The influence of Antarctic ice shelf–ocean interactions on regional and global climate in the Energy Exascale Earth System Model (E3SM)

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Abstract

Energy Exascale Earth System Model (E3SM), version 1 of which was released by the U.S. Department of Energy in April 2018, includes support for thermodynamically active ice-shelf cavities. Dynamic ice sheet–ocean interactions are under development. These new capabilities are critical for projecting Antarctica's potential future contributions to global sea level, one of three main scientific foci of the E3SM project. Here, we present results from simulations with prescribed atmospheric forcing (CORE-2, see below) at two resolutions (~30 km and ~10 km) and fully coupled pre-industrial control runs (at ~30 km resolution), showing the impacts on the global climate of melt fluxes from ice shelves and resulting feedbacks. We also acknowledge biases in the Antarctic regional ocean, particularly related to warming of warm deep water masses at mid depths, and discuss plans for correcting these biases in future simulation campaigns.

The Energy Exascale Earth System Model (E3SM)

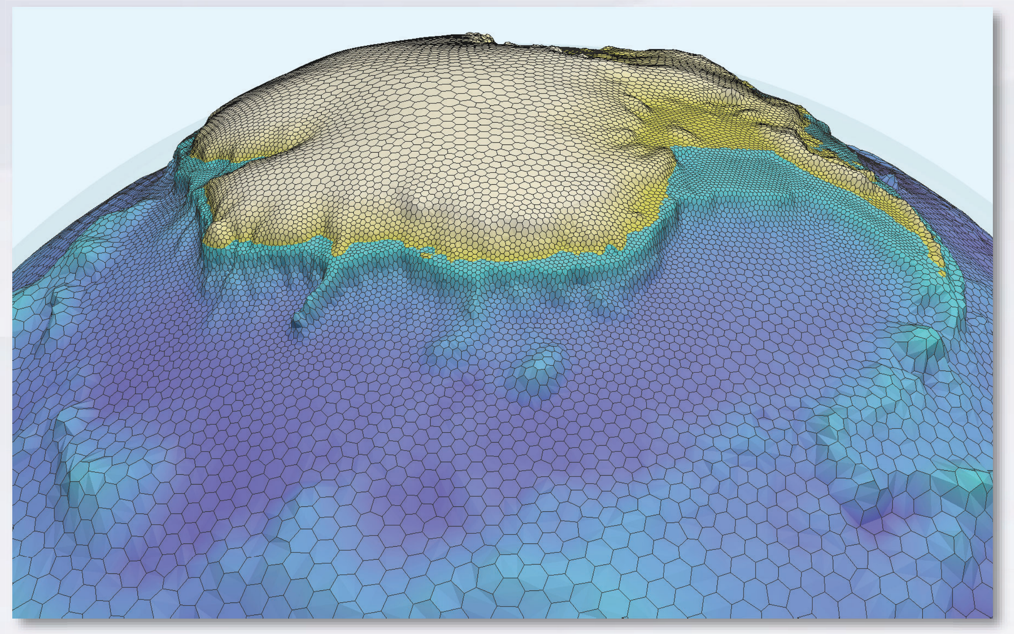

Figure 1: Example of a variable-resolution E3SM mesh with enhanced resolution near Antarctica.

Earth System Model (Petersen et al. 2019, Golaz et al. 2019) with:

- **Variable-resolution** (see Fig. 1) atmosphere, land, ocean, sea-ice, and land-ice components
- Focused on interactions between the climate system and the energy sectors
- One area of interest: **projections of sea-level change**

Configuration for the cryosphere-focused simulations:

- Global ocean/sea-ice configuration
  - Some with data atmosphere/land (**CORE-2**: Large and Yeager, 2009)
  - Some **fully coupled** (global, dynamic atmosphere, ocean, sea-ice and land)
- Static ice-shelf cavities (fixed at Bedmap2 geometry; Fretwell et al. 2013)
- Simulations **with and without melt flues**
- Two horizontal resolutions in Southern Ocean and Antarctic continental shelf:
  - **~30 km** ("low res.")
  - **~10 km** ("mid res.")
  - Plans for ~5-6 km ("high res.") focused on Antarctic
- Low res both fully coupled and CORE-2: ~110 years
- Mid res CORE-2: ~5 years (with melt fluxes) and ~10 years (without)

