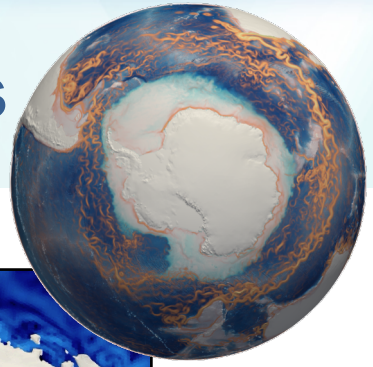
Cryosphere Campaign – Phase 2 Status



Stephen Price, Wuyin Lin, Mark Petersen, and the E3SM Cryosphere Team

High-res. E3SM simulation with ocean circulation in sub-ice shelf cavities

Science Questions

What are the impacts of ocean-ice shelf interactions on melting of the Antarctic Ice Sheet, the global climate, and sea level rise? [using V1 model]

How will the atmosphere, ocean and sea-ice systems mediate sources of sea-level rise from the Antarctic ice sheet over the next 30 years? [using V2 model]

V1 Science Question

What are the impacts of ocean-ice shelf interactions on melting of the Antarctic Ice Sheet, the global climate, and sea level rise?

Status:

- demonstrate century-scale, stable, realistic Antarctic ice shelf melt rates in global, fully coupled, low-res. configuration (Comeau et al., *in prep.*)
- exploration and demonstration of impacts of including explicit sub-shelf melt rates on S. Ocean climate (Jeong et al., *J. Climate*, 2020)
- identification / confirmation of "tipping points" in sub-shelf circulation and melting that would have significant impacts on Antarctic-sourced SLR and global climate (~10x increase in sub-shelf melt rates and S. Ocean freshwater flux; Hoffman et al., *in prep.*)
- exploration of the impacts of S. Ocean climate variability on sea-level rise from Thwaites Glacier (Hoffman et al., *JGR Earth Surf.*, 2019)
- analysis of V1 atmos. polar climate (Lee et al., *Earth Space Sci.*, 2019; *Clim. Dyn.*, 2020)
- S. Ocean climate improvements in high-res. E3SM v1 (Jeong et al., *J. Climate*, in review)
- identification of critical ocean param. improvements needed for obtaining reasonable S. Ocean climate in E3SM v1 (Comeau et al., *in prep.*)

V1 Simulation Campaign

Table 3. E3SM v1 Cryosphere experiment: Planned simulations.

Simulation	Atmos (km)	Ocean (km)	Simulated Years	Notes
Pre-industrial (1850) control with ice cavities	100	30-60	250	Water Cycle Experiment is the control. Single member -- branched at year 250 from water cycle simulation.
Historical transient (1850-2014) with ice cavities	100	30-60	175	Water Cycle Experiment is the control. Single member. Continuation of Pre-industrial (1850) control with ice cavities.
Abrupt 4xCO2 with ice cavities	100	30-60	150	Water Cycle Experiment is the control. Single member. Continuation of Pre-industrial (1850) control with ice cavities
CORE-II w/ and w/o ice cavities	data	6-18	50	The standard high-resolution ocean mesh.
CORE-II w/ and w/o ice cavities	data	6-60	300	Variable resolution ocean simulation utilizing the low-resolution ocean mesh northward of 20S and tapering to the RRS southward of 20S.

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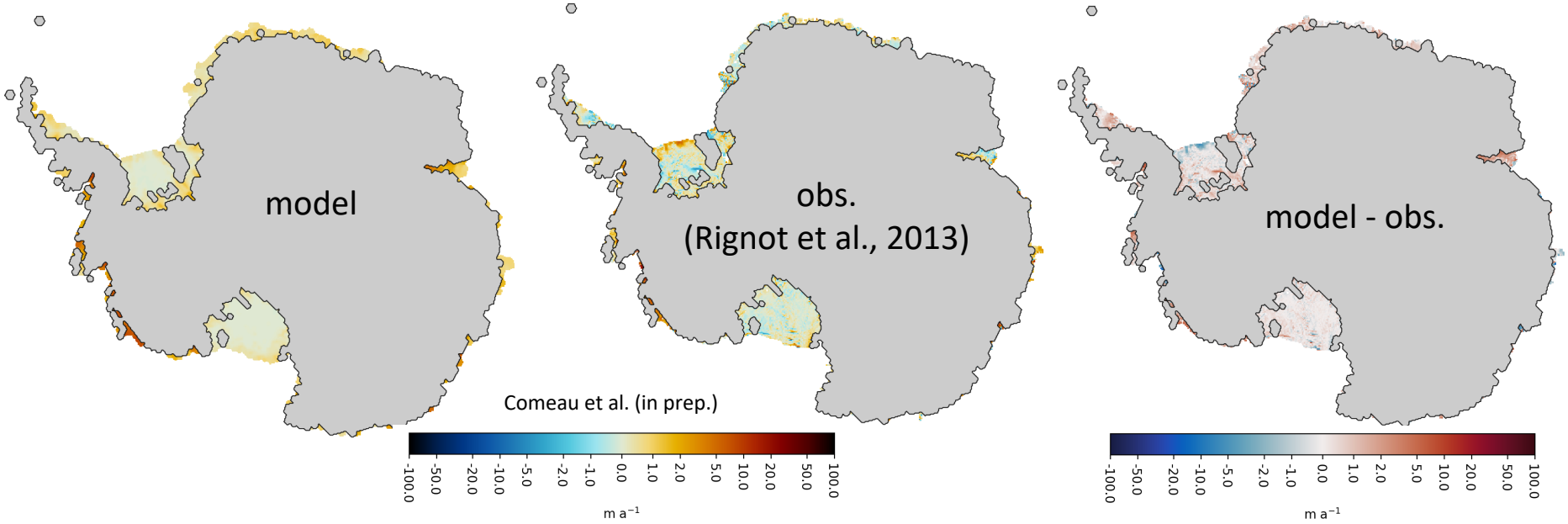
majority of effort spent on stable, realistic, coupled-model simulation under PI forcing

