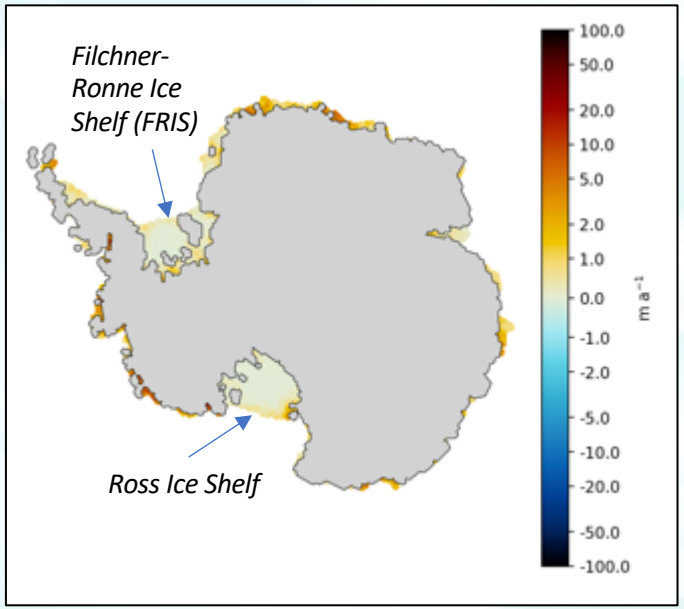
Tipping points in melting beneath Antarctic Ice Shelves

A Tale of Two Ice Shelves



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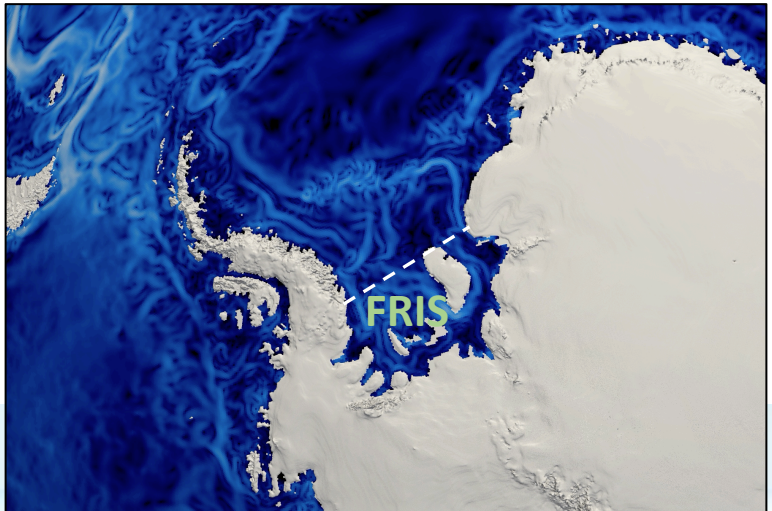
Outline

1. Background on Antarctic ice shelf melting
2. Summary of ice shelf melt tipping points seen in E3SM
3. Impact of improved ocean eddy parameterization (3D GM)
4. Results from E3SM v2 regionally refined mesh for Southern Ocean



Ice shelves are primary control on AIS SLR

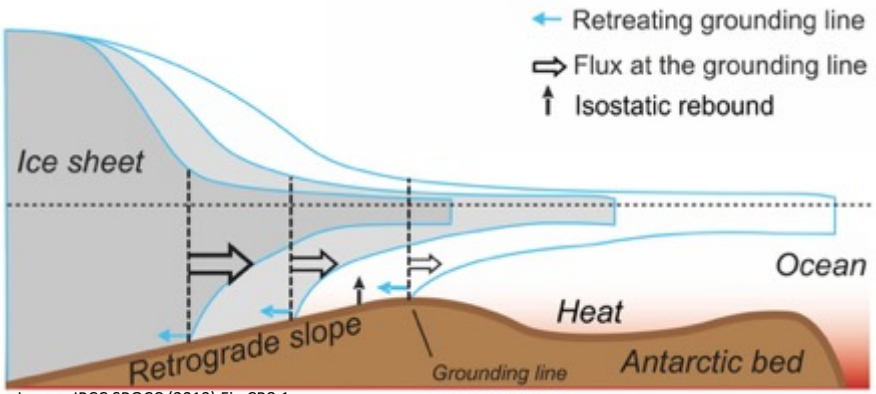
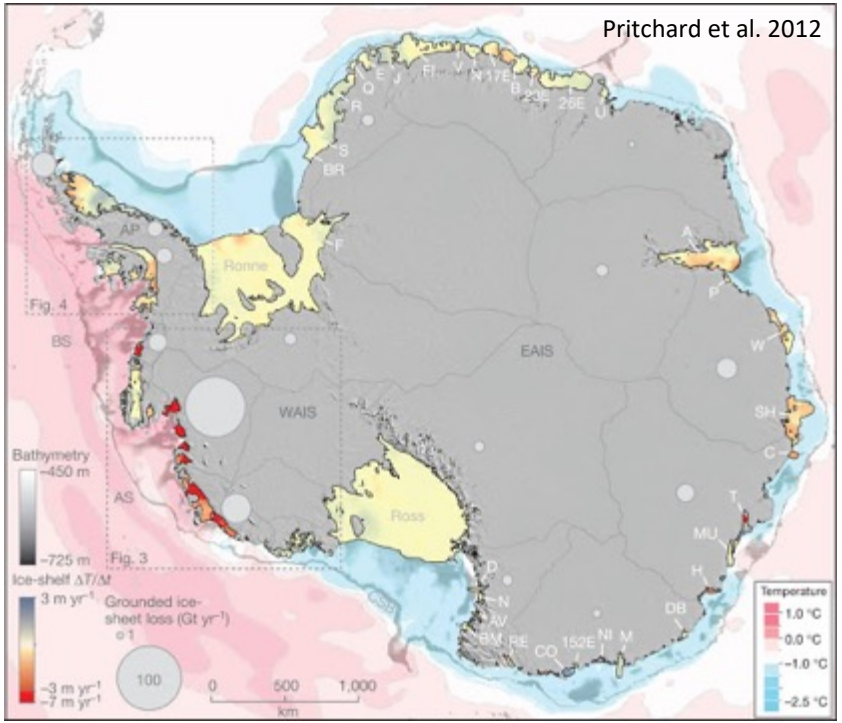


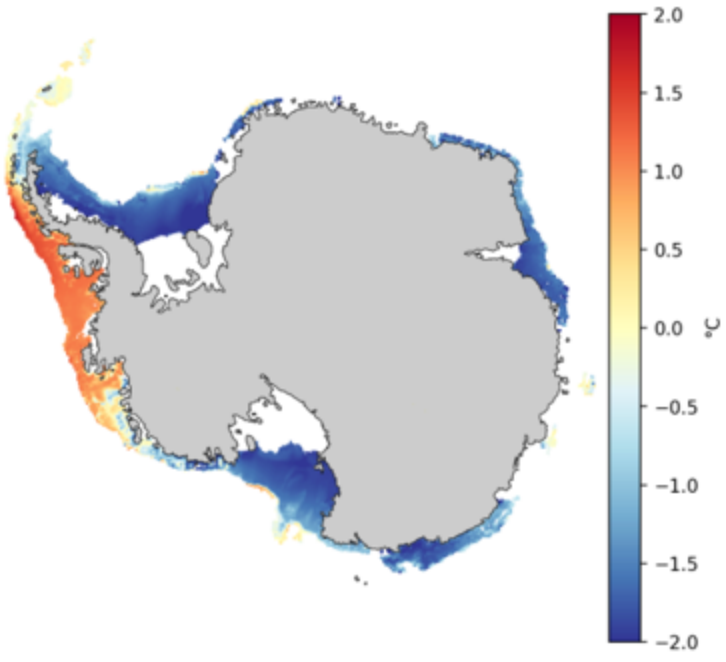
Image: IPCC SROCC (2019) Fig CB8.1a



“Warm” and “Cold” ice shelves controlled by access of Circumpolar Deep Water (CDW) to continental shelves

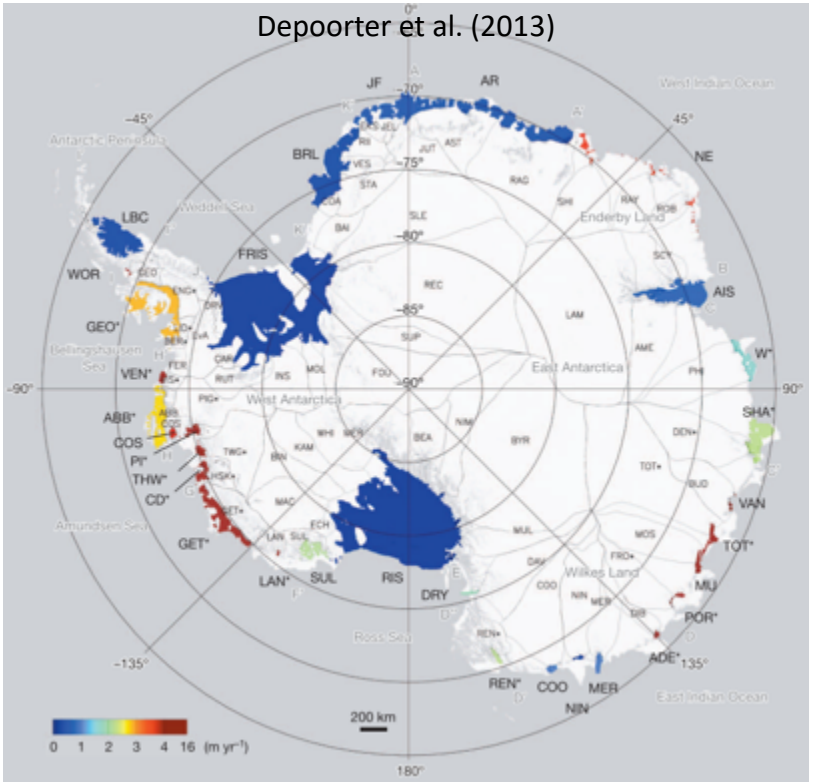
Sea floor potential temperature

Observations: Schmidtko et al. (2014)



Ice shelf melt rate

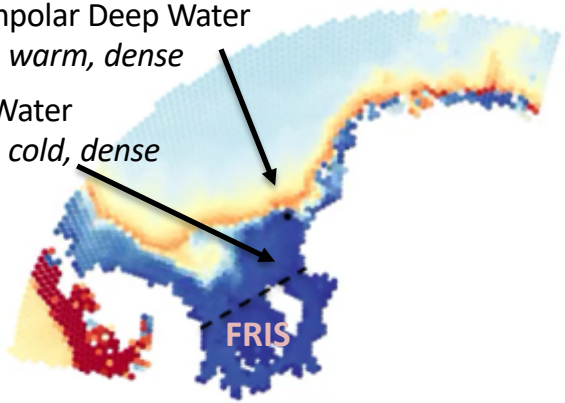
Depoorter et al. (2013)

