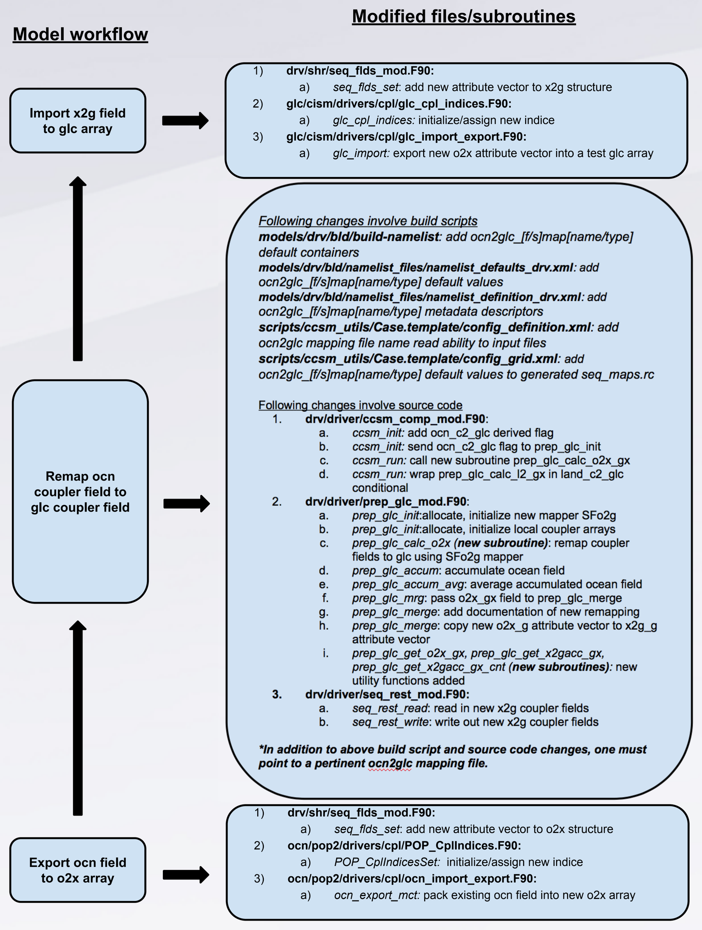
P: Progress and Challenges in Testing and Coupling Land Ice Models in ACME

[1]ACME Land Ice and [2]PISCEES Team Members

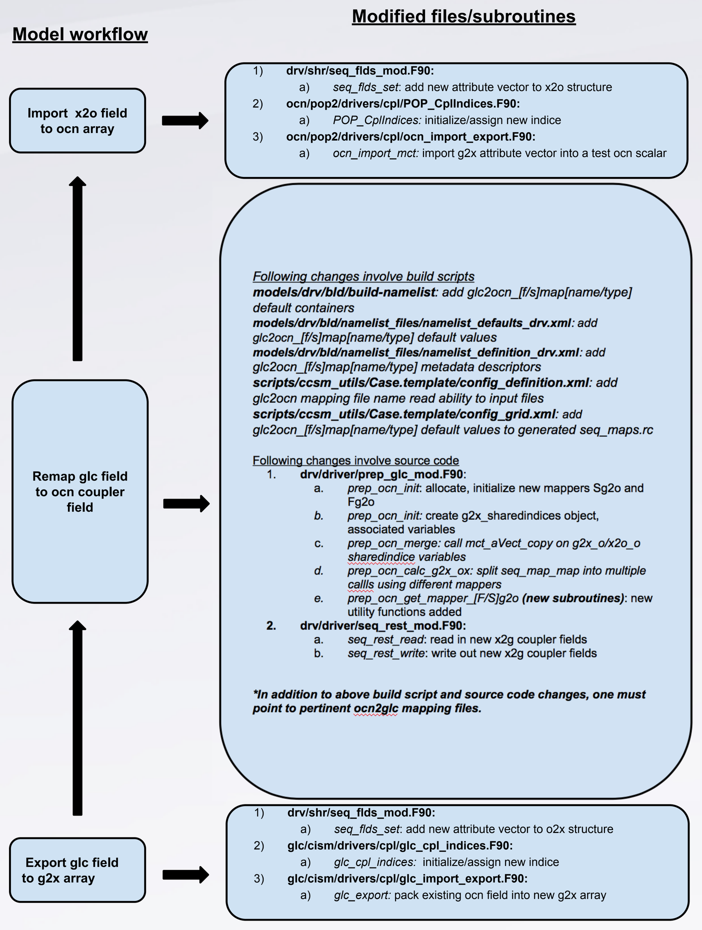
New ice/ocean coupling in ACME

Primary components of ice/ocean coupling implemented in coupler. *Upcoming challenge: moving ice sheet/shelf boundaries in coupler code.*

