Simulations of Coupled, Antarctic, Ice-Ocean Evolution Using BISICLES and POP2x

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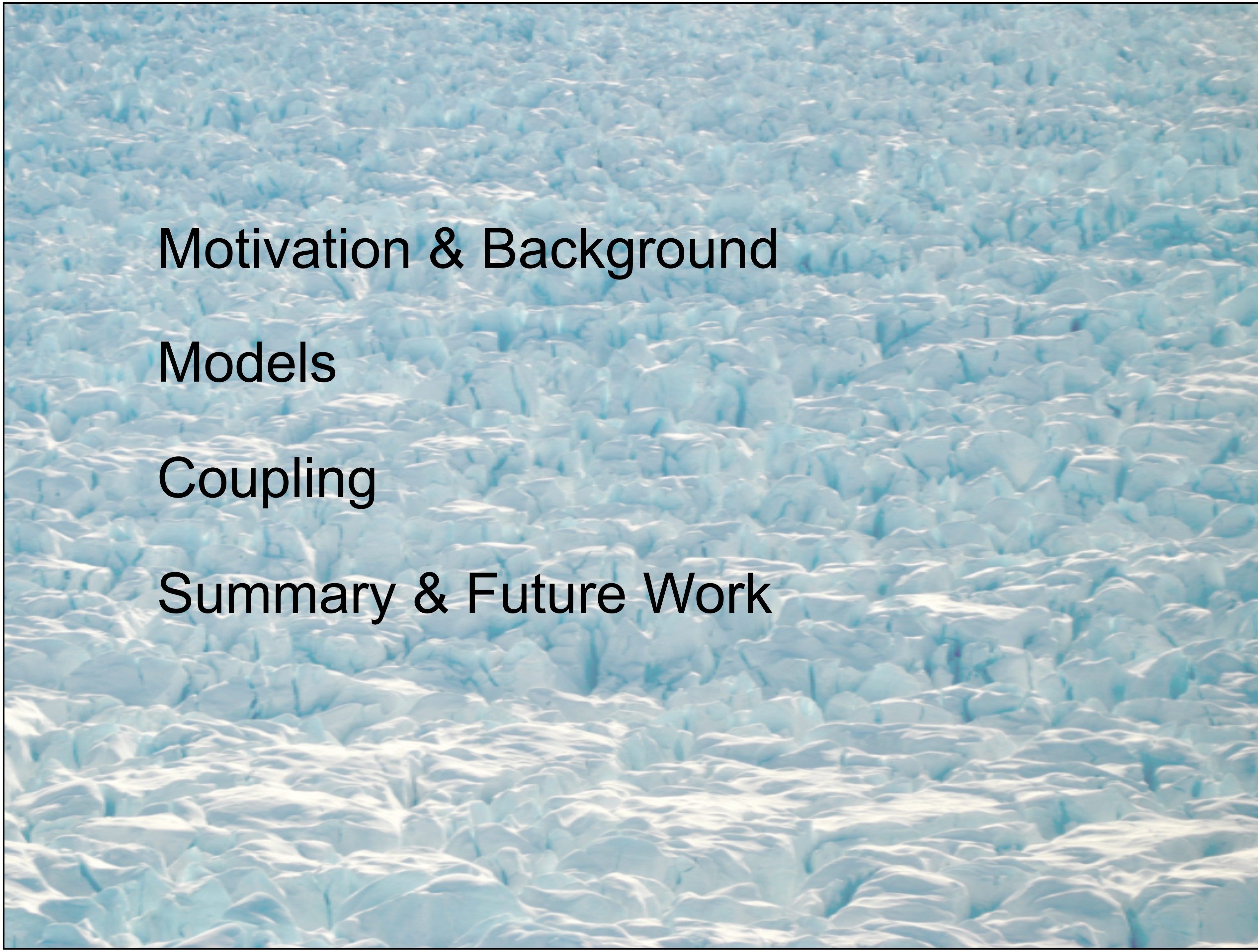

Motivation & Background

Models

Coupling

Summary & Future Work

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Motivation: Future Sea Level Rise (SLR)

Projections: For RCP8.5, [projected] global mean SLR for 2081–2100 (relative to 1986–2005) [is] 0.45–0.81 m … range at 2100 is 0.53–0.97 m

Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause [21^{st} century *SLR*] substantially above the likely range

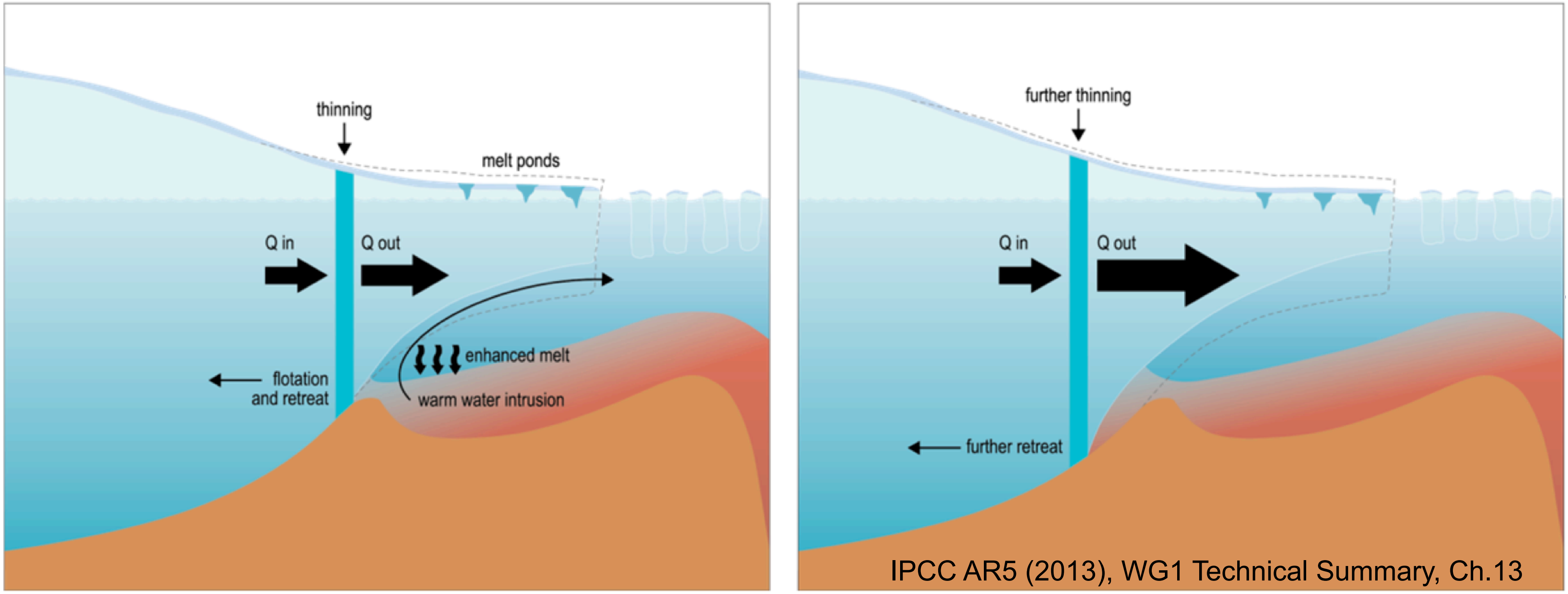
Paleorecord:

Pliocene warm intervals: CO_2 levels 250-400 ppm; temperatures 2°C to 3.5°C warmer than pre-industrial; records suggest deglaciation of West Antarctica and parts of East Antarctica *with global mean sea level not >20 m above present*

Last Interglacial: global temperatures were not more than 2°C above pre-industrial; global mean sea level at least 5 m higher than present; Greenland likely contributed 1.4 - 4.3 m*, implying a contribution from Antarctica*

IPCC AR5 (2013), WG1 Technical Summary

Motivation: Future Sea Level Rise (SLR)



IPCC AR5 (2013), WG1 Technical Summary, Ch.13

Observations and modeling argue for the importance of ice-ocean interactions in causing changes in submarine melt rates, with consequent dynamic ice sheet response, including grounding line retreat and increased mass flux to the oceans.[1, 2]

