Constraining Antarctic ice sheet stability during the Last Interglacial

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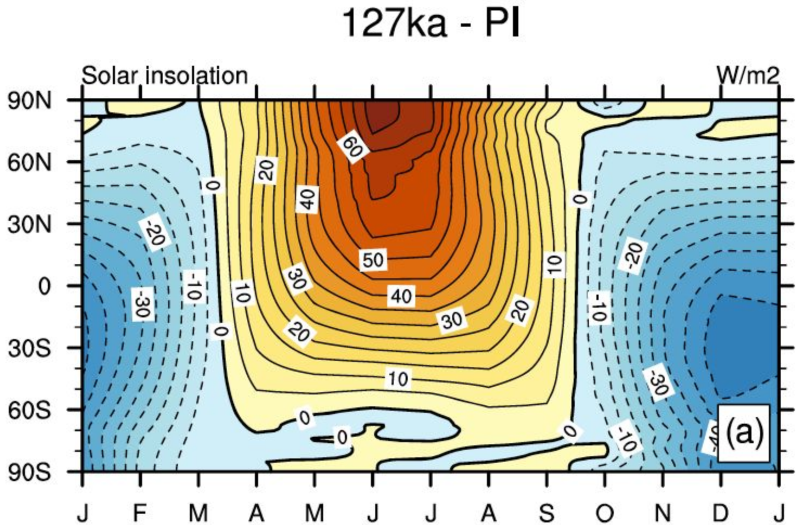
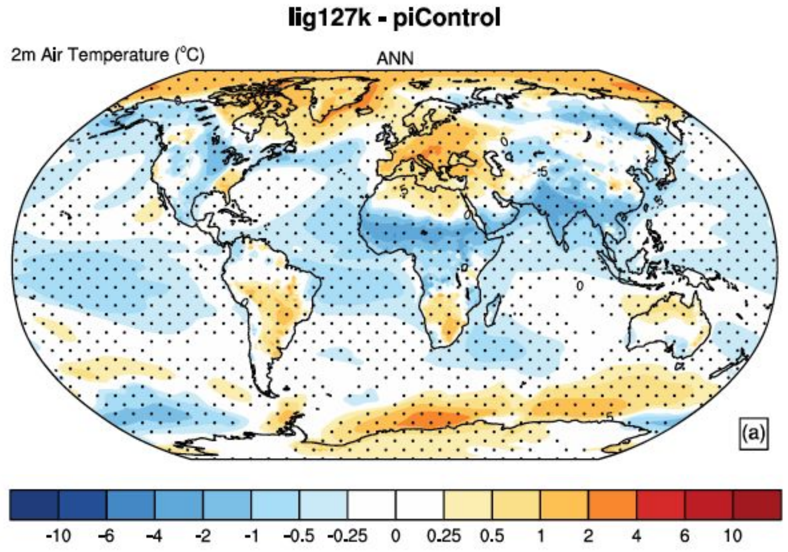
The Last Interglacial (LIG) (130,000 – 115,000 years ago)

1. Orbital configuration favored warm NH summers
    1. Perihelion was during Boreal Summer
    2. More eccentric orbit
    3. Higher obliquity
2. Much warmer Arctic than today
3. Lower CO_2 ~275 ppm