Ocean-to-land-ice coupling infrastructure: *code modifications*

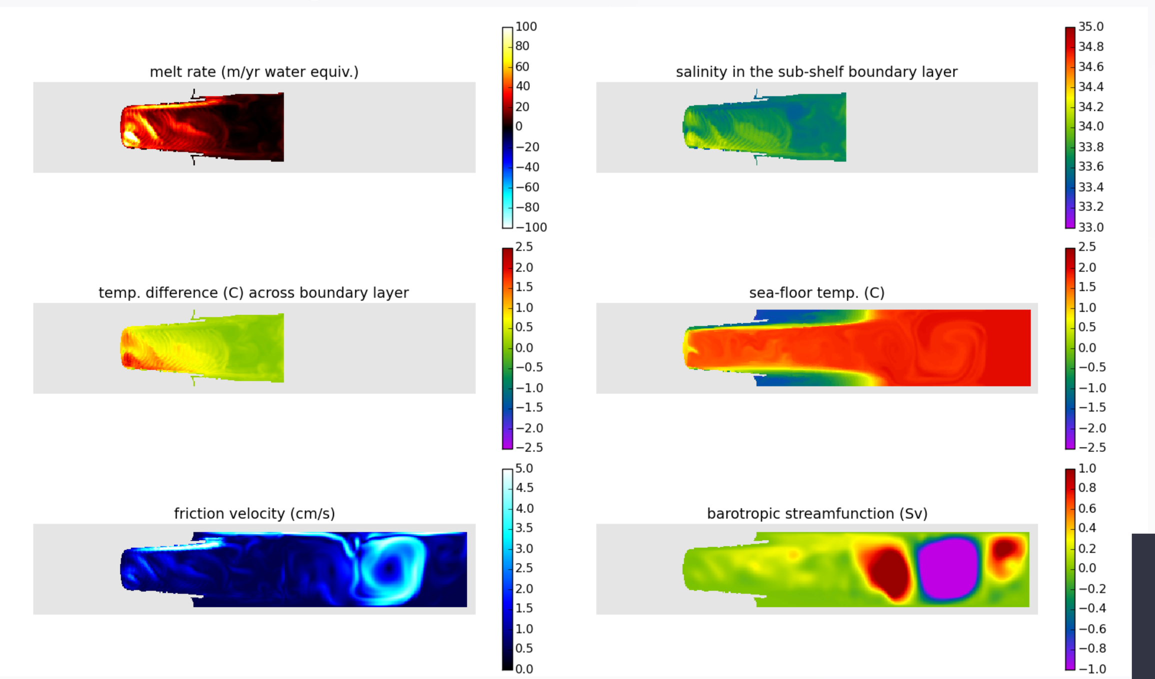


Land-ice-to-ocean coupling infrastructure: *code modifications*



Idealized ice/ocean testing

New idealized test cases for land ice/ocean interactions: ISOMIP+ and MISOMIP.
***Challenge:* Verification of land ice/ocean interactions in MPAS-O using ISOMIP test case**



