CC BY

A Tale of Two Forcings: Present-day Coupled Antarctic Ice-sheet/Southern Ocean Dynamics using the POPSICLES Model

Dan Martin

Lawrence Berkeley National Laboratory

April 16, 2015

U.S. DEPARTMENT OF ENERGY | Office of Science | BISICLES | Berkeley Lab | PIK | Los Alamos National Laboratory EST. 1943 | University of Bristol

Joint work with:

CC BY

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

Coupled Ice and Ocean Models:

- Ocean Circulation Model: POP2x

- Ice Sheet: BISICLES (CISM-BISICLES)

- POP + BISICLES = POPSICLES

U.S. DEPARTMENT OF ENERGY | Office of Science | BISICLES | Berkeley Lab | PIK | Los Alamos National Laboratory EST. 1943 | University of BRISTOL

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

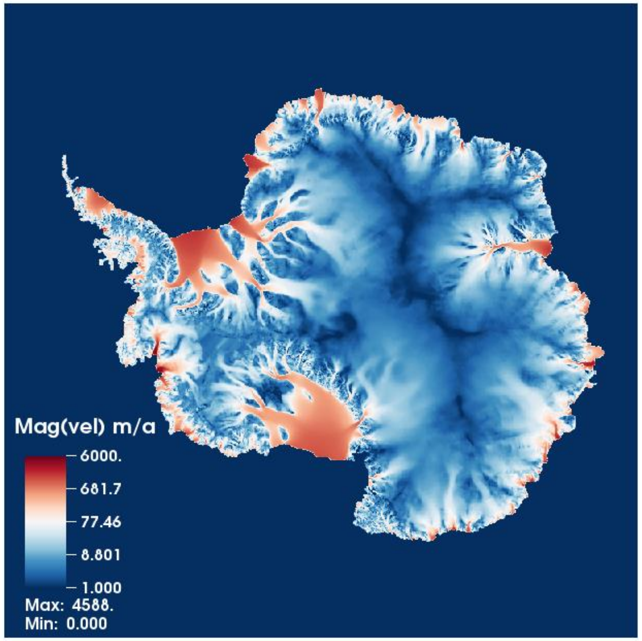
[1] Goldberg et al. (

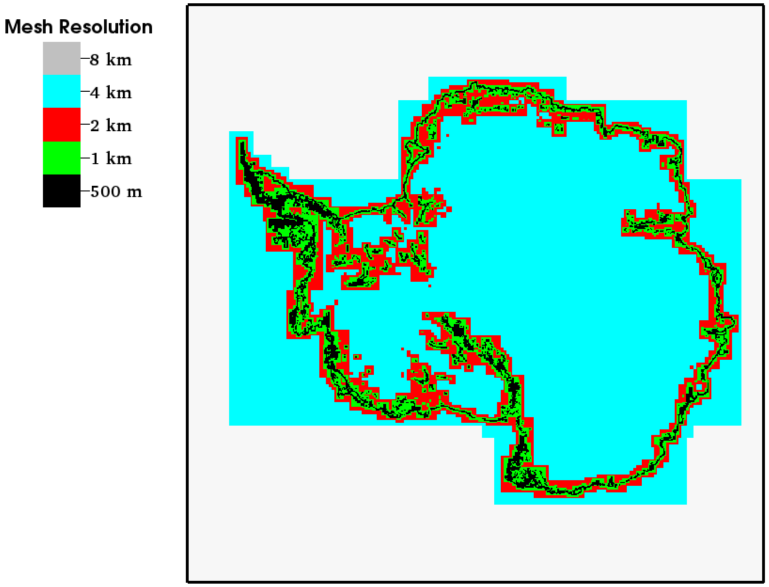
Antarctic-Southern Ocean Coupled Simulations

cc BY

BISICLES setup:

- ❑ Full-continent Bedmap2 (2013) geometry
- ❑ Initialize to match Rignot (2011) velocities
- ❑ Temperature field from Pattyn (2010)
- ❑ 500m finest resolution (adaptive mesh refinement)
- ❑ **Initialize SMB to "steady state" using POP standalone melt rate**



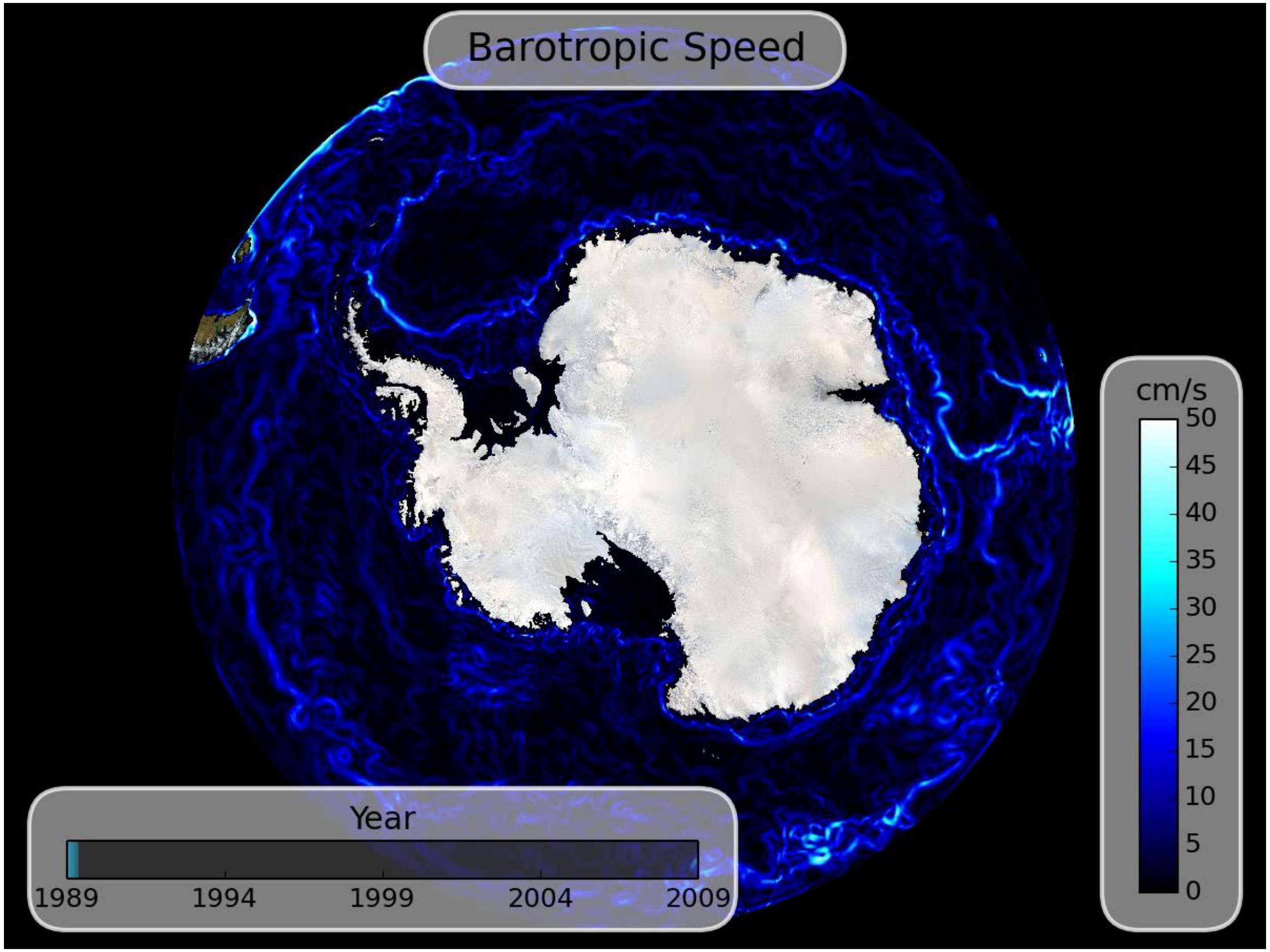


Antarctic-Southern Ocean Simulation

cc BY

POP setup:

- Regional southern ocean domain (50-85°S)
- ~5 km (0.1°) horizontal res.;
- 80 vertical levels (10m - 250m)
- Initialize with stand-alone (3 & 20 years) run;
- Bedmap2 geometry



Two forcing regimes

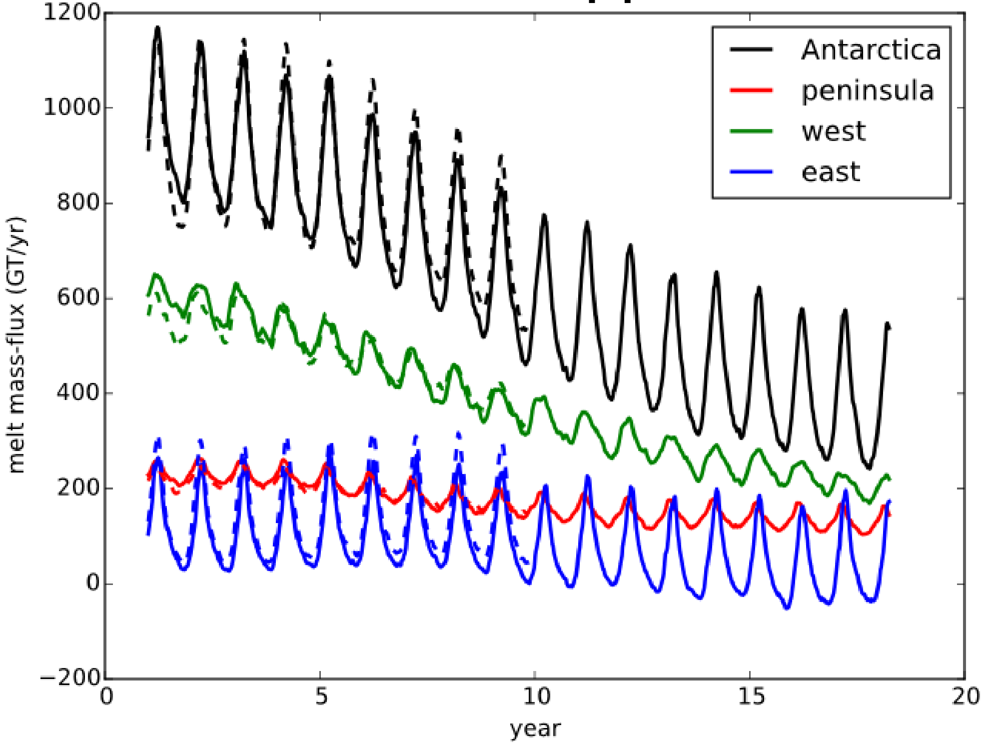
CC BY

- LANL "Normal Year" monthly mean forcing
- CORE InterAnnual Forcing (CORE-IAF)

Normal-Year Coupled Simulations

CC BY

What Happens?

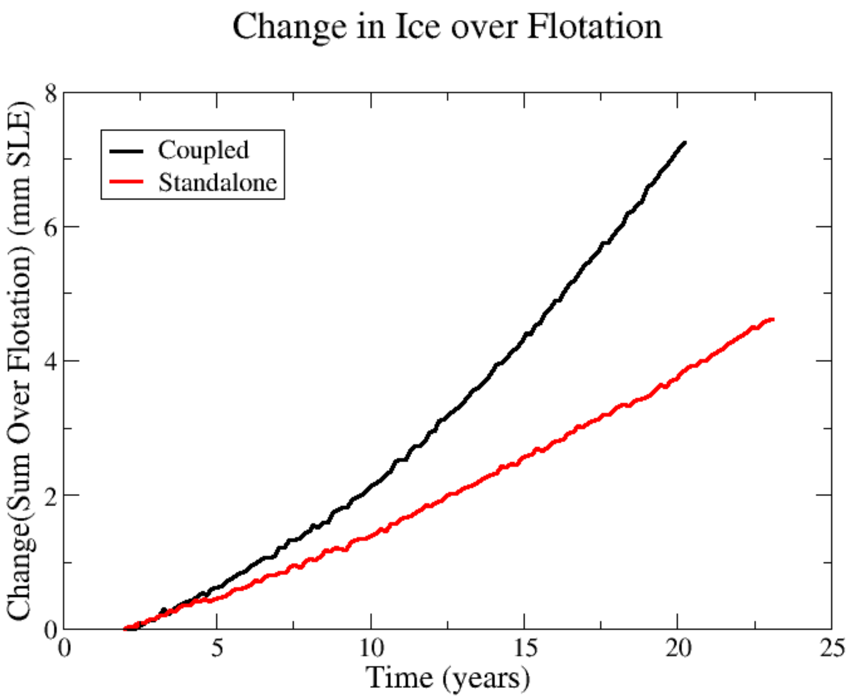


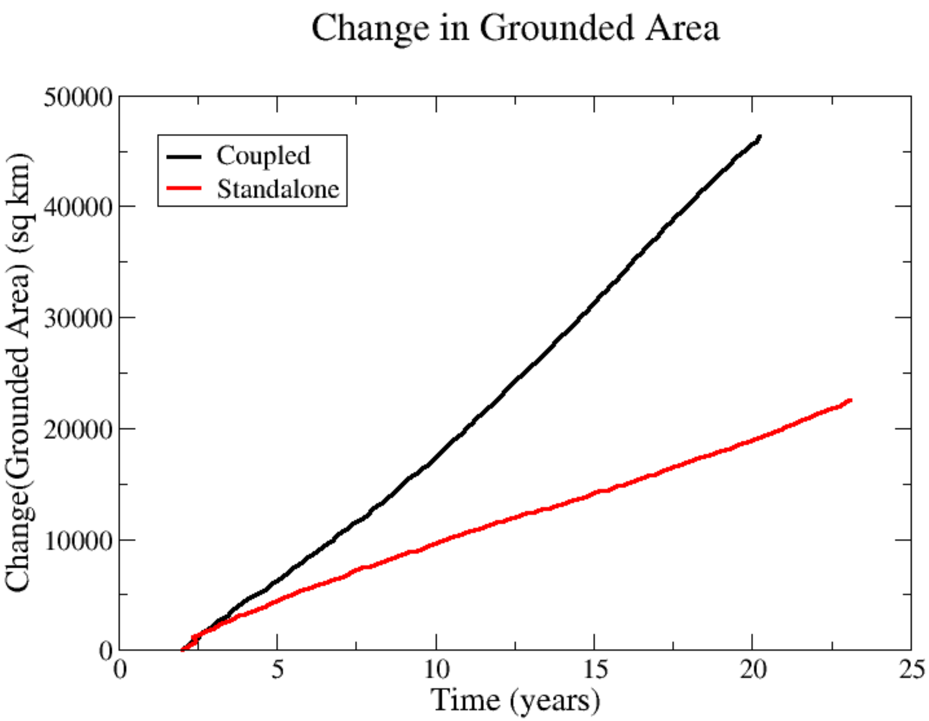
- Cold bias -- Melt rates are spinning down over time (POP issue)
- Possible causes –
  - Over-stratification (too much freshwater forcing?)
  - climate forcing?
  - no sea ice model? (Regional-mode POP issue)

