Response of the Antarctic Ice Sheet to Ocean Forcing using the POPSICLES Coupled Ice sheet-ocean model

Dan Martin

Lawrence Berkeley National Laboratory

September 25, 2014

Toward

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Joint work with:

- **Xylar Asay-Davis** (LANL/Potsdam-PIK/NYU-Courant)
- Stephen Cornford (Bristol)
- Stephen Price (LANL)
- Doug Ranken (LANL)
- Mark Adams (LBNL)
- Esmond Ng (LBNL)
- William Collins (LBNL)

Motivation: Projecting future Sea Level Rise

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

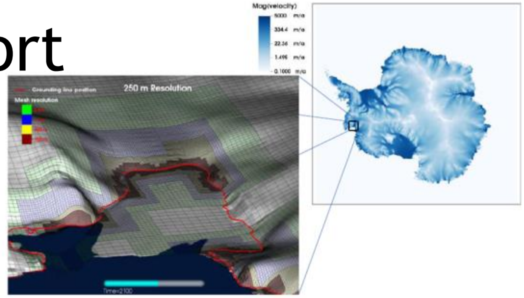
- Climate driver: subshelf melting driven by warm(ing) ocean water intruding into subshelf cavities.

- Paleorecord implies that WAIS has deglaciated in the past.

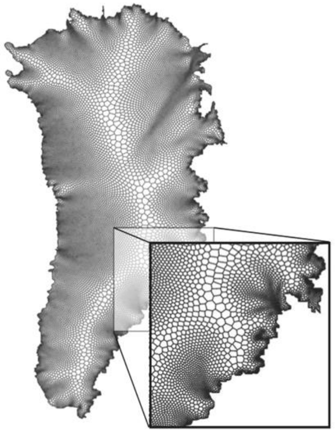
DOE Context - PISCEES and ACME

Part of the DOE "big picture" in climate

- **PISCEES** (Predicting Ice Sheet and Climate Evolution at Extreme Scales)
  - DOE-sponsored (SciDAC2) ice-sheet modeling effort
  - Leverages DOE modeling, HPC capabilities
  - Dycore development
    - BISICLES – block-structured finite-volume AMR, L1L2
    - FELIX – Finite Element unstructured mesh, Blatter-Pattyn/Stokes
  - Initialization, UQ, V&V

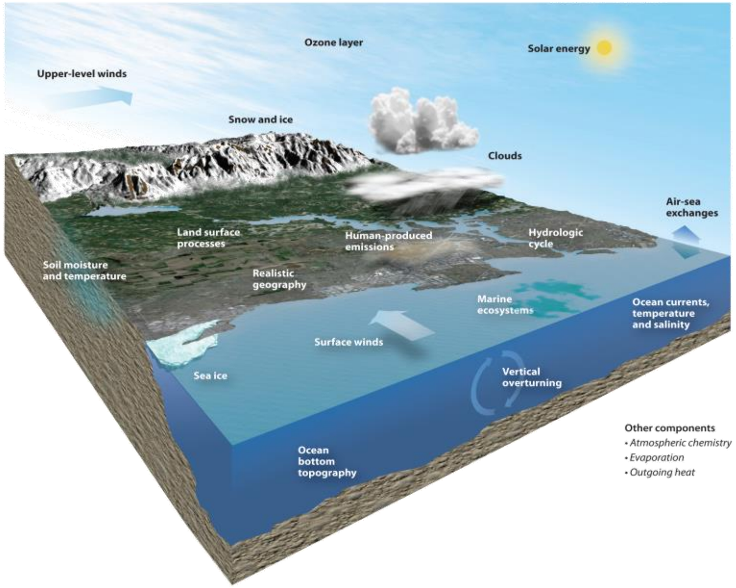


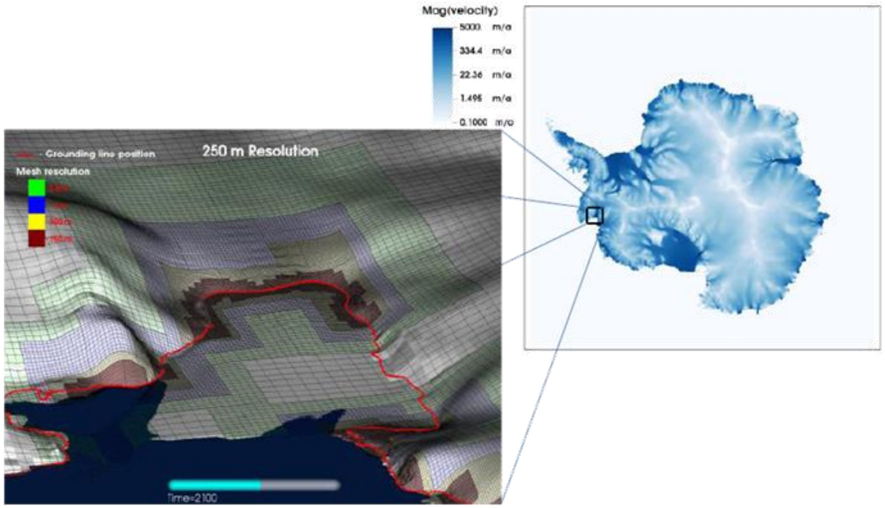
- **ACME** (Accelerated Climate Model for Energy)
  - DOE-sponsored ESM effort
    - 3 science questions (#3 is cryospheric contribution to SLR)
  - Starting point is CESM



Big Picture -- target

- Aiming for coupled ice-sheet-ocean modeling in ESM
- Multi-decadal to century timescales
- Target resolution:
  - Ocean: 0.1 Degree
  - Ice-sheet: 500 m (adaptive)
- Why put an ice-sheet model into an ESM?
  - fuller picture of sea-level change
  - feedbacks may matter on timescales of years, not just millenia





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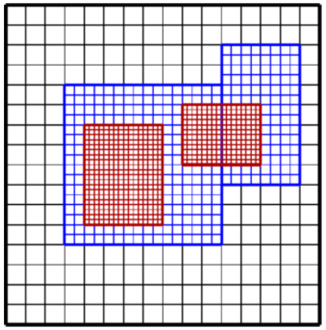
Models:

- Ice Sheet: BISICLES (CISM-BISICLES)

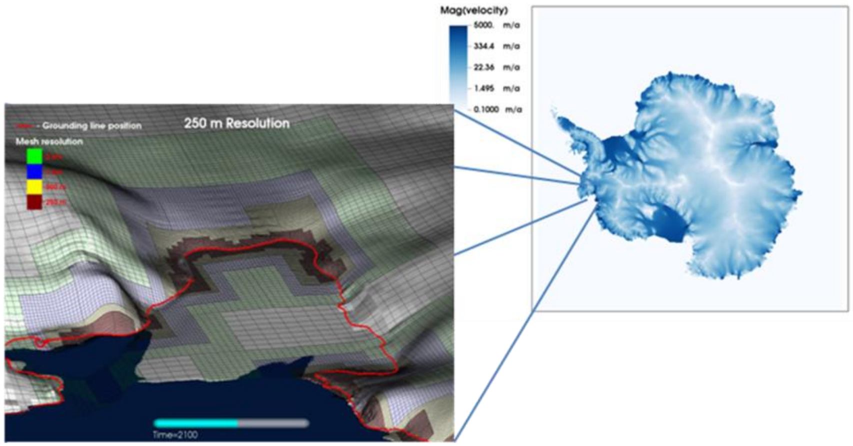
- Ocean Circulation Model: POP2x

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)

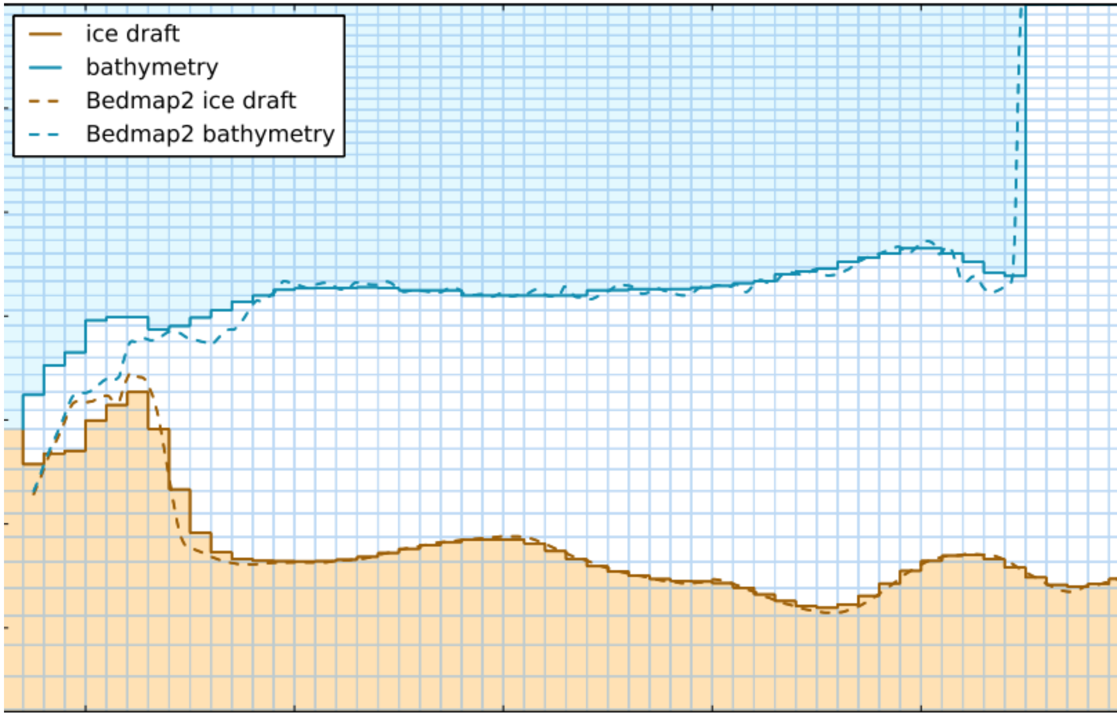


- Collaboration with Bristol (U.K.) and LANL
- Variant of “L1L2” model (Schoof and Hindmarsh, 2009)
- Coupled to Community Ice Sheet Model (CISM).
- Users in Berkeley, Bristol, Beijing, Brussels, and Berlin…



POP and Ice Shelves

- Parallel Ocean Program (POP) Version 2
  - Ocean model of the Community Earth System Model (CESM)
  - z-level, hydrostatic, Boussinesq
- Modified for Ice shelves:
  - partial top cells
  - boundary-layer method of Losch (2008)