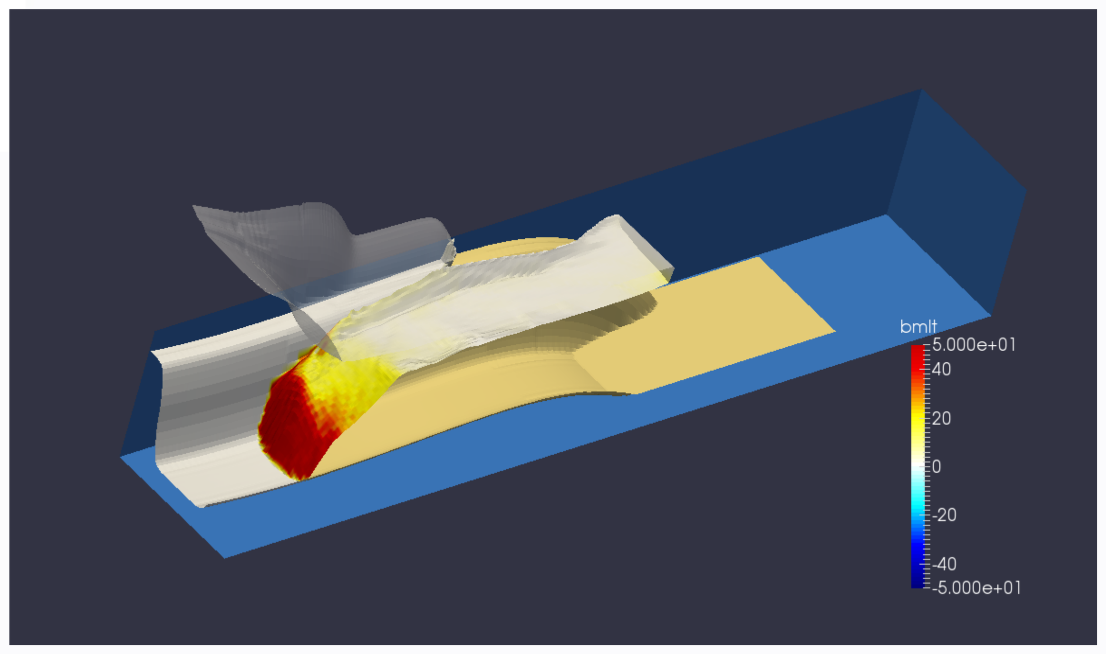
ISOMIP+, the second *Ice Shelf-Ocean Model Intercomparison Project*, is a set of idealized experiments designed by ACME participant and PISCEES collaborator Xylar Asay-Davis as part of an international, community effort to validate models of ocean circulation, freezing, and melting beneath ice shelves.

The figures above show a birds-eye view of ocean properties related to sub-shelf freezing and melting. These results were obtained from high-resolution simulations using the POP2x ocean model. These results will be used to help validate results from similar experiments (underway) using the new MPAS-Ocean component in ACME.

MISOMIP1, the first *Marine Ice Sheet-Ocean Model Intercomparison Project*, is a new idealized experiment and planned model intercomparison for coupled land ice and ocean models. It is being developed and tested as part of an international collaboration that includes ACME and PISCEES project members.

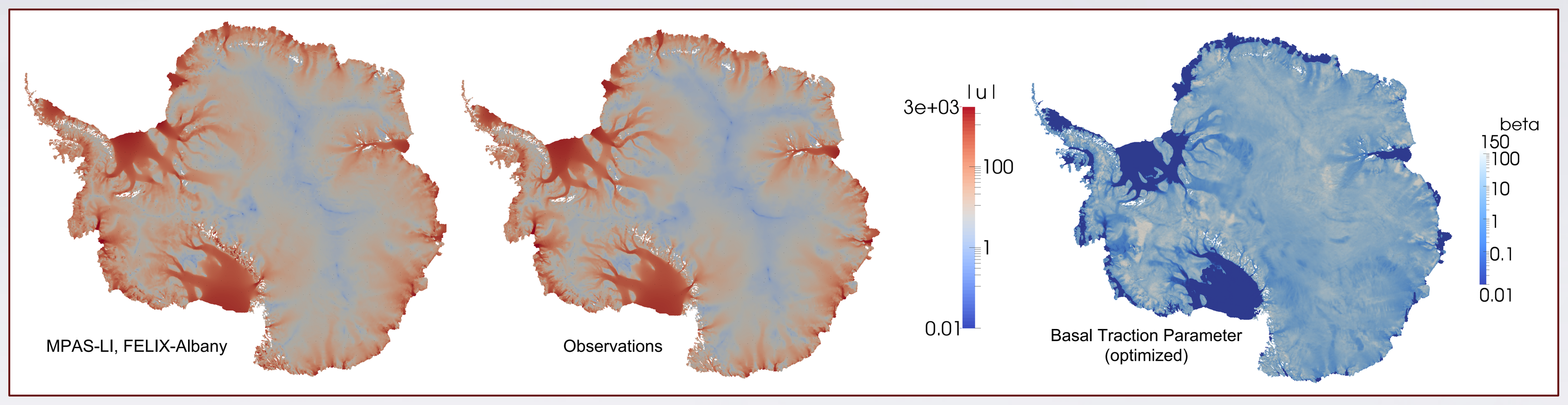
The figure below shows a cut-away view revealing the land ice surface (translucent white), the bedrock topography (beige), and the ice draft shaded according to submarine melt rates calculated as a function of the ocean model and boundary layer physics.

