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

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Joint work with:

- **Stephen Cornford** (Bristol)
- Tony Payne (Bristol)
- Vicky Lee (Bristol)
- Esmond Ng (LBNL)

- Annals of Glaciology *(to appear)*

Questions we'd like to answer:

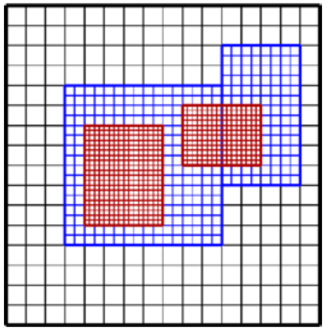
- **Demonstration that fully-resolved whole-continent simulations are possible.**

- **Mesh-resolution requirements for "realistic" Antarctic MISI (vs. MISMIP3D)**

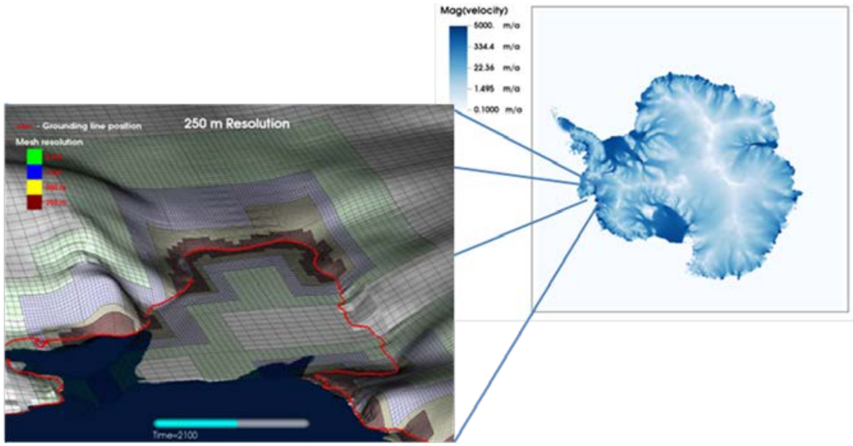
- **Can a subgrid-scale basal friction interpolation (e.g. *Feldmann et al (2014)*) alleviate resolution requirements?**

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)

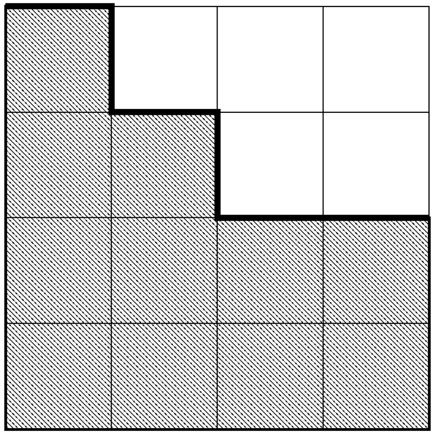


- Collaboration with Bristol (U.K.) and LANL
- Variant of “L1L2” model (Schoof and Hindmarsh, 2009)
- Coupled to Community Ice Sheet Model (CISM).
- Users in Berkeley, Bristol, Beijing, Brussels, and Berlin…



Subgrid-scale friction interpolation

- **<u>BISICLES standard GL scheme:</u>**
  - 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

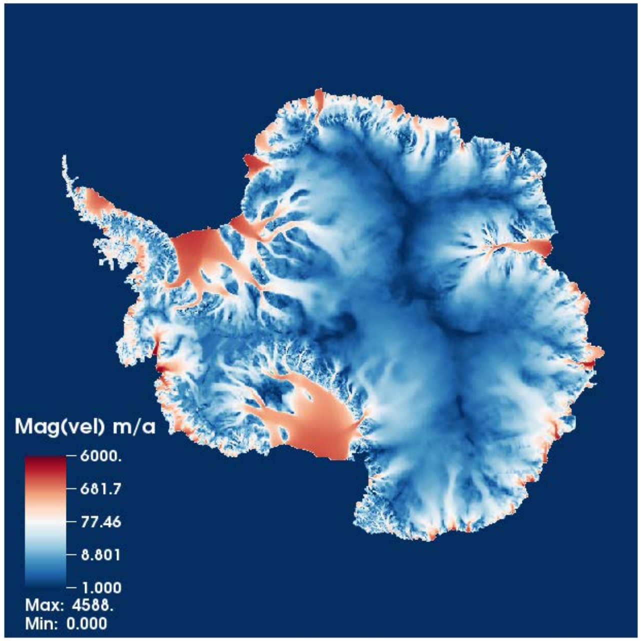
Alternative sub-grid Scheme:

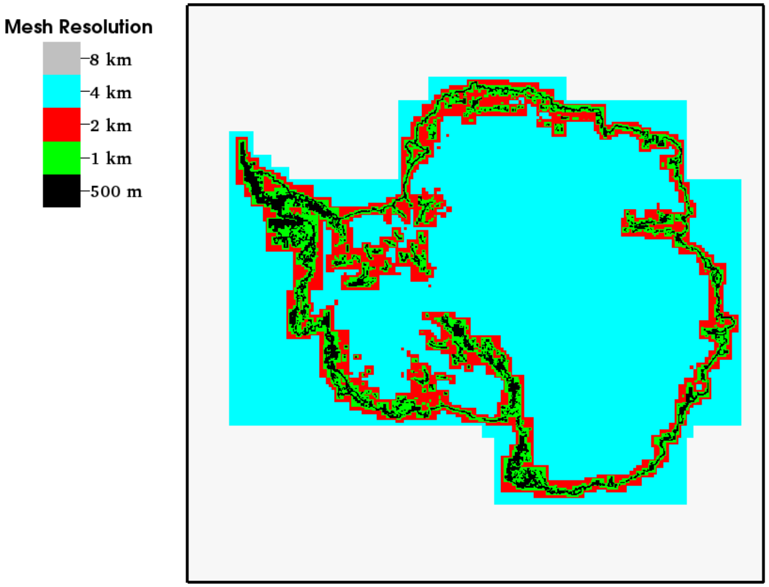
- Based on Feldmann et al (2014)
- Divide cells into quadrants.
- Bilinearly interpolate thickness over flotation $(h - h_f)$ in each quadrant based on neighboring cell centers.
- Subdivide each quadrant into $2^n \times 2^n$ sections and evaluate interpolated thickness over flotation in each segment 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
- SMB: Arthern et al (2006)
- AMR meshes: 8 km base mesh, adaptively refine to Δx_f





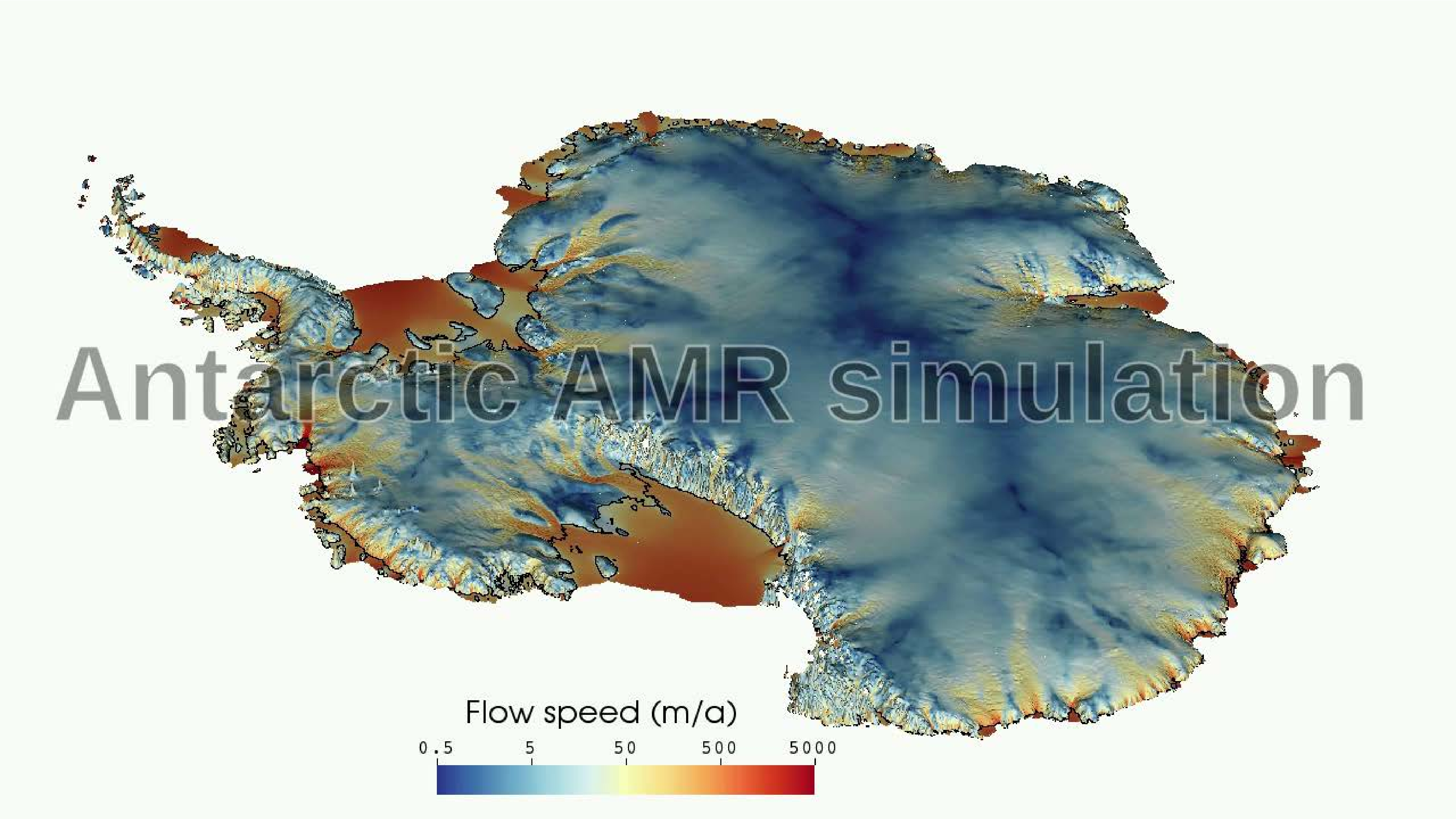
Experiment - 1000-year Antarctic simulations