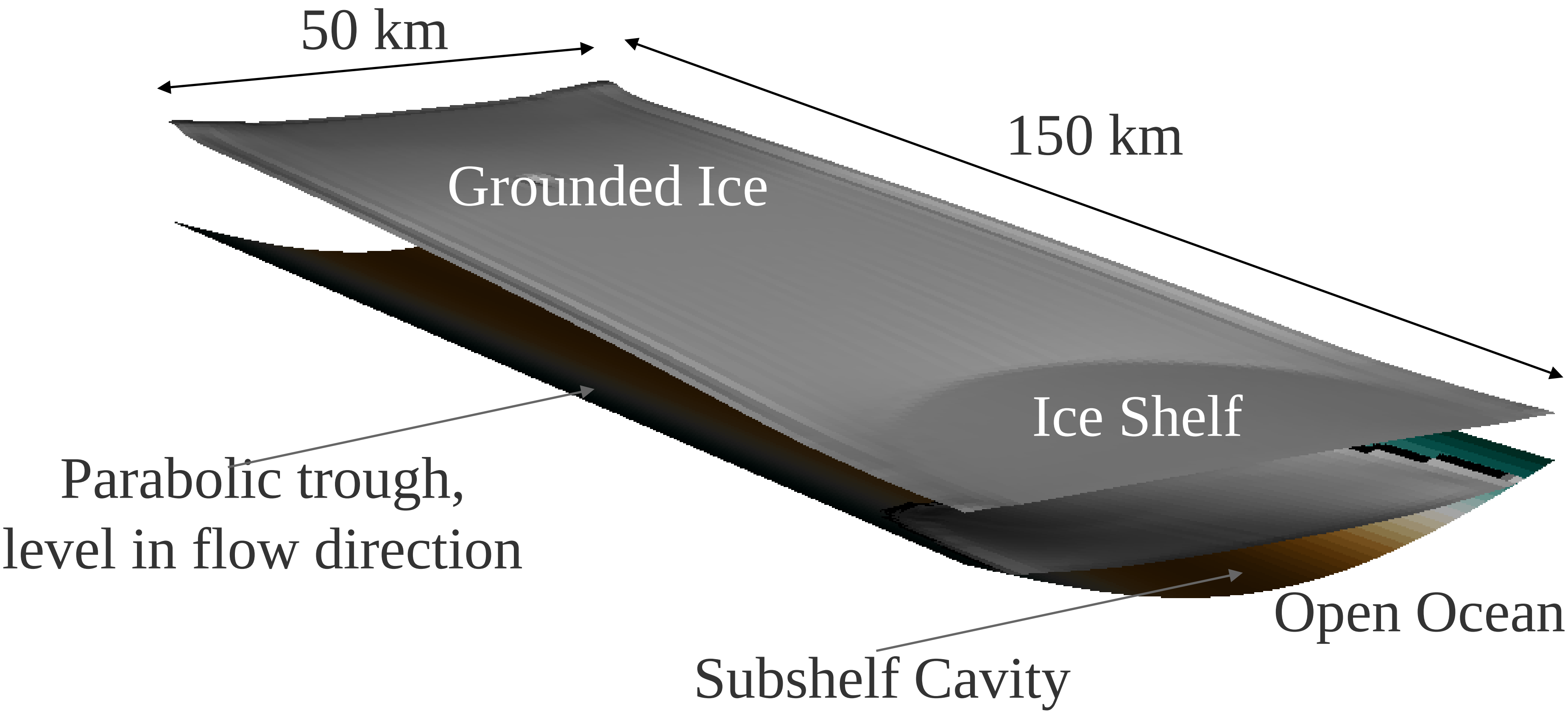
- Melt rates computed by POP:
  - sensitive to vertical resolution
  - nearly insensitive to transfer coefficients, tidal velocity, drag coefficient

Coupling: Synchronous-offline

- Monthly coupling time step ~ based on experimentation
- BISICLES → POP2x: (instantaneous values)
  - ice draft, basal temperatures, grounding line location
- POP2x → BISICLES: (time-averaged values)
  - (lagged) sub-shelf melt rates
- Coupling offline using standard CISM and POP netCDF I / O
- POP bathymetry and ice draft recomputed:
  - smoothing bathymetry and ice draft, thickening ocean column, ensuring connectivity
  - T and S in new cells extrapolated iteratively from neighbors
  - barotropic velocity held fixed; baroclinic velocity modified where ocean column thickens/thins

Idealized Coupled Simulations

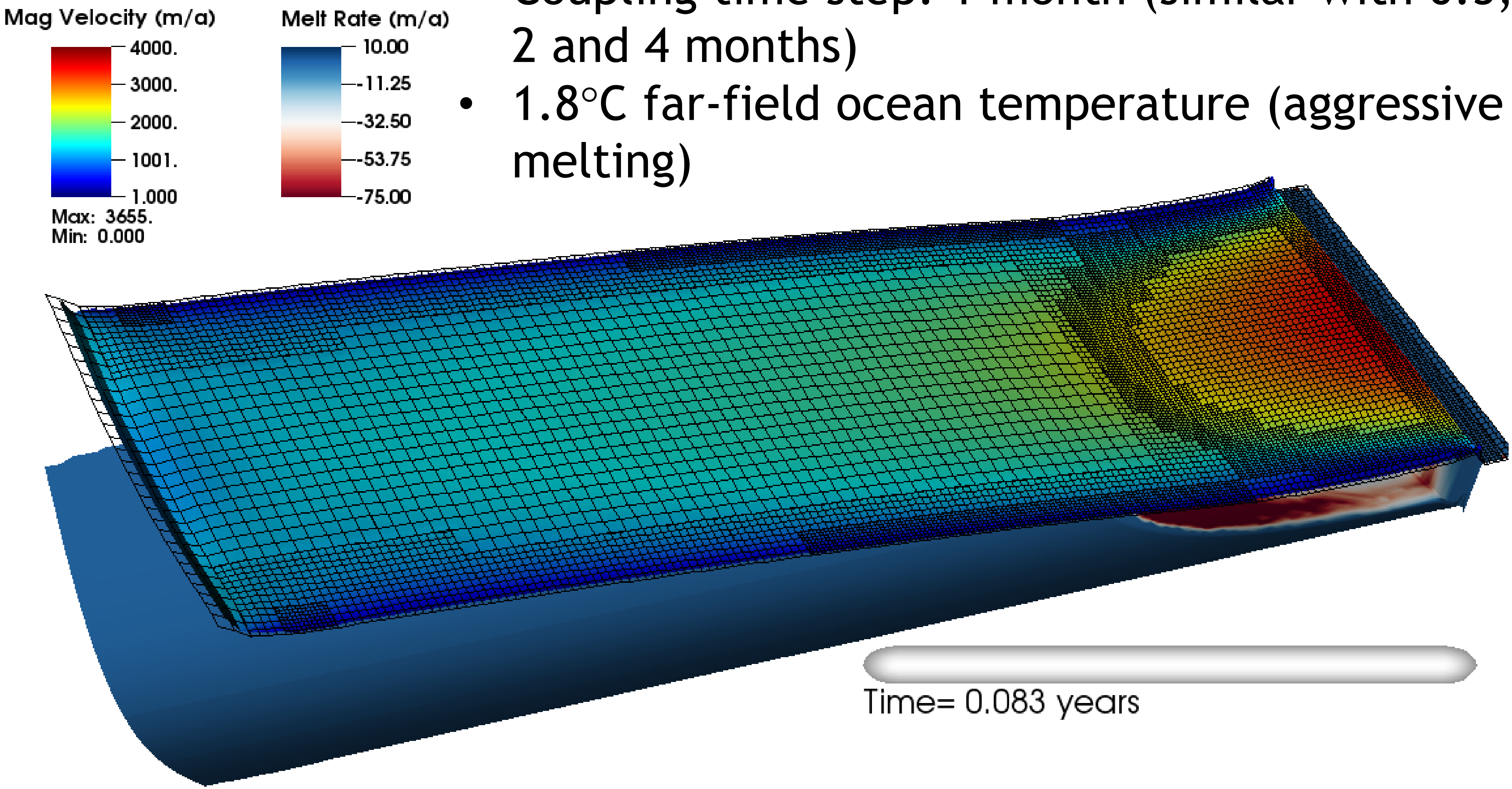
- Aims to reproduce Goldberg et al (2012)
- Cavity and Forcing similar to Pine Island Glacier



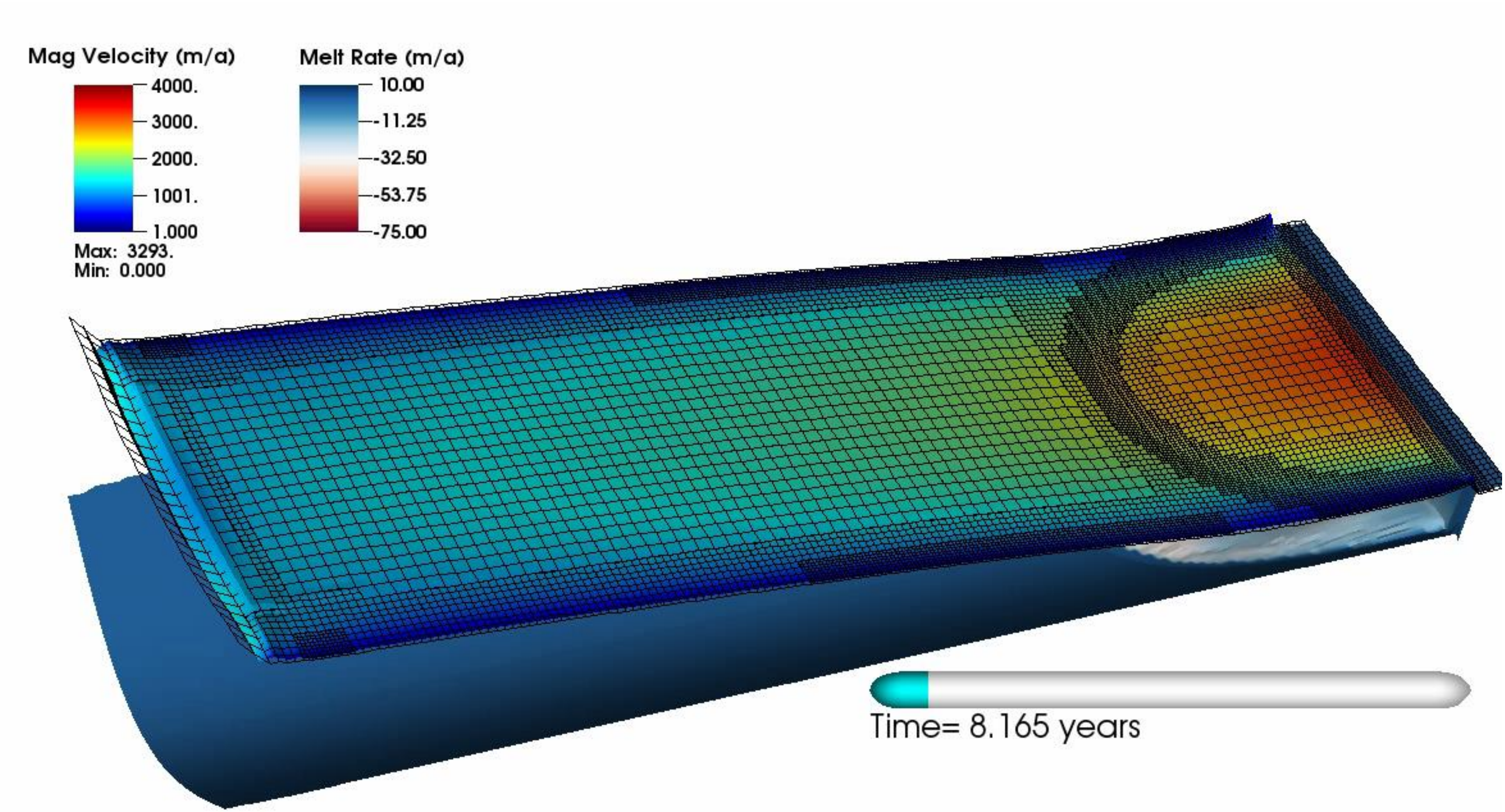
Goldberg, D. N., Little, C. M., Sergienko, O. V., Gnanadesikan, A., Hallberg, R., & Oppenheimer, M. (2012). Investigation of land ice-ocean interaction with a fully coupled ice-ocean model: 1. Model description and behavior. Journal of Geophysical Research, 117(F2), 1–16.

