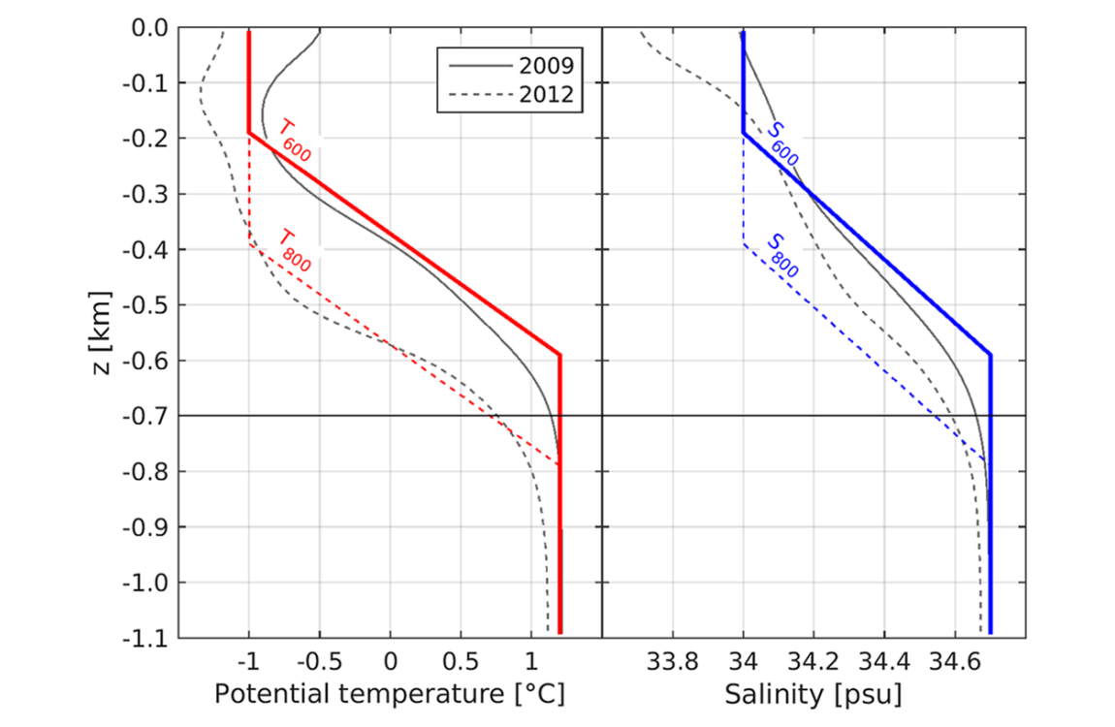
- Pine-Island Glacier-emulating geometry from DeRydt and Gudmundsson (2016)
- Streamwise parabolic trough with a transverse Gaussian ridge.
- "open-ocean" restoring at domain edge.
- Ice sheet is spun-up to steady-state with no sub-shelf melting.



Test-case geometry: (top) bathymetry, (bottom) centerline cross-section. Blue is ice, grey is bedrock, and white is ocean. Ice flow is from left to right.

Forcing:

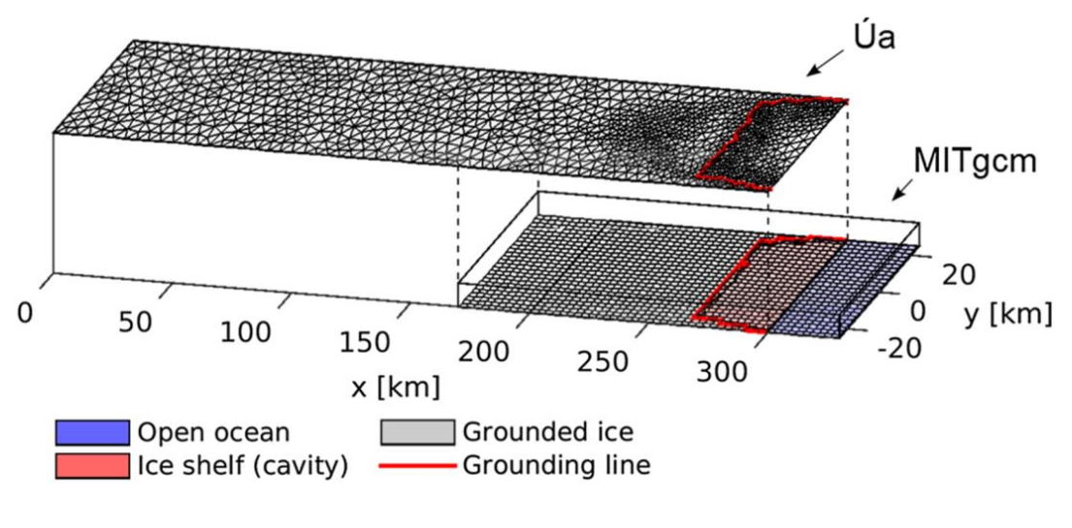
- Turn on ocean model with open-ocean thermocline restoring profile.
- Evolve coupled ice-ocean system for 100 years.