Normal-year Coupled Sims (Ice sheet)

CC BY

Compare Standalone vs. Coupled runs:

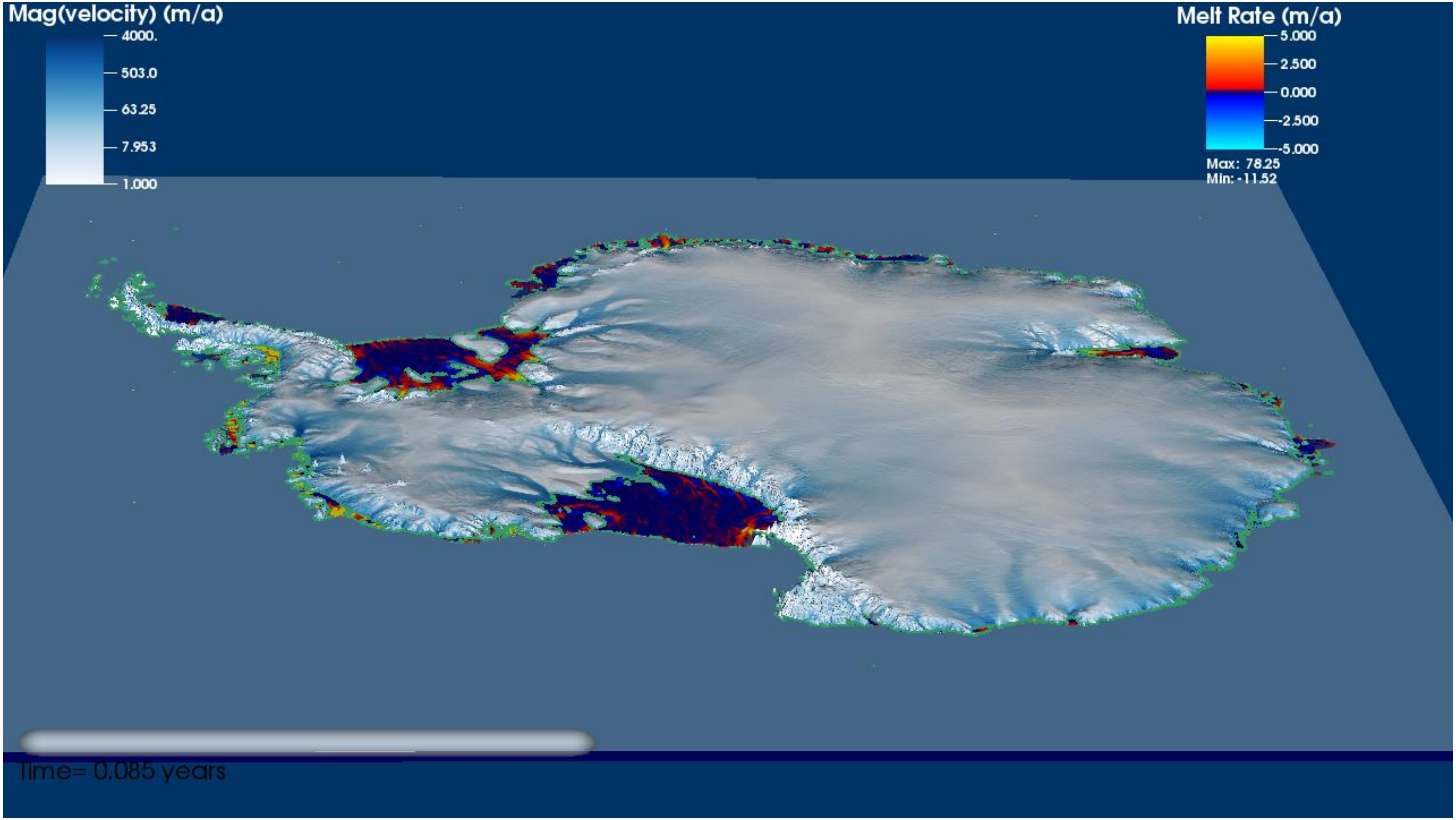




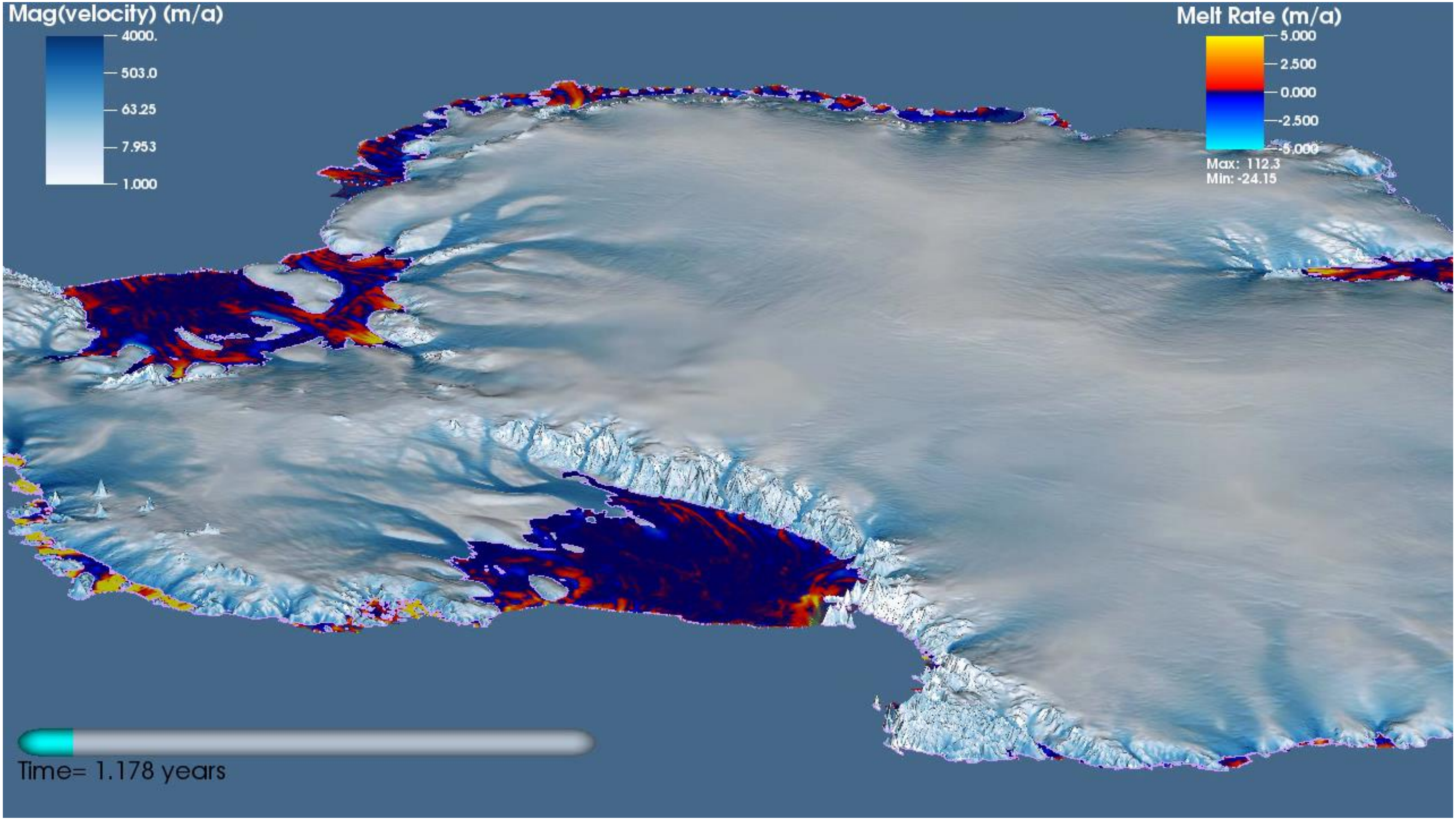
- "Steady-state" initial condition isn't quite (mass gain)
- Melt rates are spinning down over time (POP issue)
- **Can see effect of coupling (gains mass faster than standalone)**

Antarctic-Southern Ocean Coupled Sims (cont)

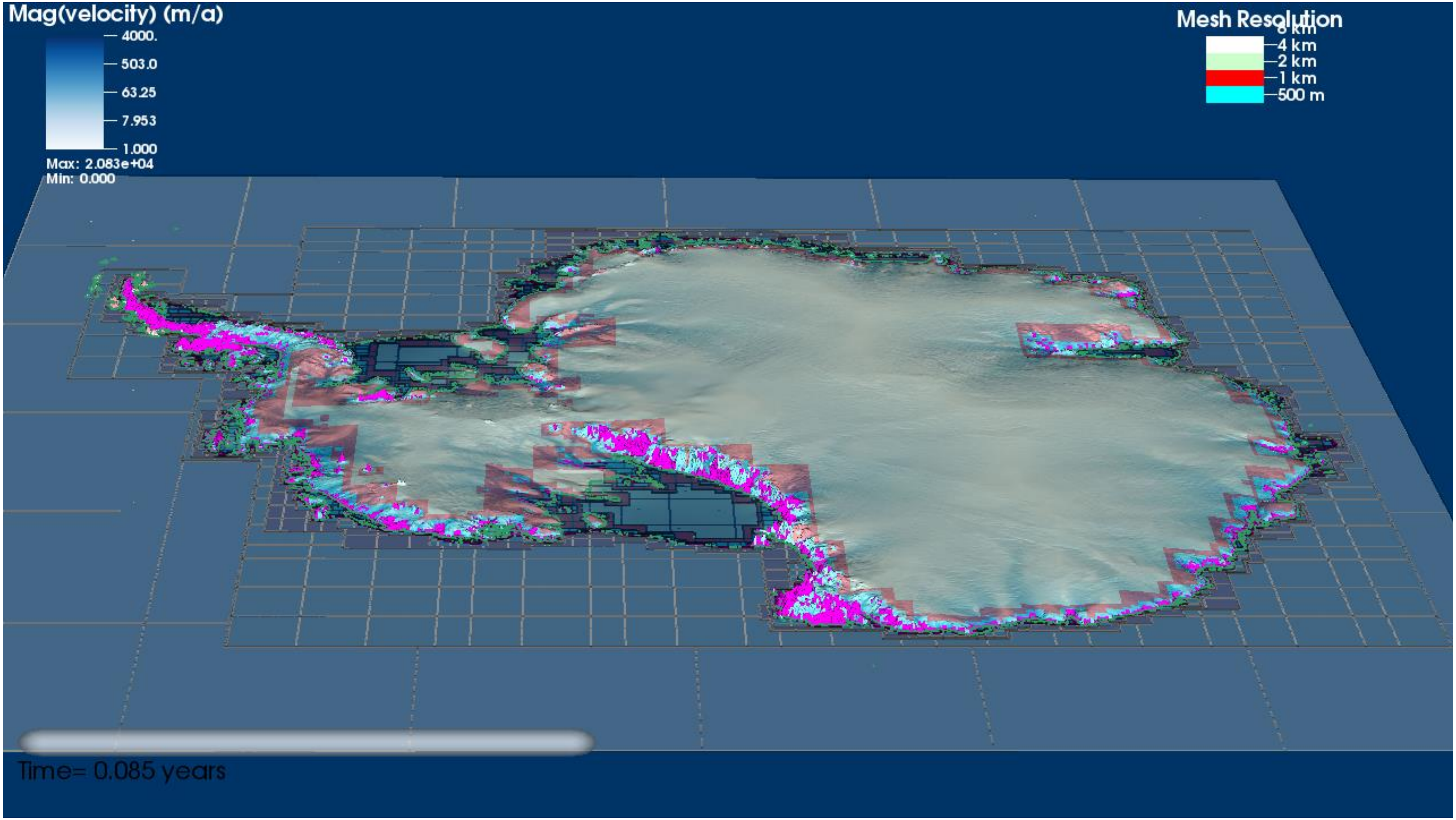
CC BY



Antarctic-Southern Ocean Coupled Sims (cont)