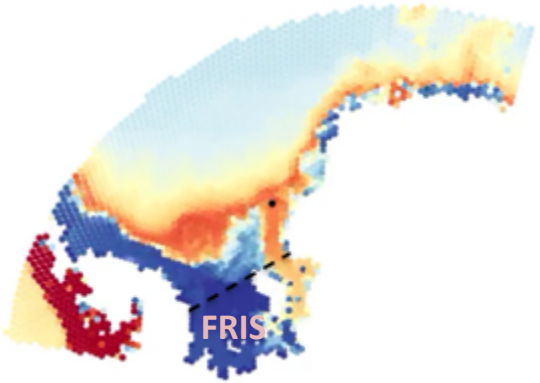


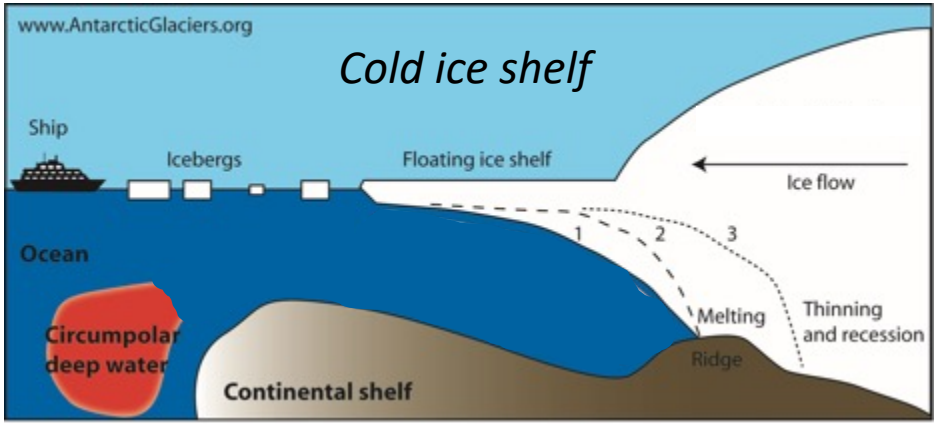
CDW access activates “melt pump” – tipping point

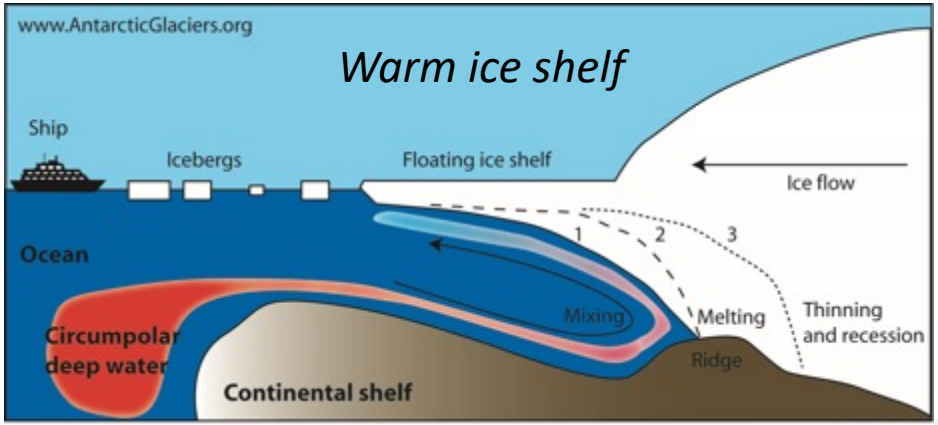
Circumpolar Deep Water
saline, warm, dense

Shelf Water
saline, cold, dense





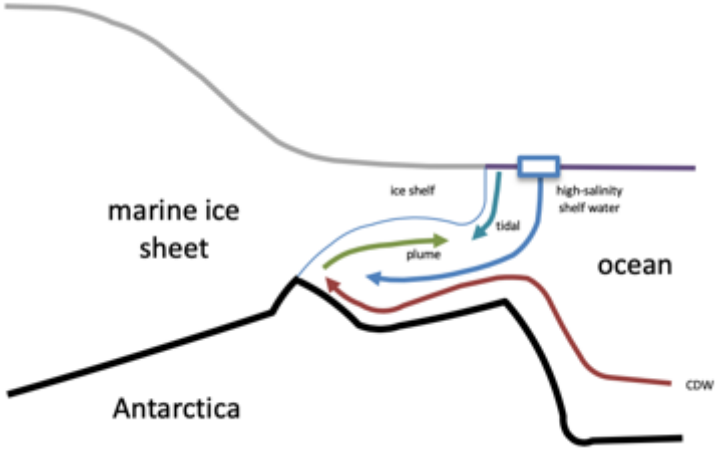




E3SM v1 Low-Res Cryosphere Configuration

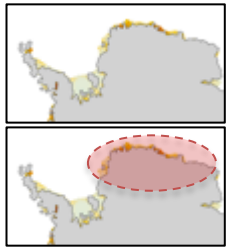
G-case: Ocean (MPAS-Ocean) + **Sea ice** (MPAS-Seaice)

- v1 Low-res: 30 km resolution in Southern Ocean (60 km at mid lats)
- **Ice shelf cavities included with fixed geometry**
- 1948-2009 NCEP reanalysis forcing repeated (CORE-II)
- Data iceberg melt climatology for Southern Ocean (Merino et al. 2016, Ocean Modeling)



Runs

- **ISMF**: **I**ce-**S**helf **M**elt **F**luxes calculated prognostically beneath ice shelves around entire AIS
- **ISMF-noEAIS**: ice-shelf melt disabled from shelves of East Antarctica. Branched off ISMF at year 50.



Additional runs (8 total):

- fully-coupled
- without ISMF
- 30-10 km resolution

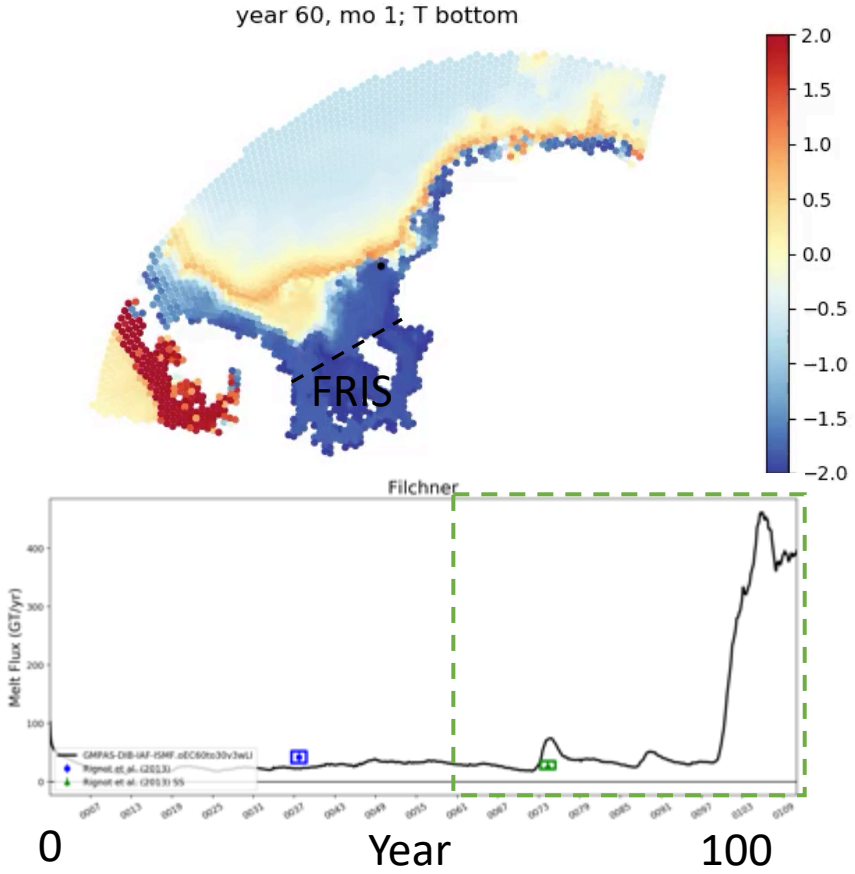
CDW intrusions and Filchner Ice Shelf melt rates

CDW intrusions under ice shelf:

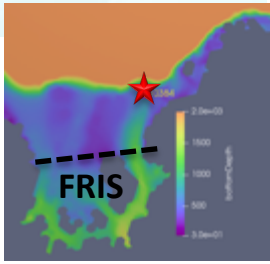
- Not observed in present climate
- Models have predicted may happen in future (Hellmer et al. 2010 *Nature*)

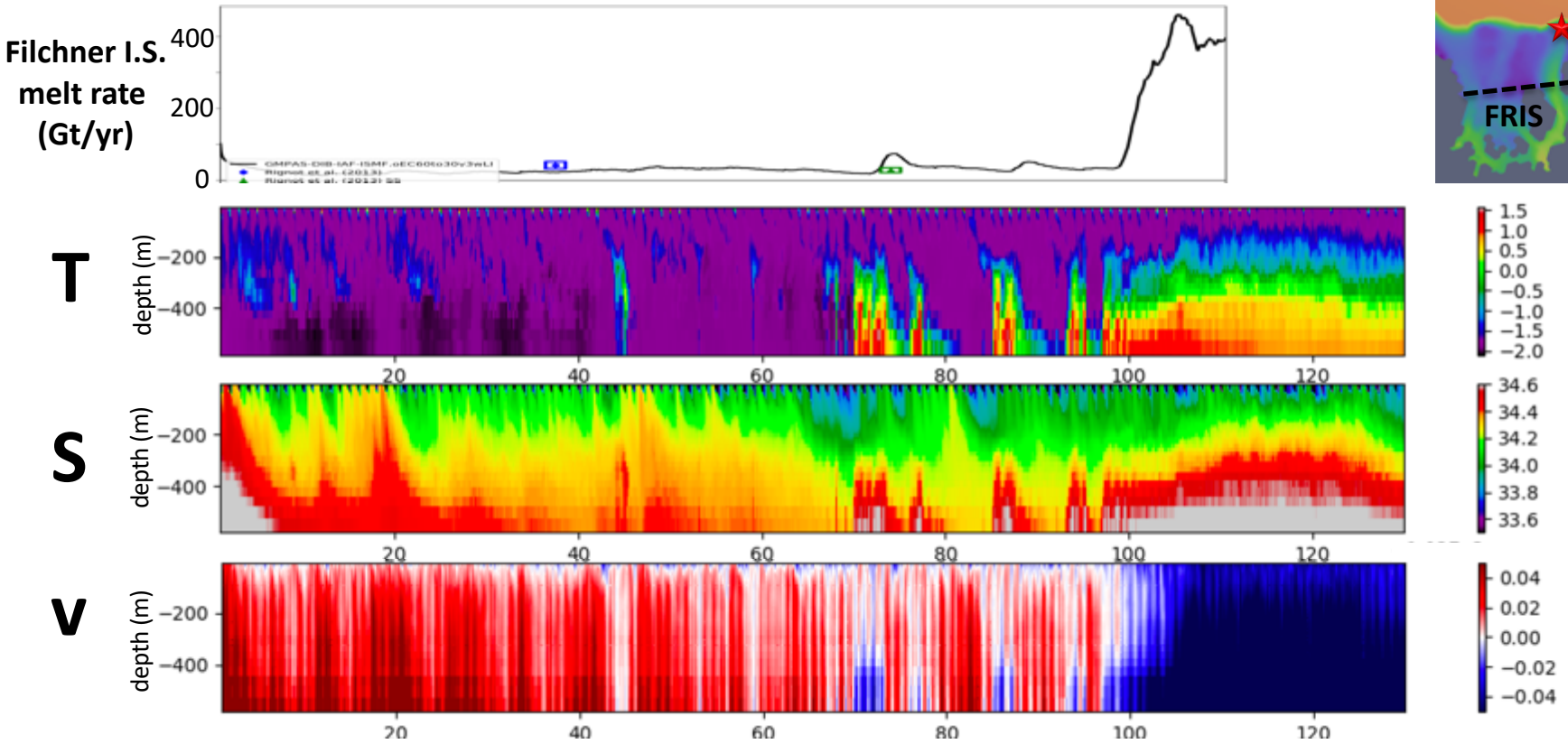
In E3SM:

- CDW intrusion & FRIS melt tipping point triggered in most runs (preindustrial and historical)
- We've found it can be prevented by:
  - Disabling melt from upstream ice shelves
  - Reducing model bias through improved eddy mixing param.