Coupled Models: Goldberg Test Problem

- Coupling time step: 1 month (similar with 0.5, 2 and 4 months)
- 1.8°C far-field ocean temperature (aggressive melting)

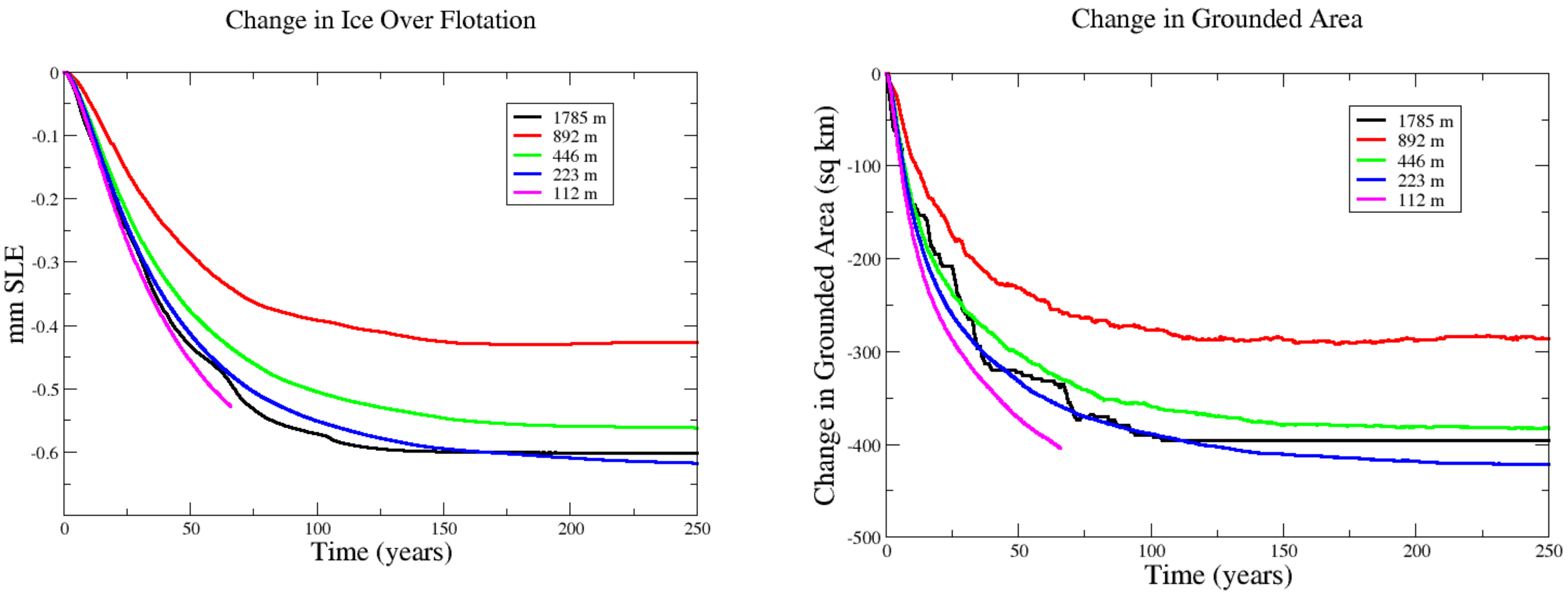


Coupled Models: Goldberg Test Problem



Goldberg Results (cont) - Mesh resolution

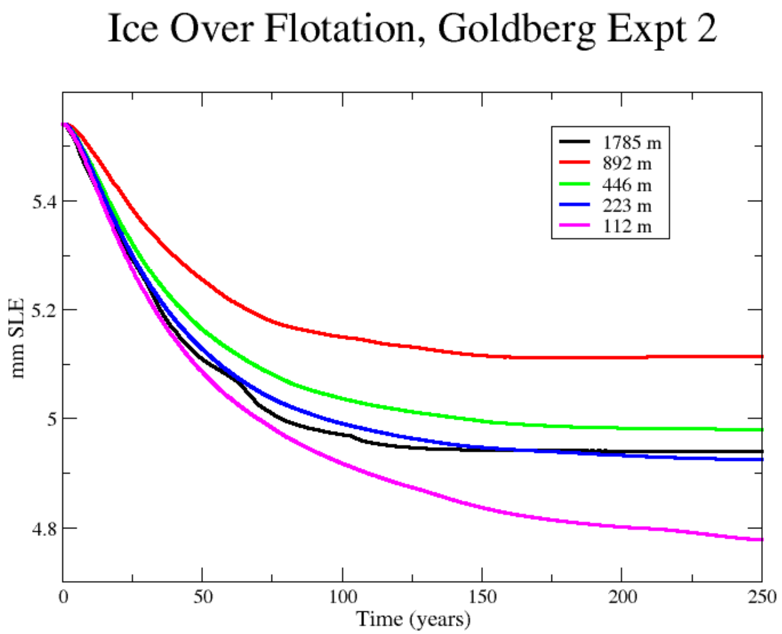
- Using AMR, computed with finest resolution Δx= 223m, 446m, 892m, 1785m

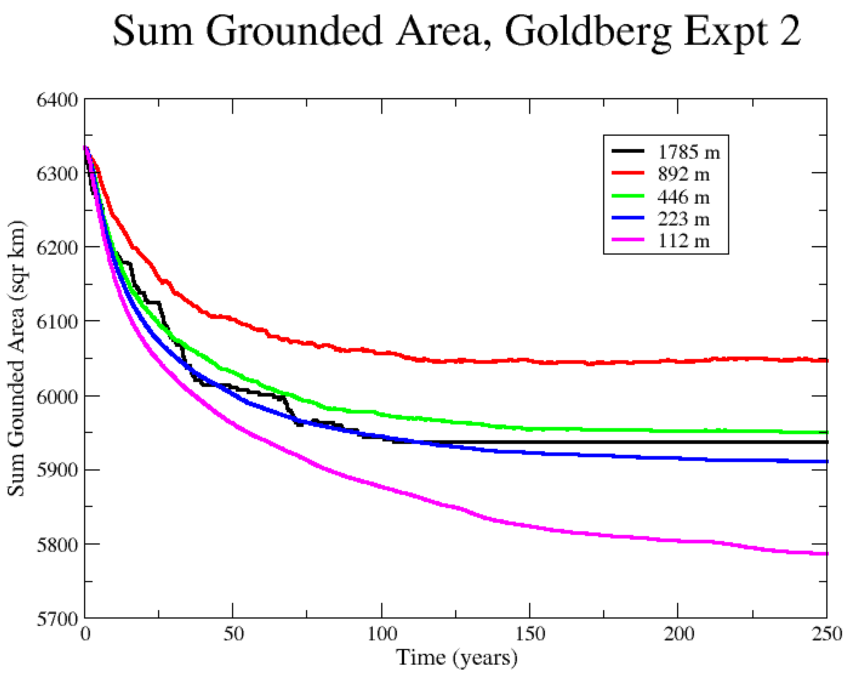


- 892m, 446m, 223m, 112m solutions converging at roughly O(Δx)
- 1785m not in the convergent ("asymptotic") regime

Goldberg Results (cont) - Mesh resolution

- Using AMR, computed with finest resolution Δx= **112m** 223m, 446m, 892m, 1785m



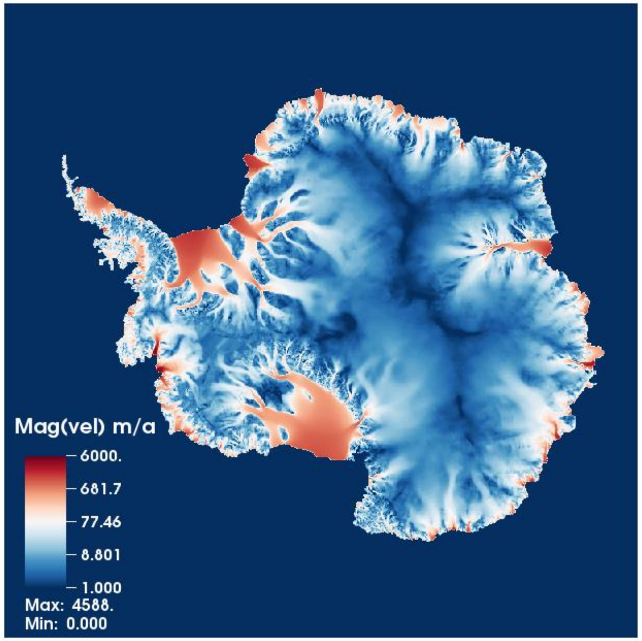


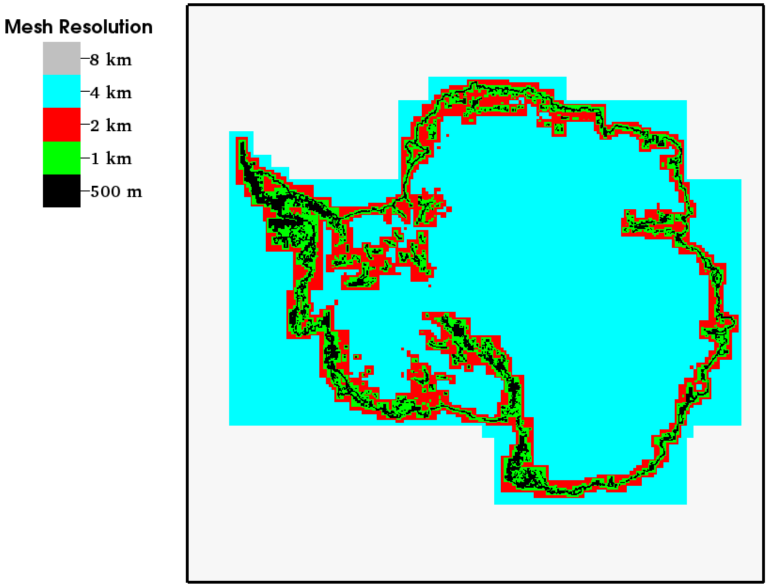
- Suddenly not looking so clean…

Antarctic-Southern Ocean Coupled Simulations

BISICLES setup:

- ❑ Bedmap2 (2013) geometry
- ❑ Initialize to match Rignot (2011) velocities
- ❑ Temperature field from Pattyn (SIA spinup)
- ❑ 500m finest resolution
- ❑ Initialize SMB to "steady state" using POP standalone melt rate