[1]Joughin & Alley (*Nat. Geosc.*, **4**, 2011) [2] Straneo et al. (*BAMS*, **94**, 2013)

Previous Work (mainly Antarctic)

*** Previous work exploring coupled ice-ocean evolution:

- idealized, stand-alone ocean modeling
- idealized, stand-along ice sheet modeling
- realistic, low / high res., stand-alone ocean modeling
- realistic, low / high res., stand-alone ice sheet modeling
- idealized, fully coupled ice-ocean modeling

Goal of current work: realistic, high resolution, fully coupled ice-ocean modeling

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- Ice Sheet Model: **BISICLES**

- Ocean Circulation Model: **POP2x**

Ice Sheet Model: BISICLES

"L1L2" momentum balance [1]

- formally 1st-order approximation to Stokes equations [2]
- velocities: 2d elliptic solve + SIA vertical column solve

Block-Structured AMR for improved accuracy in regions of dynamic complexity (e.g., grounding lines)

MISMIP3d [3] – demonstrates grounding line "reversibility" with results very similar to simulations using high-resolution Stokes [4]

Optimization on sliding param. & ice softness to match obs. vels.

Coupled to Community Ice Sheet Model (CISM)

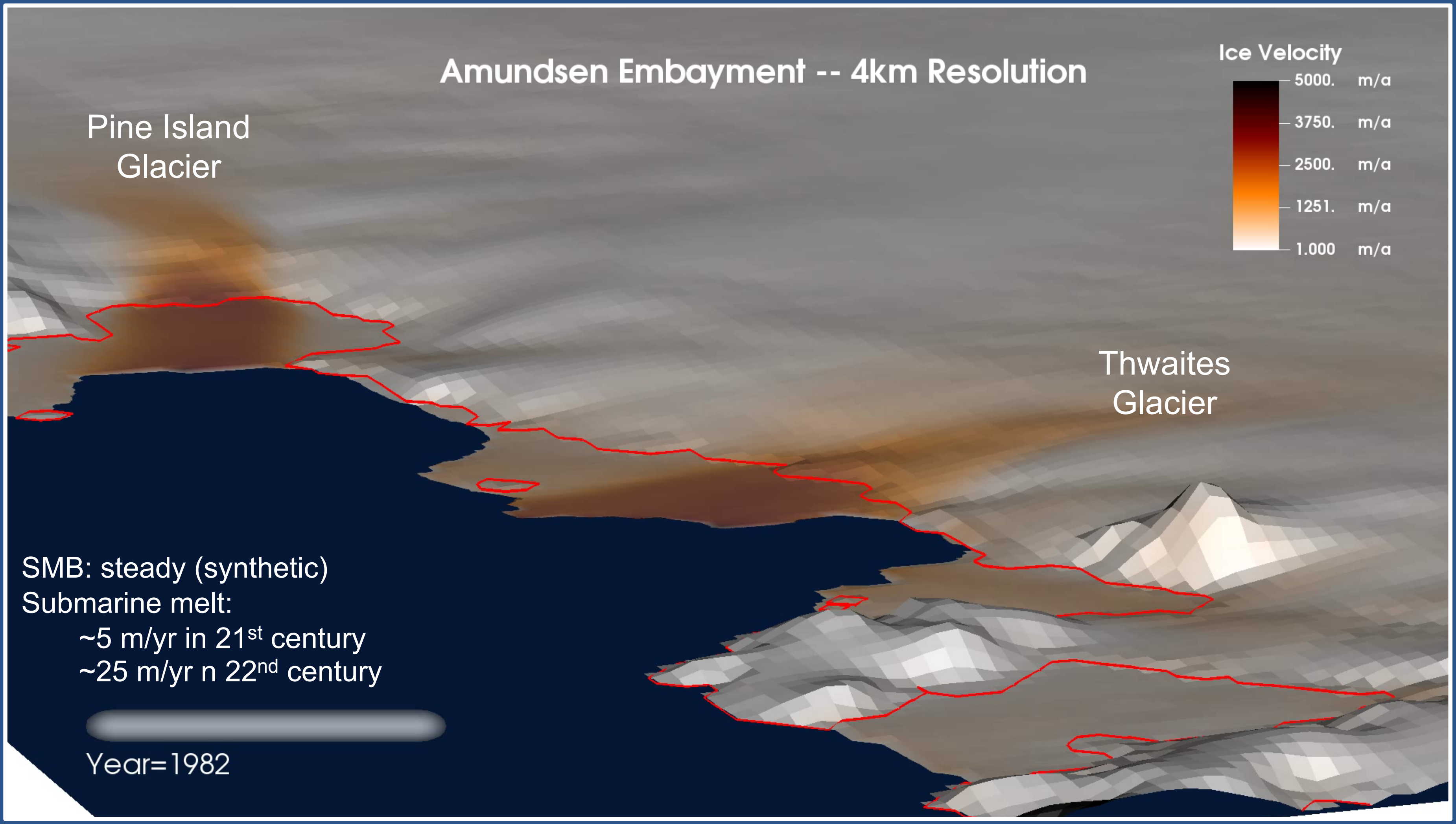
More detail in poster on Friday:

Modeling of the Cryosphere: Glaciers and Ice Sheets III

C53B-0583: *Fully resolved whole-continent Antarctica simulations using the BISICLES AMR ice sheet model* (D. Martin et al.)

[1]Cornford et al. (2012); [2]Schoof and Hindmarsh (2010); [3]Pattyn et al. (2013); [4]Pattyn & Durand (2013)

