



## The E3SM Cryosphere Simulation Campaign: Wrapping up v1 and looking towards v2

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## E3SM v1 Cryosphere Science Campaign

- Science Driver: How do rapid changes in cryospheric systems evolve with the Earth system and contribute to sea level rise and increased coastal vulnerability?
- 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?
- v1 Simulation Campaign
  - Fully coupled (atmosphere, land, ocean, and sea ice), low-resolution (1 degree atmosphere/land, variable resolution (60km to 30km) ocean/sea-ice, pre-industrial conditions.
  - Utilizes capability to extend the ocean domain to Antarctic ice-shelf cavities, and simulate Antarctic ice-shelf basal melting.
  - **Fidelity of simulations is dependent on getting the Southern Ocean right (or, less wrong).**

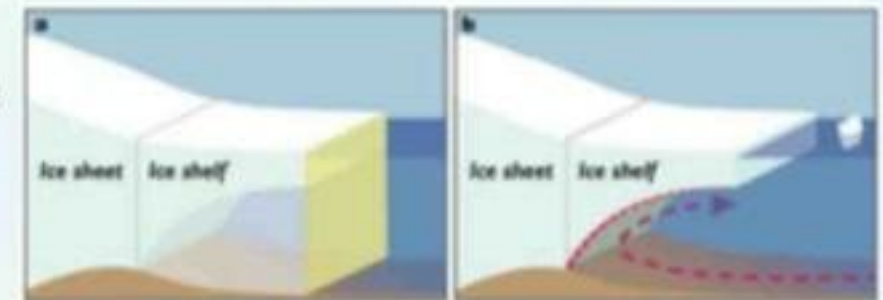


Figure credit: Matt Hoffman



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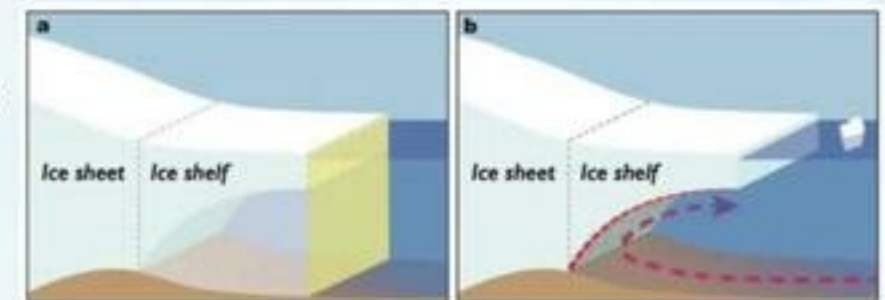
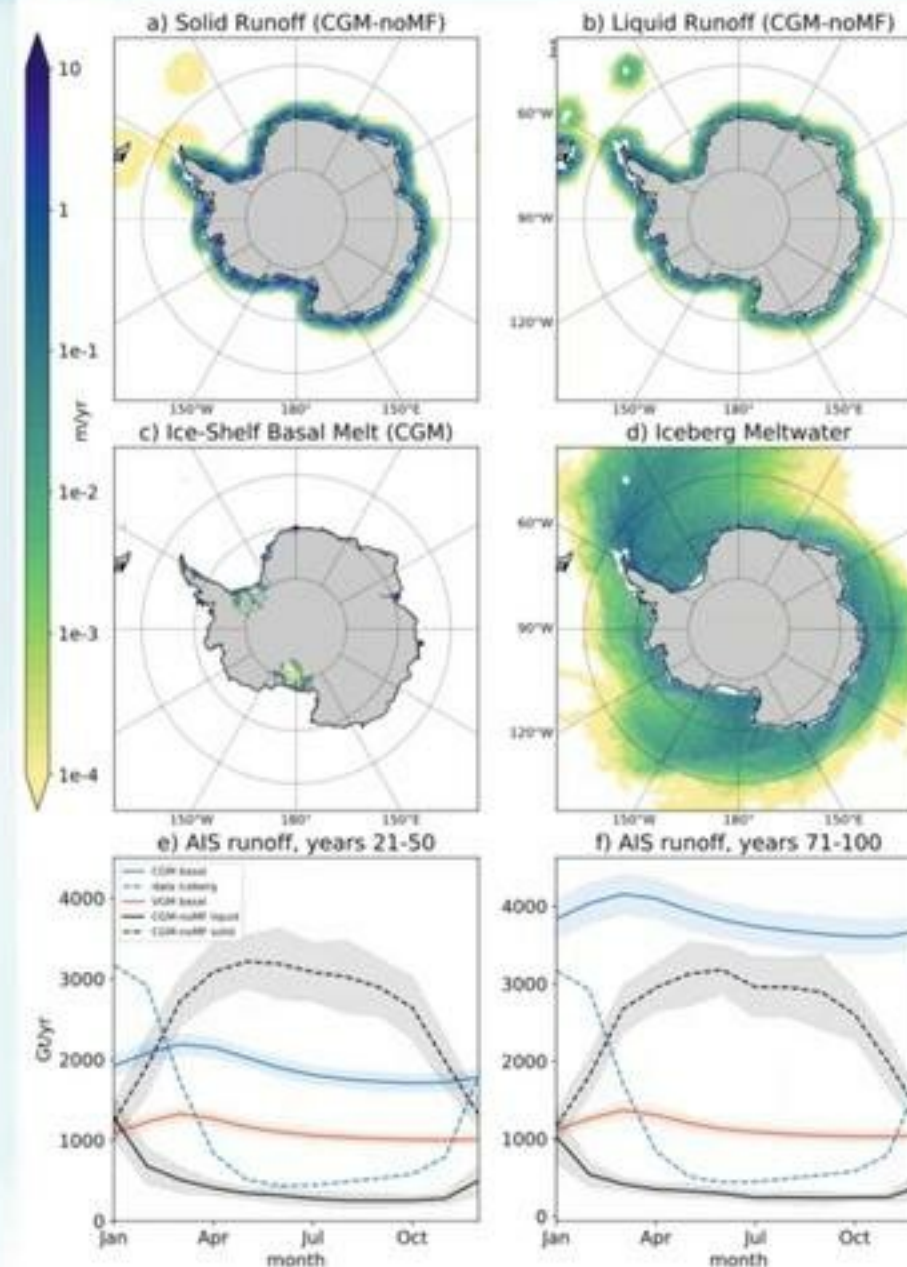


Figure credit: Matt Hoffman

# Changes to AIS runoff

- Standard Antarctic Ice Sheet (AIS) runoff; solid and liquid precipitation on Antarctica are immediately routed to the nearest coastal grid cell.
- Cryosphere AIS runoff replaces these terms with prognostic ice-shelf basal melt fluxes and prescribed iceberg meltwater forcing.





## E3SM v1 Cryosphere Overview Paper

- Submitted<sup>1</sup> to JAMES on January 6, 2021, in second round of revisions
- Focuses on two fully coupled, 100 (\*200) year Cryosphere v1 simulations
- Key points:
  - Capabilities have been added to an Earth System Model to model realistic Antarctic ice-shelf basal melt fluxes and prescribe iceberg forcing
  - Simulated basal melt rates have a strong sensitivity to the ocean mesoscale eddy parameterization
  - For one choice of the mesoscale eddy parameterization, the Filchner-Ronne Ice Shelf crosses a tipping point to a high melt regime
- \*During review process, a bug was found in the sign of the latent heat flux to the ocean due to iceberg melting. Simulations have since be rerun, and key points of the paper still hold, though main climatic event of interest occurs 90 years later.
- Second paper focusing on FRIS tipping point in G-cases also in preparation.

<sup>1</sup>Sensitivity of Ice-Shelf Basal Melt Rates in E3SM v1.2, Comeau et al



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# E3SM v1 Cryosphere Simulations

- CGM; Constant bolus kappa coefficient in Gent-McWilliams (GM) mesoscale eddy parameterization
  - SO temperature and salinity biases cause rapid transition to high melt regime under a large ice-shelf (Filchner-Ronne)
- VGM; Variable (stratification dependent) bolus kappa coefficient in GM
  - SO biases sufficiently mitigated such that tipping point not reached, total Antarctic ice-shelf basal melt fluxes remain within present-day observed range