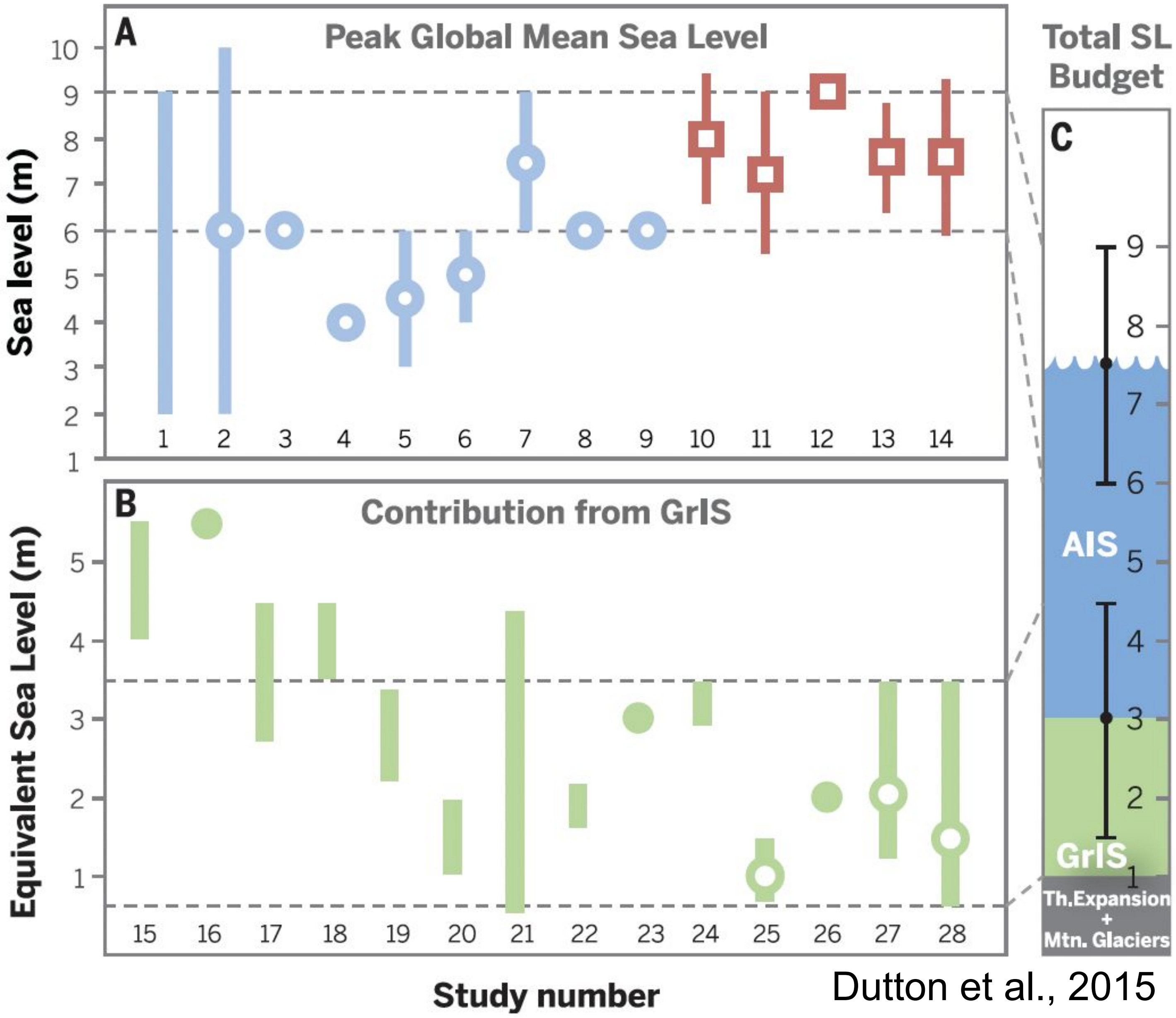


Otto-Bliesner et al., 2020

Last Interglacial sea level

Global mean sea level was **~6-9 m** higher than present

Greenland contributed **~1-3 m** of sea level rise



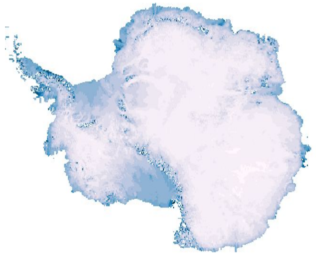
Dutton et al., 2015

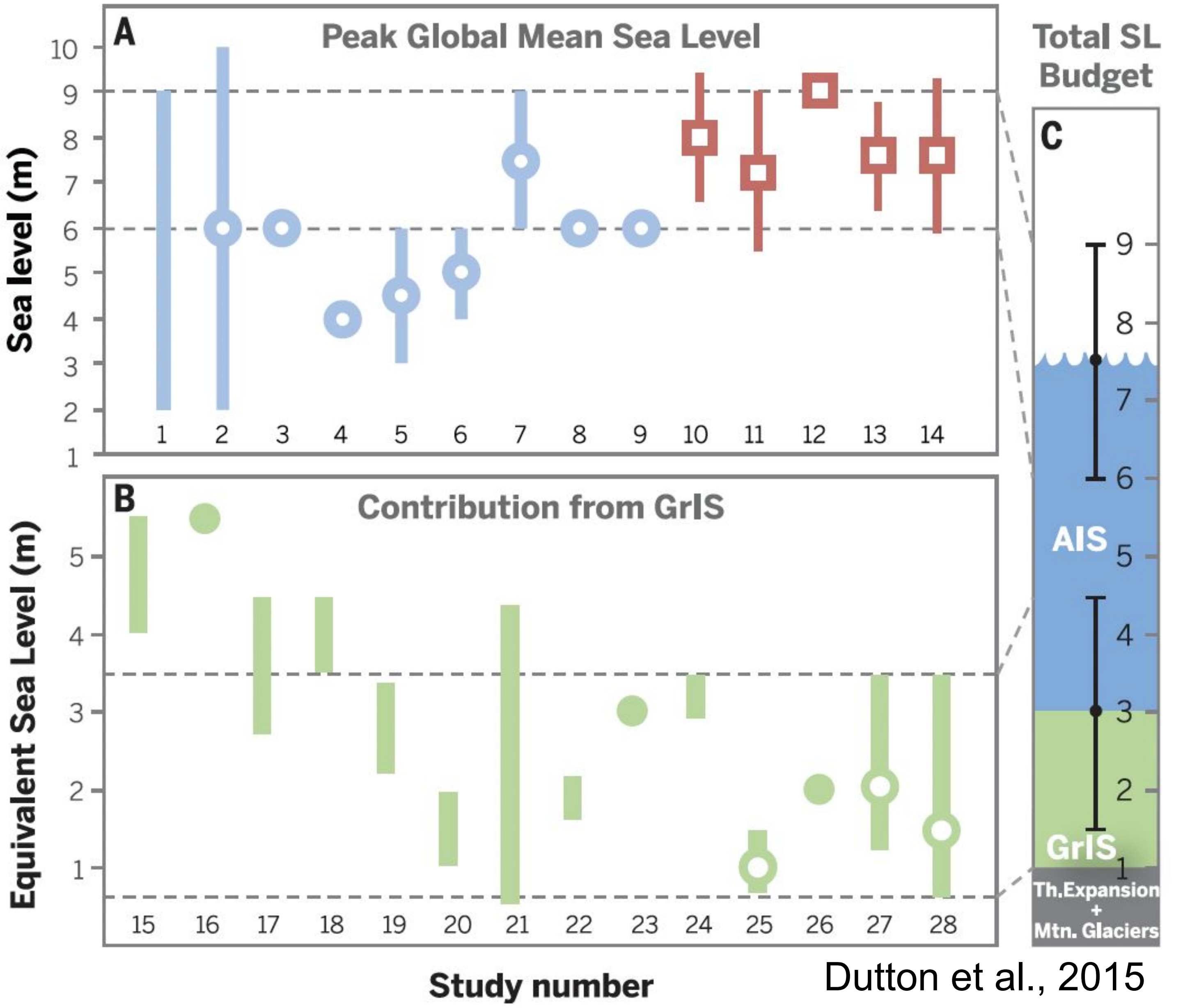
Last Interglacial sea level

Global mean sea level was **~6-9 m** higher than present

Greenland contributed **~1-3 m** of sea level rise

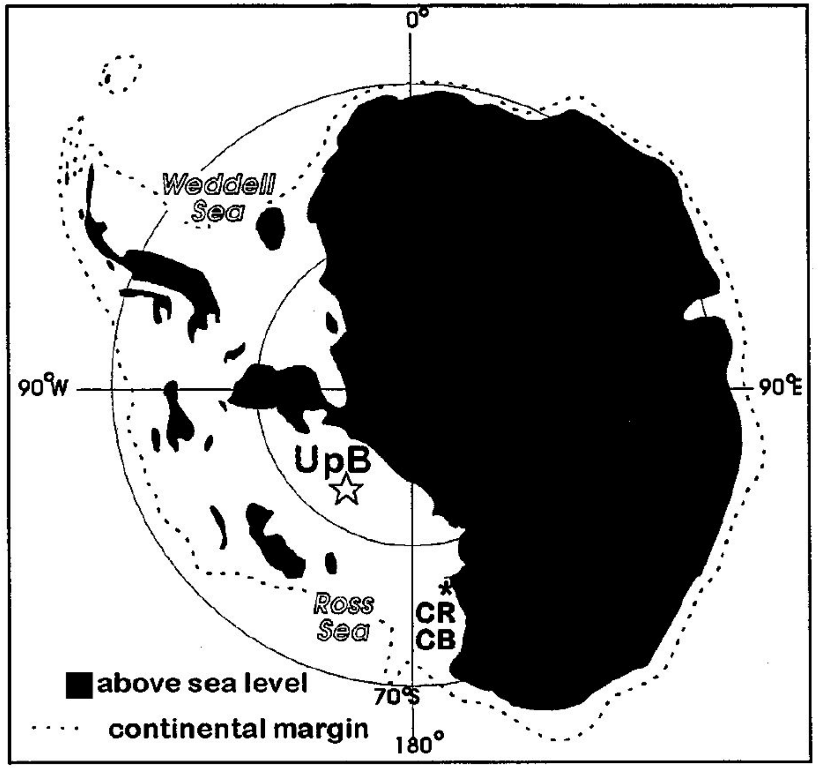
Where does the remaining ~3-6 m come from?