"Open-ocean" restoring: (left) potential temperature and (right) salinity profiles with thermocline at 600m depth.

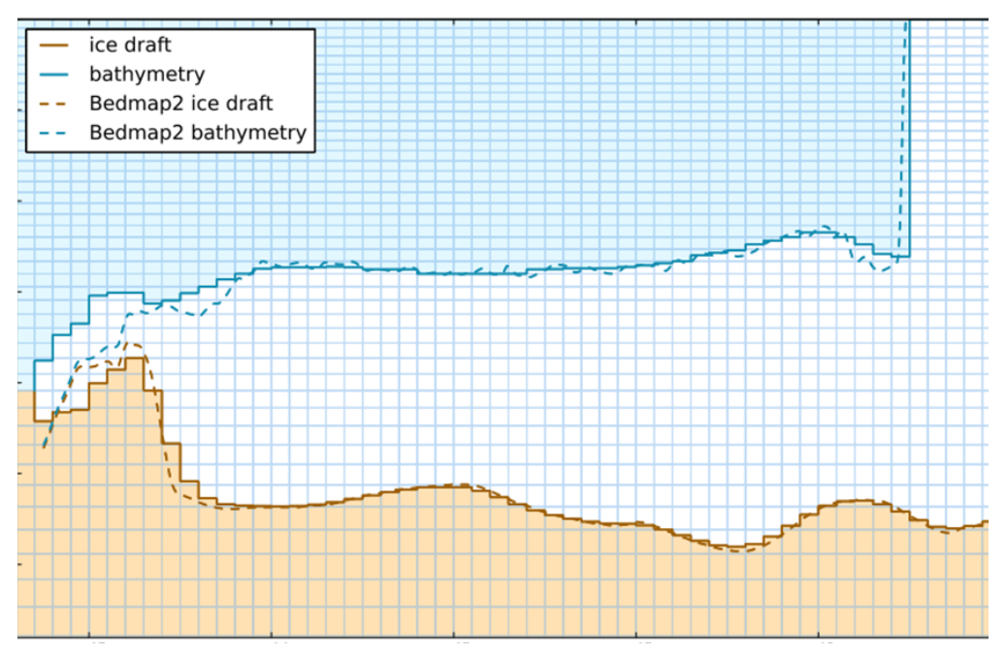
• Two Coupled Models:

- **Both models:** Ice, ocean models run autonomously, coupling through periodic exchanges of ocean-model-computed subshelf melt rates and ice-sheet-model computed shelf geometries and grounding line locations.
- **Model 1: MITgcm/Ua**
  - **Ua:** Shallow-Shelf Approximation finite-element ice sheet model.
  - **MITgcm:** finite-volume, non-hydrostatic, structured-mesh.