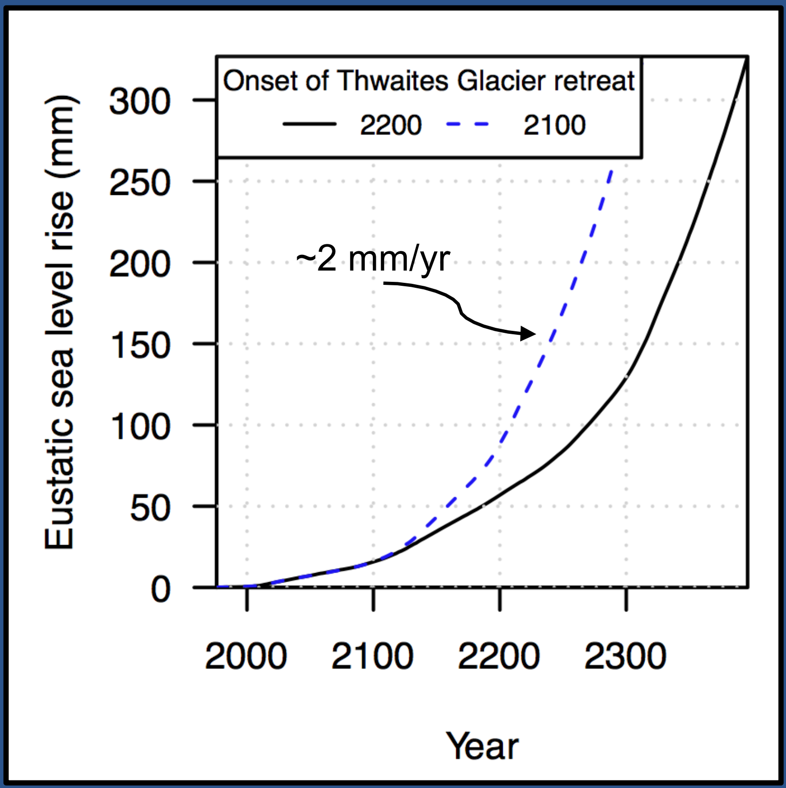
Amundsen Sea Embayment Simulation

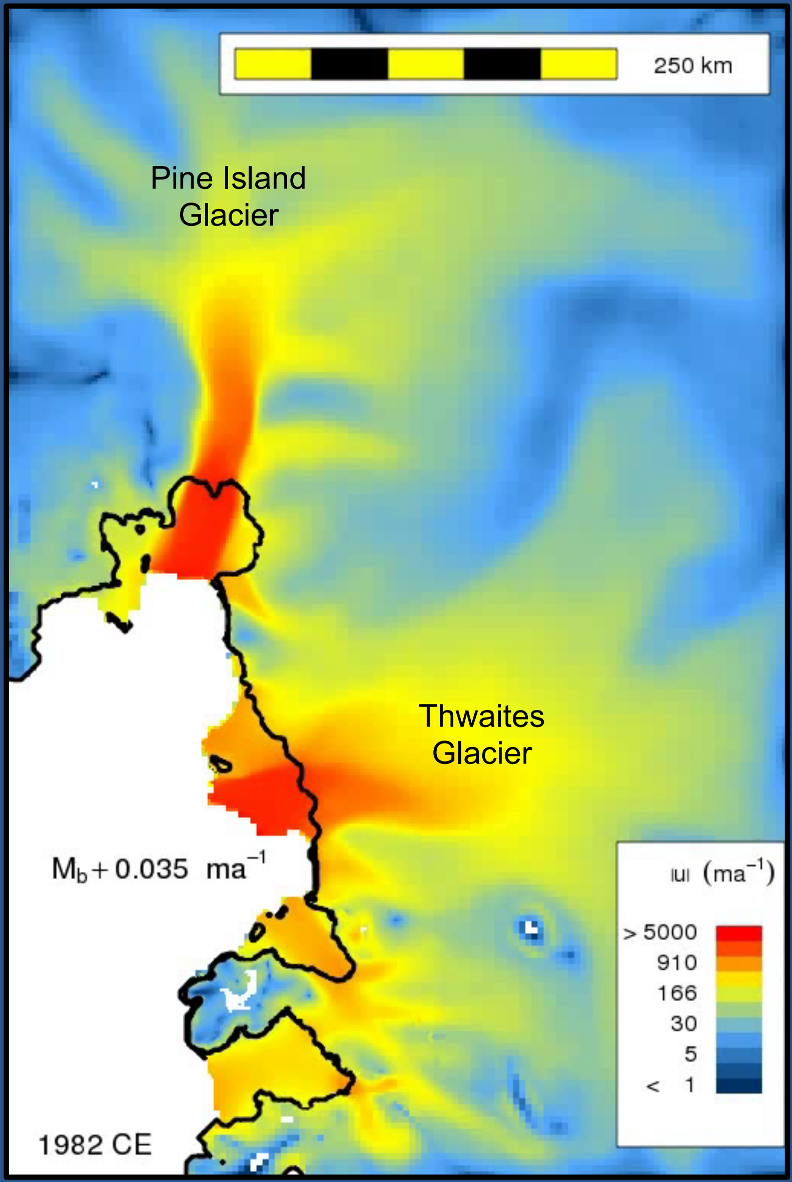


Movies courtesy of S. Cornford and D. Martin

Amundsen Sea Embayment Simulation

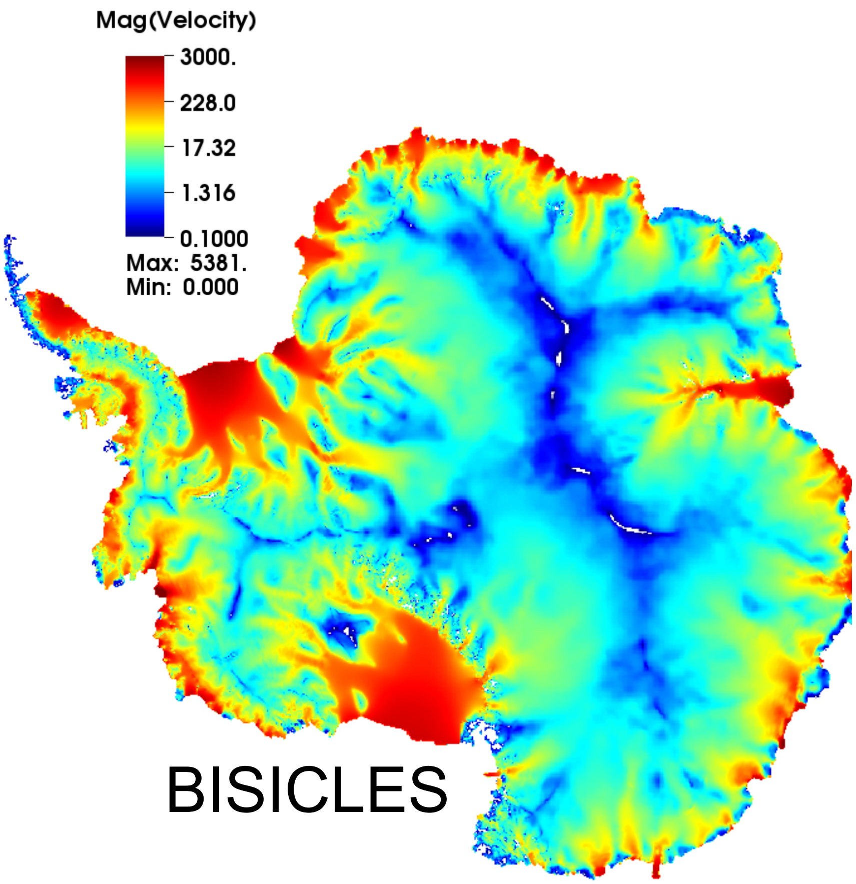
- Same forcing as previous run with submarine melting constant after 2200
- In +400 yr run, Thwaites fairly stable (until it's not)



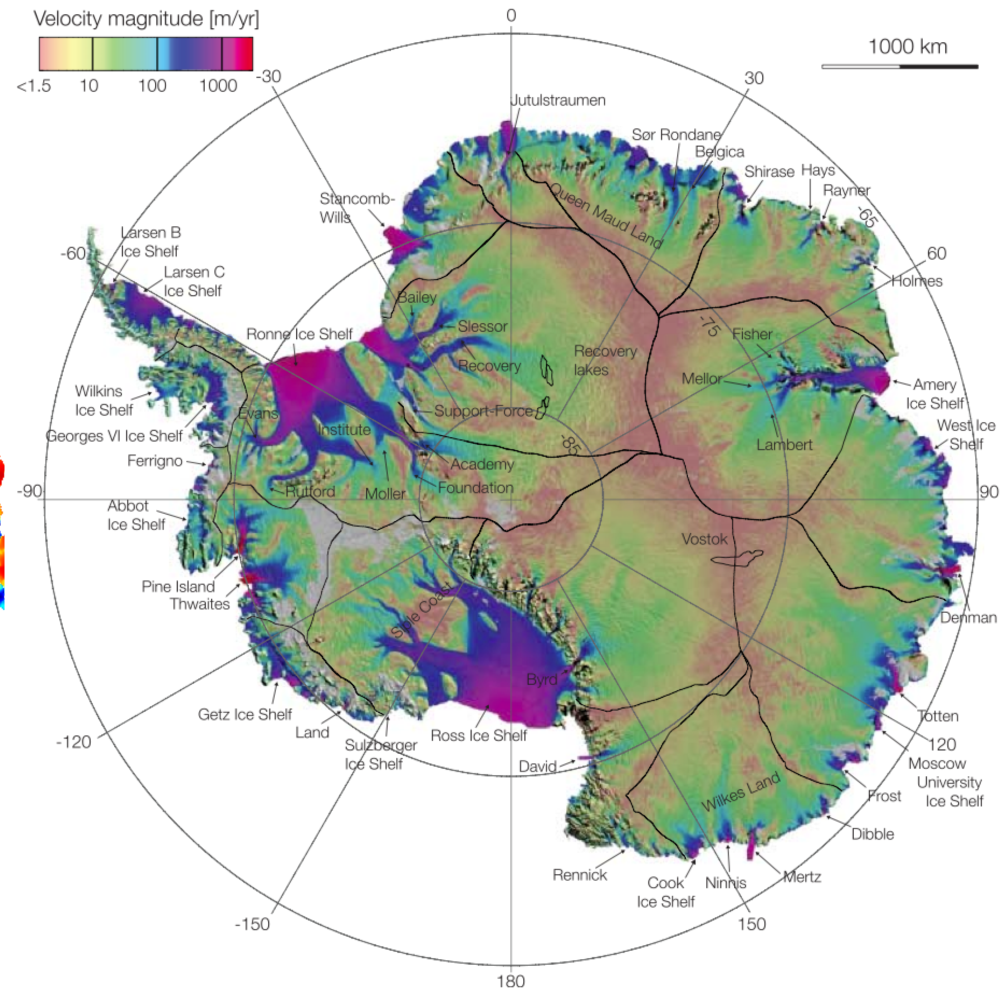


Movies courtesy of S. Cornford and D. Martin

Whole Antarctic Ice Sheet Simulations



- base level res. of 5 km, refinement to 625 m -



(courtesy of D. Martin & S. Cornford)