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

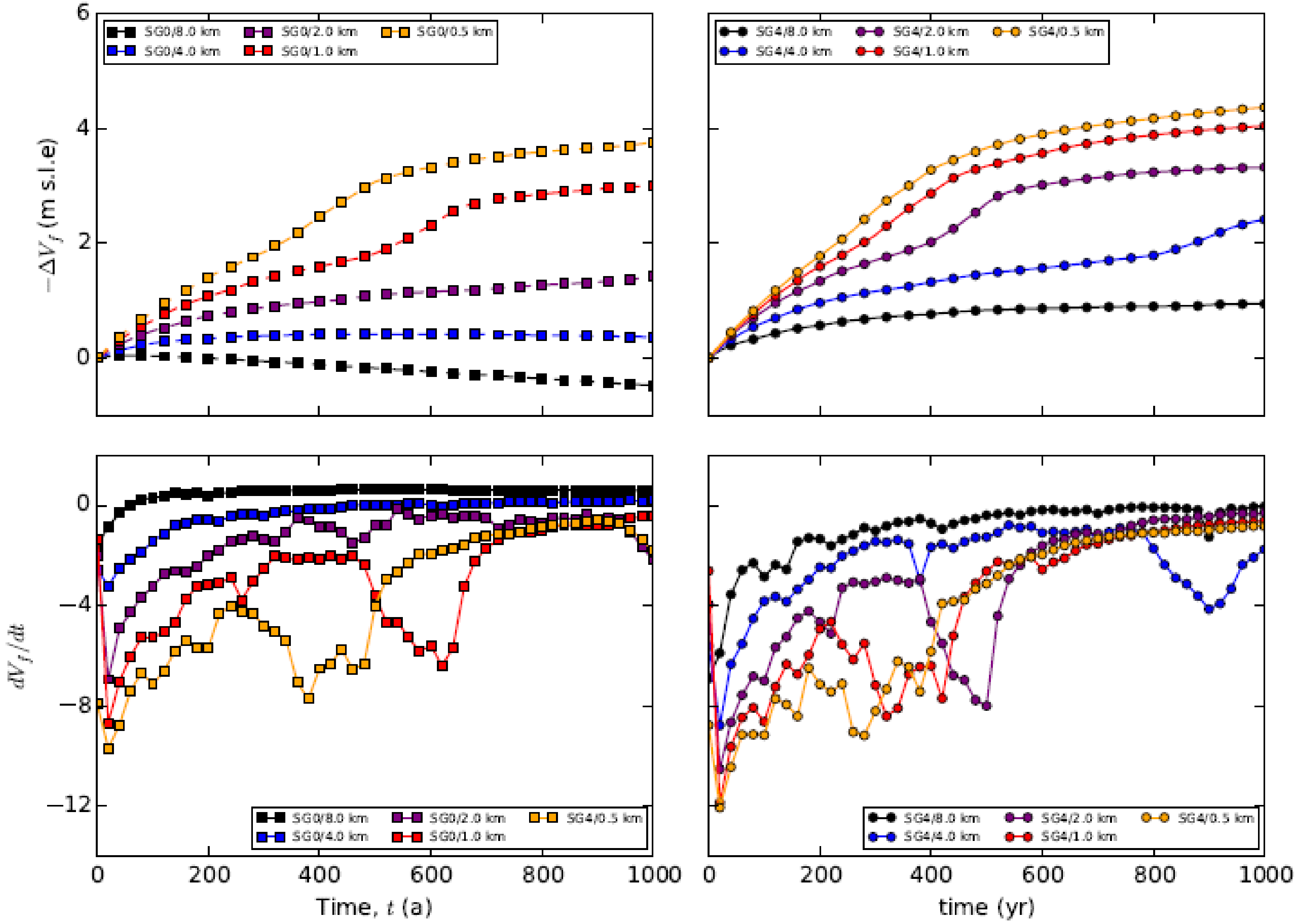
- At initial time, subject ice shelves to extreme (outlandish) melting:
  - No melt for h < 100m
  - Range up to 800m/a where h > 400m.
  - **No melt applied in partially-grounded cells**