<sup>1</sup>Danabasoglu and Marshall, *Ocean Modelling*, 2007

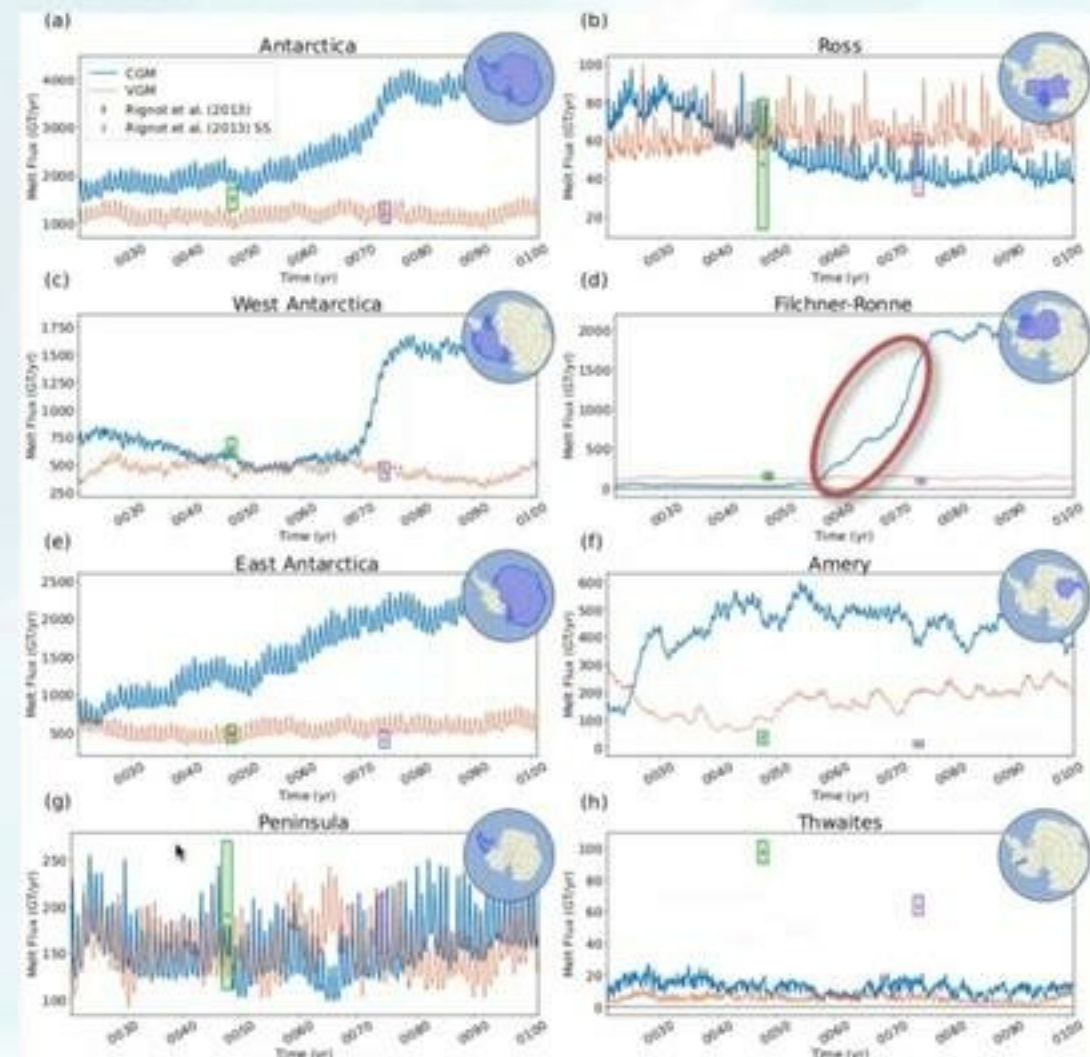
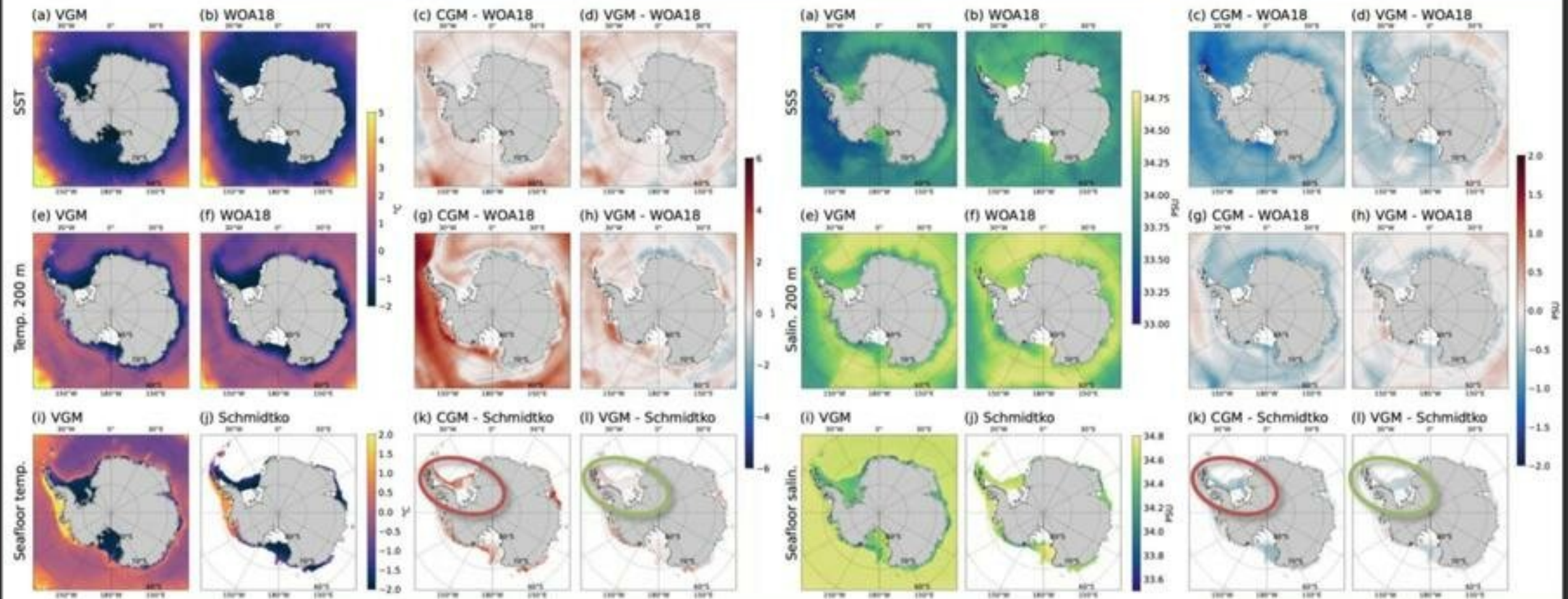


Figure credit: Xylar Asay-Davis



# Potential temperature and salinity

Years 21-50 (prior to large melt increase)



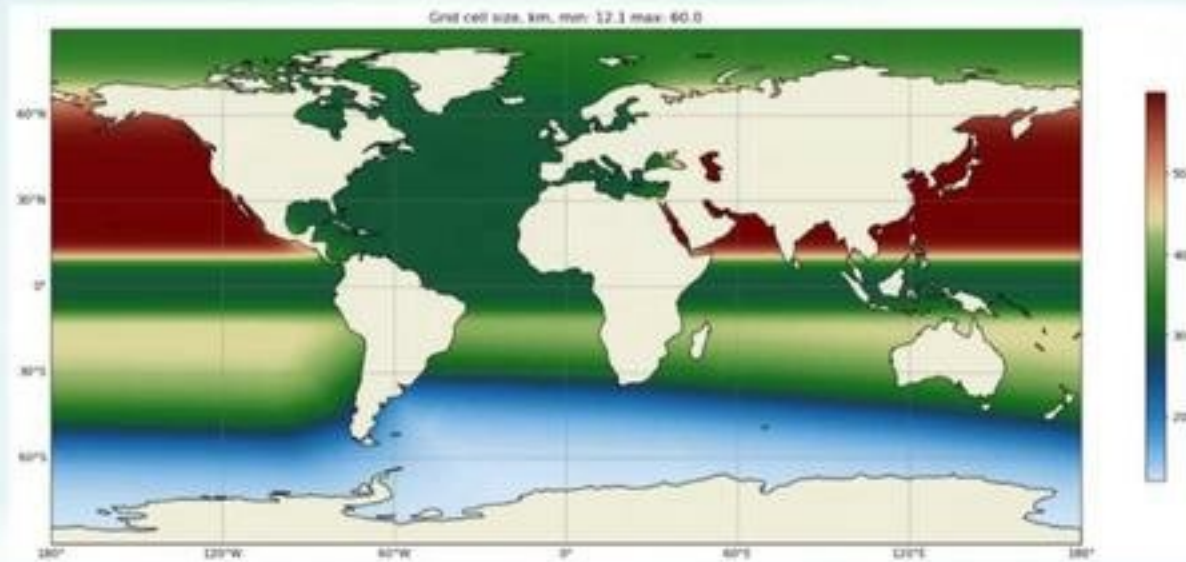
General surface fresh, subsurface warm biases in CGM

Figure credit: Xylar Asay-Davis



## E3SM v2 Cryosphere Science Campaign

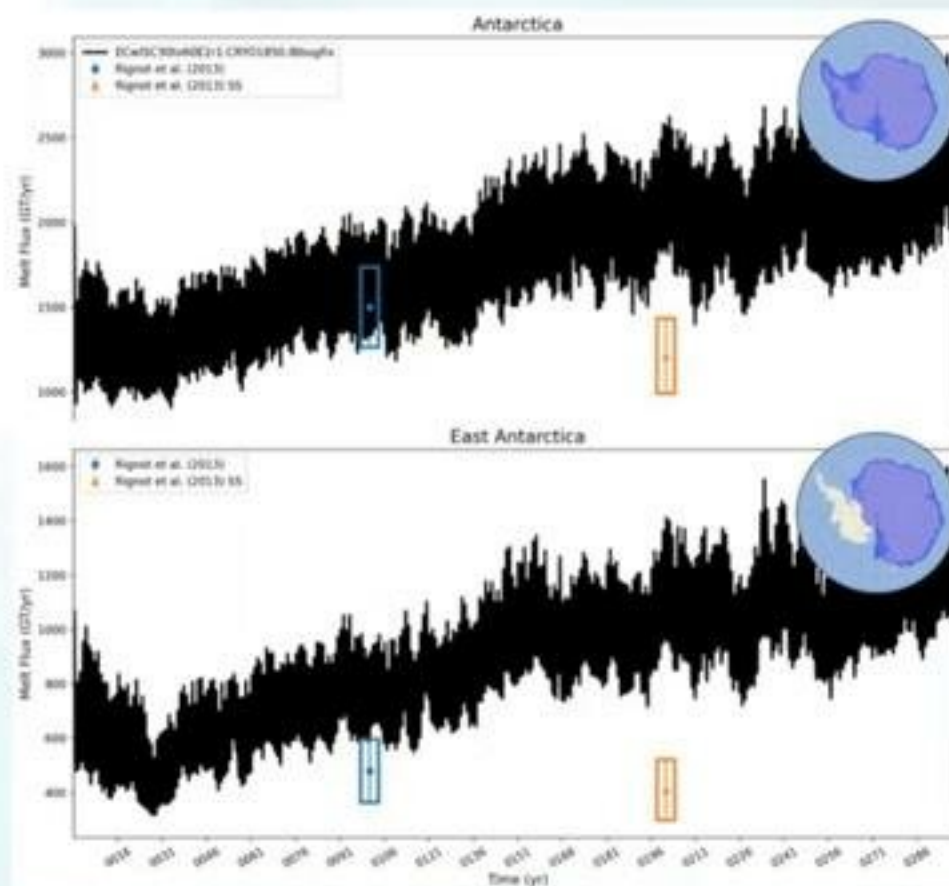
- v2 Science Question: How will the atmosphere, ocean, and sea-ice systems mediate sources of sea-level rise from the Antarctic ice sheet over the next 30 years?
- v2 Simulation Campaign
  - In addition to standard low resolution, we will also be using Southern Ocean Regionally Refined Mesh (SORRM) configuration for ocean/sea-ice (12km to 60km).
    - 200 year spinup with 1850 conditions (low resolution) and 1950 conditions (SORRM)
    - 5 historical ensemble members
    - 2 SSP scenarios
    - 4xCO2 scenario



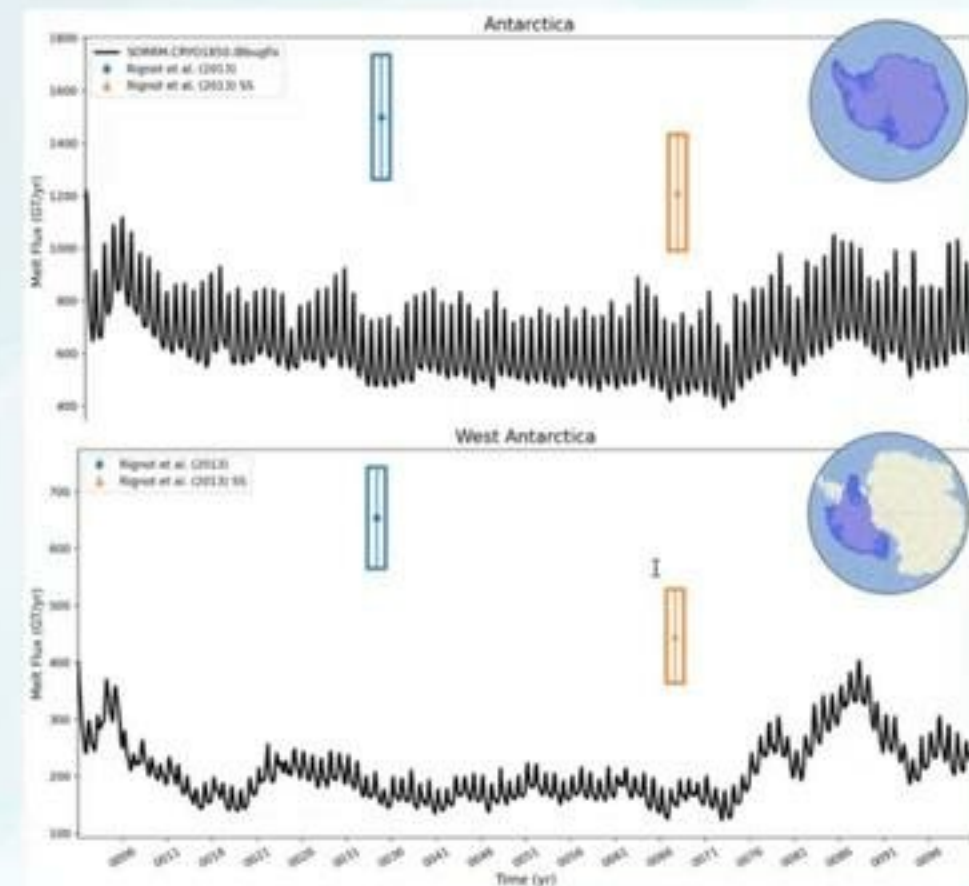
## E3SM Cryosphere v2 – Preliminary results

- We have run 300 years of v2 (Water cycle tunings) low resolution CRYO1850, 100 years of SORRM CRYO1850.