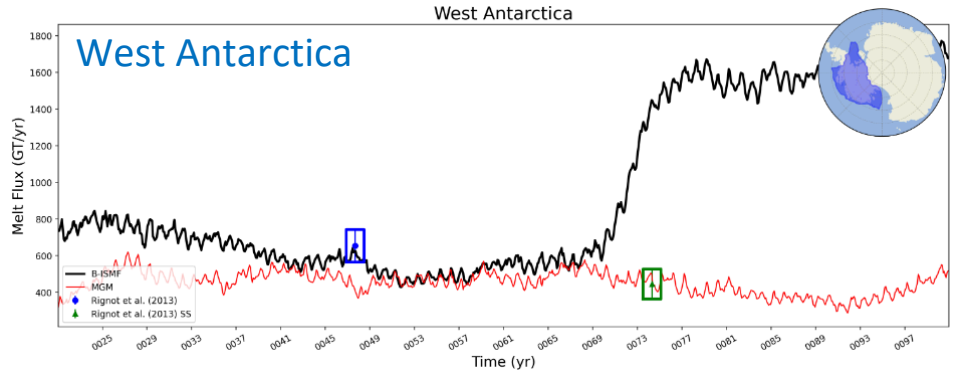
V1 Results: standard resolution configuration

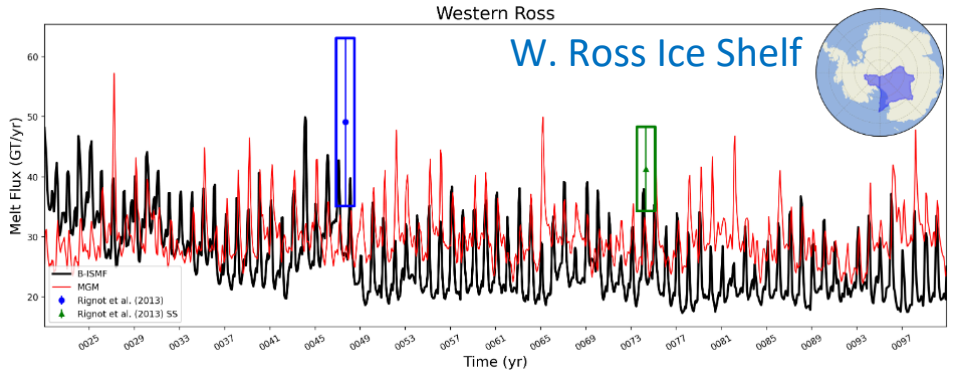
- 60 km res. at mid. lats.; 30 km res. at high lats. (GM eddy closure)
- ocean circulation and freshwater / heat fluxes exchanged in (fixed) Antarctic ice shelf cavities
- data iceberg climatology for Southern Ocean (Merino et al. 2016)
- global, coupled (active atmos., ocean, sea ice), pre-industrial forcing

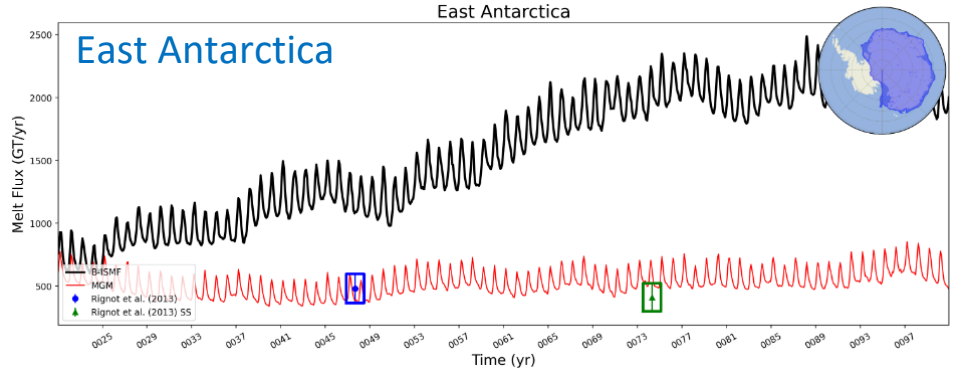


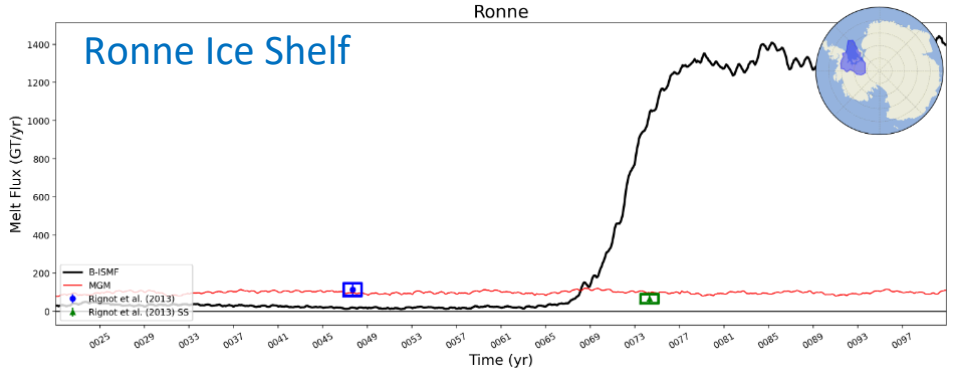
*** see *Comeau et al.* poster #1; *Lin et al.* poster (PS1, Tues. afternoon) ***

