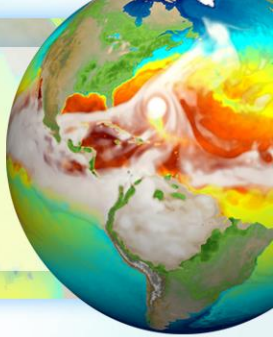


Recent Findings from the E3SM Cryosphere Science Campaign

Darin Comeau, Milena Veneziani, Xylar Asay-Davis

Carolyn Begeman, Kristin Hoch, Matt Hoffman, Hyein Jeong, Wuyin Lin, Mark Petersen, Steve Price, Luke Van Roekel, Jon Wolfe

Outline

- Current Status of E3SM Cryosphere Campaign
- Preliminary Simulations Results
- Investigating Biases

E3SM Cryosphere Campaign: Goals and Plans

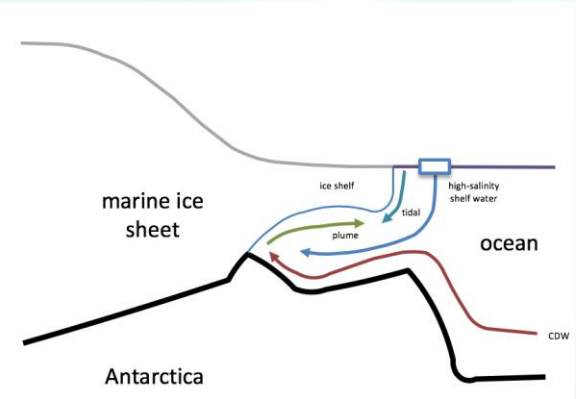
- V1 Science Question:
  - What are the impacts of ocean-ice shelf interactions on melting of the Antarctic Ice Sheet, the global climate, and sea level rise?
- Simulation Plan:

Table 3. E3SM v1 Cryosphere experiment: Planned simulations.

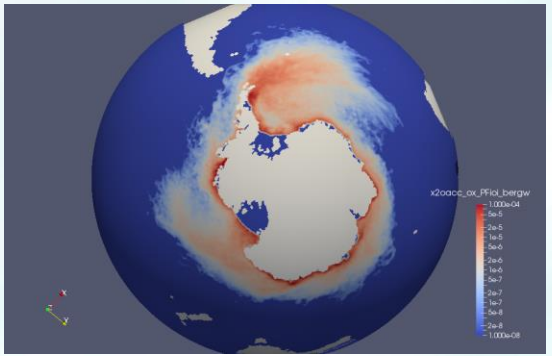
	Simulation	Atmos (km)	Ocean (km)	Simulated Years	Notes
We are still here	Pre-industrial (1850) control with ice cavities	100	30-60	250	Water Cycle Experiment is the control. Single member -- branched at year 250 from water cycle simulation.
We should be here	Historical transient (1850-2014) with ice 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
We may skip this	CORE-II w/ and w/o ice cavities	data	6-18	50	The standard high-resolution ocean mesh.
Working on this	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.

Cryosphere Model Configuration

- Ocean circulation within ice shelf cavities
  - Allows for prognostic calculation of ice shelf melt fluxes (ISMF).



- Different treatment of Antarctic runoff
  - To avoid 'double-counting' runoff due to ISMF, Antarctic runoff is disabled.
  - To account for iceberg calving, data iceberg forcing is used.



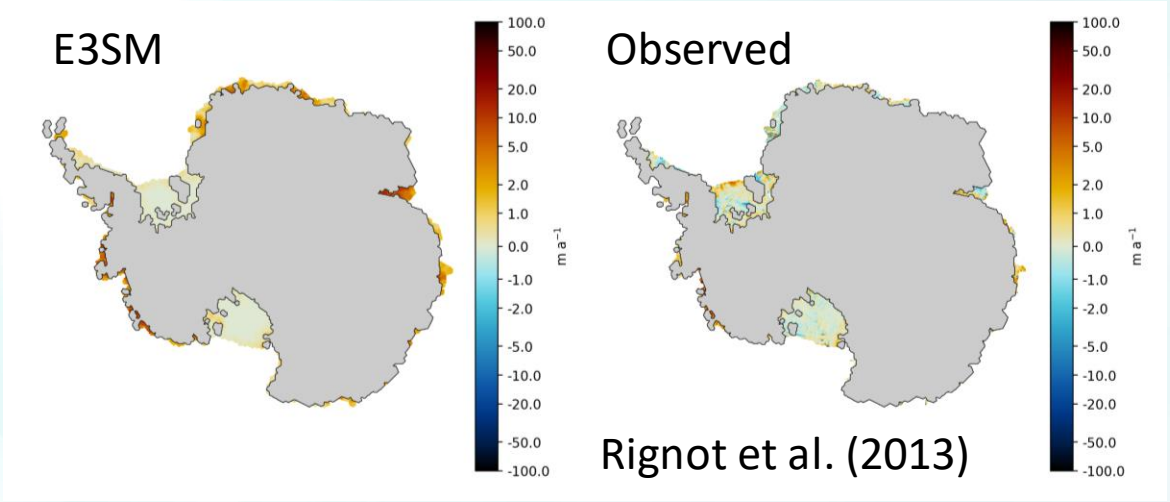
Current Status of Cryosphere Simulations

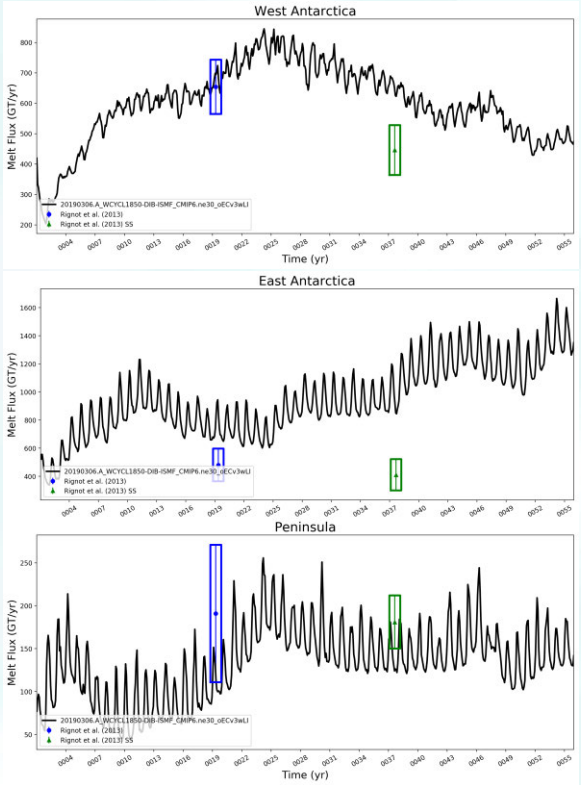
- We began running production simulations in the beginning of March 2019

Simulation	Ocean Grid	Ice Shelf Cavities	Ice Shelf Melt Fluxes	Data Icebergs	AIS Runoff*	Simulated Years
A_WCYCL1850_CMIP6	60to30km	☑	☑	☑	☐	156
A_WCYCL1850_CMIP6	60to30km	☑	☐	☑	☐	153
A_WCYCL1850_CMIP6	60to30km	☑	☐	☐	☑	30
GMPAS-IAF	60to30km	☑	☑	☑	☐	174
GMPAS-IAF	60to30km	☑	☑	☐	☑	131
GMPAS-IAF	60to30km	☑	☐	☑	☑	181
GMPAS-IAF	60to30km	☑	☐	☐	☑	132
GMPAS-IAF	30to10km	☑	☑	☑	☐	26
GMPAS-IAF	30to10km	☑	☐	☑	☑	30

*G-cases use modified AIS to avoid double-counting

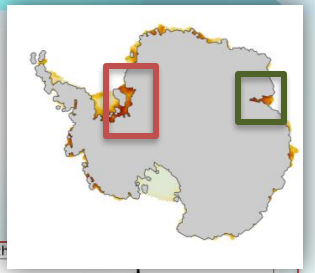
Cryosphere Simulation Preliminary Results: Fully coupled simulation, years 25-55



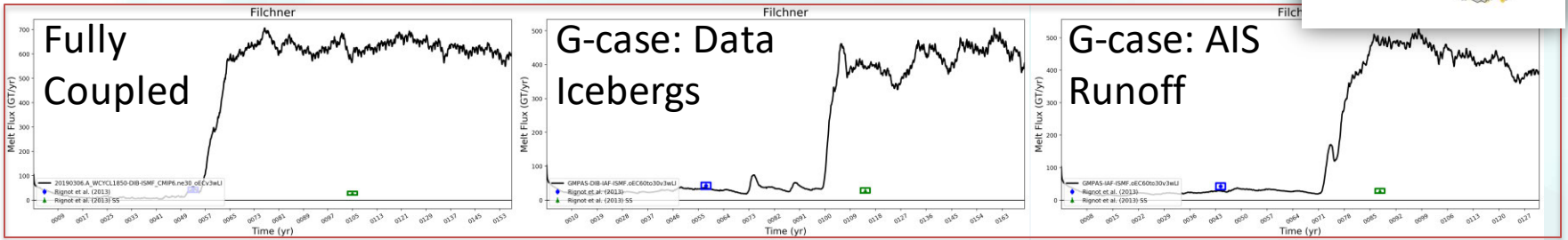


The Showstopper

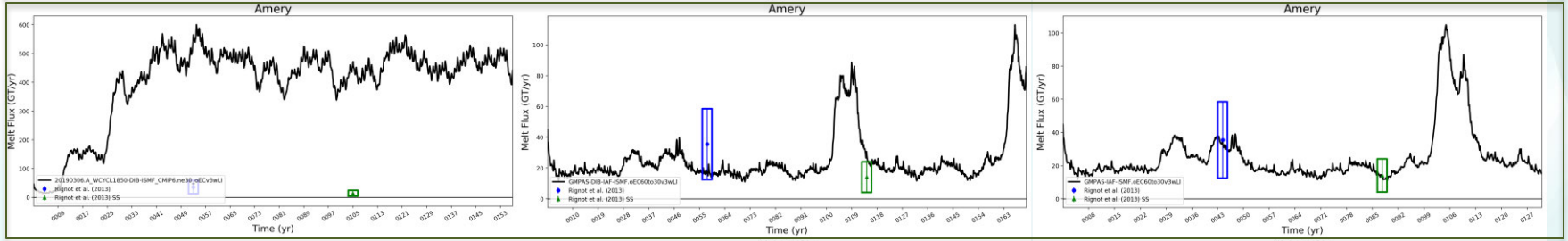
- Certain ice shelves experience a rapid, then sustained, increase in melt rates