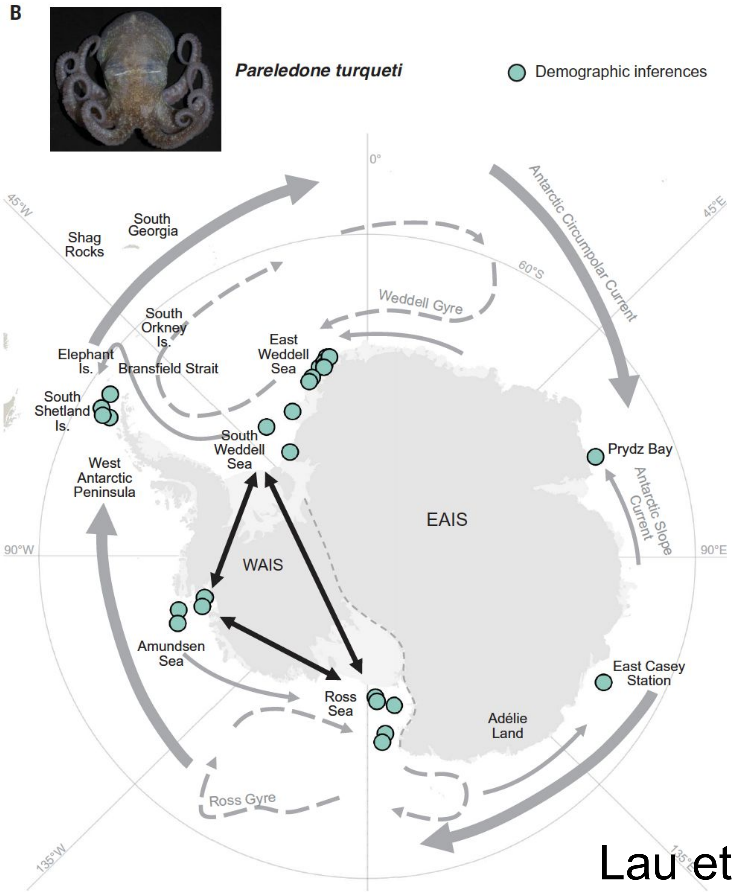
Dutton et al., 2015

Evidence of a reduced Antarctic ice sheet during the LIG



Scherer et al, 1998

Late Pleistocene marine diatoms under the West Antarctic Ice sheet.



Lau et al, 2023

Genomic evidence of open ocean gateway through the West Antarctic Ice Sheet during the Last Interglacial.

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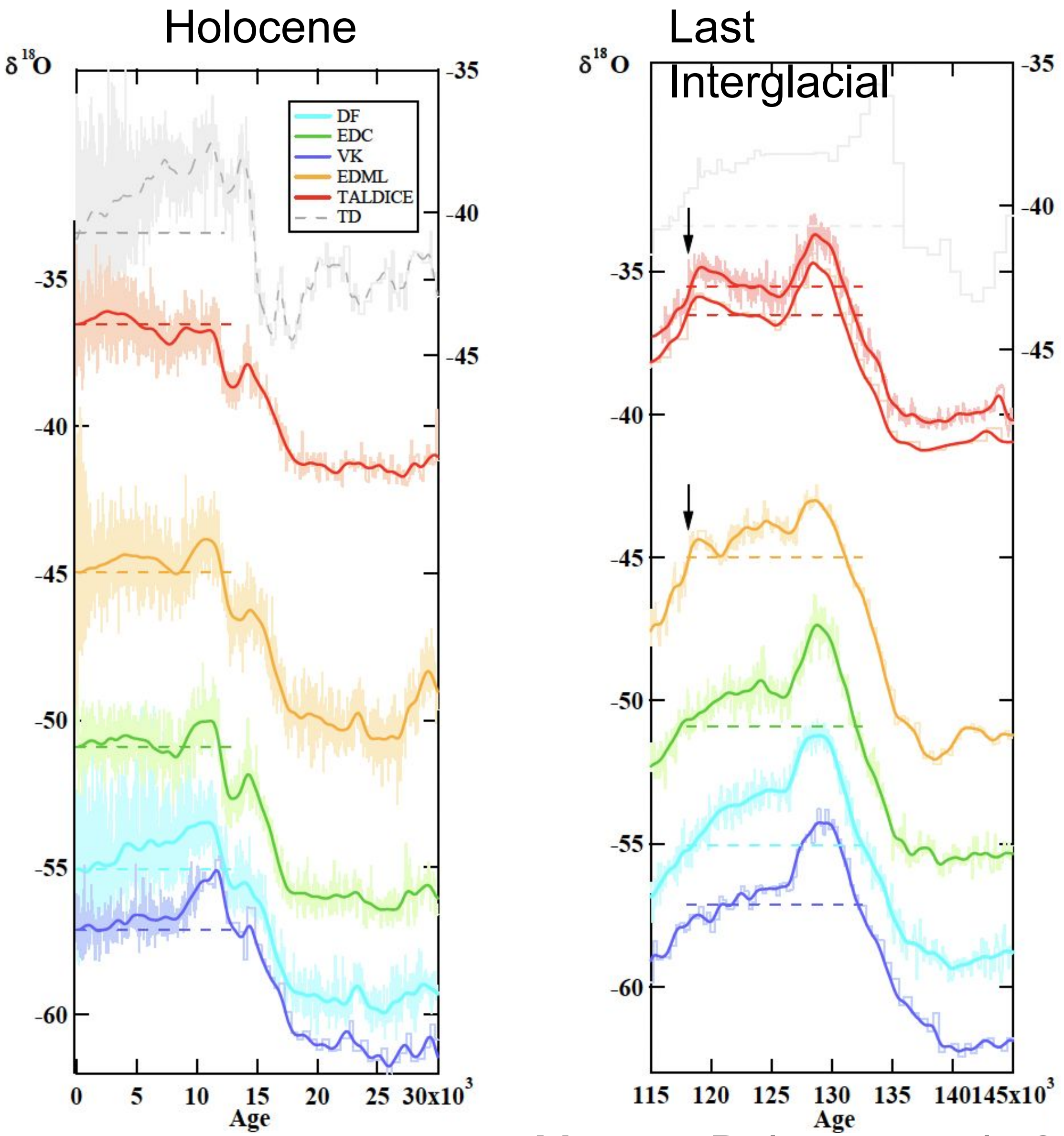
Let's ask the ice sheet what happened