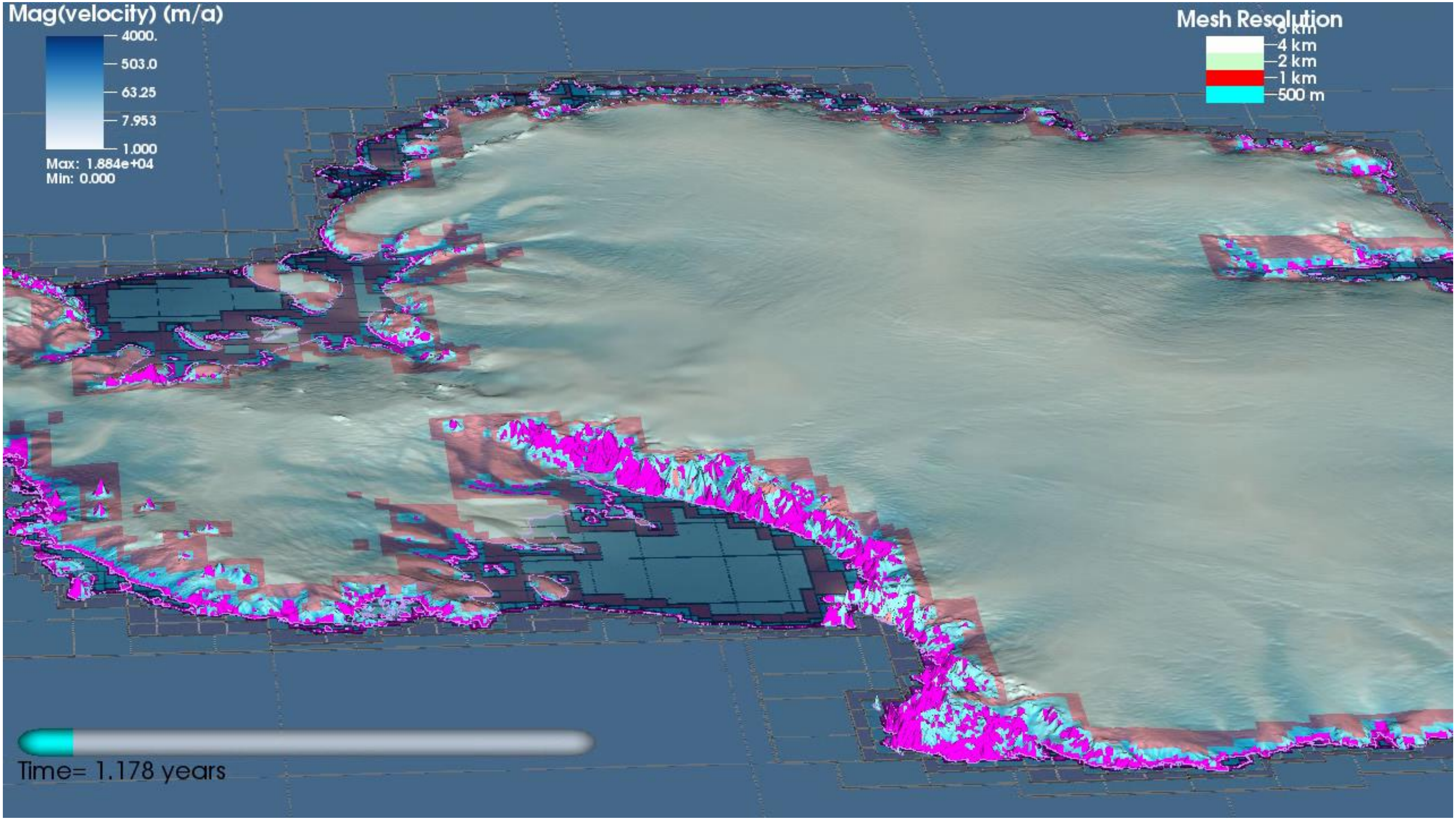


Antarctic-Southern Ocean Coupled Sims (cont)



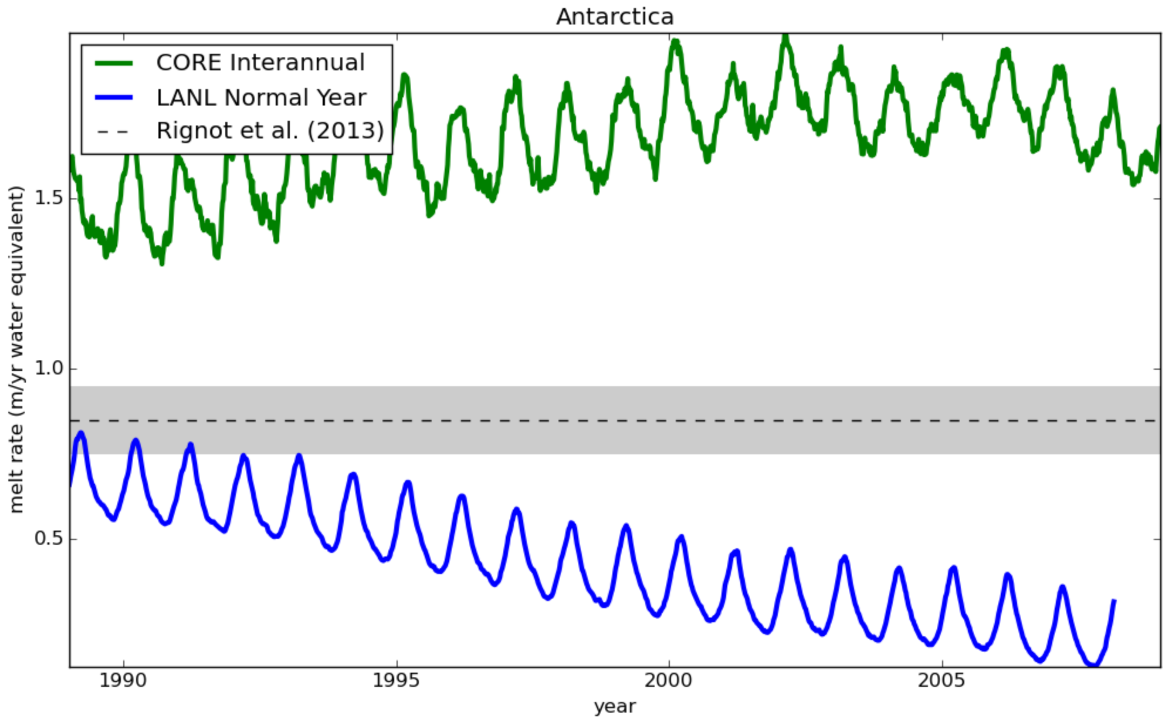
Antarctic-Southern Ocean Coupled Sims (cont)

CC BY



Normal Year vs. CORE-IAF: Impact on melt rates

cc BY

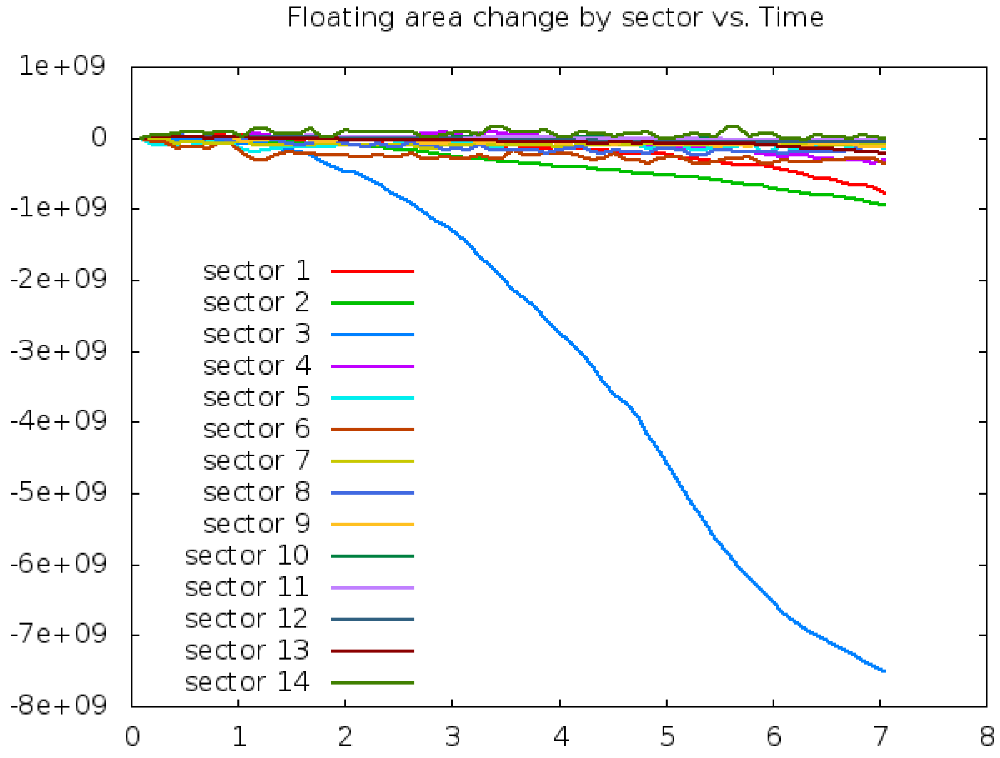


Switching to CORE-IAF forcing switches cold bias to warm…

- **Mixing of CDW into upper ocean**
- Destratification from freshwater forcing? (Joakim Kjellsson's talk Tuesday)
- Lack of Dynamic Sea Ice?

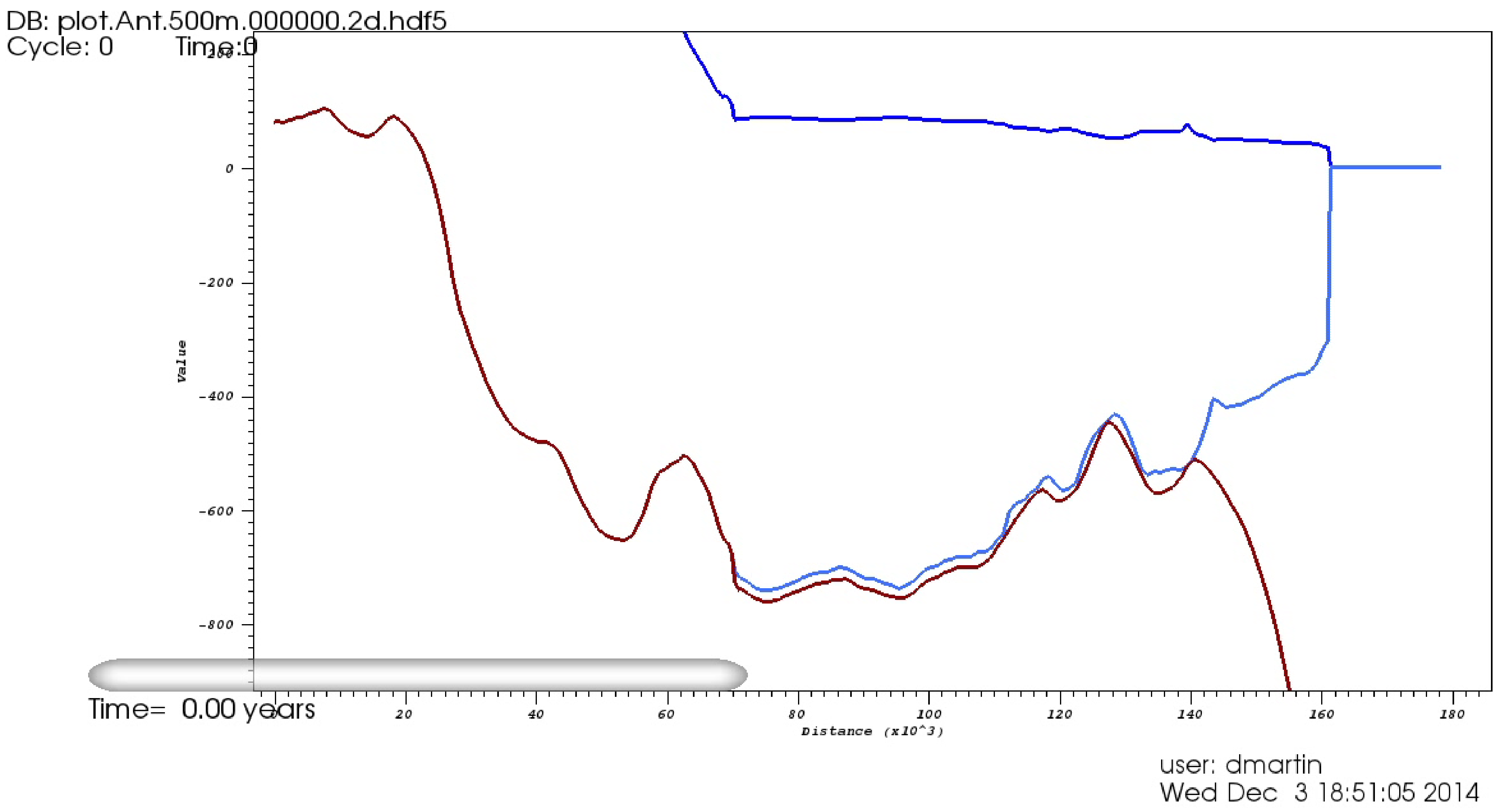
Coupled Antarctica: Core-IAF

CC BY



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

Getz Ice shelf -- Regrounding instability (cont)