Conditions at Filchner Sill control CDW intrusion





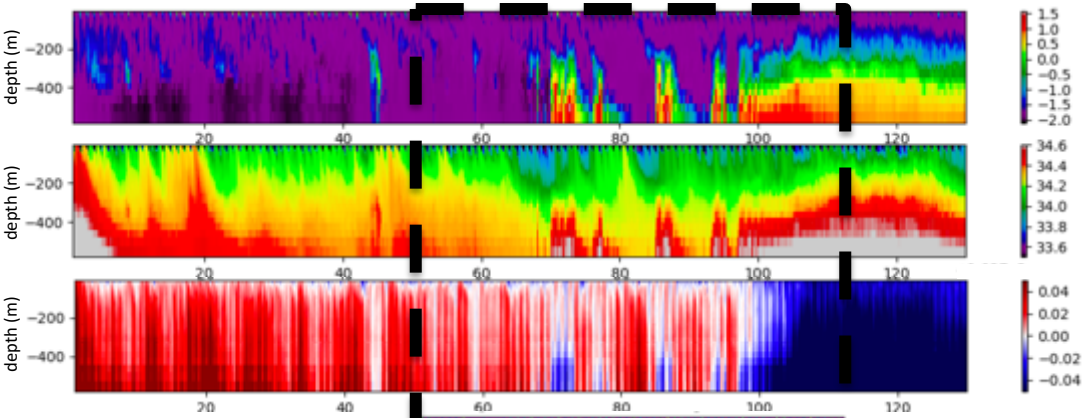
Impact of melt from neighboring shelves

ISMF

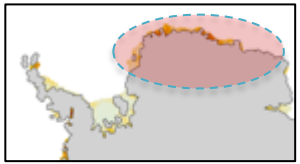
T

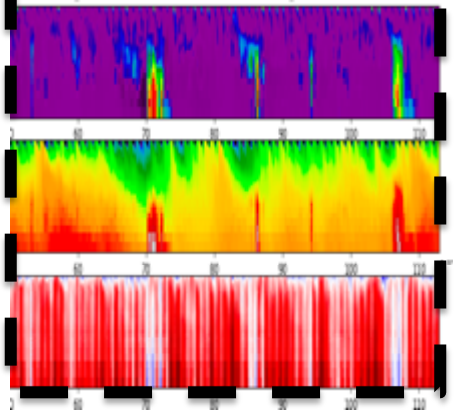
S

v



ISMF-noEAIS

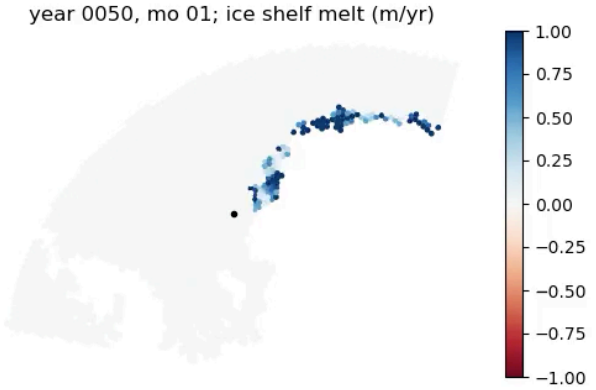


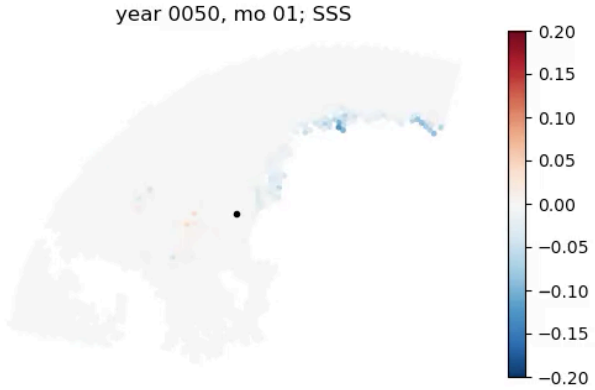


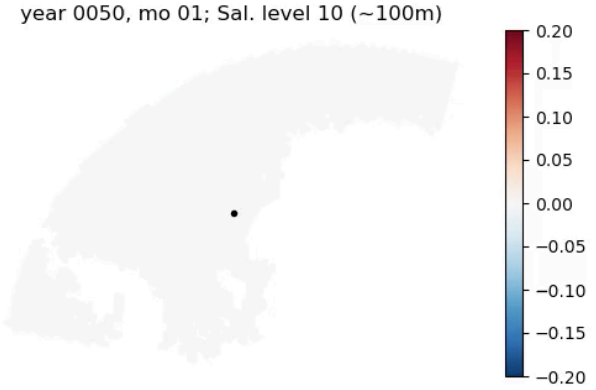
year

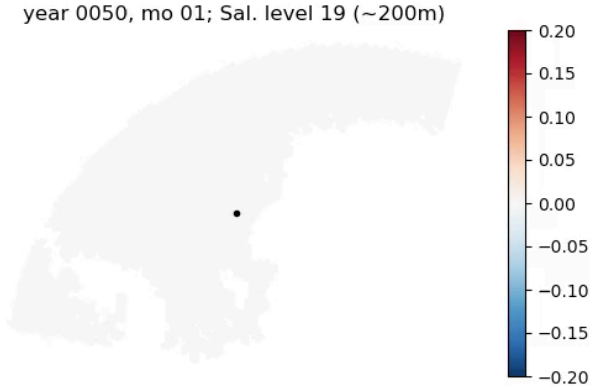
Disabling ice shelf melt upstream prevents sustained CDW intrusion and FRIS melt tipping point!