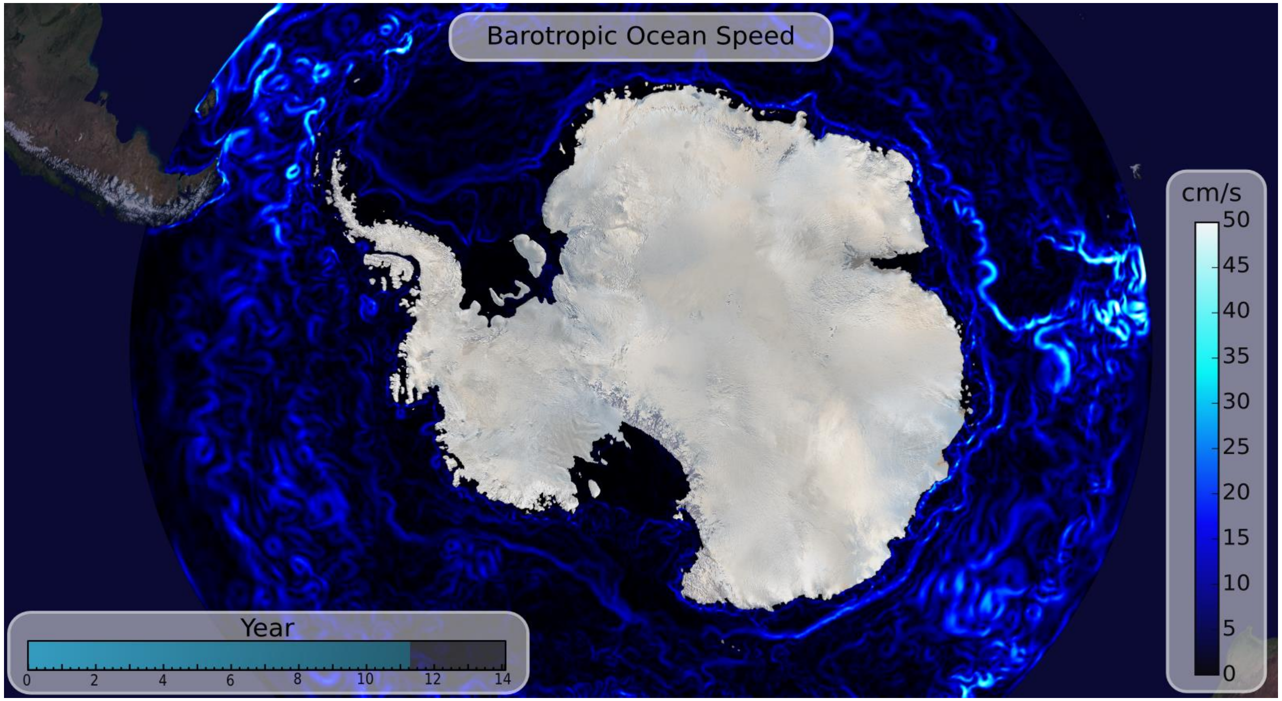




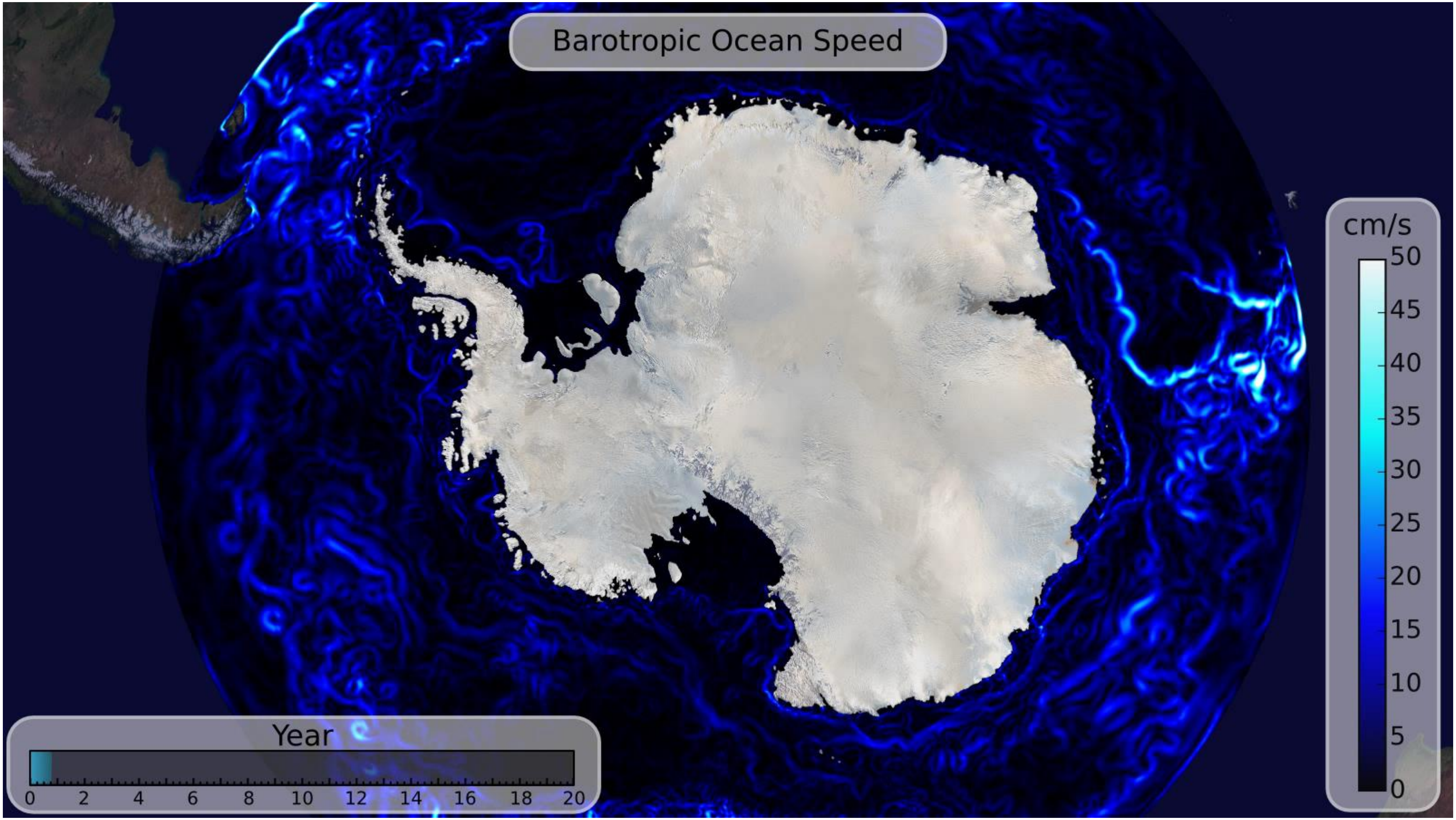
Antarctic-Southern Ocean Simulation

POP setup:

- Regional southern ocean domain (50-85°S)
- ~5 km (0.1°) horizontal res.; 80 vertical levels (10m - 250m)
- Monthly mean climatological ("normal year") forcing with
- monthly restoring to WOA data at northern boundaries
- Initialize with 3-year stand-alone run; Bedmap2 geometry



Antarctica-Southern Ocean Simulation -- POP



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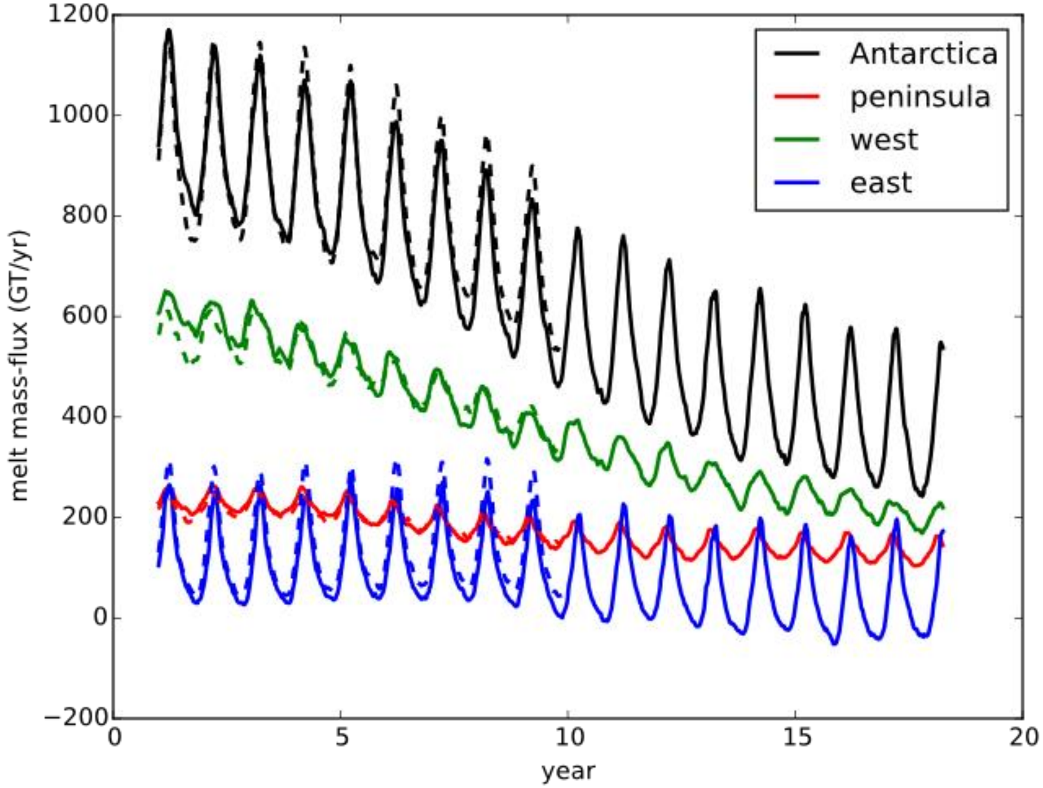
Antarctic-Southern Ocean Coupled Sims (cont)

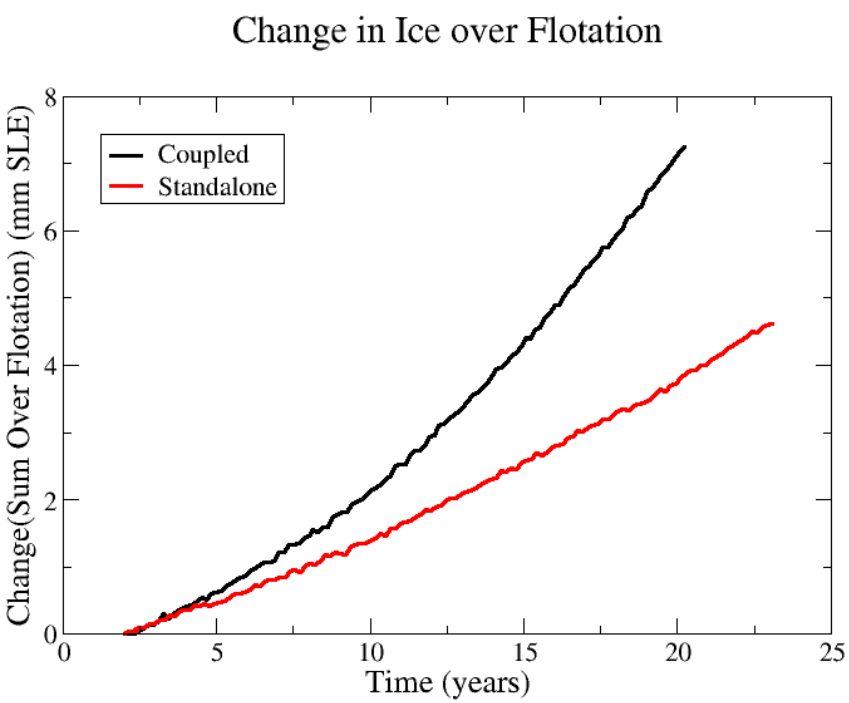
What Happens?

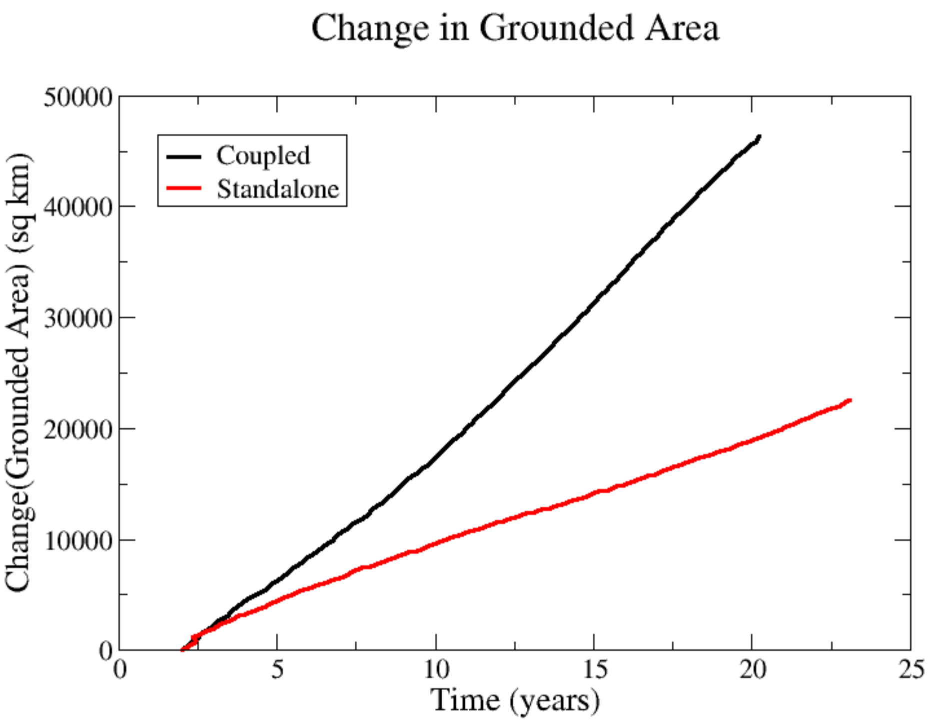


- Melt rates are spinning down over time (POP issue)
- Possible causes – climate forcing? no sea ice model?