Low-res



SORRM

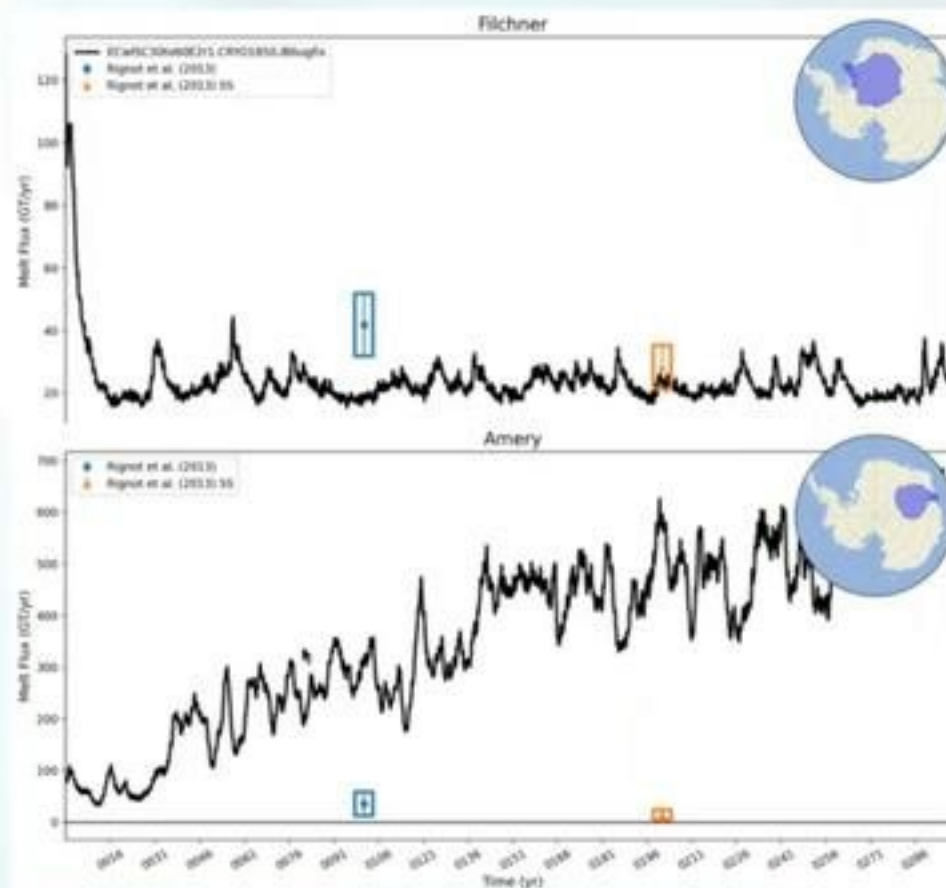




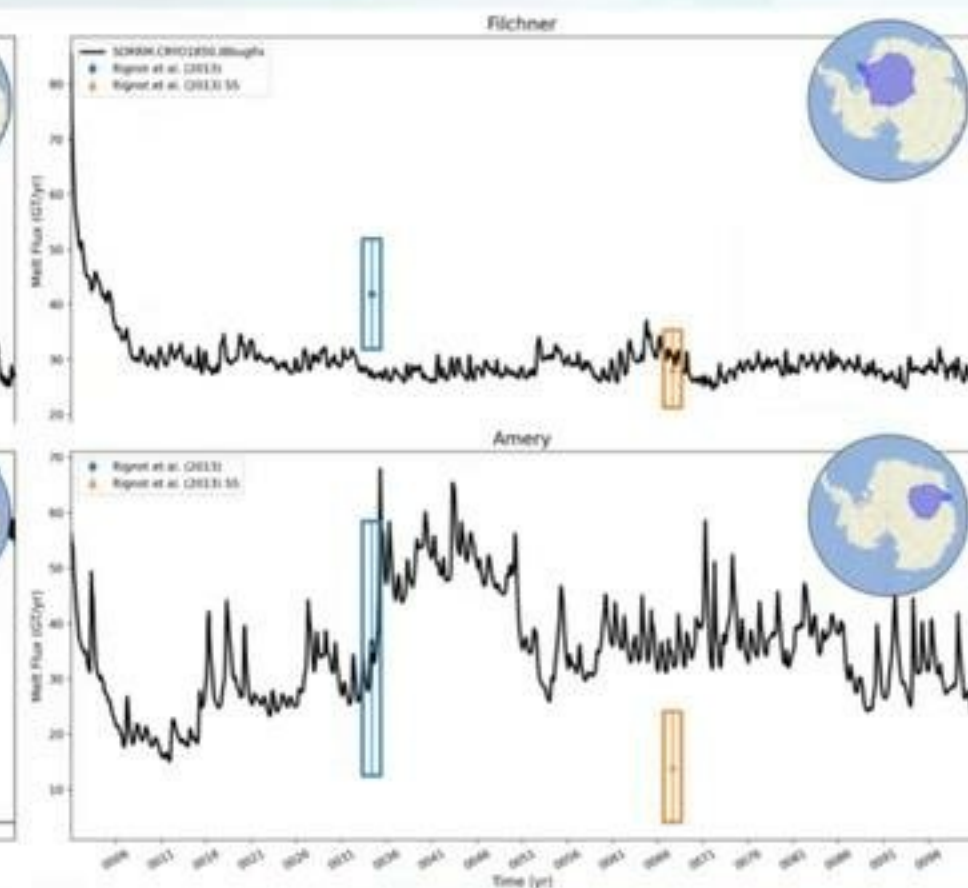
## E3SM Cryosphere v2 – Preliminary results

- Filchner-Ronne instability leading to high melt-regime not present in either configuration, though other ice shelves have melting that is too high or low.

