

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

Dan Martin

Lawrence Berkeley National Laboratory

February 3, 2014



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Toward

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Joint work with:

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



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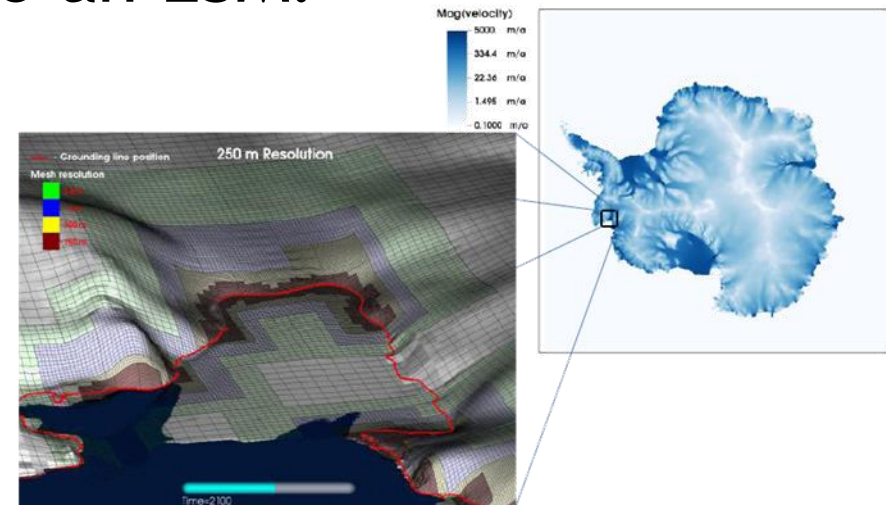
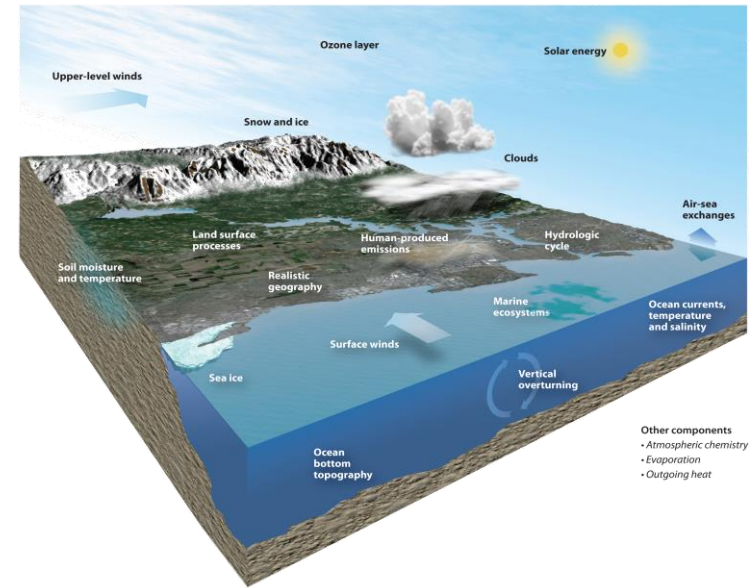
Motivation: Projecting future Sea Level Rise

- ❑ 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.



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



Models:

- ❑ Ocean Circulation Model: POP2x
- ❑ Ice Sheet: BISICLES (CISM-BISICLES)
- ❑ POP + BISICLES = POPSICLES



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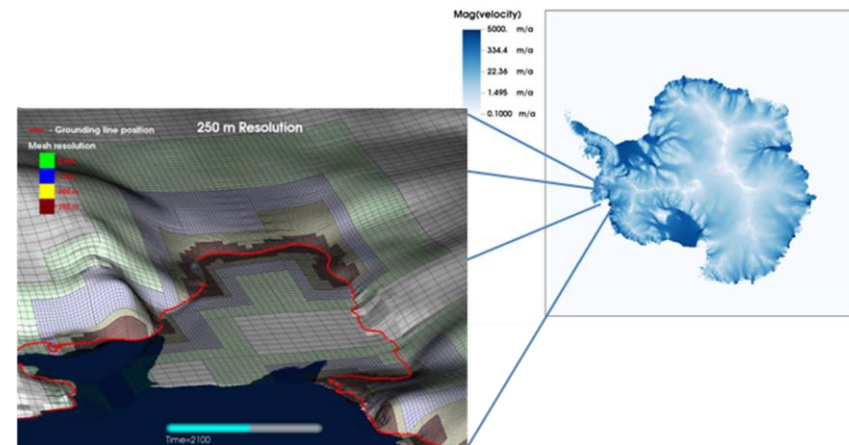
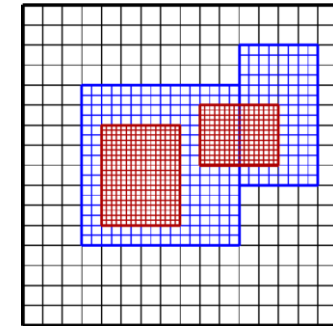
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BISICLES Ice Sheet Model

- ❑ 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

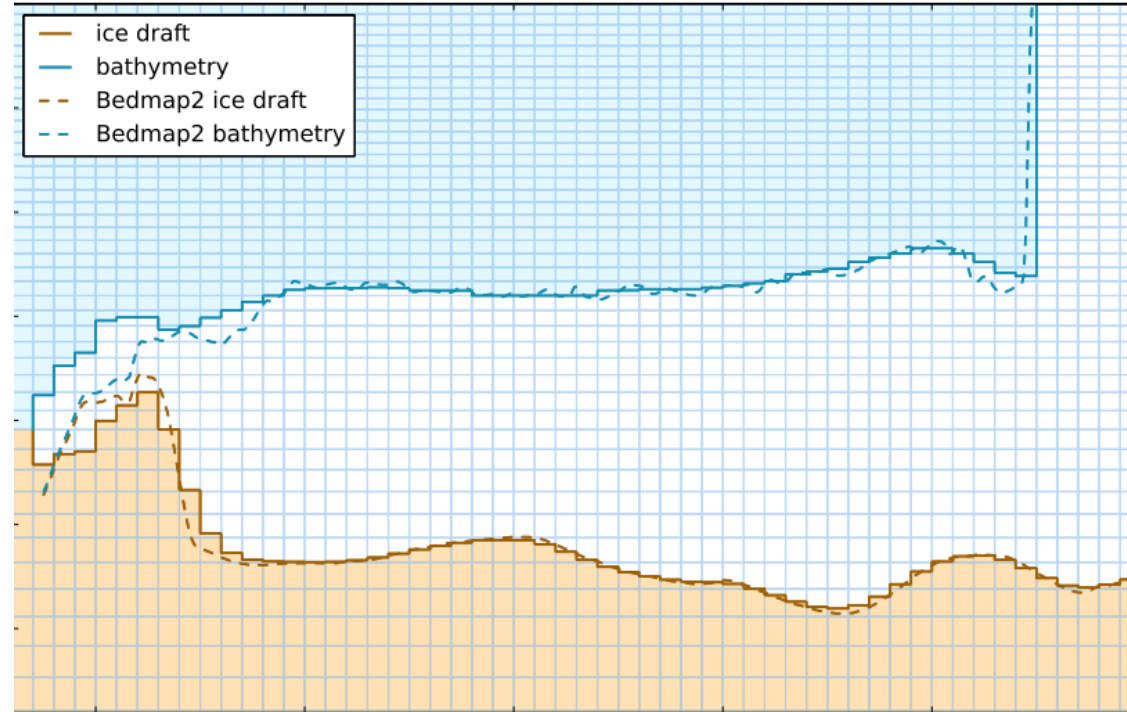
- Ocean model of the Community Earth System Model (CESM)
- z-level, hydrostatic, Boussinesq