Difference between ISMF and ISMF-noEAIS

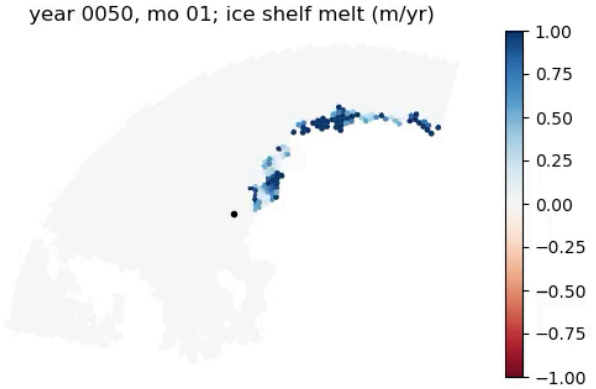


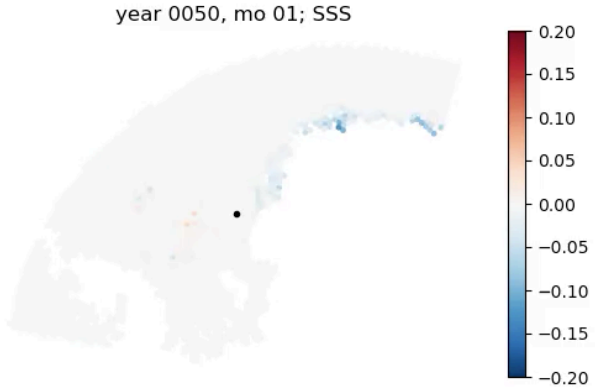


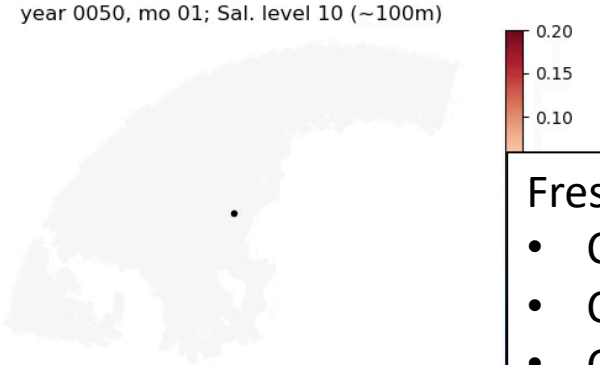


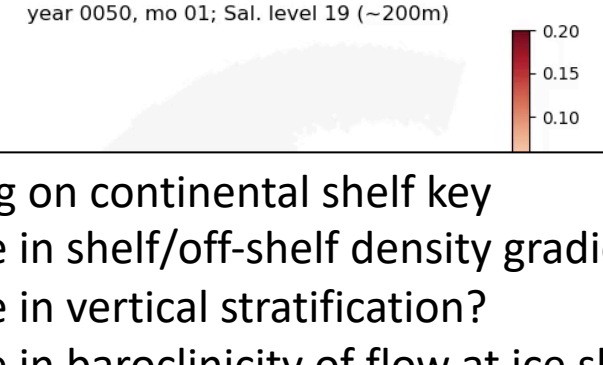


Difference between ISMF and ISMF-noEAIS





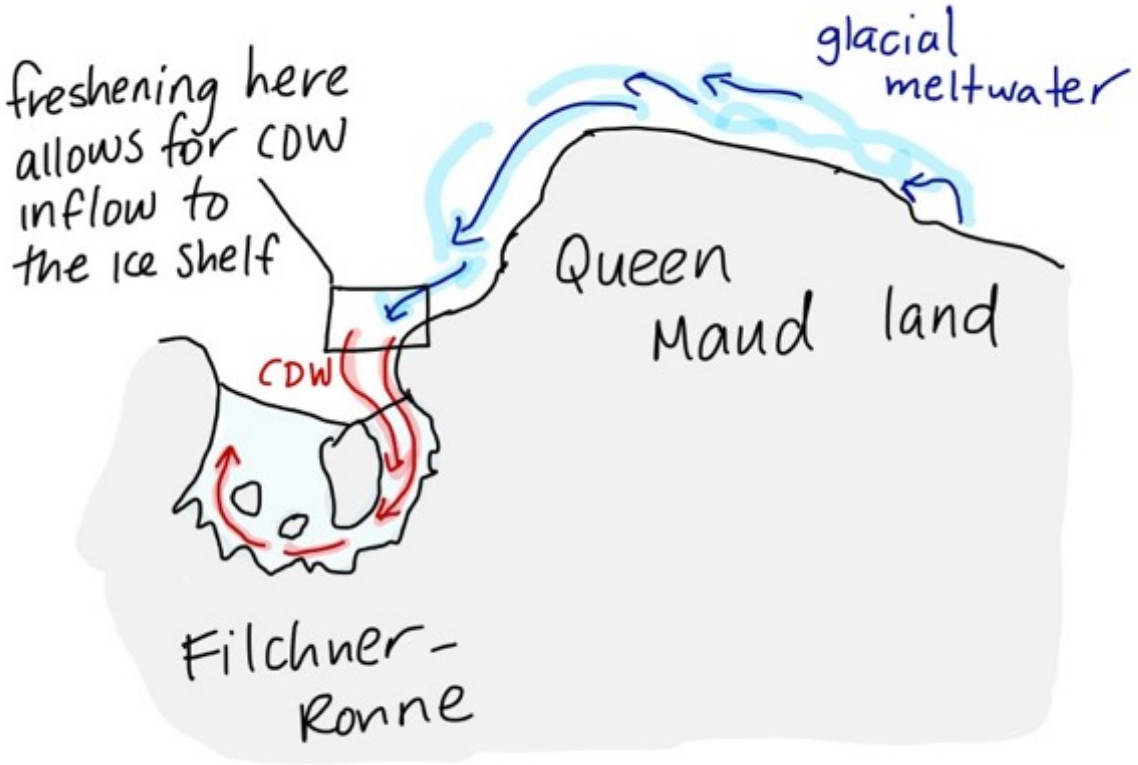




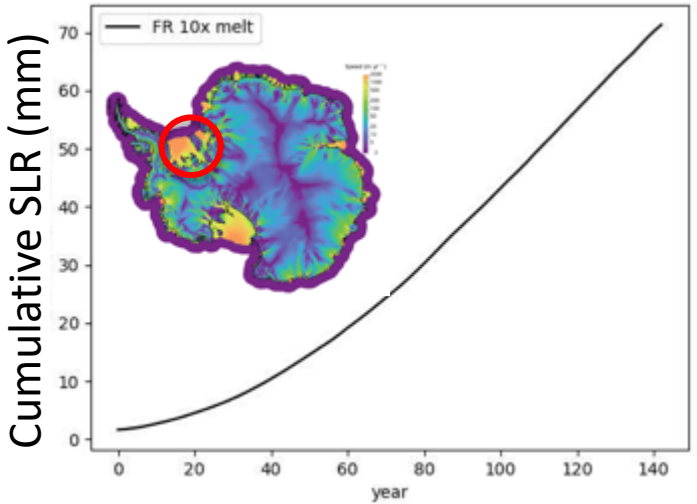
Freshening on continental shelf key

- Change in shelf/off-shelf density gradient?
- Change in vertical stratification?
- Change in baroclinicity of flow at ice shelf front?

Summary so far



Kiya Riverman **@cryotoons**



10x increase in FRIS melting ->
~10 cm sea level rise in 200 years

3D Gent-McWilliams parameter (3DGM)

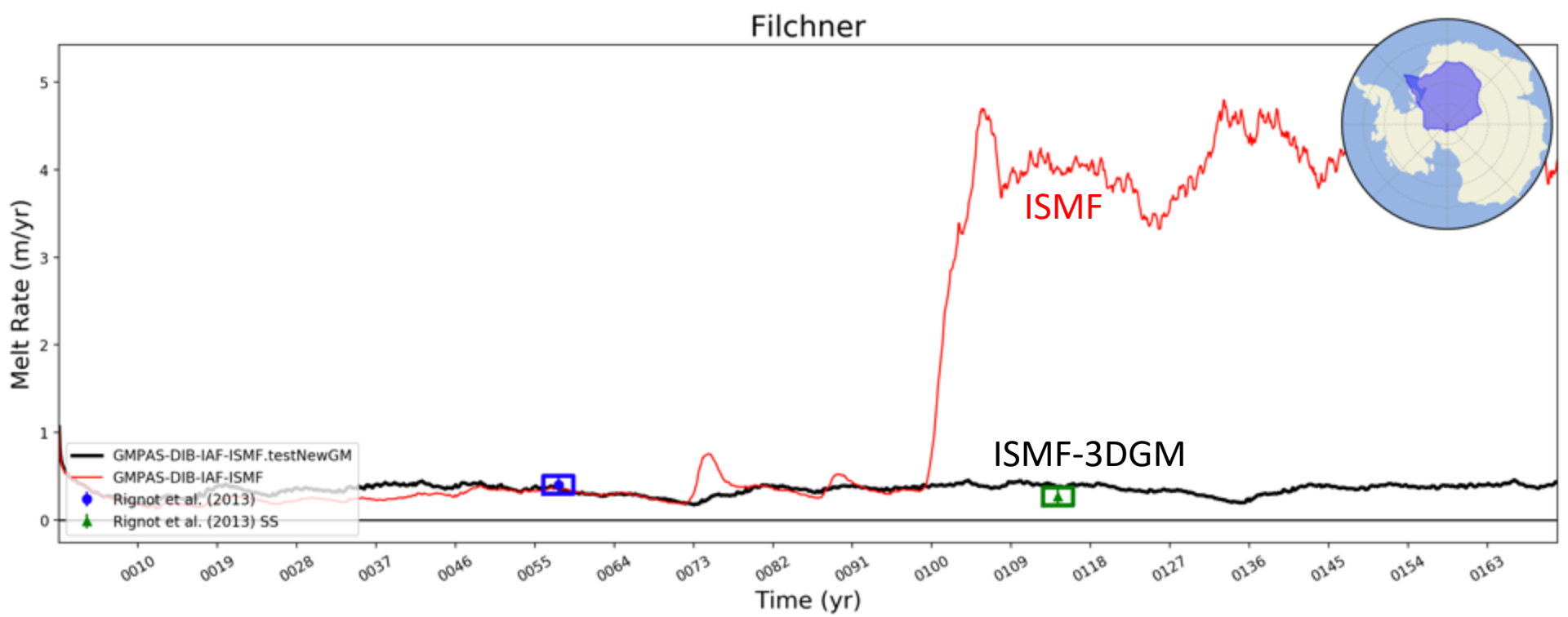
Improvement to Gent-McWilliams (GM) ocean eddy parameterization

- Used at coarse resolution where eddies are not resolved
- Represents missing eddy-induced velocity
- MPAS-O has used a GM strength that is constant in space
- Recent improvement allows GM strength to vary horizontally and vertically – more realistic

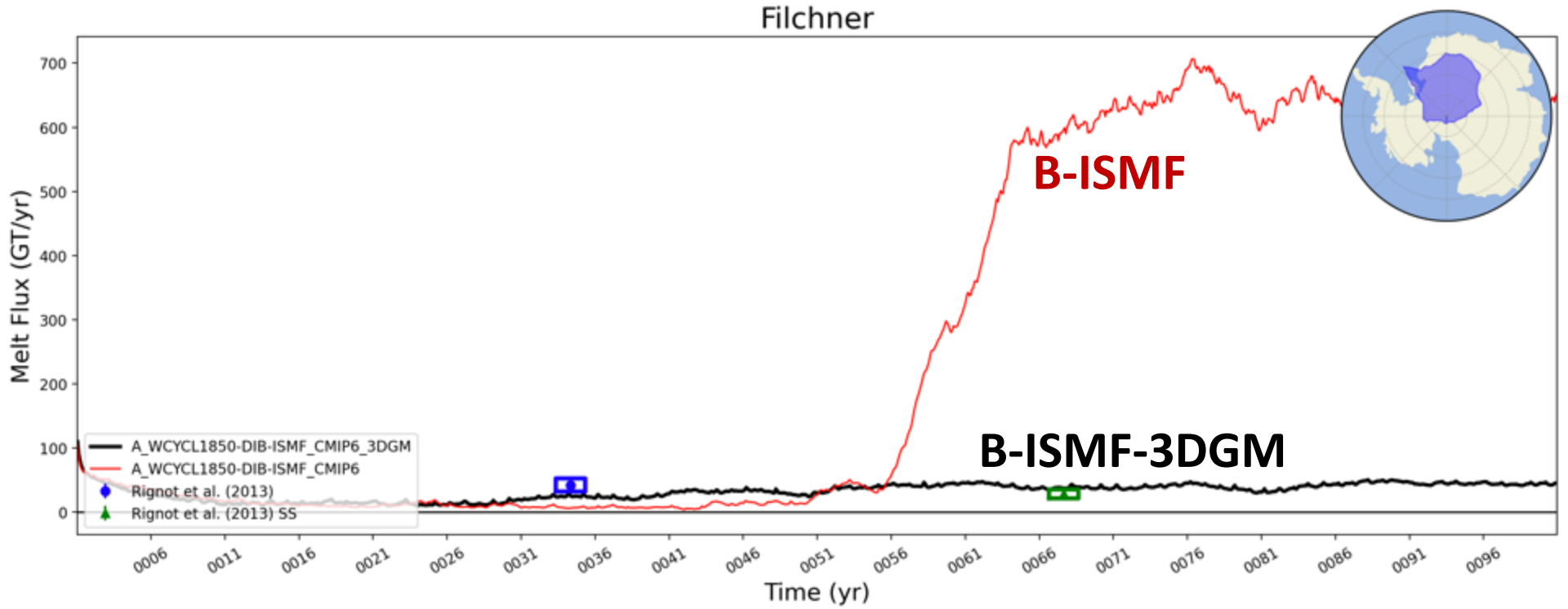
Tested on:

1. G-cases (ocean/sea-ice only)
2. B-cases (fully coupled)

3DGM G-case: No melt instability



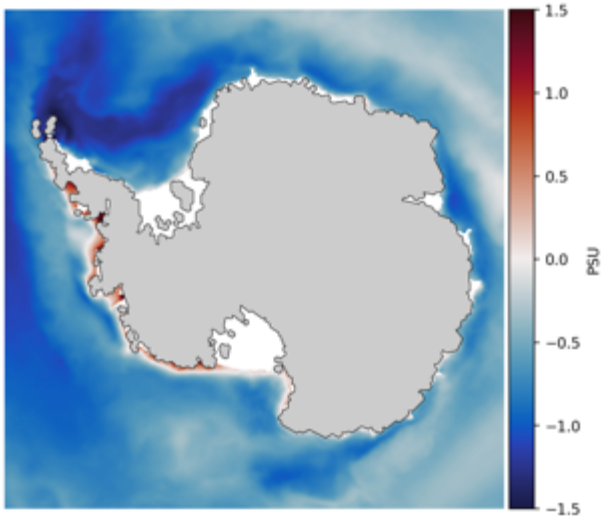
3DGM B-case*: No melt instability



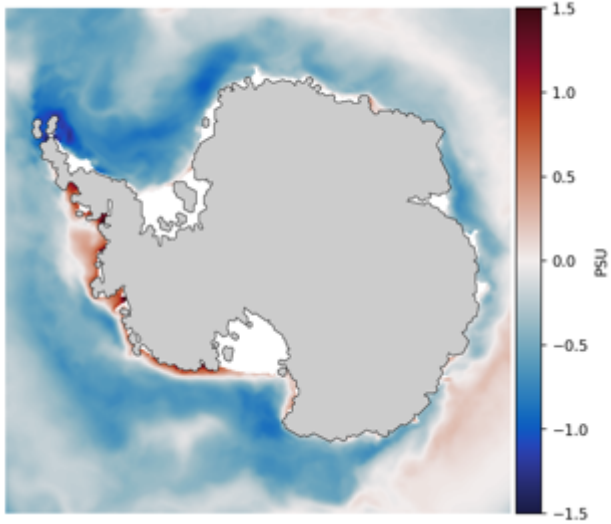
* B-case is preliminary: uses incorrect ATM settings and needs to be rerun

