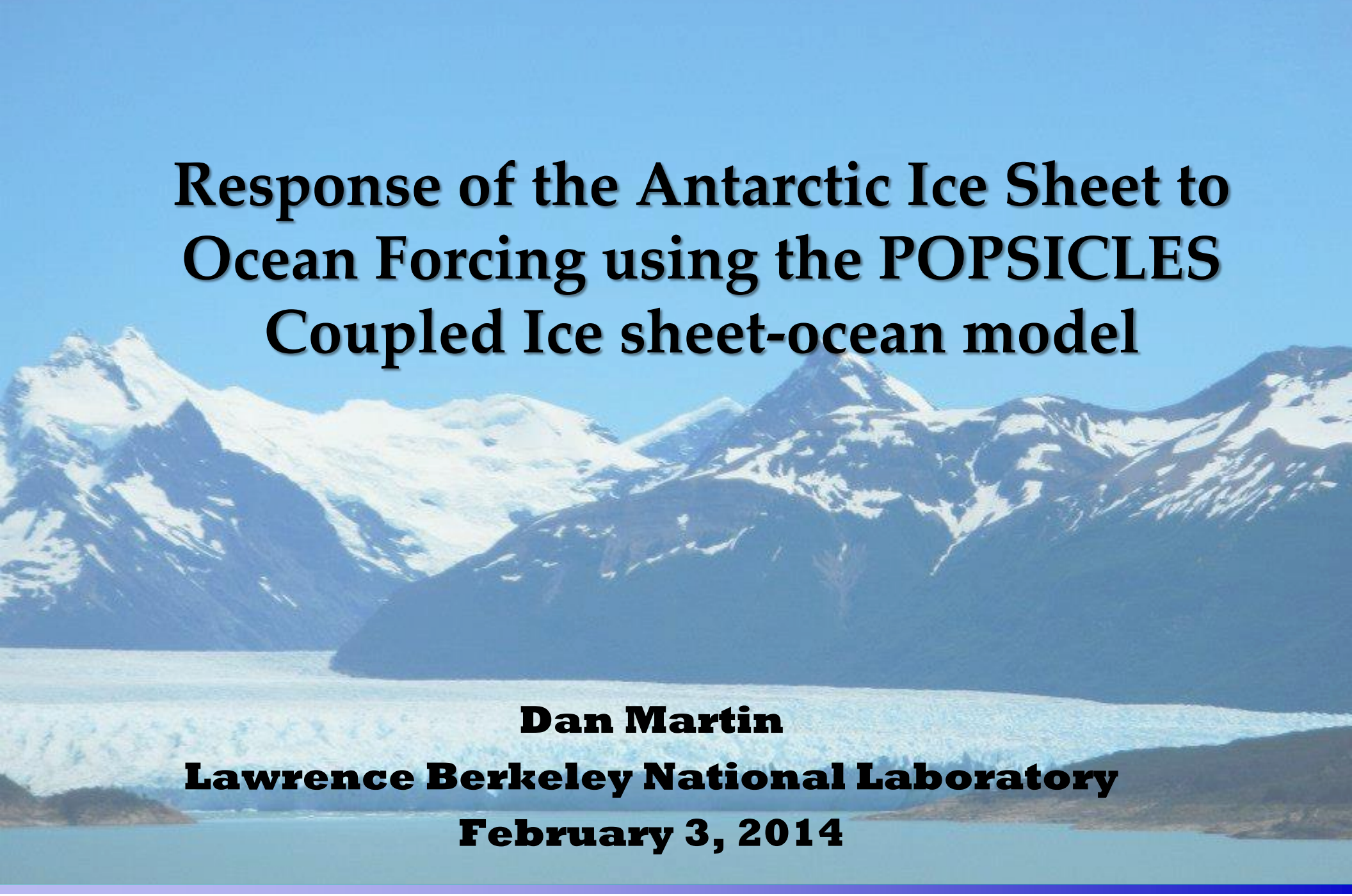
Response of the Antarctic Ice Sheet to Ocean Forcing using the POPSICLES Coupled Ice sheet-ocean model



Dan Martin

Lawrence Berkeley National Laboratory

February 3, 2014

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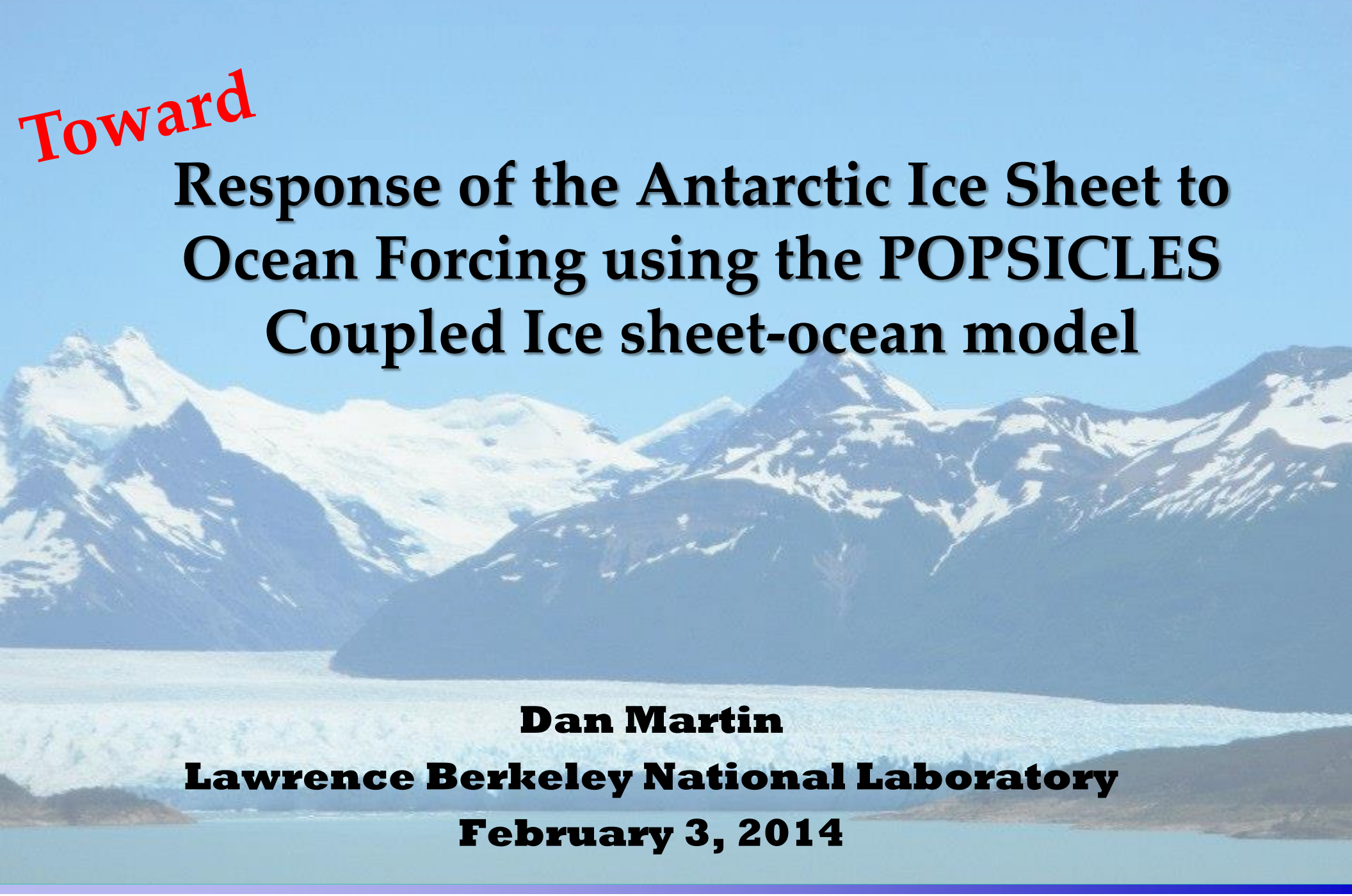

Toward Response of the Antarctic Ice Sheet to Ocean Forcing using the POPSICLES Coupled Ice sheet-ocean model

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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)

Motivation: Projecting future Sea Level Rise

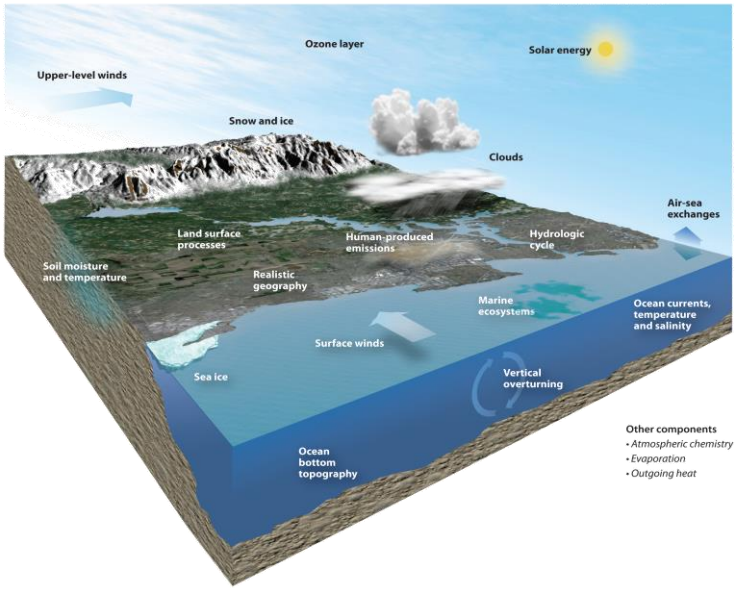
- Potentially large Antarctic contributions to SLR resulting from marine ice sheet instability, particularly from WAIS.