Rignot et al., *Science*, **333** (2011)

Ocean Model: POP2x

- POP2 = **P**arallel **O**cean **P**rogram version 2 (hydrostatic, Boussinesq, primitive equations)[1]
- z-level vertical coordinate, partial bottom cells
- "x" = eXtended to include ice shelf cavity circulation using partial top cells[2]
- sub-shelf mixed layer thickness = dz (vert. mixing scheme[2], not physics based)
- For idealized experiments[2], sub-shelf circulation in POP2x compares very well with previously published results

[1]Smith et al., (2010); [2]Losch (2008)

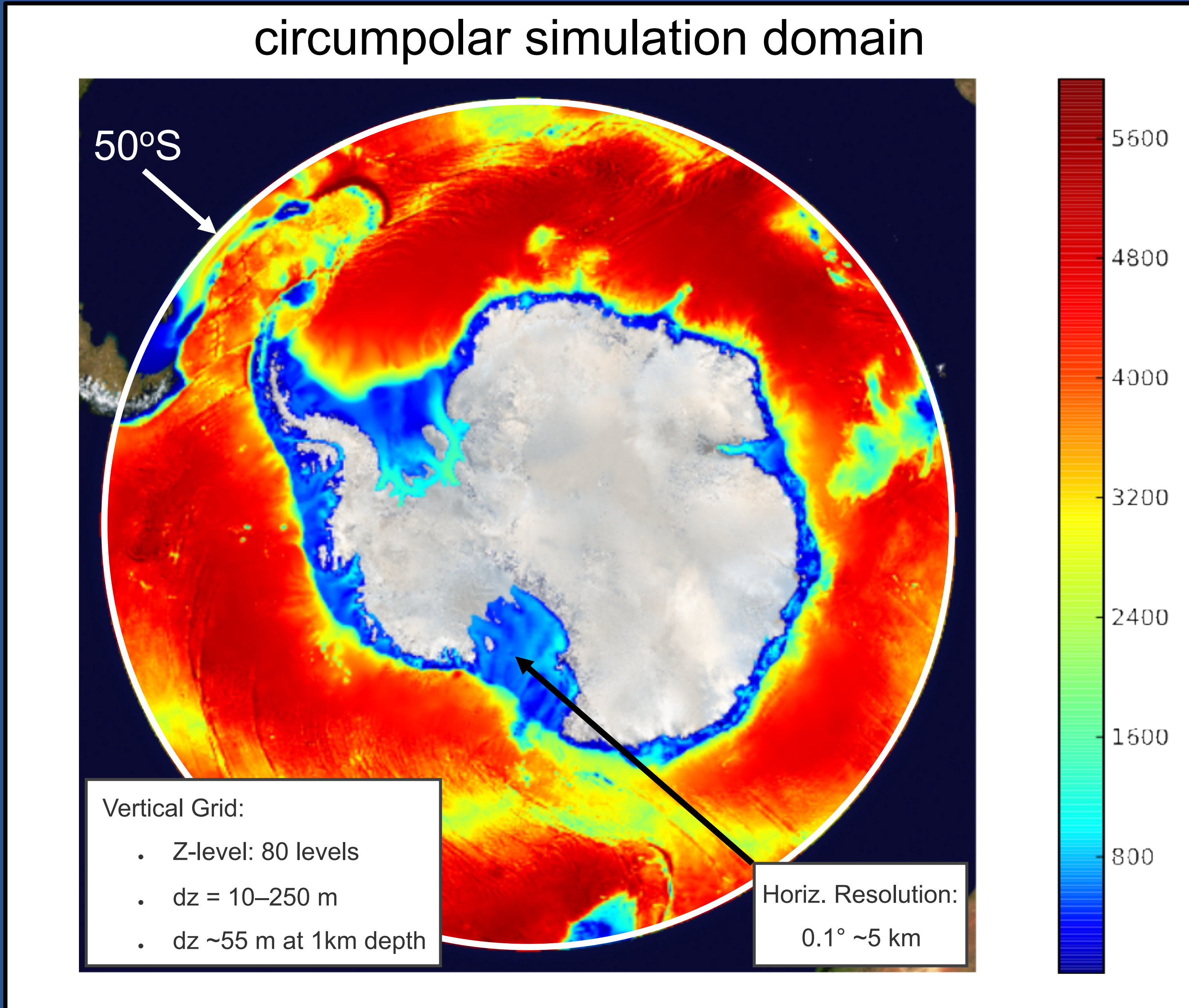
POP2x: realistic experiments (uncoupled)

Experimental Setup:

- hi-res (eddying) ocean model with circulation under static ice shelves
- regional southern ocean domain (50-90 deg. south)
- ~5 km horiz. res. near ice shelves of interest
- "Normal Year"[1] forcing with monthly restoring to WOA data at northern boundaries
- bathymetry and ice draft from Bedmap2 [2]

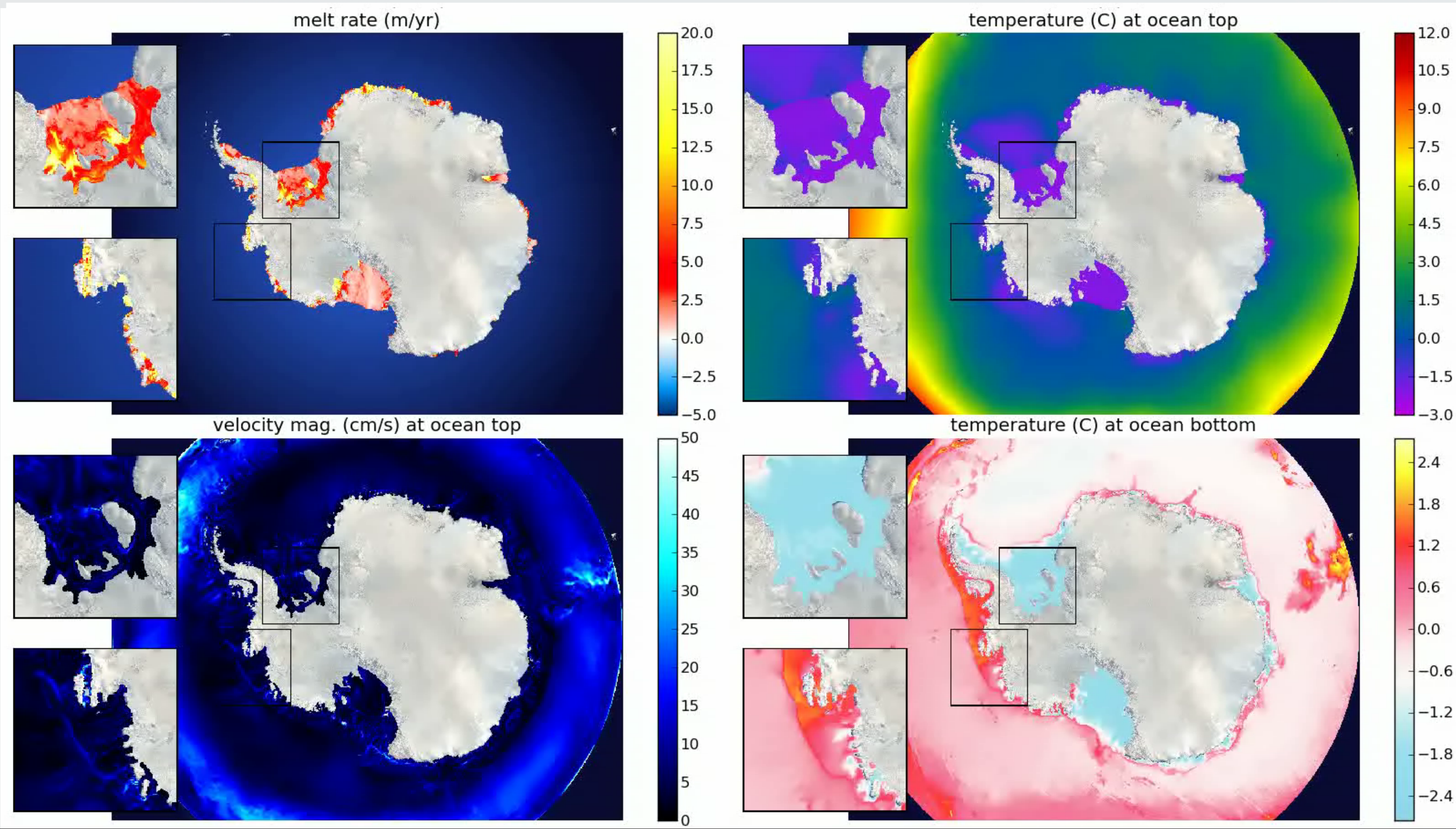
[1]Large and Yeager (2008); [2]Fretwell et al. (2013)