3DGM SSS bias improved

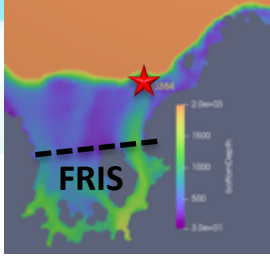
B-ISMF bias



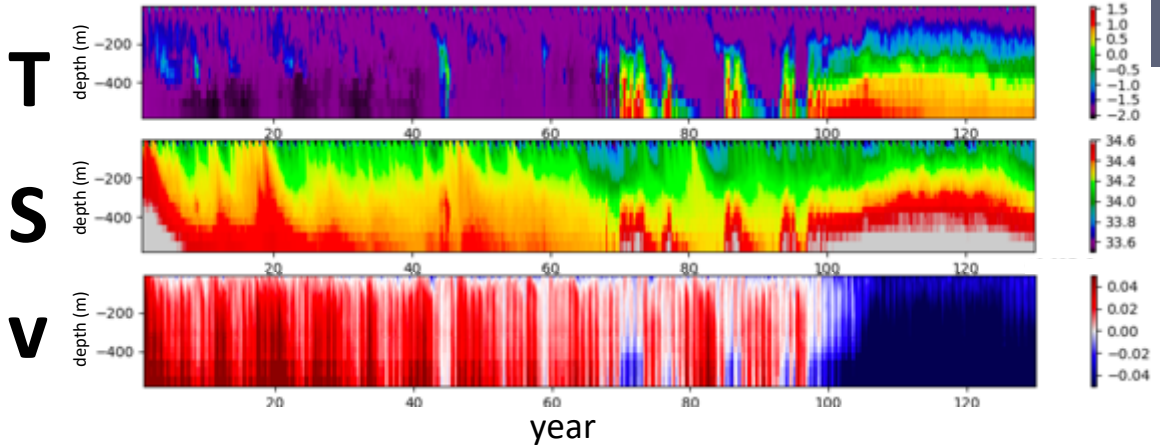
B-ISMF-3DGM bias



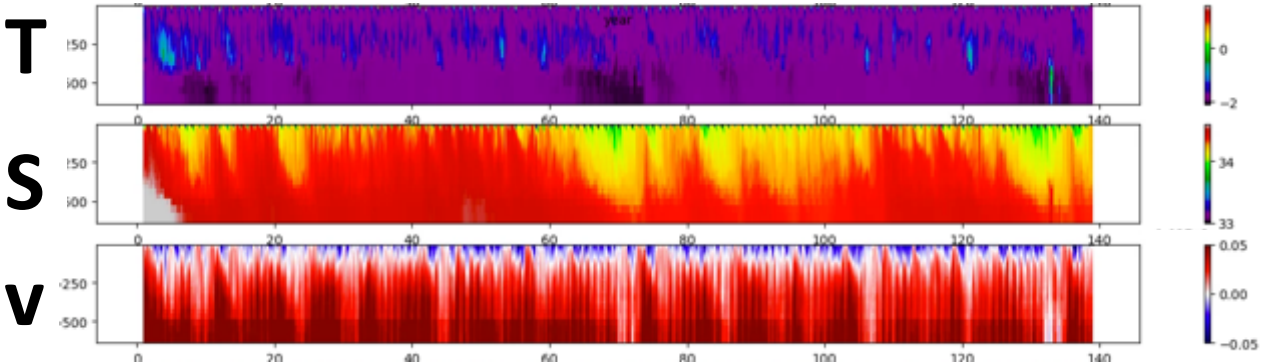
Impact of 3DGM at Filchner Sill



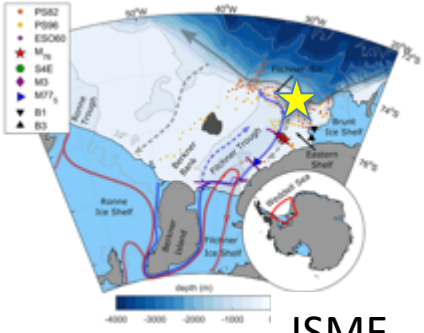
ISMF

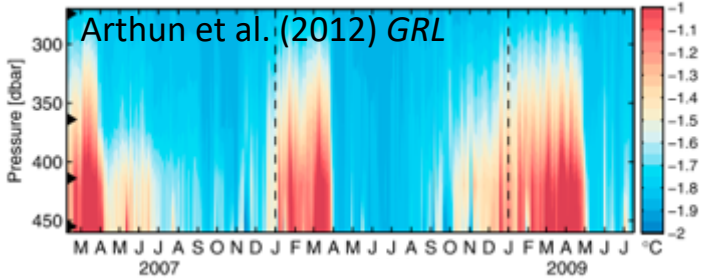


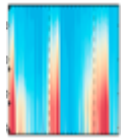
ISMF-3DGM



3DGM improves seasonal cycle



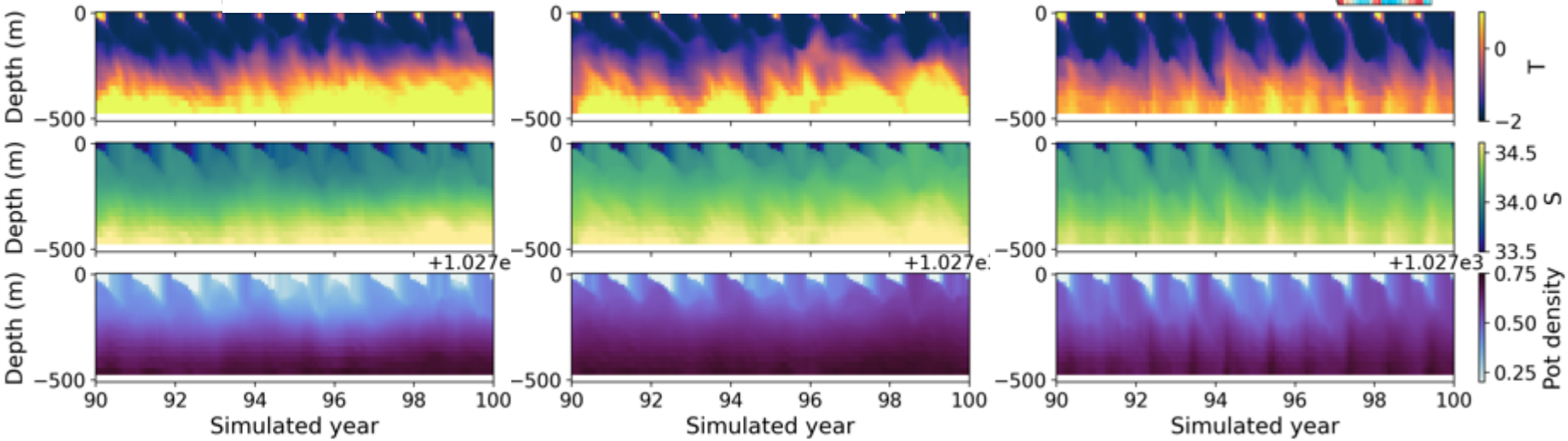




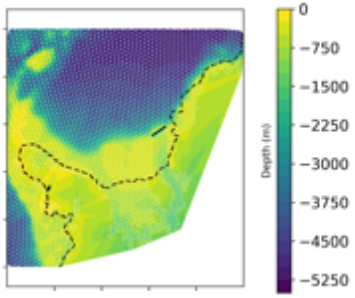
ISMF

ISMF-noEAIS

ISMF-3DGM



3DGM blocks intrusions more strongly than disabling melt