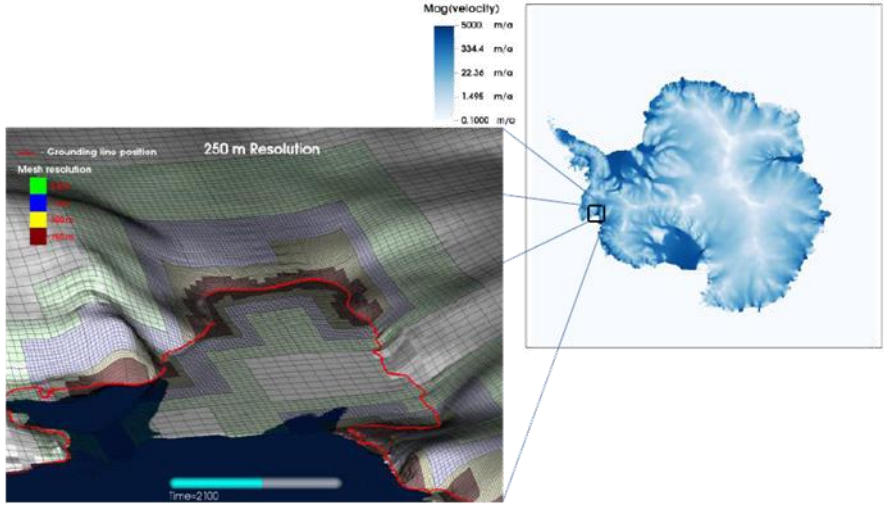
- Climate driver: subshelf melting driven by warm(ing) ocean water intruding into subshelf cavities.

- 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



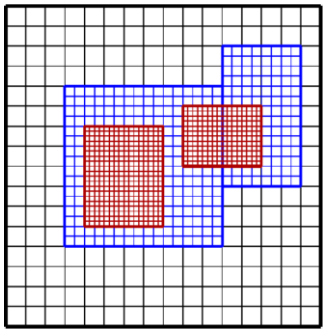


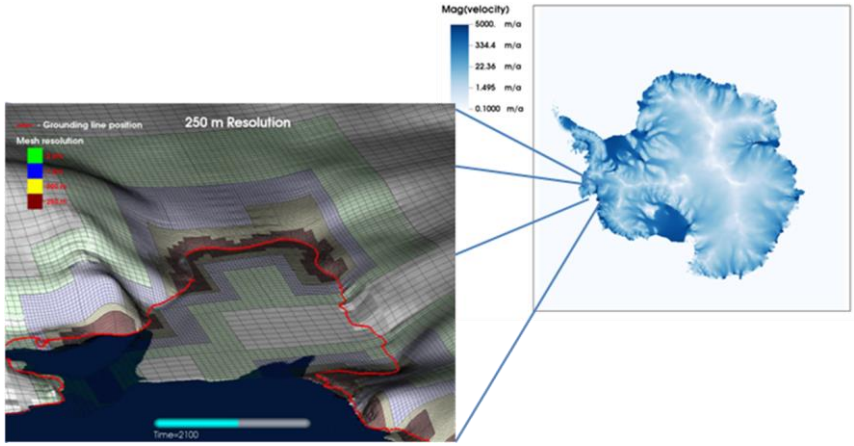
Models:

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

BISICLES Ice Sheet Model

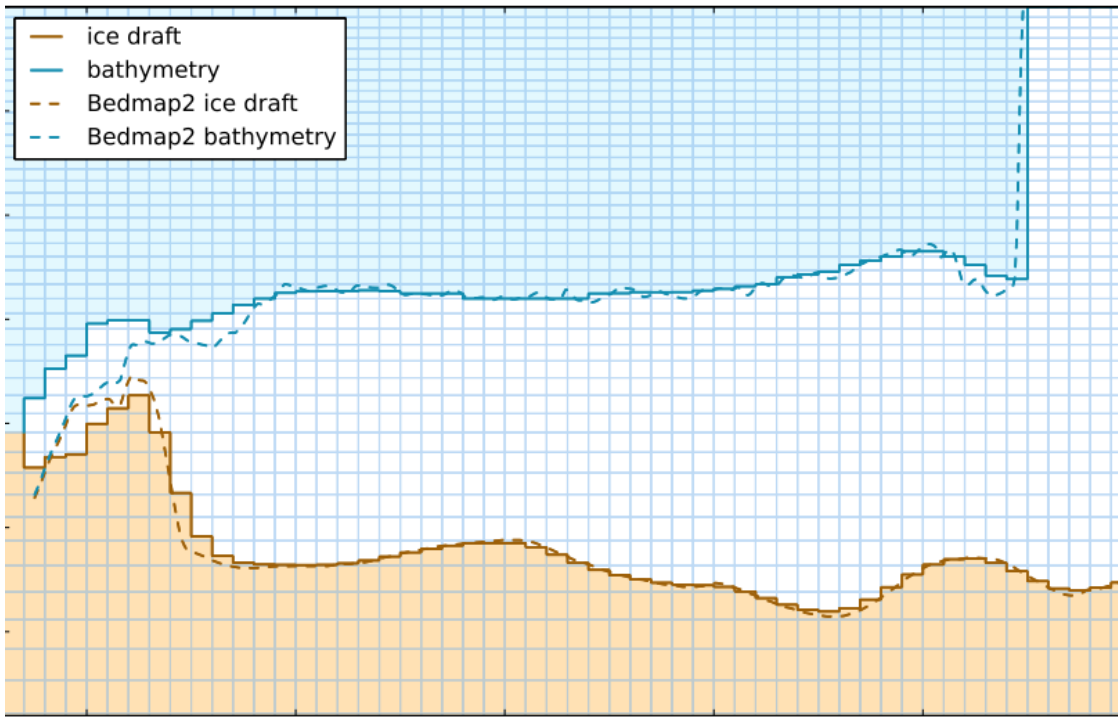
- Scalable adaptive mesh refinement (AMR) ice sheet model
  - Dynamic local refinement of mesh to improve accuracy
- Chombo AMR framework for block-structured AMR
  - Support for AMR discretizations
  - Scalable solvers
  - Developed at LBNL
  - DOE ASCR supported (FASTMath)
- Collaboration with Bristol (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



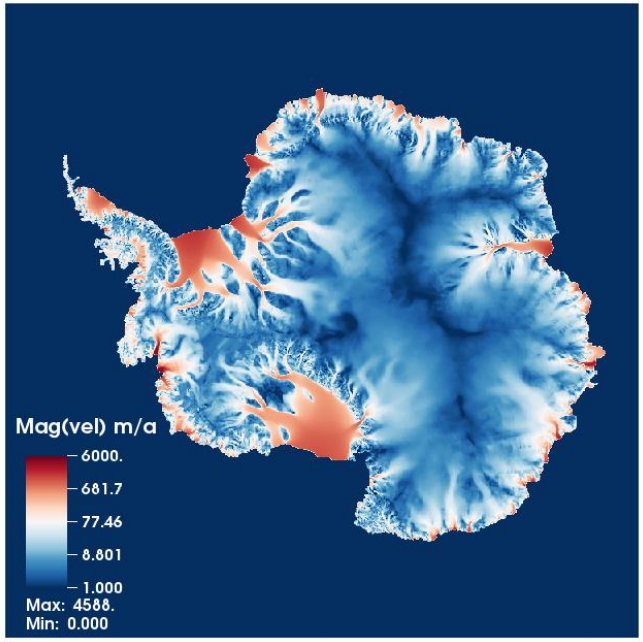
Coupling: Synchronous-offline

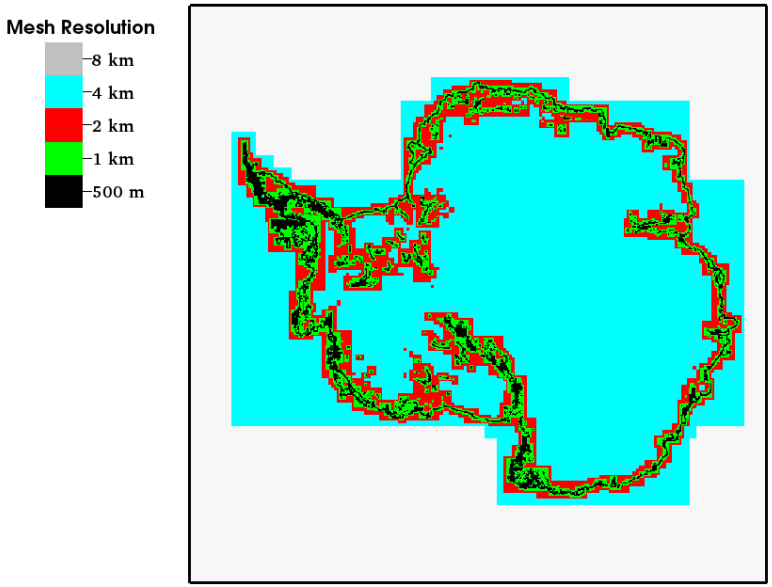
- Monthly coupling time step ~ based on experimentation
- BISICLES → POP2x: (instantaneous values)
  - ice draft, basal temperatures, grounding line location
- POP2x → BISICLES: (time-averaged values)
  - (lagged) sub-shelf melt rates
- Coupling offline using standard CISM and POP netCDF I / O
- POP 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