Antarctic Melt Rates

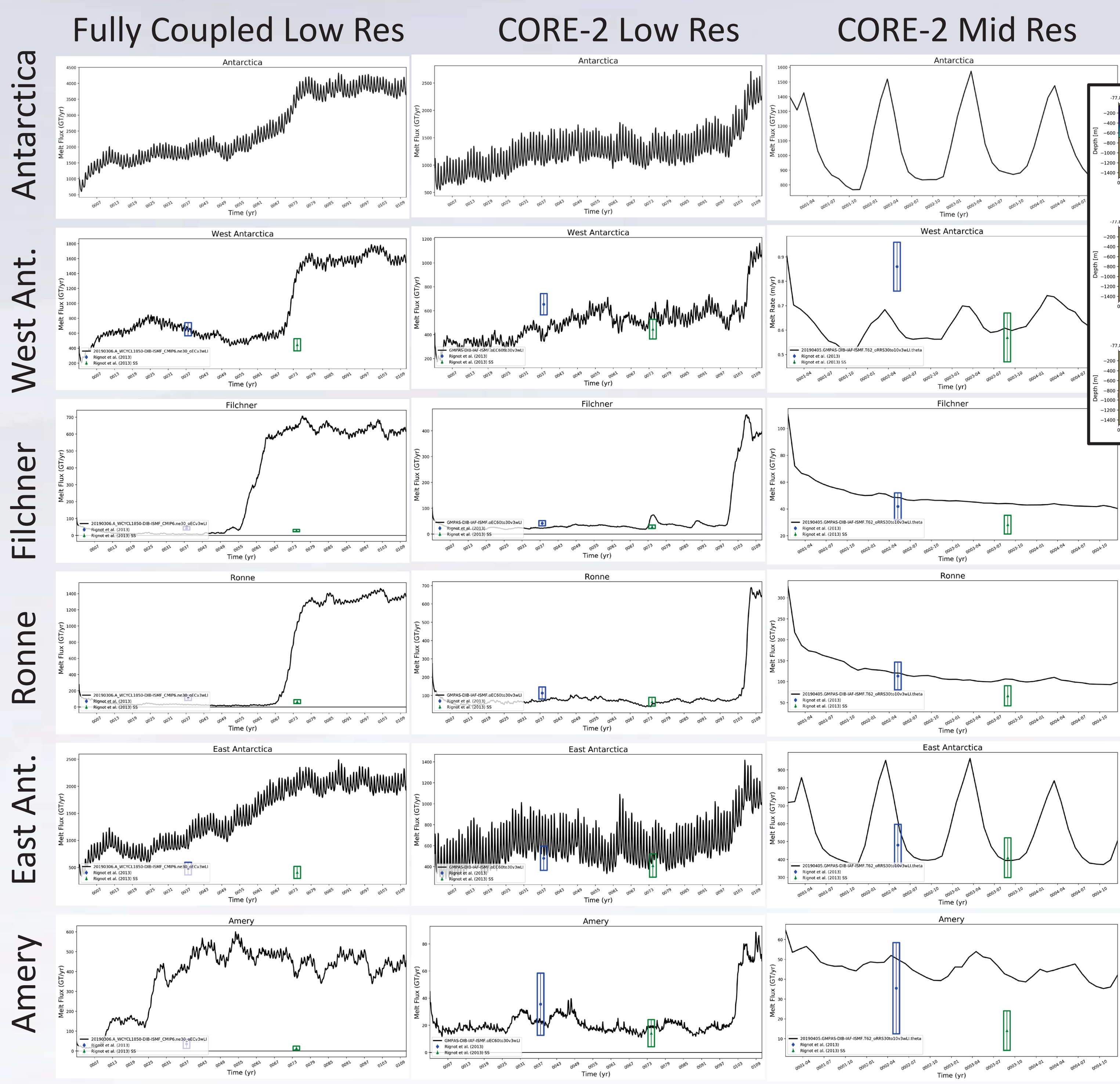

Figure 2: Time series of Antarctic melt rates from various regions in both fully coupled and CORE-2-forced simulations at both low res (~30 km) and mid res (~10 km).