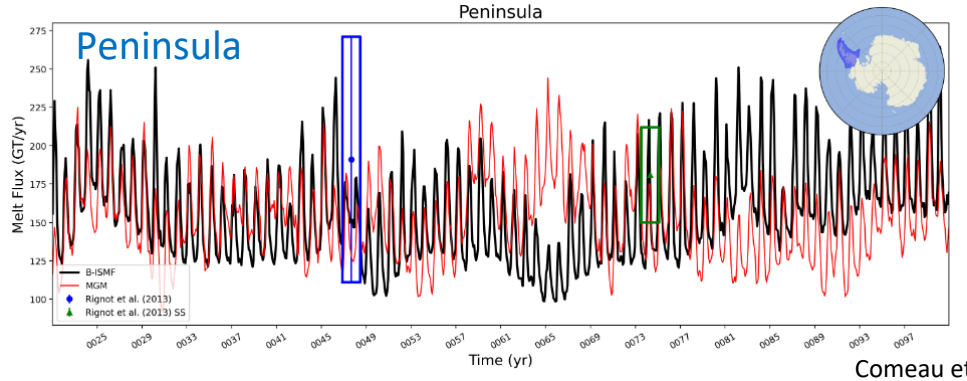
V1 Results: simulated sub-ice shelf melt rates

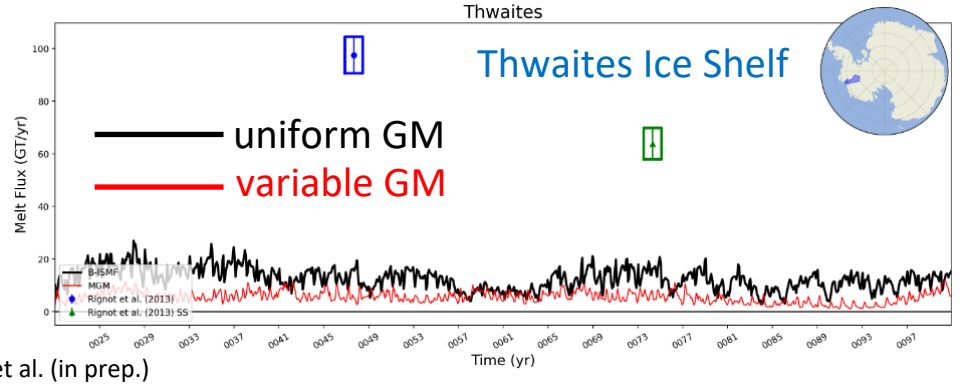








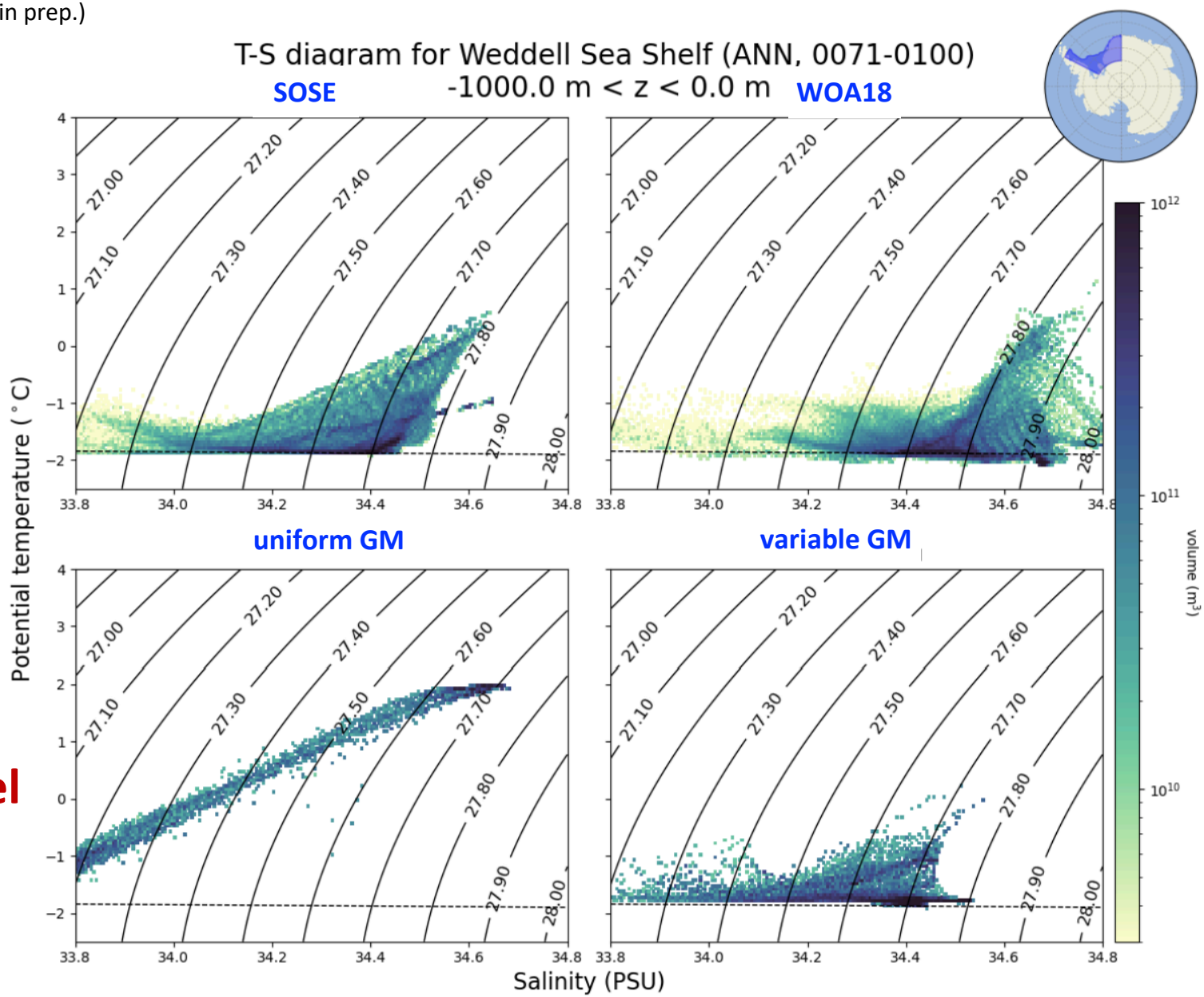




Comeau et al. (in prep.)