- For each resolution, evolve for 1000 years

Results:



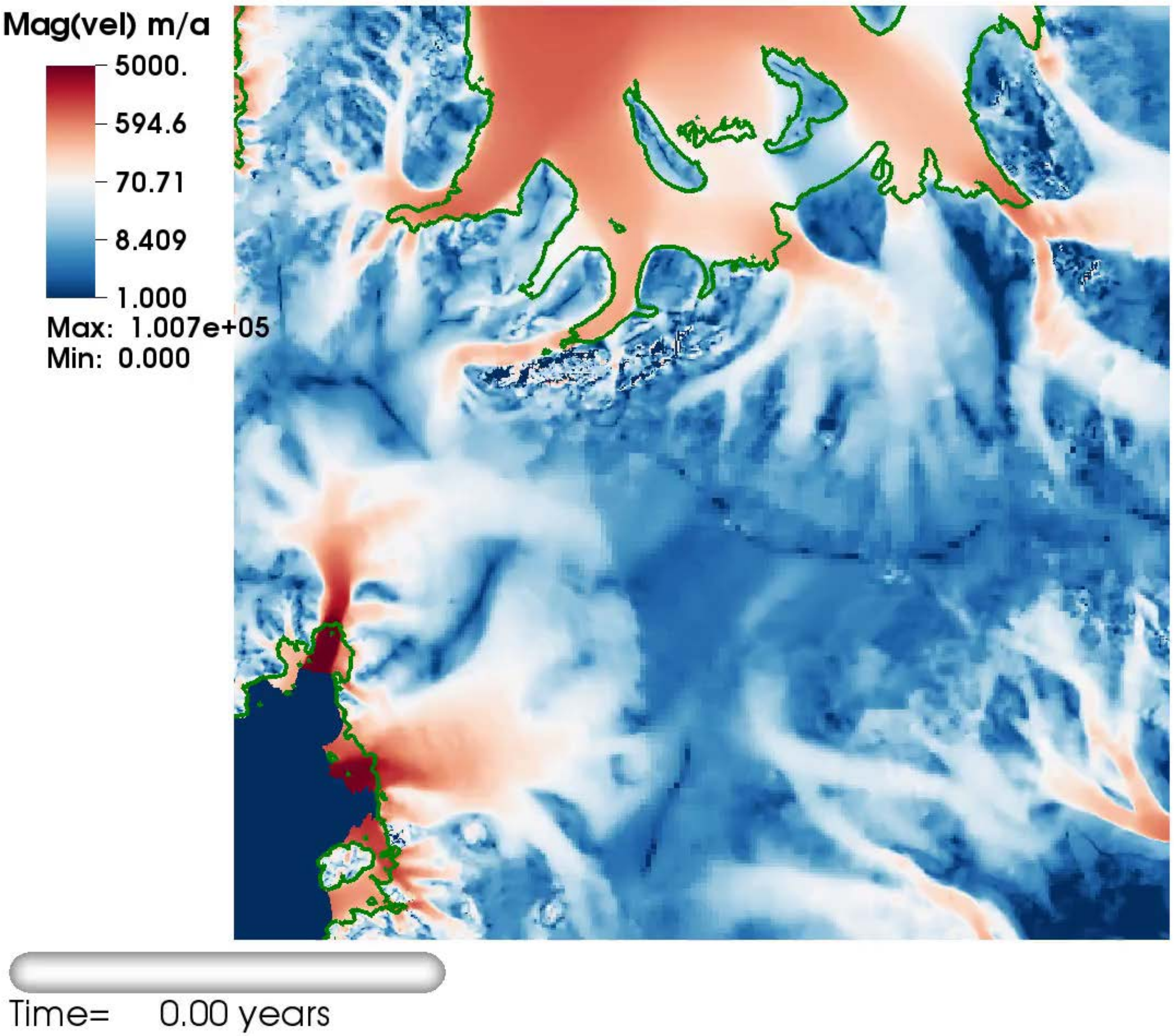
Results, cont.