□ 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



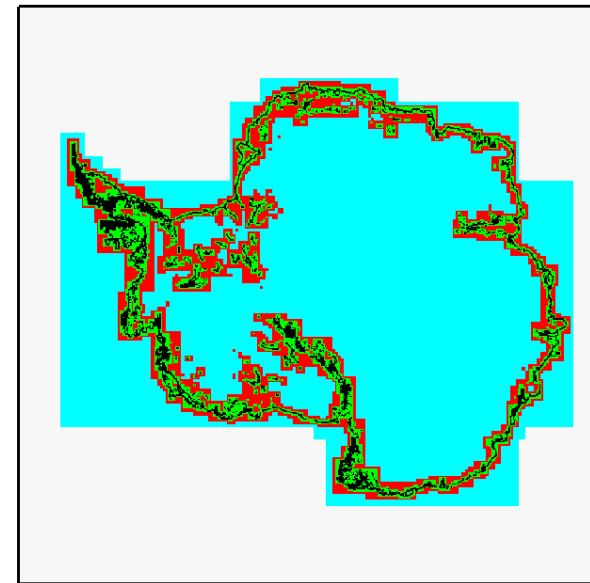
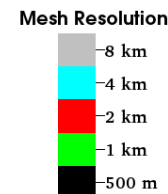
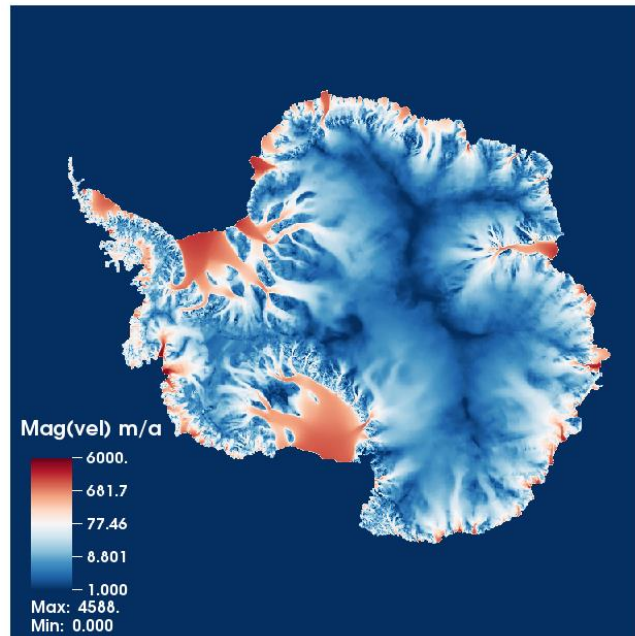
Coupling: Synchronous-offline

- 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

Antarctic-Southern Ocean Coupled Simulations

BISICLES setup:

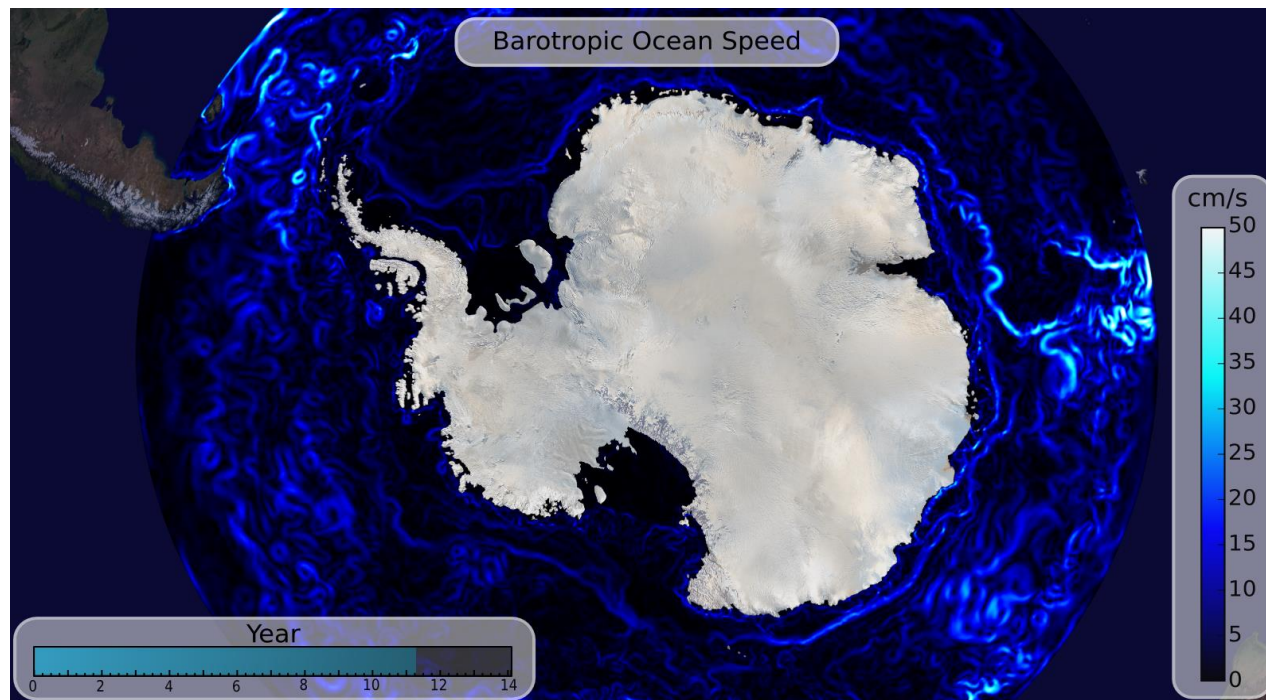
- ❑ Bedmap2 (2013) geometry
- ❑ Initialize to match Rignot (2011) velocities
- ❑ Temperature field from Pattyn (2010)
- ❑ 500m finest resolution
- ❑ Initialize SMB to “steady state” using POP standalone melt rate



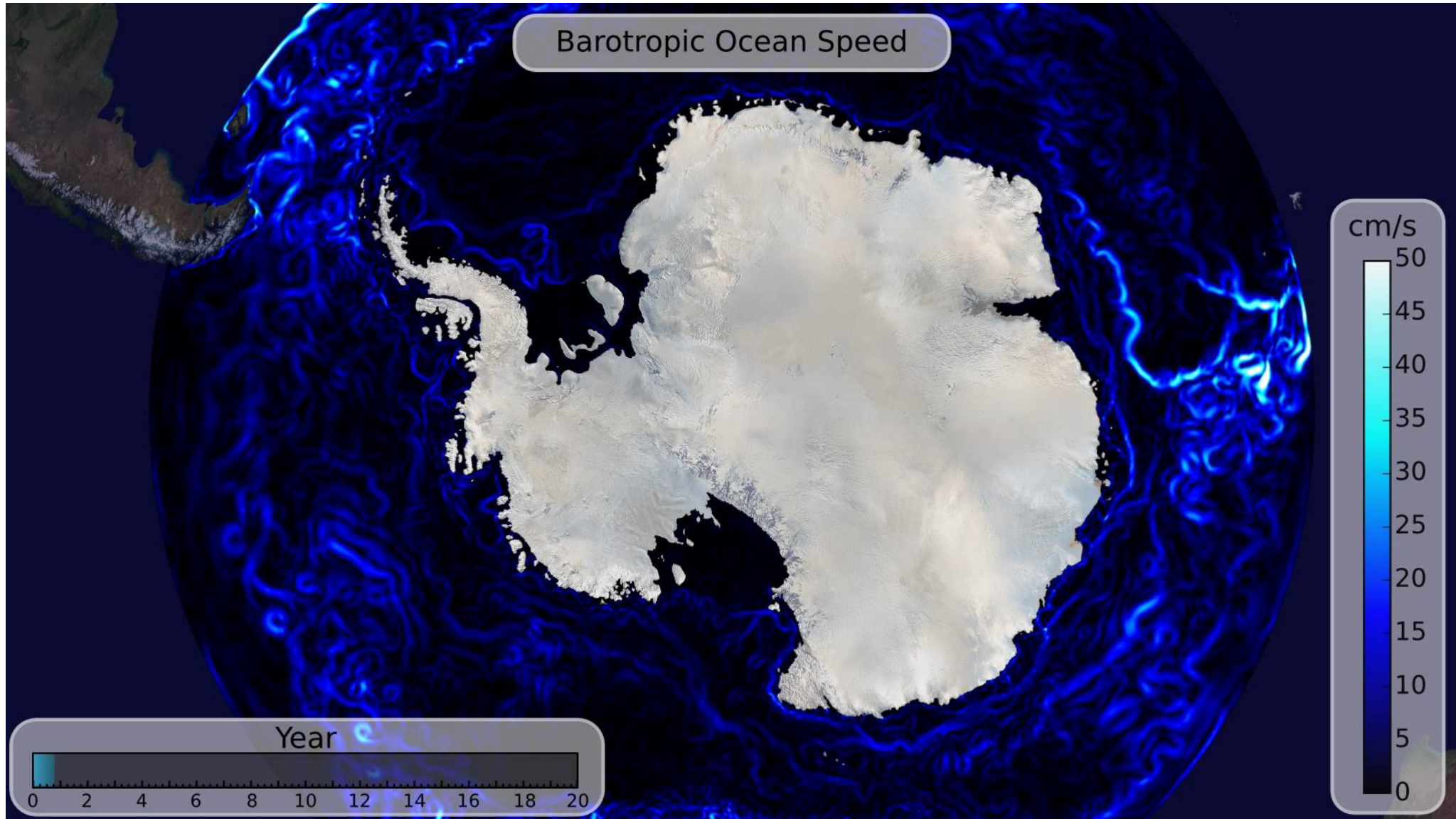
Antarctic-Southern Ocean Simulation

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 stand-alone (3 & 20 years) run; Bedmap2 geometry