Low-res

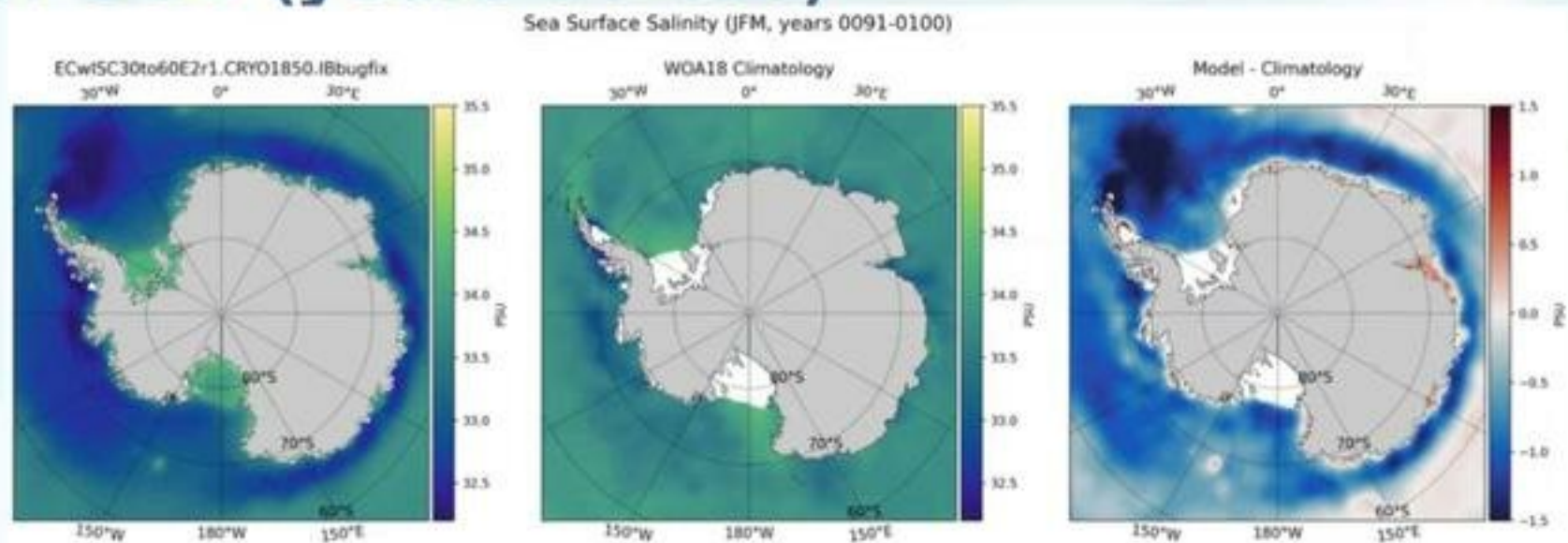


SORRM

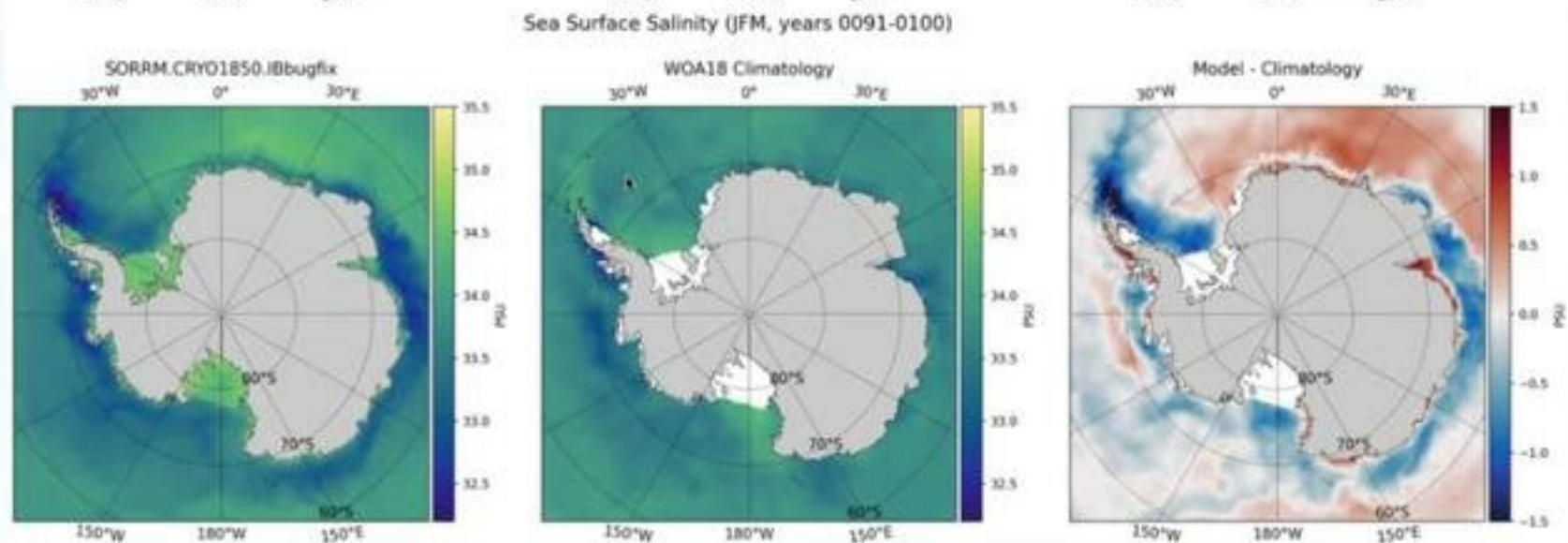


# Summer SSS (years 91-100)

Low-res



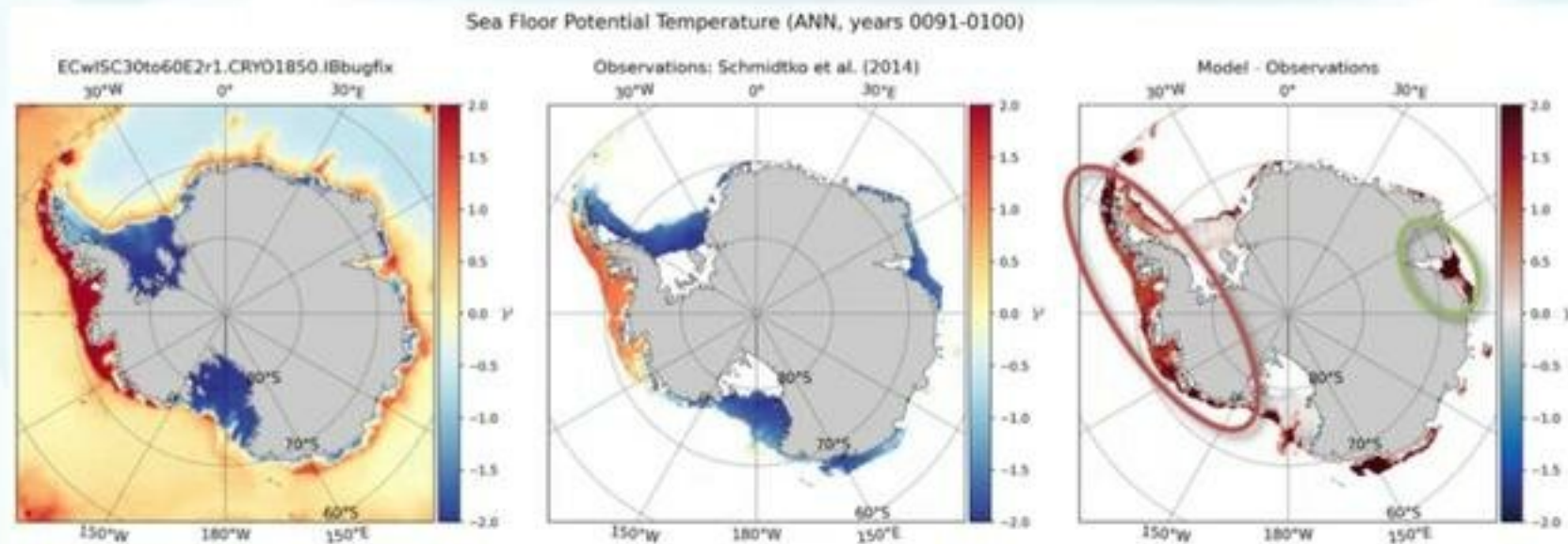
SORRM



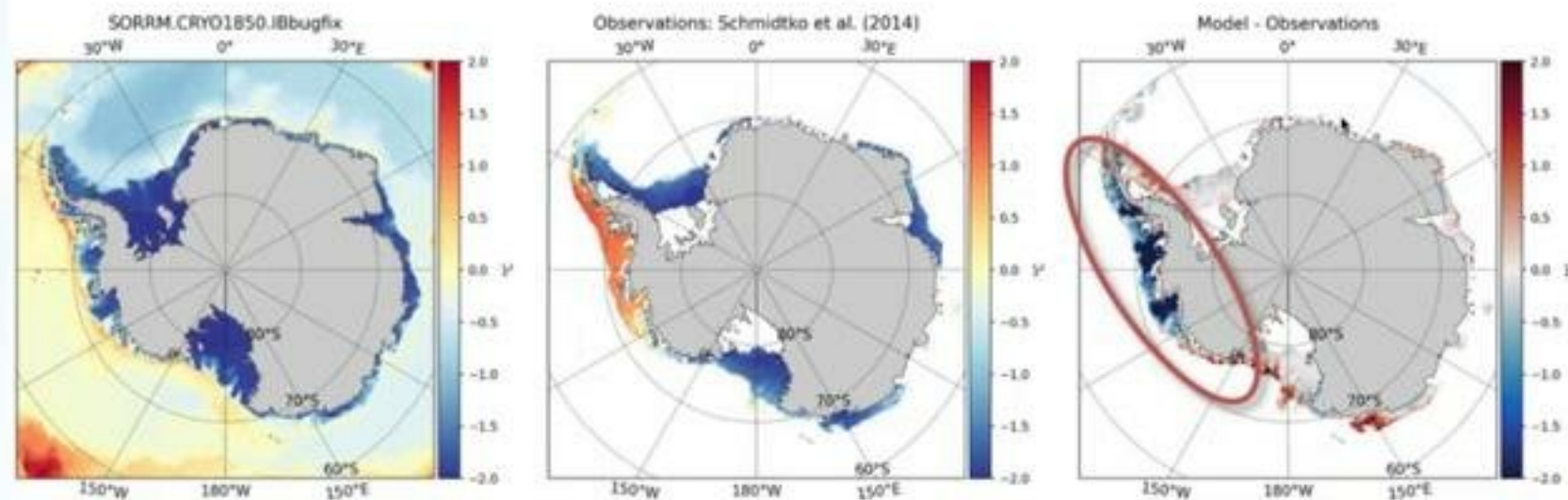


# Seafloor temperature (years 91-100)

Low-res

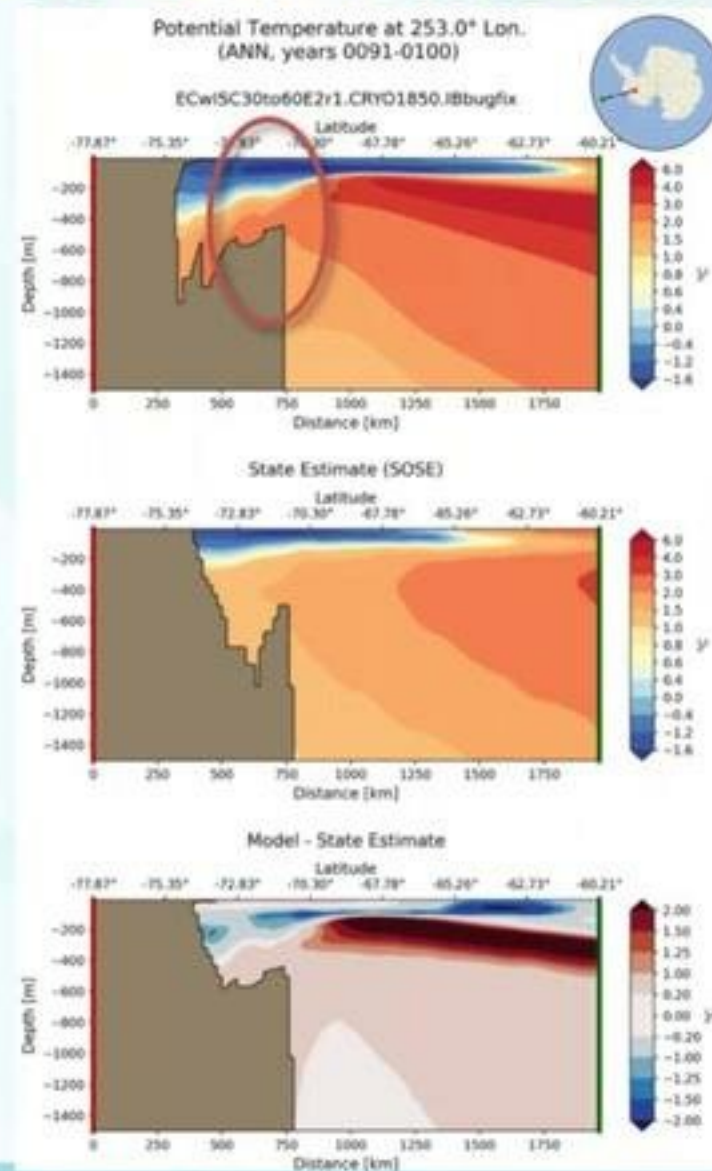