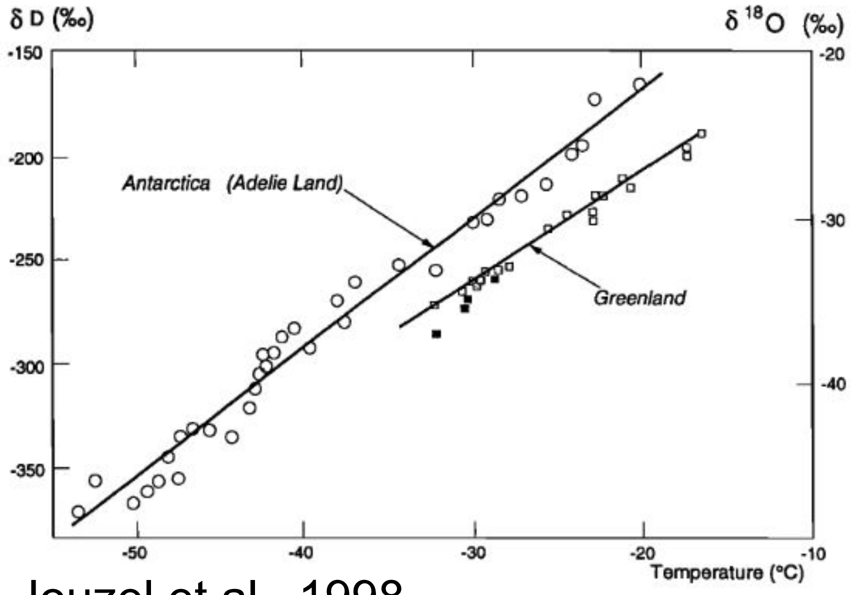
Antarctic ice core records from the LIG



Masson-Delmotte et al., 2011

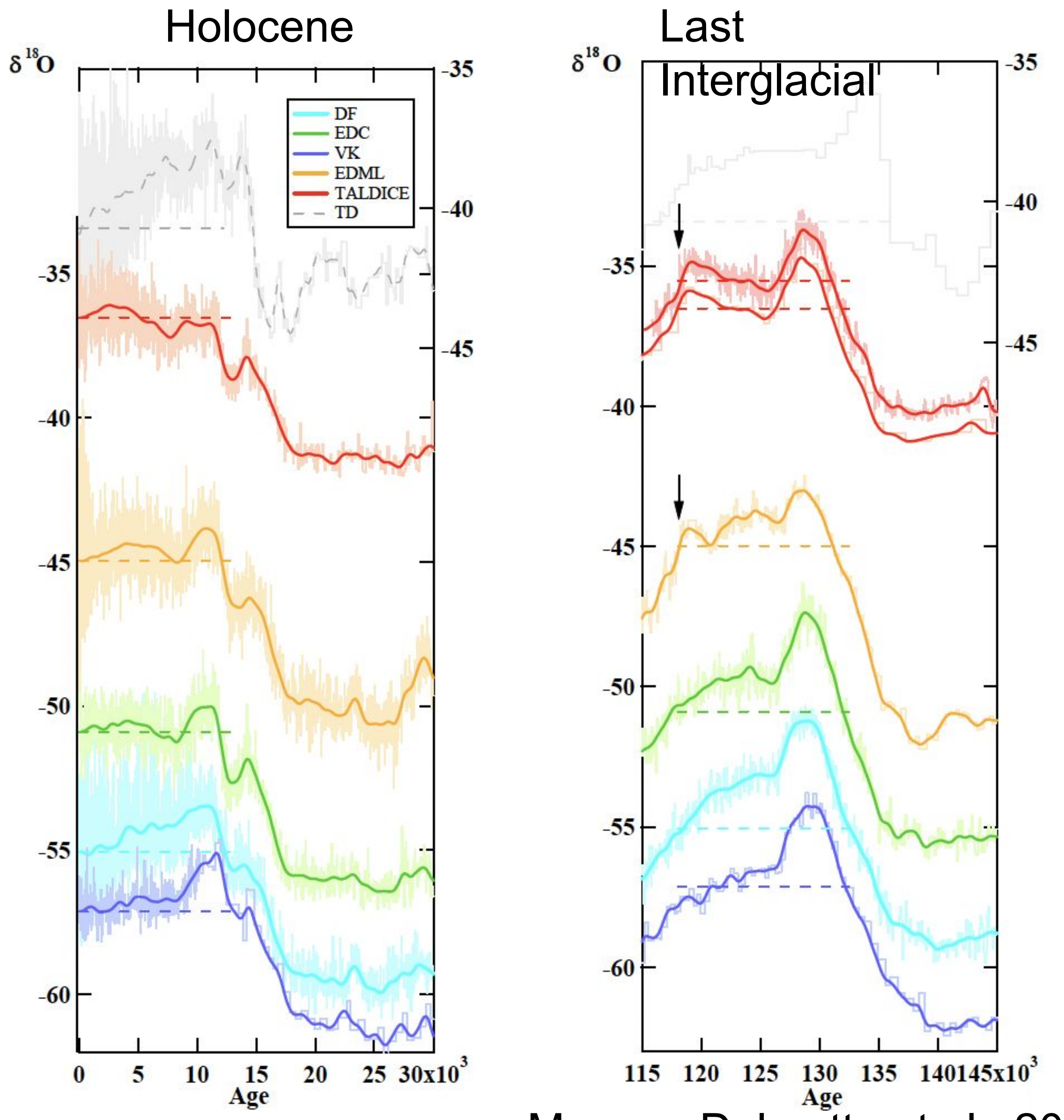
Antarctic ice core records from the LIG

Could Antarctic ice core $\delta^{18}O$ contai information about past ice sheet stability?