Getz Ice shelf -- Regrounding instability (cont)

CC BY

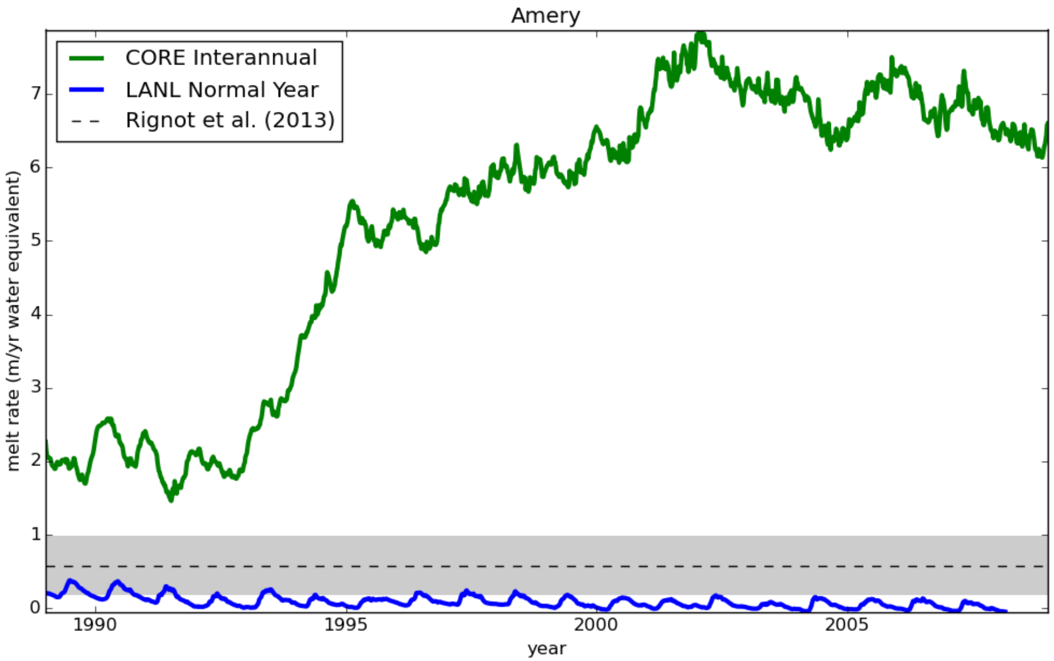
What happened?

- Bedmap2 – poorly constrained subshelf bathymetry
  - "Made stuff up" -- 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….

Warmwater incursion - Amery

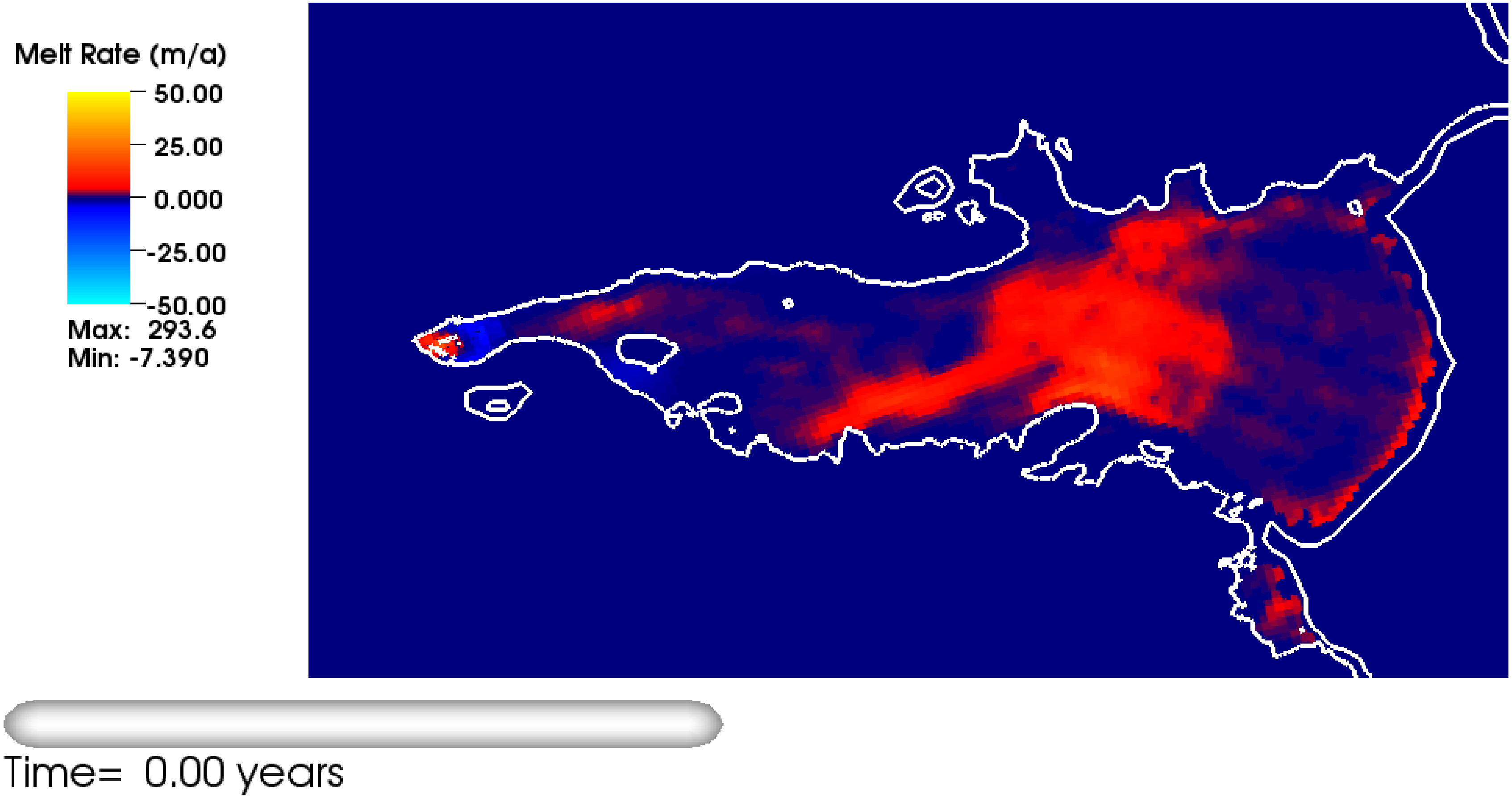
cc BY

- Warmwater incursion in Amery basin
- Increased melt rate – front reaches end of cavity in 9-10 years
- Moderate GL retreat



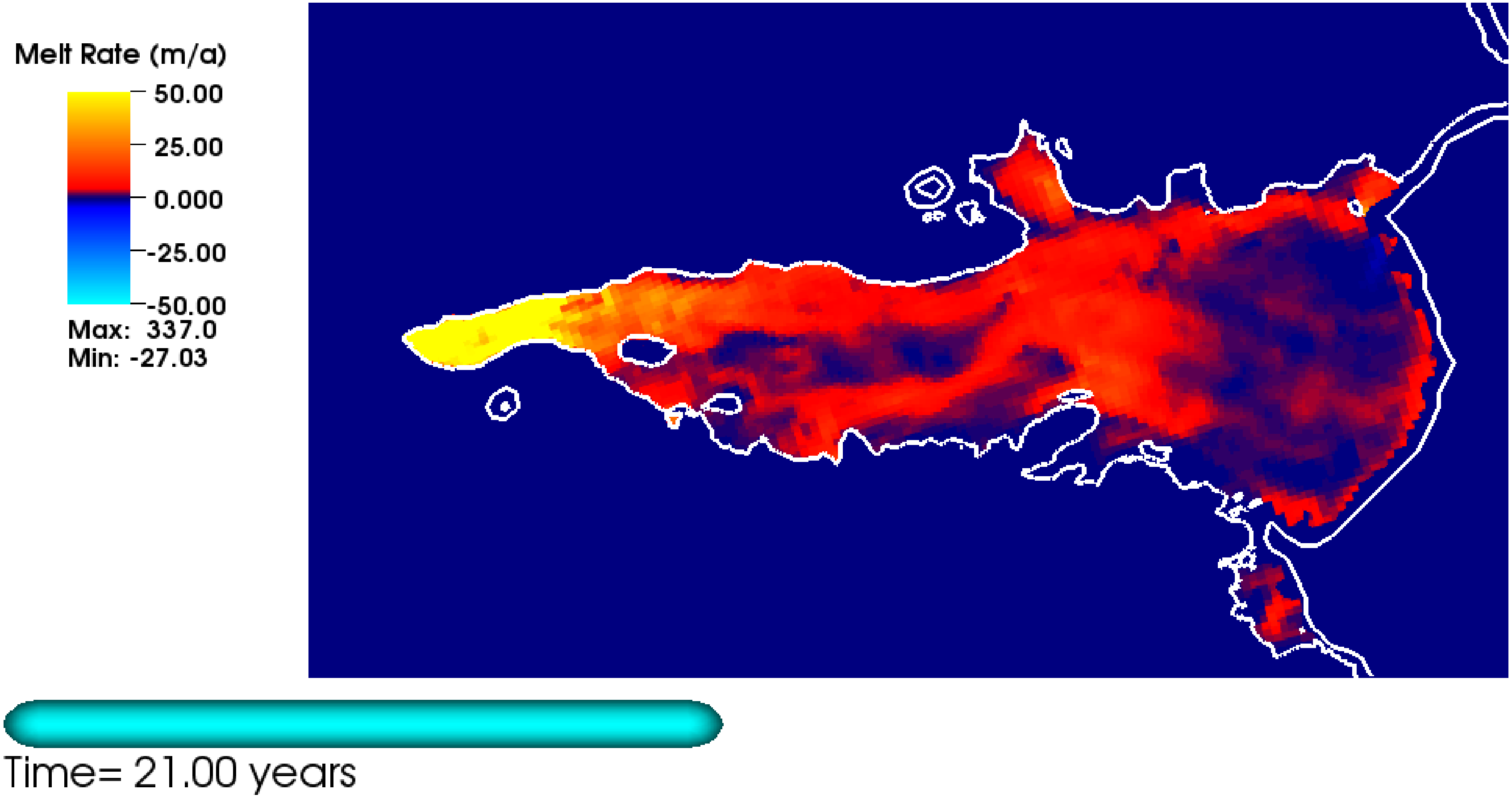
Warmwater Incursion – Amery (cont)

CC BY



Warmwater Incursion - Amery (cont)