SORRM

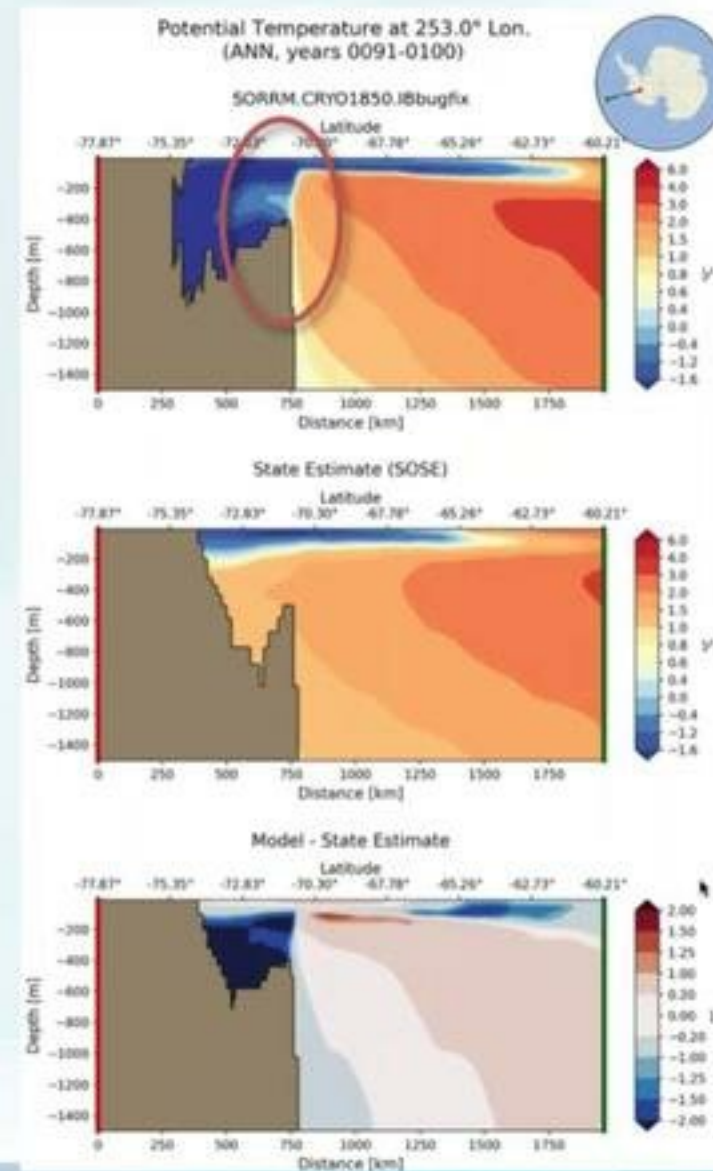


# Amundsen Sea Transect

Low-res



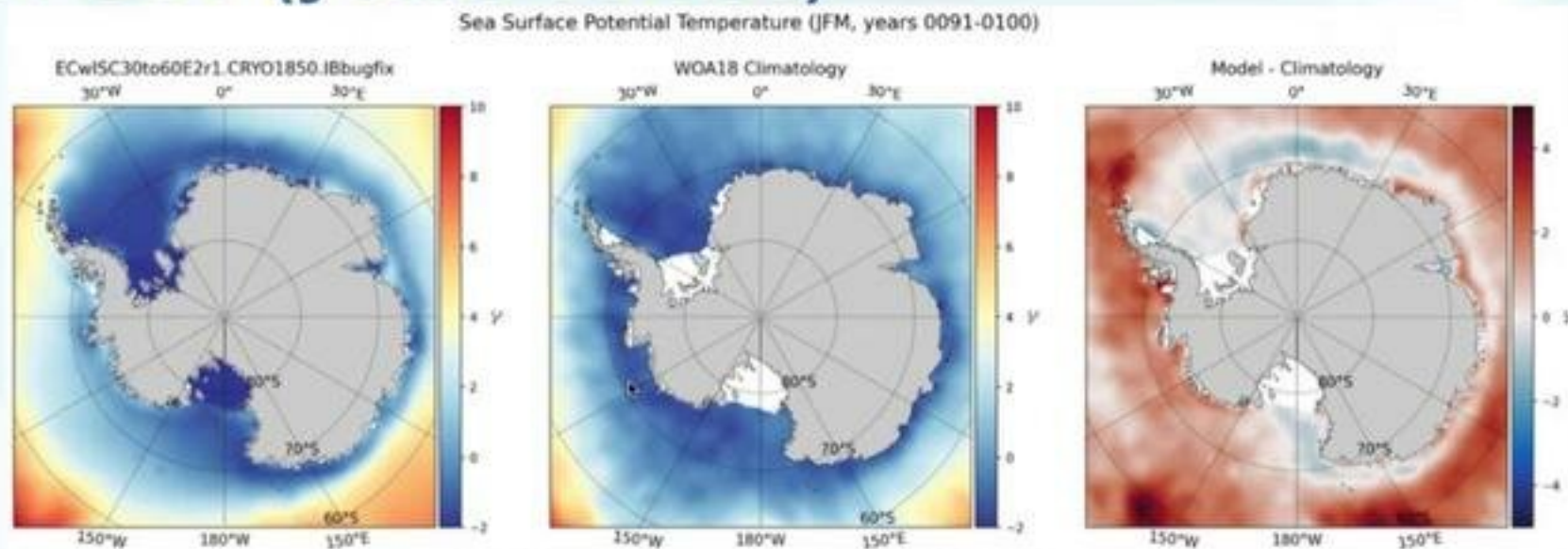
SORRM



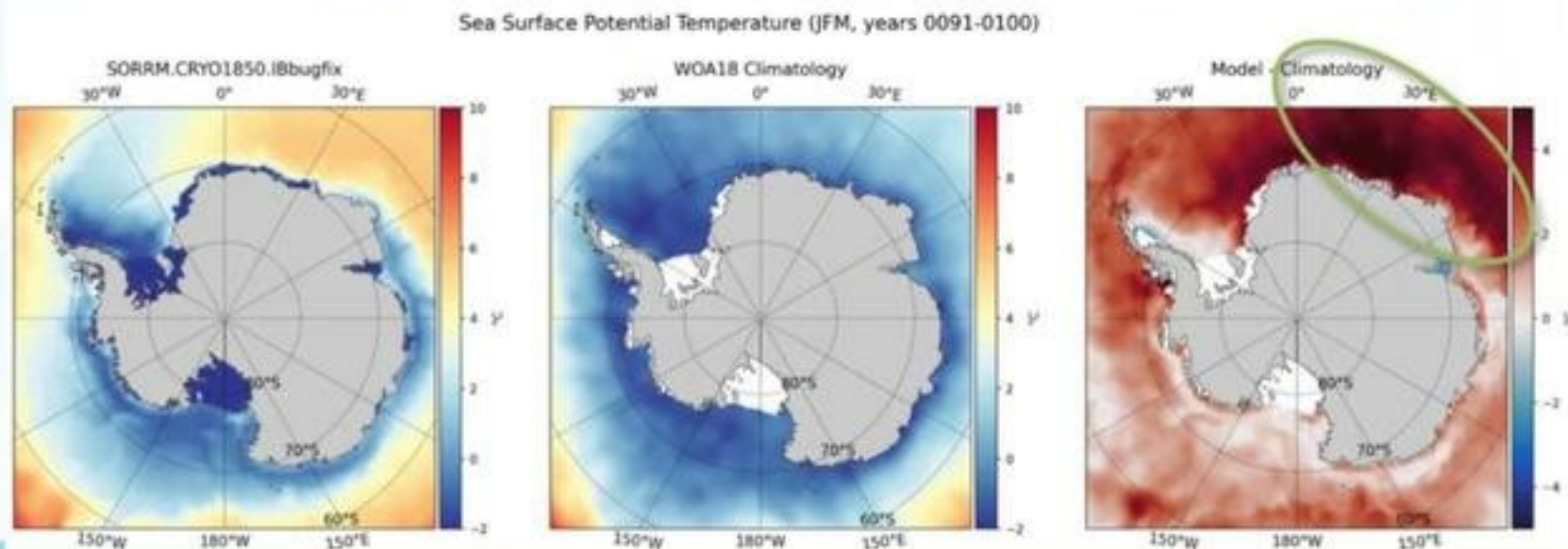


# Summer SST (years 91-100)

Low-res



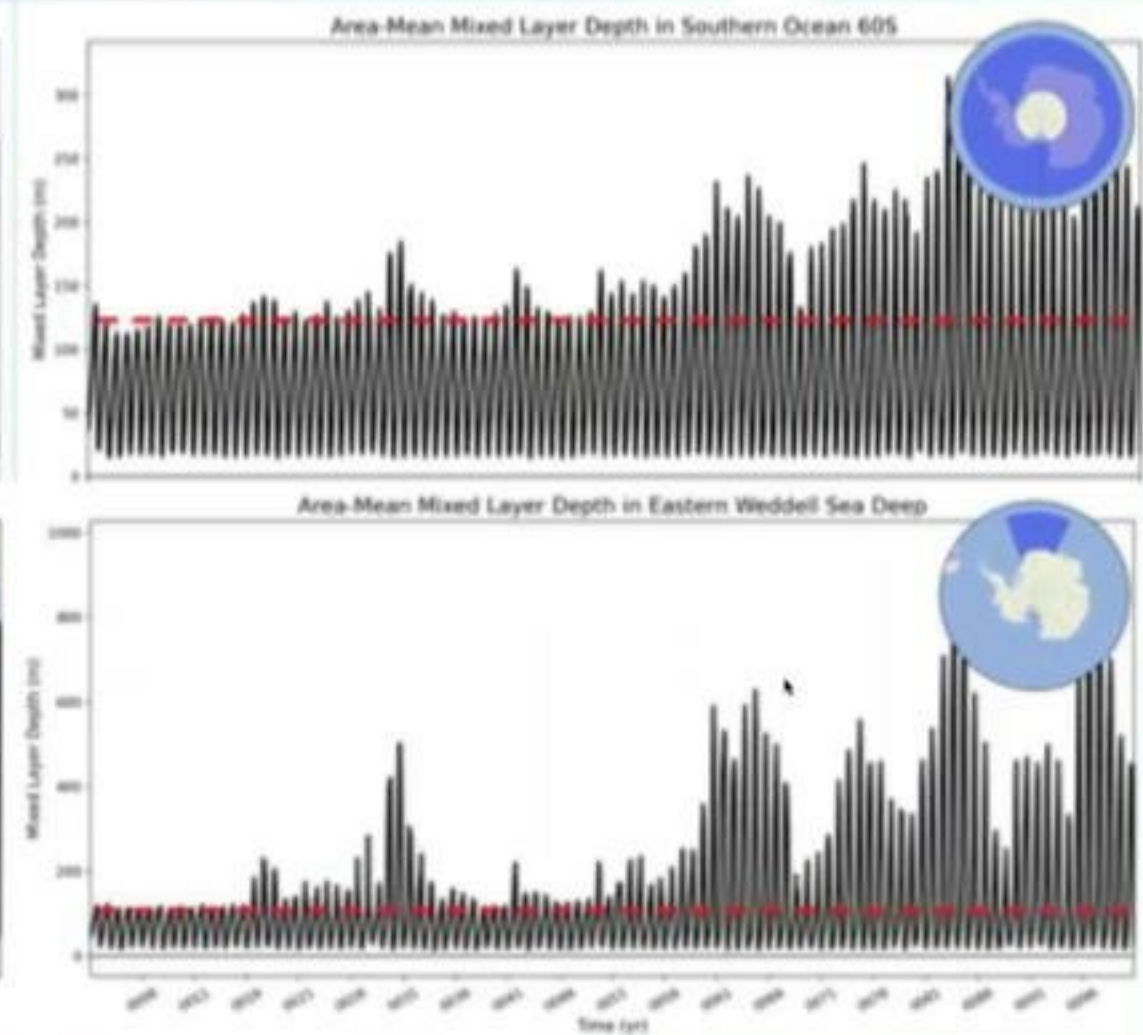
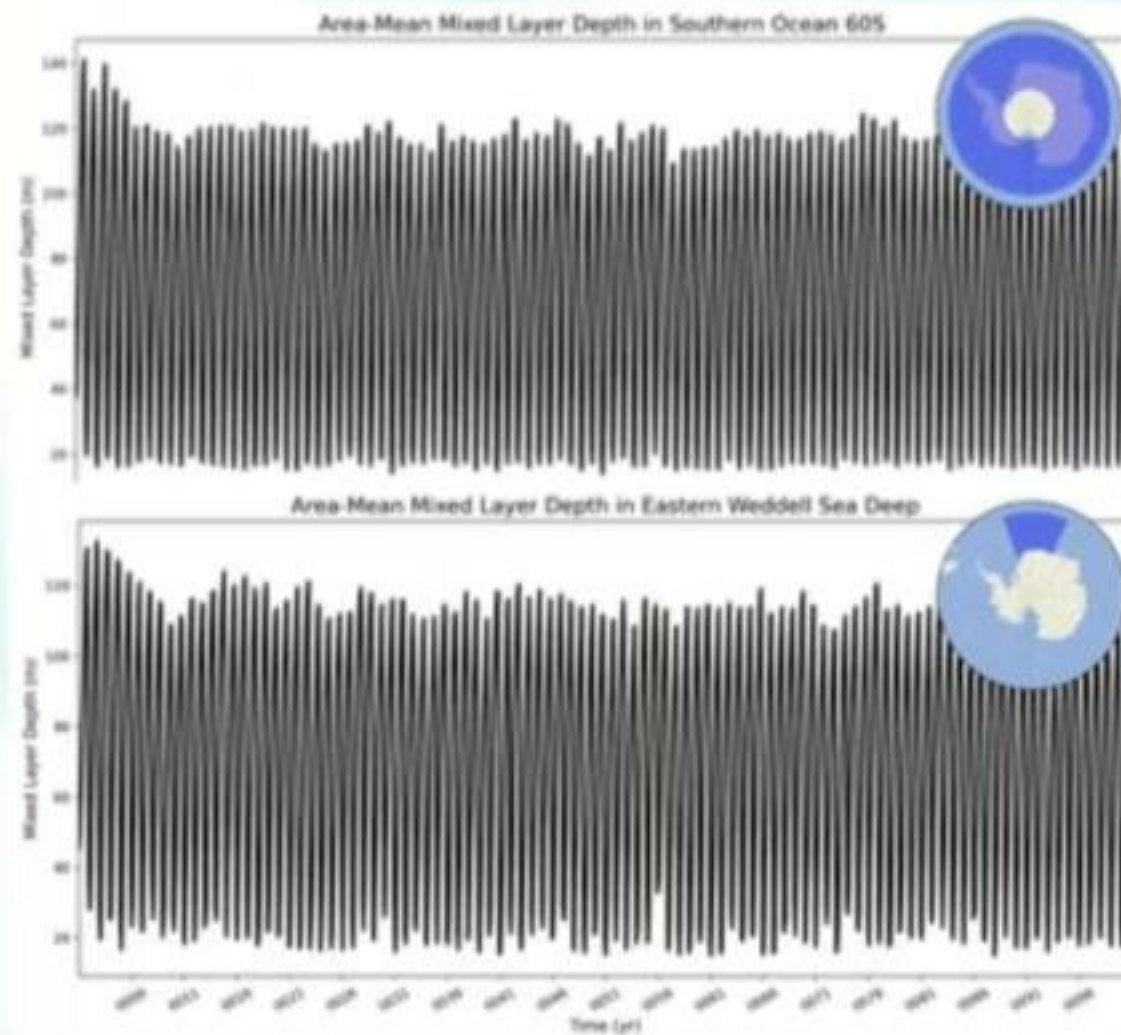
SORRM



