Climate Modeling: Ocean Cavities below Ice Shelves

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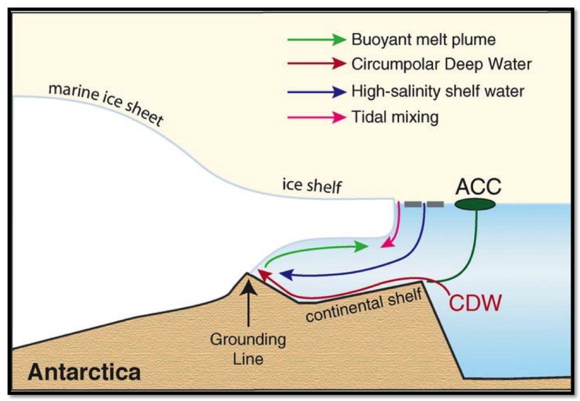
The Accelerated Climate Model for Energy (ACME), a new initiative by the U.S. Department of Energy, includes unstructured-mesh ocean, land-ice, and sea-ice components using the Model for Prediction Across Scales (MPAS) framework [3]. The ability to run coupled high-resolution global simulations efficiently on large, high-performance computers is a priority for ACME.

Sub-ice shelf ocean cavities are a significant new capability in ACME, and will be used to better understand how changing ocean temperature and currents influence glacial melting and retreat. These simulations take advantage of the horizontal variable-resolution mesh and adaptive vertical coordinate in MPAS-Ocean[1], in order to place high resolution below ice shelves and near grounding lines.

The edge of an ice shelf, with boat for scale. This ice was created by snowfall on Antarctica over many centuries. The ice is pushed out to the continental margins, where it floats above the ocean water for hundreds of kilometers. The ice eventually calves off the shelf edge into icebergs and floats into the open ocean, as seen in the foreground.

Background and Motivation

Ice shelf-ocean interactions are important to the global climate system. Warmer ocean currents may speed up ice shelf melting and retreat. At the same time, changing land ice fluxes could affect ocean temperature, salinity, and currents below ice shelves, altering Southern Ocean water mass formation. The Ronne-Filchner and Ross ice shelves sit on top of areas of ocean, each at least the size of California. Despite this, ice shelf cavities have not been included in any fully coupled global climate model to date because of the numerical modeling challenges and lack of observational data for validation.



Cross-section of an Antarctic ice shelf, where warm Circumpolar Deep Water (CDW) moves up the continental shelf and melts the ice near the grounding line. This produces a fresh, buoyant plume that ascends along the bottom surface of the ice shelf and influences the formation of Antarctic Bottom Water.

Description

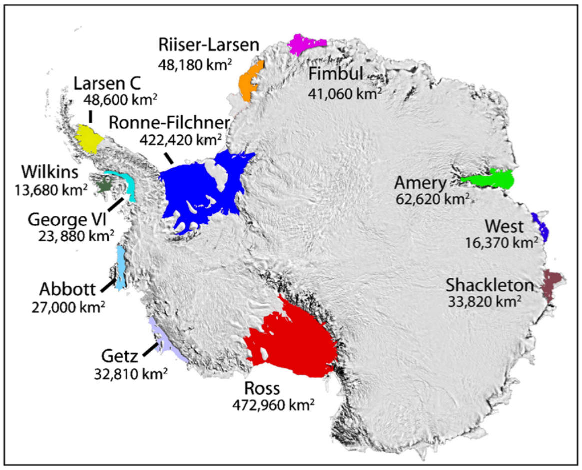
Several improvements were required for MPAS-Ocean to be able to run below ice shelves:

1. New pressure gradient formulation: Tilted layers and nonlinear equation of state required a new pressure gradient based on a Jacobian expansion of temperature and salinity.

2. Ice pressure-ice draft balance on initialization: The buoyancy of the ice shelf de-

pends on the density of the surrounding water, while ice draft is from observations. A stable balance required iterative initialization to update the pressure.

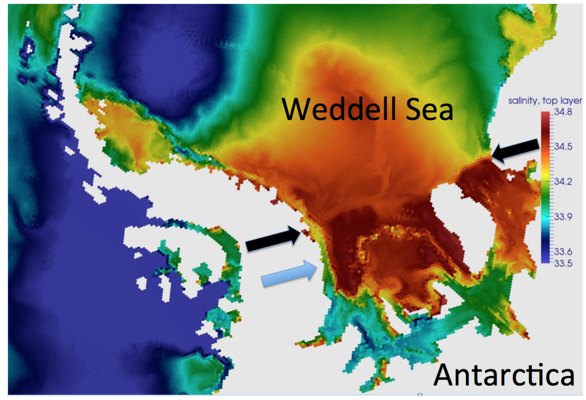
3. Land ice melt fluxes: Addition of standard three-equation fluxes to compute heat and mass fluxes at the ice-ocean interface, based on ocean temperature and salinity.



Locations of ice shelves in Antarctica. These are all floating on ocean water, and are expected to melt and retreat with warmer ocean currents. Previously, ocean model domains ended at the ice shelf edge and did not include water underneath.

Anticipated Impact

Because of the improvements described here, MPAS-Ocean can run with ocean cavities below ice shelves. In standard idealized test comparisons, MPAS-Ocean is within the spread of five other models for all statistics. Future high-resolution ACME simulations will include ice cavities after further validation. This success was contingent upon the flexible vertical coordinate that was built into MPAS-Ocean from the early design [1]. The arbitrary Lagrangian-Eulerian (ALE) vertical coordinate provided the freedom to expand and contract ocean layers horizontally [2]. This allows layers to follow the ice shelf bottom, and ensure numerical stability by preventing severe tilting of thin layers. A new grid initialization below ice shelves implements these features.



Salinity in MPAS-Ocean simulation with ocean cavities, using 10 km grid cells. The Ronne-Filchner ice shelf lays above this ocean layer in the embayment, with its edge at the black arrows. The fresh-water plume (blue arrow) is due to advection of fresh melt water from below the ice shelf into the open ocean.

Path Forward

Ocean simulations with ice shelves will evaluate the effects of warming currents on ice melt and ice sheet retreat. These may in turn alter ocean water properties and currents.

Acknowledgements

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References

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[2] S.M. Reckinger, M.R. Petersen, and S.J. Reckinger. A study of overflow simulations using mpas-ocean: Vertical grids, resolution, and viscosity. *Ocean Modelling*, 96, Part 2:291 – 313, 2015.

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