Results, cont

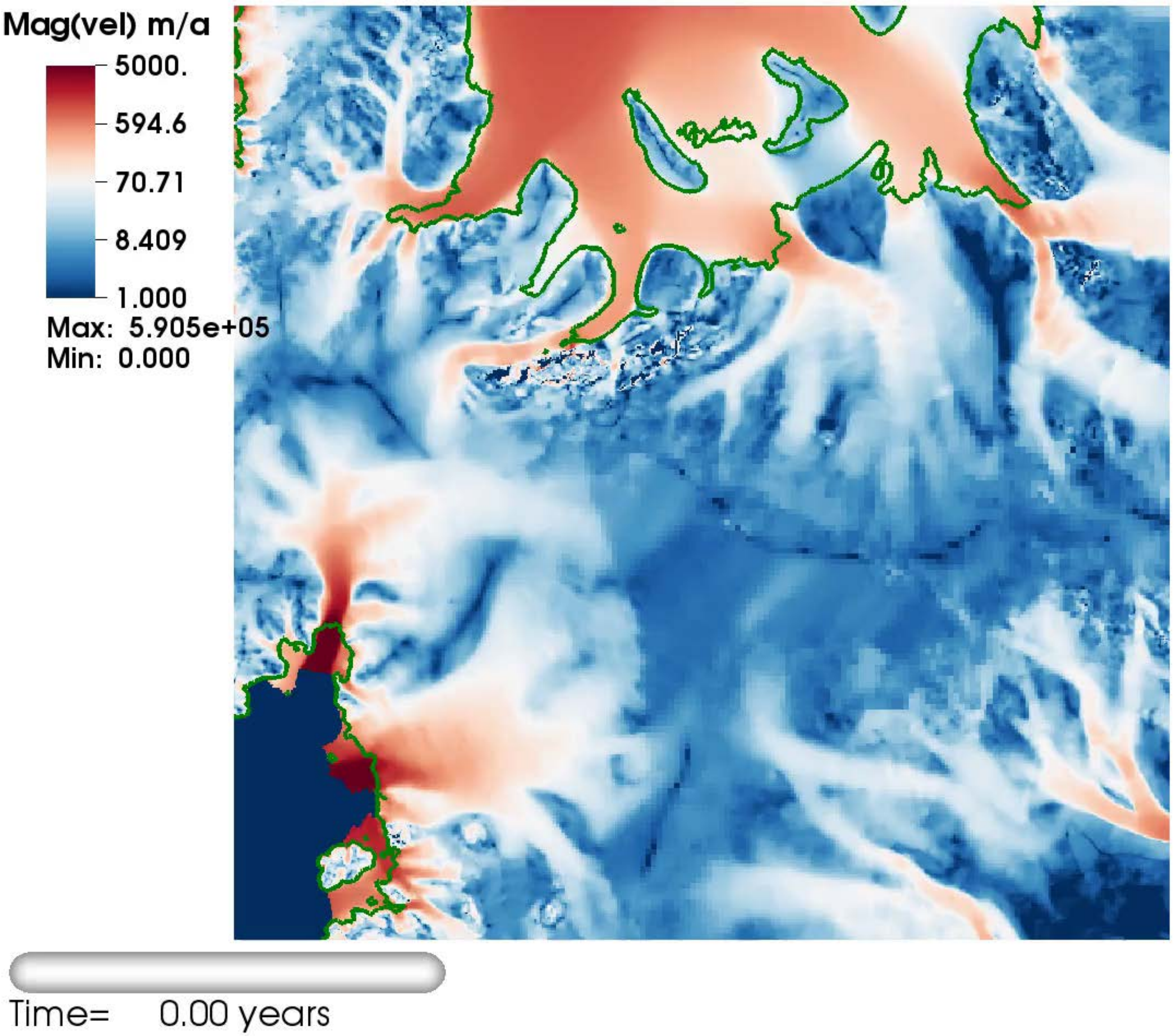
- Complete WAIS collapse in sufficiently-resolved runs.
- Lower-resolutions produce lower GL mobility, lower SLR contributions.
  - PIG: no or delayed retreat for coarser resolutions (4 km)
- Qualitative difference between under-resolved and sufficiently resolved (in the asymptotic regime)
- Subgrid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