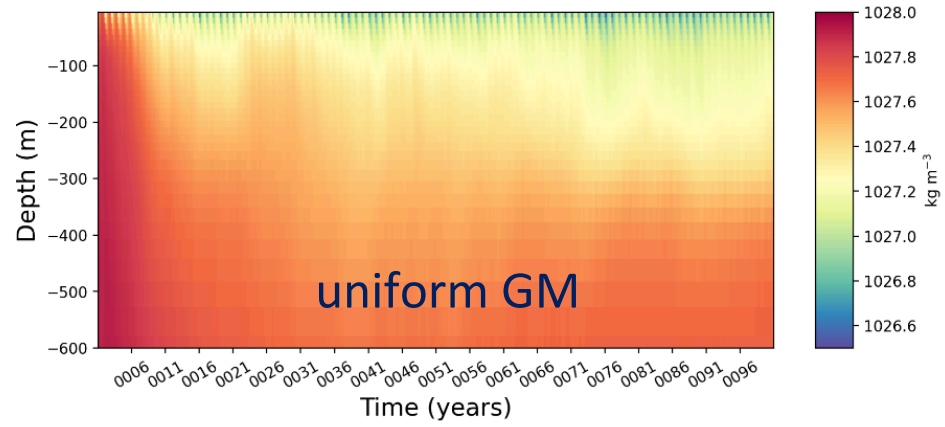
Weddell Sea Shelf T, S, rho

Comeau et al. (in prep.)

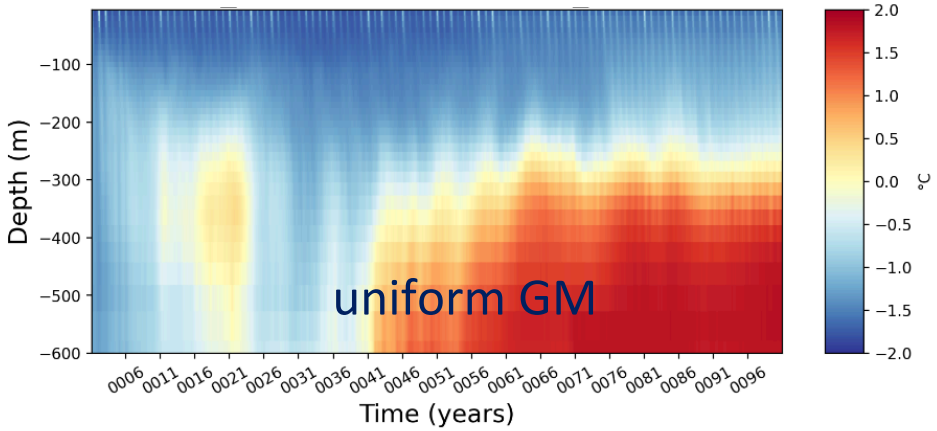


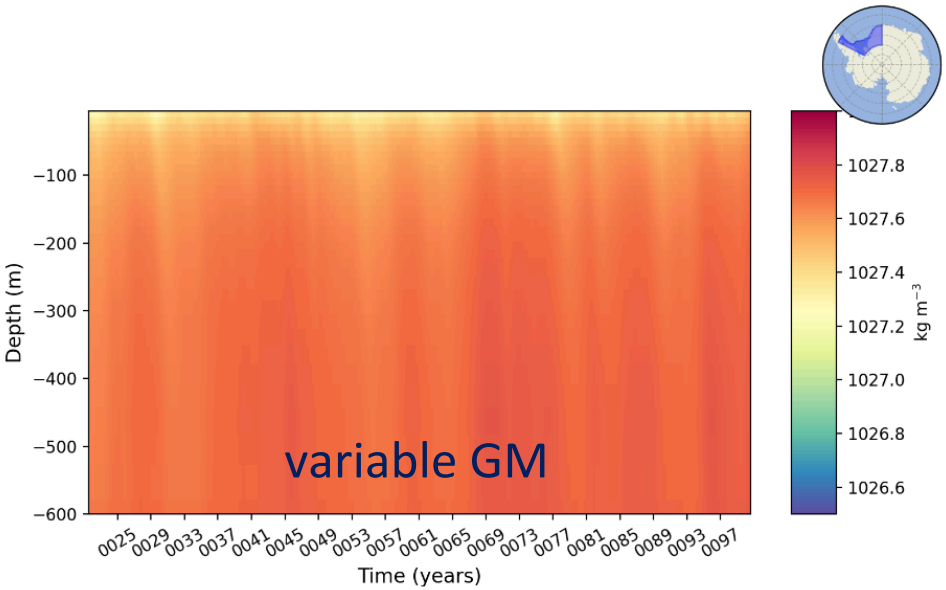
Weddell Sea Shelf density & T over time

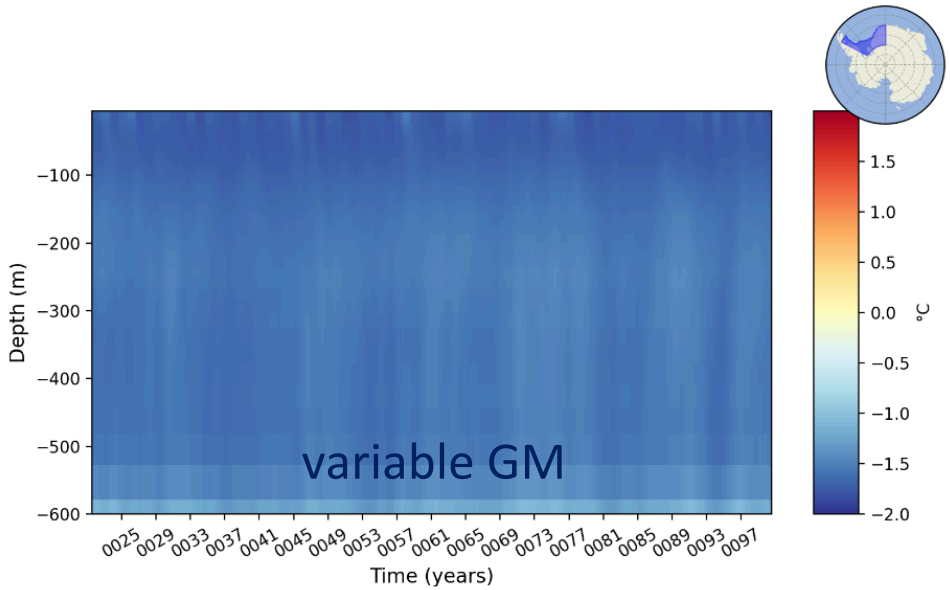
potential density



potential temperature







Comeau et al. (in prep.)