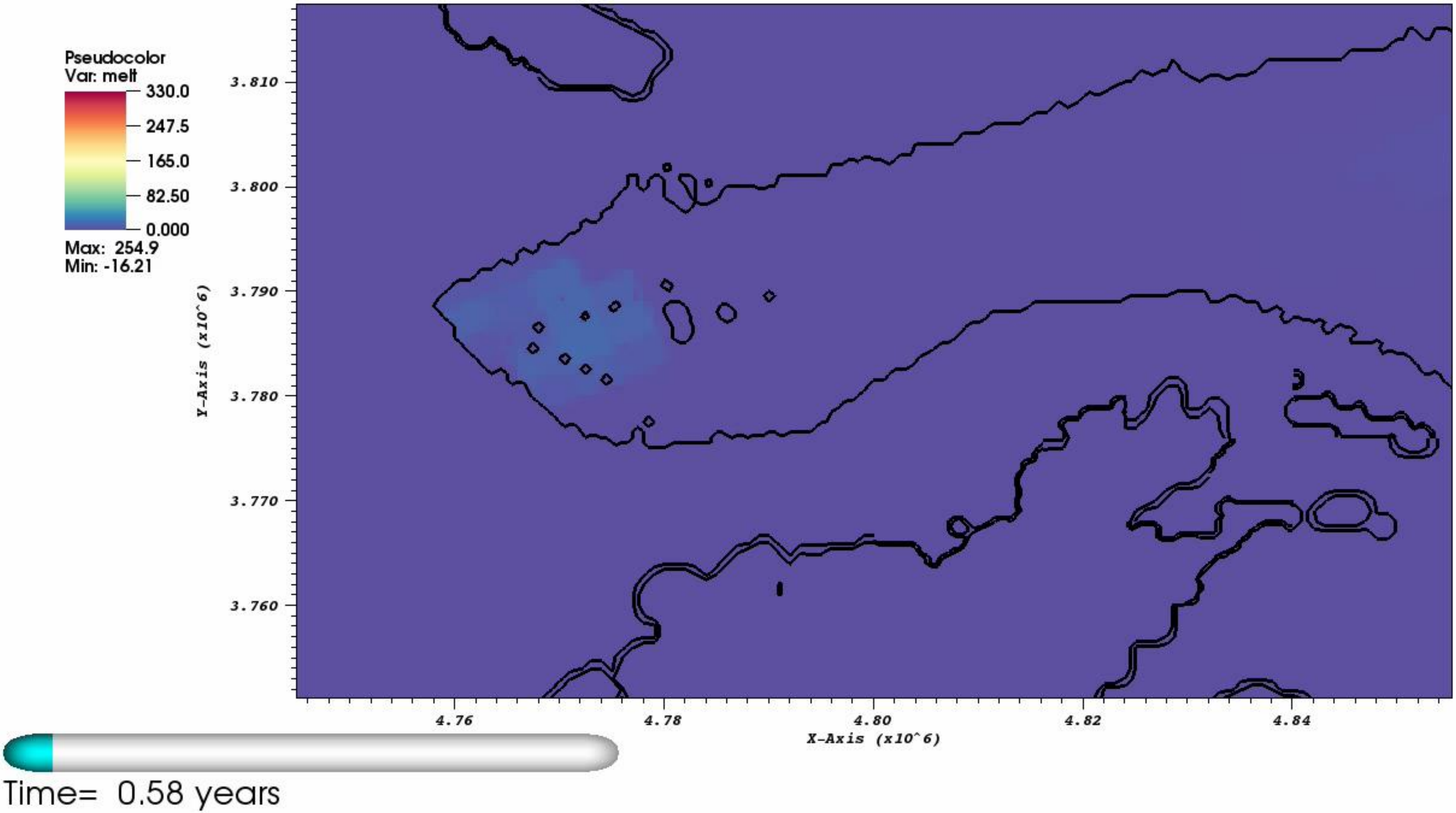
cc BY



U.S. DEPARTMENT OF ENERGY
Office of Science
BISICLES
BERKELEY LAB
PIK
Los Alamos NATIONAL LABORATORY EST. 1943
University of BRISTOL

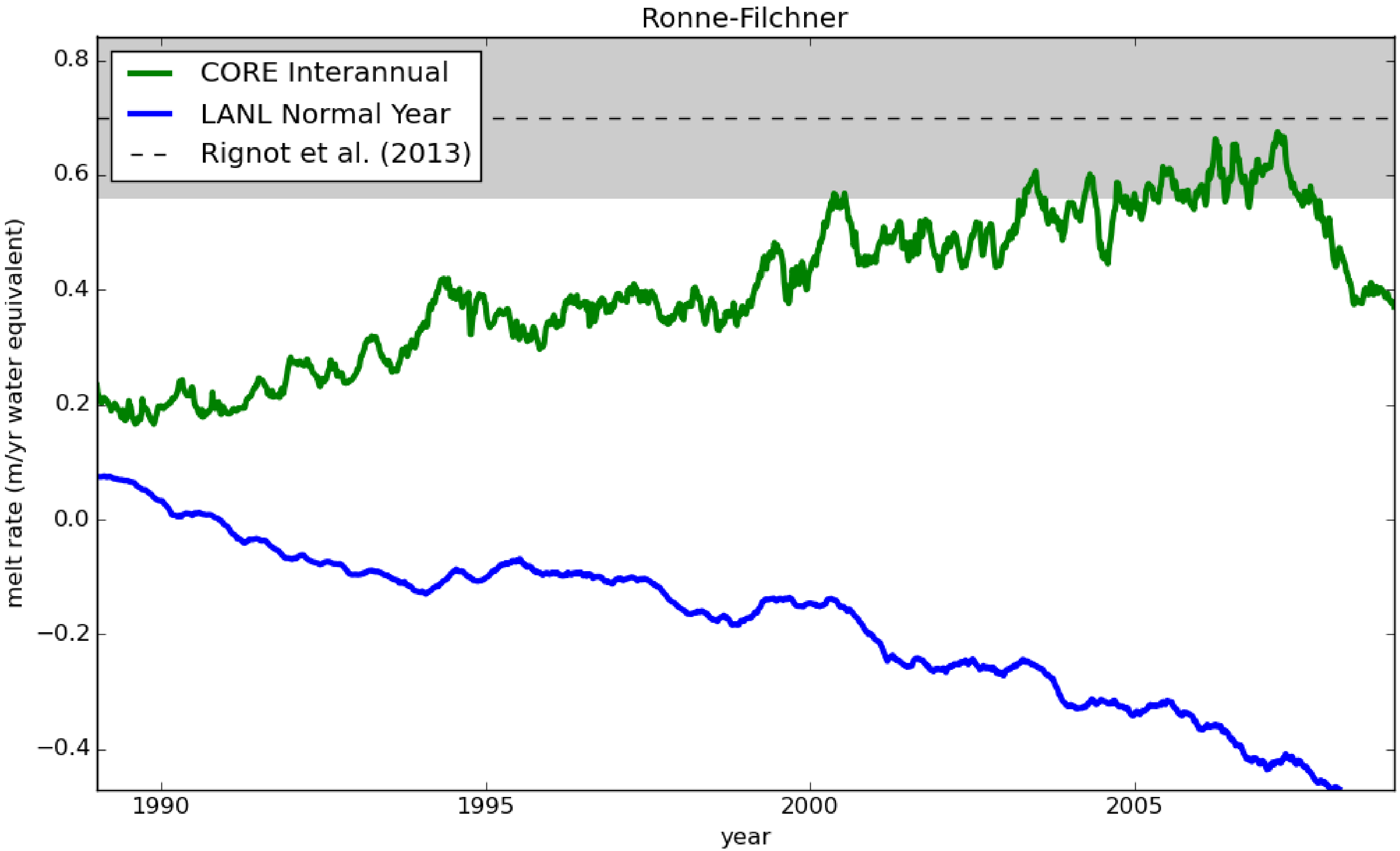
Warmwater incursion – Amery (cont)

CC BY



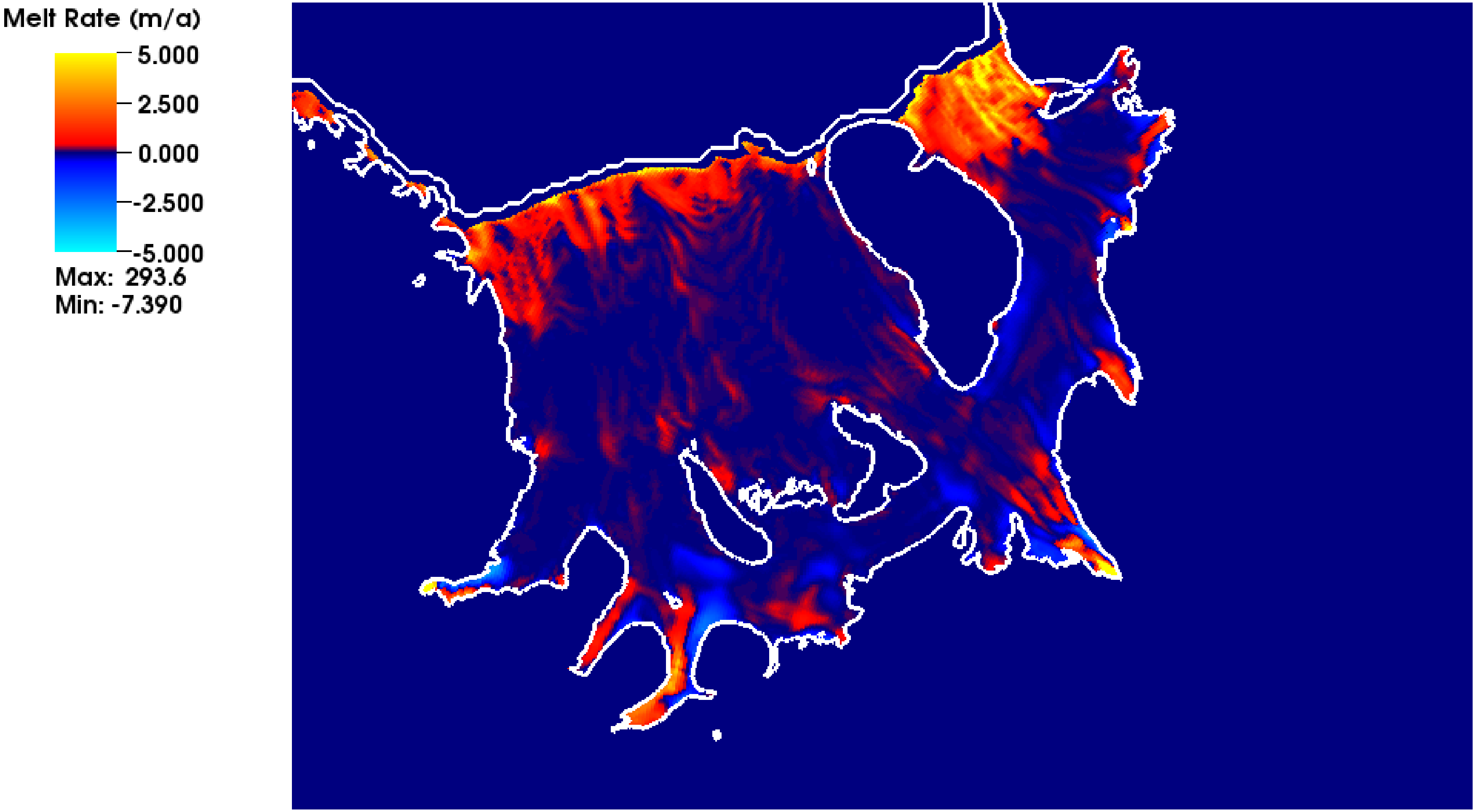
Ronne-Filchner

CC BY



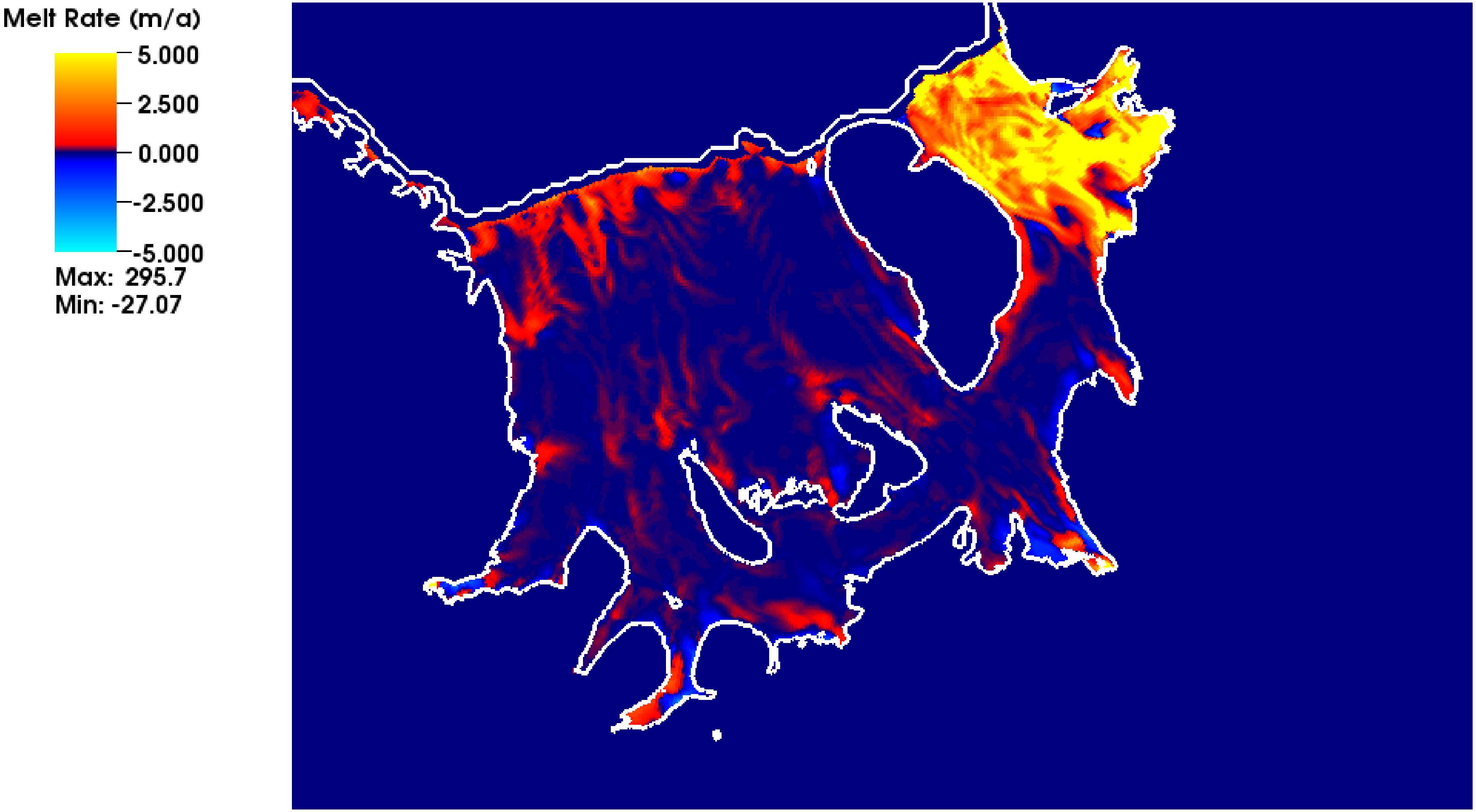
U.S. DEPARTMENT OF ENERGY | Office of Science | BISICLES | Berkeley Lab | PIK | Los Alamos National Laboratory EST. 1943 | University of BRISTOL