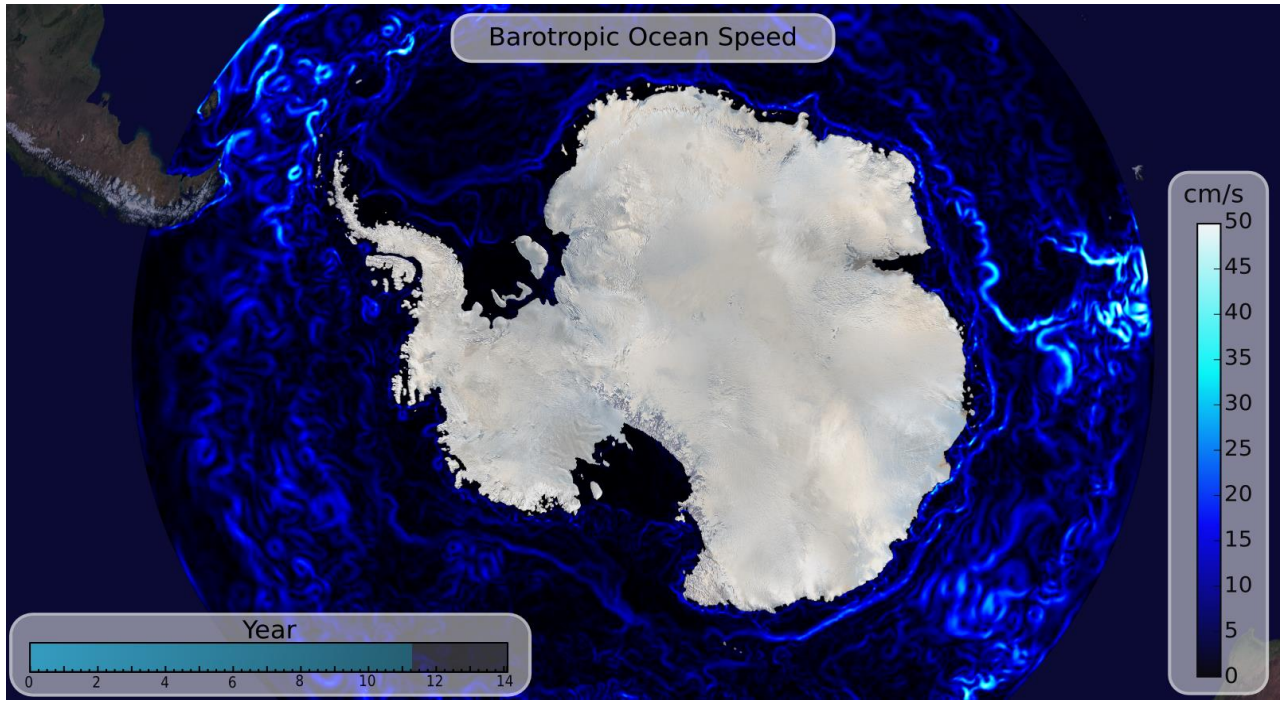




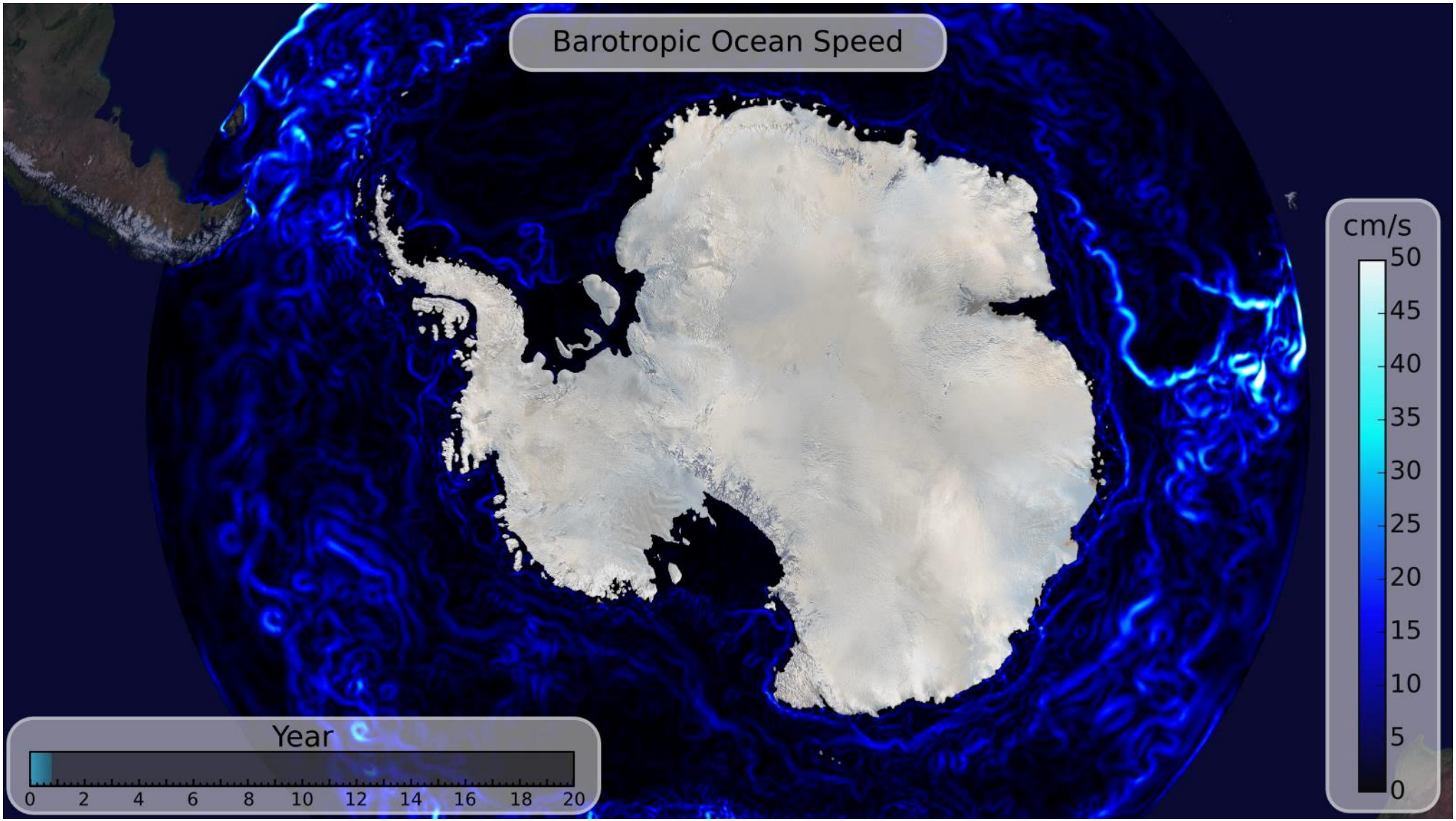
Antarctic-Southern Ocean Simulation

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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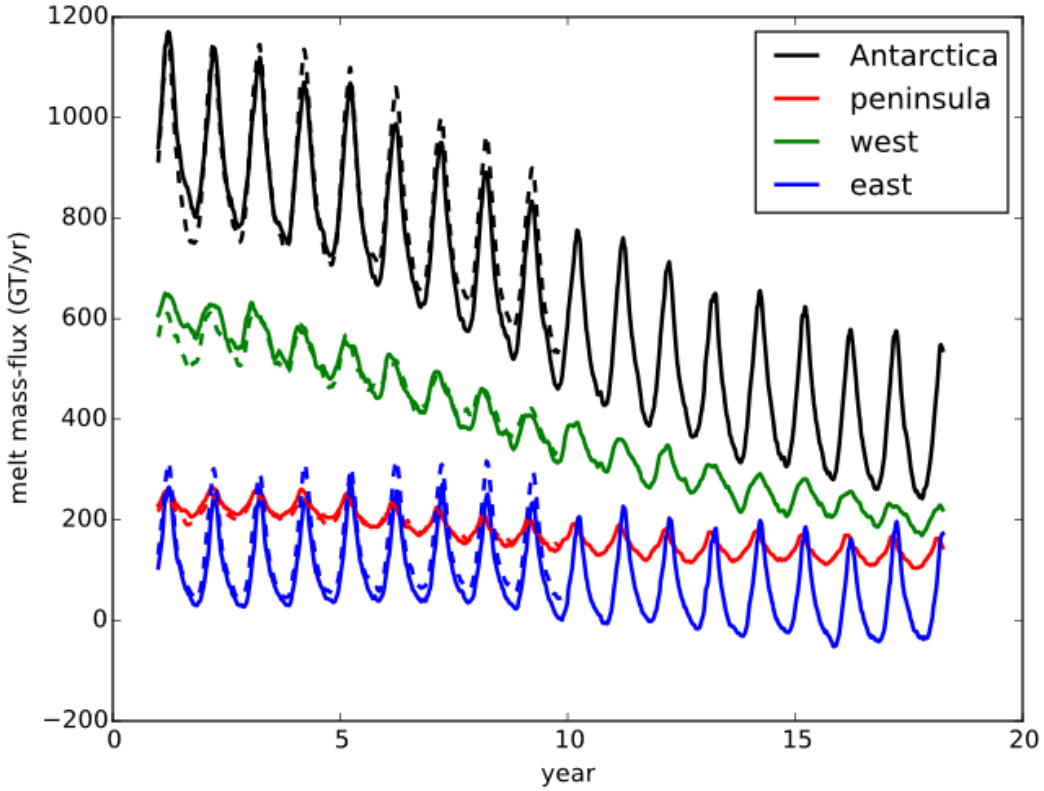
Antarctic-Southern Ocean Coupled Sims (cont)