V2 Science Question

How will the atmosphere, ocean and sea-ice systems mediate sources of sea-level rise from the Antarctic ice sheet over the next 30 years?

Status:

- simulations with prototype S. Ocean Regionally Refined Mesh (SORRM) configurations also give reasonable melt rates and S. Ocean climate
- analysis of V1, high-resolution simulation (no ice shelf cavities) provides insight on biases and their causes (Jeong et al., *J. Climate*, in review); we are likely to see same biases in our SORRM configured simulations:
  - S. Ocean low pressures systems and winds too strong in hi-res. atmos.
  - Ant. Slope Front (ASC) & Current (ASC) OK for EAIS; too strong for WAIS
    - "fresh shelves" nearly everywhere
    - "dense shelves" absent => deep water formation and density structure
    - "warm shelves" absent => ice sheet / ocean interactions
  - wind biases impact sea ice, which in turn impacts dense water formation on continental shelves, which in turn impacts ocean density structure

*** see *Roberts et al.* talk (Thurs. afternoon) ***

V2 Simulation Campaign

Table 6. *Simulations for the cryosphere system using E3SM v2. All simulations will be conducted with ice shelf cavities.*

CORE-II with and without ice cavities	Data	6-60	50	Restart from end of related v1 CORE II simulation but with v2 model physics
Historical transient (1950-2020)	100	6-60	70	Uses CORE-II spinup for ocean & sea ice initial conditions
SSP5-8.5 scenario (2020-2070) *with* ozone holes	100	6-60	50	Branched from historical run (5 ensemble members)
SSP5-8.5 scenario (2020-2070) *without* ozone holes	100	6-60	50	Branched from historical run
Historical transient (1950-2020)	25-100	6-60	70	as above but with hi-res RRS atmosphere
SSP5-8.5 scenario (2020-2070)	25-100	6-60	50	as above but with hi-res RRS atmosphere

V2 Simulation Campaign

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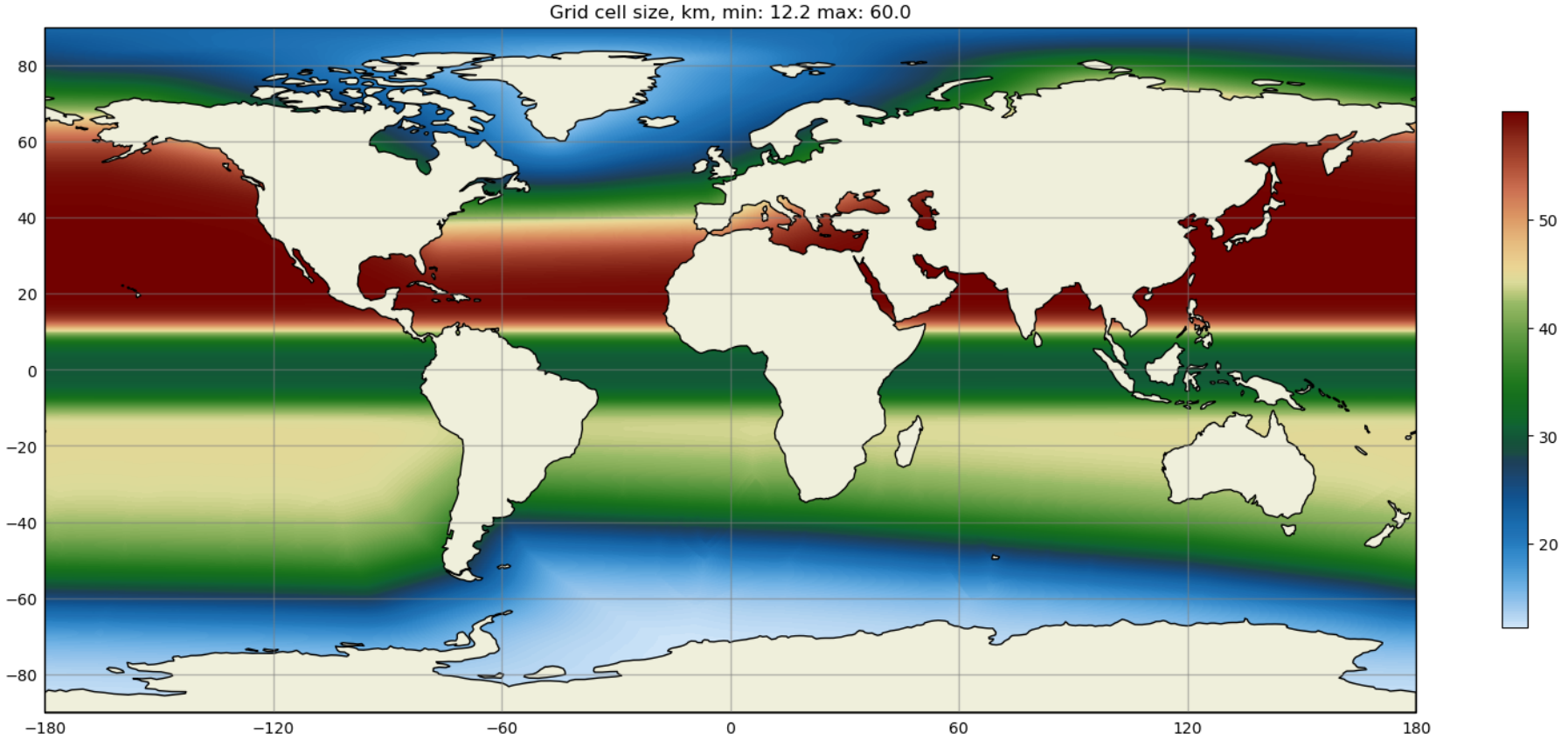
Historical transient (1950-2020)	25-100	6-60	70	as above but with hi-res RRS atmosphere
SSP5-8.5 scenario (2020-2070)	25-100	6-60	50	as above but with hi-res RRS atmosphere

???