Jouzel et al., 1998

$\delta^{18}O \leftrightarrow$ temperature $\leftrightarrow$ background climate, elevation, etc.

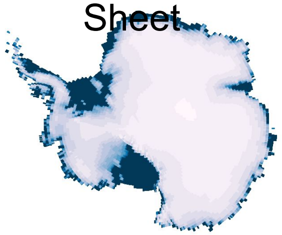


Masson-Delmotte et al., 2011

LIG iCESM simulations

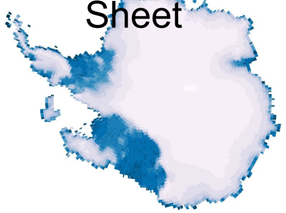
Ice Sheet Configuration:

PI Antarctic Ice Sheet



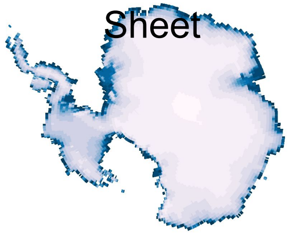
~0 m SLE

Minimally Collapsed West Antarctic Ice Sheet



~3 m SLE

Partially Collapsed West Antarctic Ice Sheet



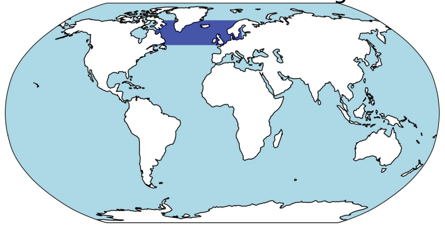
~3 m SLE

Fully Collapsed West Antarctic Ice Sheet

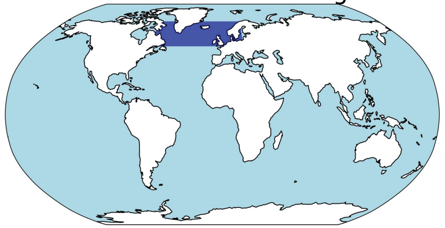
~6 m SLE

North Atlantic Freshwater:

_NAFWF



0.2 Sv x 1000 years



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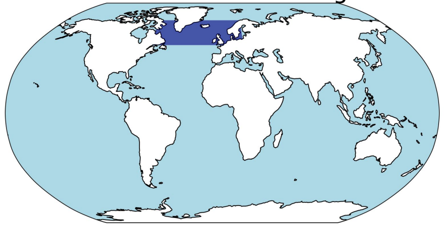

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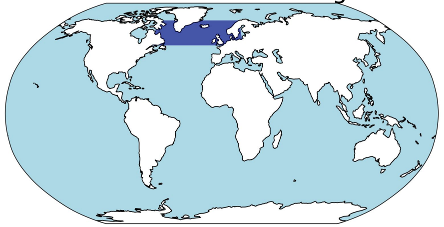
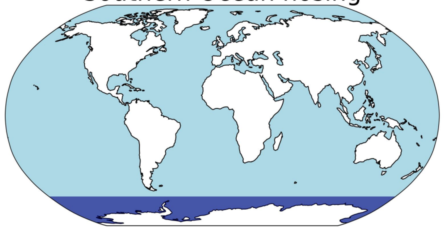


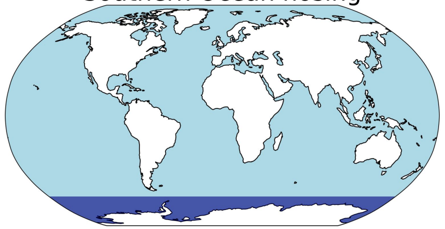
0.2 Sv x 1000 years

Southern Ocean Freshwater:

_SOFWF



0.2 Sv x 500 years



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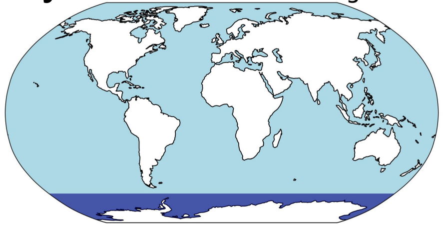
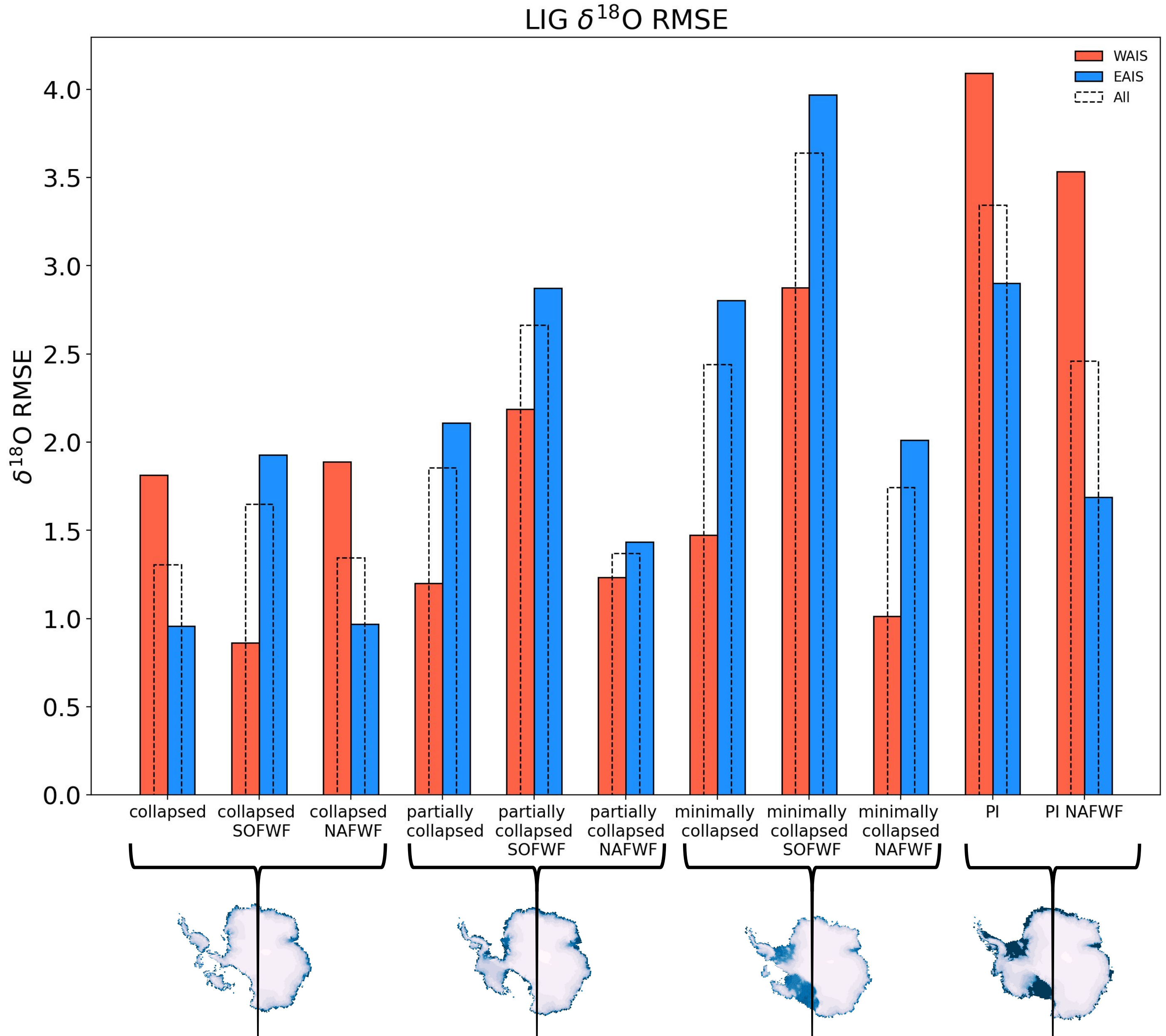