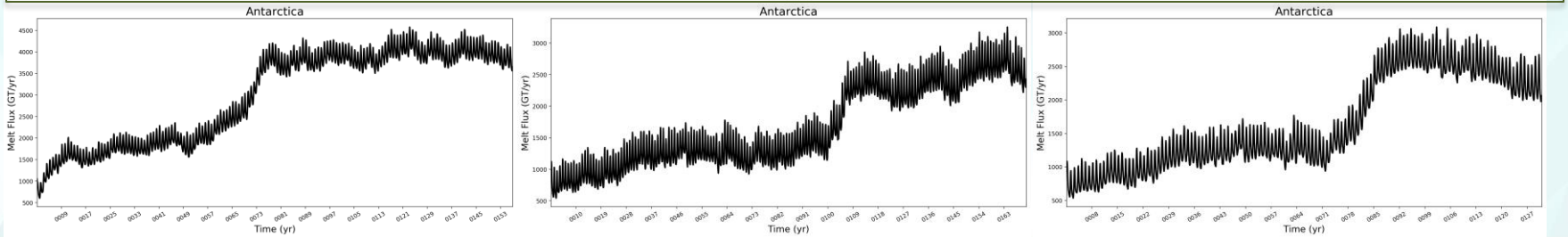
Filchner



Amery

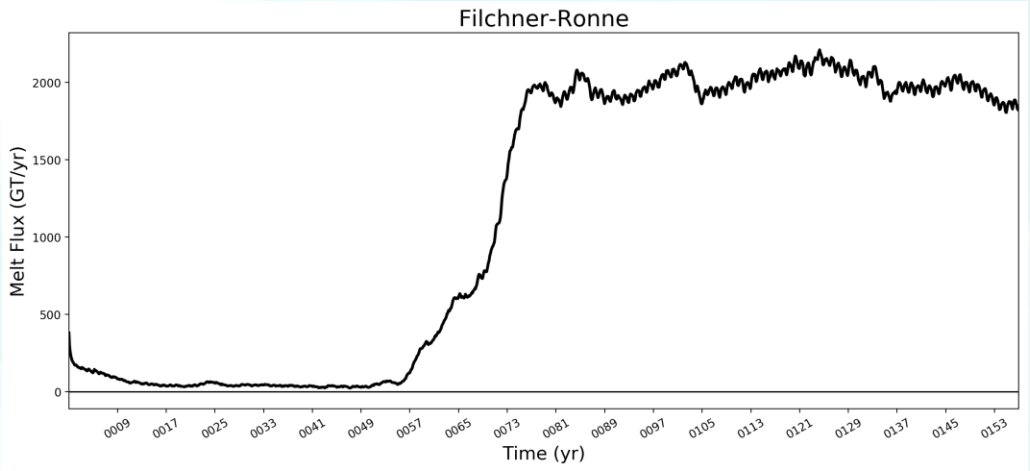


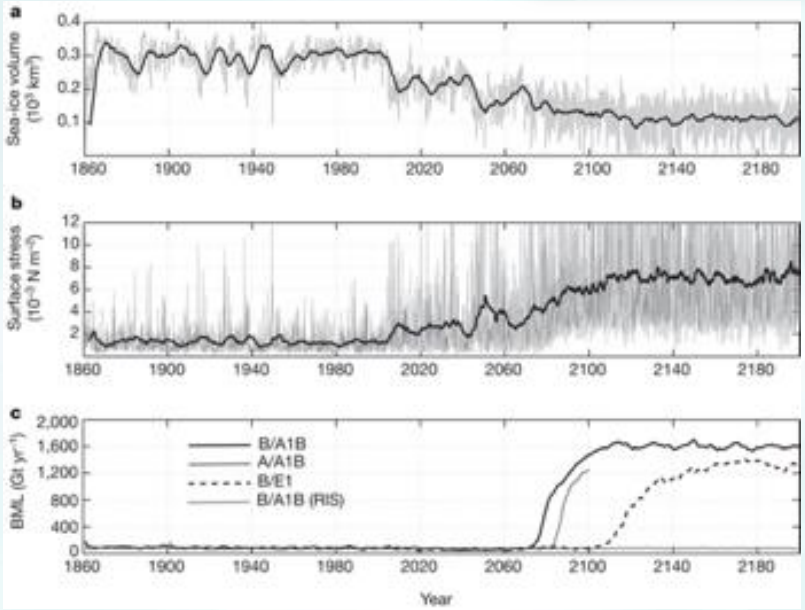
Antarctica



The Showstopper

- Others have seen this before...

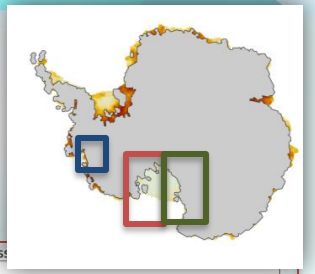




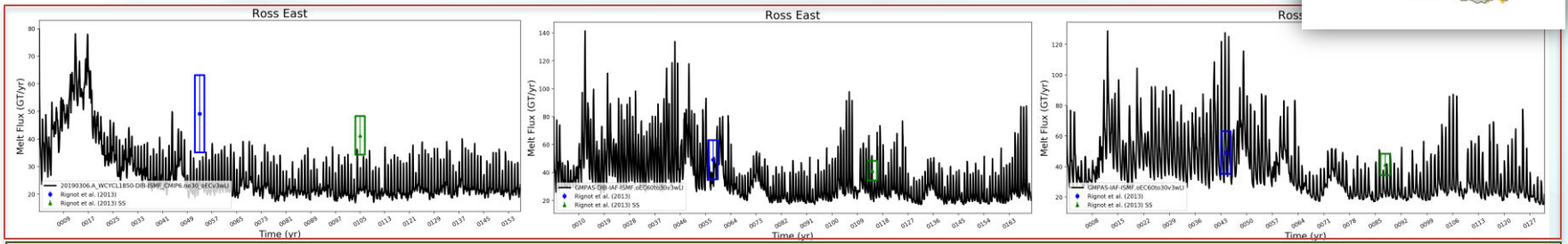
HH Hellmer *et al. Nature* **485**, 225-228 (2012)
doi:10.1038/nature11064

The Showstopper

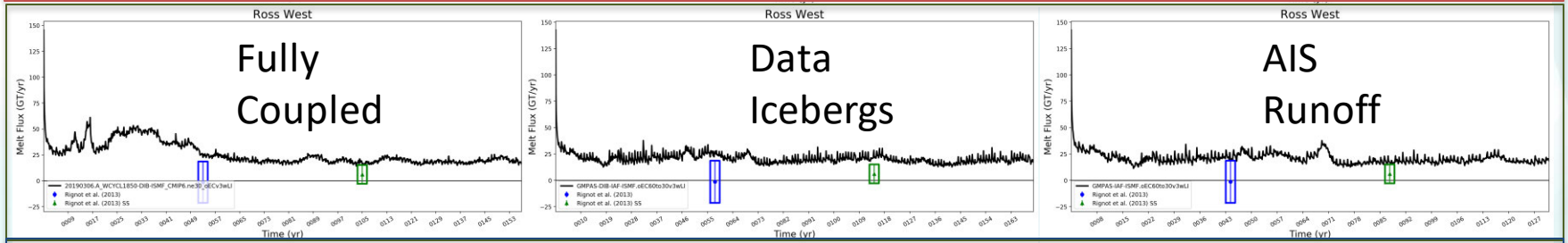
- Not all ice shelves are affected



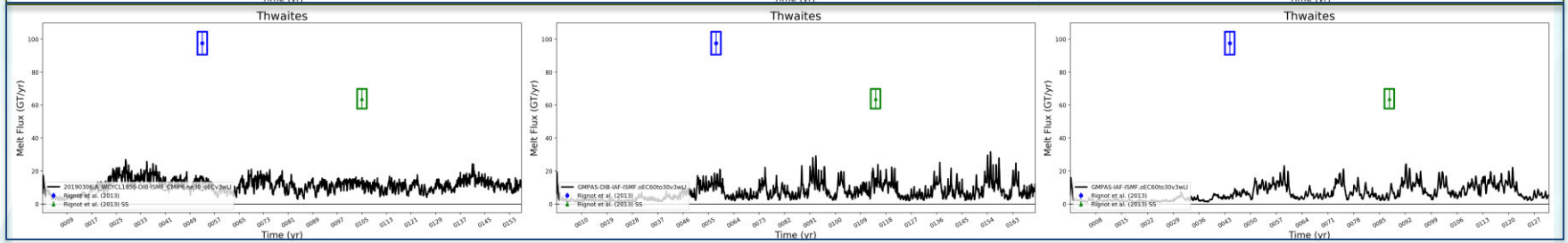
Ross East



Ross West

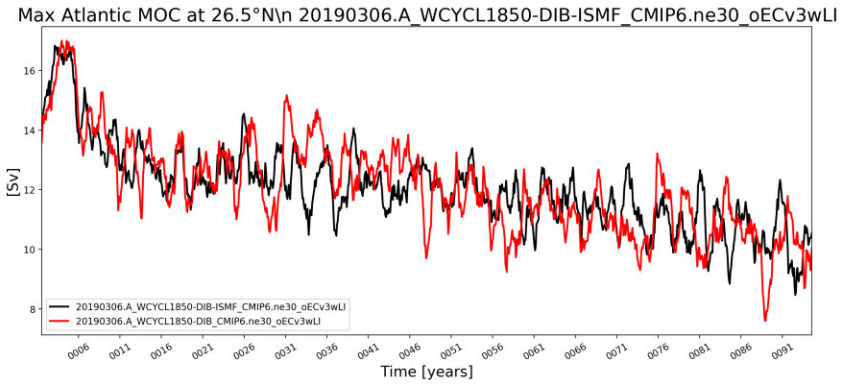


Thwaites



Cryosphere Simulation Preliminary Results: Fully-coupled, global metrics

- Global Meridional Overturning Circulation (MOC)
- Comparison w/ ISMF vs. w/o



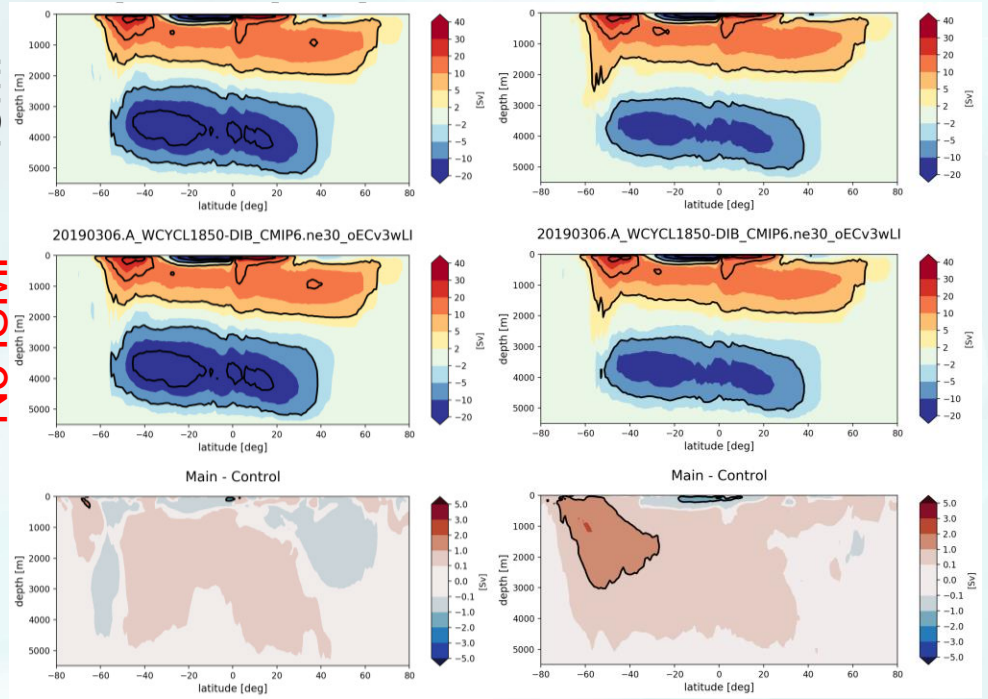
Max at 26.5 N

Years 25-55

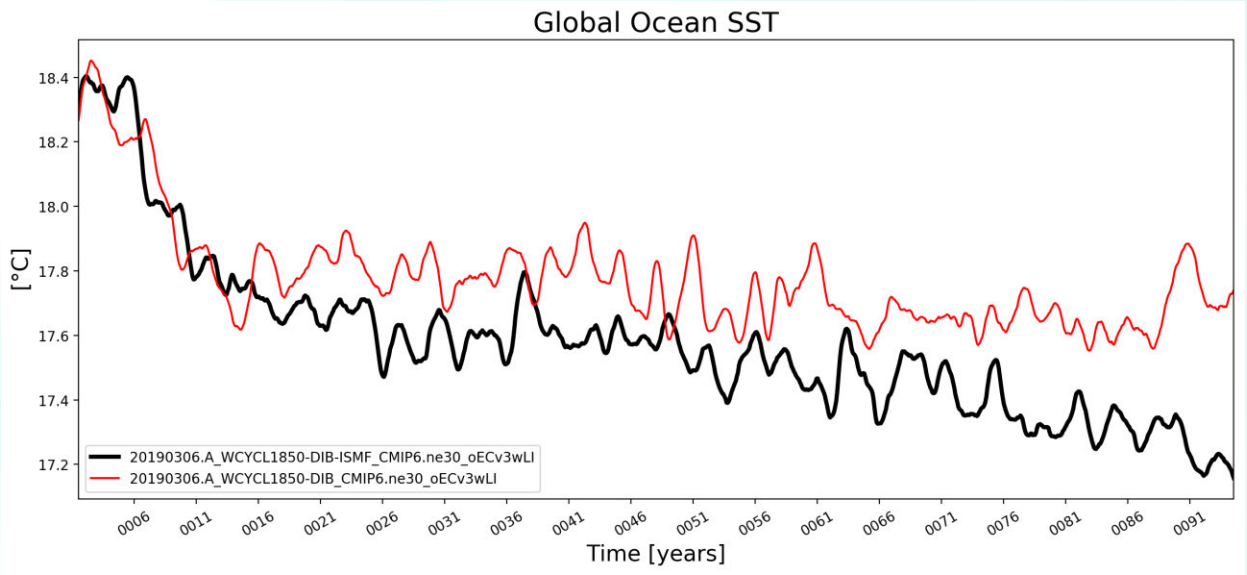
Years 44-94

ISMF

No ISMF

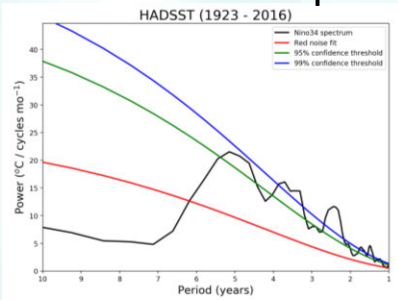


Cryosphere Simulation Preliminary Results: Fully-coupled, global metrics

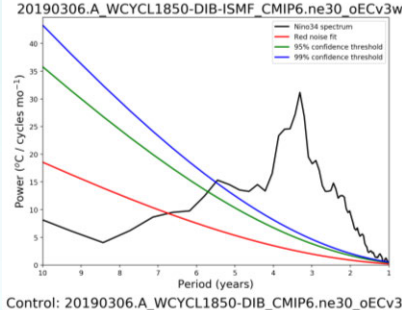


El Nino 3.4 Power Spectrum

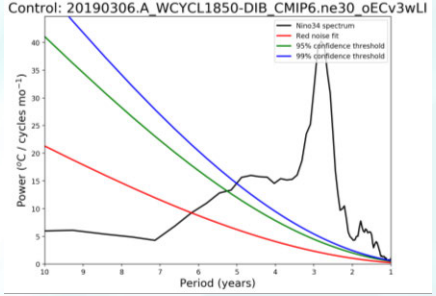
Obs.