POP2x: realistic experiments (uncoupled)



POP2x: realistic experiments (uncoupled)

Monthly Core2 *Normal Year* atmospheric and sea-ice forcing
World Ocean Atlas initial condition/boundary restoring



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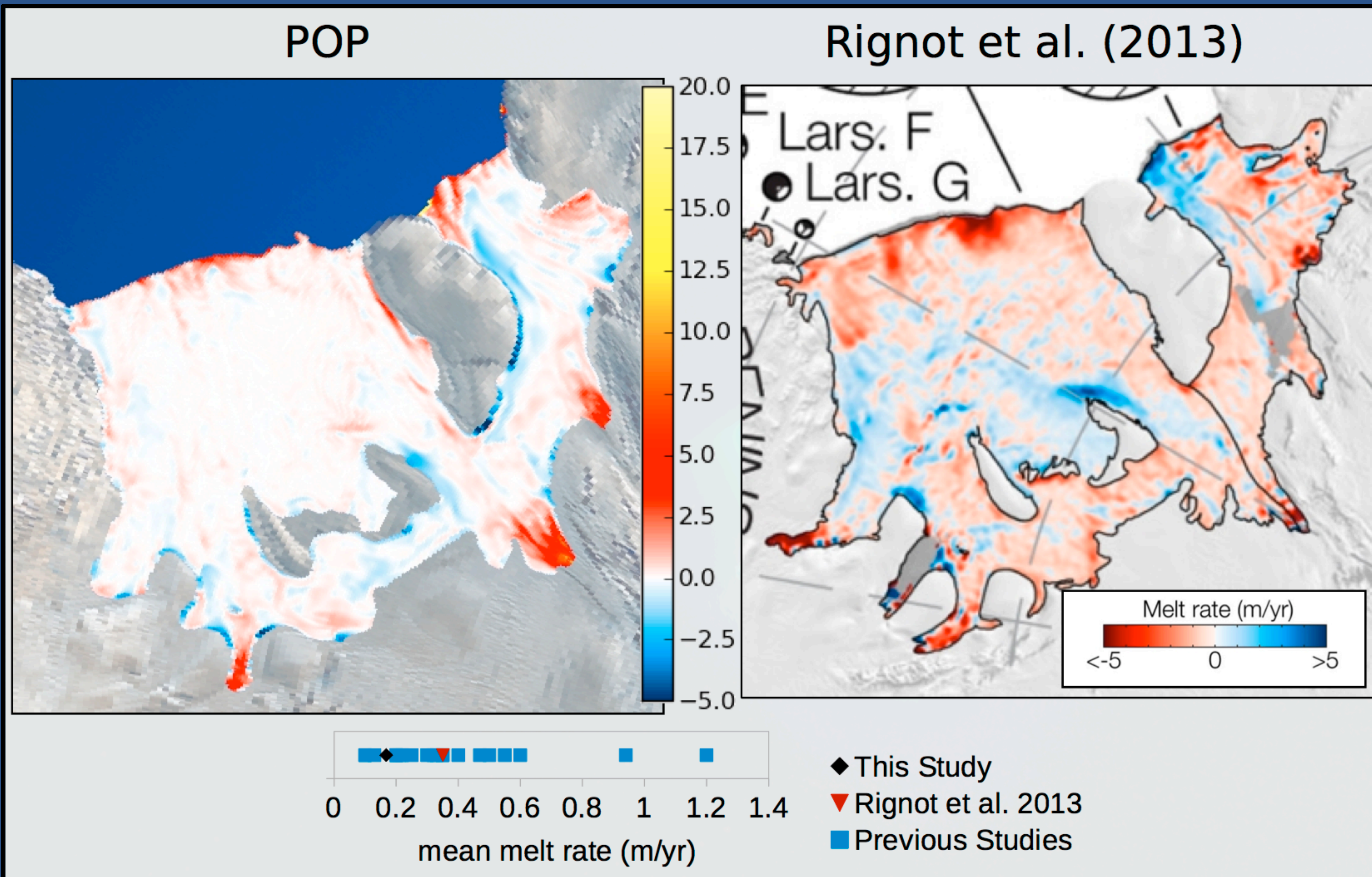

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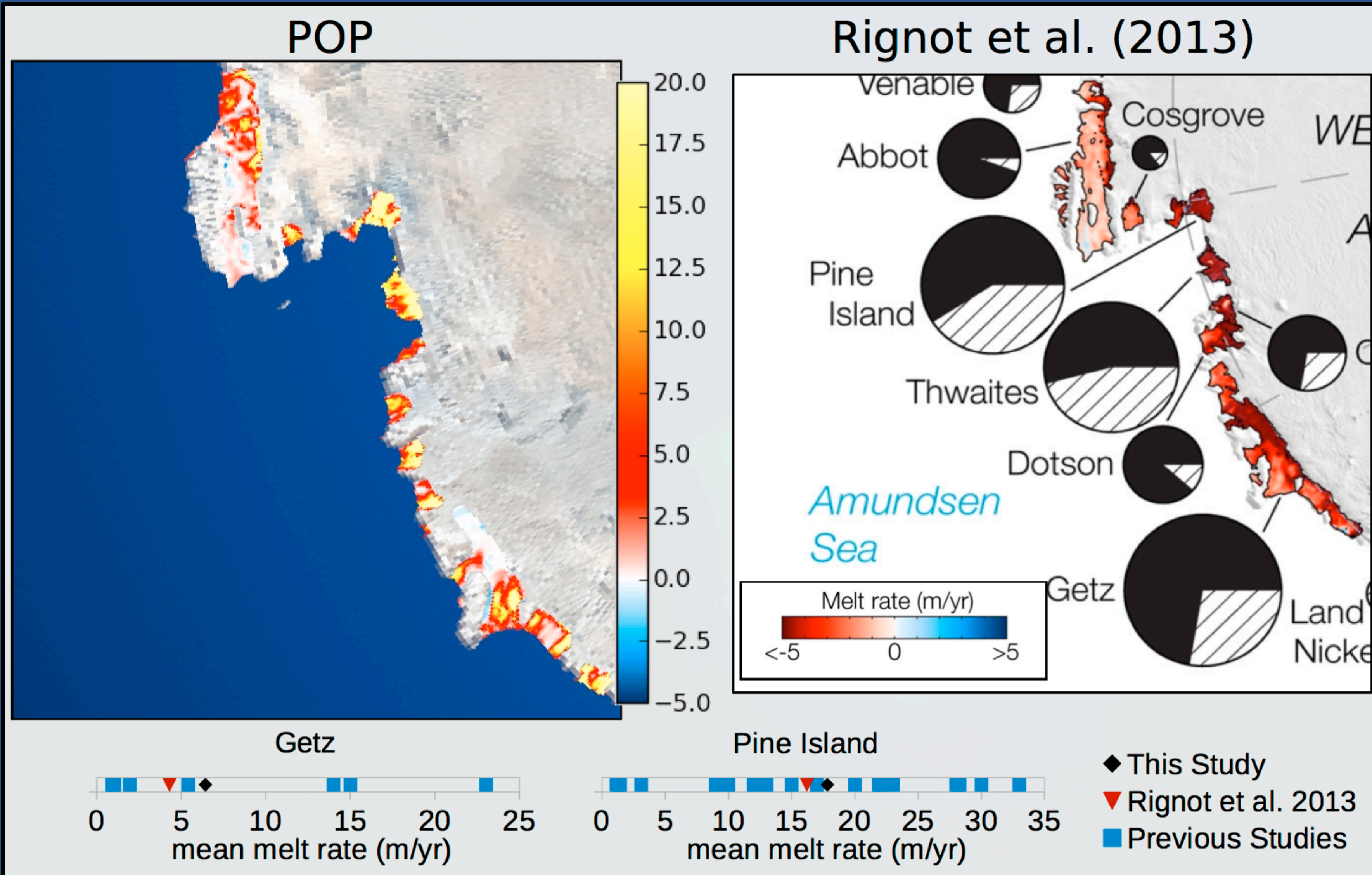