- possible addition of similar suite of runs using low-res. configuration (if ocean-heat-content biases can be resolved at low-resolution)

V2 Results: variable resolution configuration



*** see *Asay-Davis et al.* poster (PS1, Tues. afternoon) ***

V2 Results: variable resolution configuration

- 60 km res. at mid. lats.; ~10 km res. in S. Ocean (eddy permitting)
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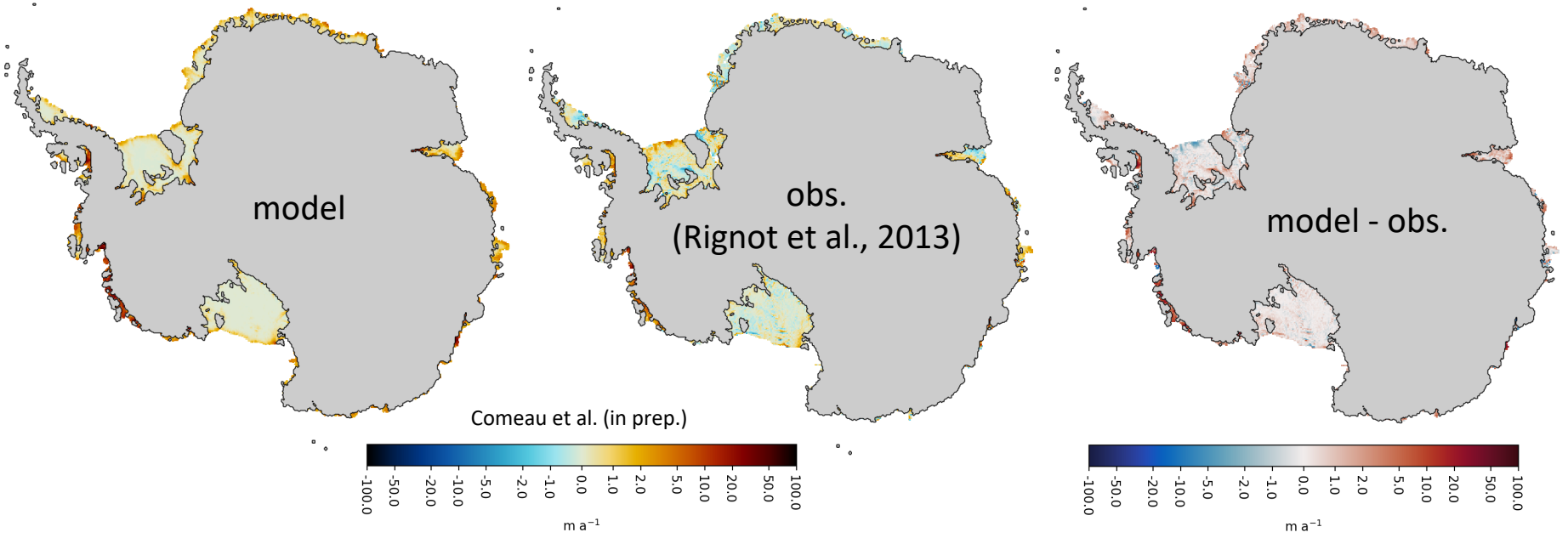
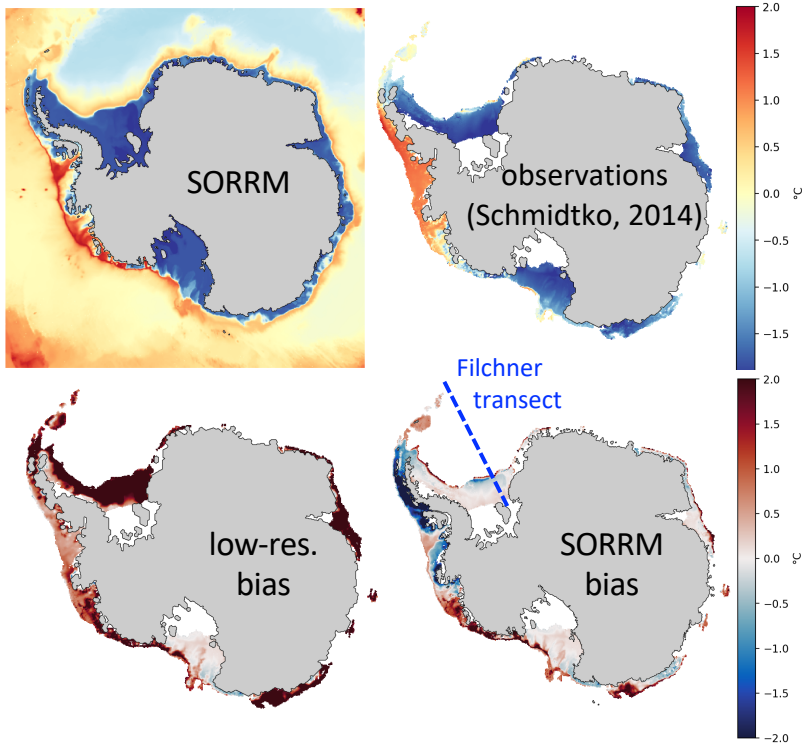
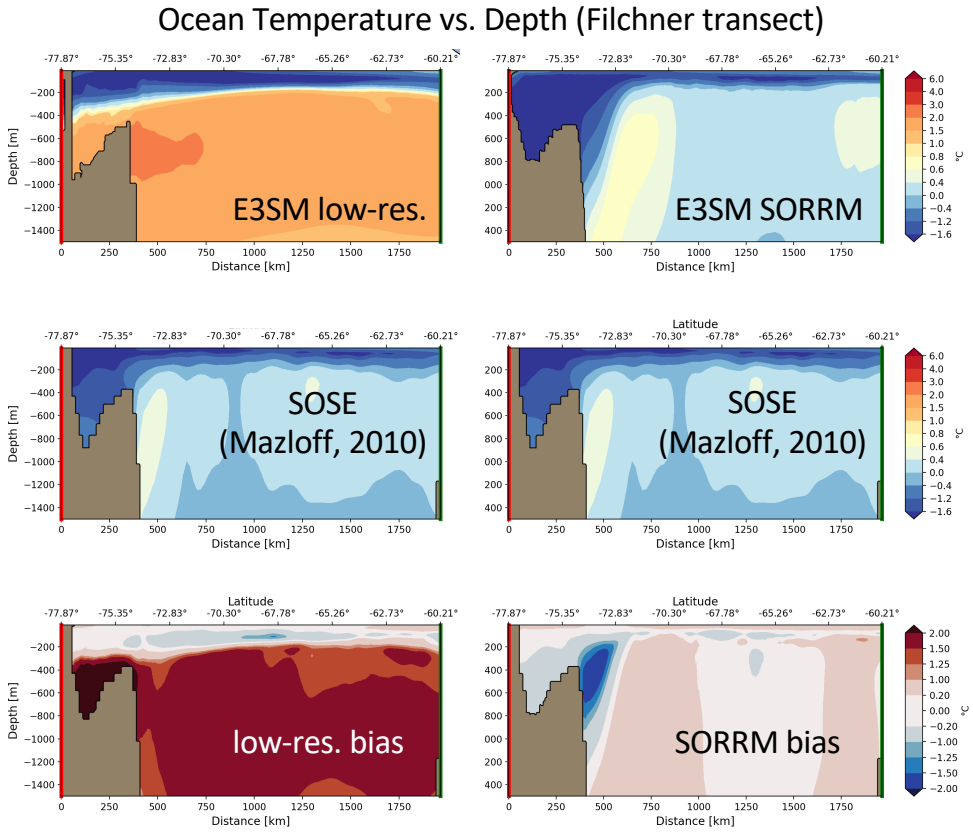
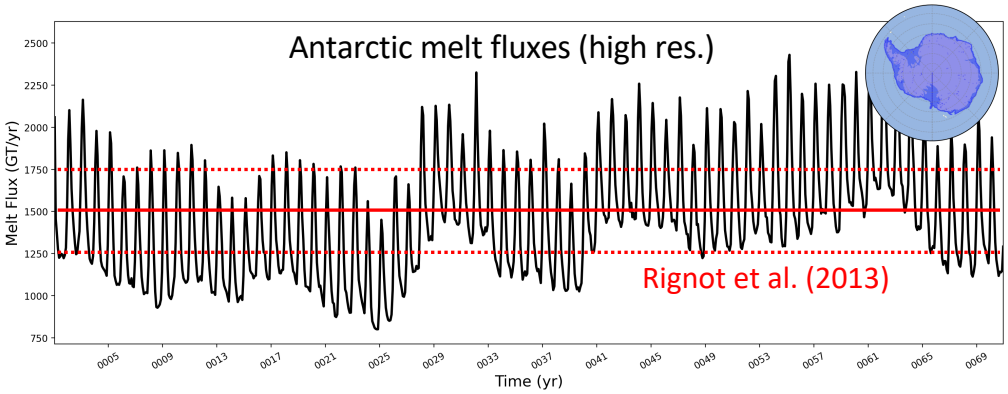