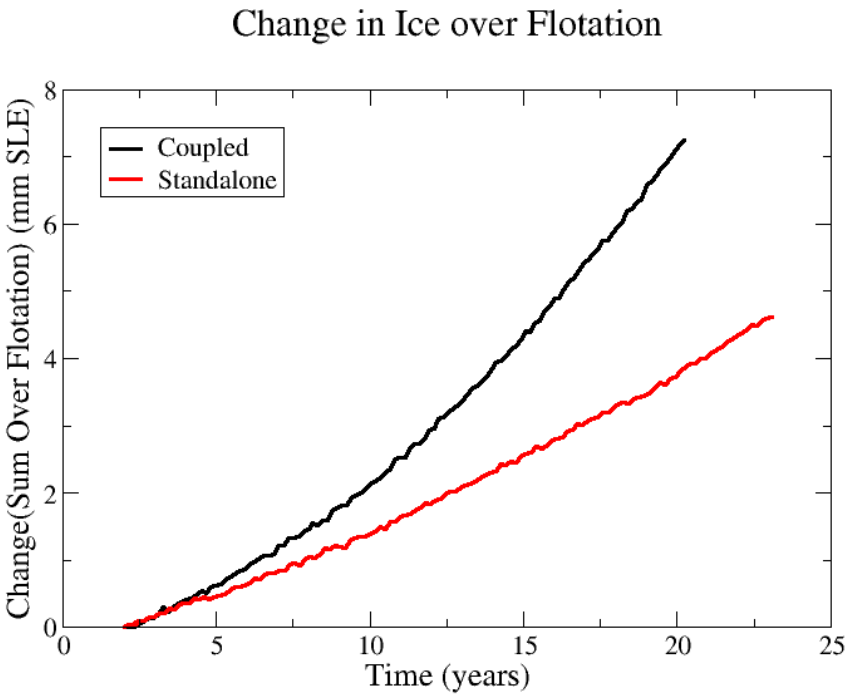
What Happens?

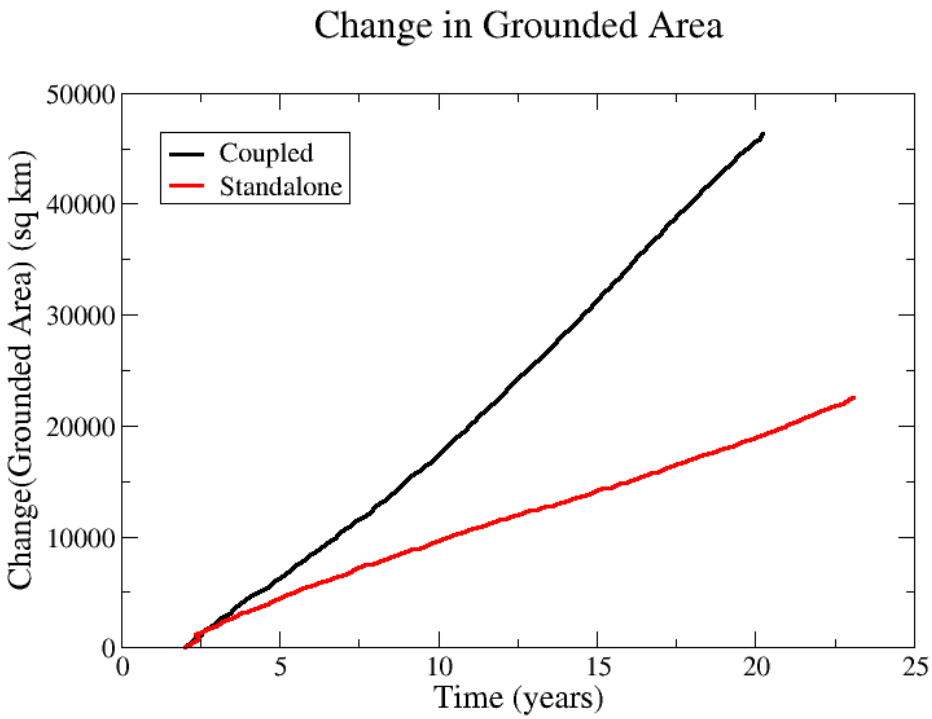


- Melt rates are spinning down over time (POP issue)
- Possible causes – climate forcing? no sea ice model?

Antarctic-Southern Ocean Coupled Sims (cont)

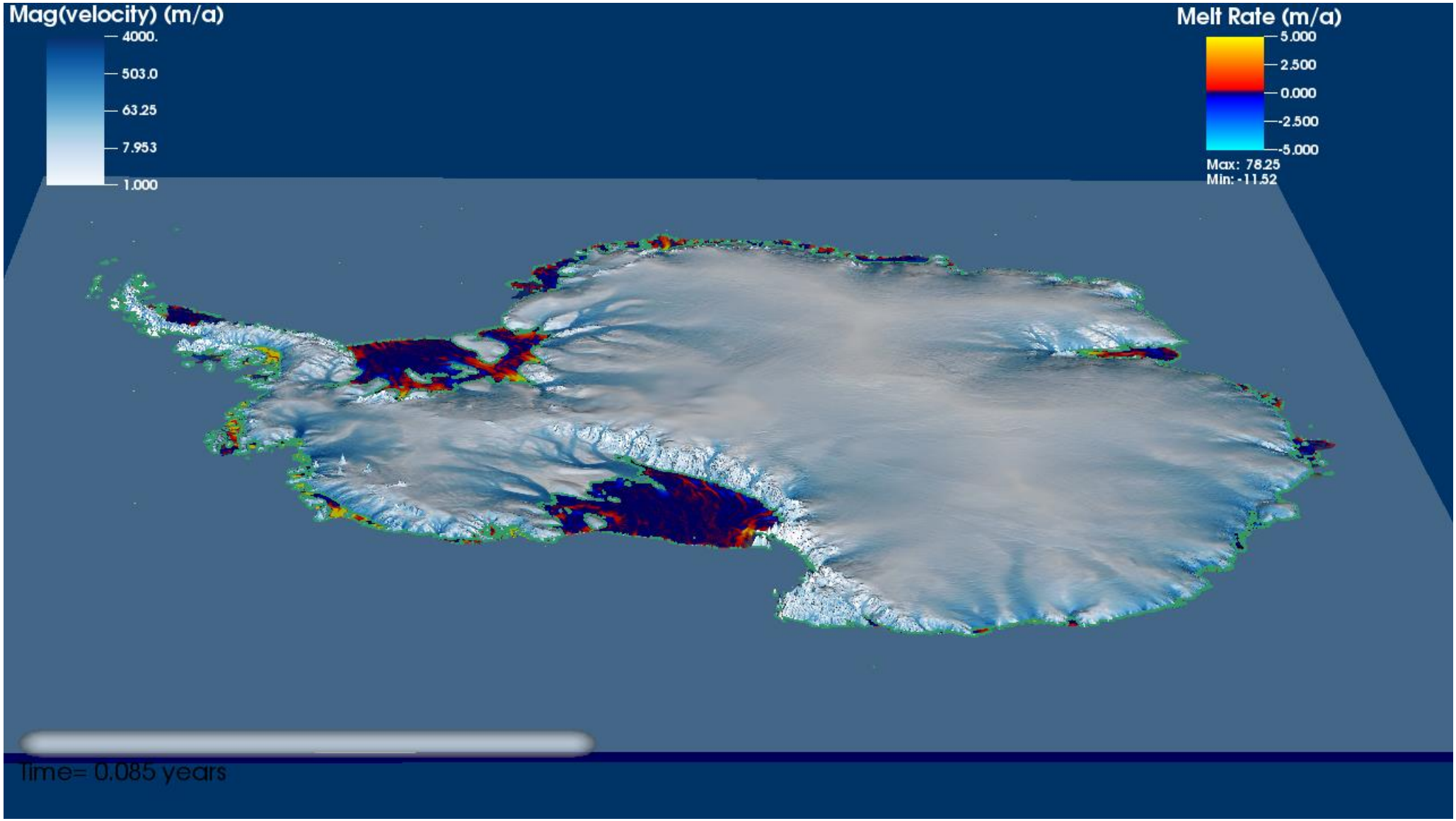
Compare Standalone vs. Coupled runs:



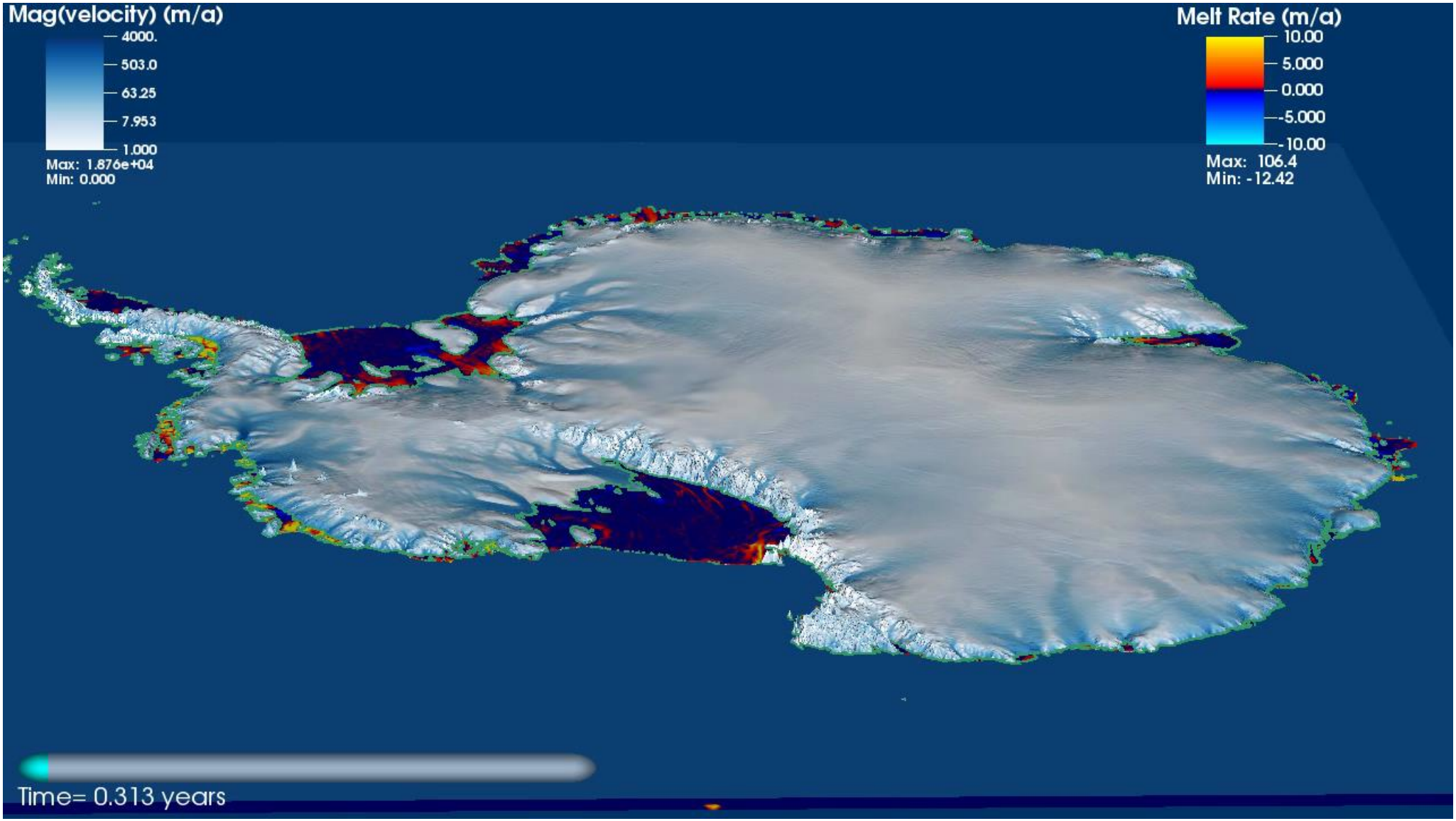


- "Steady-state" initial condition isn't quite (mass gain)
- Melt rates are spinning down over time (POP issue)
- **Can see effect of coupling (gains mass faster than standalone)**

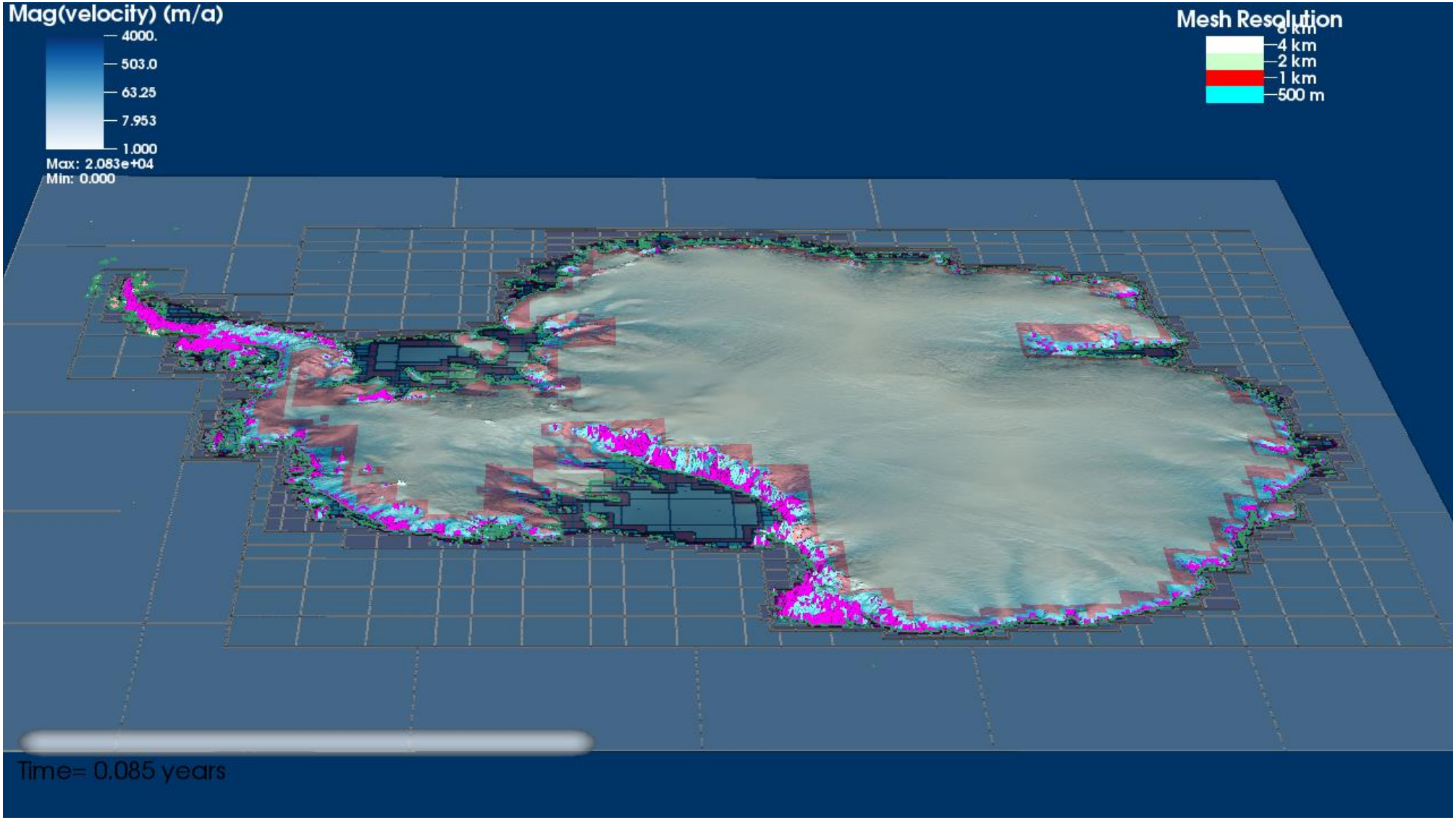
Antarctic-Southern Ocean Coupled Sims (cont)