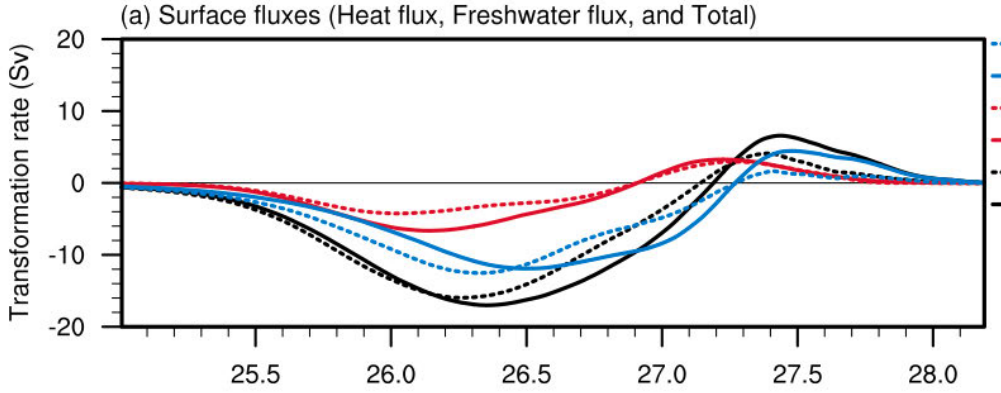
ISMF



No ISMF

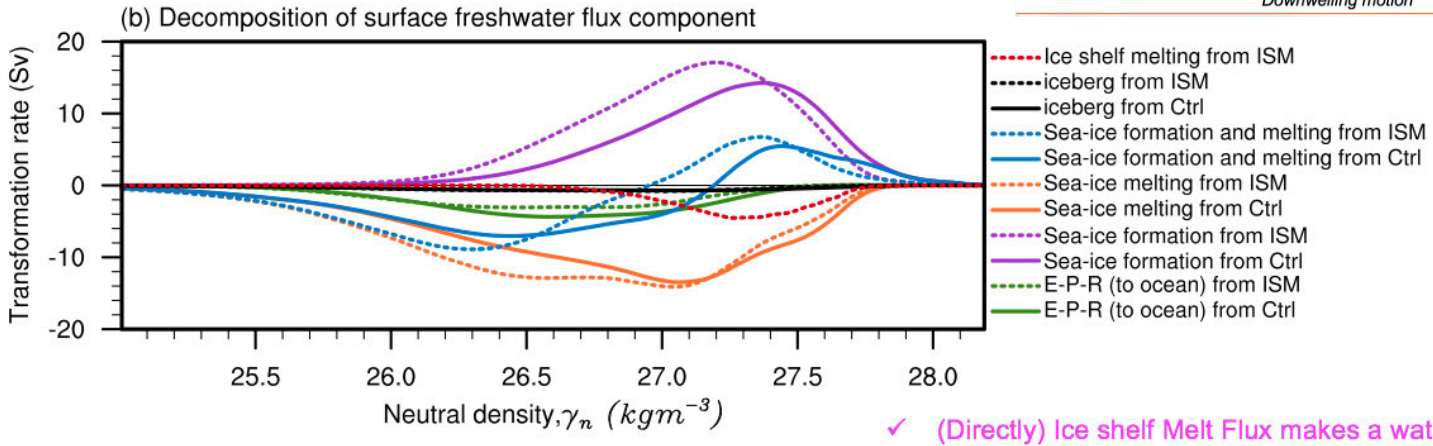


Annual water-mass transformation rate, last 30 years



✓ Freshwater flux term is changed a lot

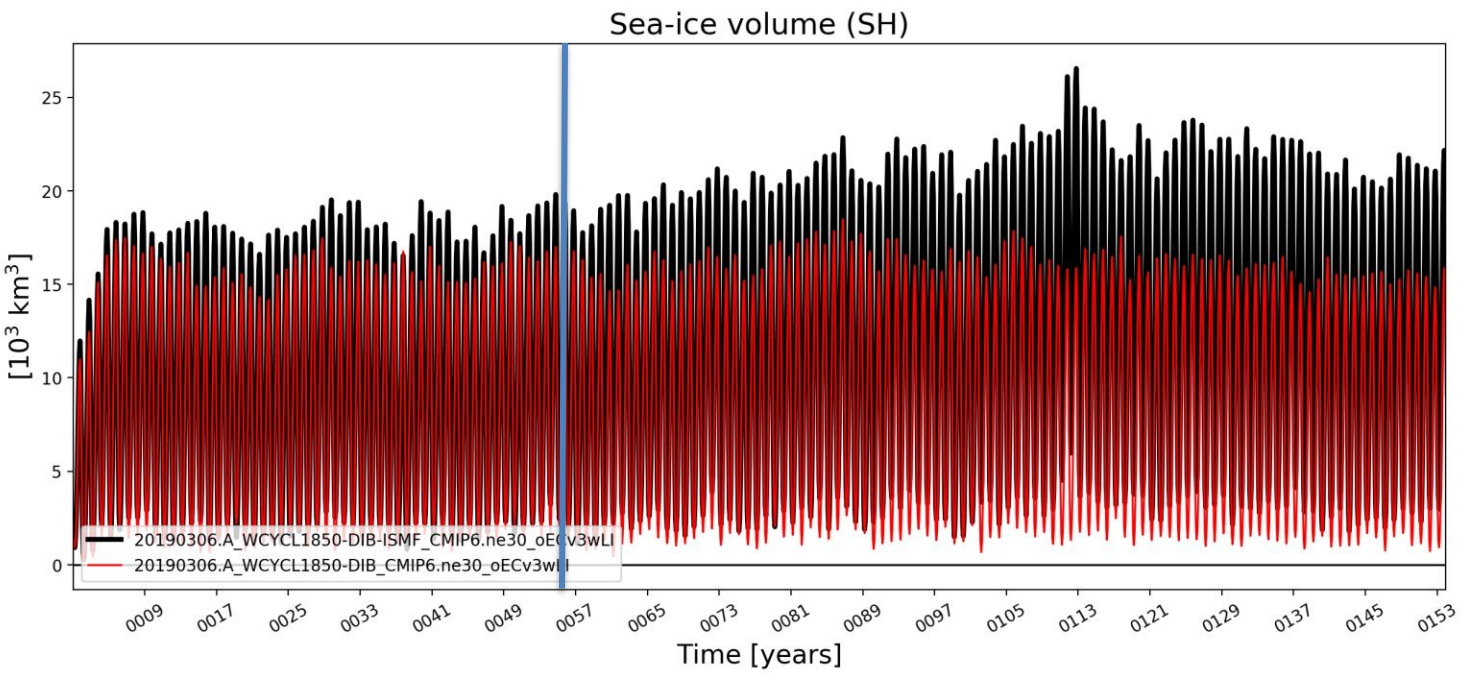
	Positive	Negative
Transformation rates	*Denser* *Lose buoyancy*	*Lighter* *Gain buoyancy*
Formation rates	*Water convergence* *Downwelling motion*	*Water divergence* *Upwelling motion*



✓ (Directly) Ice shelf Melt Flux makes a water lighter
✓ (Indirectly) sea-ice formation and melting changed

Credit: Hyein Jeong

Fully-coupled, sea ice volume

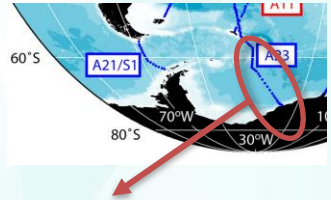


w/ ISMF

w/o ISMF

Focus on near-shelf results in the SO

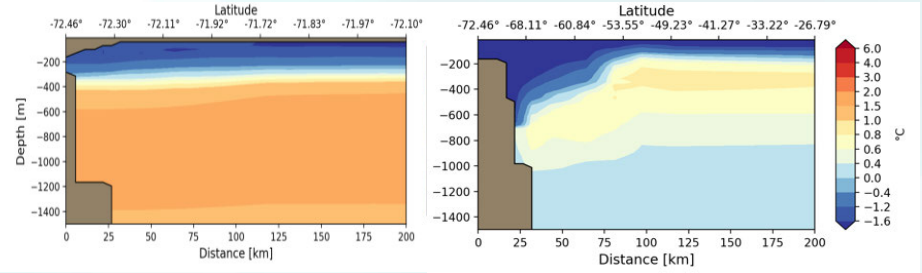
Stratification near the shelf and the associated Antarctic slope current are very important for cross-shelf water transport

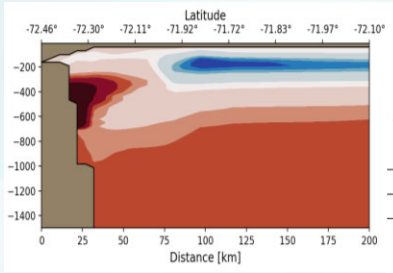


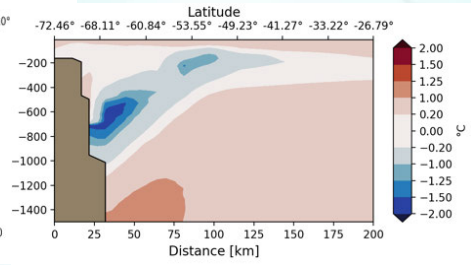
Comparison of low-res (30 km) and high-res (6 km) runs against WOCE observations

E3SM-LR-ISMF | **Obs** | **E3SM-LR-ISMF bias** | **E3SM-HR bias**

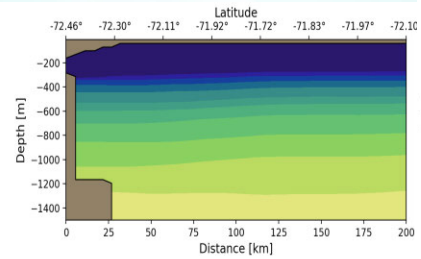
Temperature transect

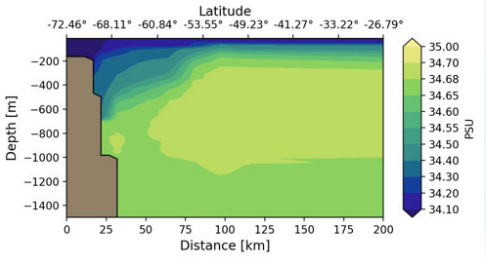


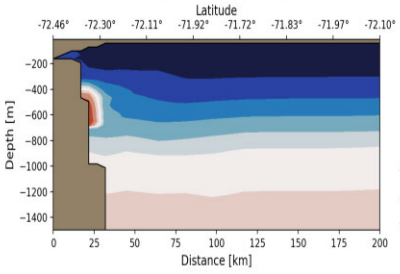


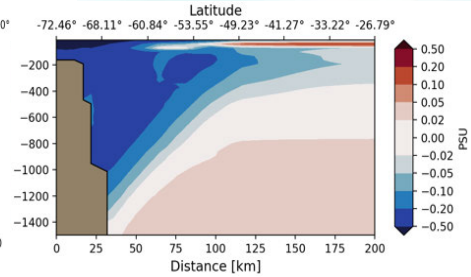


Salinity transect









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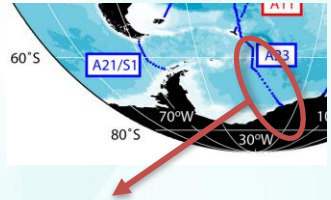
Stratification near the shelf and the associated Antarctic slope current are very important for cross-shelf water transport