Antarctic-Southern Ocean Coupled Sims (cont)

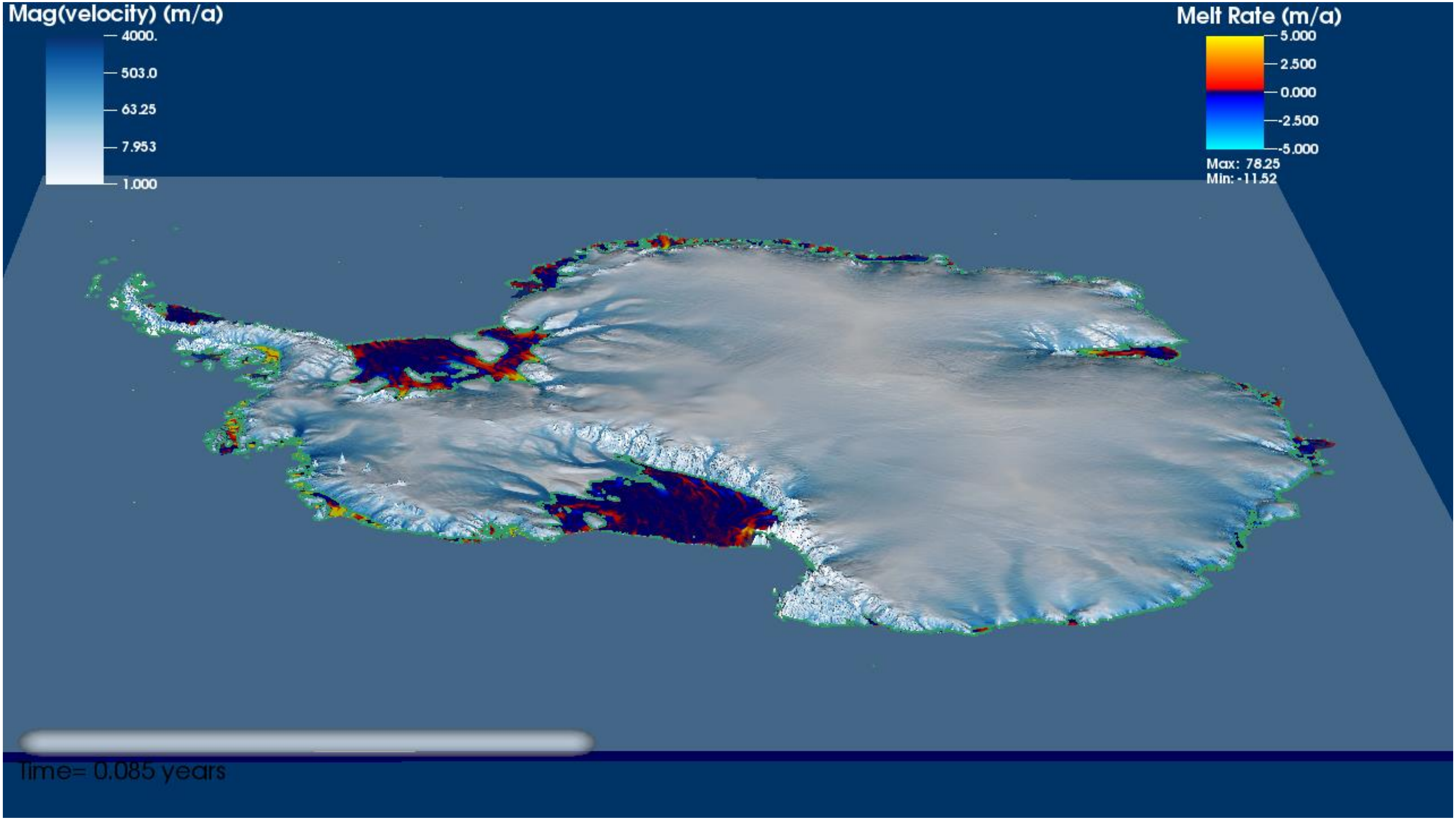
Compare Standalone vs. Coupled runs:



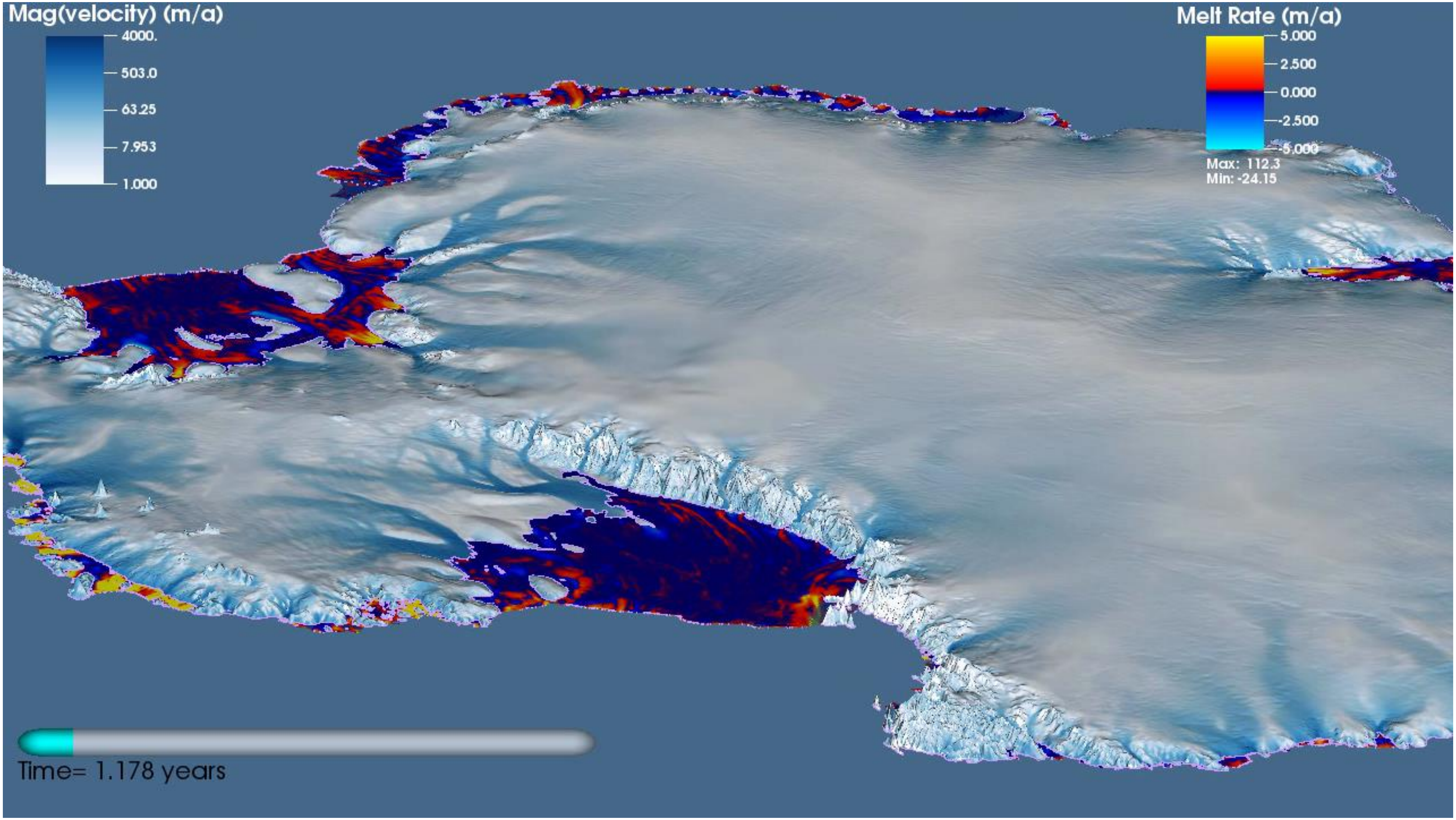


- “Steady-state” initial condition isn’t quite (mass gain)
- Melt rates are spinning down over time (POP issue)
- **Can see effect of coupling (gains mass faster than standalone)**

Antarctic-Southern Ocean Coupled Sims (cont)



Antarctic-Southern Ocean Coupled Sims (cont)