0.2 Sv x 500 years

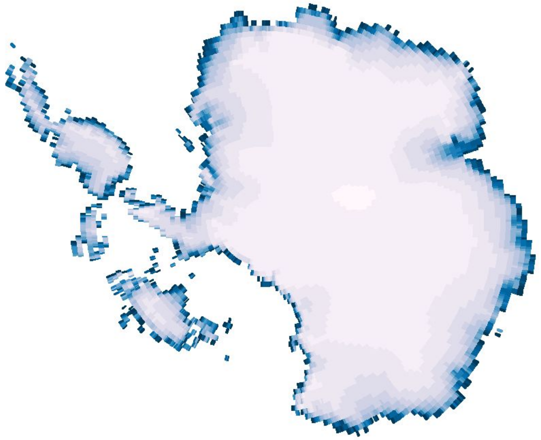
12 Simulations in total (11 LIG, 1 PI control)

Which simulation reproduces LIG $\delta^{18}O$ best?

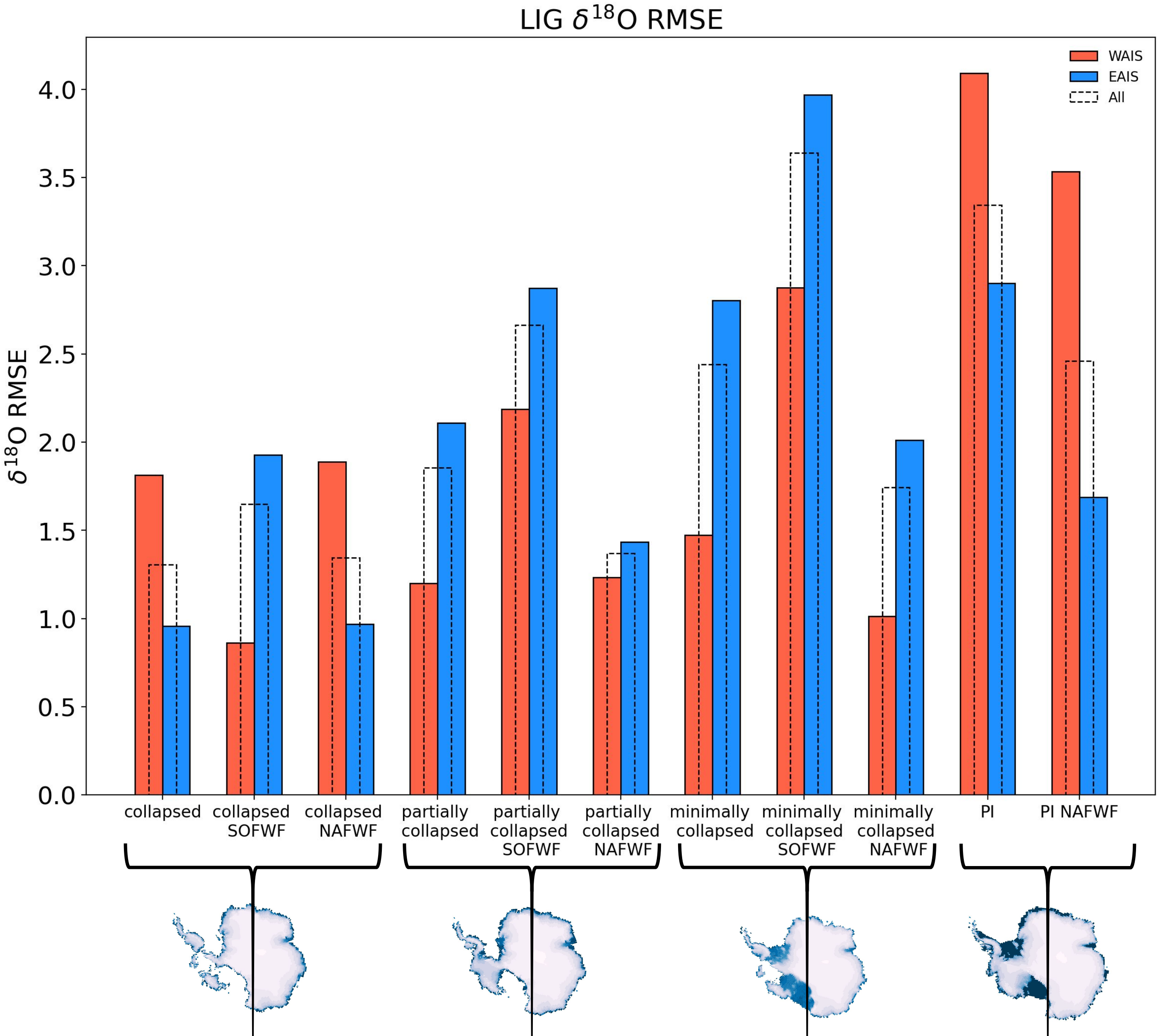


Which simulation reproduces LIG $\delta^{18}O$ best?