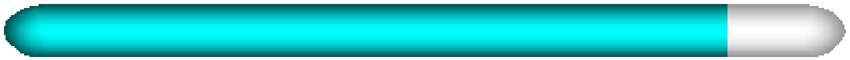
Ronne-Filchner Ice Shelf



Time= 0.00 years

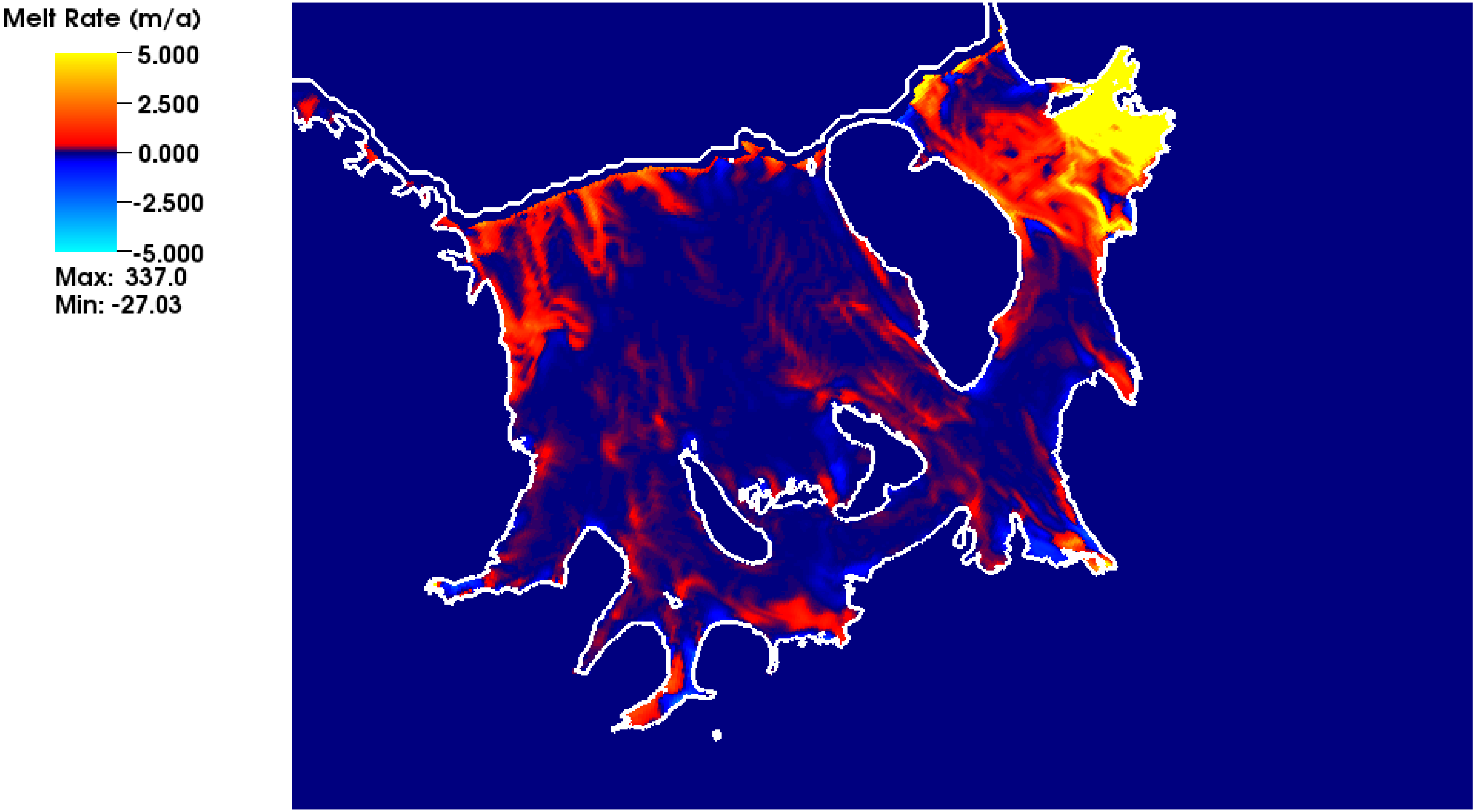
Ronne-Filchner Ice Shelf





Ronne-Filchner Ice Shelf

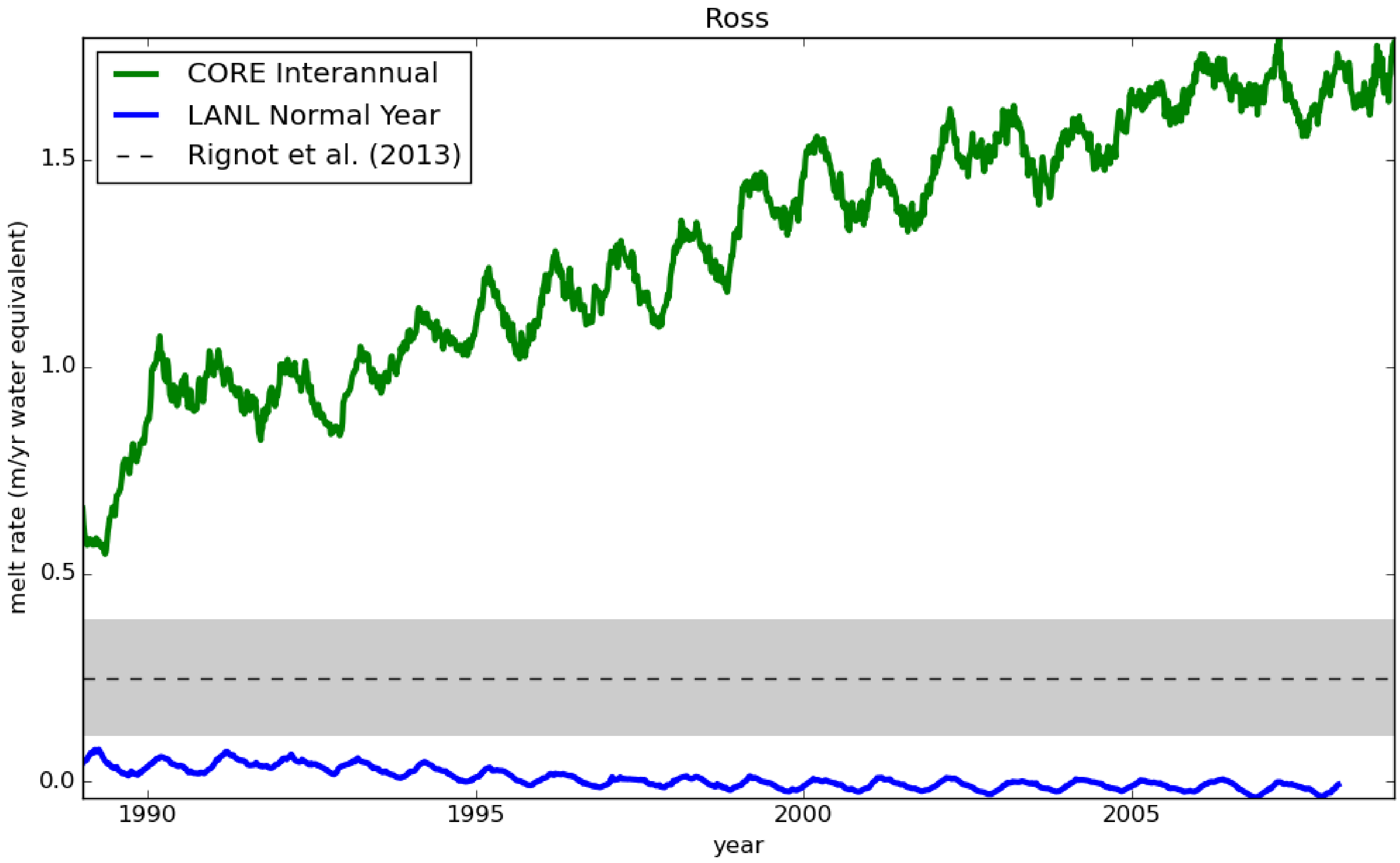
CC BY



Time= 21.00 years

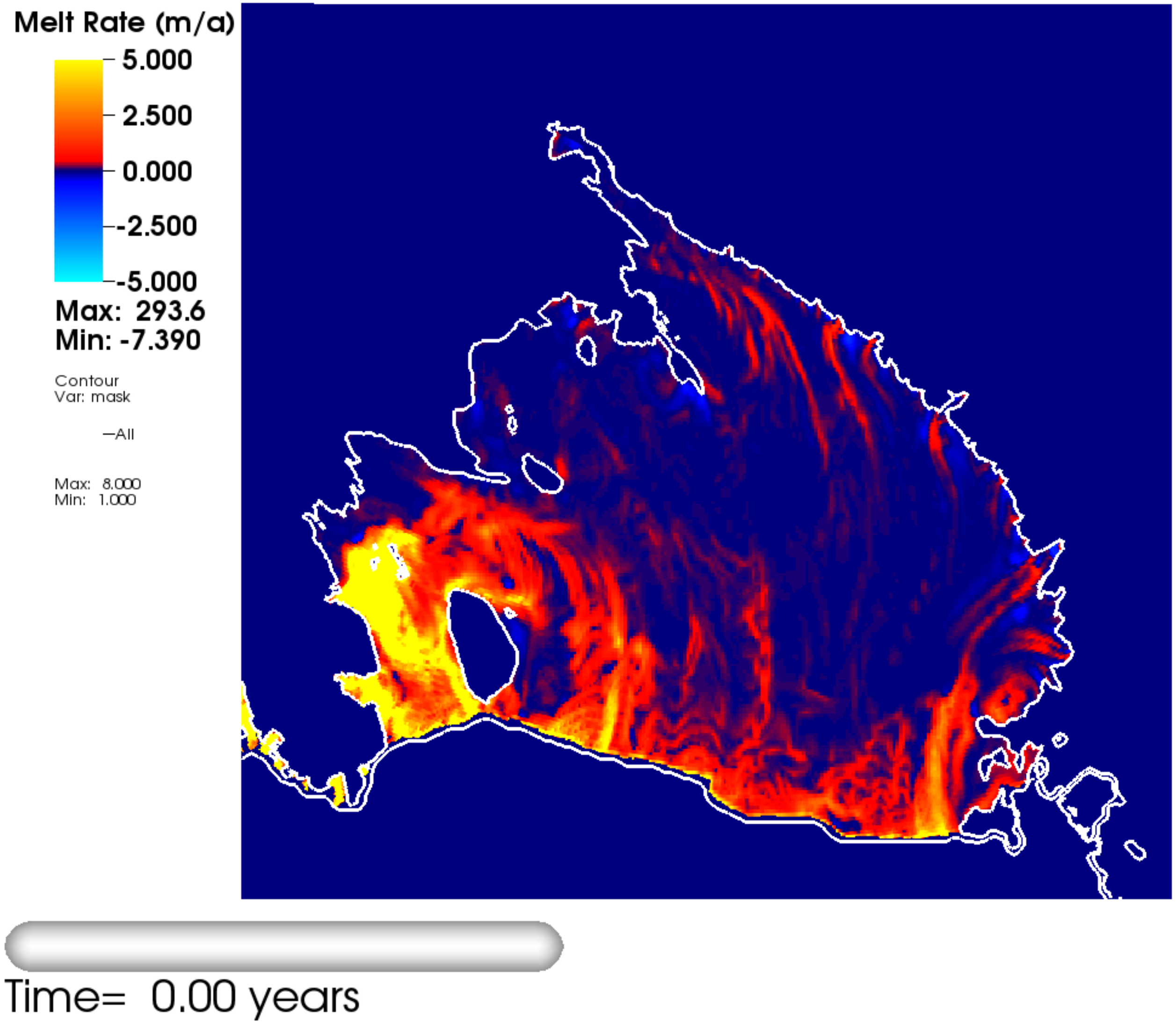
Ross Ice Shelf

cc BY



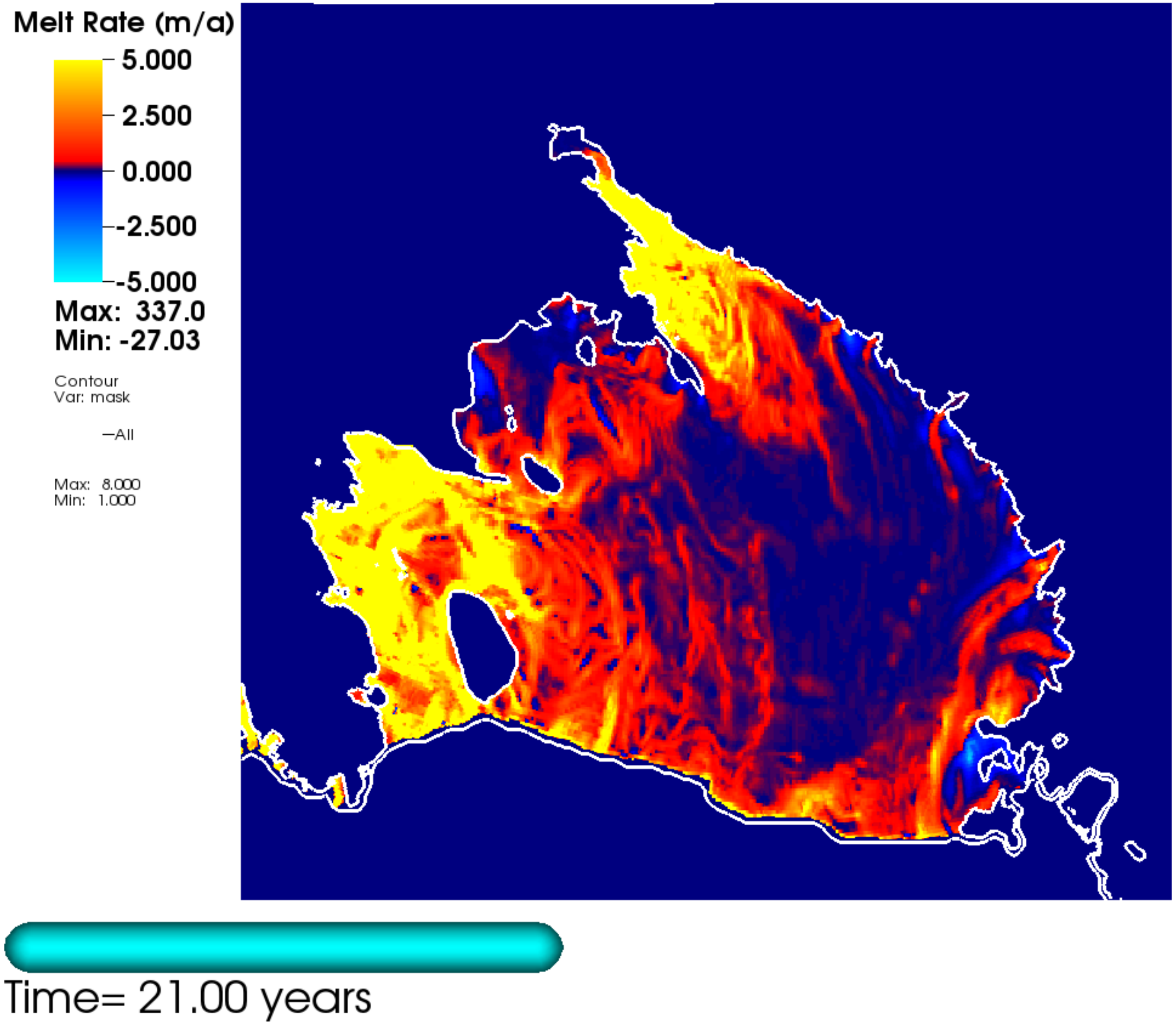
Ross Ice Shelf

CC BY



Ross Ice Shelf

CC BY



Future work

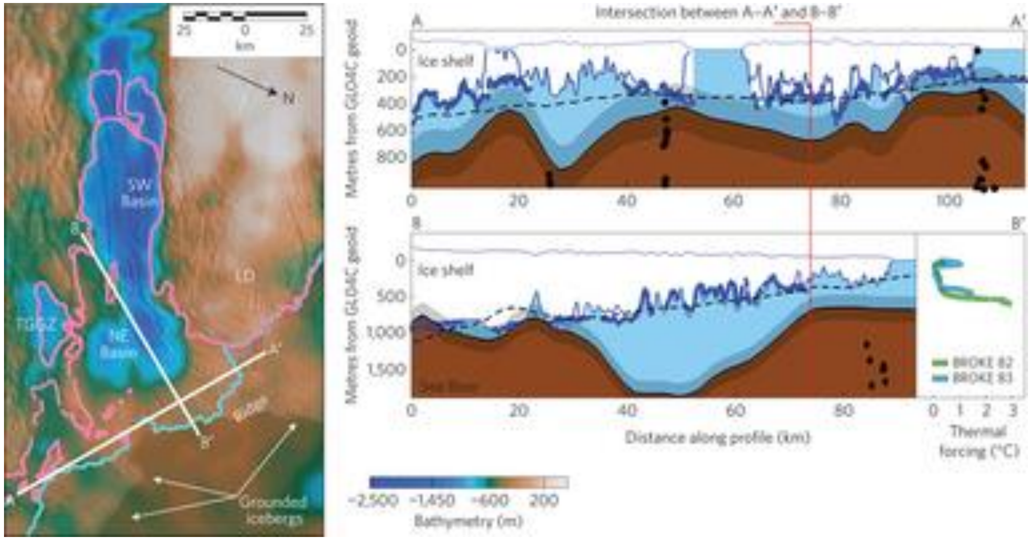
- Fix issues exposed during coupled run and try again.
  - Deepen bathymetry in problem regions (RTOPO1)
  - BISICLES initial condition -- realistic (Arthern?) SMB

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

U.S. DEPARTMENT OF ENERGY | Office of Science | BISICLES | Berkeley Lab | PIK | Los Alamos National Laboratory EST. 1943 | University of BRISTOL

Deepening bathymetry -- Totten

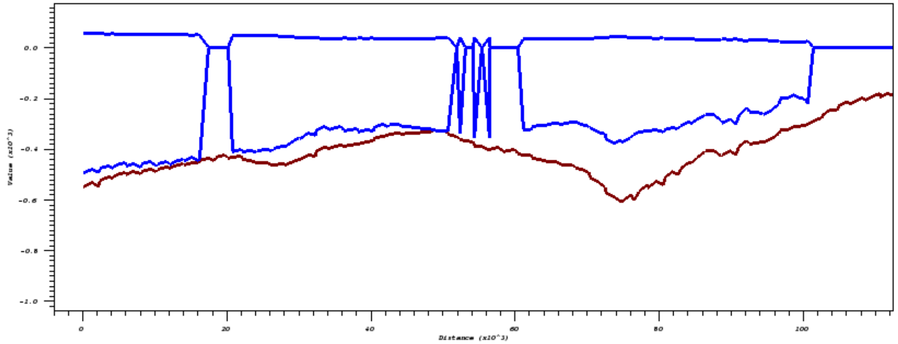