Warm, fresh biases

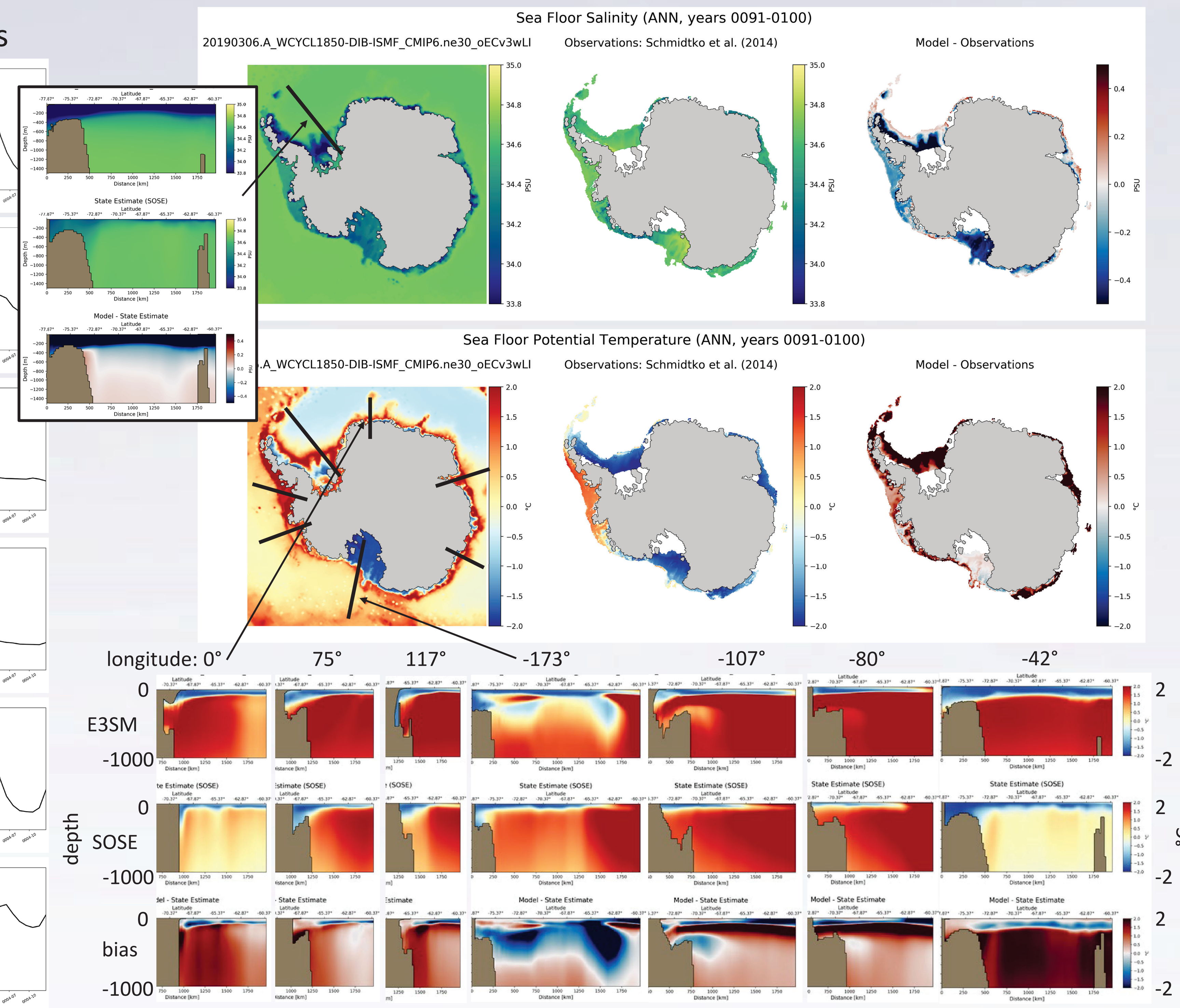

Figure 3: Salinity and potential temperature from a fully coupled, low res E3SM simulation compared with observations (Schmidtko et al. 2014) and with the Southern Ocean State Estimate (Mazloff et al. 2010), showing fresh, warm biases at depth.