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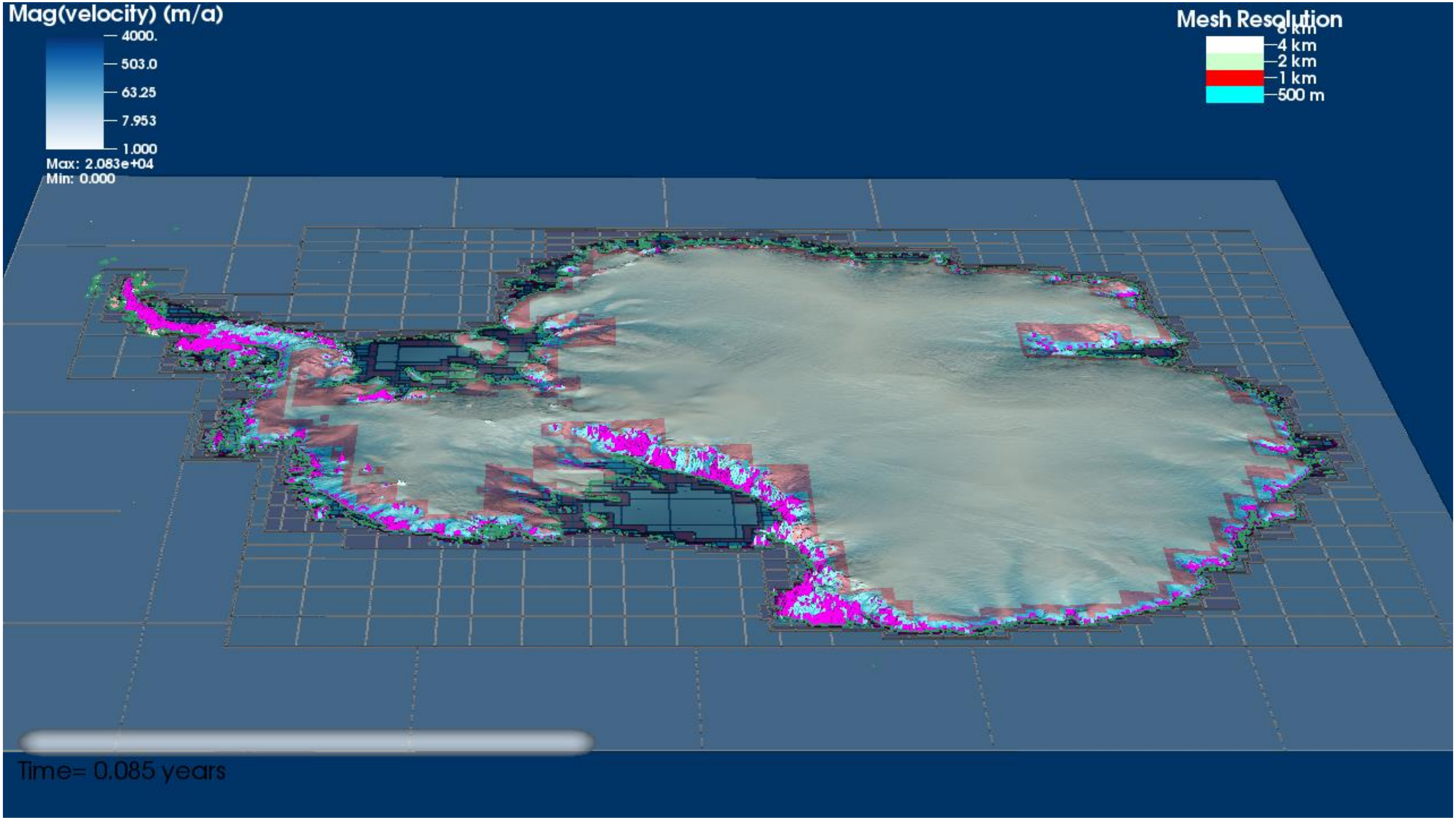
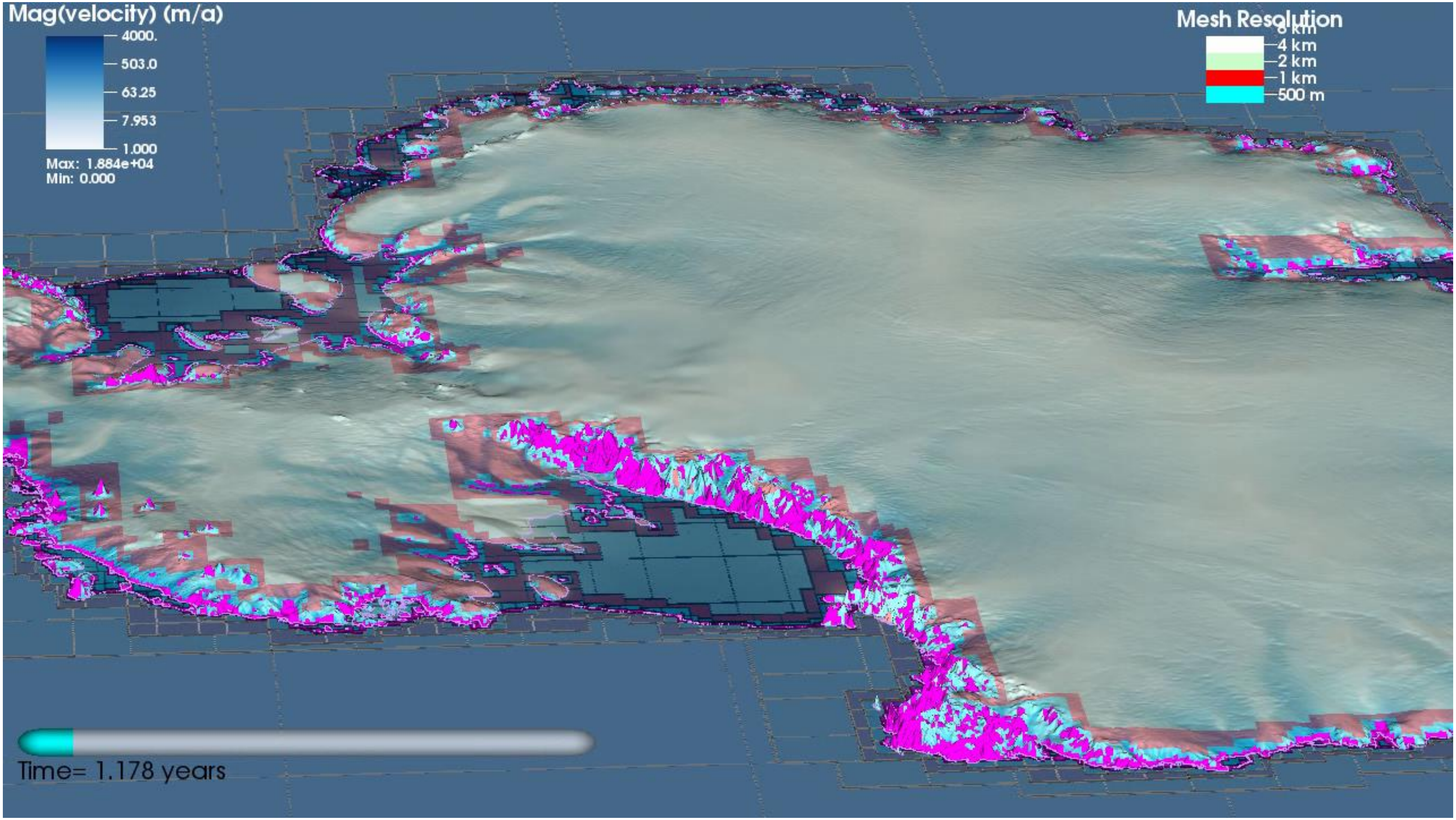


Antarctic-Southern Ocean Coupled Sims (cont)



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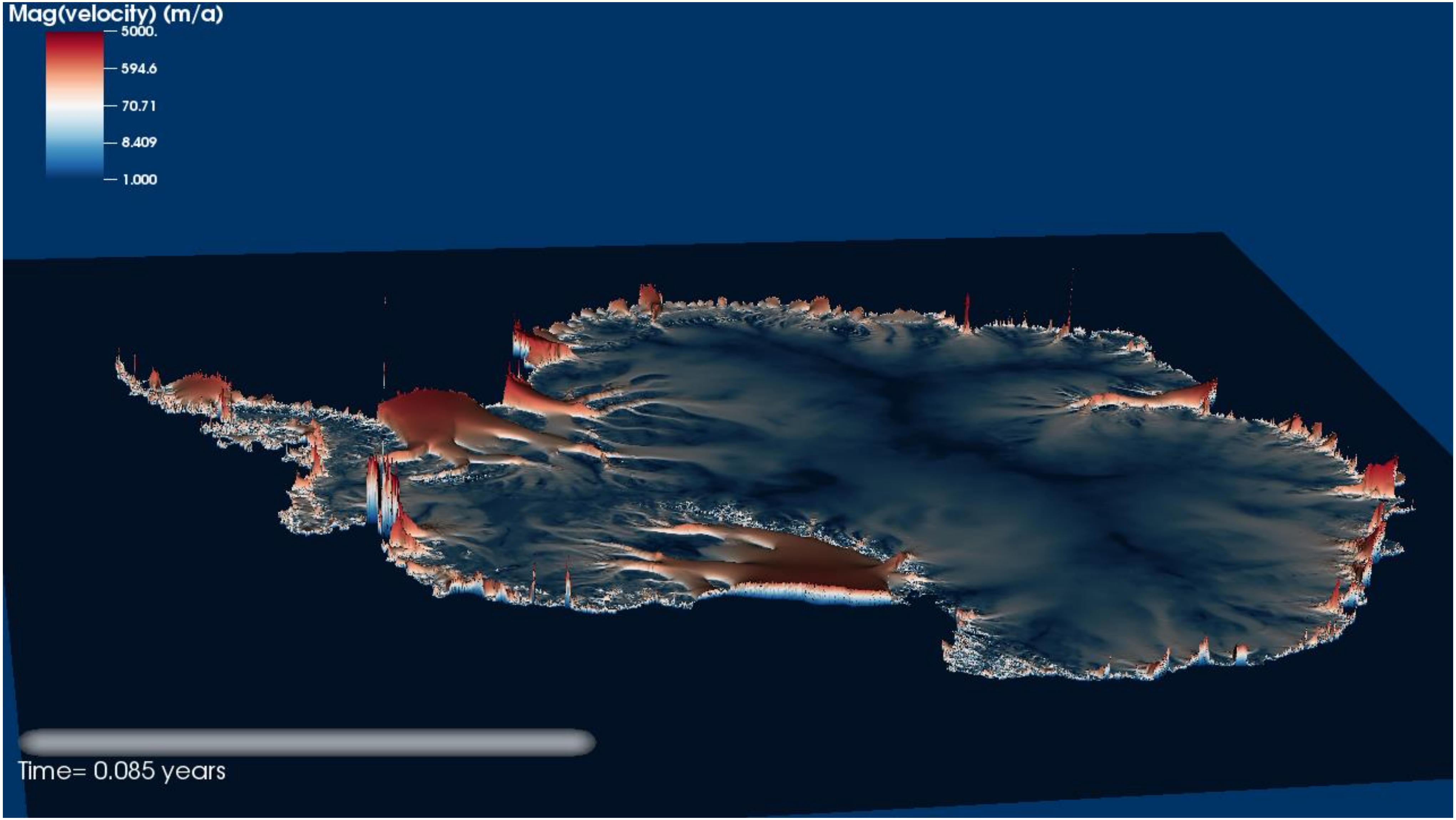

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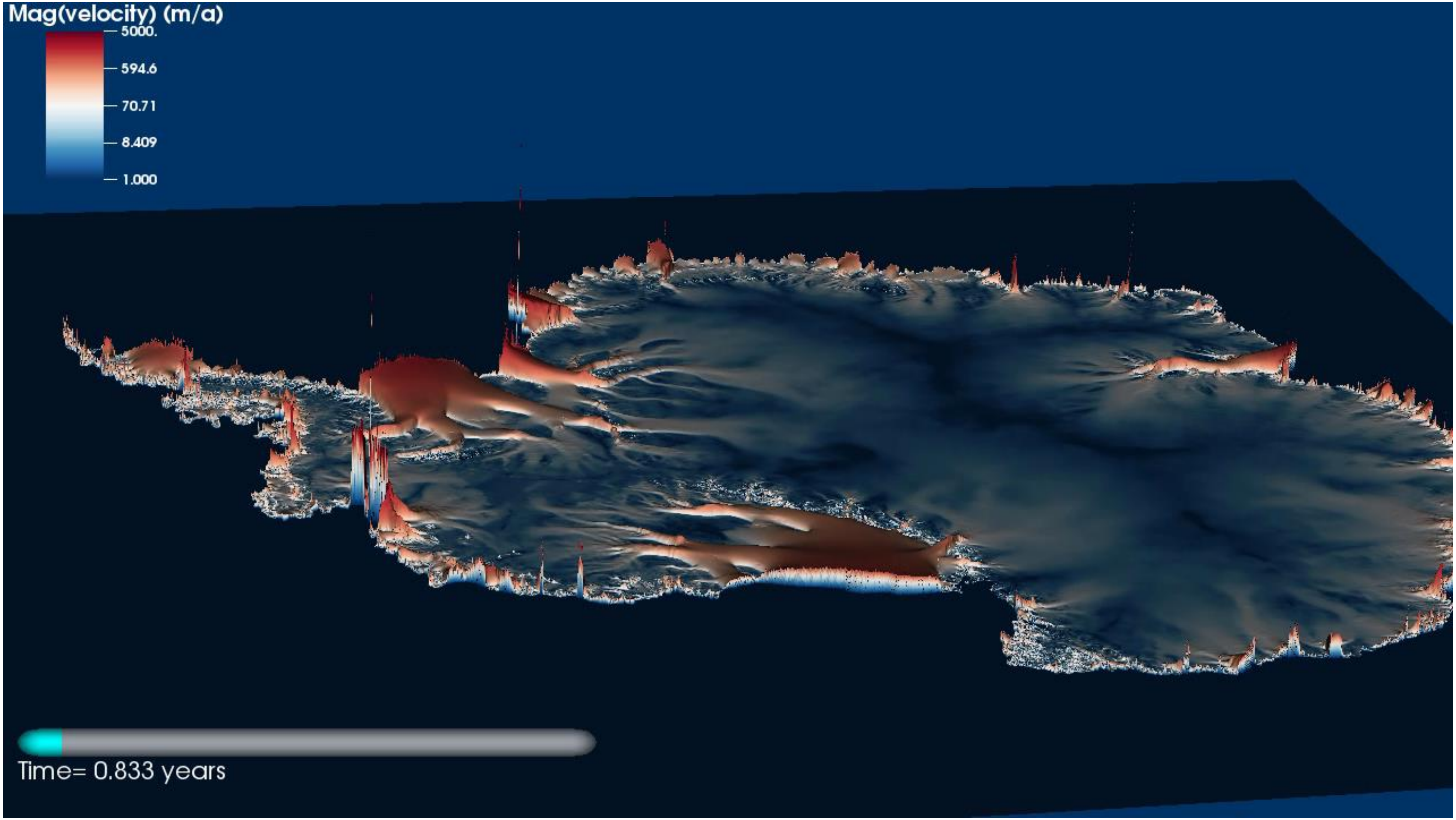
Antarctic-Southern Ocean Coupled Sims (cont)



