Community Ice Sheet Model (CISM2) Development and Marine Ice Simulations

William Lipscomb and Gunter Leguy
Los Alamos National Laboratory
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CISM 2.0

CISM2 was released in Oct. 2014:

- Successor of Glimmer-CISM
- Supported by DOE SciDAC
- Available at http://oceans11.lanl.gov/cism/; git repo at https://github.com/cism
- Parallel dynamical core (Glissade) with a suite of higher-order velocity solvers (SIA, SSA, L1L2, Blatter-Pattyn)
- New test cases (shallow-ice and higher-order)
- Improved coupling interface
- New build system, documentation, etc.

CISM2 is now in CESM, giving reasonable results in Greenland simulations.
Toward CISM 2.1

- **Streamlined Glad coupling interface** (for sending and receiving fields on the native ice-sheet grid)
- **Enthalpy-based thermodynamics** (code developed at CU)
- **Depth-integrated viscosity solver** (Goldberg 2011)
  - Solve for the depth-integrated mean velocity (2D elliptic solve), then reconstruct the velocity in each column
  - Similar to L1L2, but more accurate and robust for some problems
- **Grounding-line parameterization**
  - Smoother transition between grounded and floating ice, as required to model marine ice sheets
Grounding line parameterization (GLP)

**Goal:** To accurately track grounding-line migration (critical for the evolution of marine ice sheets) at moderate grid resolution (~1 km).

- Following Gladstone (2010): \( f_P = \frac{-\rho_w b}{\rho_i H} \equiv \frac{H_f}{H} \)  
  \( (b = \text{bed depth}, \ H = \text{ice thickness}, \ H_f = \text{flotation thickness}) \)
- A thickness point is grounded if \( f_P \leq 1 \) and floating if \( f_P > 1 \).
- \( f_P \) is interpolated bilinearly between adjacent cell centers.
- \( f_{\text{ground}} \) at a velocity point is equal to the grounded fraction in a bounding box defined by the four neighboring cell centers.

- The basal shear stress at a velocity point is proportional to \( f_{\text{ground}} \).

CISM schematic: 4 grid cells with \( H \) at cell center; velocity at vertex; bounding box in *lt. green*; reconstructed GL in *blue*. 
Basal friction parameterization (Leguy et al. 2014)

• Basal shear stress: \( \tau_b = \beta u \)

• \( \beta \) is a function of effective pressure \( N \)
  • Large \( N \): \( \tau_b = C|u|^{(1-n)/n} u \)
  • Small \( N \): \( \tau_b \propto CN \)

• Effective pressure \( N \) is a function of flotation thickness:
  \[
  N(p) = \rho_i g H \left( 1 - \frac{H_f}{H} \right)^p
  \]
  • \( p = 0 \) \( \Rightarrow \) \( N \) is large up to the GL, abruptly drops to 0
  • \( p = 1 \) \( \Rightarrow \) \( N \) falls gradually to 0 approaching the GL
Marine Ice Sheet Model Intercomparison Project (MISMIP)

- Idealized experiments that test a model’s ability to track grounding-line advance and retreat. Does the GL return to its stable starting position?

**MISMIP** (Pattyn et al. 2011)
- Flowline; no lateral variation or buttressing
- Linear bed (stable) and polynomial bed (with an unstable region)
- Model solution compared to Schoof (2007) semi-analytic solution

**MISMIP3d** (Pattyn et al. 2013)
- Perturbed basal sliding parameters give lateral variation and buttressing, with curved grounding lines
MISMIP tests with CISM

- Three velocity solvers
  - SSA, DIVA, Blatter-Pattyn
- Two grid resolutions
  - 2 km and 1 km on a fixed rectangular grid (results at 0.5 km similar but not shown)
- **Grounding line parameterization** for basal shear stress
  - On or off
- **Basal friction parameterization** (Leguy et al. 2014):
  - $p = 0$ (sharp transition between grounded and floating ice)
  - $p = 1$ (transition spread over several km, assuming support from a basal water system connected to the ocean)
MISMIP: 2 km, p = 0

GL position for p=0.00 and Res = 2km

**SSA**: with GLP (*) and without GLP (+); large errors without GLP

**DIVA**: with GLP(*) and without GLP (+); modest difference from SSA due to vertical shear stress

*Blue* = advance; *red* = retreat; *black* line shows semi-analytic solution
With GLP: **DIVA** (+) and **Blatter-Pattyn** (*): barely any difference.
MISMIP3d: 1 km, $p = 0$

**SSA with GLP:**
GL returns to start position (598 km), close to analytic solution (612 km)

**SSA without GLP:**
GL too far retreated at start (504 km) and fails to return

Black = starting position; red = advance; lt. blue = return
MISMIP3d: 1 km, \( p = 0 \)

**SSA with GLP:**
GL returns to start position (598 km), close to analytic solution (612 km)

**DIVA with GLP:**
GL returns to start position (558 km); ice is softer with vertical shear stresses

Black = starting position; red = advance; lt. blue = return
MISMIP3d: 1 km, $p = 1$

**SSA without GLP:**
GL returns to start position
(346 km; cf. 349 km with GLP)

**DIVA without GLP:**
GL returns to start position
(341 km; cf. 344 km with GLP)

*Black* = starting position; *red* = advance; *lt. blue* = return
Summary of results

• For $p = 0$ (sharp transition in basal shear stress):
  • SSA agrees well with the analytic solution at 1–2 km resolution, *provided we use a GLP*.
  • DIVA results differ from SSA, as expected; the ice is softer and the grounding line less advanced when vertical shear stress is included.
  • DIVA results are similar to Blatter-Pattyn, at lower cost.
  • Results without a GLP are not as good (and for some configurations are very bad).
Summary of results

• For $p = 1$ (smooth transition in basal shear stress):
  • The steady-state grounding line is much farther inland (~200 km) compared to $p = 0$, even though the transition zone is only a few km wide.
  • DIVA and BP results are similar to SSA results, since vertical shear stress is less important.
  • A grounding-line parameterization is unnecessary (though it doesn’t hurt).
Summary of results

• Very high resolution (~200 m) does not seem to be necessary for smooth, accurate grounding-line resolution. Even with sharp transitions zones ($\rho = 0$), resolution of $\sim 1$ km is adequate.

• When in doubt, use a GLP.

• DIVA could be an accurate and efficient compromise between Blatter-Pattyn and SSA.

• The grounding-line location is sensitive to poorly constrained basal physics ($0 < \rho < 1$). Use data to invert for $\rho$?
Implications for CESM

• These results are not directly relevant for CESM2 simulations with Greenland, which has little floating ice.

• But they suggest that models with fixed, uniform grids could be practical for whole-ice-sheet simulations, even for marine-based ice. (A uniform grid resolution of \(~1\) km for all Antarctica may be practical; resolution of 200 m is not.) Something to keep in mind as CESM evolves...

• Given its new features (portable and efficient, with many runtime options and flexible coupling), CISM2 could be a very useful tool for coupled ice-sheet/climate experiments in CESM.

• Now the model needs a larger user base for stress testing and applications.