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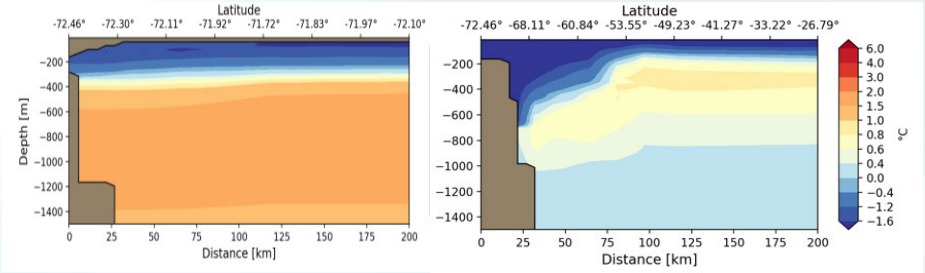
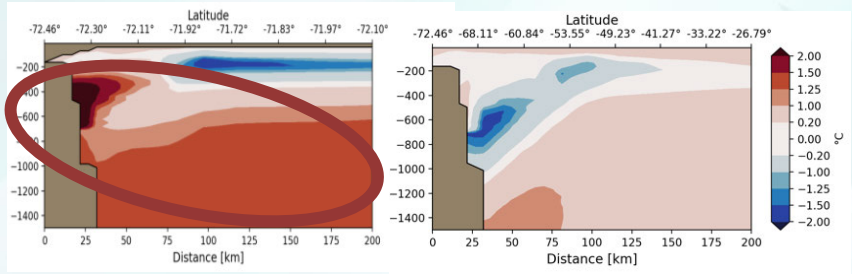
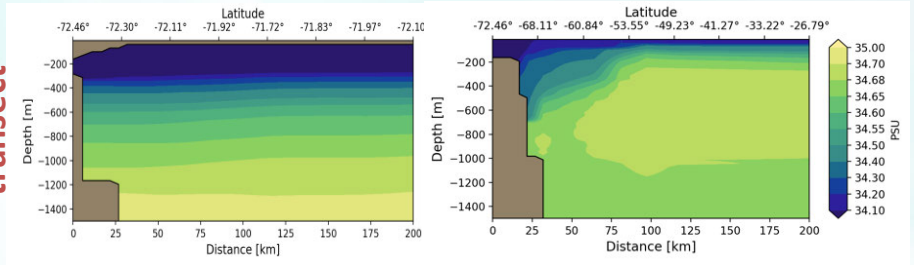
E3SM-LR-ISMF | **Obs** | **E3SM-LR-ISMF bias** | **E3SM-HR bias**

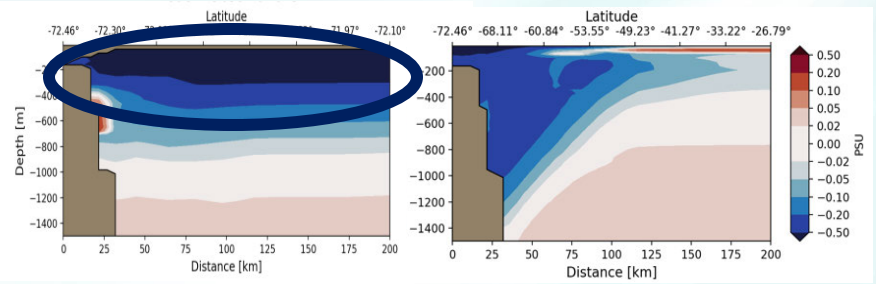
Temperature transect





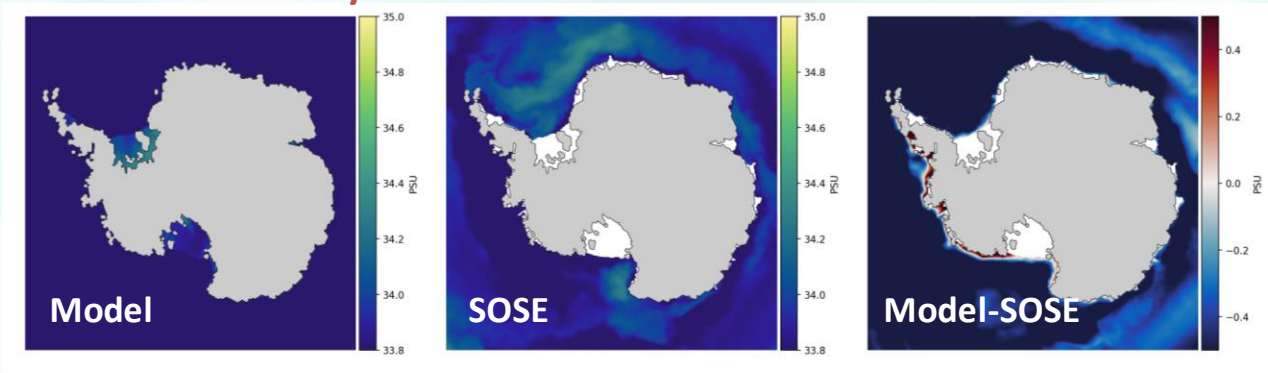
Salinity transect



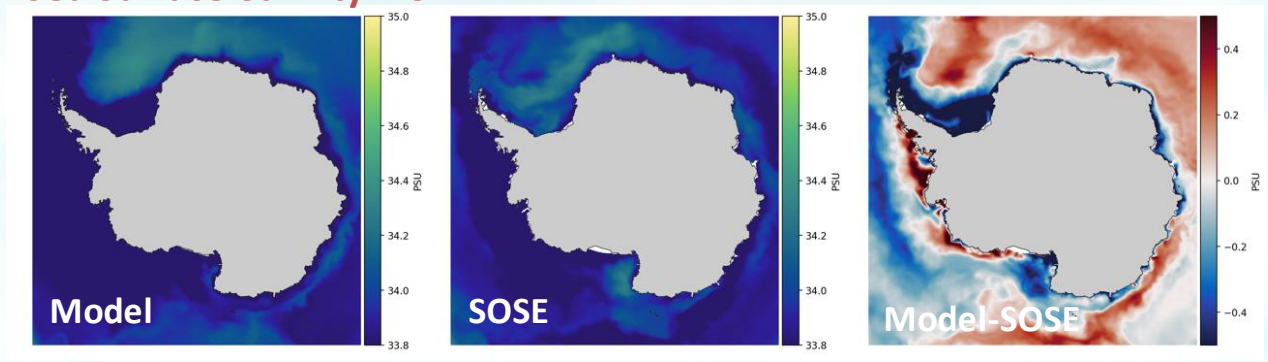


Southern Ocean upper ocean Salinity bias

Sea Surface Salinity from LR

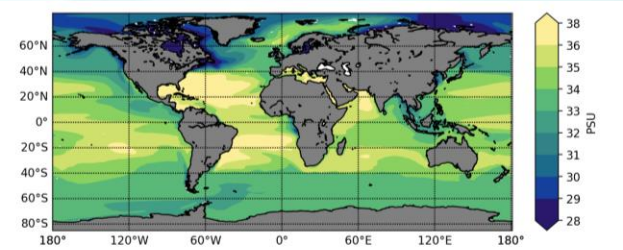


Sea Surface Salinity from HR

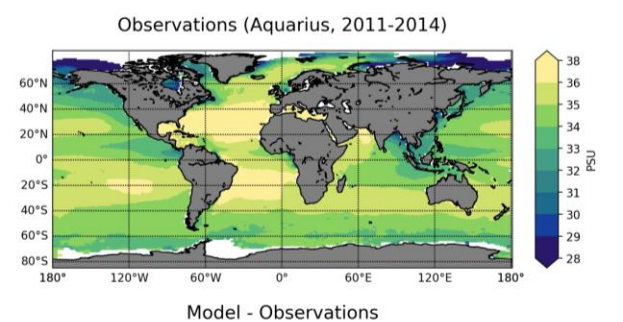


Surface salinity fresh bias is an almost global feature in LR E3SM (not just in cryo-experiments)

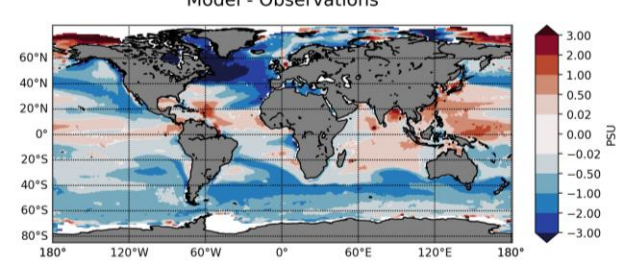
E3SM-LR-ISMF Years 16-55



Obs



Model-Obs



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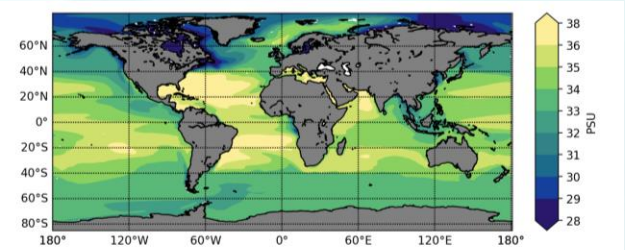
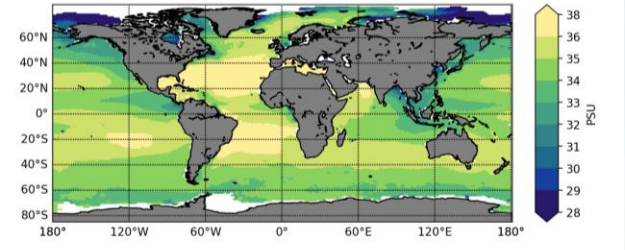
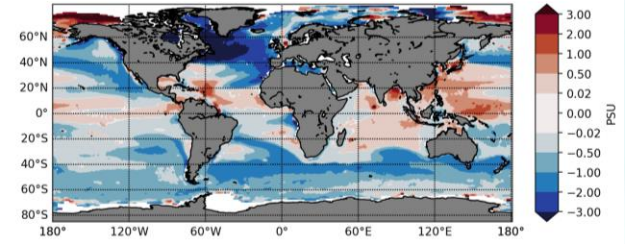
E3SM-LR-ISMF
Years 16-55