# Mixed layer depths

Low-res

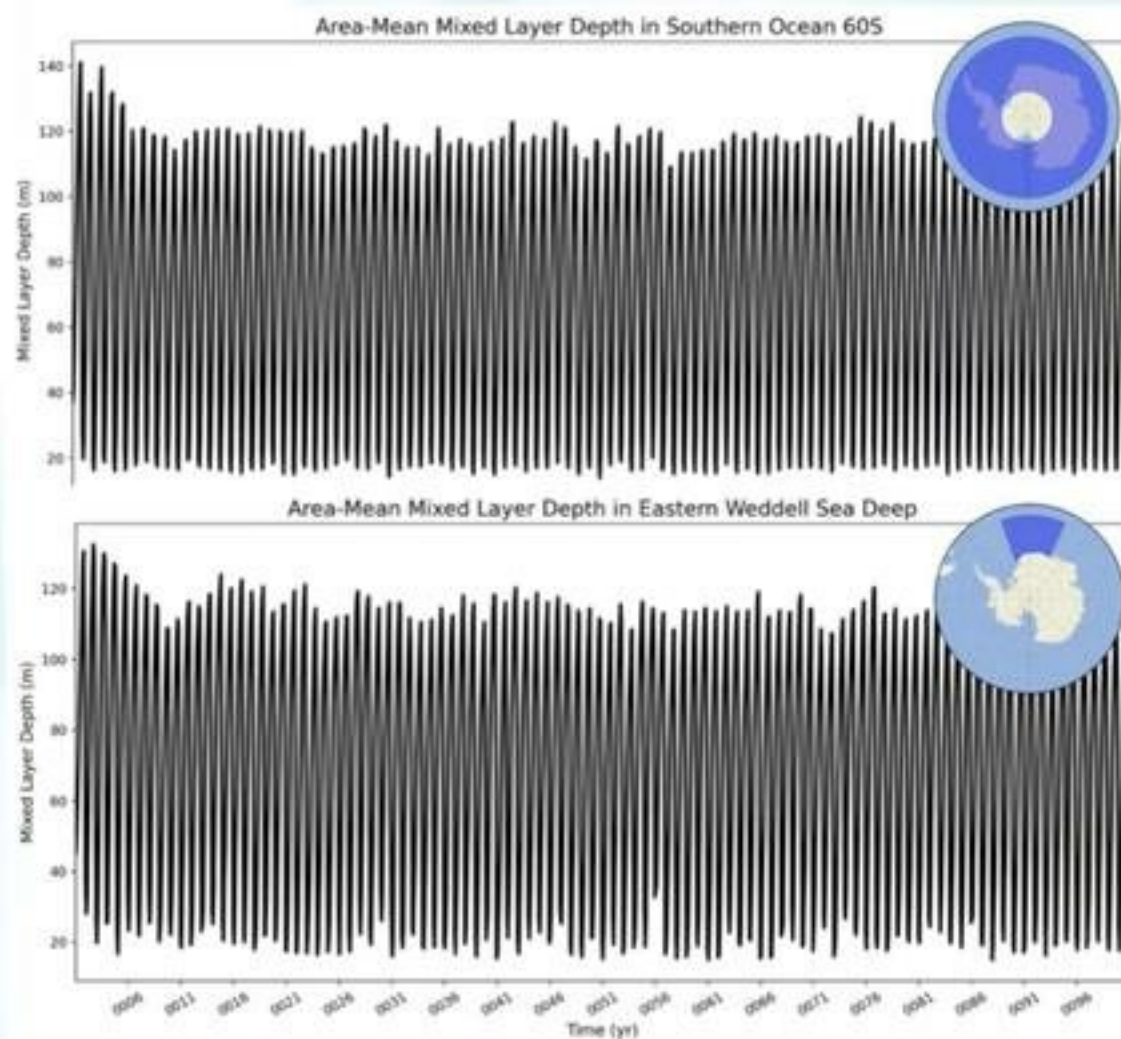
SORRM



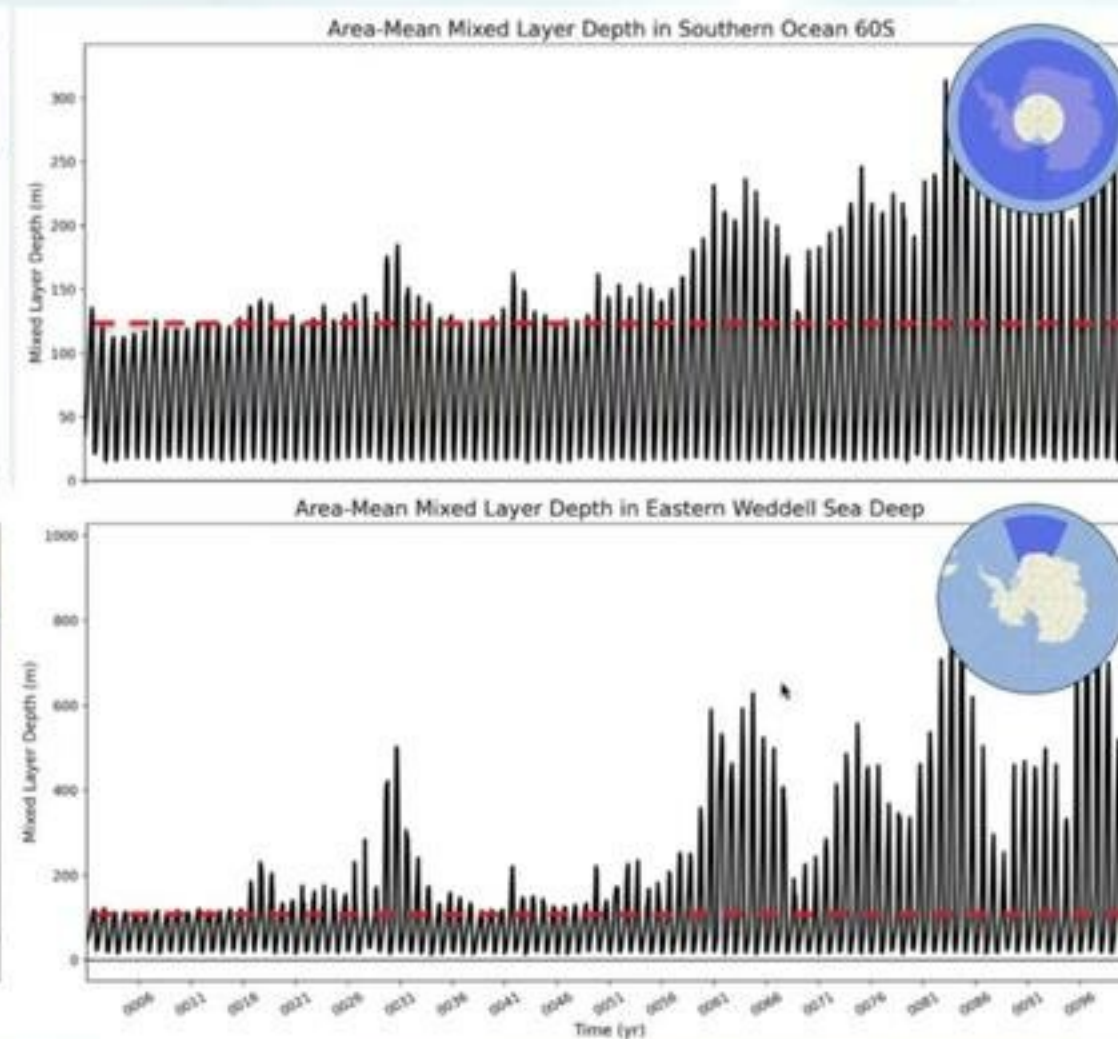


# Mixed layer depths

Low-res

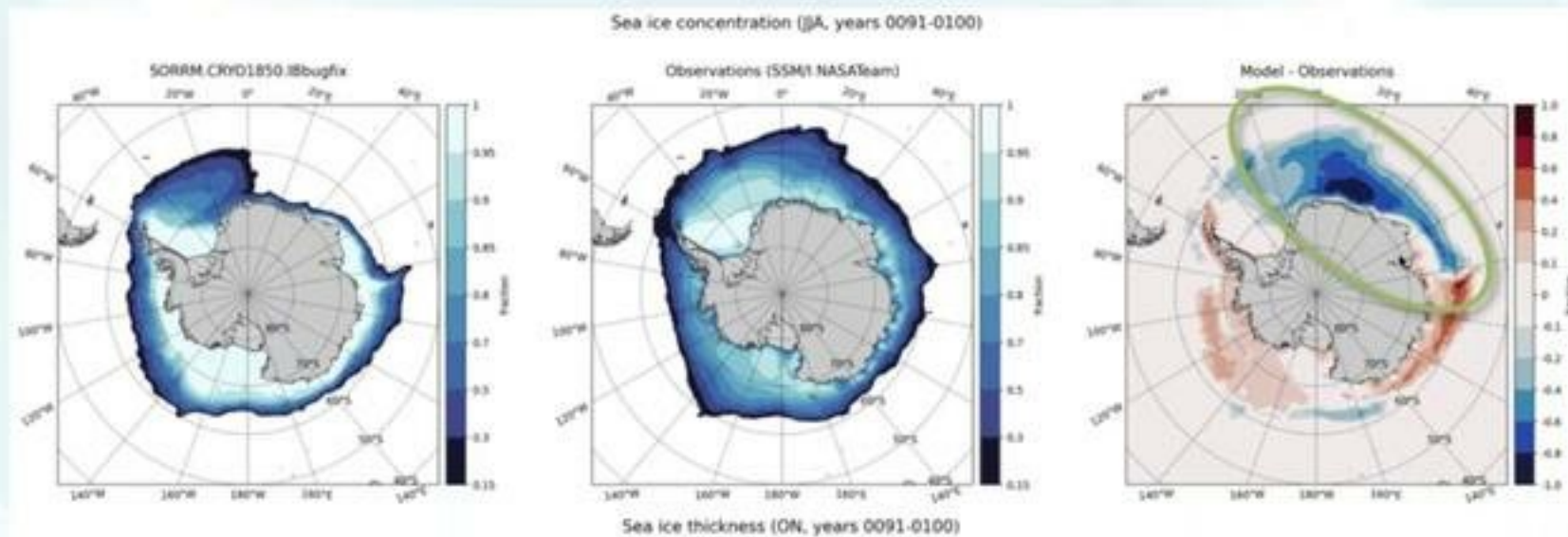


SORRM

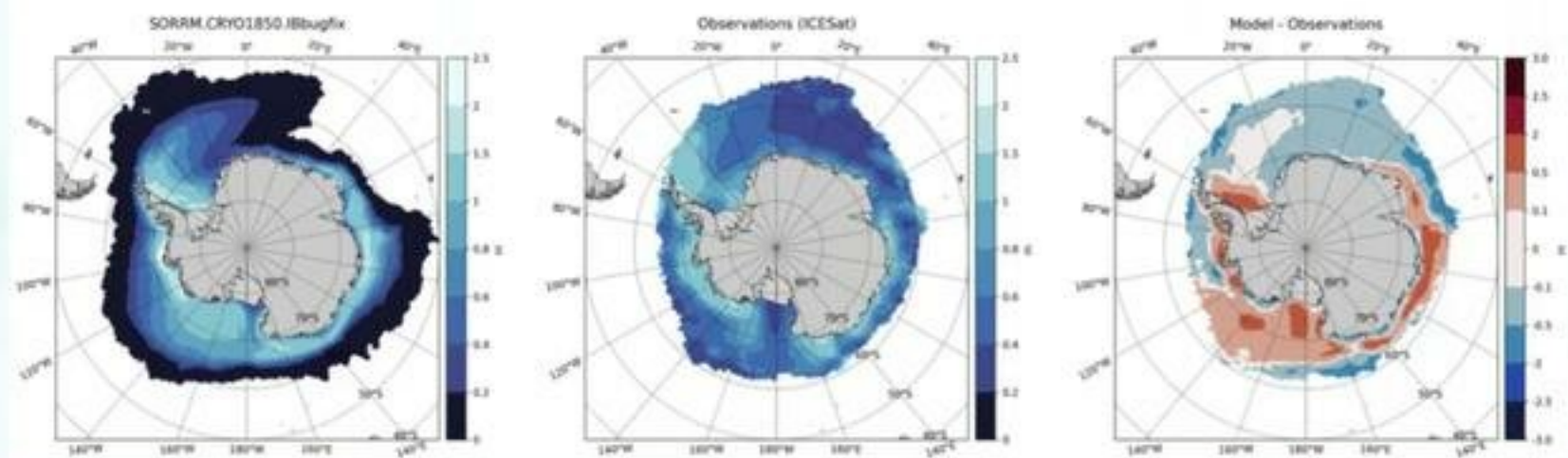


# SORRM Winter Sea Ice

Concentration



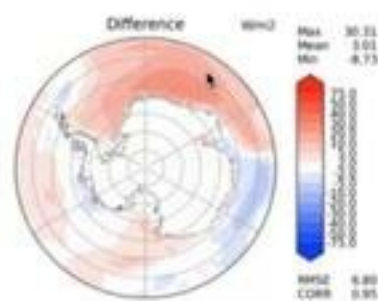
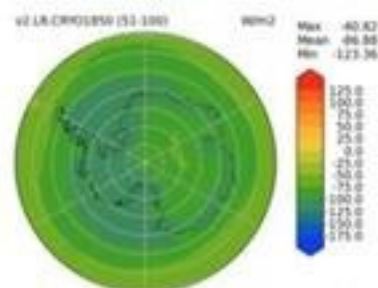
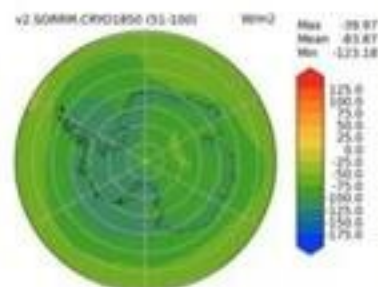
Thickness



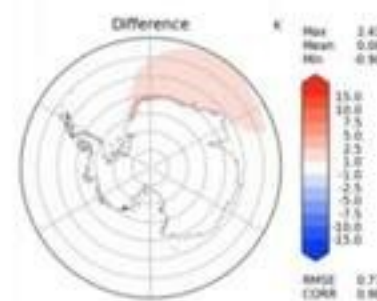
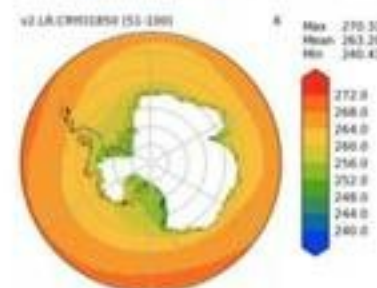
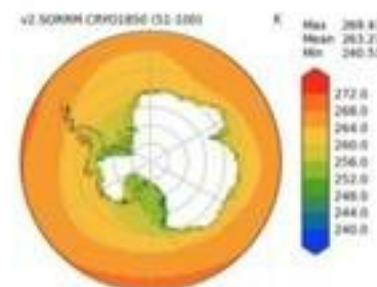


# Atmospheric impacts of SORRM sea ice loss

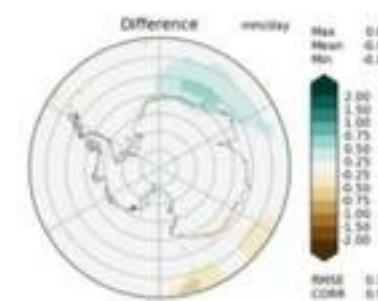
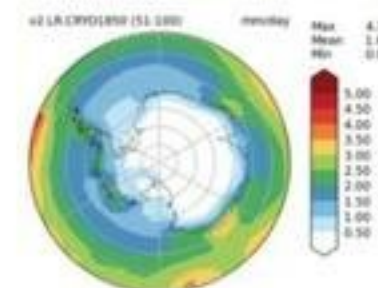
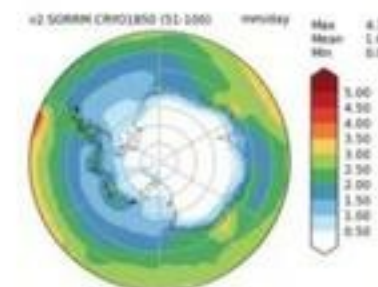
RESTOM ANN polar\_S



T 850 mb ANN polar\_S