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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)

Issues emerging from coupled Antarctic Runs

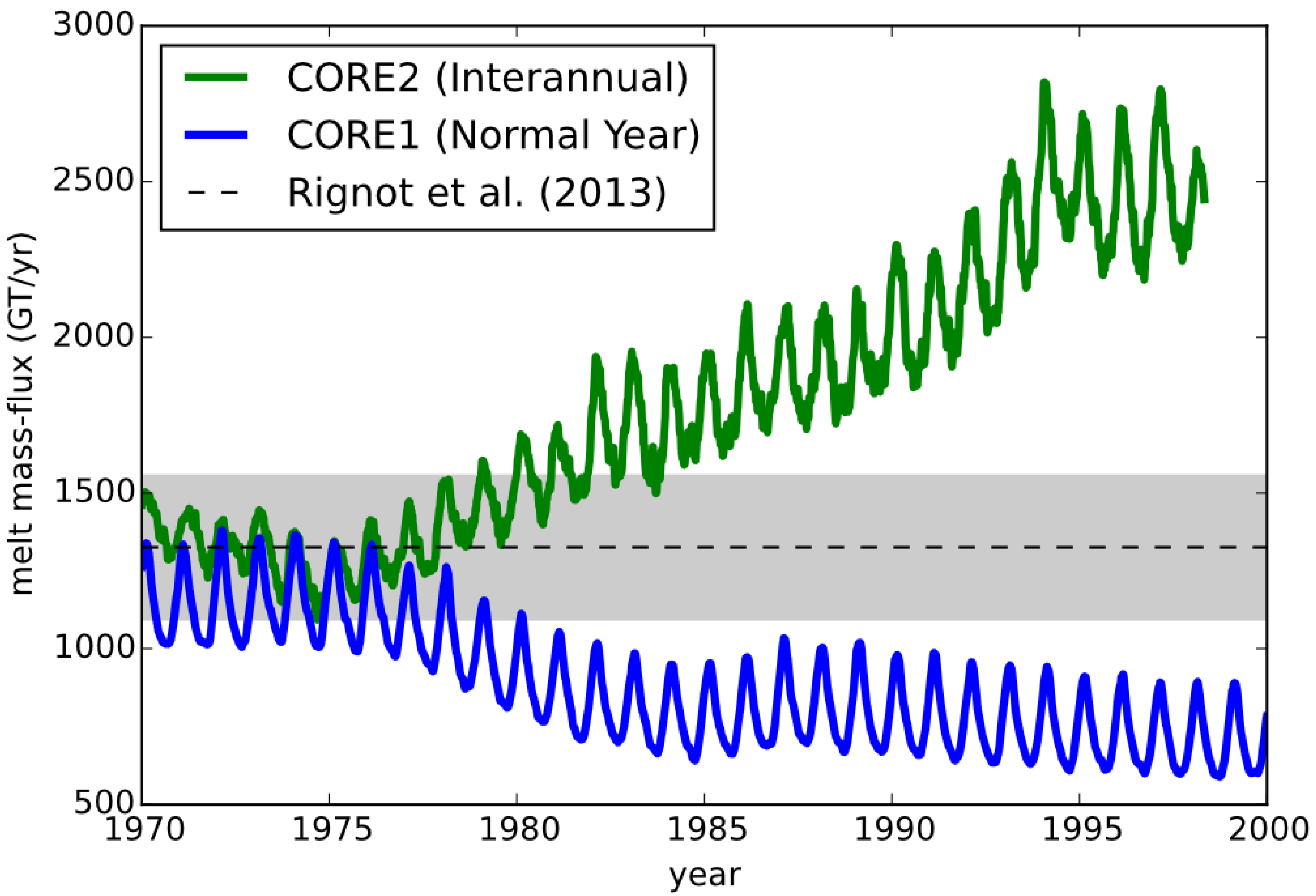
- Fixed POP error in freezing calculation.
  - (resulted in overestimated refreezing)

- POP cold bias (spin-down of melt rates)

- Issue with artificial shelf-cavity geometry in Bedmap2
  - Bedmap2 specifically mentions Getz, Totten, Shackleton
  - Very thin subshelf cavities (constant 20 m!) result in high sensitivity to regrounding
  - Interacted with POP Thresholding cavity thickness

- Need better initialization (On tap for next run)

Different climate forcing on POP melt rates



Switching to CORE2 forcing removes cold bias – now too warm…

Thank you!

Future work

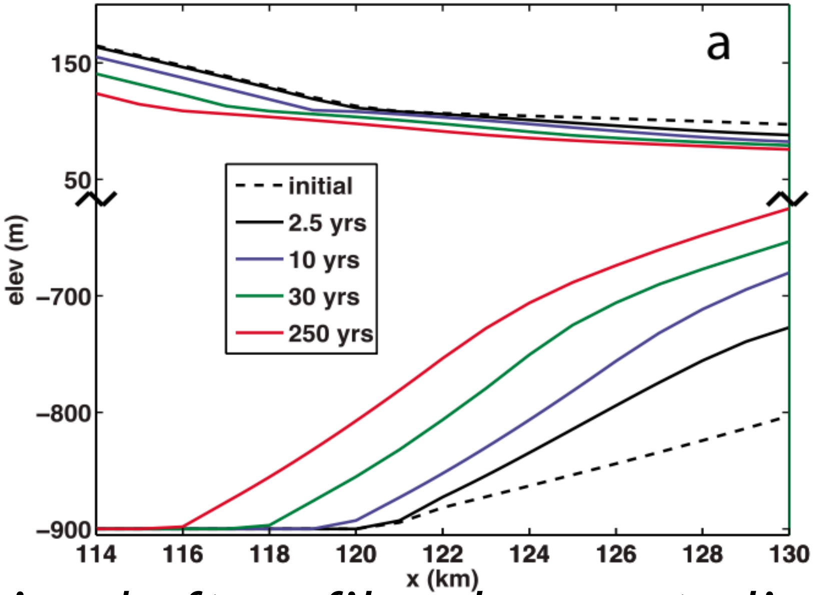
- Fix issues exposed during coupled run and try again.
  - BISICLES initial condition
  - POP cold bias

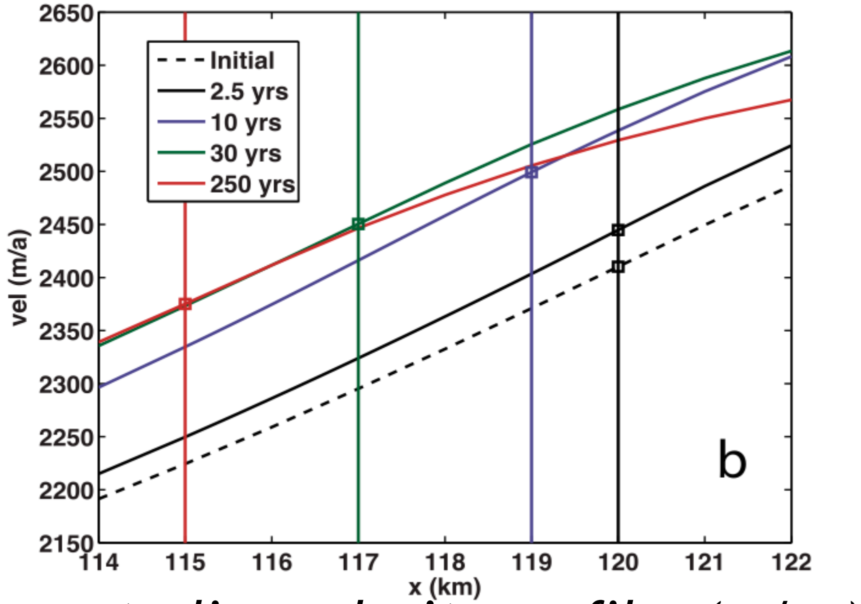
- More realistic climatology/forcing leading to “real” projections

Comparison with Goldberg et al.

Far-field T=0.6°C

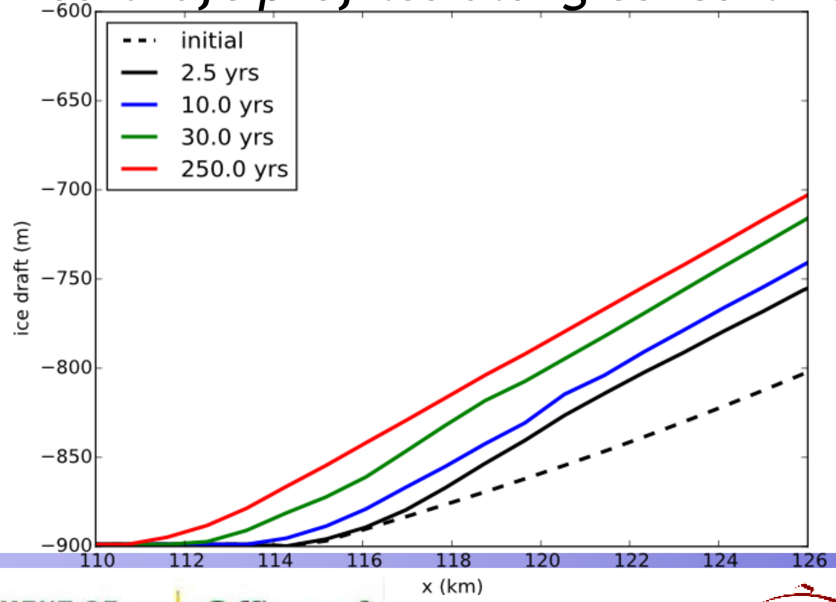
Goldberg et al. (2012a)