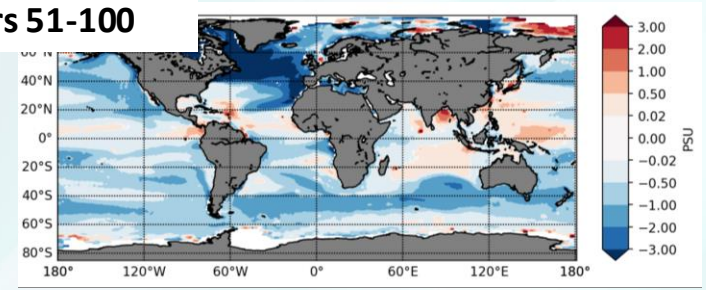
Obs



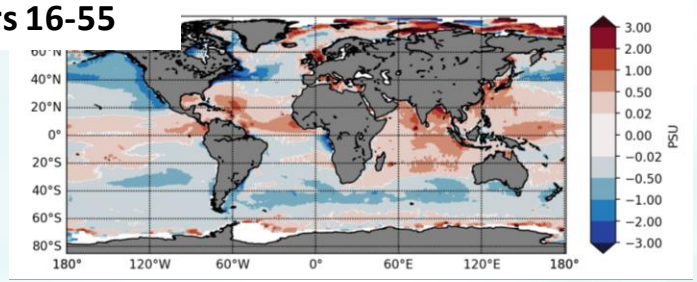
Model-Obs



E3SM-LR-v1Deck
Years 51-100



E3SM-HR
Years 16-55



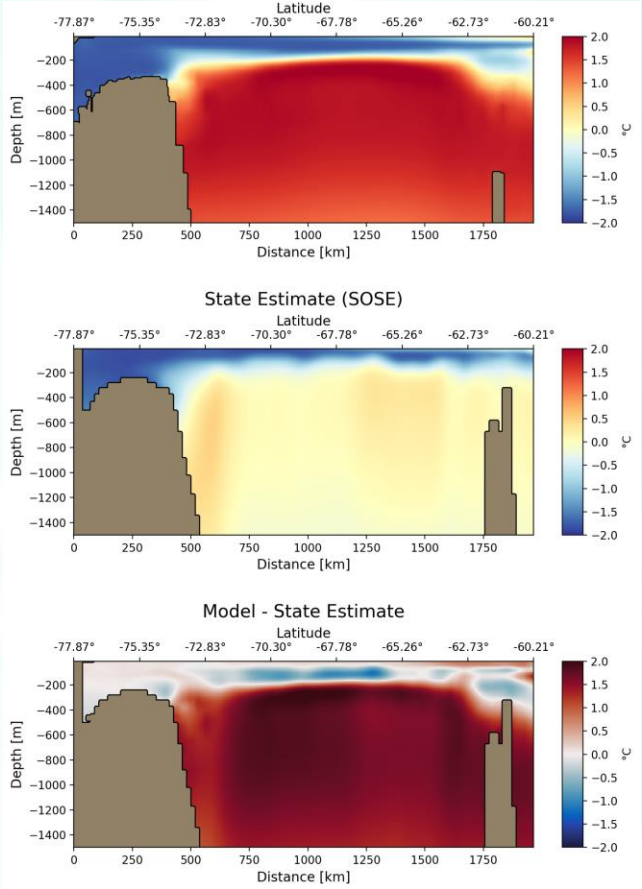
Understanding biases – early in simulation (25-55)