Antarctica-Southern Ocean Simulation -- POP



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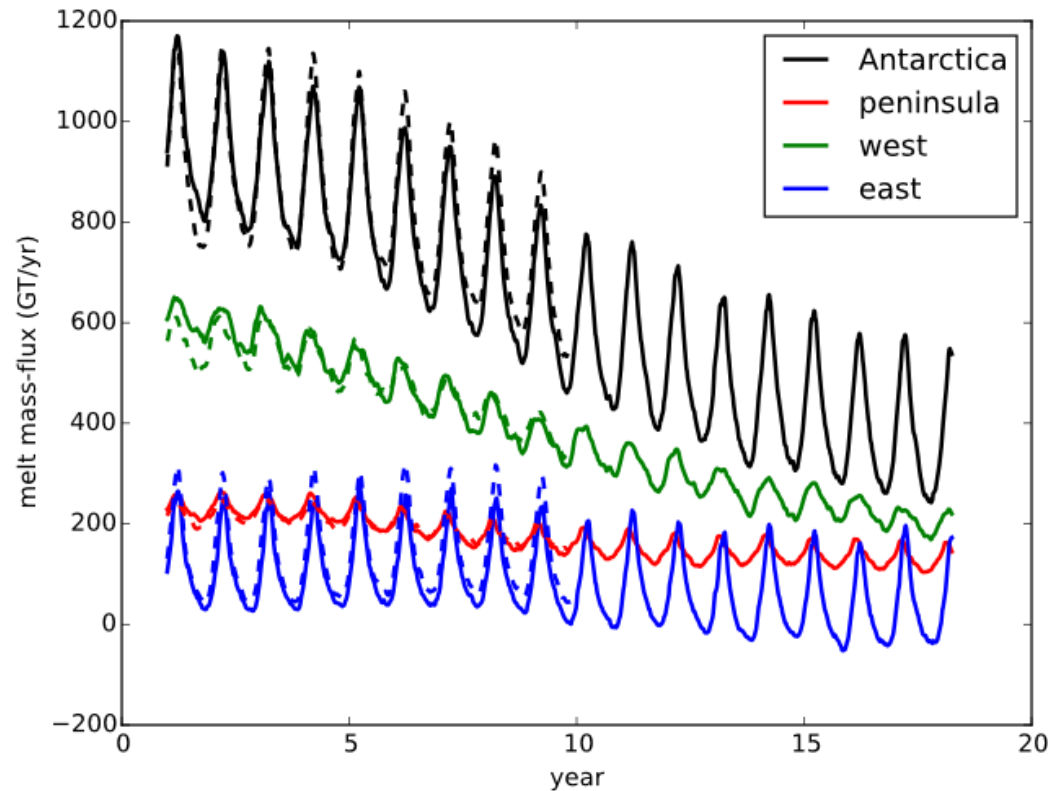
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Antarctic-Southern Ocean Coupled Sims (cont)

What Happens?

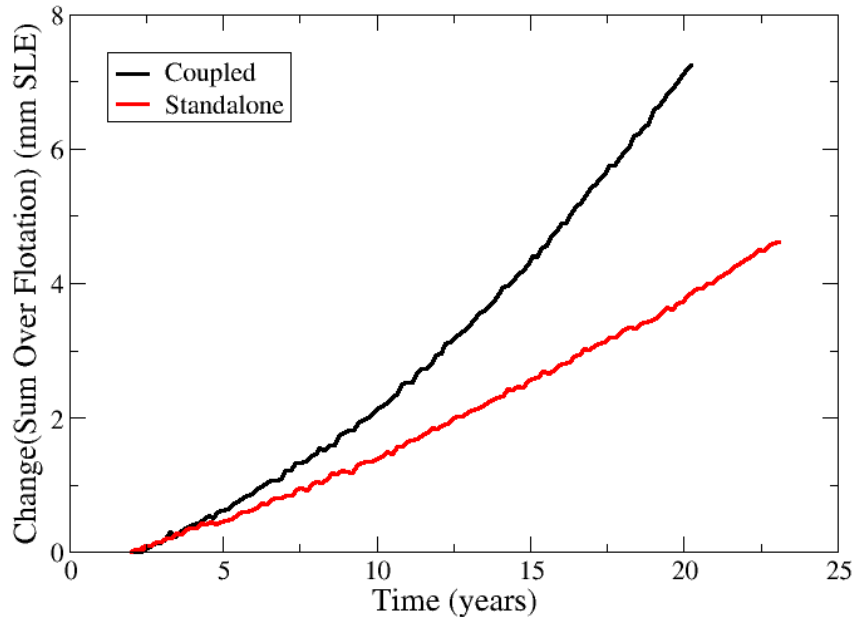


- Melt rates are spinning down over time (POP issue)
- Possible causes - climate forcing? no sea ice model?

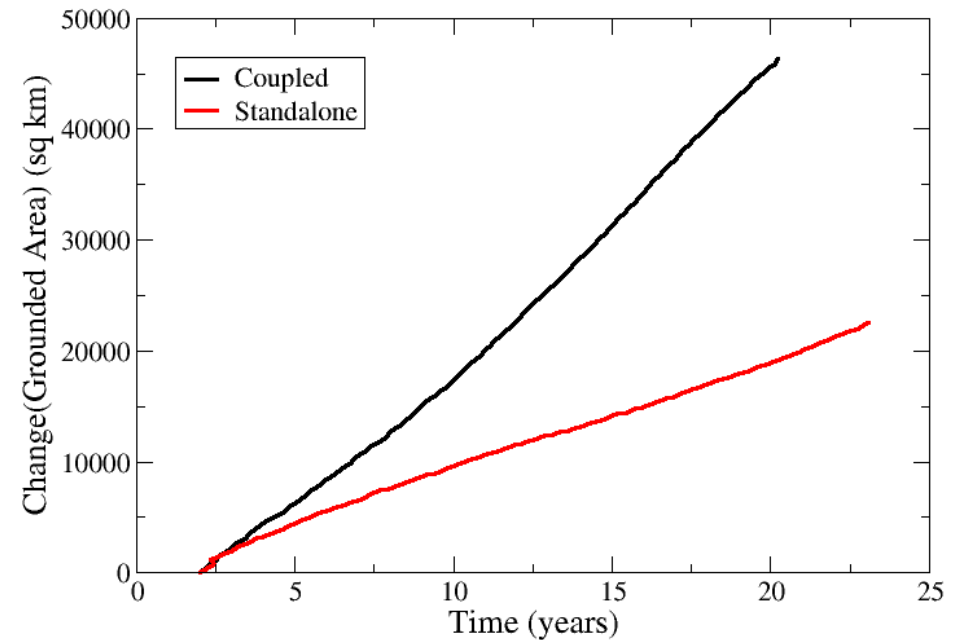
Antarctic-Southern Ocean Coupled Sims (cont)

Compare Standalone vs. Coupled runs:

Change in Ice over Flotation

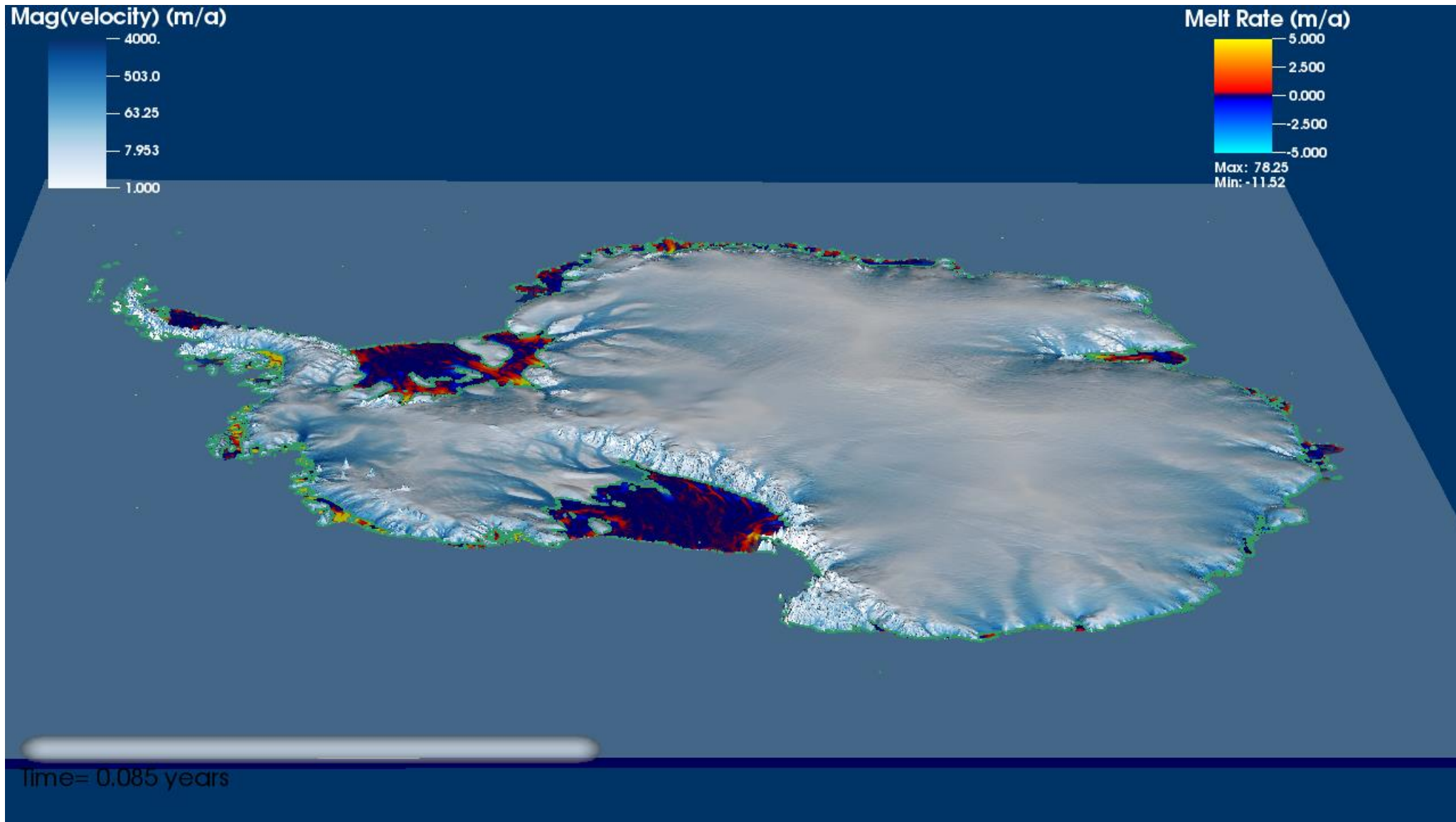


Change in Grounded Area



- “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)



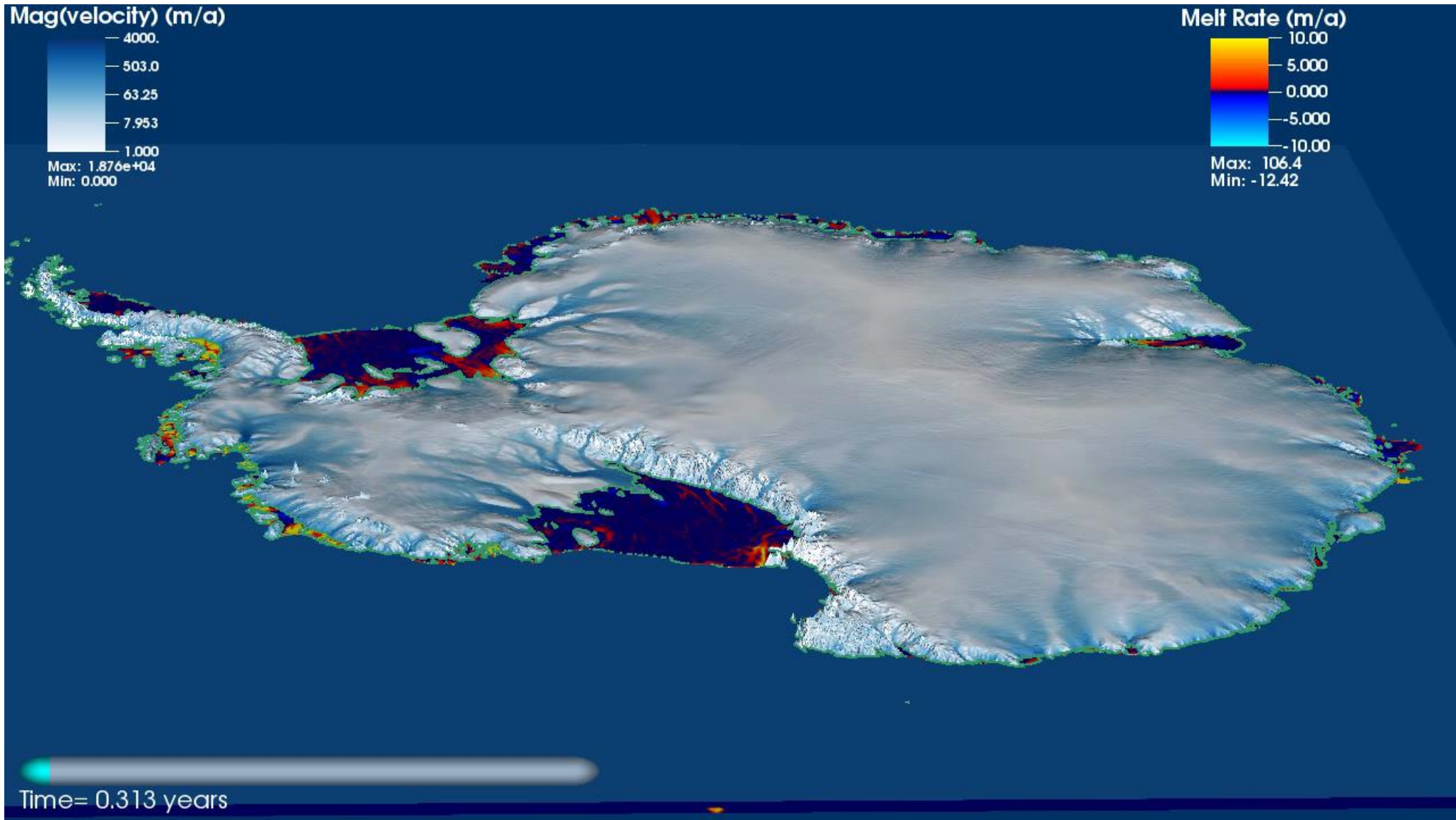
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Antarctic-Southern Ocean Coupled Sims (cont)



