Adaptive mesh refinement versus sub-grid interpolation in simulations of Antarctic ice dynamics.

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Joint work with:

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- Annals of Glaciology (to appear)
Questions we’d like to answer:

- Demonstration that fully-resolved whole-continent simulations are possible.

- Mesh-resolution requirements for “realistic” Antarctic MISI (vs. MISMIP3D)

- Can a subgrid-scale basal friction interpolation (e.g. Feldmann et al (2014)) alleviate resolution requirements?
BISICLES Ice Sheet Model

- Scalable adaptive mesh refinement (AMR) ice sheet model
  - Dynamic local refinement of mesh to improve accuracy
- Chombo AMR framework for block-structured AMR
  - Support for AMR discretizations
  - Scalable solvers
  - Developed at LBNL
  - DOE ASCR supported (FASTMath)
- Collaboration with Bristol (U.K.) and LANL
- Variant of “L1L2” model (Schoof and Hindmarsh, 2009)
- Coupled to Community Ice Sheet Model (CISM).
- Users in Berkeley, Bristol, Beijing, Brussels, and Berlin...
**Subgrid-scale friction interpolation**

- **BISICLES standard GL scheme:**
  - Grounding line located at cell faces
  - Individual cells either grounded or floating
  - Basal friction is located at cell centers
  - Use one-sided differences to compute quantities like driving stress
  - (better approximation based on cut-cells is in development)
Subgrid-scale friction interpolation

Alternative sub-grid Scheme:

- Based on Feldmann et al (2014)
- Divide cells into quadrants.
- Bilinearly interpolate thickness over flotation \((h - h_f)\) in each quadrant based on neighboring cell centers.
- Subdivide each quadrant into \(2^n \times 2^n\) sections and evaluate interpolated thickness over flotation in each segment to compute weighted grounded area.
- Then can scale basal friction by the grounded fraction in each cell.

In this work, use \(n = 4\).
Initial Condition for Antarctic Simulations

- Full-continent Bedmap2 (2013) geometry
- Temperature field from Pattyn (2010)
- Initialize basal friction to match Rignot (2011) velocities
- AMR meshes: 8 km base mesh, adaptively refine to $\Delta x_f$
Experiment - 1000-year Antarctic simulations

- Range of finest resolution from 8 km (no refinement) to 500m (4 levels of factor-2 refinement)

- At initial time, subject ice shelves to extreme (outlandish) melting:
  - No melt for \( h < 100 \text{m} \)
  - Range up to 800m/a where \( h > 400 \text{m} \).
  - No melt applied in partially-grounded cells

- For each resolution, evolve for 1000 years
Results:

Antarctic AMR simulation

Flow speed (m/a)
Results, cont.
Results, cont

- Complete WAIS collapse in sufficiently-resolved runs.
- Lower-resolutions produce lower GL mobility, lower SLR contributions.
  - PIG: no or delayed retreat for coarser resolutions (4 km)
- Qualitative difference between under-resolved and sufficiently resolved (in the asymptotic regime)
- Subgrid scheme is worth about a factor of 2 in mesh spacing.
- Max change in VoF is approx. 4 m S.L.E.
Thwaites-Rutford - 1km Resolution with GLI
Thwaites-Rutford, 2km, with GLI
Thwaites-Rutford - effect of resolution
Mesh evolution (500m mesh)
Mesh evolution (500m finest mesh)
No-regridding

Mag(velocity) m/a

- 5000.
- 594.6
- 70.71
- 8.409
- 1.000

Max: 1.007e+05
Min: 0.000

Mesh resolution

- 8 km
- 4 km
- 2 km
- 1 km

Time = 0.00 years
No-regridding

Mag(velocity) m/a

-5000.
-594.6
-70.71
-8.409
1.000
Max: 2.392e+04
Min: 0.000

Mesh resolution

-8 km
-4 km
-2 km
1 km

Time= 29.00 years
Conclusions

- For this exercise, subgrid GL interpolation scheme is worth roughly a factor of 2 in resolution (one level of AMR refinement for us)

- 1 km or better resolution needed to get dynamics right

- Under-resolution can produce qualitatively wrong response

- Fine resolution needed at the GL at all times.

- Final conclusion - better topography needed inland.
Overall Conclusion

It’s up to us as modelers to demonstrate that our models are sufficiently resolved!
Thank you!
Computational Cost

- Run on NERSC’s Edison

- For each 1-month coupling interval:
  - POP: 1080 processors, 50 min
  - BISICLES: 384 processors, ~30 min
  - Extra “BISICLES” time used to set up POP grids for next step

- Total:
  1464 proc x 50 min = ~15,000 CPU-hours/simulation year
  (~1.5M CPU-hours/100 years)
Motivation: Projecting future Sea Level Rise

- Potentially large Antarctic contributions to SLR resulting from marine ice sheet instability, particularly from WAIS.

- Climate driver: subshelf melting driven by warm(ing) ocean water intruding into subshelf cavities.

- Paleorecord implies that WAIS has deglaciated in the past.