Thwaites-Rutford - 500m Resolution



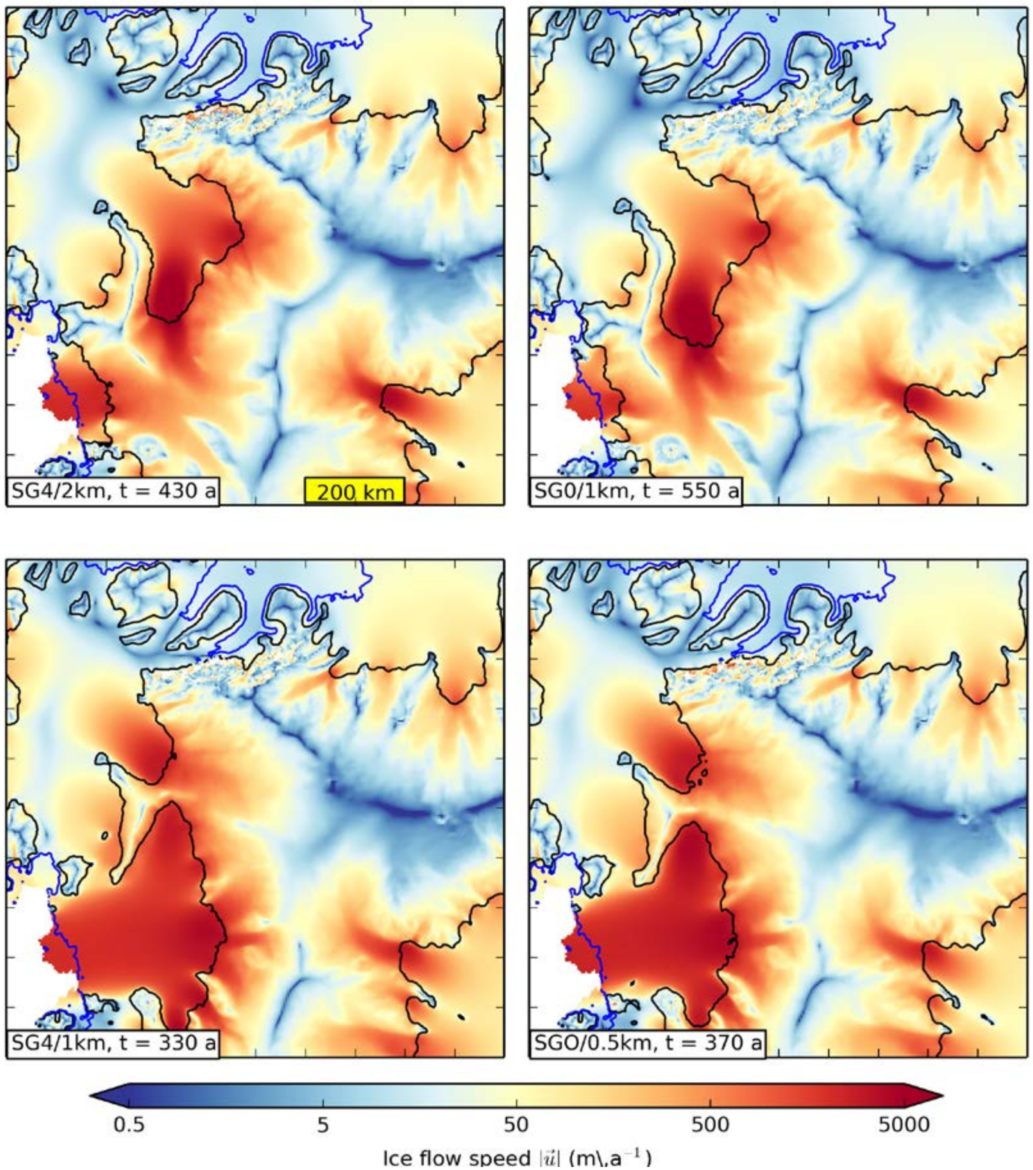
Thwaites-Rutford - 1km Resolution with GLI