PRECIP ANN polar\_S



## E3SM v2 Cryosphere Simulation Biases

- SORRM Southern Ocean biases present a problem with moving forward
  - Regional surface warm bias leads to sea ice loss
  - In Amundsen/Bellingshausen seas, seafloor temperatures far too cold, leading to too low melt rates
- In the SORRM configuration, the ocean's mesoscale eddy parameterization, GM, is turned off by default in the Southern Ocean.
- However 12km is too coarse to fully resolve these eddies.
- Additional 50 year tuning runs were done to assess impact on Southern Ocean biases
  - GM off (default)
  - GM on (constant GM, same as low resolution)
  - GM taper (Visbeck GM parameterization, min kappa value set)

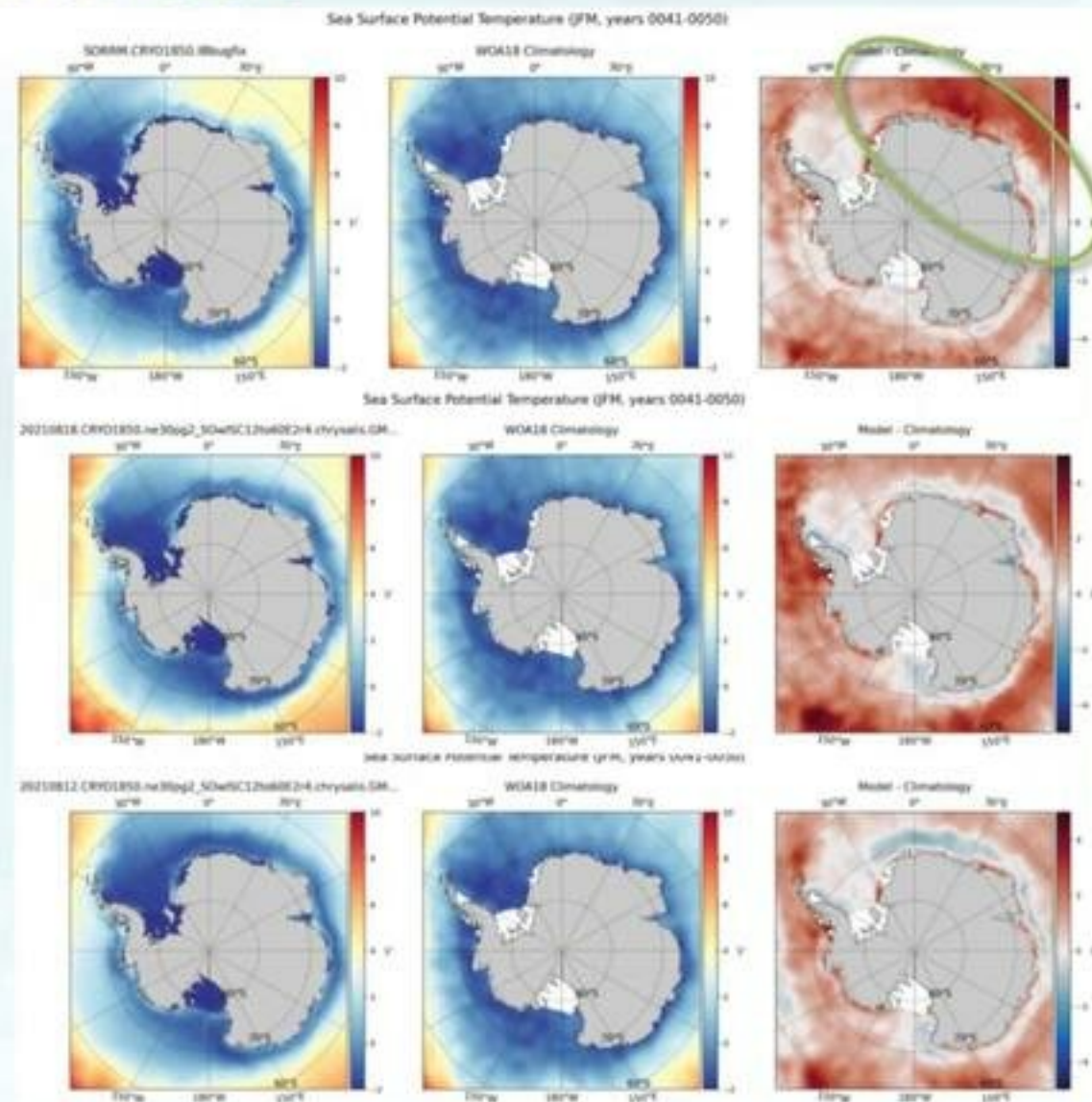


# SORRM Summer SST

GM off (default)