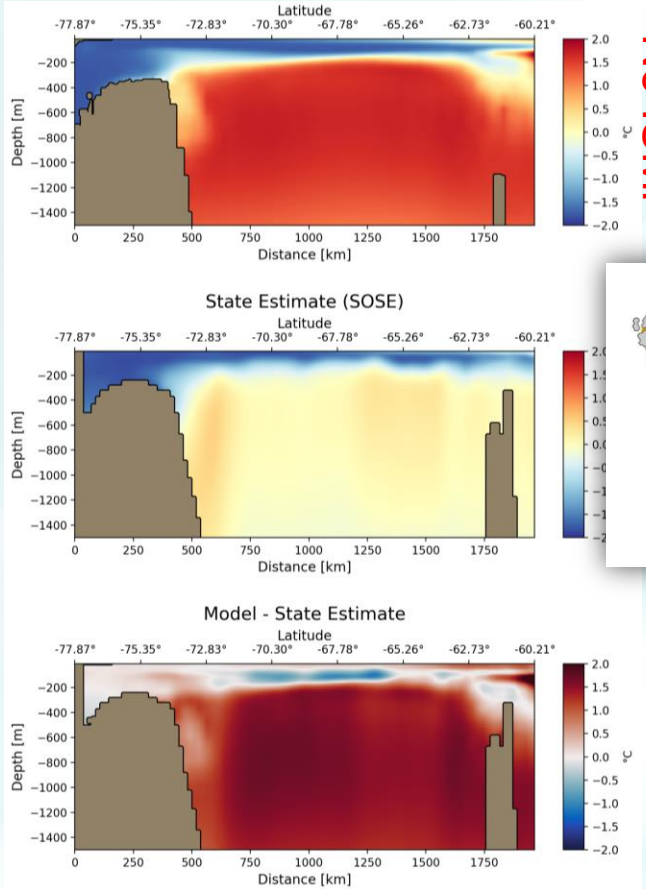
ISMF

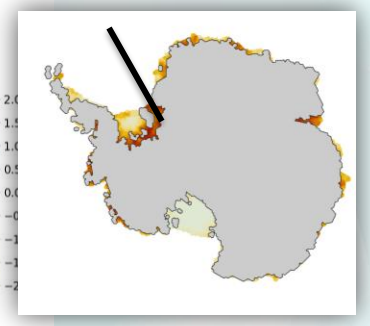
Reanalysis

Bias

No ISMF

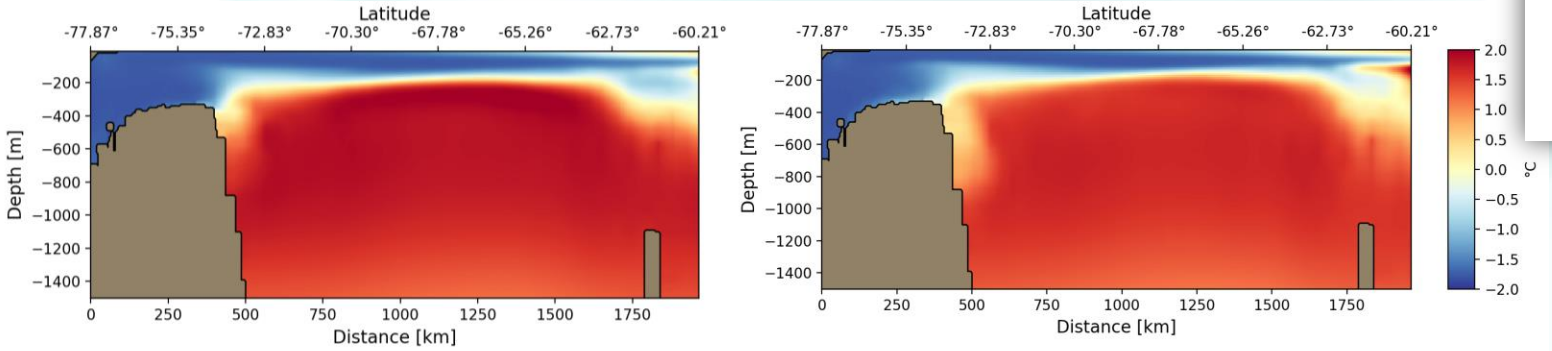




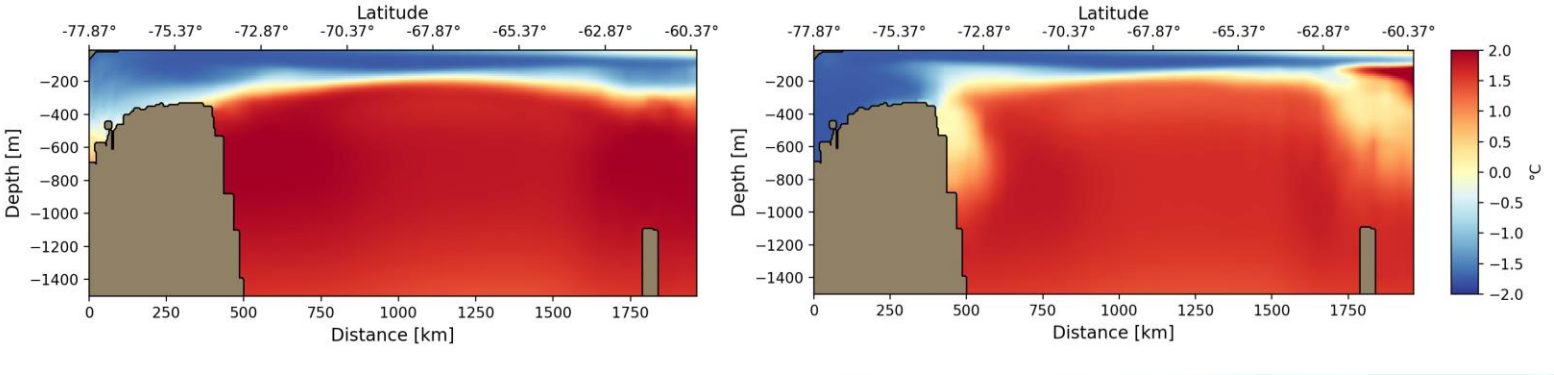


Understanding biases – late in simulation

ISMF Years 25-55 No ISMF

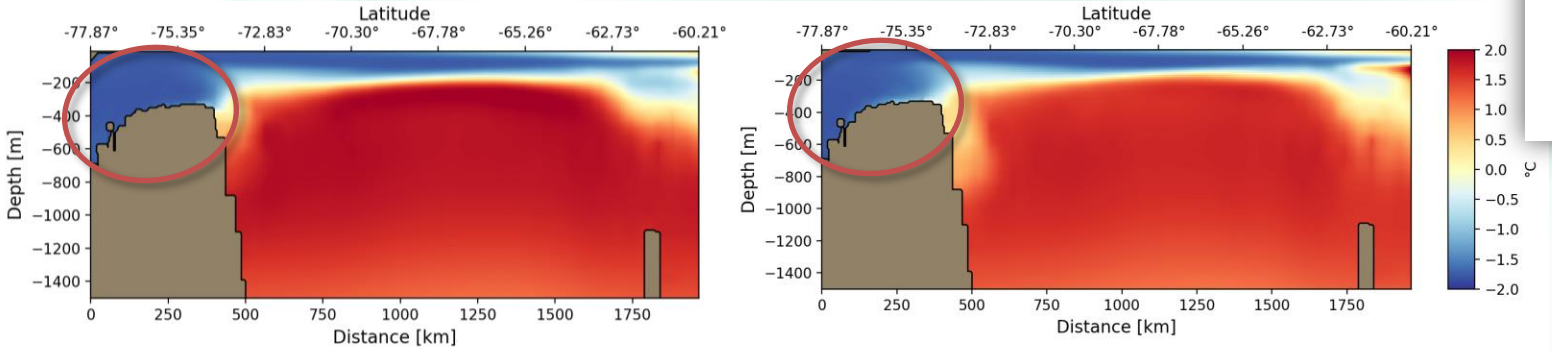


ISMF Years 44-94 No ISMF

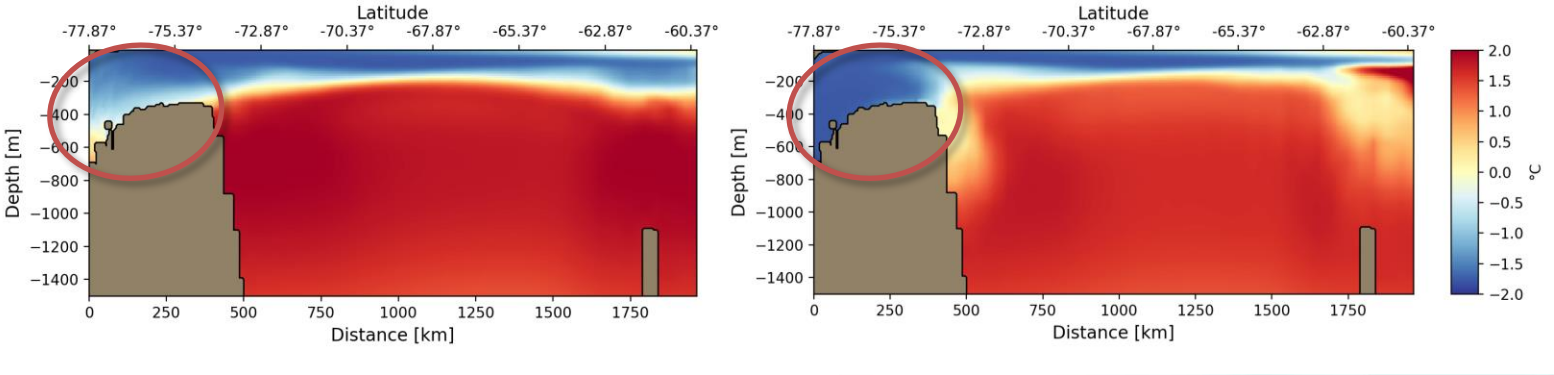


Understanding biases – late in simulation

ISMF Years 25-55 No ISMF

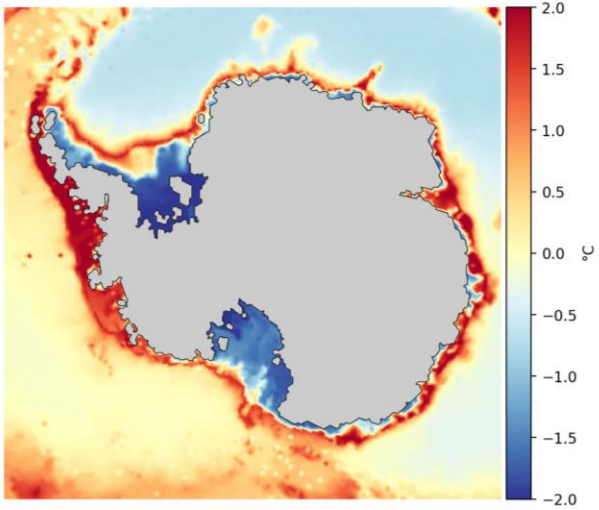


ISMF Years 44-94 No ISMF

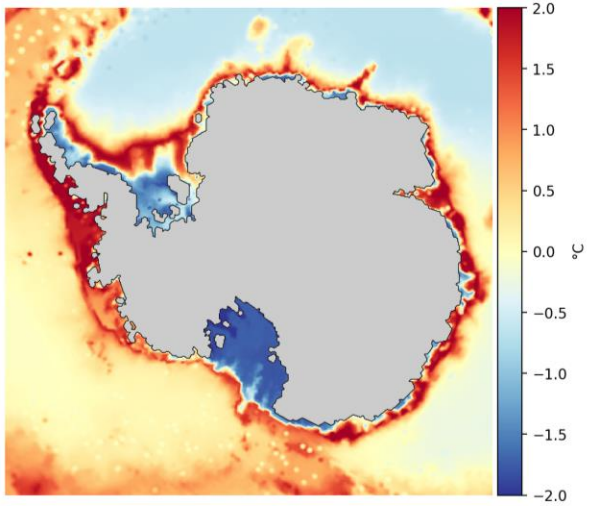


Understanding biases: Sea-floor Temperature

Years 25-55



Years 44-94



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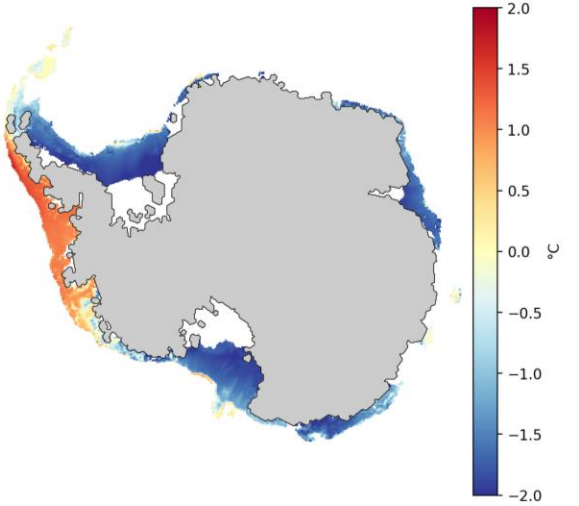
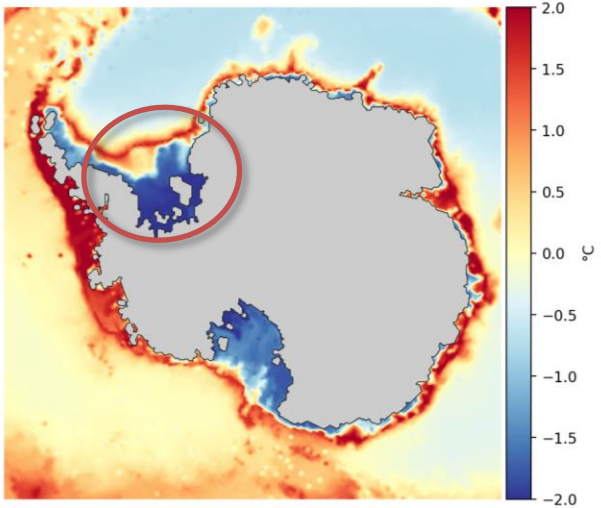
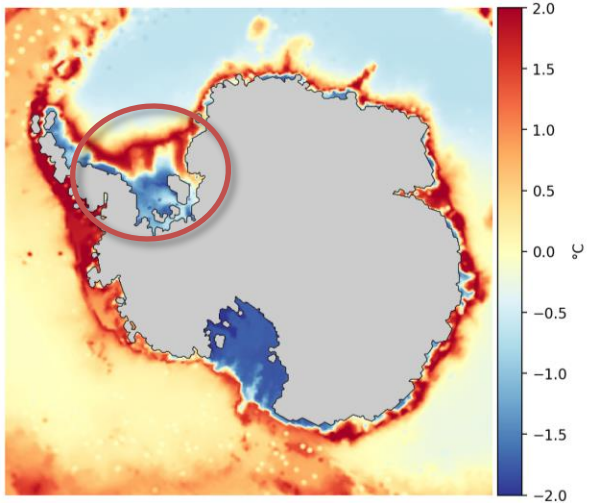


Understanding biases: Sea-floor Temperature

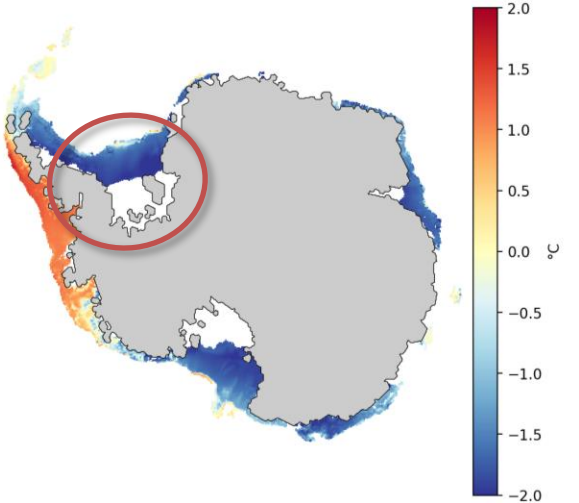
Years 25-55



Years 44-94



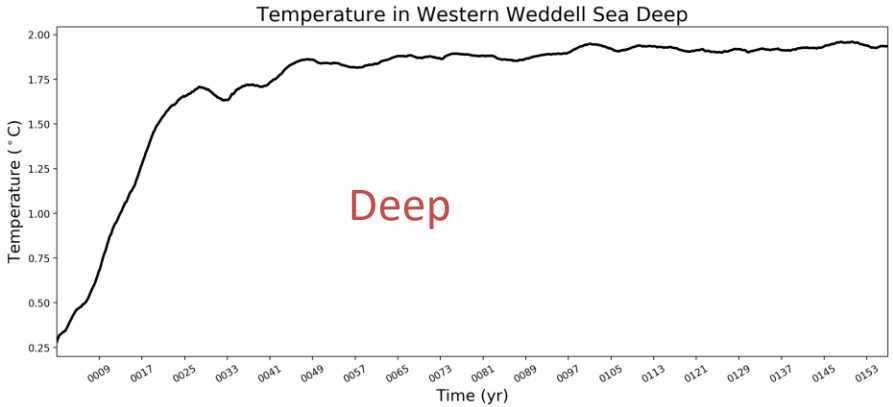
Obs.