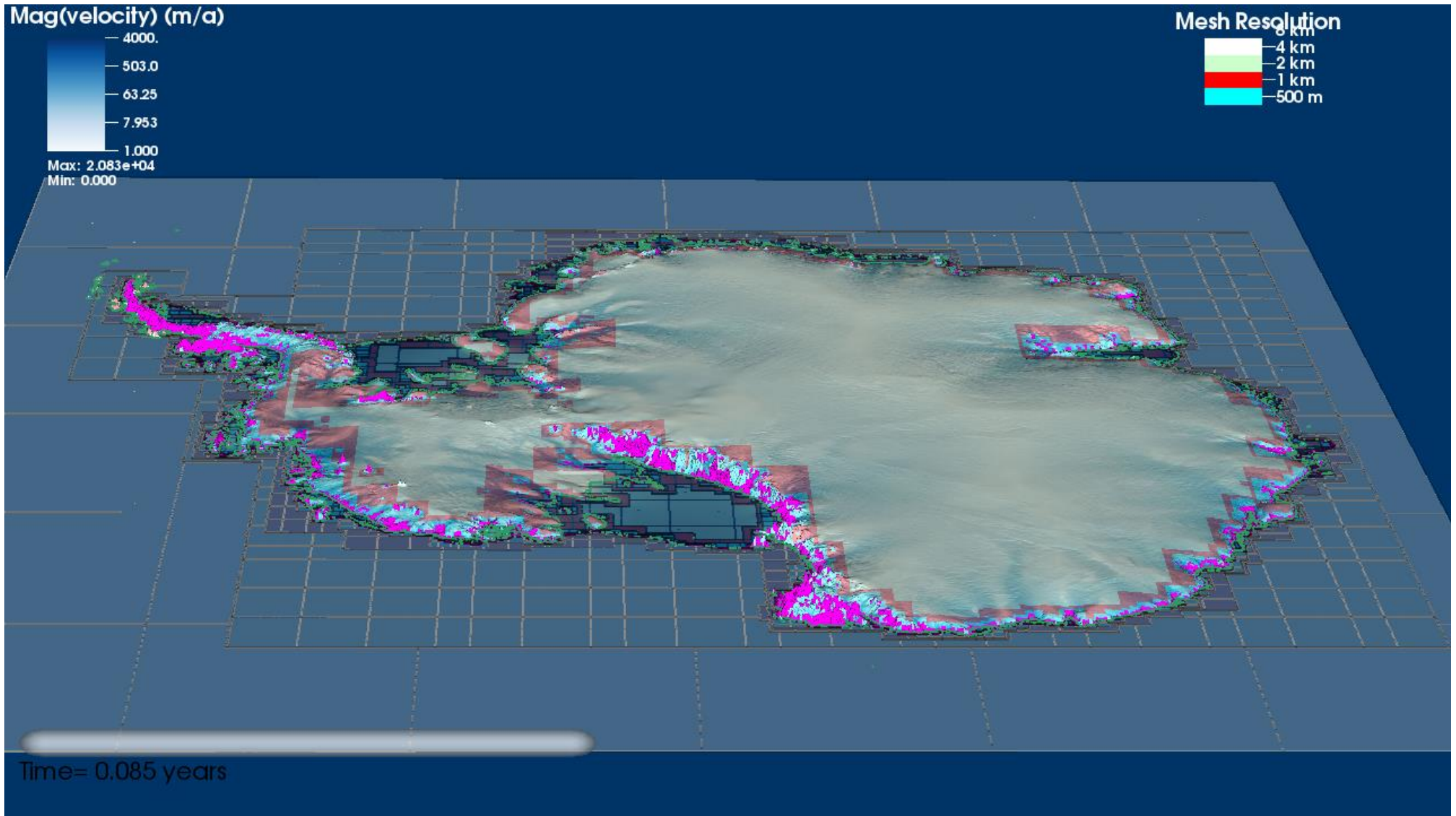
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Antarctic-Southern Ocean Coupled Sims (cont)



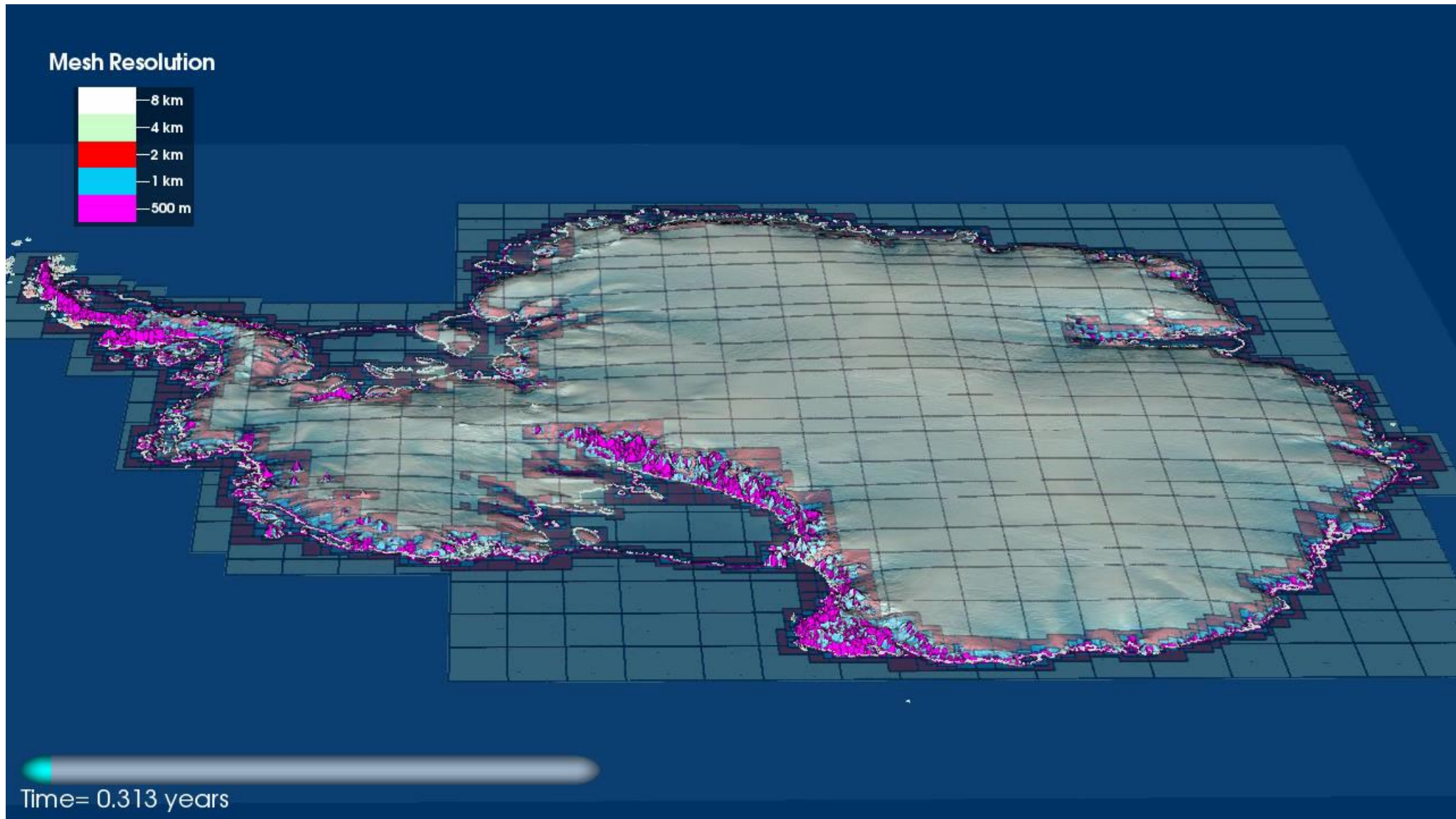
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Antarctic-Southern Ocean Coupled Sims (cont)



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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 1st coupled Antarctic Runs

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

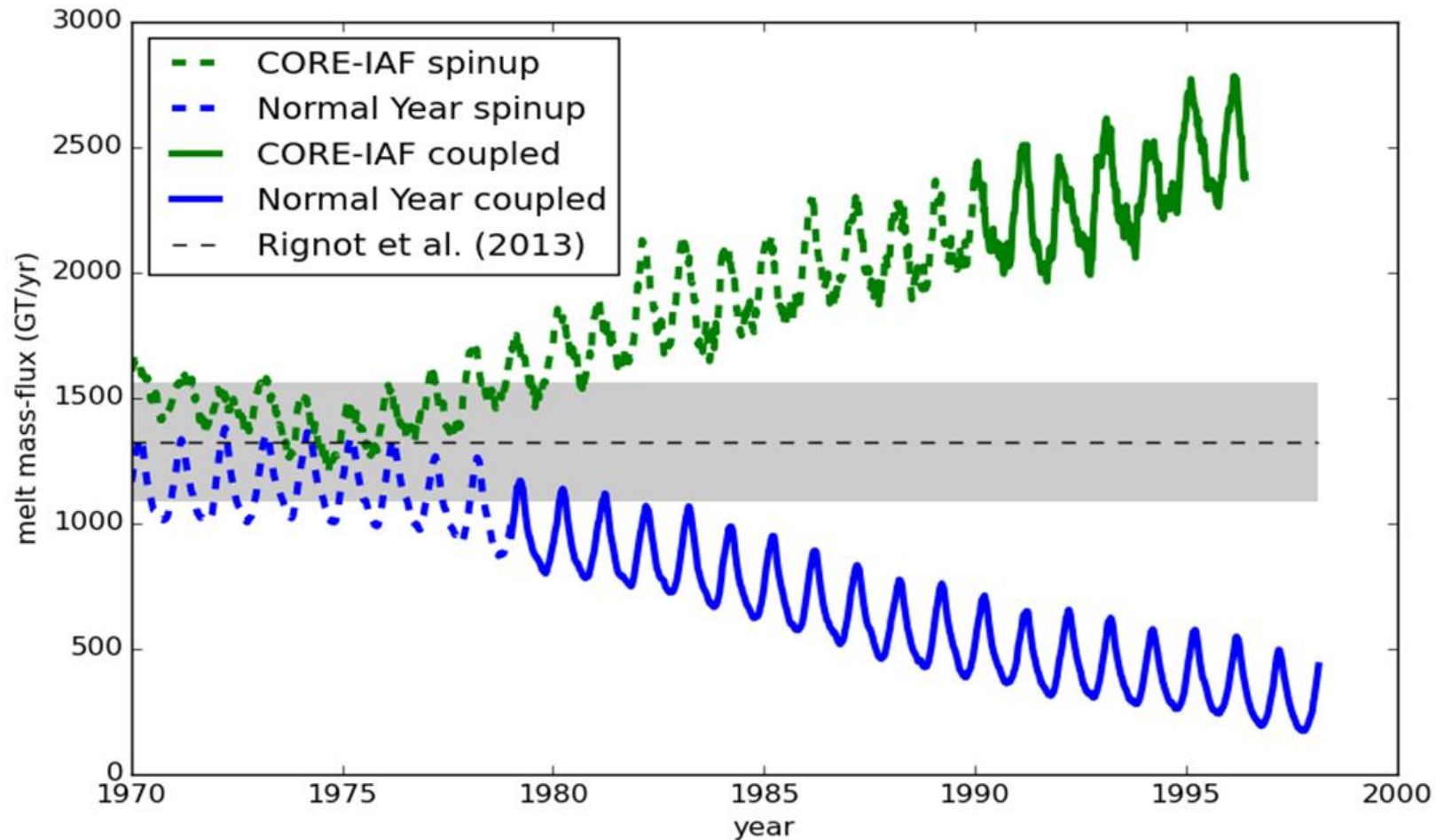
- ❑ **POP cold bias (spin-down of melt rates)**