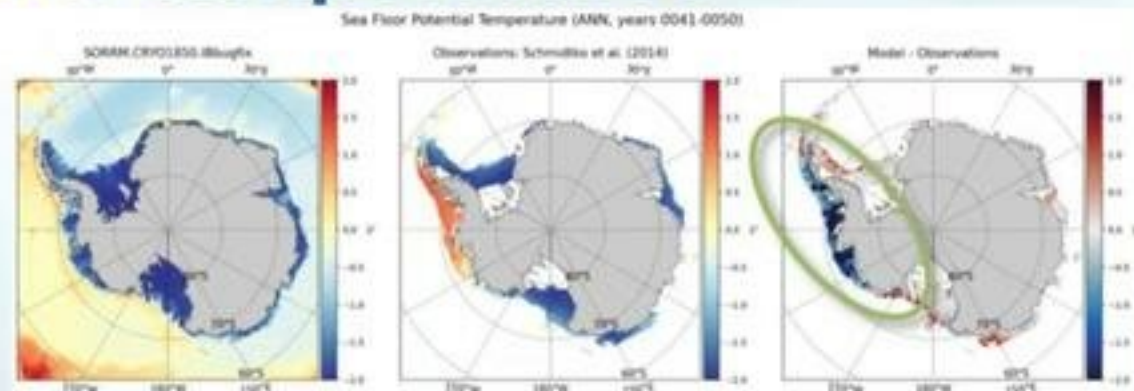
GM taper

GM on

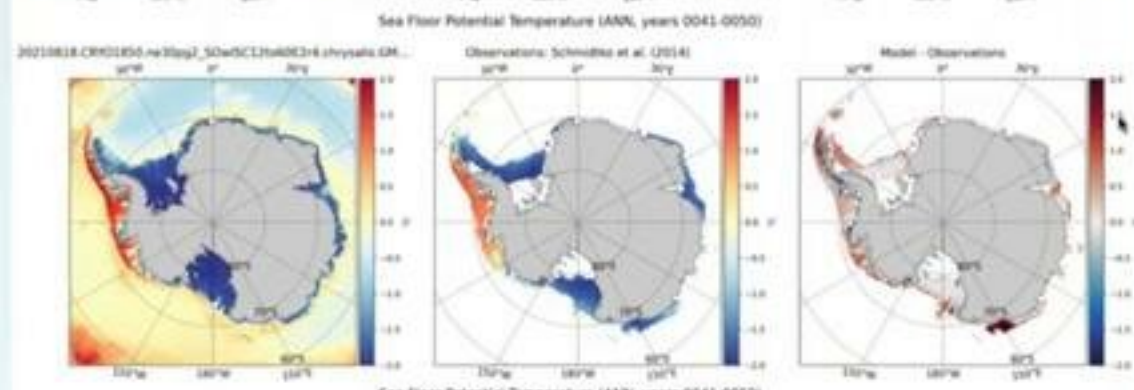


# SORRM Seafloor temperatures

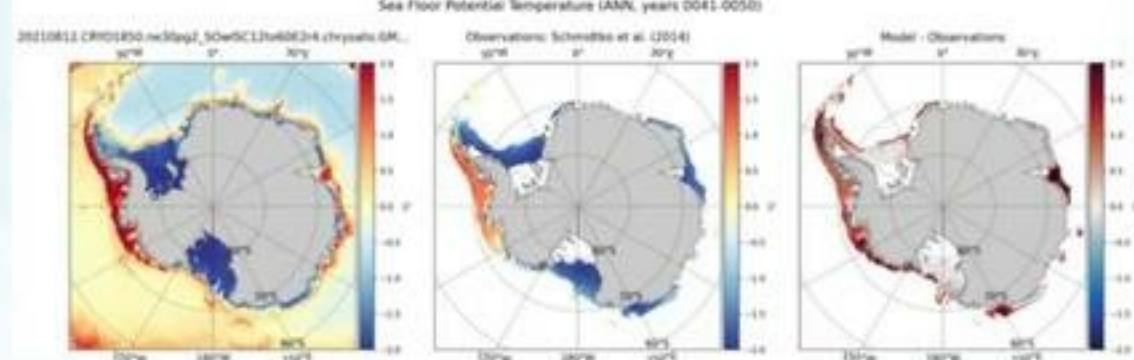
GM off (default)



GM taper



GM on



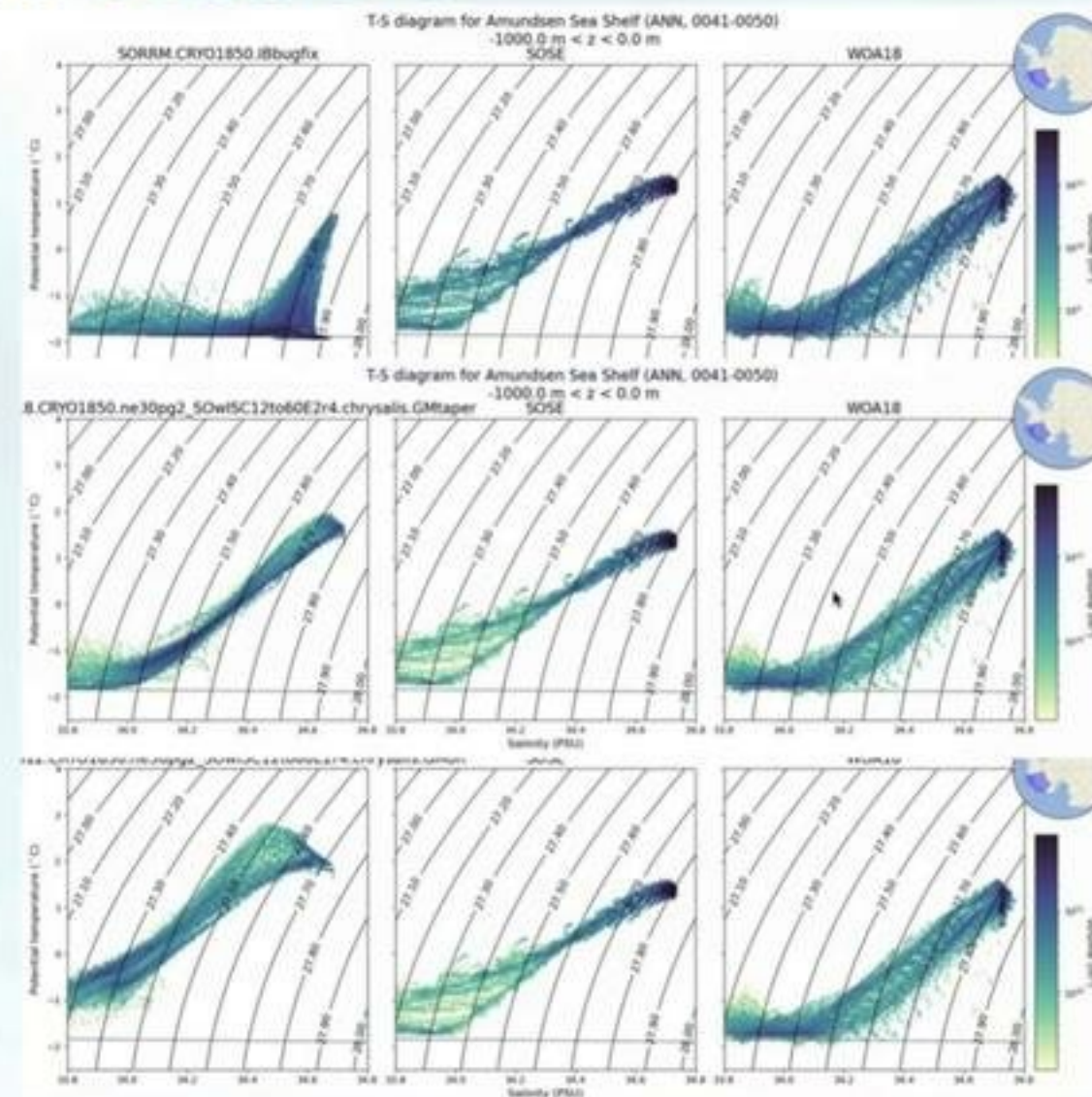


# Amundsen Sea Shelf T-S

GM off (default)

GM taper

GM on

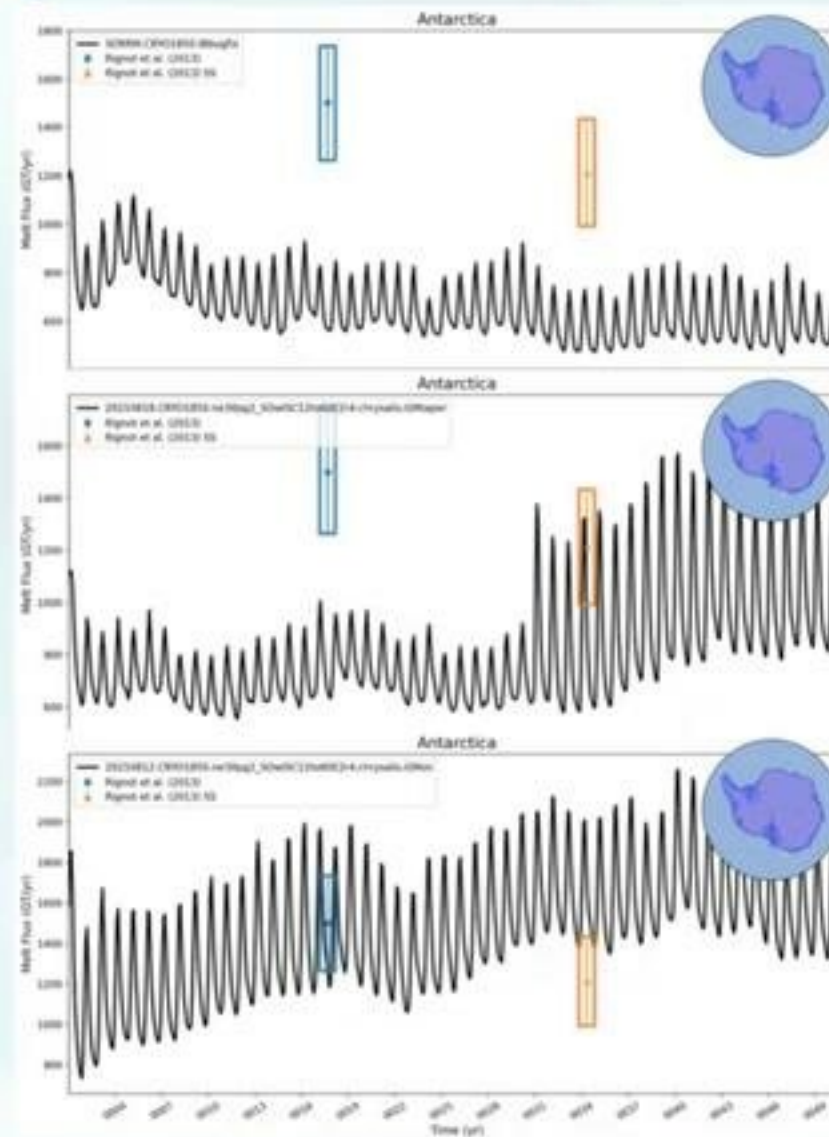


# SORRM Melt rates

GM off (default)

GM taper (incorrect GM  
parameter reset at year 30)

GM on





## Summary

- Southern Ocean in E3SM v1 (low resolution)
  - With standard GM parameterization, leads to 'tipping point' to high melt regime under large Antarctic ice shelf (under pre-industrial forcing); simulation unusable to branch to historical/scenario runs.
  - Improving upon GM parameterization with variable (stratification-dependent) bolus kappa coefficient sufficiently mitigates biases; simulation produces 'stable' Antarctic ice-shelf melt rates in line with present-day observations.
  - This model 'fix' was sufficient, perhaps not necessary; higher resolution, improved model physics (e.g. better representation of tidal forcing) may also help alleviate SO T-S biases.
- Southern Ocean in E3SM v2 (SO regionally-refined grid)
  - Preliminary low resolution and SORRM piControl simulations show promise with respect to melt rate stability, though problematic biases still exist.
  - Tuning is ongoing to reduce these biases; middle ground between GM off and standard GM on seems promising.
  - With stable simulations, will be able to begin transient simulations.

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