ISMF

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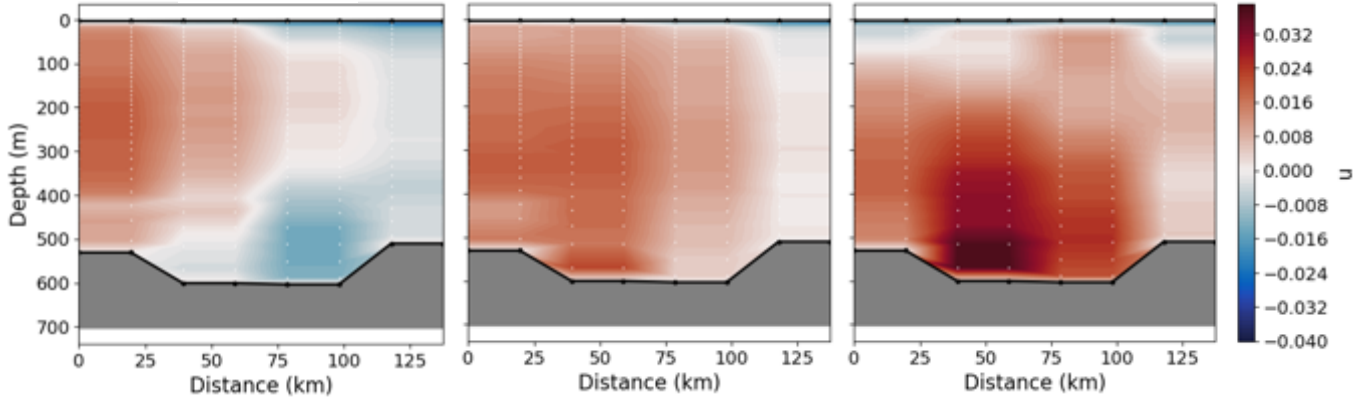
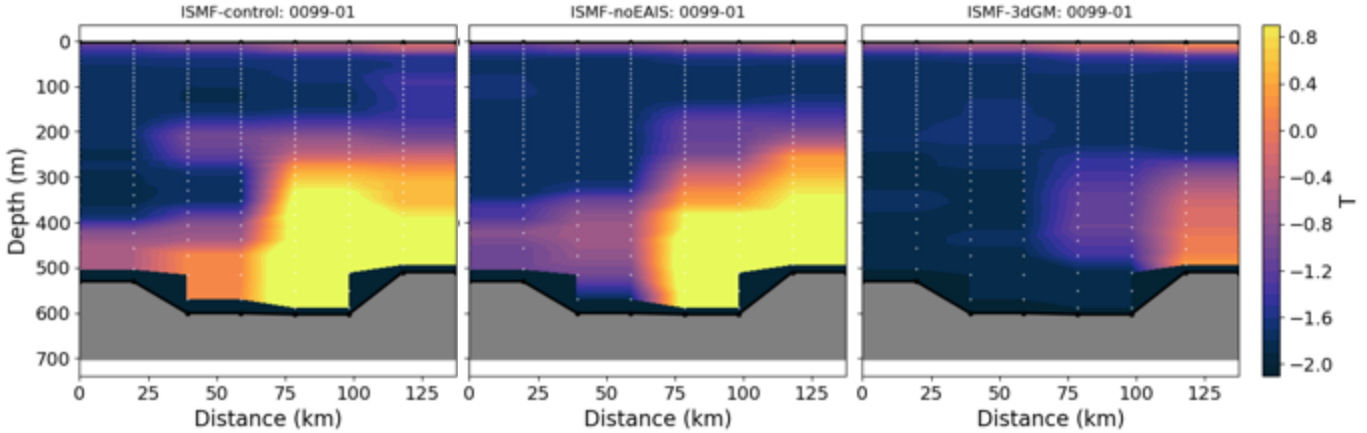
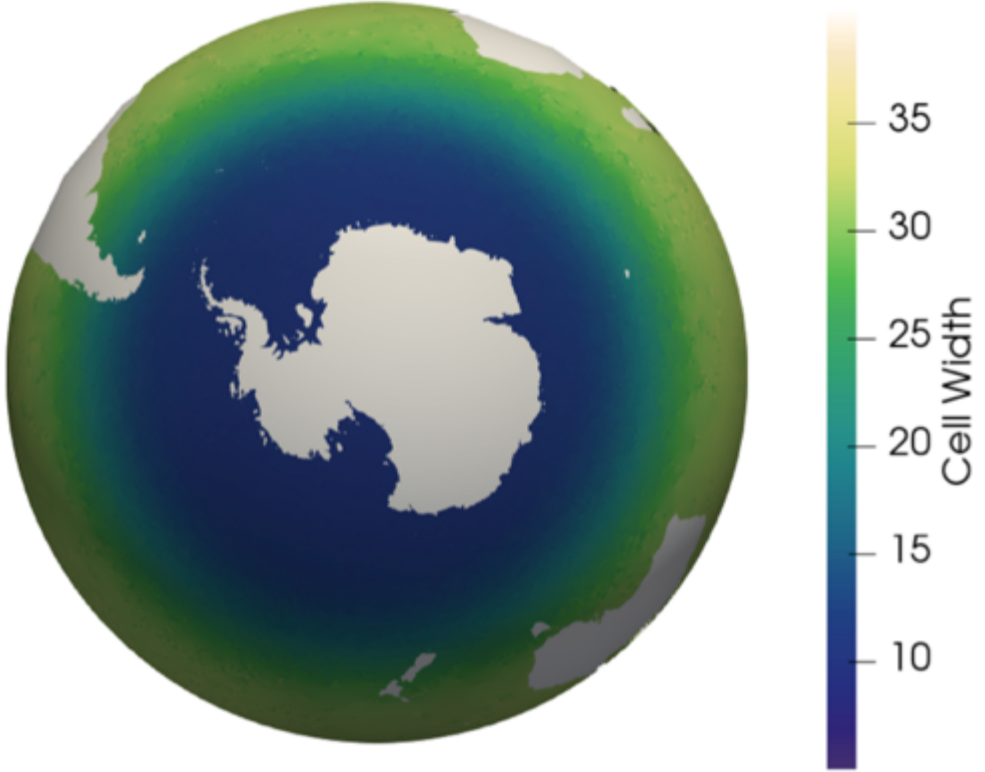




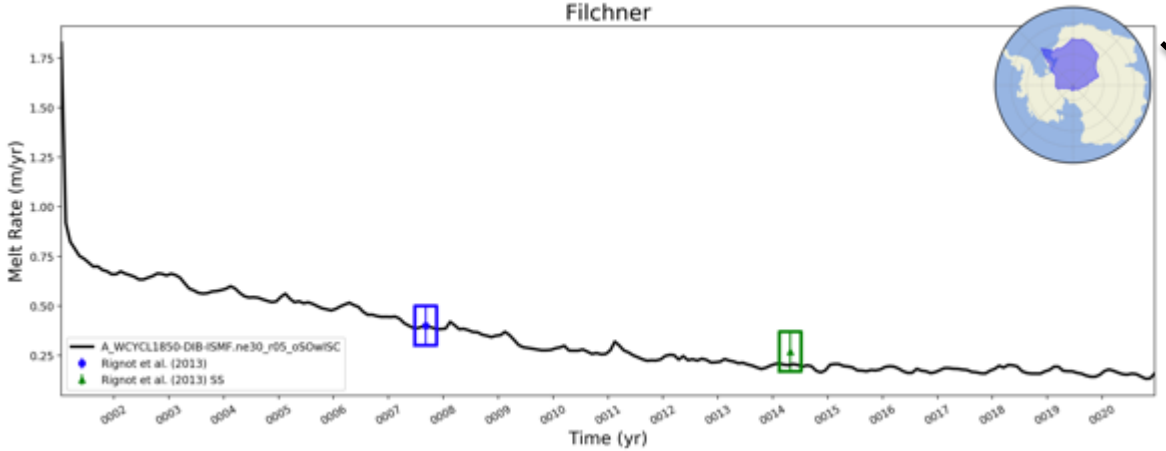
Southern Ocean Regionally Refined Mesh (SORRM)

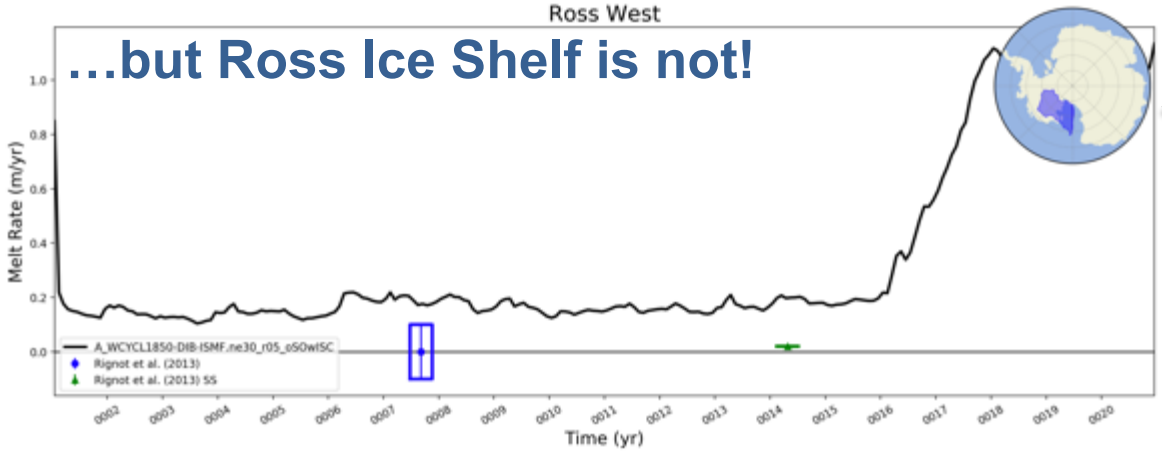
Cryo Campaign v2 mesh

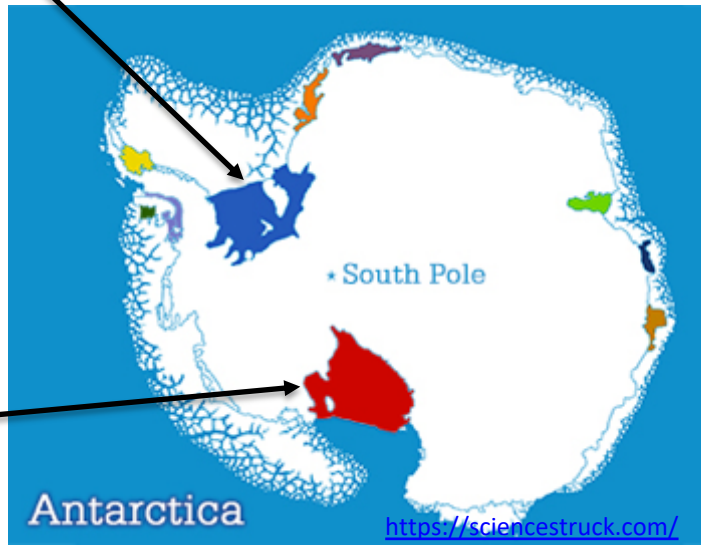
- First Cryo mesh to truly exploit regional refinement
  - “r0”: first attempt
- 60 vertical levels
- 727,755 horizontal cells
  - 3x v1 low-res
- Refined to 10 km through Southern Ocean