These simulations, conducted in collaboration with PISCEES using "POPSICLES" (a combination of the POP2x ocean model and the BISICLES ice sheet model) will be used to validate similar idealized model configurations and experiments with MPAS Ocean and MPAS Land Ice components.

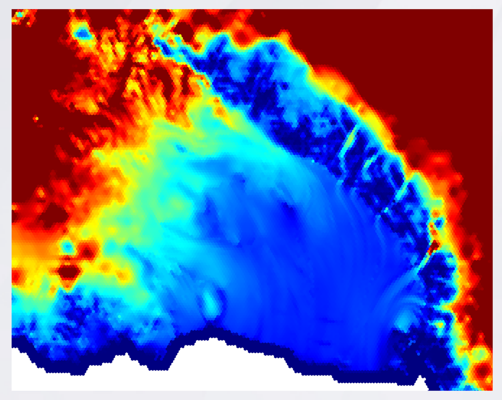


Realistic and Robust ice sheet simulations

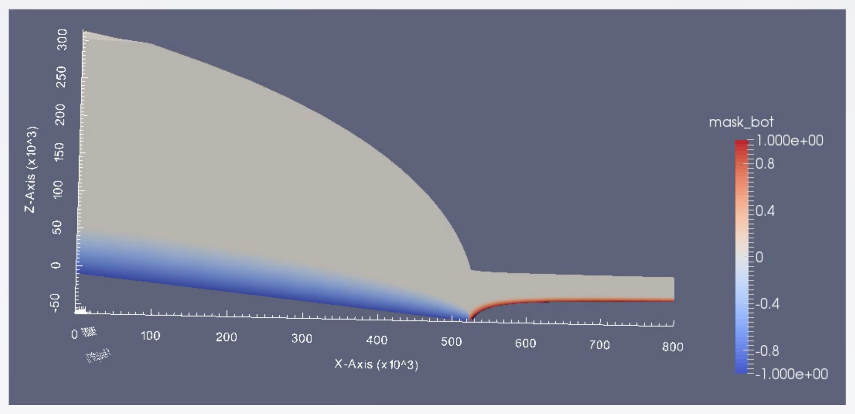
Progress towards realistic, high-resolution, whole-ice sheet simulations with MPAS-Land Ice. *Challenges: Robust solver convergence and evolution using refined meshes and resolutions adequate to resolve grounding line dynamics.*



Modeled Antarctic ice sheet surface speed (left) compared with observations (middle) after applying formal optimization methods to tune the basal traction parameter field (right). Optimization and solution of the momentum balance equations was done using FELIX-Albany (a dynamical core developed under the SciDAC PISCEES project), which is coupled to MPAS-Land Ice (Figures and modeling courtesy of M. Perego, I. Tezaur, A. Salinger).