Thwaites-Rutford, 2km, with GLI

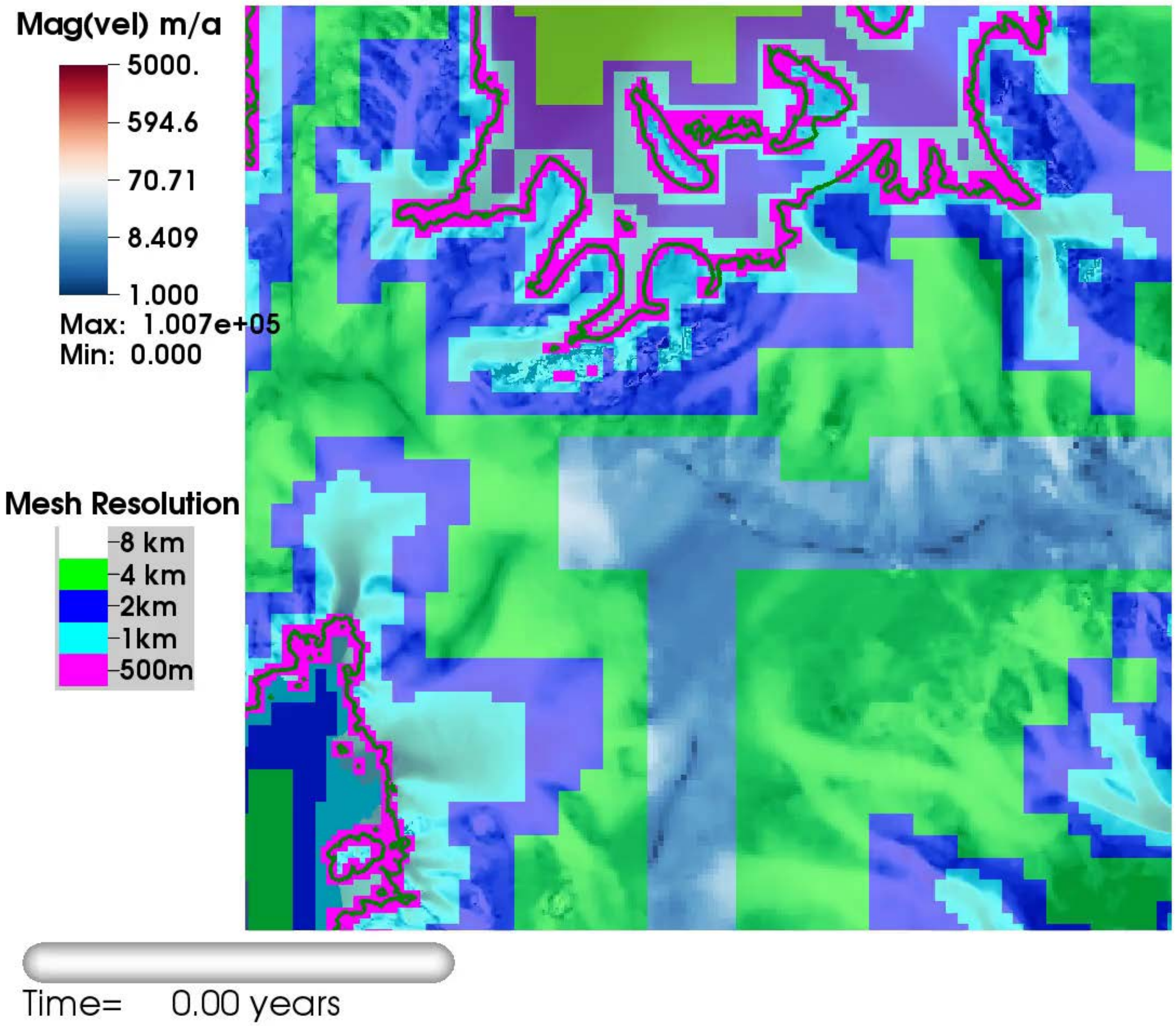


Thwaites/Rutford, 2 km, with GLI

Thwaites-Rutford - effect of resolution

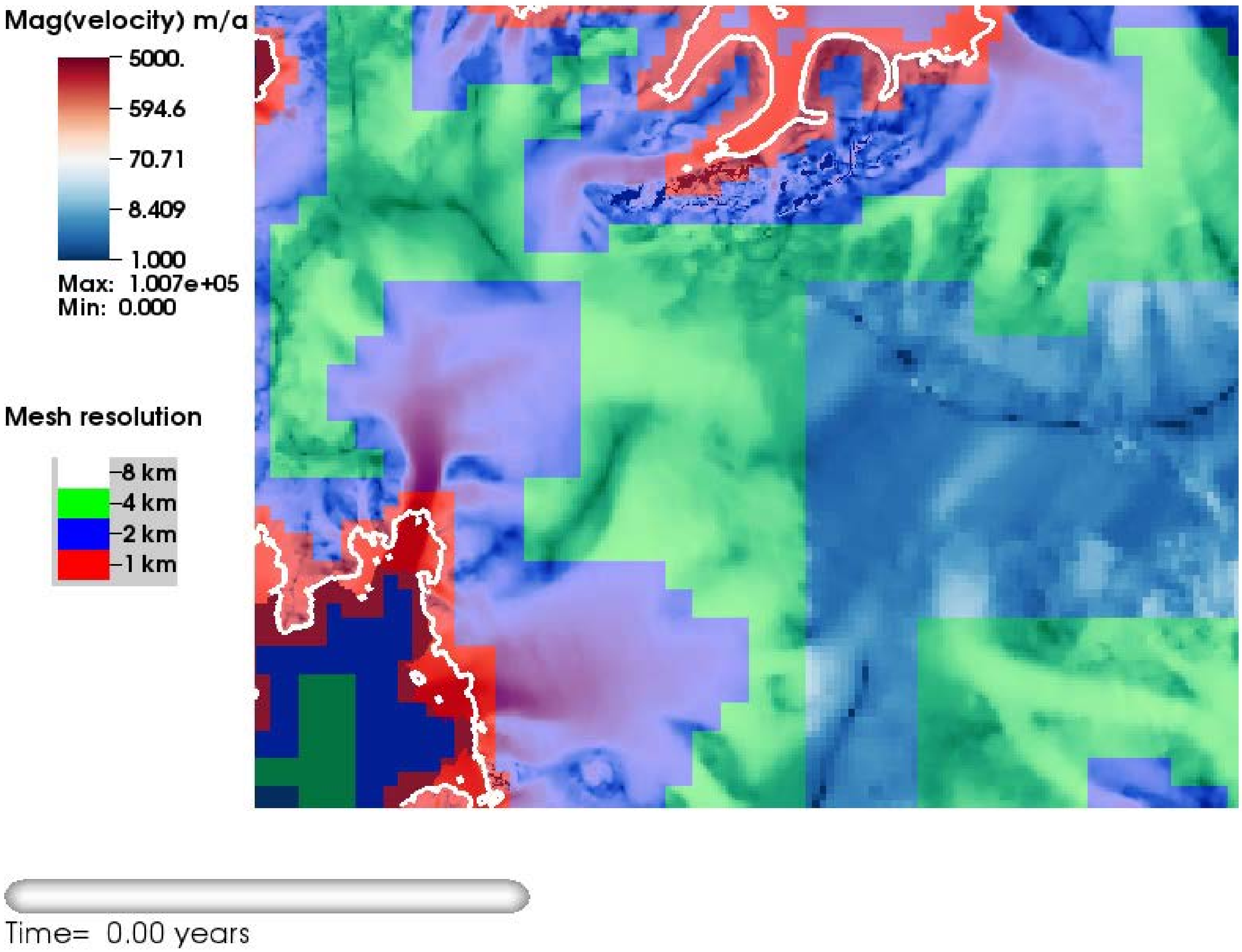


Mesh evolution (500m mesh)