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Coupling: Asynchronous[1]

Assumes that relevant $dt_{ice\_sheet} >> dt_{ocean}$ such that sub-shelf circulation is always in quasi-equilib. with ice sheet forcing

Coupling time step ~ ice sheet evolution time step

BISICLES → POP2x:

- ice draft
- basal temperatures
- grounding line location

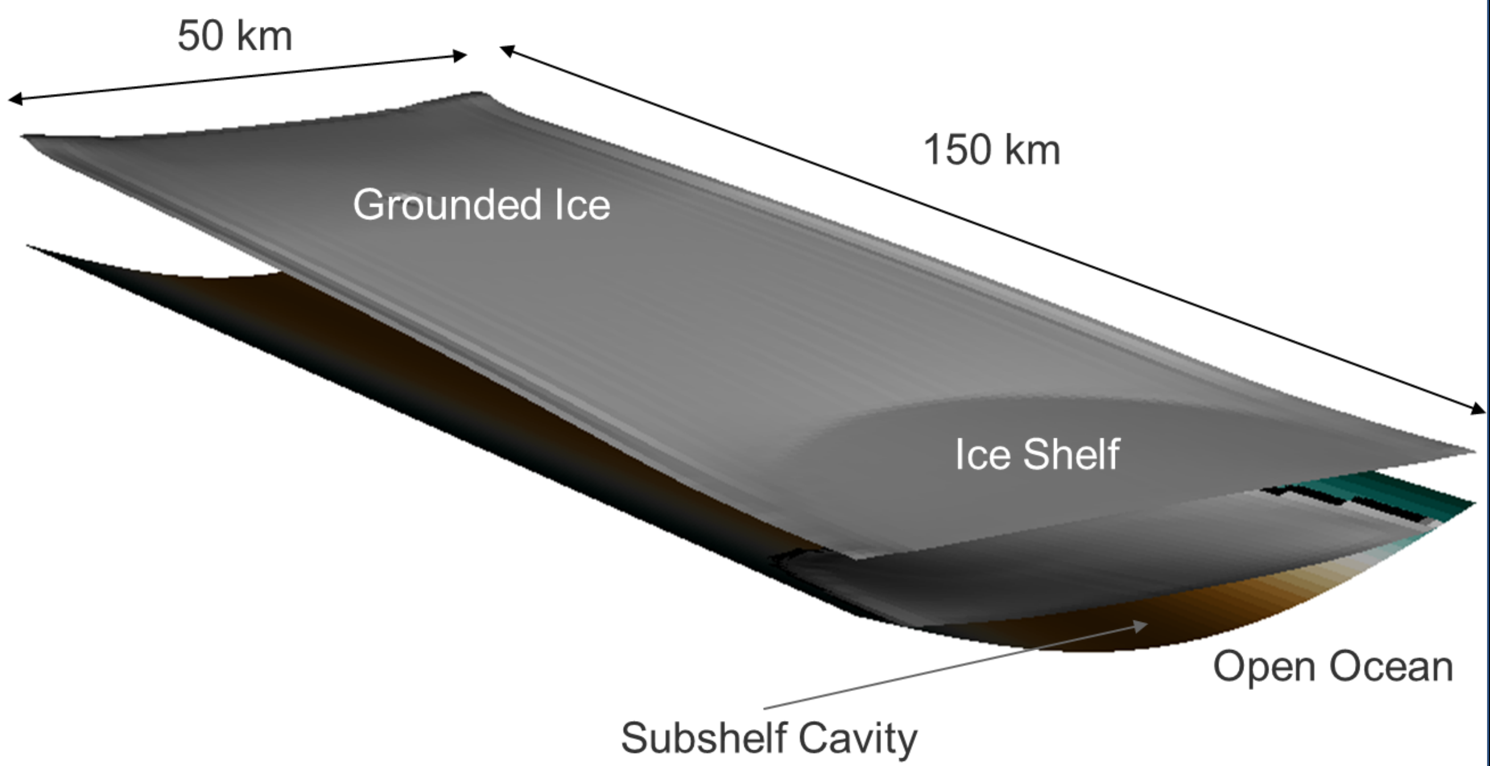
POP2x → BISICLES:

- time averaged sub-shelf melt rates

Coupling offline using standard CISM and POP netCDF I / O

[1]Goldberg et al. (2012)

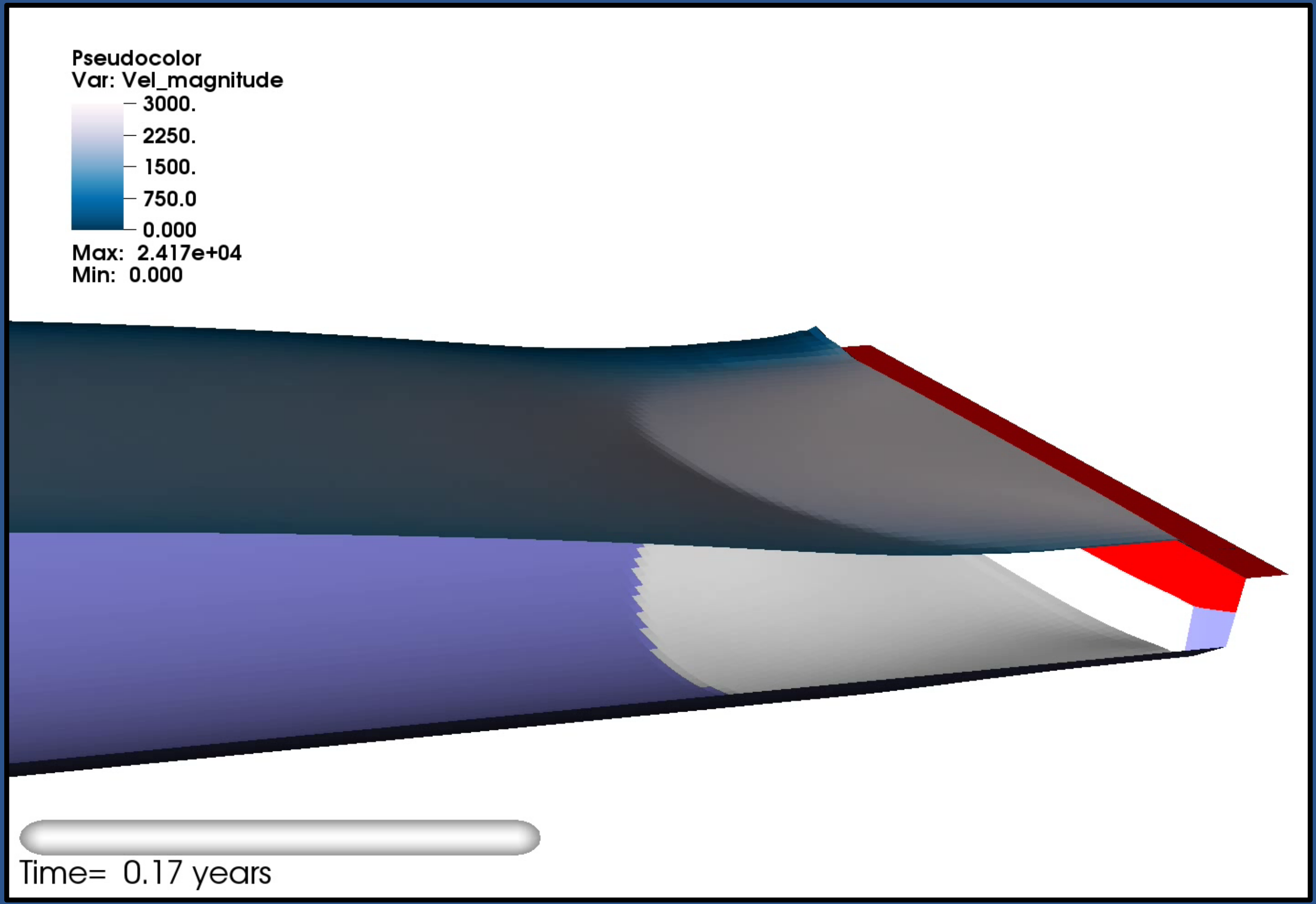
BISICLES + POP2x: coupled, idealized experiments