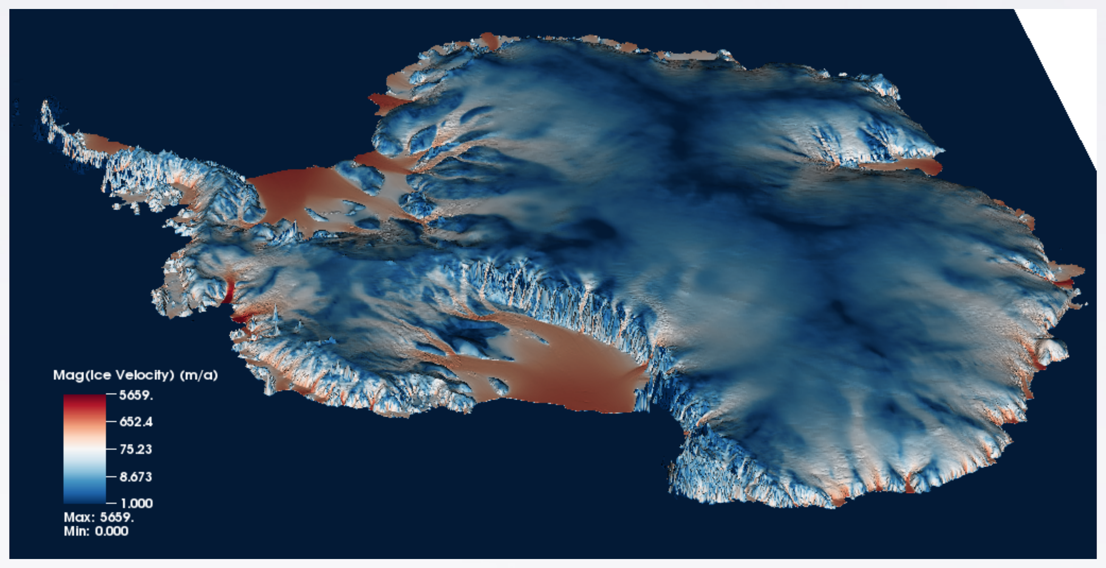


Zoom into Ross Ice Shelf region for a moderate resolution MPAS-LI mesh (ice thickness is plotted), to be used in initial tests of land ice and ocean coupling in ACME.



Steady-state ice sheet geometry (along-flow profile) and grounding line position for the MISMIP3D "standard" experiment as computed by the FELIX-S (S= "Stokes") ice sheet model, developed under the SciDAC PISCEES project. Grounded ice is shaded in blue and floating ice is shaded in red.

For non-trivial ice sheet geometries and boundary conditions, a high- resolution Stokes model, generally too expensive to be applied at the continental scale, is used to generate results taken as the "truth" and used for comparing against output from less expensive, reduced-order models. Benchmark experiments like these will be used to verify performance and fidelity of stand-alone MPAS-LI and CISM-BISICLES on problems involving grounding line dynamics (Figure and modeling courtesy of T. Zhang, L. Ju, and M. Gunzburger).



Antarctic ice sheet surface speeds modeled by BISICLES draped over Antarctic surface topography. BISICLES, a dynamical core developed under SciDAC PISCEES, uses block-structured, adaptive mesh refinement to focus computational resources in areas of dynamic complexity, such as along ice stream shear margins and grounding lines. Collaborative efforts under PISCEES and ACME will focus on the coupling of both the BISICLES (via CISM) and FELIX (via MPAS) dynamical cores to ACME (Figures and modeling courtesy of D. Martin and E. Ng).

Challenges for MPAS-LI as a GLC component

Challenges in Software Engineering/ACME Capabilities:
MPAS-LI has been added as a GLC component to ACME. However, *GLC currently has no functional coupling to other climate components in ACME.*

- GLC-LND coupling:
  - GLC in CESM was not a fully developed component but was intimately tied to the LND component. (e.g., there was no GLC grid)
  - Land / ice sheet coupling and downscaling (of precipitation and temperature) in CESM was dependent on CISM code, which is not part of or available to MPAS-LI.
  - Recent work has generalized GLC coupling in CESM to remove these restrictions. It is unclear when these changes will be available in ACME.
  - Existing land/ice sheet coupling and downscaling in ACME may be adversely impacted by proposed land model changes.
- GLC-OCN coupling:
  - Currently being developed in ACME (see top left panel for details).
  - Addition of wetting / drying and grounding-line representation in ocean model remains to be implemented and tested.
- Works towards enabling support of multiple MPAS components within the same executable (ACME) is ongoing.
- Currently, SE support for the coupling of land ice models in ACME is limited to LANL efforts towards coupling of MPAS-LI

Challenges in Scientific Quality:

- Ice sheet spin-up/initialization within a high-resolution climate model
- Quantifying acceptable biases in coupled Antarctica / climate simulations
- Ocean model initialization while coupled to ice sheet model
- ACME sub-ice-shelf melt rates in agreement with observations, requiring:
  - Depth and temperature of Warm Deep Water (WDW) in Southern Ocean
  - Transport and mixing of WDW on the continental shelf and under ice shelves
  - Formation and transport of dense, salty water through sea-ice growth and export

ACME Accelerated Climate Modeling for Energy

For additional information, contact:
Stephen Price
T-3, Los Alamos National Laboratory
(505) 665-1000, sprice@lanl.gov

[1]**ACME Land Ice Team Contributors:** X. Asay-Davis, J. Fyke, M. Hoffman, W. Lipscomb, S. Price

[2]**PISCEES Contributors:** M. Gunzburger, L. Ju, D. Martin, E. Ng, M. Perego, I. Tezaur, A. Salinger, R. Tuminaro, T. Zhang

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