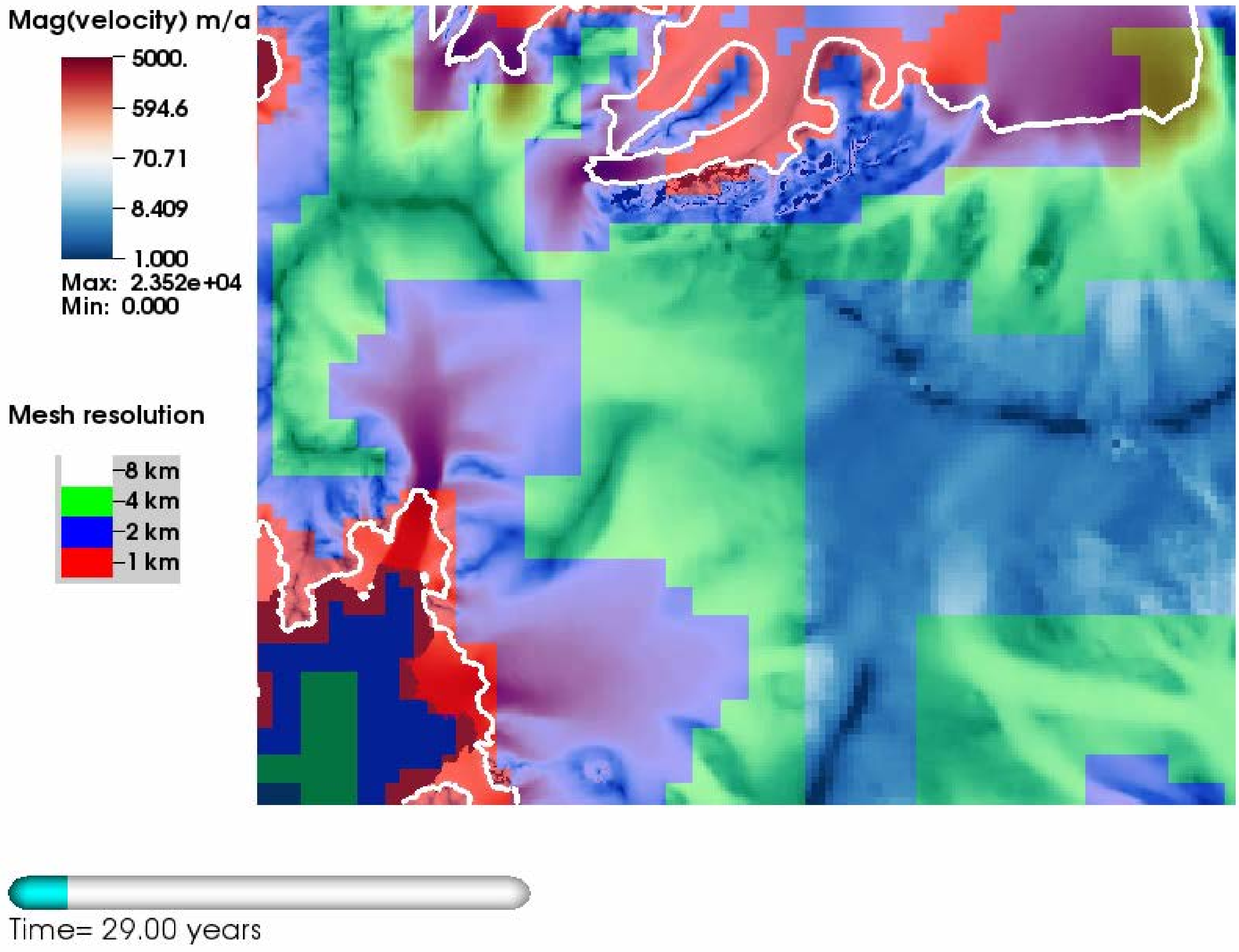


Mesh evolution (500m finest mesh)

No-regridding



No-regridding



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!

Extras

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.