SORMM: Filchner Ice Shelf appears stable…



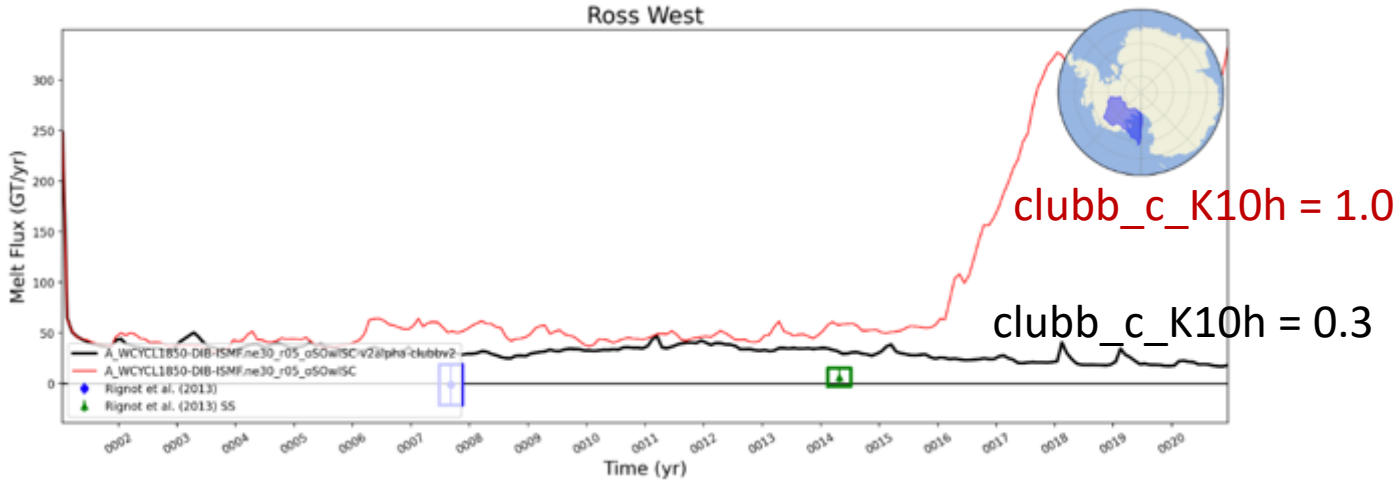




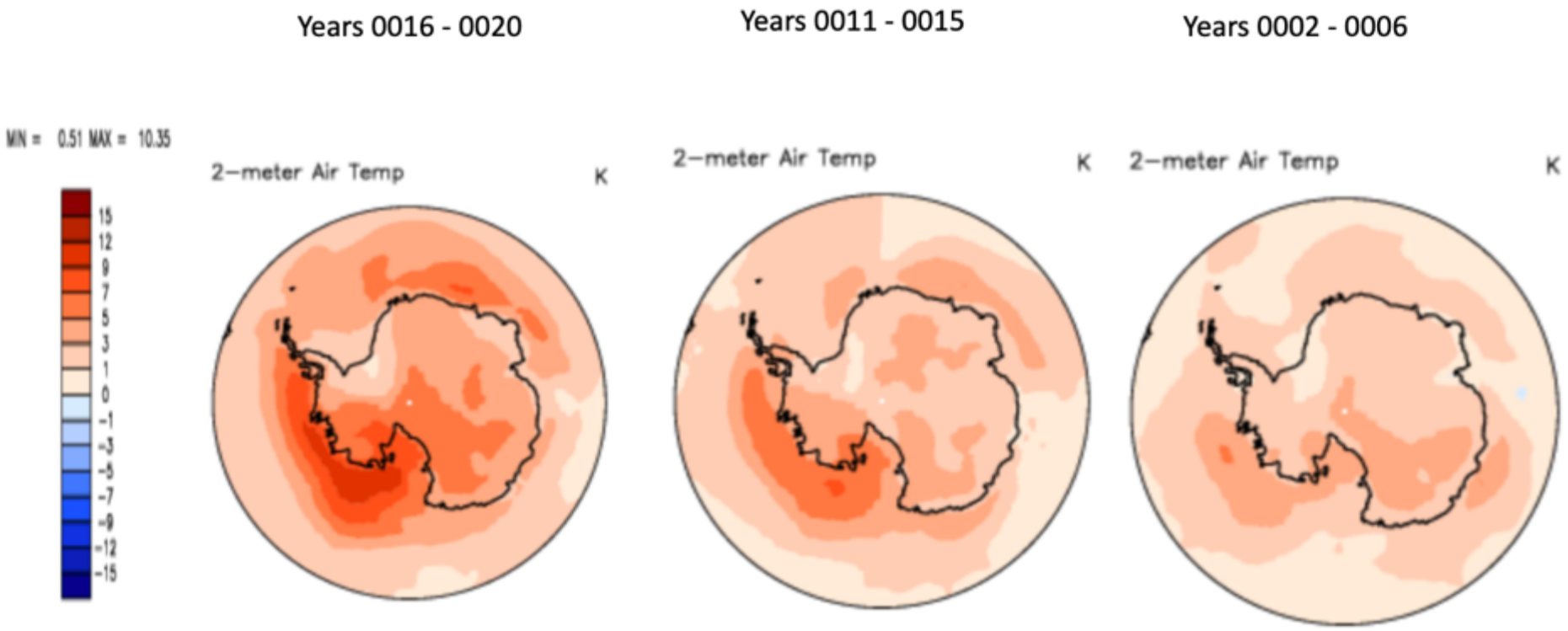
Ice shelf melt instability sensitive to ATM forcing

CLUBBv2 eddy mixing parameter, c_k10:

- SORRM run incorrectly used untuned value for c_k10h (scalar mixing parameter)
- Correctly setting c_k10h=0.3 remains stable (60 yr)

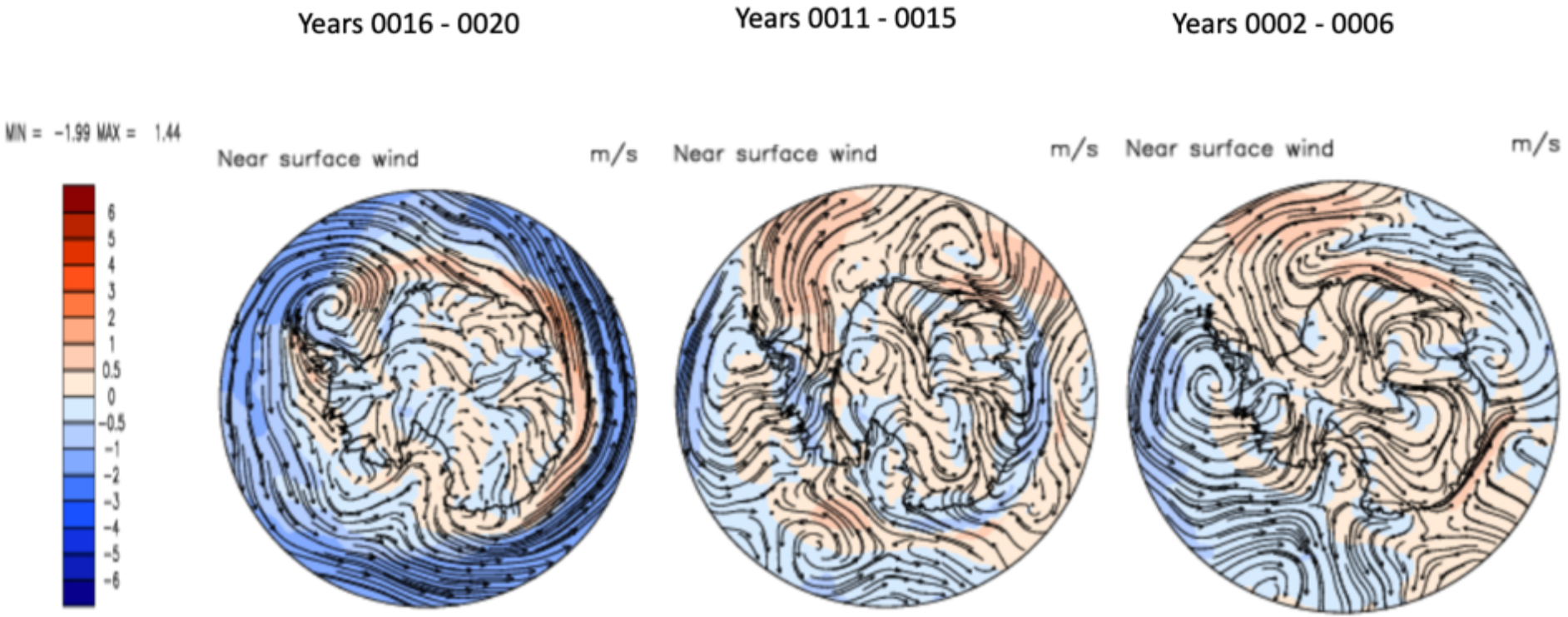


Air temperature difference (winter)



15° difference in first two decades

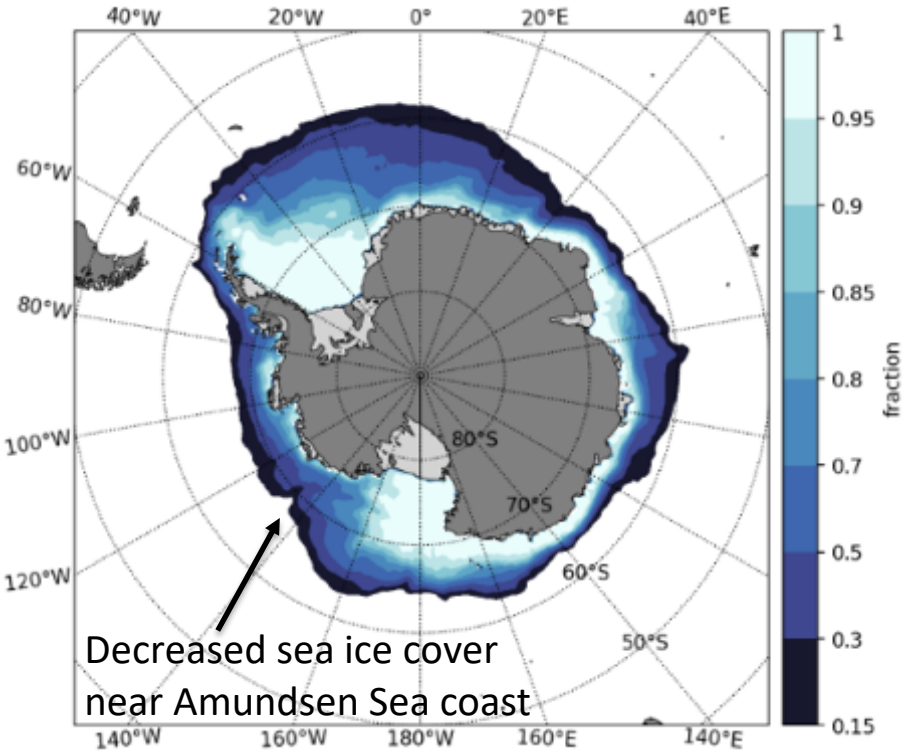
Annual near surface wind difference



More onshore winds

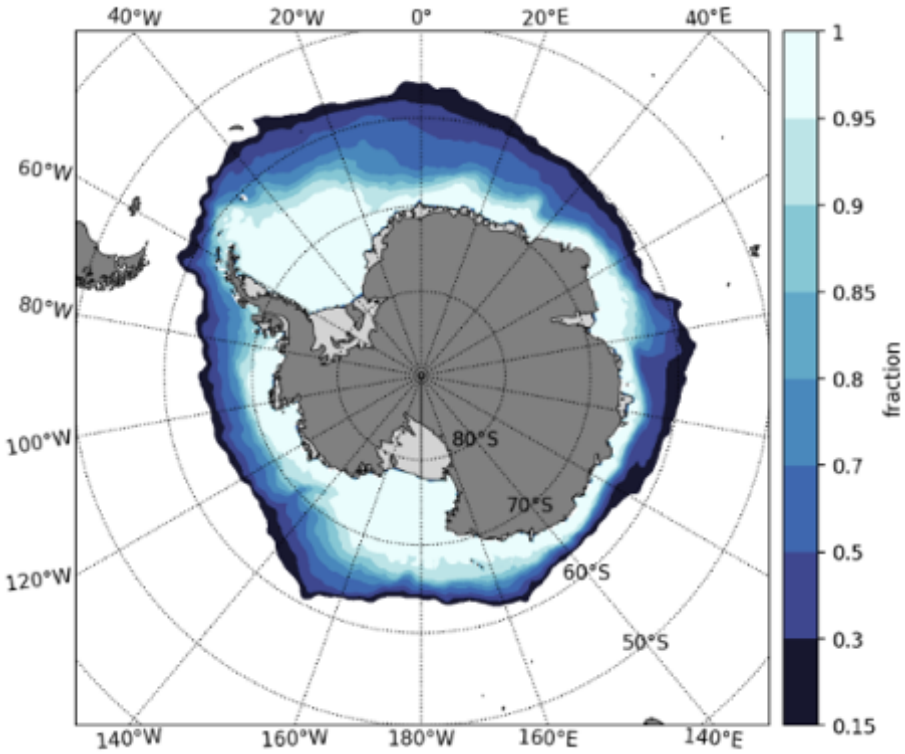
Sea ice concentration (JJA, years 11-20)