[1]Goldberg et al. (2012)

- Idealized domain[1]
- Forcing = strong restoring to init. T,S profile at cavity front (every ~15 min)
- Ice sheet resolved to sub-km resolution

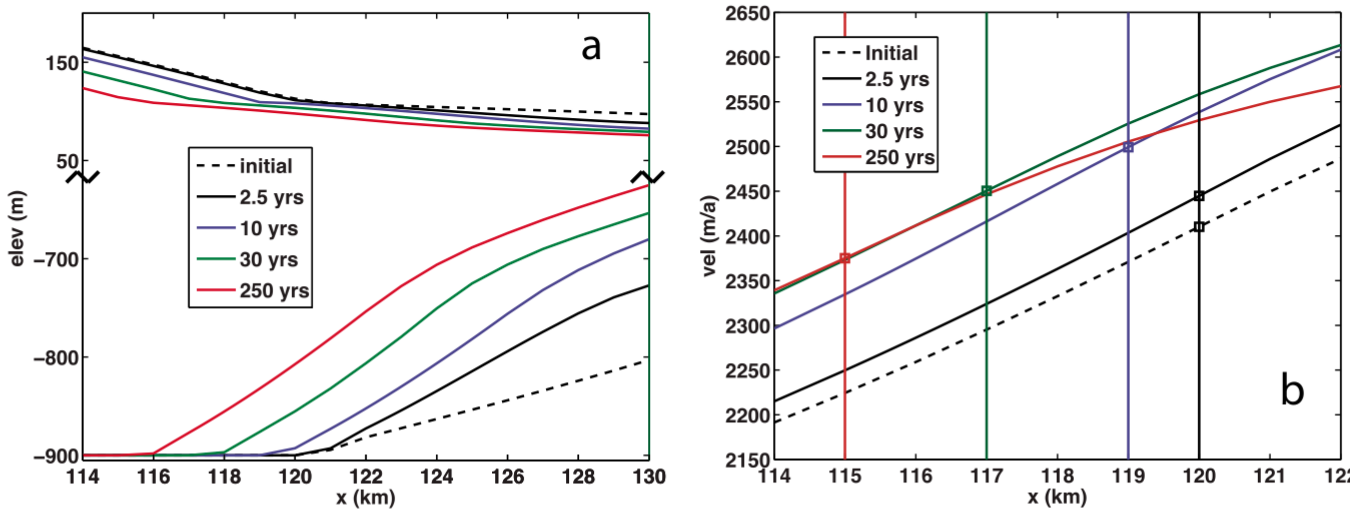
BISICLES + POP2x: coupled, idealized experiments



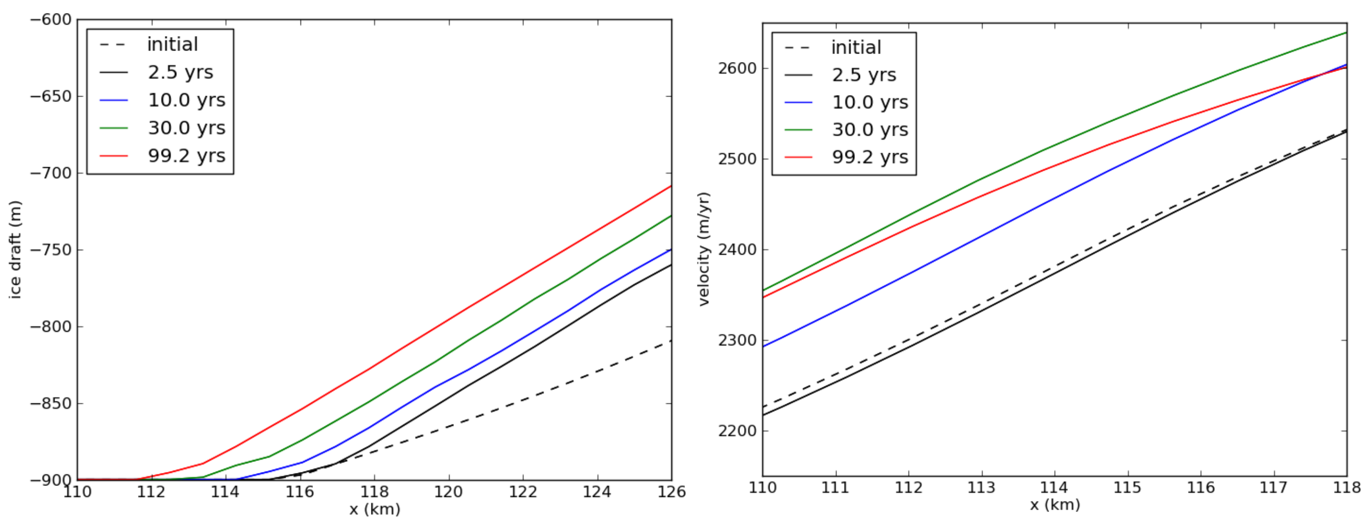
This study vs. Goldberg et al. (2012):

- z-level with 60 layers vs. 4 layer isopycnal model (our melt rates are sensitive to no. of layers)
- 1 month ocean spin-up vs. 5 days
- averaging melt over 1 ocean month vs. 10 days
- 60 day ice-sheet time steps (coupling interval) vs. 30 days (tried 15 days to 2 yrs)

BISICLES + POP2x: coupled, idealized experiments



Ice shelf base profiles, $z_b(t)$ Centerline velocity profiles (m/yr)



BISICLES + POP2x: coupled, realistic experiments

Offline ice-ocean coupling time step once per year:

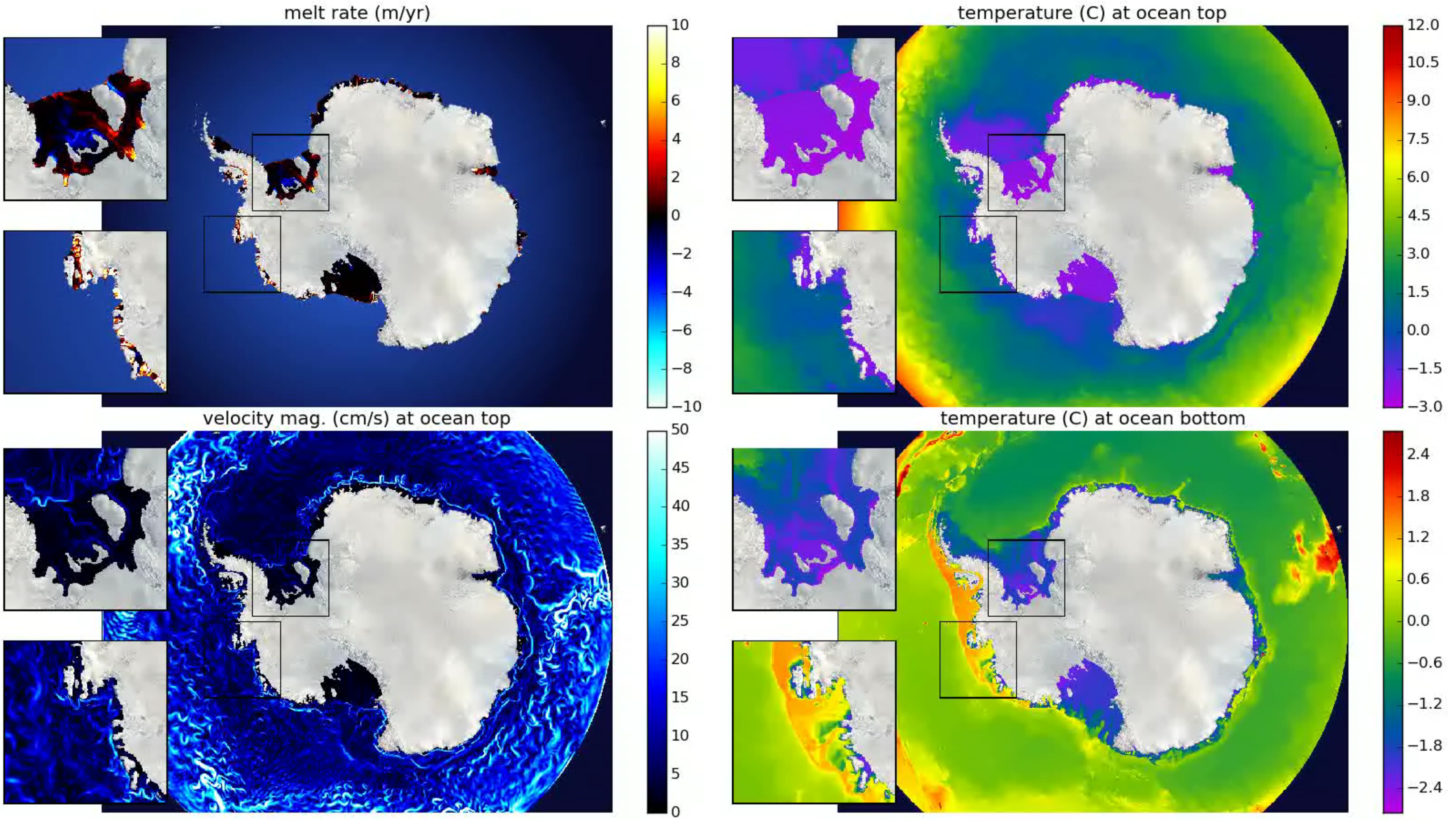
- re-grid / filter ocean geom. after shelf geom. change
- ++run 2 months of ocean model spin-up
- **run additional 1 yr of ocean model
- average 1 yr of melt rates (minus 2 month spin-up) and pass to ice sheet model
- time step ice sheet model (with sub-shelf melt)

Notes:

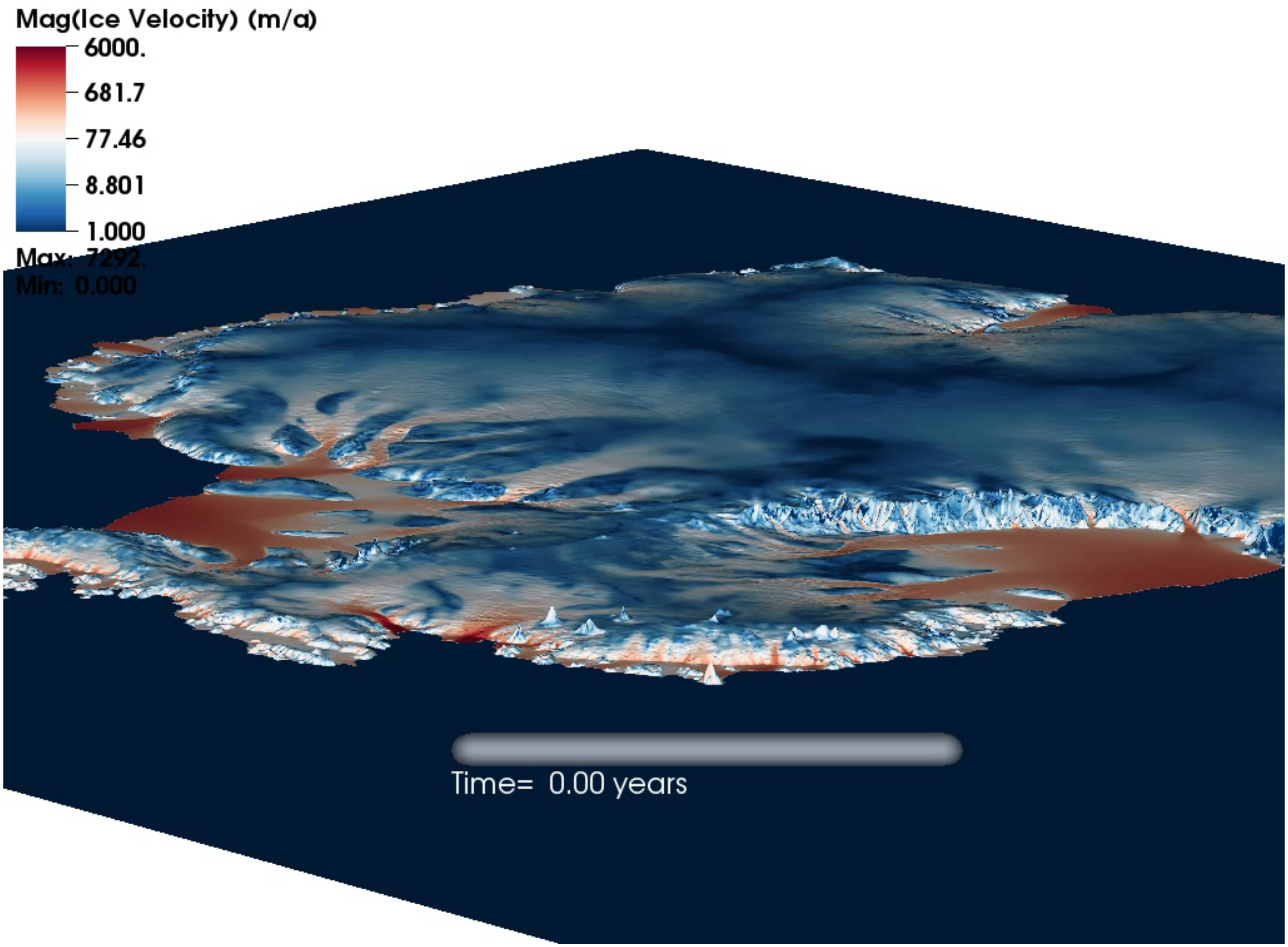
++ baratropic mode initialization difficult with anything other than model at rest and sea-surface height = 0

** 1 yr coupling freq. is somewhat arbitrary initial choice, but supported by results (in general, no large, unrealistic changes in ice geometry)

BISICLES + POP2x: coupled, realistic experiments (8 yrs)



BISICLES + POP2x: coupled, realistic experiments (8 yrs)



Summary & Future Work

High-resolution, whole-Antarctic forward model integrations with realistic, large-scale ocean-model forcing are stable on decadal (to century?) timescales

Future work will focus on:

- Correcting ocean-model biases
- Validation of ice sheet, ocean, and coupled model output
- Coupled, forward model integrations under range of RCPs
- Static shelf coupling in CESM? (active ocean + data ice sheet)
- Development of ice-ocean coupling capability in MPAS-Ocean

See Friday Poster:

C52B-0582, *Simulating Land Ice Evolution within the MPAS Climate Modeling Framework*, S. Price et al.