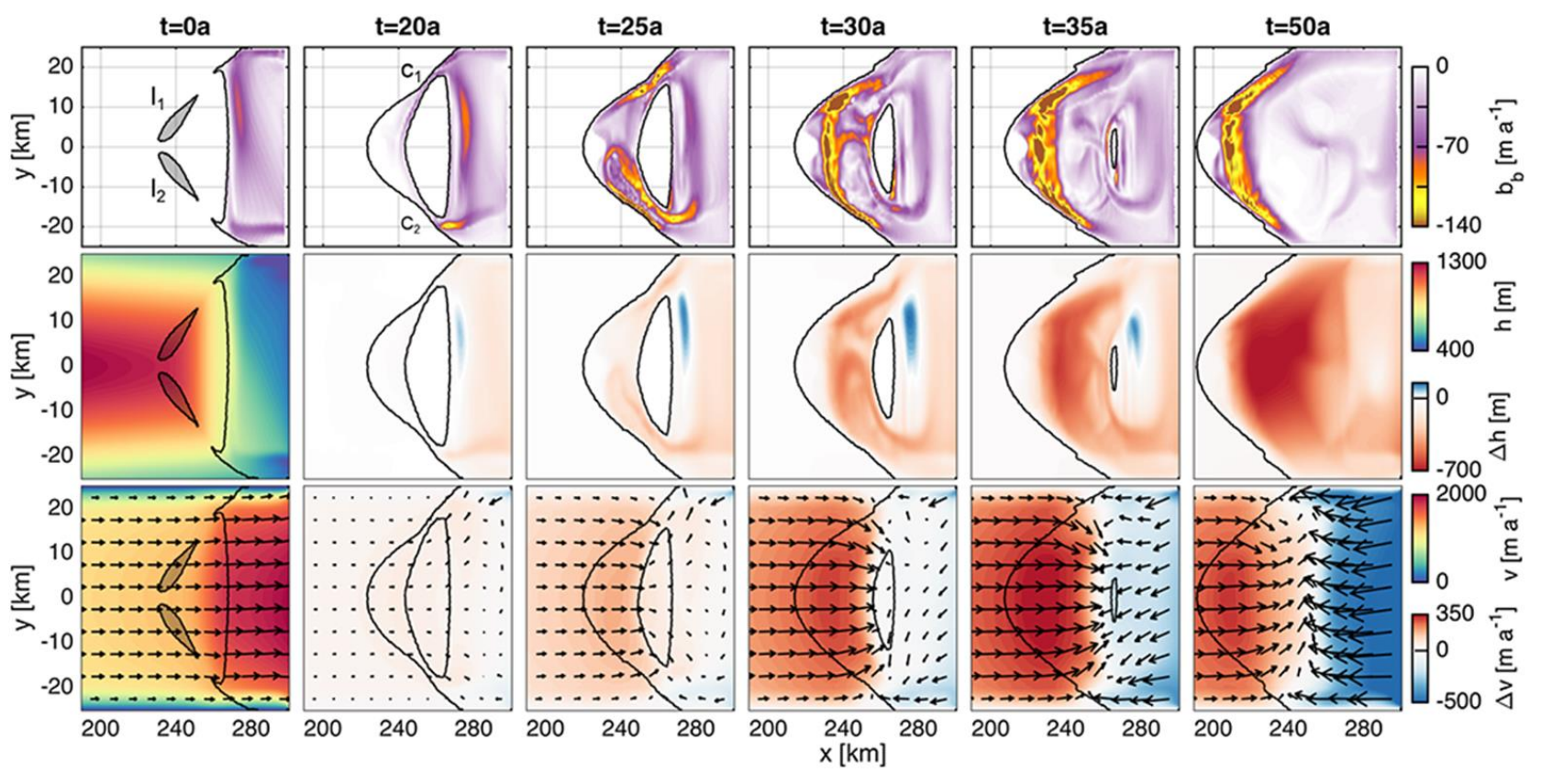
Schematic of Ua-MITgcm coupled domain. Meshes are representative; actual computational meshes are finer.

- **Model 2: POP2x/BISICLES (POPSICLES)**
  - **BISICLES:** Modified L1L2 finite-volume adaptive mesh refinement ice sheet model
  - **POP2x:** Version of POP modified to support flow in cavities under ice shelves using partial top cells as well as partial bottom cells. Model is z-level, hydrostatic, Boussinesq.