Regional and Global Impacts of Melt

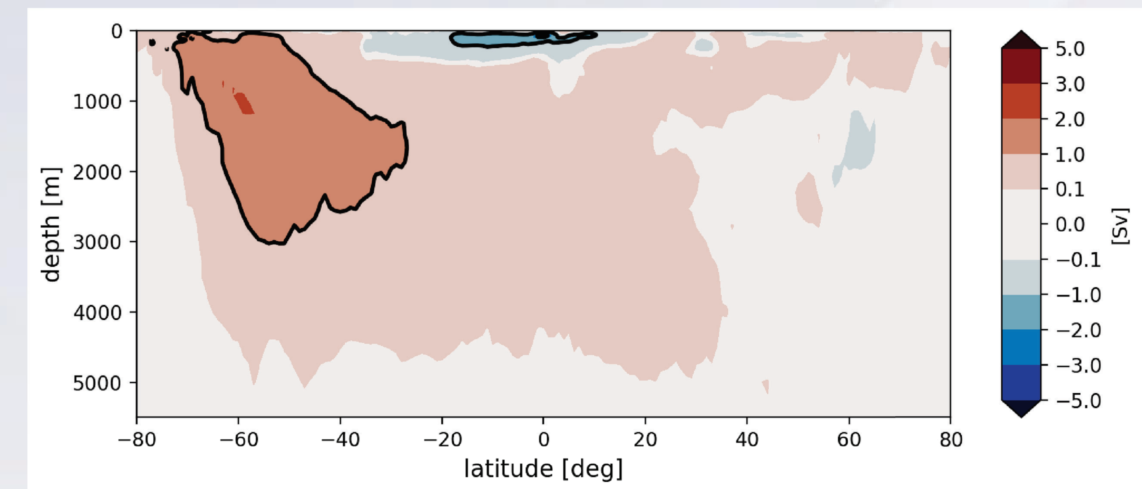

Figure 4: The **Global Meridional Overturning Circulation** with melt fluxes minus that without, averaged over years 44-94 of a fully coupled, low res. simulation. A strengthening of the MOC occurs south of 30 S, possibly due to biases.

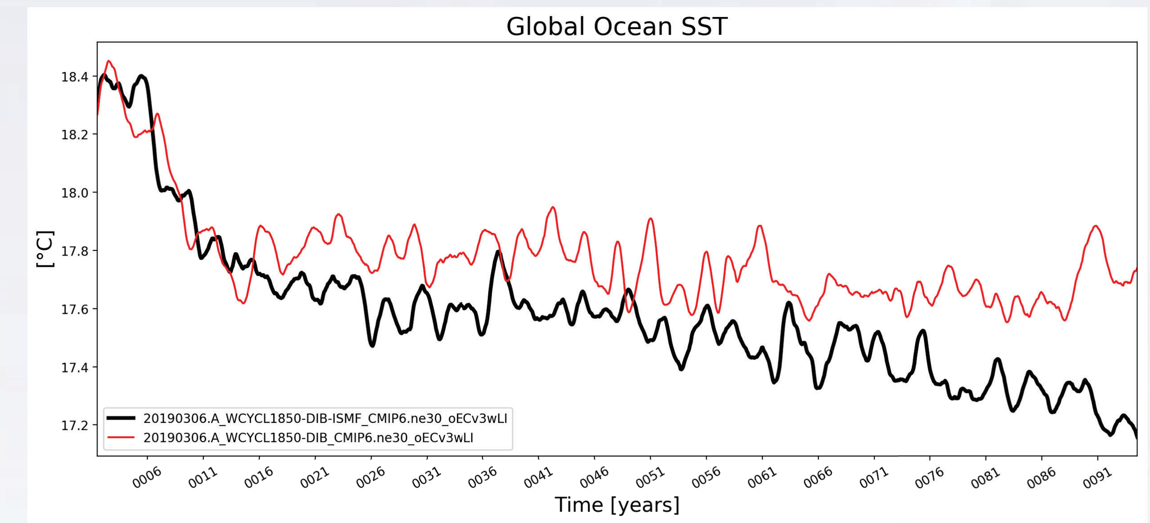

Figure 5: Global mean **Sea Surface Temperature** with melt fluxes (black) and without (red), showing that melt fluxes produce a net cooling that has not equilibrated even after 100 years.

Future Work

- Explore and address warm, fresh biases:
  - Distribute freshwater fluxes deeper than top layer (so far, this has little effect)
  - Reduce GM Bolus (default is 1800, trying 600 and 400), vary GM Bolus in the vertical
  - Make ocean freezing function of S, not just T
  - Higher vertical resolution (especially near surface – 1.5 m instead of 10 m)
  - Add Redi mixing
  - Switch to TEOS 10
  - Run at high res (5-6 km)
- Run historical and (eventually) projections
- Couple to MALI ice-sheet model (Hoffman et al. 2018)

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E3SM Energy Exascale Earth System Model

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