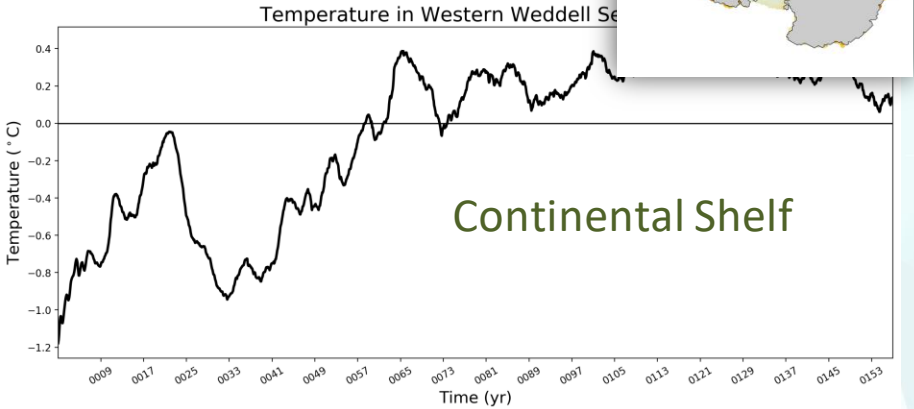


Understanding biases: Weddell Sea

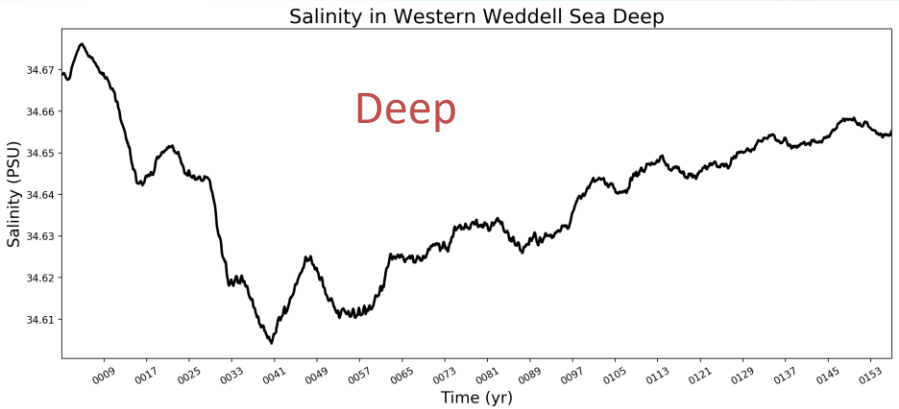
- Filchner intrusion driven by salinity

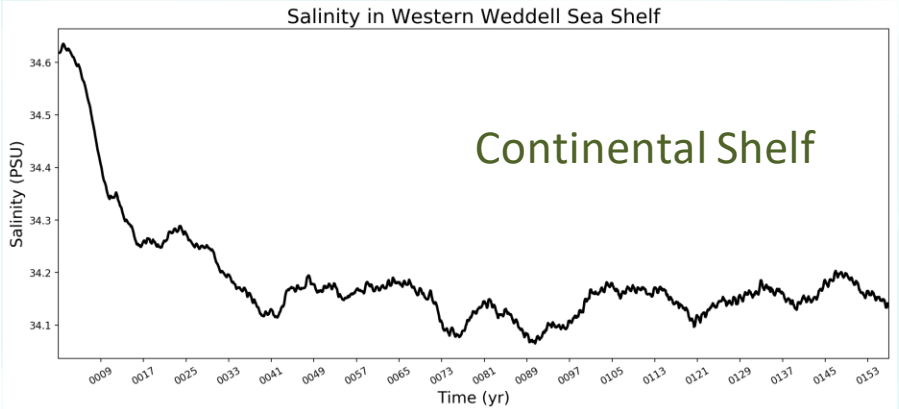
Temperature





Salinity





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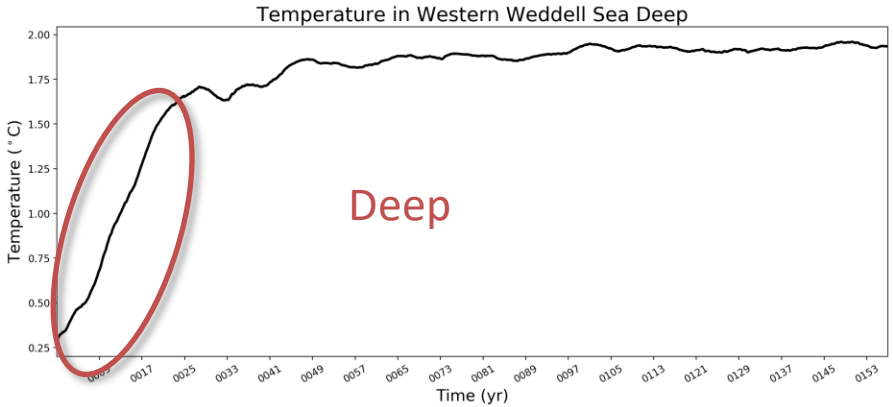
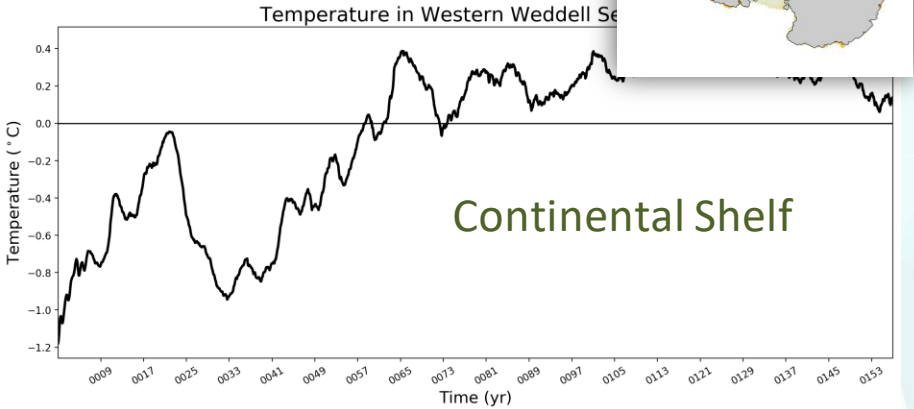
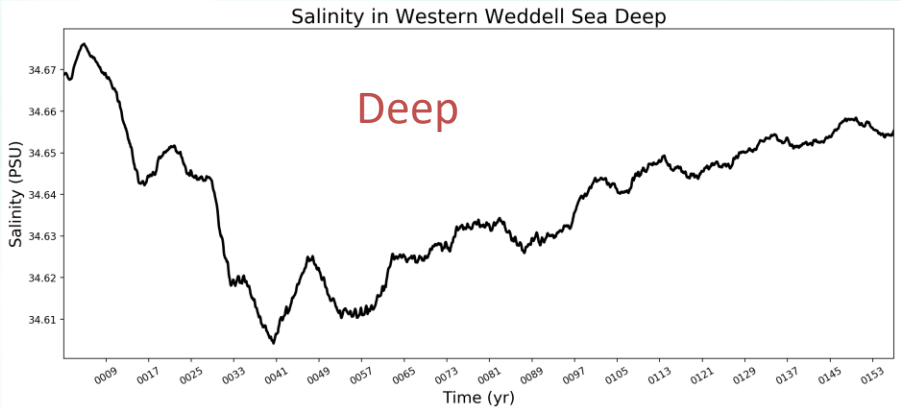
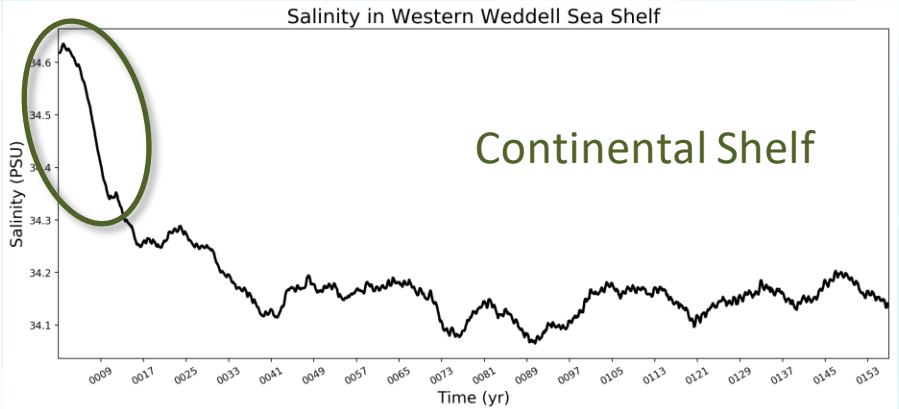




Salinity





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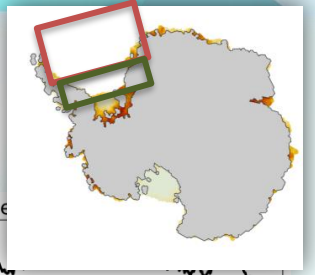
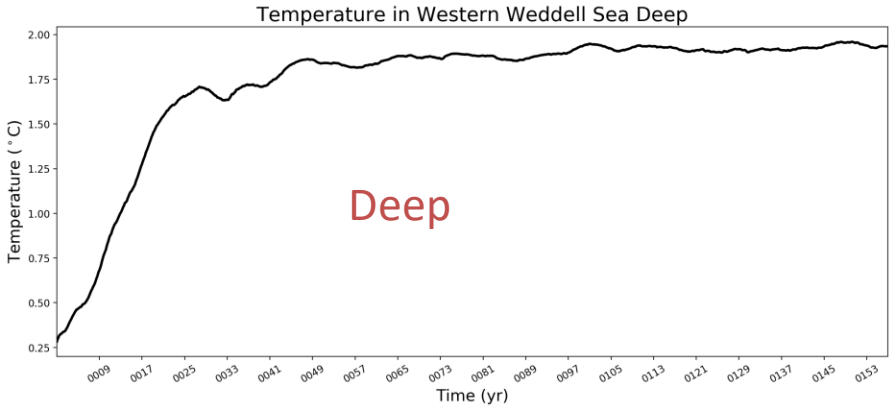
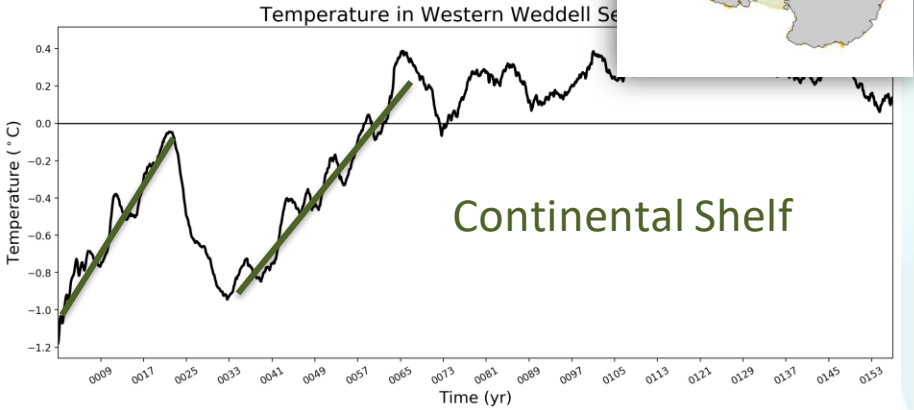
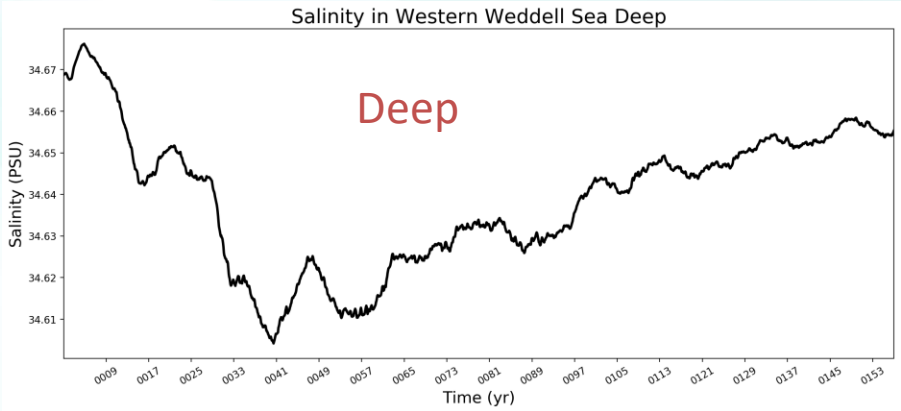


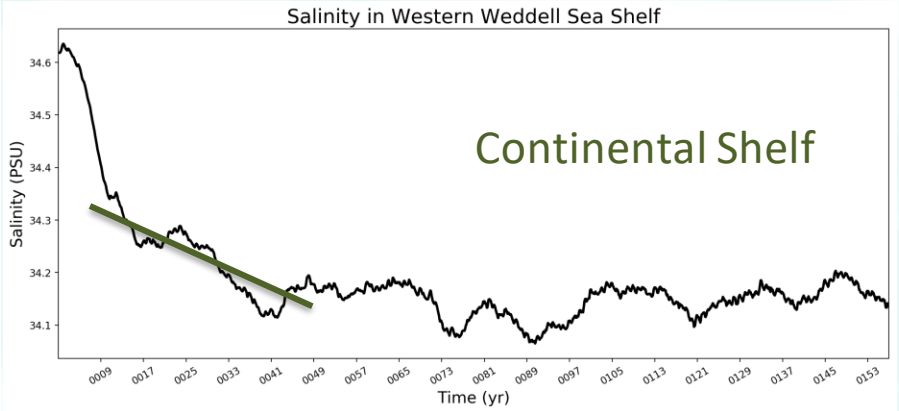
Temperature





Salinity





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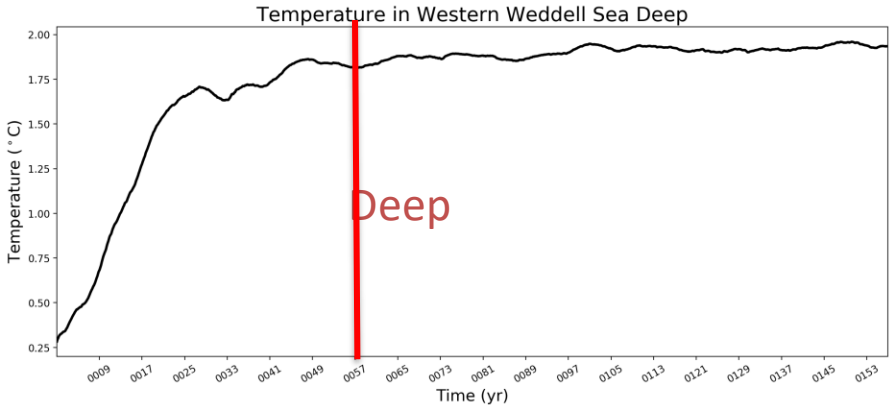
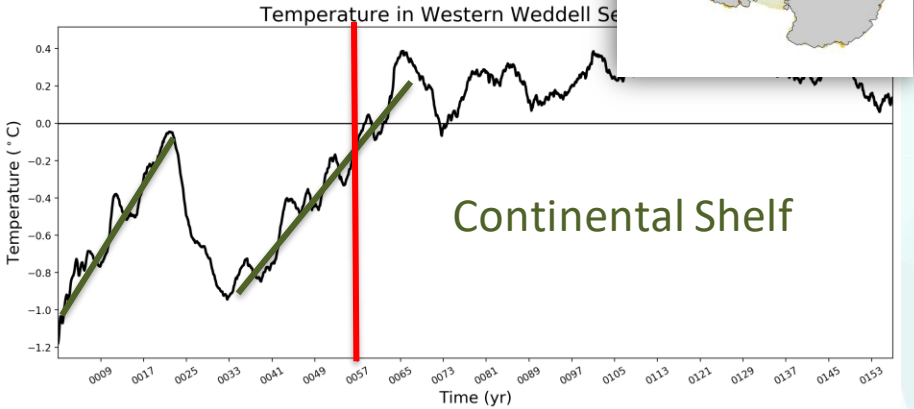
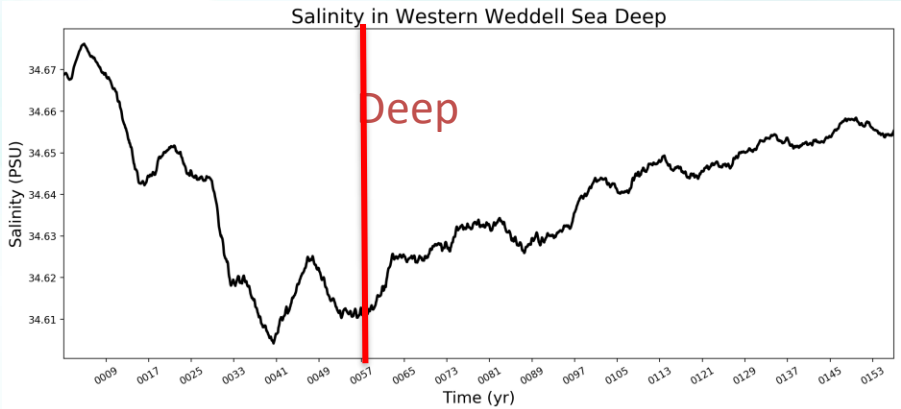
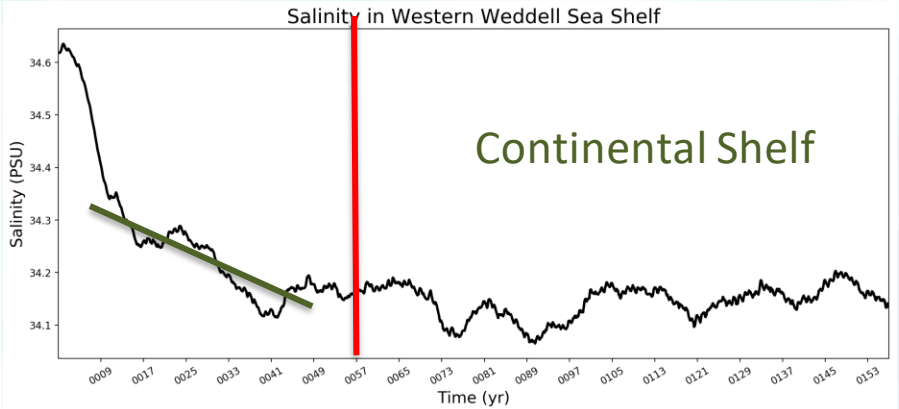