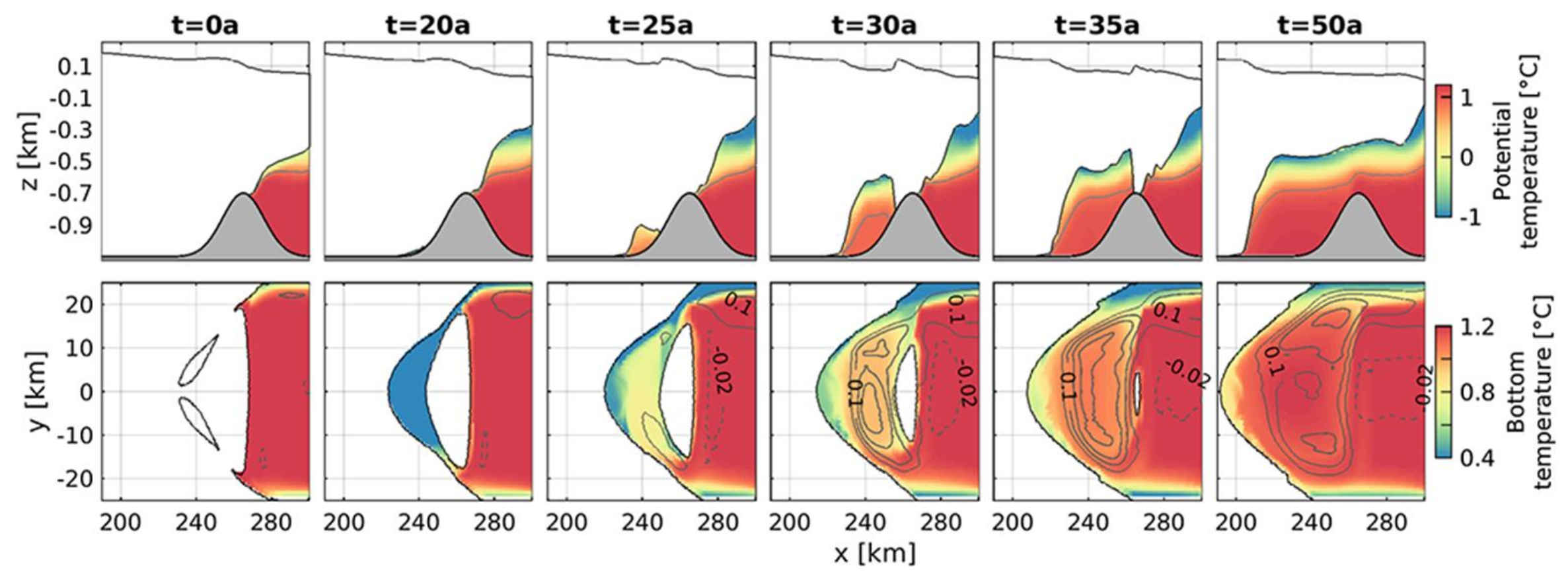


Schematic of POP2x subshelf cavities.

Model 1 Results



Left: *(top row) A time series of melt rates, (middle row) changes in ice thickness, (bottom row) and changes in surface velocity, as the glacier retreats from the subglacial ridge at x = 265 km in response to warm ocean conditions. The black line indicates the position of the grounding line. (from De Rydt and Gudmundsson (2016)*