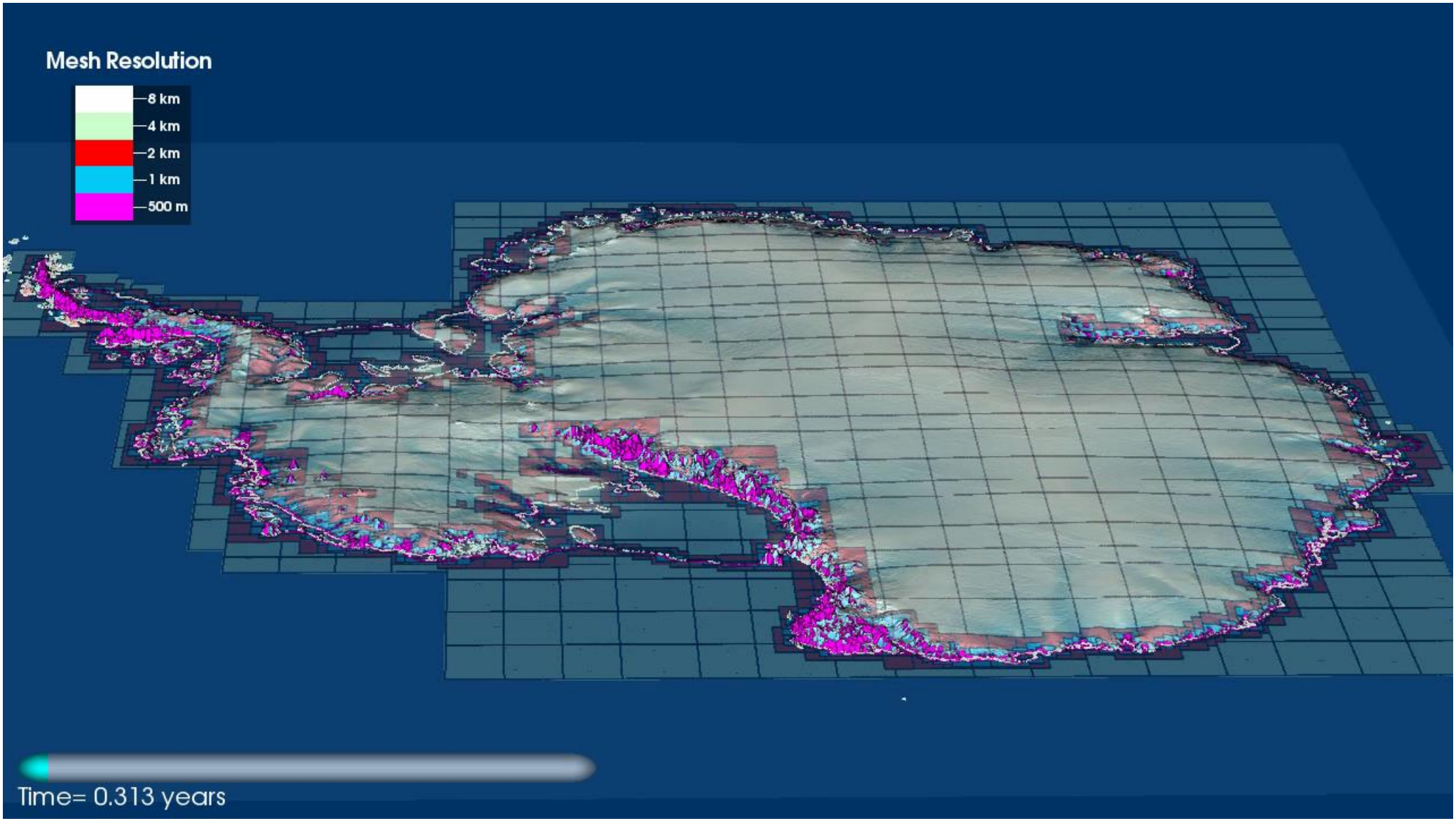
Antarctic-Southern Ocean Coupled Sims (cont)



Antarctic-Southern Ocean Coupled Sims (cont)



Antarctic-Southern Ocean Coupled Sims (cont)



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

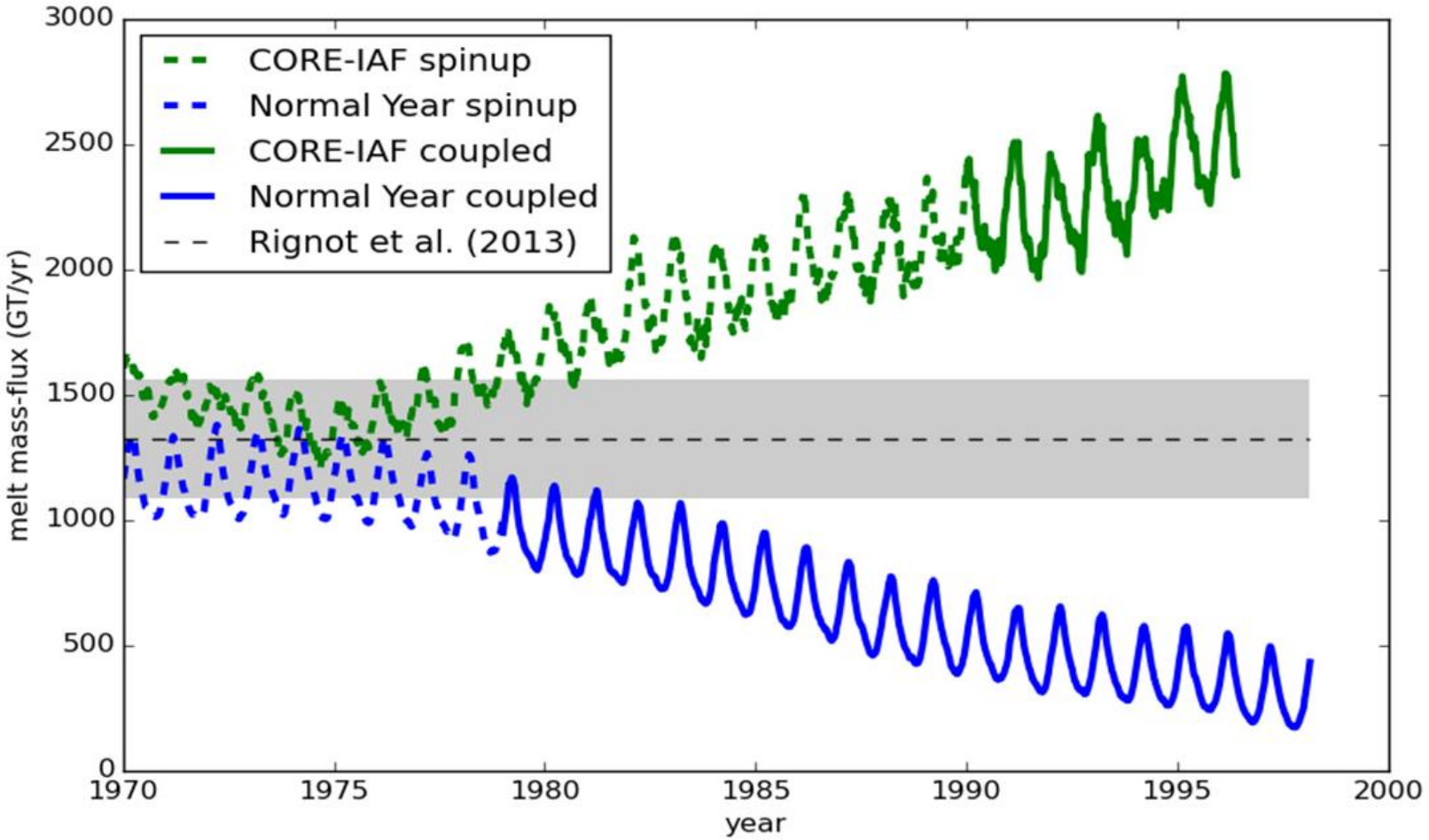
- Fixed POP error in freezing calculation.
  - (resulted in overestimated refreezing)

- **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

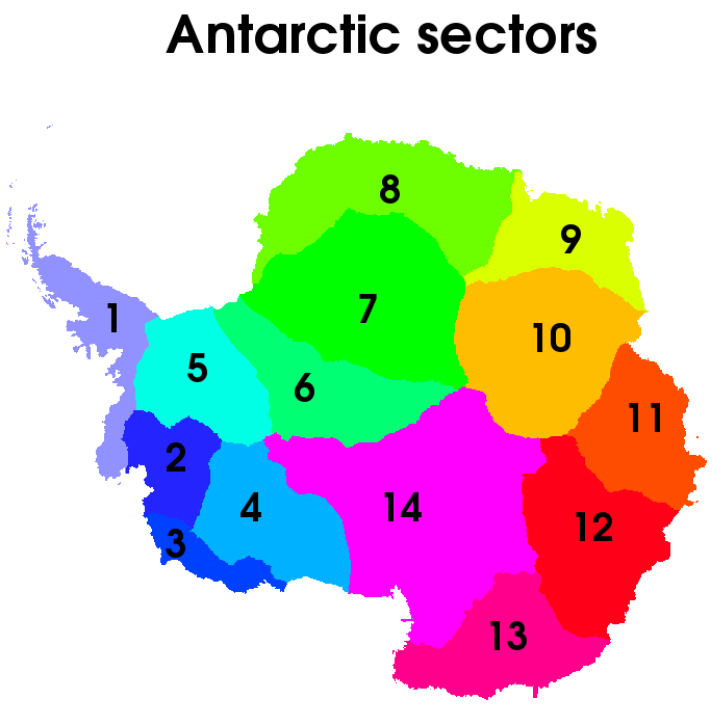
- **Need better initialization (On tap for next run)**

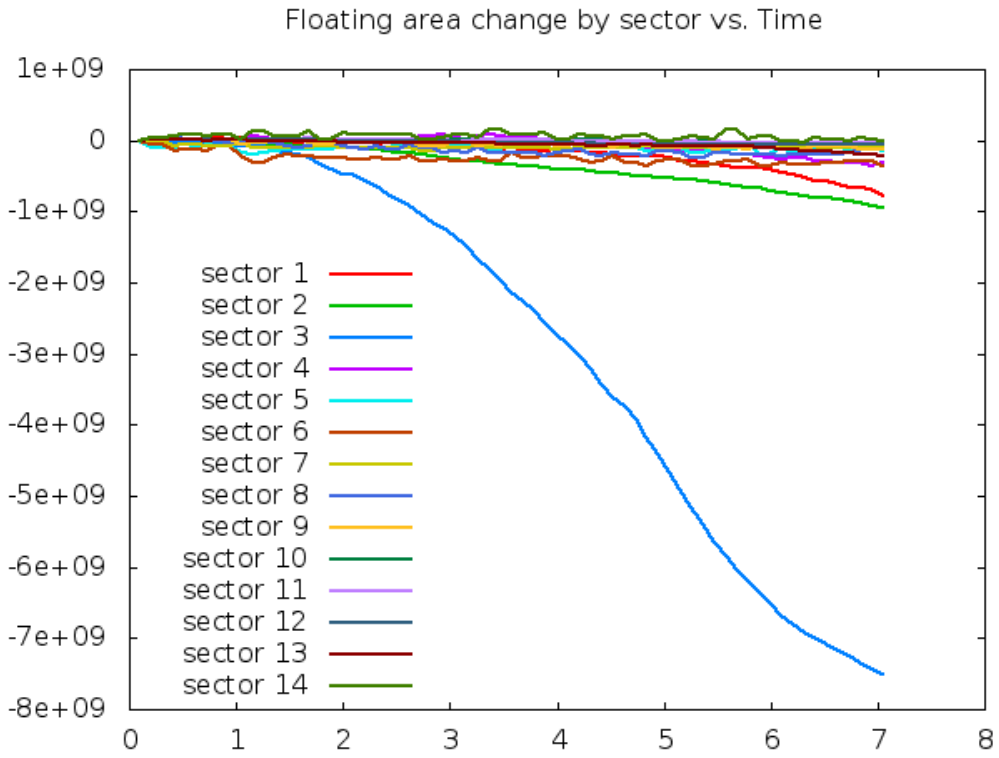
Different climate forcing on POP melt rates



