Simulating marine ice sheets with the Community Ice Sheet Model

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Abstract

Version 2 of the open-source Community Ice Sheet Model (CISM) includes a higher-order velocity solver. CISM uses finite-element methods on a structured grid to solve several sets of flow equations, including the shallow-shelf approximation (SSA), a higher-order depth-integrated-velocity approximation (DIVA), and the Blatter-Pattyn approximation.

We have applied CISM to several test problems of the Marine Ice Sheet Model Intercomparison Project (MISMIP) and the Marine Ice Sheet–Ocean Model Intercomparison Project (MISOMIP). Here we show results for MISMIP3d (part of MISMIP) and MISMIP+ (the ice-sheet component of MISOMIP) using a subgrid grounding-line parameterization (GLP), simulations at moderate resolution (~1 km) agree well with published benchmarks. For flow on a downward-sloping bed, SSA results are in good agreement with the boundary-layer solution of Schoof (2007). For cases with basal-sliding perturbations, CISM successfully simulates reversible migration of curved grounding lines without a GLP, much higher resolution is needed for similar accuracy. These results suggest that a resolution of ~1 km may be sufficient for accurate simulation of whole marine ice sheets.

MISMIP3d and MISMIP+

Fig. 1: (a) Schematic setup for (a) MISMIP3d and (b) MISMIP+.

MISMIP (Pattyn et al. 2012) and MISMIP3d (Pattyn et al. 2013) test the ability of marine ice-sheet models to simulate grounding-line migration. Flow is in the x direction from a grounded ice sheet onto a floating shelf (Fig. 1a). The basal stress is discontinuous at the grounding line. For the experiments shown here, the bed geometry is linear, implying that there is a unique steady-state grounding-line position for a given set of input parameters (Schoof 2007). MISMIP3d includes perturbation experiments with a spatially varying basal traction field to generate curved grounding lines with buttressing effects. Fixed-grid models with grid resolution of ~1 km typically make large errors compared to the analytic solution unless a GLP is used (Leguy et al. 2014).

MISMIP+ (Asay-Davis et al. 2015) includes a set of ice-sheet-only experiments with idealized bed topography (Fig. 1b) and forcing. These experiments complement ocean-only (ISOMIP+ and ice-sheet/ocean coupled ISOMIP1) experiments. The ice sheet is run to steady state without basal melting, then is forced to retreat by strong sub-shelf melting, and finally is allowed to re-advance with the melting turned off.

Grounding Line Parameterization

CISM2 (http://oceans11.lant.gov/cism/) is a 3D, parallel, higher-order ice sheet model that runs on a rectangular horizontal mesh. We plan to use CISM2 for whole-ice-sheet simulations that are cost-prohibitive at resolutions finer than ~1 km. In order to robustly simulate grounding-line migration at this resolution, we have developed a GLP based on Gladstone (2010), but extended to a 2D bed. As in Seroussi et al. (2014), the basal traction is weighted by the grounded ice fraction in the cell surrounding a velocity point. A GLP greatly improves accuracy at a given resolution when there is a discontinuous transition in basal friction at the grounding line. The GLP in CISM can be used with three flow approximations: (1) SSA, (2) DIVA (Goldberg 2011), or (3) Blatter-Pattyn (Pattyn 2003).

MISMIP3d Results

The SSA assumes that vertical shear stresses are negligible compared to horizontal-plane stresses. If the GLP works well, CISM results with the SSA should be close to the benchmark solutions of Schoof (2007). The upper panels of Fig. 2 show results for MISMIP3d. Without a GLP (left), the steady-state grounding line (before applying a basal perturbation) lies at 515 km, ~100 km from the benchmark solution. It advances by ~20 km but retreats only ~10 km. With a GLP (right), the initial steady state is at 598 km, only 13 km from the benchmark of ~611 km, and the motion is reversible as desired. The lower panels of Fig. 2 show MISMIP3d results for DIVA, without and with a GLP. DIVA results are similar, since the flow has little vertical shear.

MISMIP+ Results

Fig. 3 shows the magnitude of the basal traction for various stages of MISMIP+ Experiment Ice1, which consists of 100 years of retreat driven by strong basal melting, followed by 900 years of re-advance with melting turned off. CISM was run using the SSA with a basal traction law that transitions from power-law to Coulomb behavior near the grounding line (Tsai et al. 2015). Results using DIVA (not shown) are similar, since the flow has little vertical shear.

Future Work

These results suggest that DIVA with a GLP at 1-km resolution is an attractive option for simulating marine ice sheets with physics similar to MISMIP3d. Next, we will test CISM for more realistic geometries, including the whole Antarctic ice sheet. To improve efficiency and realism, CISM developers are working on more efficient, scalable preconditioners; implicit methods for thickness evolution to allow a longer time step; and a damage-based scheme for iceberg calving.

References