CC BY

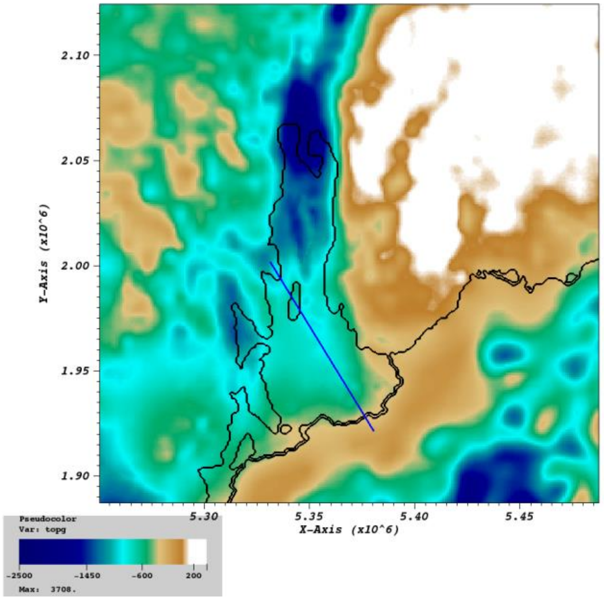


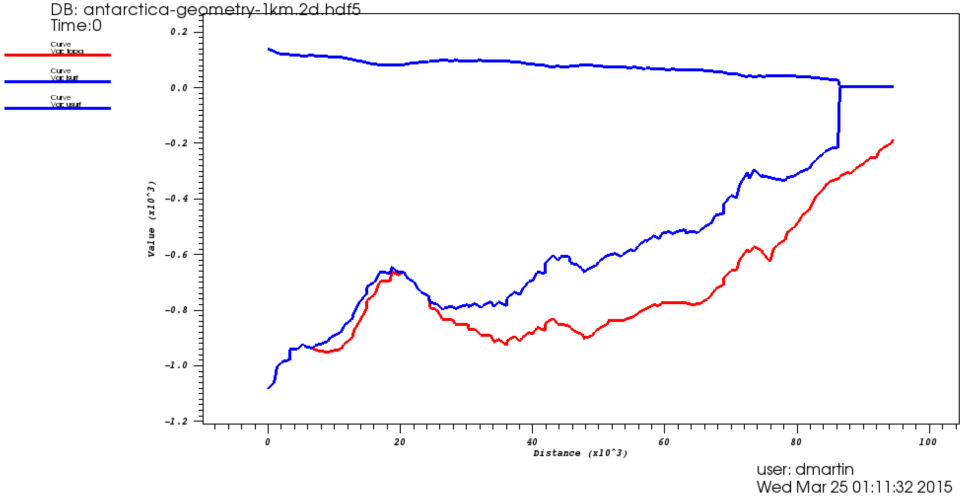
LETTERS
PUBLISHED ONLINE: 16 MARCH 2015 | DOI: 10.1038/NGEO2388
nature geoscience

Ocean access to a cavity beneath Totten Glacier in East Antarctica

J. S. Greenbaum[1]*, D. D. Blankenship[1], D. A. Young[1], T. G. Richter[1], J. L. Roberts[2,3], A. R. A. Aitken[4], B. Legresy[2,5,6], D. M. Schroeder[7], R. C. Warner[2,3], T. D. van Ommen[2,3] and M. J. Siegert[8]







Thank you!

CC BY

Extras

Computational Cost

CC BY

- 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

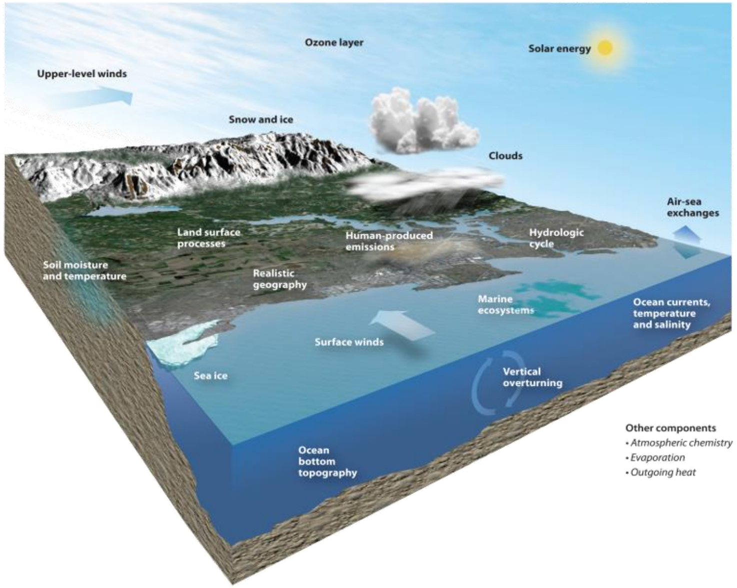
- Potentially large Antarctic contributions to SLR resulting from marine ice sheet instability, particularly from WAIS.

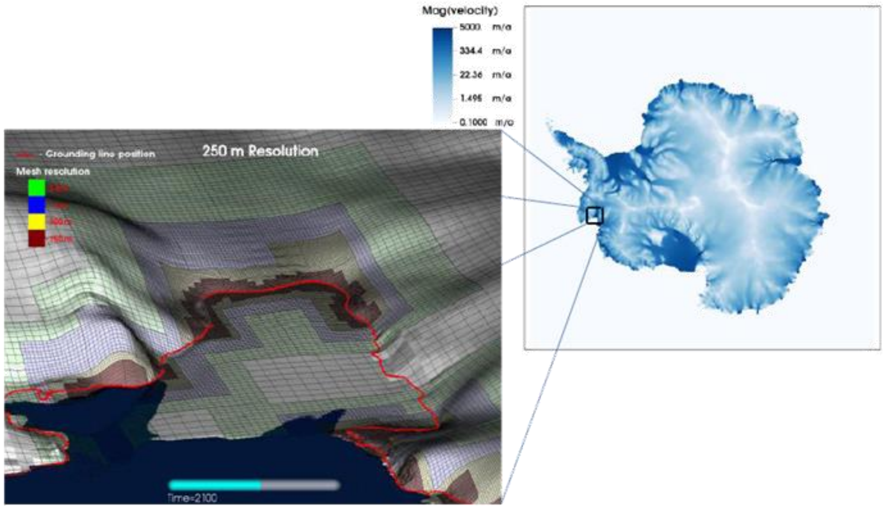
- Climate driver: subshelf melting driven by warm(ing) ocean water intruding into subshelf cavities.