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

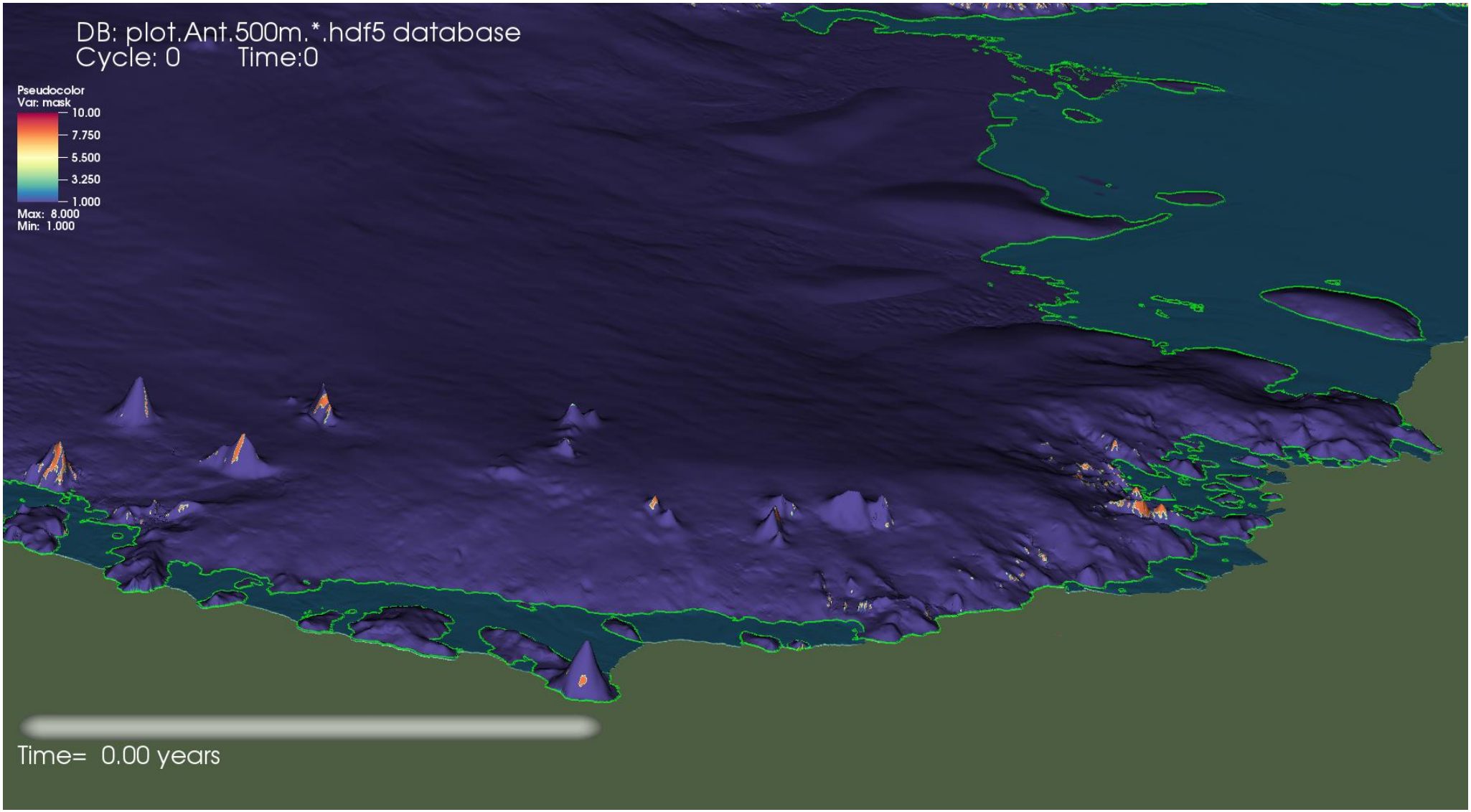
Coupled Antarctica: Core-IAF



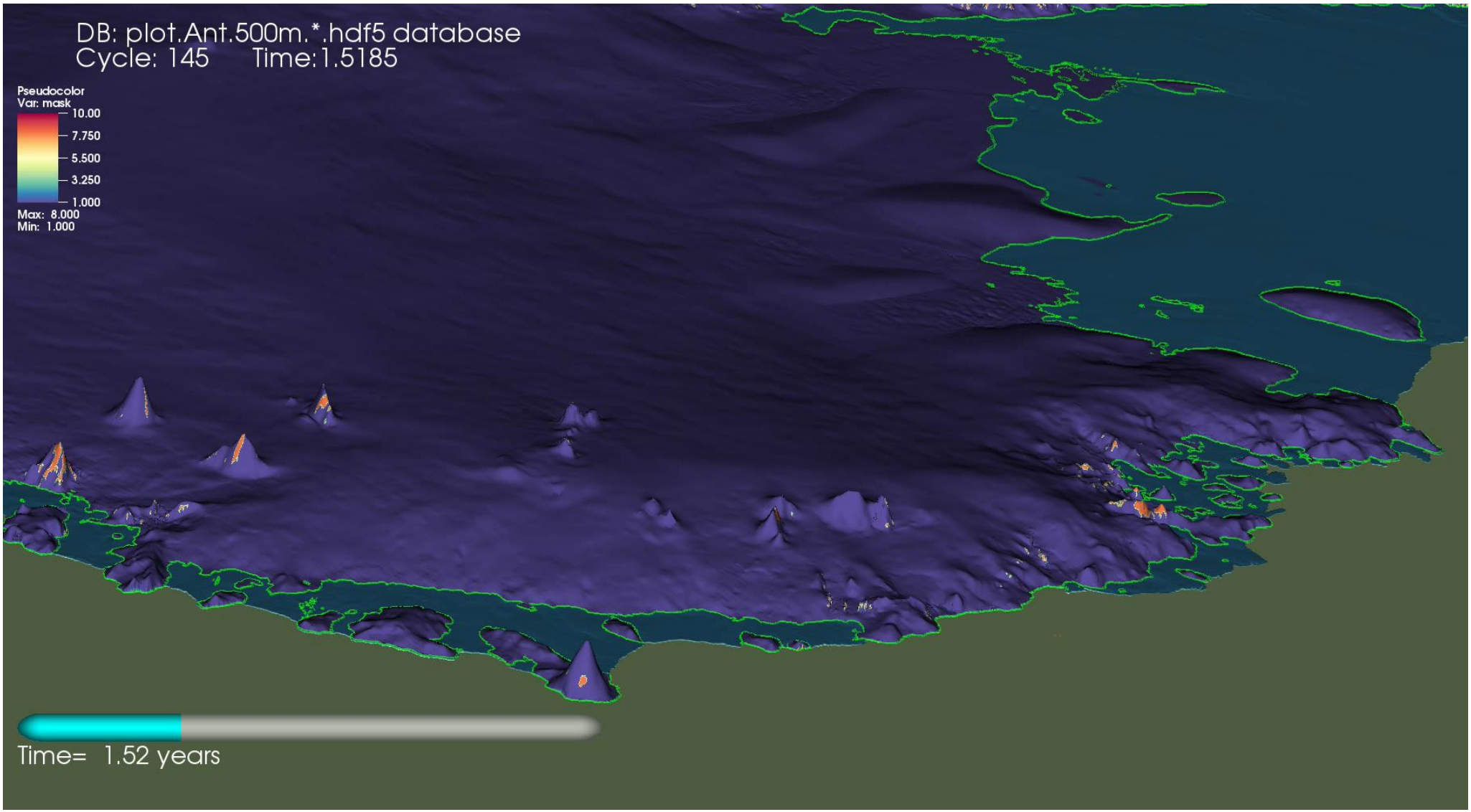


- Response dominated by loss of floating area in a few sectors
- This was supposed to be the **warming** scenario
- **What happened?** (Getz sector!)