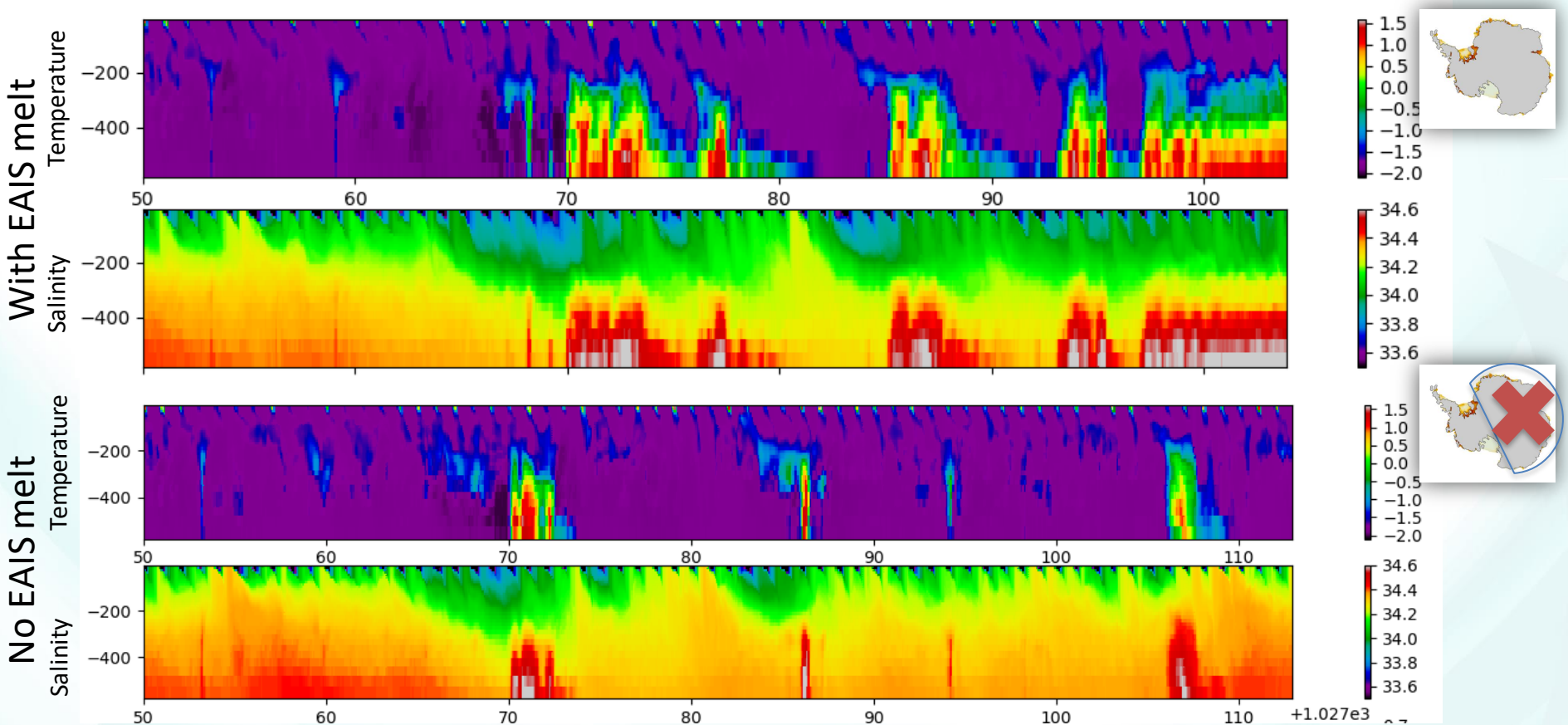


Salinity



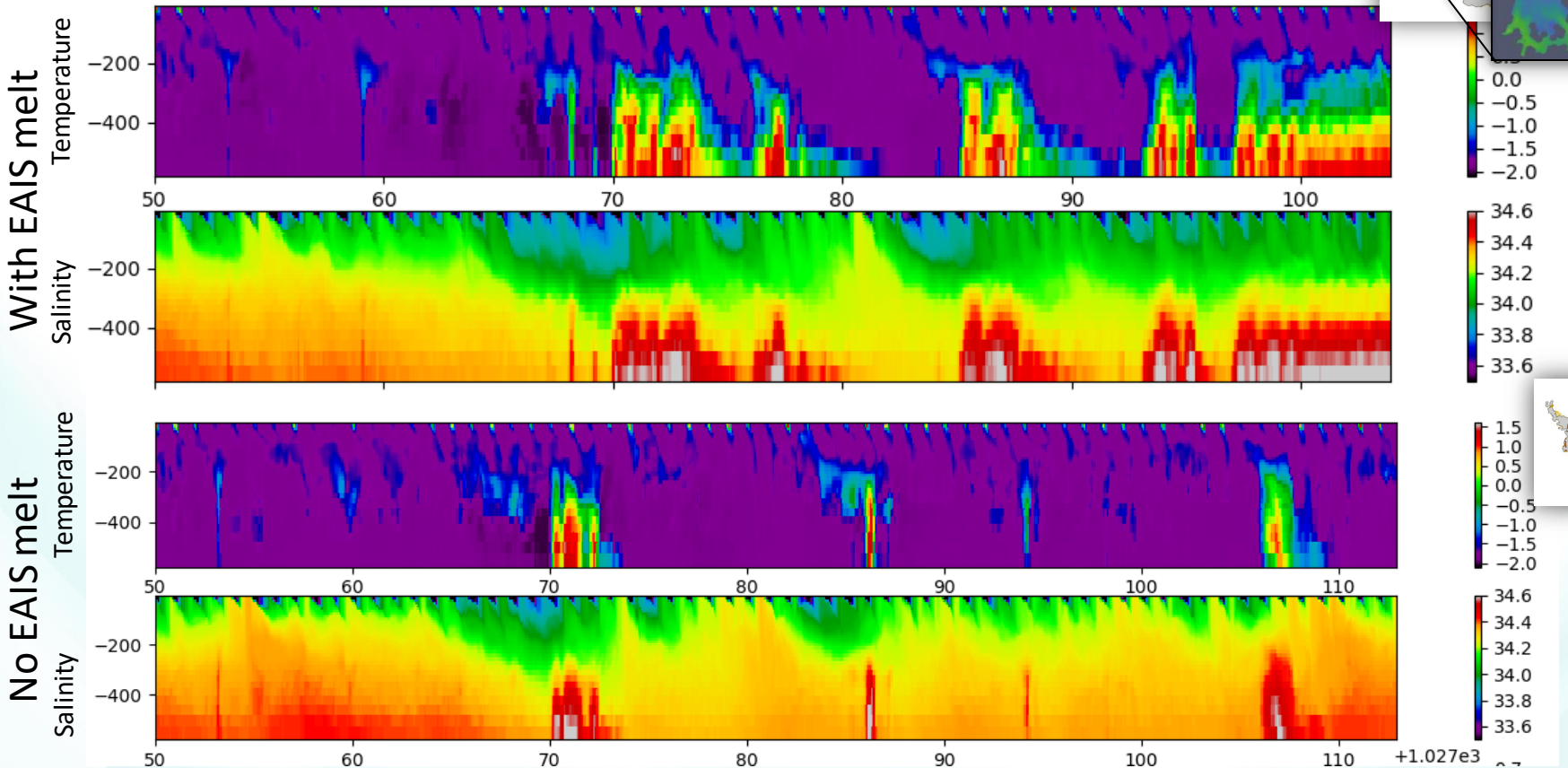


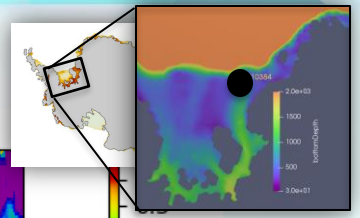
One cause: too much East Antarctic melt?



Credit: Matt Hoffman

One cause: too much East Antarctic melt?

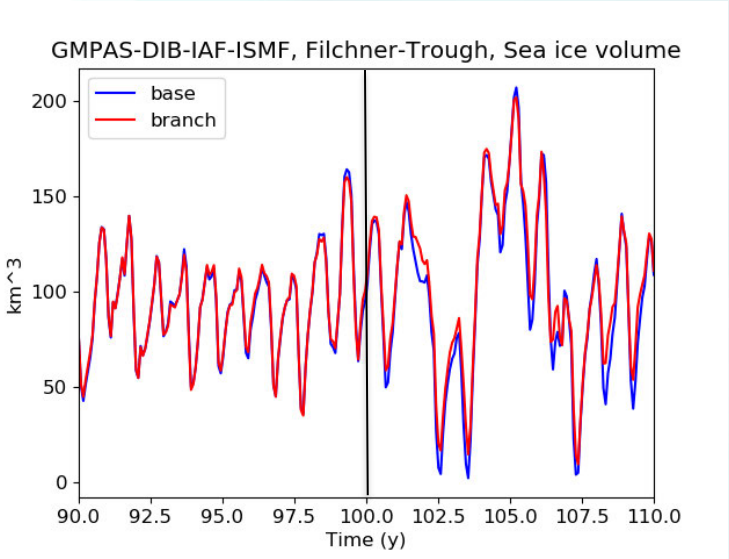


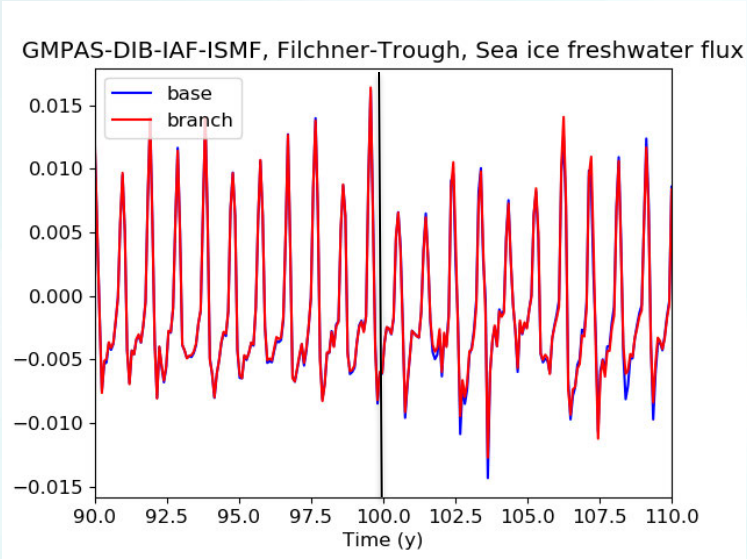


Credit: Matt Hoffman

Sea ice metrics

- Sea ice not likely to play direct role in triggering instability.
- Sea ice volume and freshwater flux very similar between CORE-forced runs; original goes unstable, and branch run remains stable.





Ongoing work exploring biases

- There is indication that **ocean mixing** (vertical and horizontal) is at least partially responsible for the upper ocean fresh bias in low-resolution E3SM. Therefore, we are performing several **sensitivity studies** to explore possible improvements:
  - Changing the global GM parameter (done)
  - Variable GM with depth (planned)
  - Changing KPP parameters (in progress)
  - Spreading thickness fluxes vertically (done)
  - Adding Redi mixing (planned)
- Also need to explore **sea-ice budget terms** and their spatial distribution (planned)
- Make **freezing** of ocean waters a **function of salinity**, not only temperature (planned)

Concluding Remarks / Future plans

- Instability arises that leads to **high melt rates, inconsistent with the preindustrial climate**, under certain Antarctic ice shelves in Cryosphere simulations.
- Because the bias directly affects **melt rates, the field of primary interest** to the Cryosphere campaign's science goals, it impedes **progress toward historical and future-climate scenarios**.
- **Southern Ocean biases** unrelated to ice-shelf melting (some also present globally) facilitate conditions that **trigger the instability**.
- Actively working to understand and **mitigate biases** on multiple fronts.
- **Higher resolution** alleviates these underlying biases, raising priority of a **Southern Ocean regionally refined mesh** (under development).