- Paleorecord implies that WAIS has deglaciated in the past.

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 millennia

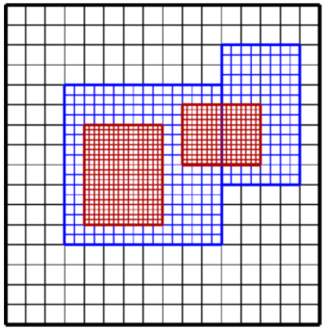




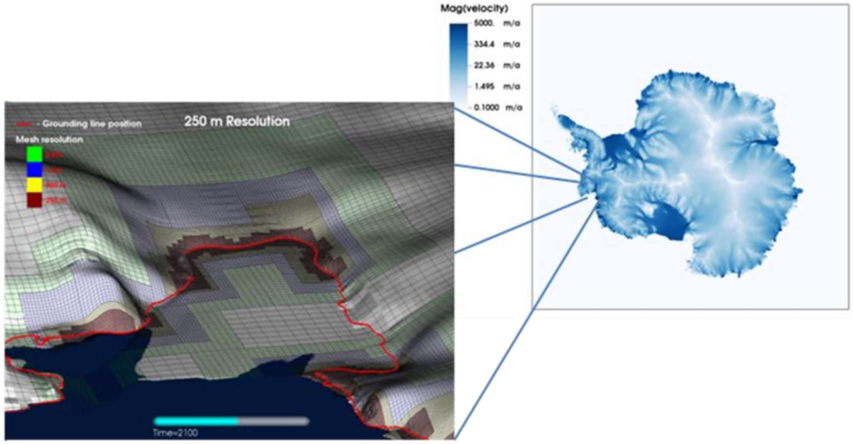
BISICLES Ice Sheet Model

cc BY

- 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)



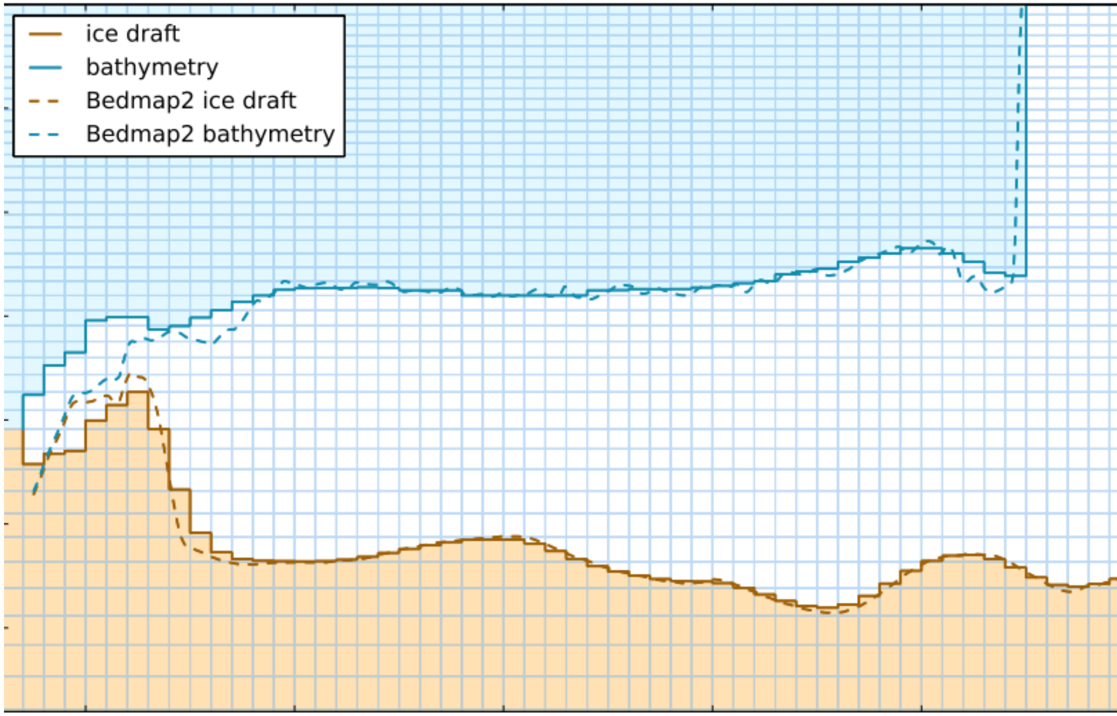
- Collaboration with Bristol (U.K.) and LANL
- Variant of "L1L2" model (Schoof and Hindmarsh, 2009)
- Coupled to Community Ice Sheet Model (CISM).
- Users in Berkeley, Bristol, Beijing, Brussels, and Berlin…



POP and Ice Shelves

cc BY

- 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



Issues emerging from 1st coupled Antarctic Runs

CC BY

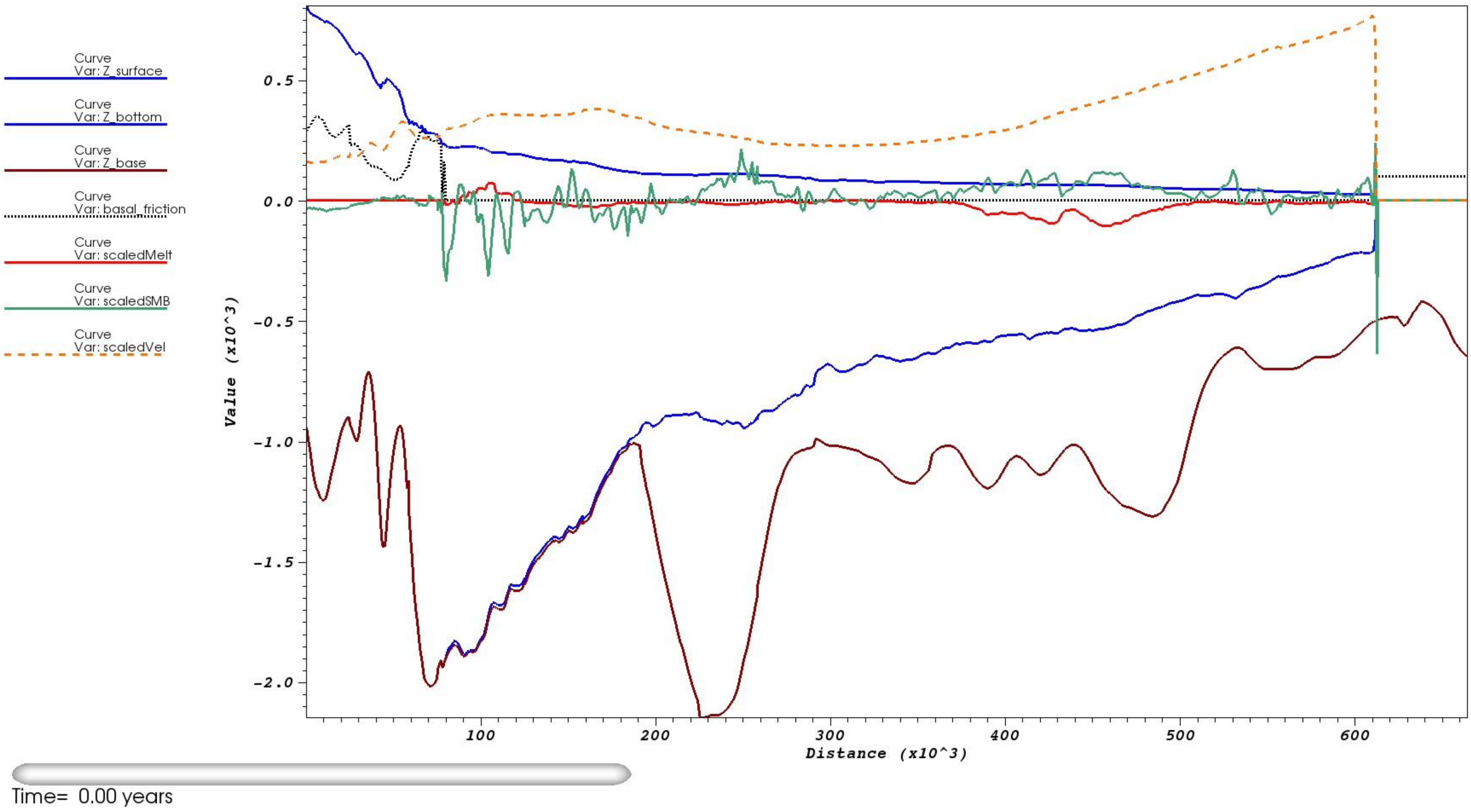
- Fixed POP error in freezing calculation.
  - (resulted in overestimated refreezing)

- **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

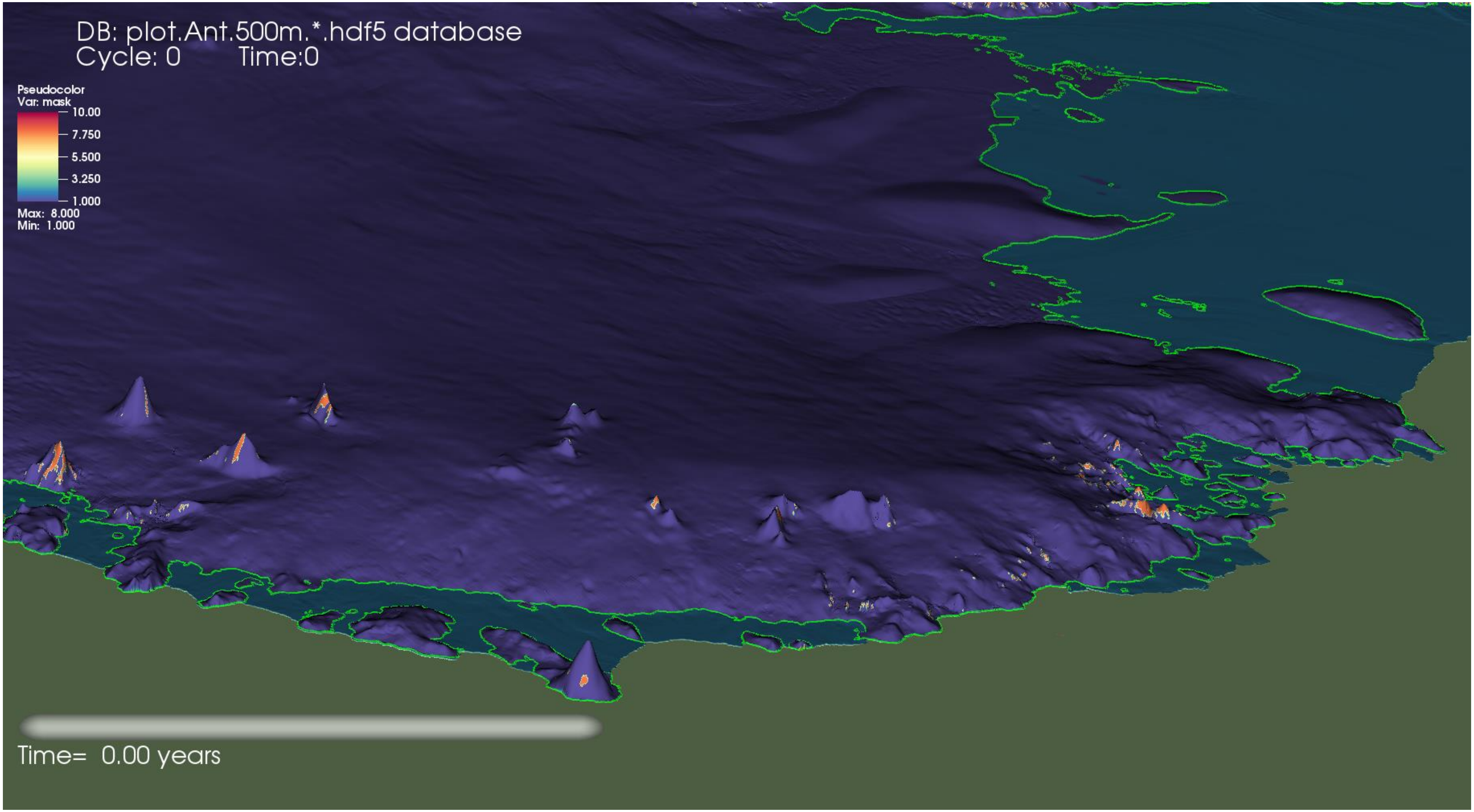
- **Need better initialization**

Warmwater incursion - Amery (cont)



U.S. DEPARTMENT OF ENERGY | Office of Science | BISICLES | Berkeley Lab | PIK | Los Alamos National Laboratory EST. 1943 | University of BRISTOL

Getz Ice Shelf – Regrounding Instability



Getz Ice shelf -- Regrounding instability