*** see *Comeau et al.* poster #2 (PS1, Tues. afternoon); *Lin et al.* talk (Thurs. afternoon) ***

V2 Results: variable resolution configuration







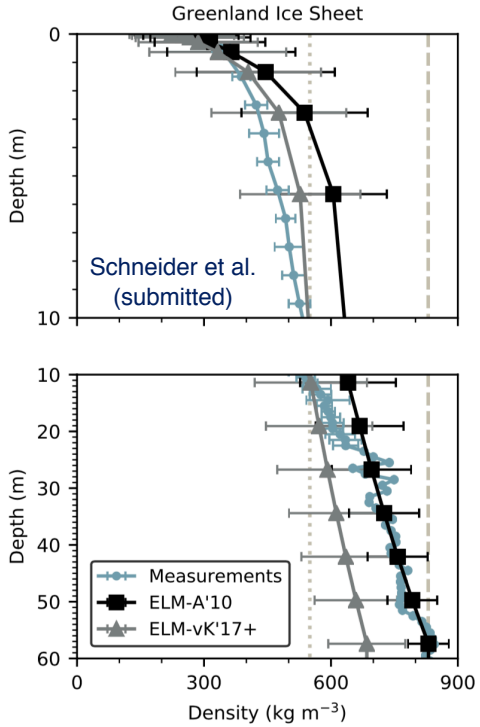
Higher ocean / ice res. around Antarctica improves on low-res. biases in regions with no GM closure