- ❑ 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)**



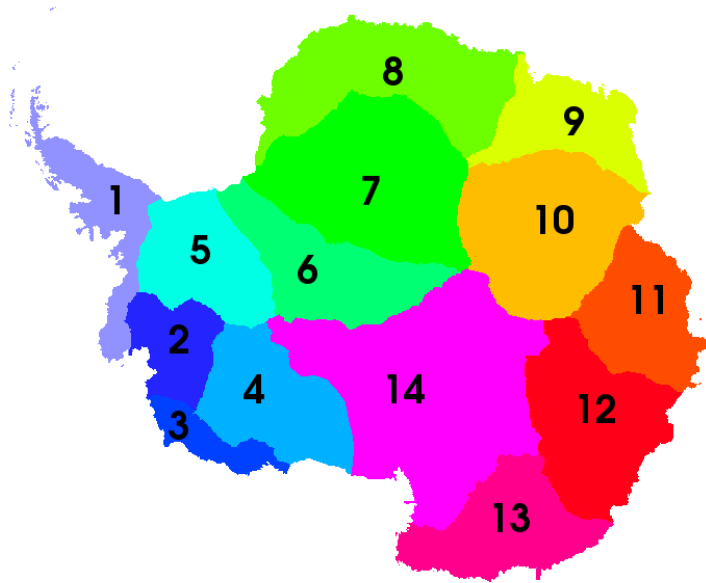
Different climate forcing on POP melt rates



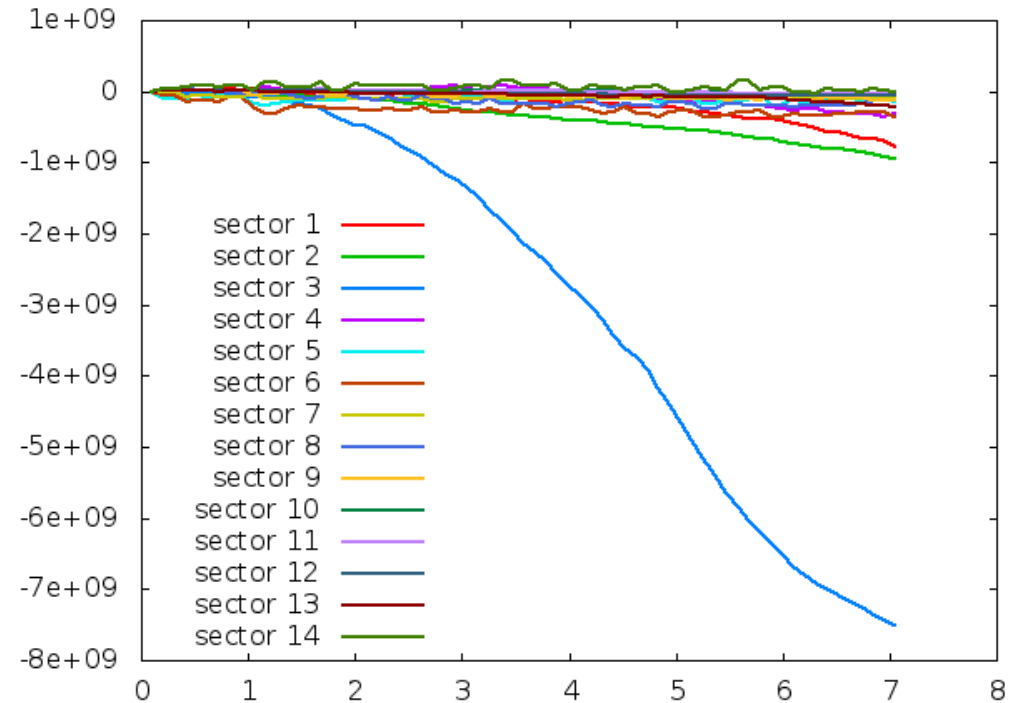
Switching to CORE-IAF forcing removes cold bias – now too warm...

Coupled Antarctica: Core-IAF

Antarctic sectors

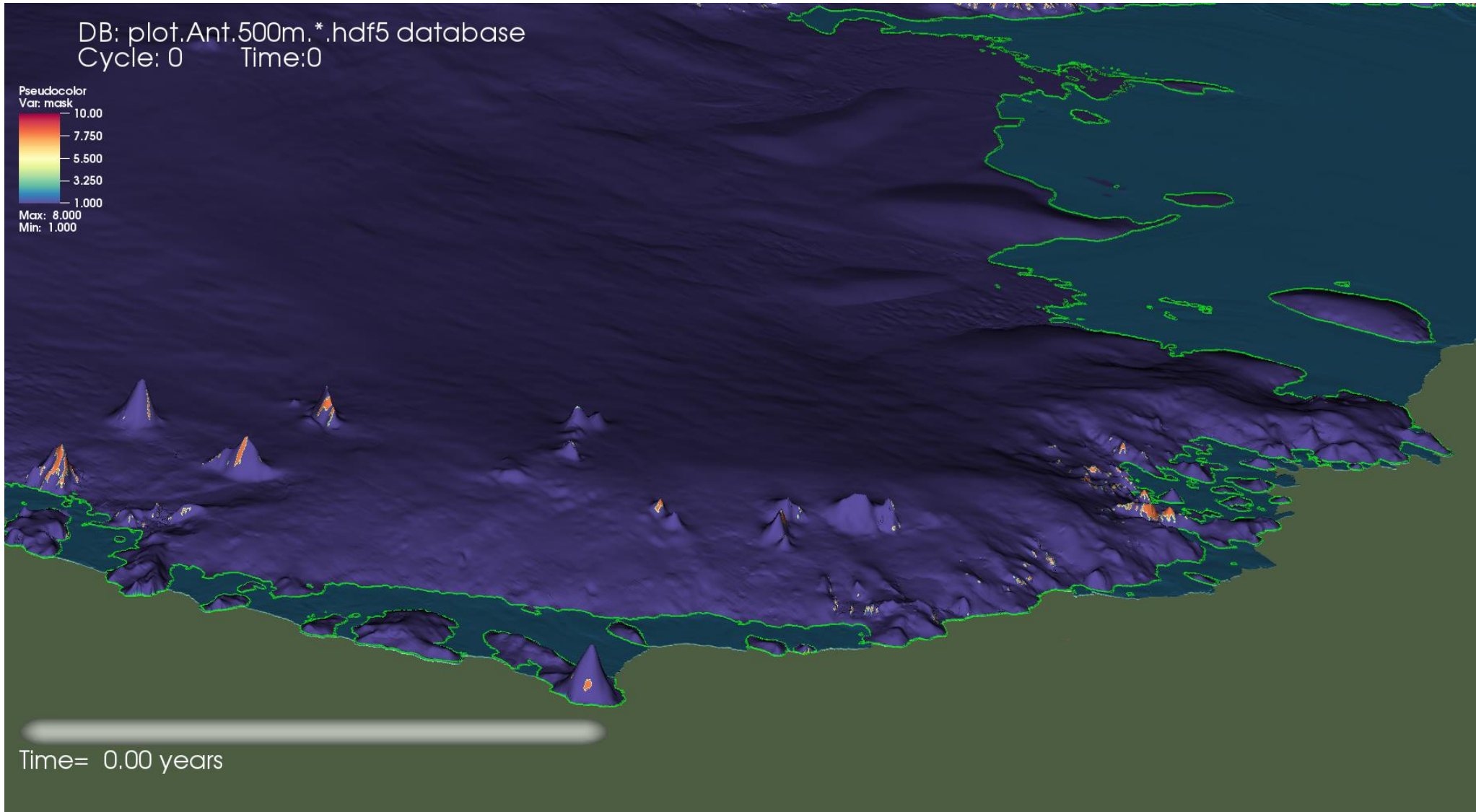


Floating area change by sector vs. Time



- Response dominated by loss of floating area in a few sectors
- This was supposed to be the **warming** scenario
- **What happened?** (Getz sector!)

