Resolving Grounding Line Dynamics using the BISICLES Adaptive Ice Sheet Model

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Berkeley-ISICLES (BISICLES)

- DOE ISICLES-funded project to develop a scalable adaptive mesh refinement (AMR) ice sheet model/dycore
  - Local refinement of computational mesh to improve accuracy
- Use Chombo AMR framework to support block-structured AMR
  - Support for AMR discretizations
  - Scalable solvers
  - Developed at LBNL
  - DOE ASCR supported (FASTMath)
- Interface to CISM (and CESM) as an alternate dycore
- Collaboration with LANL and Bristol (U.K.)
Why is this useful? (another BISICLE for another fish?)

- Ice sheets -- Localized regions where high resolution needed to accurately resolve ice-sheet dynamics (500 m or better at grounding lines)
- Antarctica is really big - too big to resolve at that level of resolution.
- Large regions where such fine resolution is unnecessary (e.g. East Antarctica)
- Well-suited for adaptive mesh refinement (AMR)
- Problems still large: need good parallel efficiency
- Dominated by nonlinear coupled elliptic system for ice velocity solve: good linear and nonlinear solvers

[Rignot & Thomas, 2002]
“L1L2” Model (Schoof and Hindmarsh, 2010).

- Uses asymptotic structure of full Stokes system to construct a higher-order approximation
  - Expansion in $\varepsilon$ -- ratio of length scales $\frac{h}{x}$
  - Computing velocity to $O(\varepsilon^2)$ only requires $\tau$ to $O(\varepsilon)$

- Computationally much less expensive -- enables fully 2D vertically integrated discretizations. (can reconstruct 3d)

- Similar formal accuracy to Blatter-Pattyn $O(\varepsilon^2)$
  - Recovers proper fast- and slow-sliding limits:
    - SIA ($1 \ll \lambda \leq \varepsilon^{-1/n}$) -- accurate to $O(\varepsilon^2 \lambda^{n-2})$
    - SSA ($\varepsilon \leq \lambda \leq 1$) - accurate to $O(\varepsilon^2)$
Discretizations

- Baseline model is the one used in Glimmer-CISM:
  - Logically-rectangular grid, obtained from a time-dependent uniform mapping.
  - 2D equation for ice thickness, coupled with 2D steady elliptic equation for the horizontal velocity components. The vertical velocity is obtained from the assumption of incompressibility.
  - Advection-diffusion equation for temperature.

- Use of Finite-volume discretizations (vs. Finite-difference discretizations) simplifies implementation of local refinement.
- Software implementation based on constructing and extending existing solvers using the Chombo libraries.
Experiment P75R:
(Pattyn et al (2011))

- Begin with steady-state (equilibrium) grounding line.
- Add Gaussian slippery spot perturbation at center of grounding line.
- Ice velocity increases, GL advances.
- After 100 years, remove perturbation.
- Grounding line should return to original steady state.
- Figures show AMR calculation:
  - $\Delta x_0 = 6.5\, km$ base mesh,
  - 5 levels of refinement
  - Finest mesh $\Delta x_4 = 0.195\, km$.
  - $t = 0, 1, 50, 101, 120, 200\, yr$
- Boxes show patches of refined mesh.
MISMIP3D (cont)

- Plot shows grounding line position $x_{GL}$ at $y = 50km$ vs. time for different spatial resolutions.

- $\Delta x = 0.195 km \rightarrow 6.25 km$

- Appears to require finer than 1 km mesh to resolve dynamics

- Converges as $O(\Delta x)$ (as expected)

PIG configuration from LeBrocq:
- AGASEA thickness
- Isothermal ice, $A=4.0 \times 10^{-17} \, Pa^{-1/3} \, m^{-1/3} \, a$
- Basal friction chosen to roughly agree with Joughin (2010) velocities

Specify melt rate under shelf:

$$M_s = \begin{cases} 
0 & H < 50m \\
\frac{1}{9} (H - 50) & 50 \leq H \leq 500m \\
50 & H > 500 \, m 
\end{cases} \, m/a$$

Constant surface flux = 0.3 m/a

Evolve problem - refined meshes follow the grounding line.

Calving model and marine boundary condition at calving front
$4\ km$ uniform mesh

$1\ km$ finest resolution
PIG, cont

1 km finest resolution

250 m finest resolution

Time=29
Coloring is ice velocity, $\Gamma_{gl}$ is the grounding line. Superscripts denote number of refinements. Note resolution-dependence of $\Gamma_{gl}$
Continental-scale: Antarctica

- Ice2sea geometry: LeBrocq, Timmerman, Jenkins, Nitsche
- Temperature field from Pattyn and Gladstone
Antarctica, cont

- Refinement based on Laplacian(velocity), grounding lines
- 5 km base mesh with 3 levels of refinement
  - base level (5 km): 409,600 cells (100% of domain)
  - level 1 (2.5 km): 370,112 cells (22.5% of domain)
  - Level 2 (1.25 km): 955,072 cells (14.6% of domain)
  - Level 3 (625 m): 2,065,536 cells (7.88% of domain)
Parallel scaling, Antarctica benchmark

(Preliminary scaling result – includes I/O and serialized initialization)
BISICLES - Next steps

- More work with linear and nonlinear velocity solves.
  - PETSc/AMG linear solvers look promising (in progress)
- Semi-implicit time-discretization for stability, accuracy.
- Finish coupling with existing Glimmer-CISM code and CESM
- Full-Stokes for grounding lines?
- Embedded-boundary discretizations for GL’s and margins.
- Performance/scaling optimization and autotuning.
- Refinement in time?