The fully collapsed Antarctic ice sheet configuration reduces RMSE the most.



- NAFWF and SOFWF bracket $\delta^{18}O$ anomalies.
- Reality is somewhere in between?



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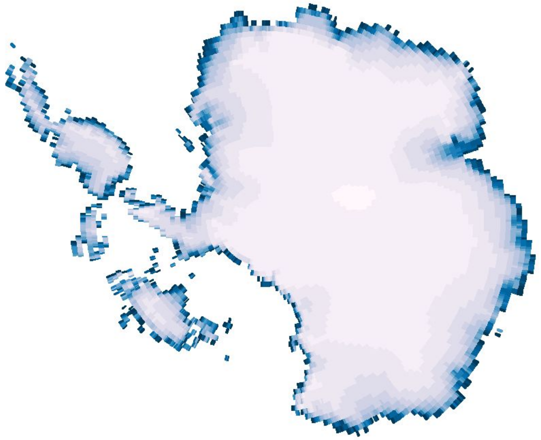
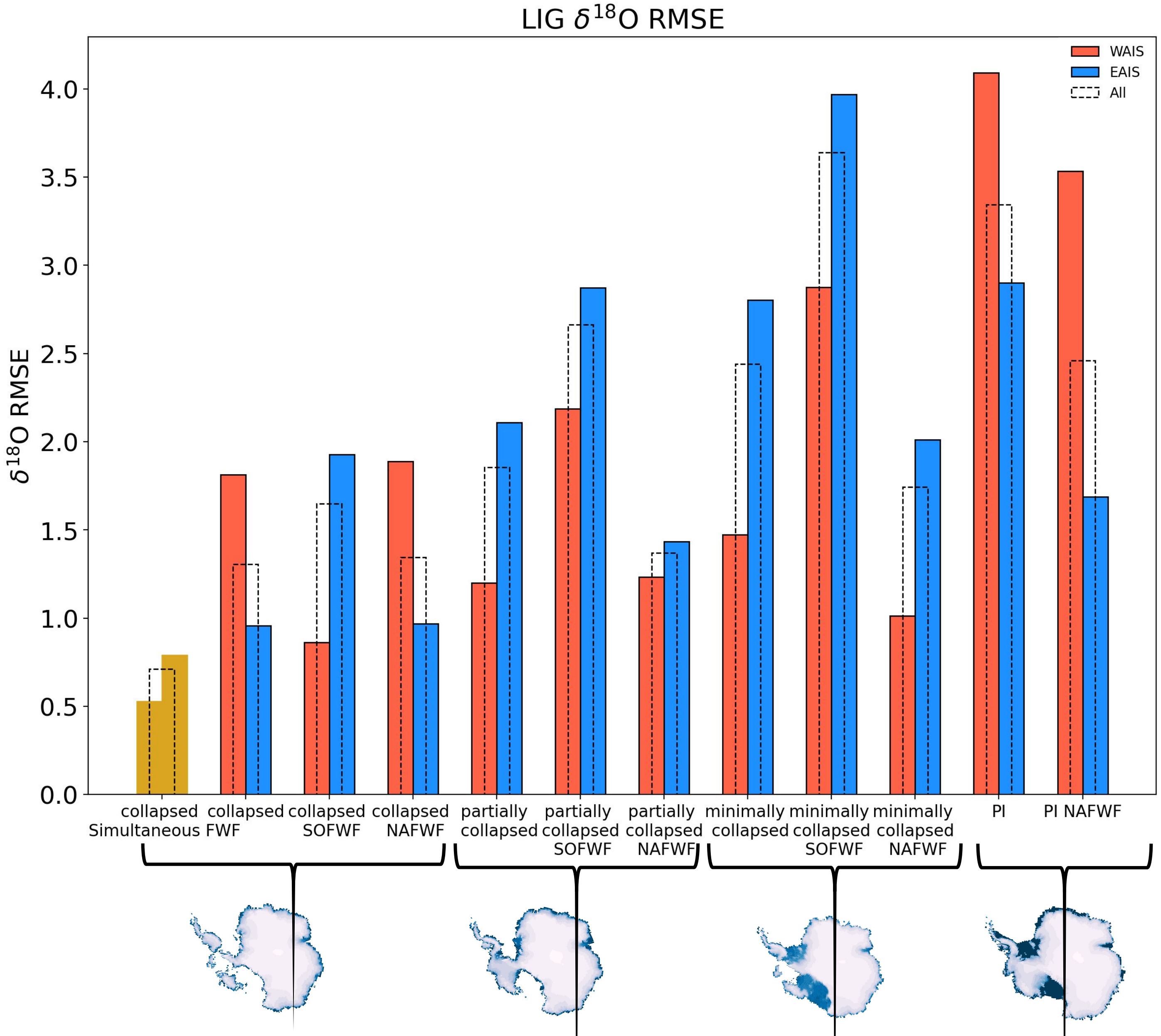


- NAFWF and SOFWF bracket $\delta^{18}O$ anomalies.
- Reality is somewhere in between?
- Applying the SOFWF impact to the collapsed WAIS with NAFWF gives lowest RMSE