Getz Ice Shelf - Regrounding Instability



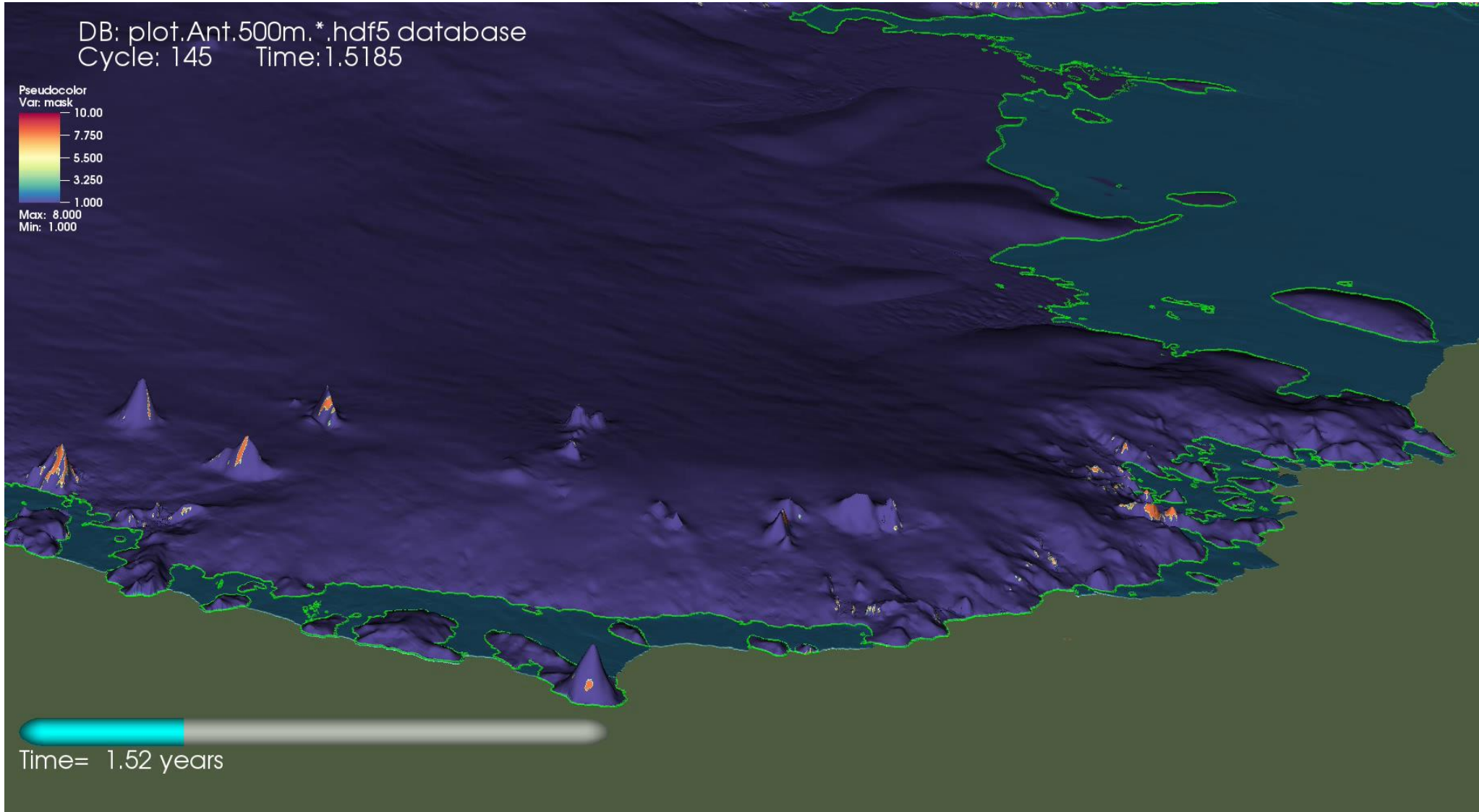
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Getz Ice shelf -- Regrounding instability



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Getz Ice shelf -- Regrounding instability (cont)

What happened?

- ❑ Bedmap2 - poorly constrained subshelf bathymetry
 - “Made stuff up” - did something reasonable from the ice-sheet perspective
 - Resulted in very thin (< 100m) subshelf cavities under the ice
- ❑ Nominal/standalone POP2x melt rates fairly high
- ❑ Large synthetic accumulation field to balance melt and keep shelf in steady state
- ❑ Time-dependent runs - *instability*
 - Small relative fluctuations in melt-rate forcing can result in thickness changes which are $O(\text{cavity thickness})$
 - Localized grounding
 - Subself melting turns off - unbalanced (and large!) accumulation
 - Leads to more regrounding -> more unbalanced melt....



Getz Ice Shelf - Regrounding Instability (cont)



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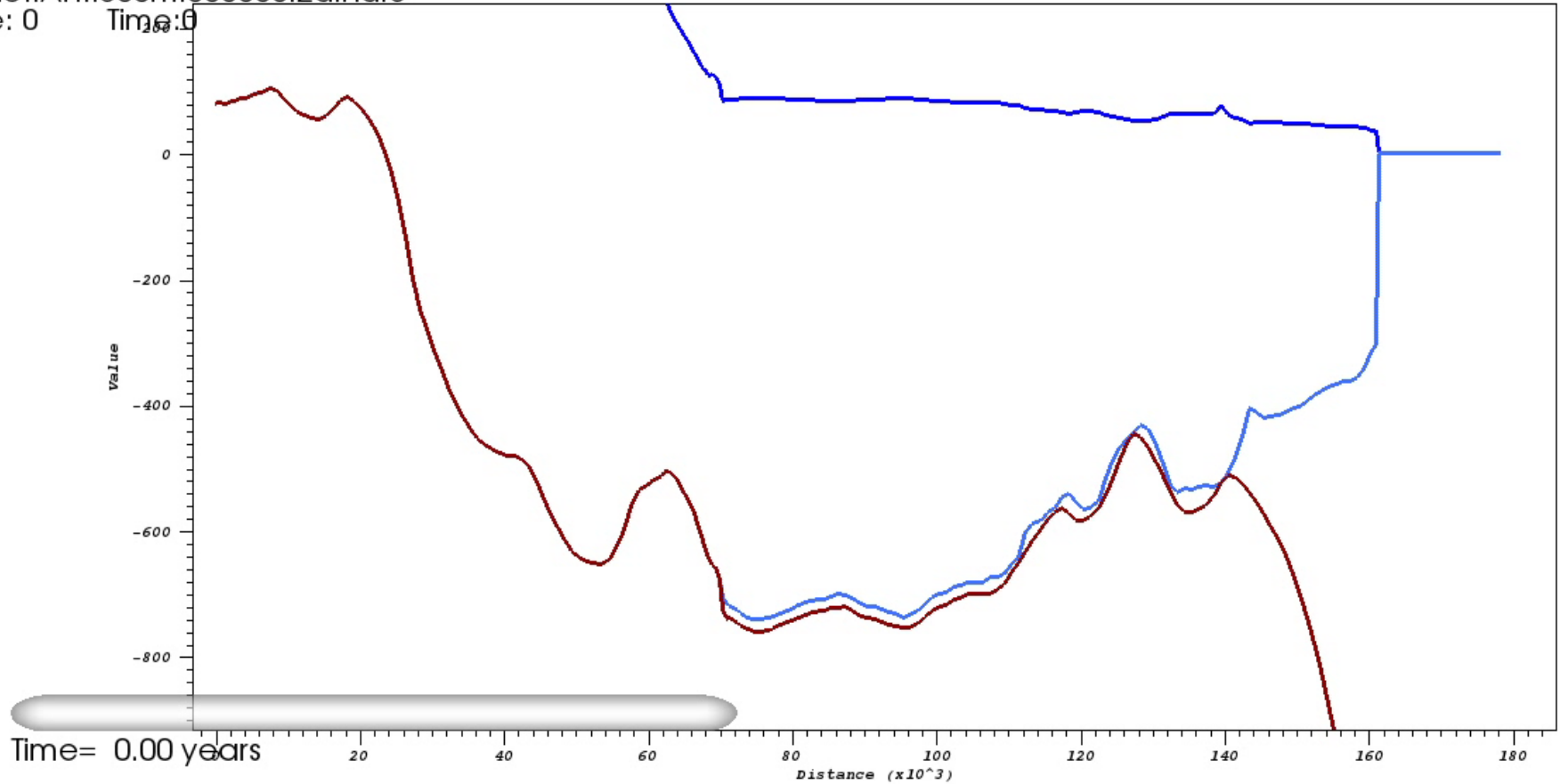
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Getz Ice shelf -- Regrounding instability (cont)