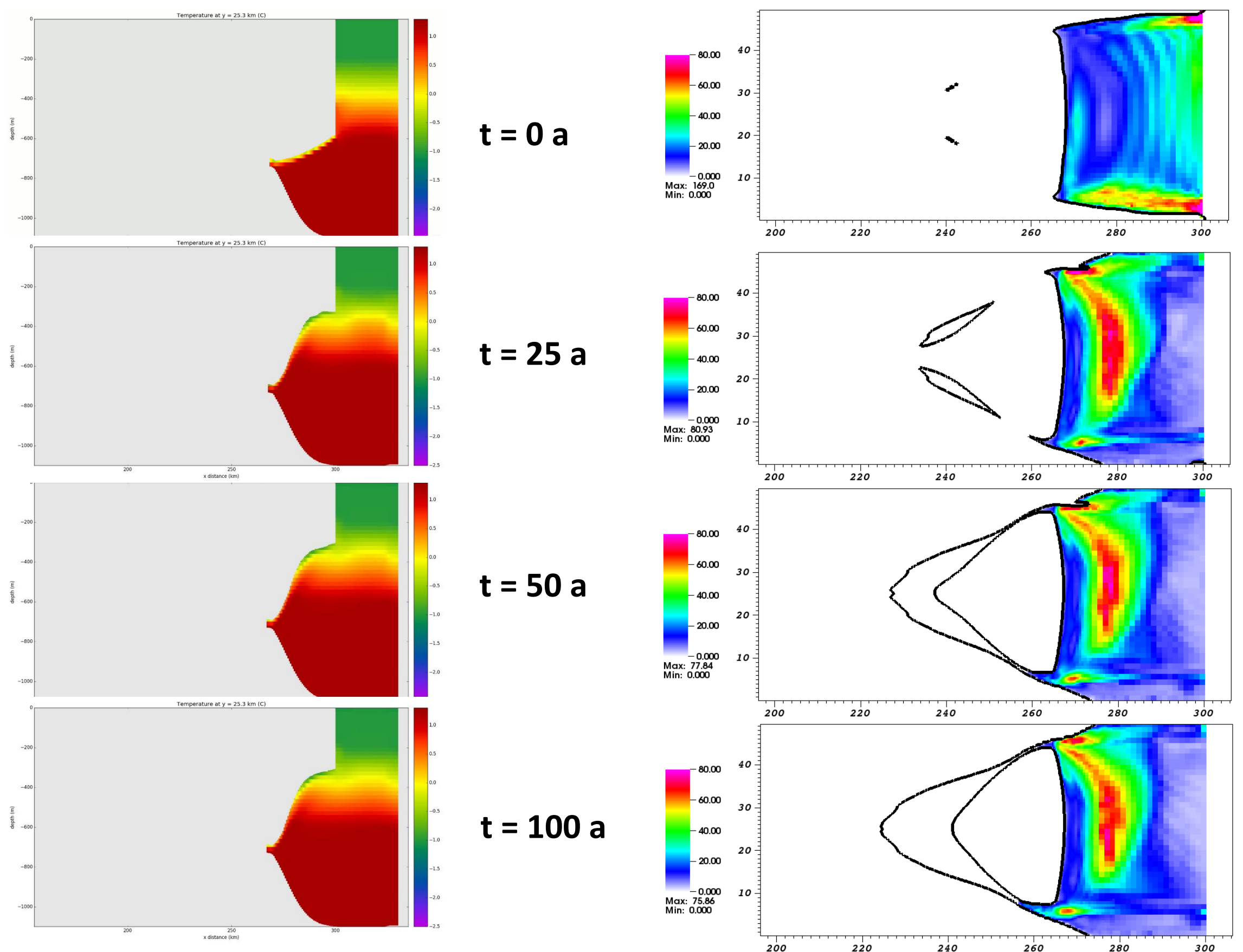
(top row) Cross sections of ice shelf geometry and ocean temperature along the centerline, and (bottom row) ocean bottom temperature and contours of the depth-averaged barotropic stream function

- Note the two subglacial lakes behind the grounding line at the initial time.
- In Model 1, channels form along the topographical seam which connect these lakes to the subshelf cavity and the warm water located there.
- Once hydrological connections to the subshelf cavity form, warm water is able to flood through these channels to the subglacial lakes.
- The lakes then activate as sources of melting -- enlarging, merging, and driving dramatic thinning, grounding line retreat and resulting ice loss.
- **Formation of and flow through the channels is key to the dramatic dynamic response in this model.**
- This model spun its ocean model to steady-state from rest for every coupling interval, which potentially increased this effect by enabling more warm water to reach the lakes.

Reference

De Rydt, J., and G. H. Gudmundsson (2016), Coupled ice shelf-ocean modeling and complex grounding line retreat from a seabed ridge, *J. Geophys. Res. Earth Surf.*, 121, 865–880, doi:10.1002/2015JF003791.

Model 2 Results



(left) Ocean model temperature cross section along the centerline. (right) subshelf melt rates, black lines indicate grounding line locations

- Similar subglacial lakes at initial time in both models (resulting from ice-sheet model spinup)
- In Model 2, channels form, but never completely hydrologically connect the subglacial lakes to the main subshelf cavity.
- As a result, the subglacial lakes never receive the influx of warm water that was seen in Model 1.
- Consequently, they don't grow and become dynamically active.
- Without the forcing from the lakes, grounding line retreat stalls on the ridge, resulting in a much-reduced ice sheet response, even after 100 years.

Conclusions

- Connections to subglacial hydrology features like subglacial lakes can strongly influence dynamics of coupled ice-ocean systems.
- Need to better understand how this coupling occurs, possibly by incorporating methods (like channel formation) currently being used to investigate subglacial hydrology evolution.

- **Future work:**
  - Model 1 has switched to restarting the ocean model, rather than spinning-up from rest at every ice-ocean coupling interval; seems to have an effect.
  - Explore the response of the two models to different scenarios both with and without subglacial lakes to better understand dynamic response.