Getz Ice Shelf - Regrounding Instability



Getz Ice shelf -- Regrounding instability



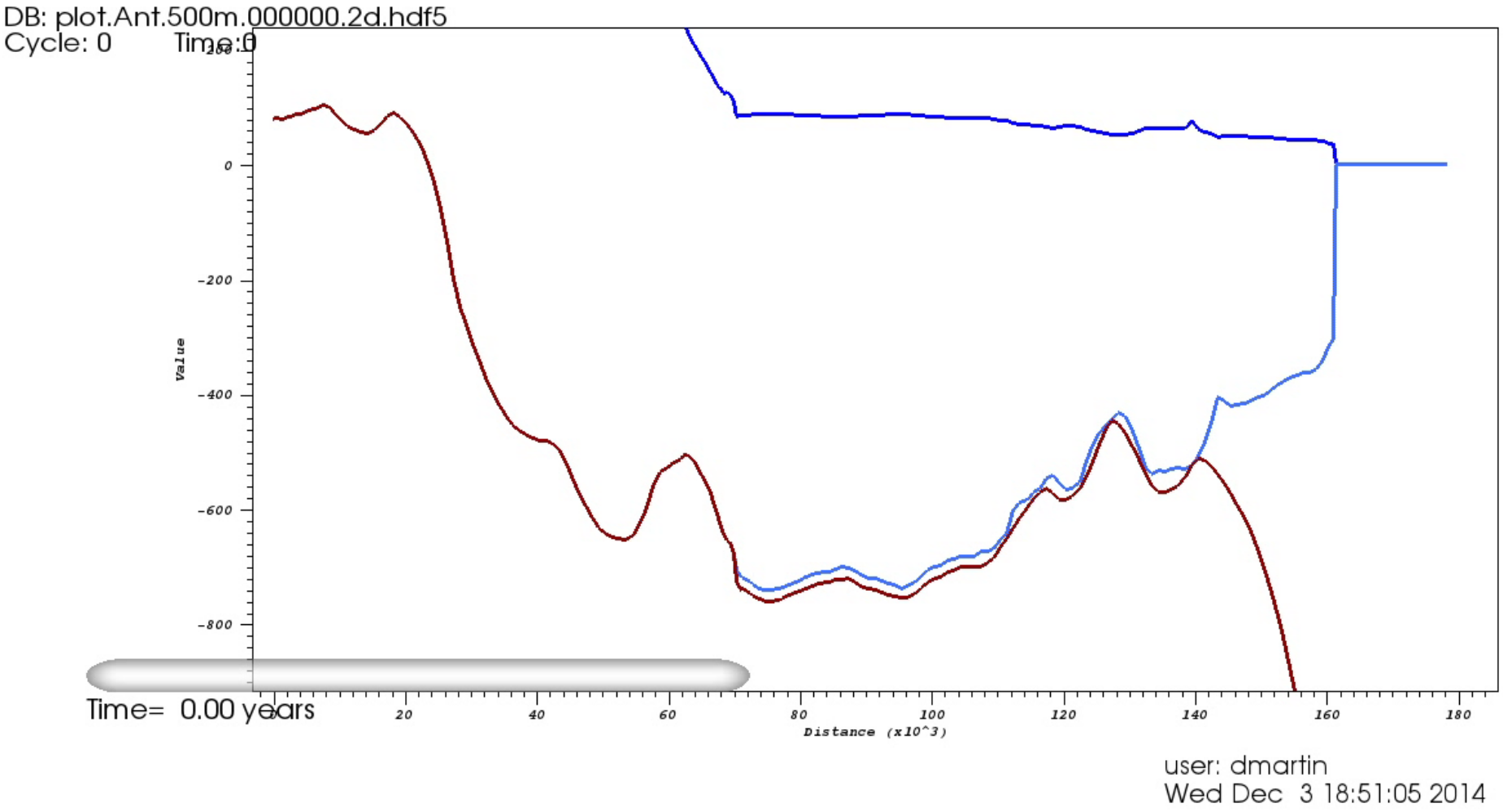
Getz Ice shelf -- Regrounding instability (cont)

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(** 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)

Getz Ice shelf -- Regrounding instability (cont)



Future work

- Fix issues exposed during coupled run and try again.
  - Deepen bathymetry in problem regions (RTOPO1)
  - BISICLES initial condition -- realistic (Arthern?) SMB

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

"Family" of 3 New MIPs

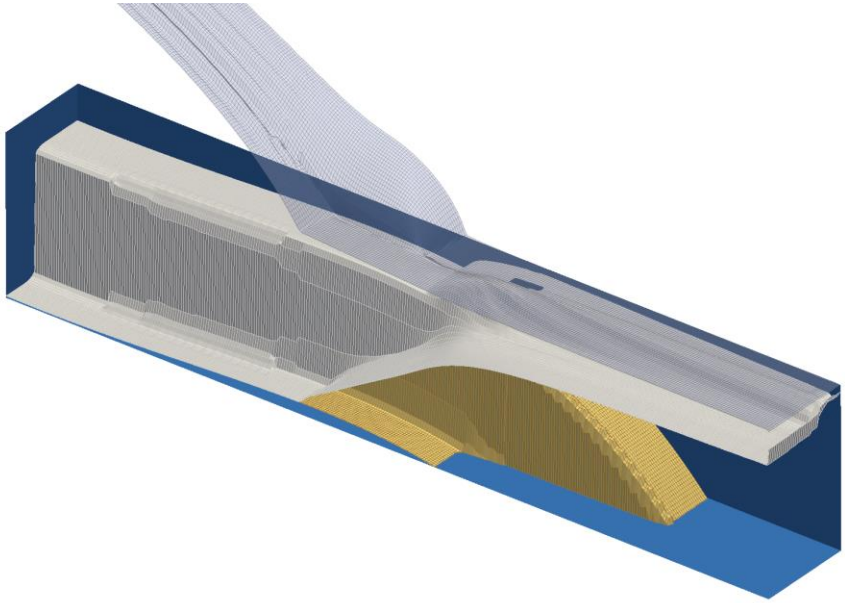
- Ice sheets: MISMIP+
- Ocean Models: ISOMIP+
- Coupled Models: MISOMIP

MISMIP+

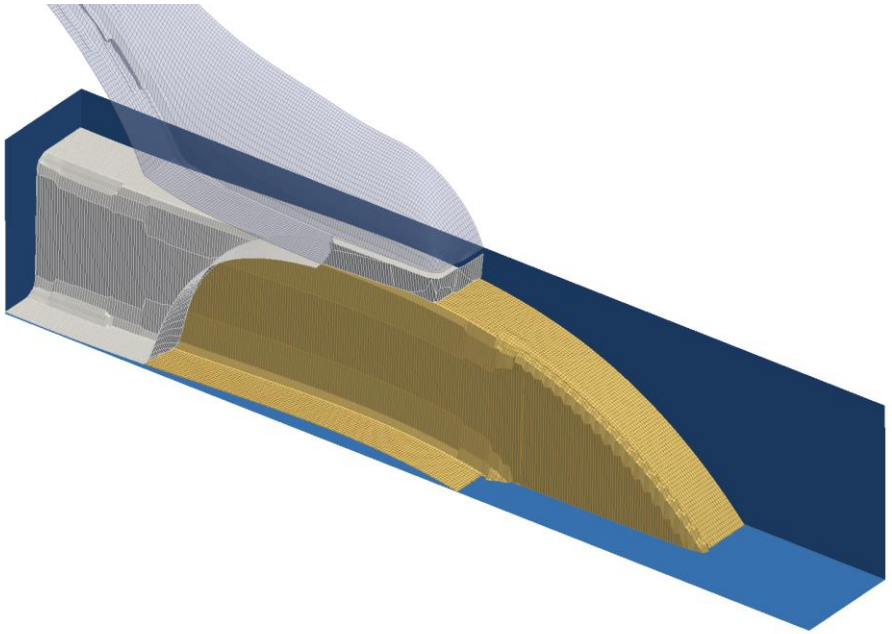
- "Child of MISMIP3D"
  - Examined GL response of models to a localized change in bed friction
  - Clarified resolution requirements for reversible GL dynamics
  - **Large variation in steady-state GL position among models**
  - Conclusions about dynamical results clouded by this difference
  - Said 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)



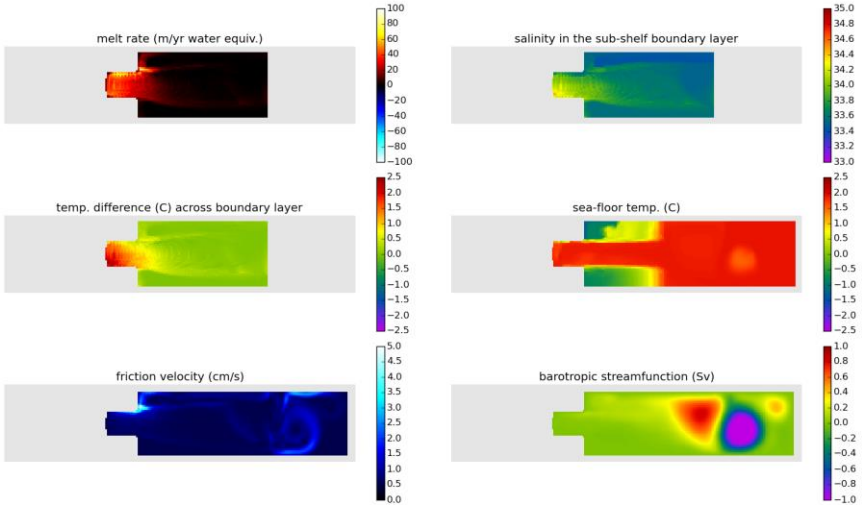
Steady-state initial condition



Fully-retreated condition

ISOMIP+

- 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 experiements planned
- Details rely on details of MISMIP+ and ISOMIP+
- Primary contact: Xylar Asay-Davis (Potsdam-PIK)

Thank you!