DB: plot.Ant.500m.000000.2d.hdf5
Cycle: 0 Time: 0



user: dmartin
Wed Dec 3 18:51:05 2014



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Future work

- ❑ Fix issues exposed during coupled run and try again.
 - Deepen bathymetry in problem regions (RTOP01)
 - BISICLES initial condition -- realistic (Arthern?) SMB

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



“Family” of 3 New MIPs

- ❑ Ice sheets: MISMIP+
- ❑ Ocean Models: ISOMIP+
- ❑ Coupled Models: MISOMIP



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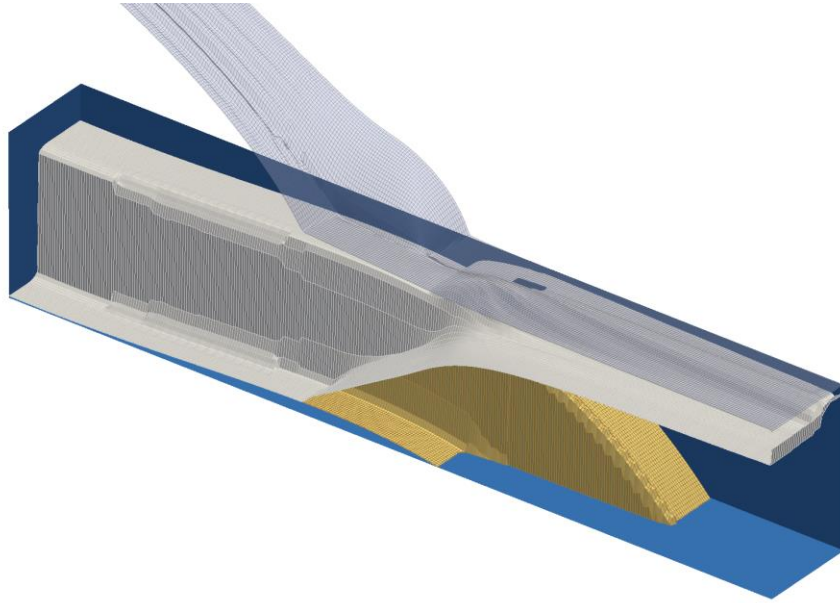
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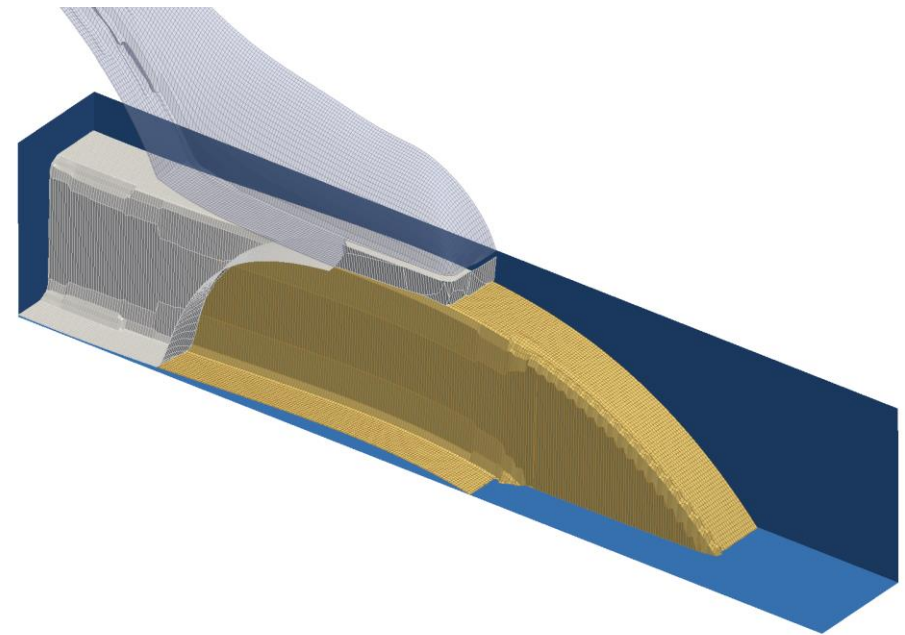
- ❑ “Child of MISMIP3D”
 - Examined GL response of models to a localized change in bed friction
 - Clarified resolution requirements for reversible GL dynamics
 - **Large variation in steady-state GL position among models**
 - Conclusions about dynamical results clouded by this difference
 - Said nothing about response to subshelf melt forcing (buttressing?)

- ❑ Specific details still under development
 - Steady-state with reduced variation between models
 - Steady-state on upward-sloping bed (buttressing) -- Gudmundsson (2012)
 - Narrow-ish channel (still under discussion)
 - Perturbation due to subshelf melt anomaly - GL retreat
 - Reversibility? (return timescale seems long)
 - Primary contact - Steph Cornford (Bristol)

MISMIP+ (cont)



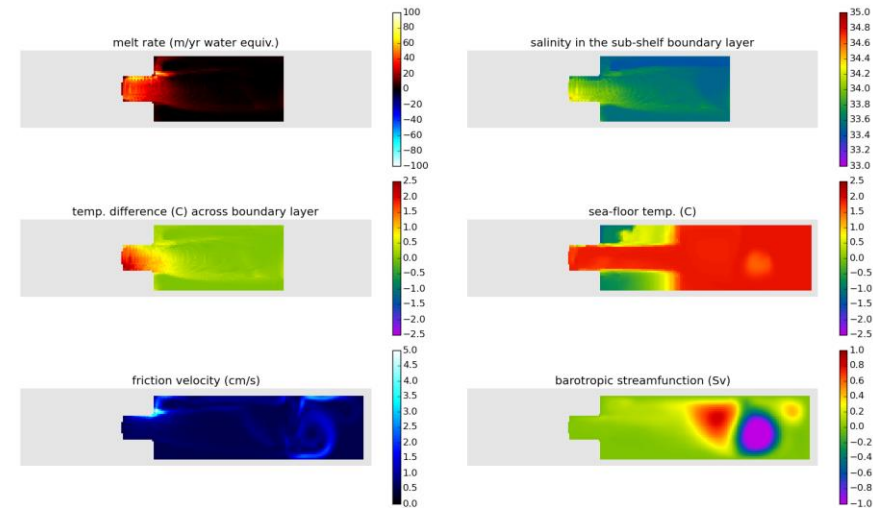
Steady-state initial condition



Fully-retreated condition



- ❑ The latest Ice Shelf-Ocean Model Intercomparison Project
- ❑ Stand-alone ocean model with prescribed ice-shelf geometry
- ❑ “Informed by” MISMIP+ geometry
 - Communication between developers
 - (widening of the ice-sheet domain, modifying bathymetry, ice shelf)
 - Ocean properties (T and S) prescribed in the far-field to be similar to ASE.
- ❑ 3 Experiments:
 1. Cold-to-warm forcing with prescribed (static) geometry
 2. Warm-to-cold forcing with prescribed (static) geometry
 3. Prescribed (retreat and advance) time-varying ice shelf
- ❑ Primary contact: Xylar Asay-Davis (Potsdam-PIK)



MISOMIP

- ❑ Fully coupled model test -- MISMIP+ with ISOMIP+
- ❑ Both retreat and advance experiments planned
- ❑ Details rely on details of MISMIP+ and ISOMIP+
- ❑ Primary contact: Xylar Asay-Davis (Potsdam-PIK)



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