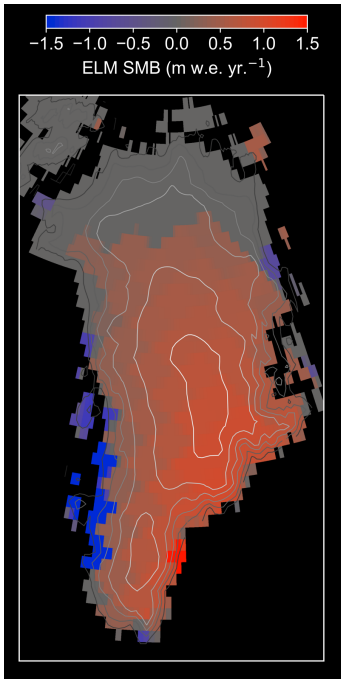
V2: other model developments

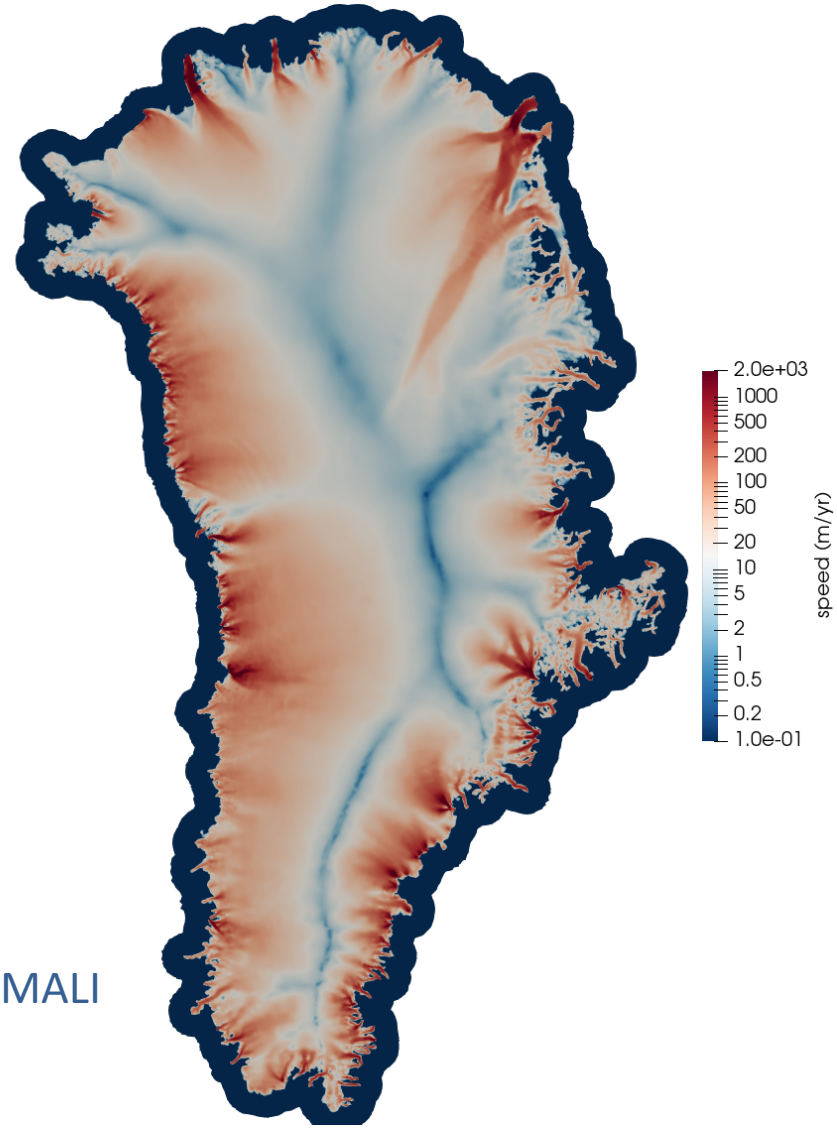
- regionally refined atmos. mesh (testing / coupling w/ SORRM in progress)
- improved ozone chemistry and simulation of S. hemis. ozone hole
- improved cloud water liquid vs. ice ratio (improved cloud radiative forcing over S. Ocean and Antarctica)

- systematic improvements in ocean/ice mesh generation and QC
- numerous improvements to low- and high-resolution ocean/ice meshes
- unification of snow radiation scheme (for snow on land vs. sea ice)
- multiple improvements to snow-on-sea ice physics and radiation schemes

V2+: Dynamic Greenland Ice Sheet in E3SM







ELM snowpack model improvements (above left)

Greenland surface mass balance spun-up in E3SM (above right).

Greenland ice sheet surface speed from optimized MALI initial condition in E3SM (right)

*** see *Price et al.* poster (PS2, Weds. afternoon) ***

Summary

V1 configuration (low resolution):

- more effort than anticipated to get reasonable S. Ocean climate and stable ice shelf melt rates under PI forcing
- important model biases identified and addressed
- physically realistic (and relevant to future?) sub-ice shelf circulation and melting instabilities identified
- hope is to continue with hist., 4xCO2, SSPs, etc. using similar low res. config.

V2 configuration (high / var. resolution):

- better S. Ocean climate and stable / realistic melt rates using SORRM; initial simulations look good (out to ~60 years)
- important coupled model biases (atmos., ocean, sea ice), identified from analysis of high-res. simulation are likely to apply here too
- waiting for final v2 tunings to proceed further

Other Related Work

Roberts et al. – E3SM polar climate in E3SM v1 and v2 (Thurs. Cryo breakout)
Wang et al. – drivers of Greenland ice sheet melt in v1 (Thurs. Cryo breakout)
Lin et al. – S. Ocean refined polar atmos. in v2 (Thurs. Cryo breakout)
Roberts et al. – Interdisciplinary Research for Arctic Coastal Envs. – InterFACE (Tues. afternoon)
Hoffman et al. – towards a regional sea-level enabled E3SM (Tues. afternoon)
Price et al. – SciDAC ProSPect Project (Wed. afternoon)
Turner et al. – SciDAC DEMSI Project (Wed. afternoon)

Comeau et al. – v1 Cryo low res. ocean/ice results (PS1)
Lin et al. – v1 Cryo low res. atmos. results (PS1)
Asay-Davis et al. – v2 Cryo var. res. mesh generation (PS1)
Comeau et al. – v2 Cryo var. res. ocean/ice results (PS1)
Price et al. – towards a coupled Greenland ice sheet in E3SM (PS2)
Hillibrand et al. – future SLR contribution of Humboldt glacier, Greenland (PS2)
Haeger et al. – subglacial drainage beneath Thwaites Glacier, Antarctica (PS2)
Book et al. – coupled solid earth and Thwaites Glacier evolution, Antarctica (PS2)
Schneider et al. – improved ELM snowpack model for ice sheets (PS1)
Martin et al. – BISICLES ice sheet model NGD (PS2)
Hunke et al. – CICE Consortium (PS2)