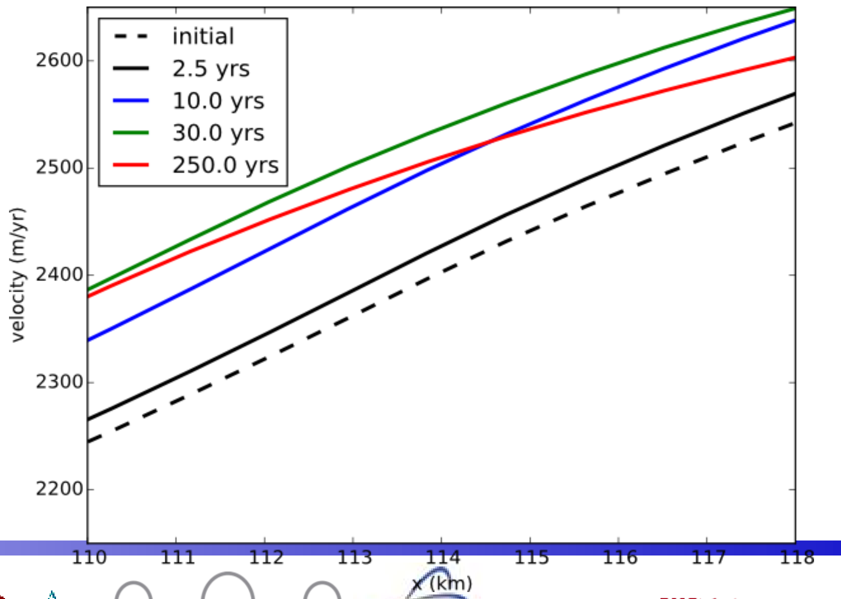




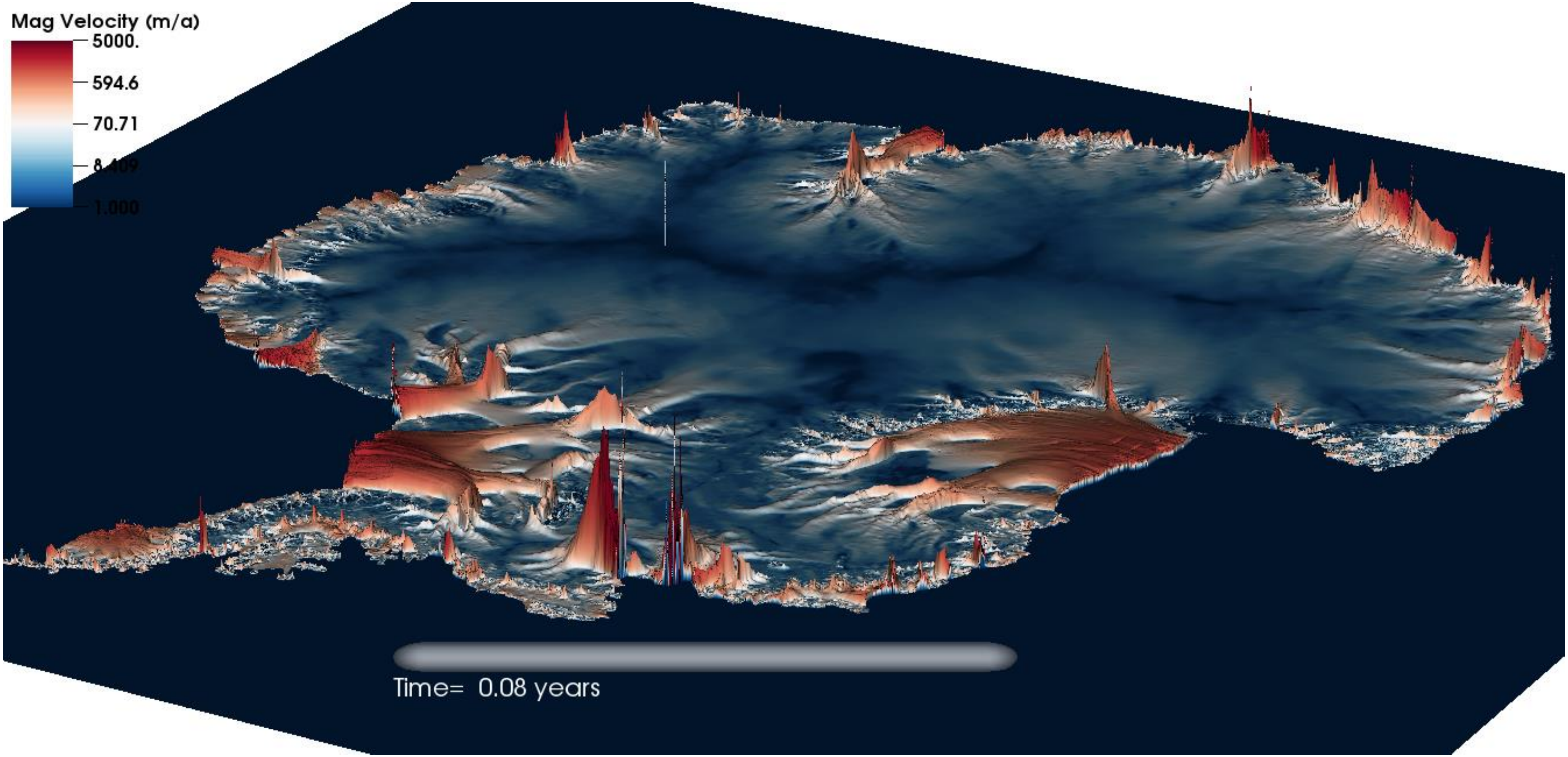
ice-draft profiles along centerline   *centerline velocity profiles (m/yr)*

POP-BISICLES





Antarctic-Southern Ocean Coupled Sims (cont)



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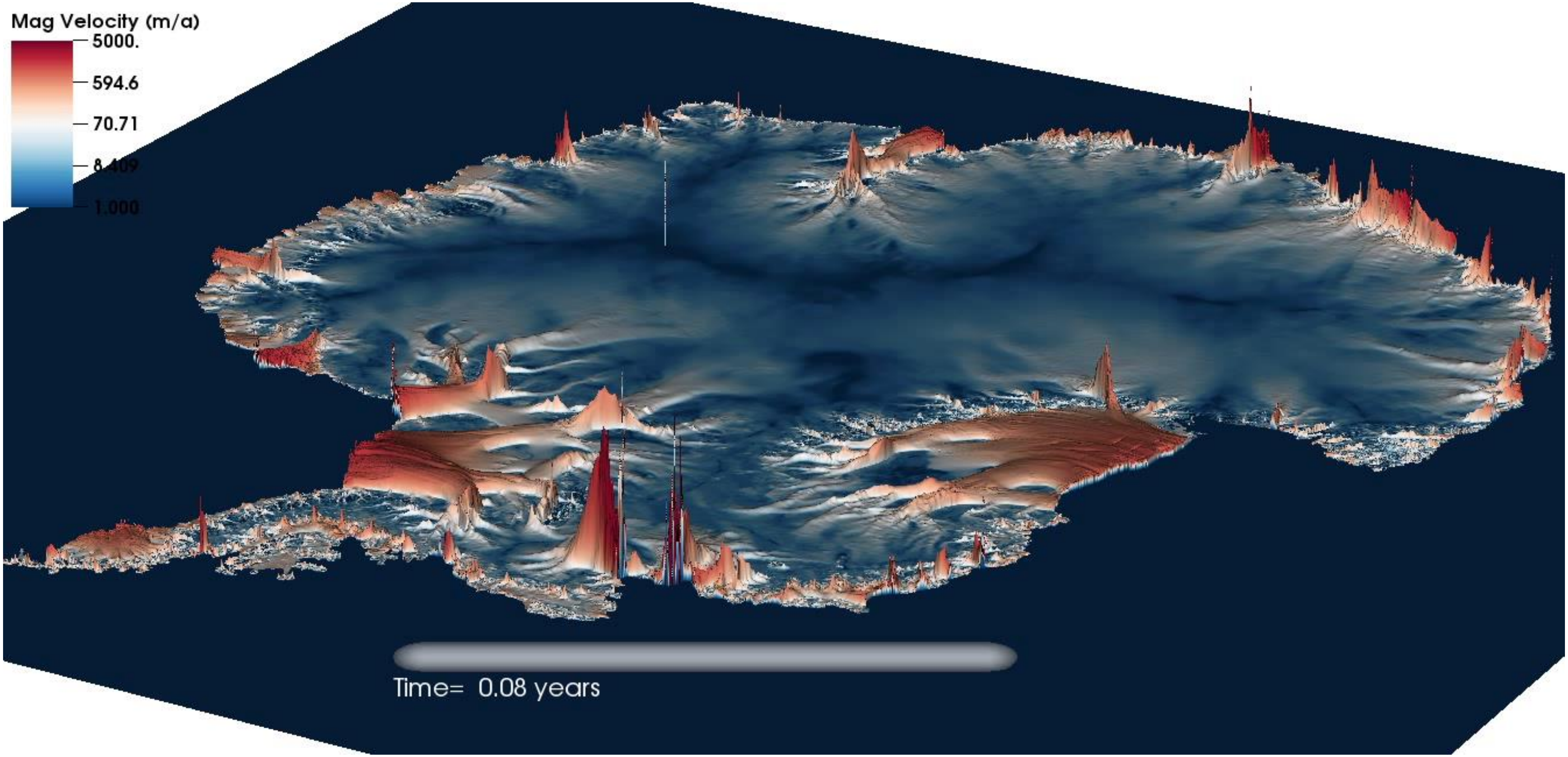
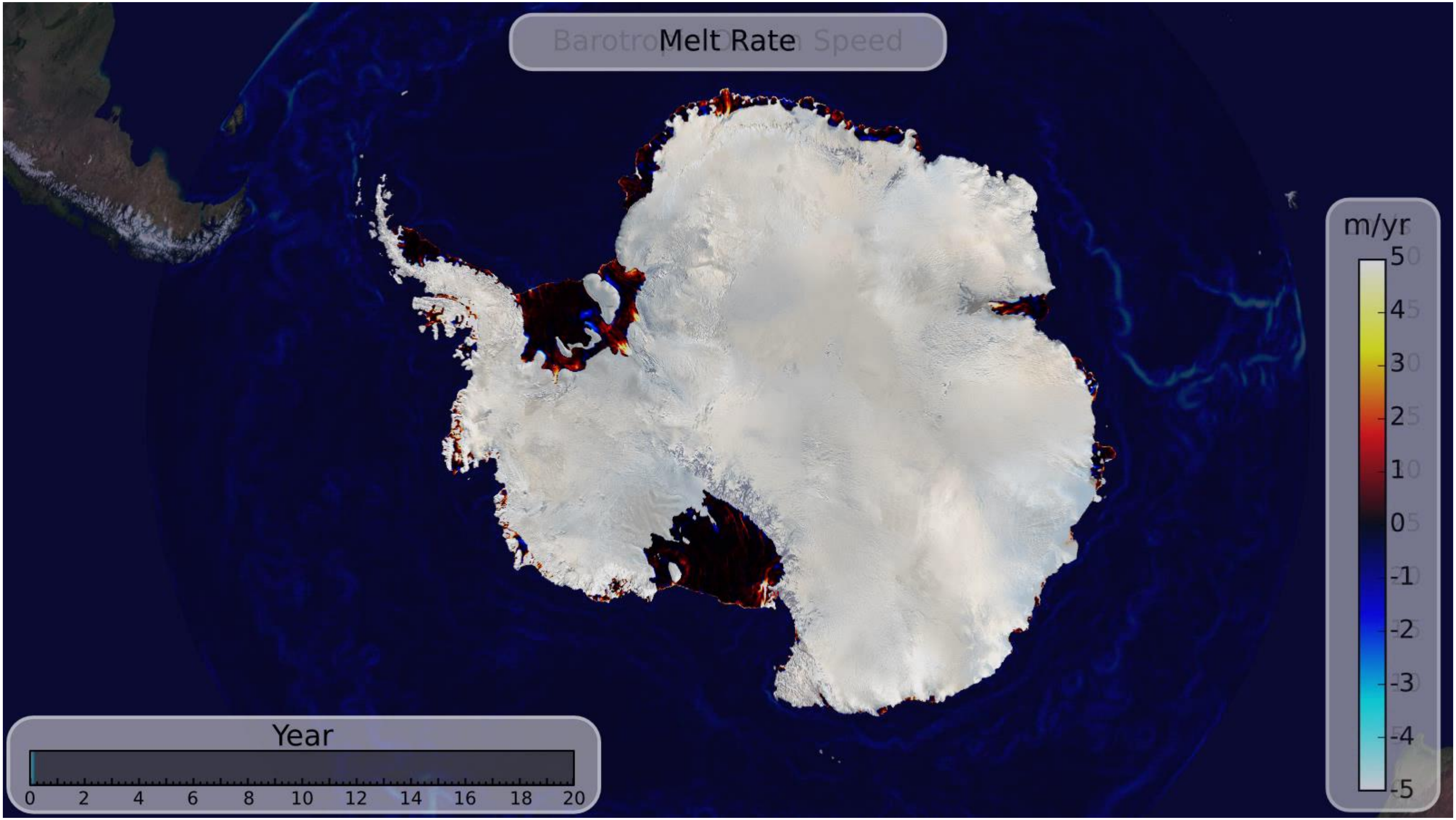


Antarctica-Southern Ocean Simulation -- POP



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