clubb_c_K10h = 1.0



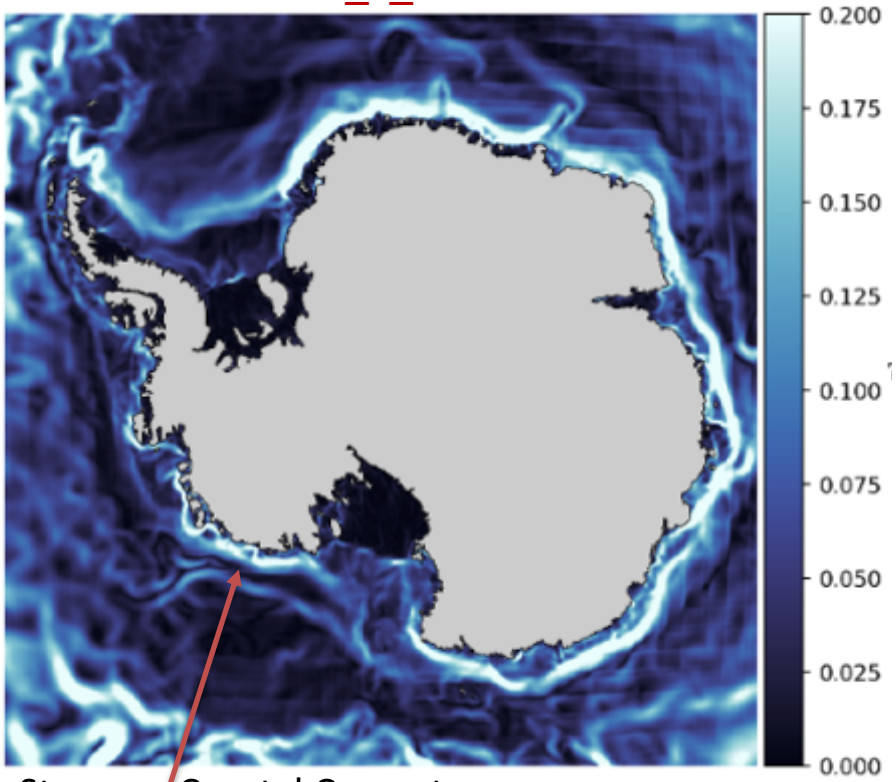
Decreased sea ice cover near Amundsen Sea coast

clubb_c_K10h = 0.3



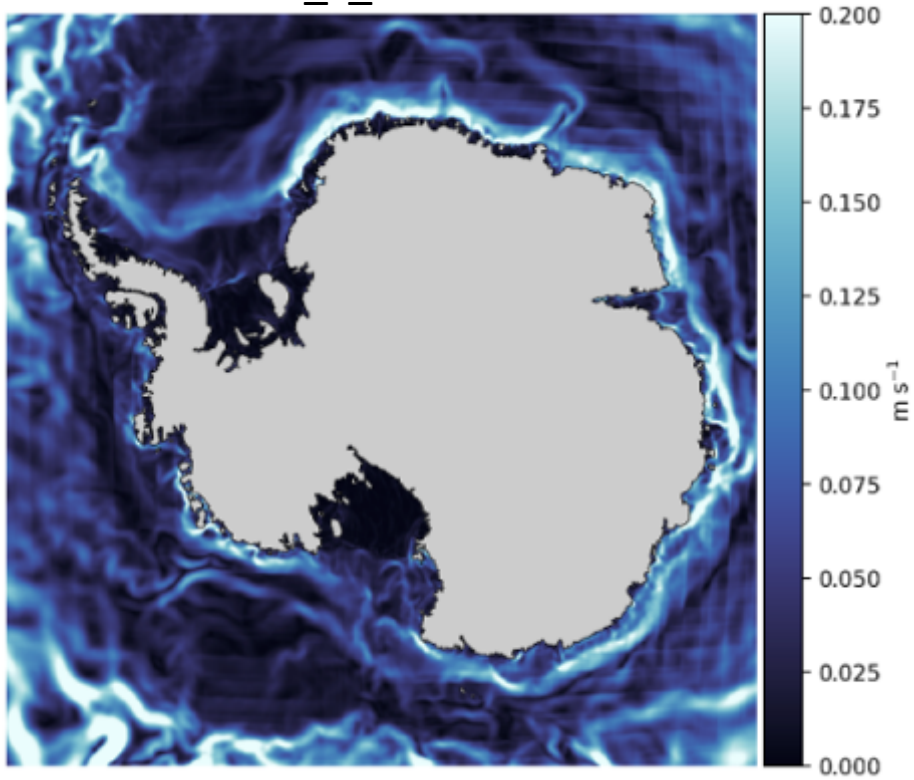
Sea surface speed

clubb_c_K10h = 1.0



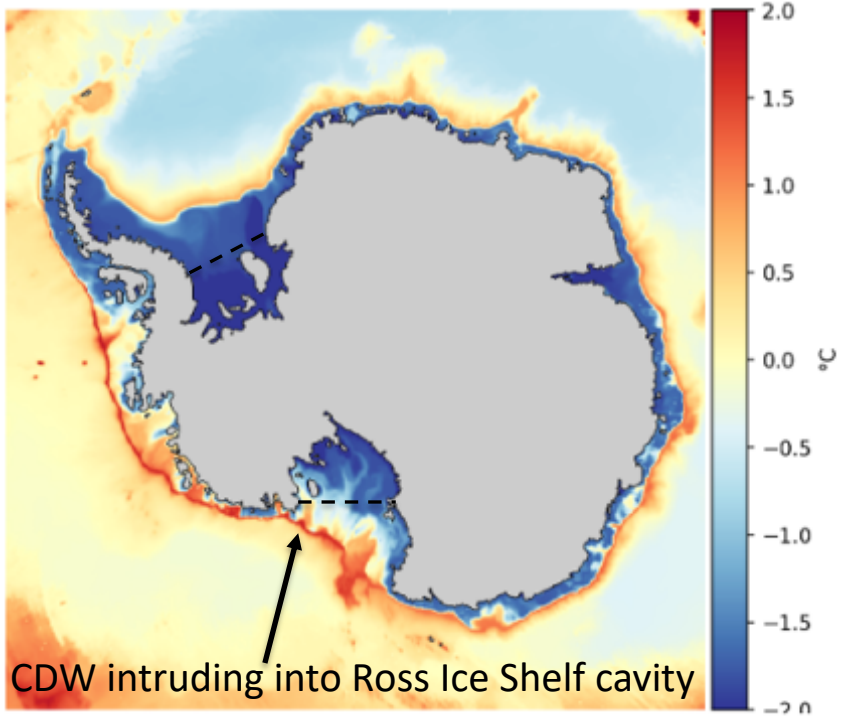
Stronger Coastal Current

clubb_c_K10h = 0.3

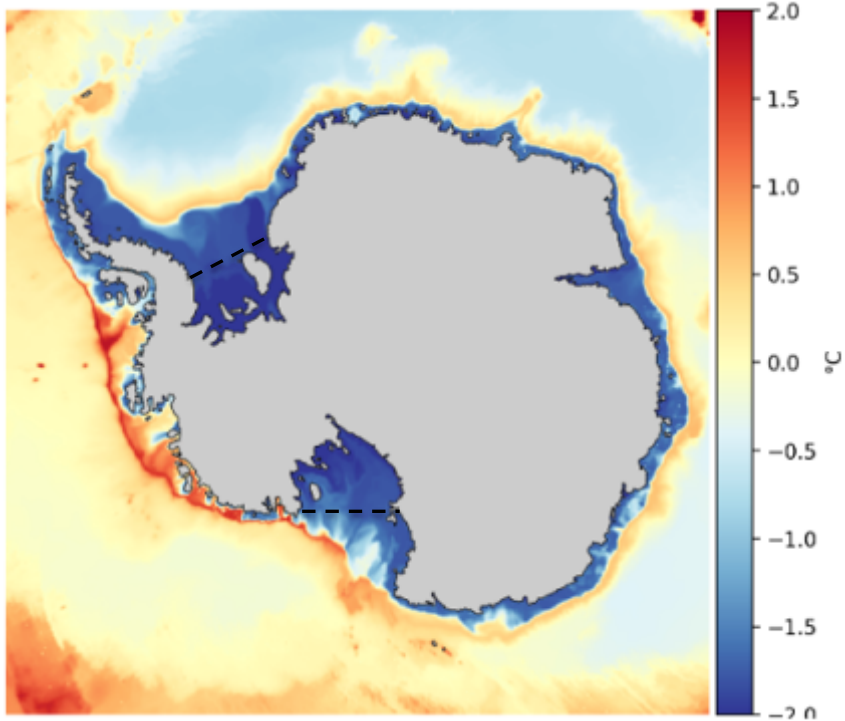


Sea floor potential temperature

clubb_c_K10h = 1.0



clubb_c_K10h = 0.3

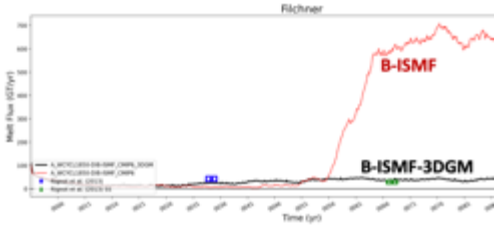


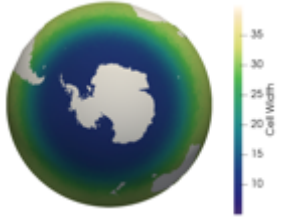
Summary

- E3SM tends to trigger tipping point in Antarctic ice shelf melt
- Melt from upstream ice shelves a previously unrecognized factor

- 3DGM parameterization reduces biases that lead to premature tipping point activation

- v2 SORRM mesh appears stable and provides 3x resolution
  - Tipping point sensitive to atmosphere model

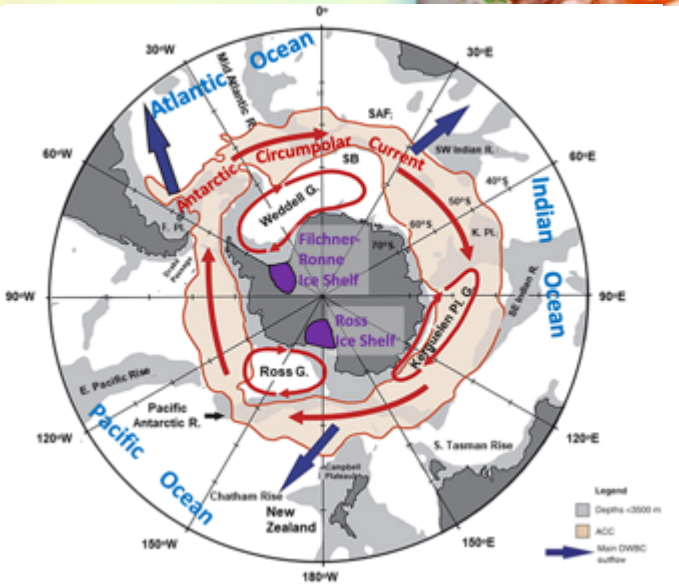




Future Work

Ongoing

- Analysis and paper on ice shelf melt domino effect
- Continue 3DGM preindustrial control
  - Complete Cryo config. model description paper
  - Finally permit historical & future scenario runs for Cryo Campaign!
- Finalize SORRM mesh and configuration
  - Begin v2 production runs for Cryo Campaign



Time-permitting

- Investigate regional & global climate impacts of freshwater flux increase after FRIS tipping point
- Investigate theoretical Ross Ice Shelf melt tipping point
  - Are regional & global climate impacts different than for FRIS tipping point?