Antarctic response to ice sheet collapse and hosing

- LIG orbit + GHGs cause some regional warming
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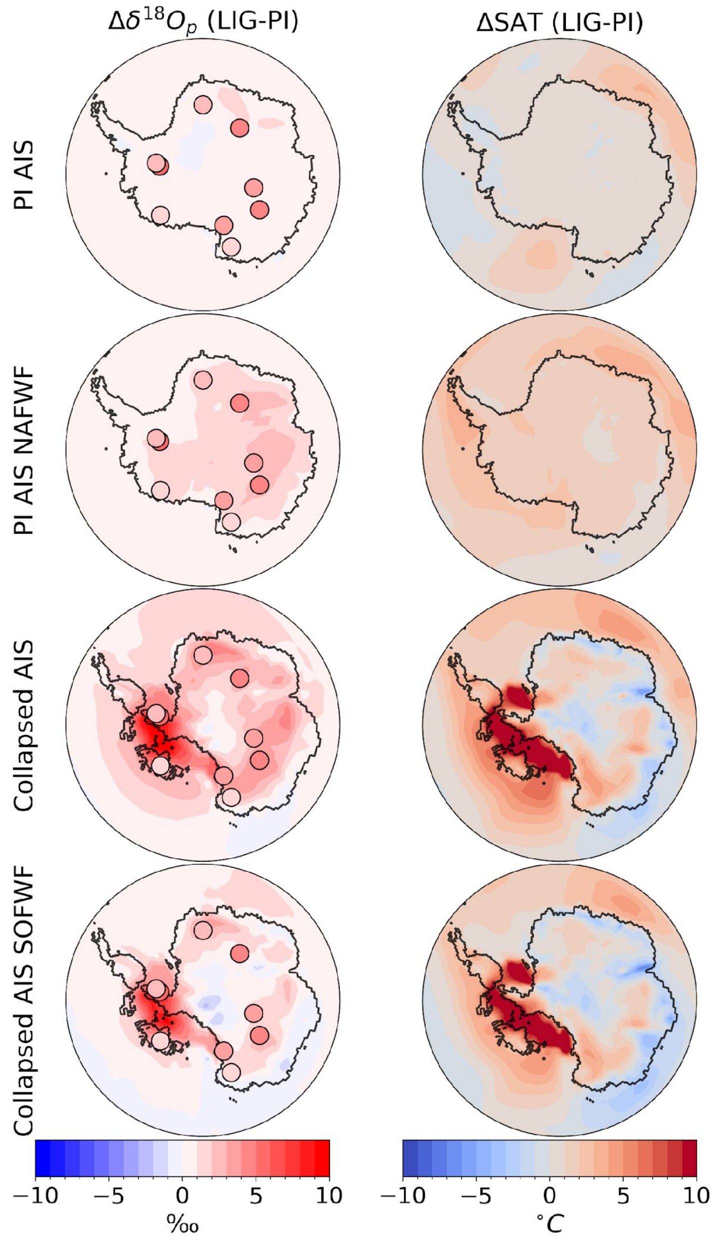
- Southern Ocean hosing has a weaker impact on Antarctic surface temperatures than topographic change.



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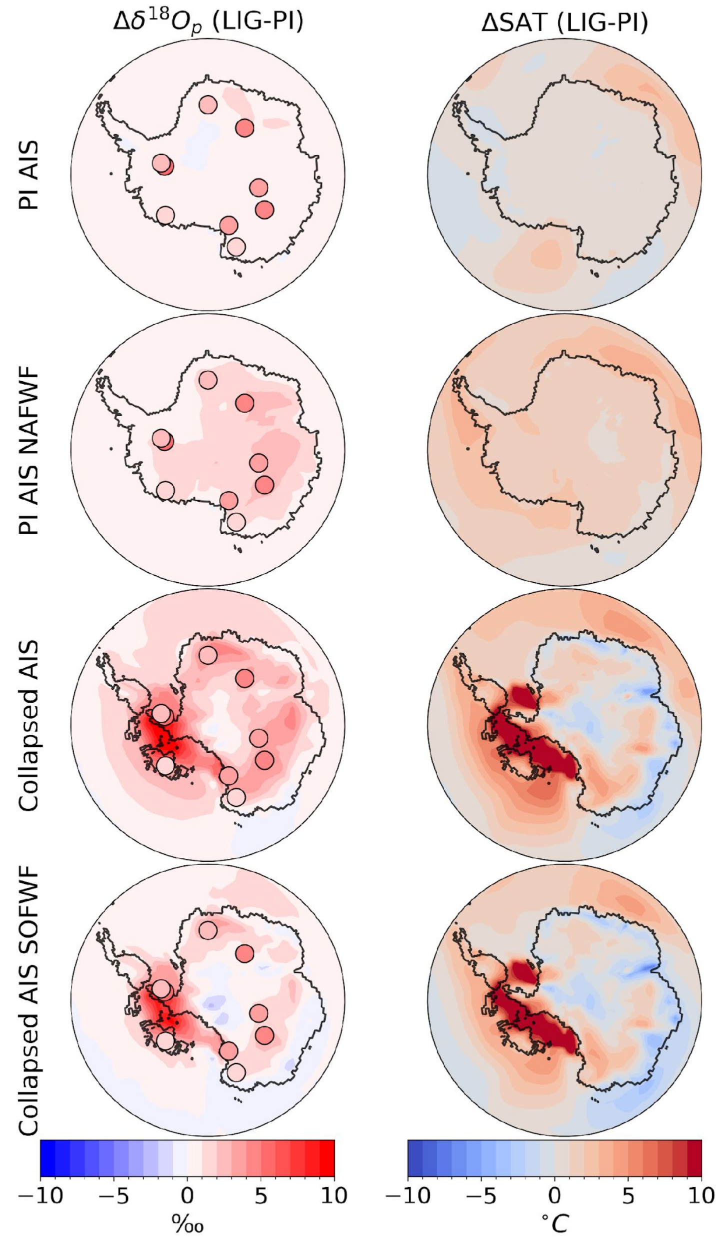
Two potential controls on precipitation δ¹⁸O:

1. Lower Elevation □ Warmer condensation temperatures □ enriched δ^{18}O
2. Reduced ice sheet □ regional warming □ more local precipitation □ enriched δ^{18}O



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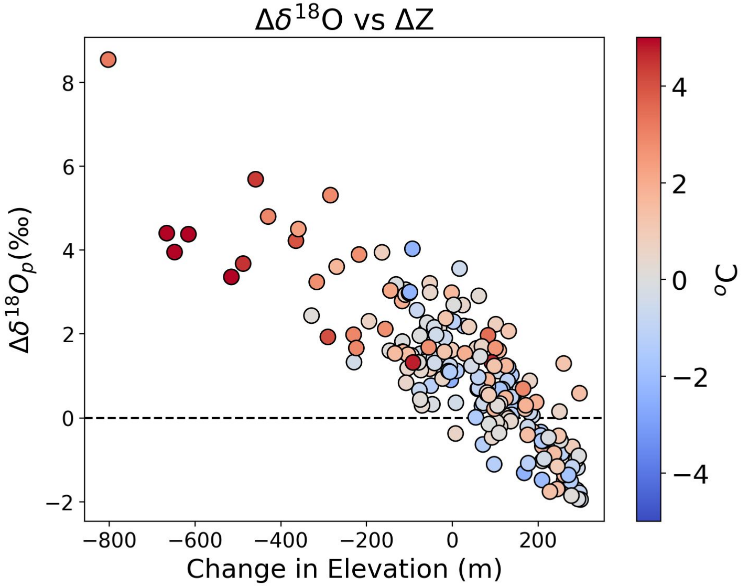
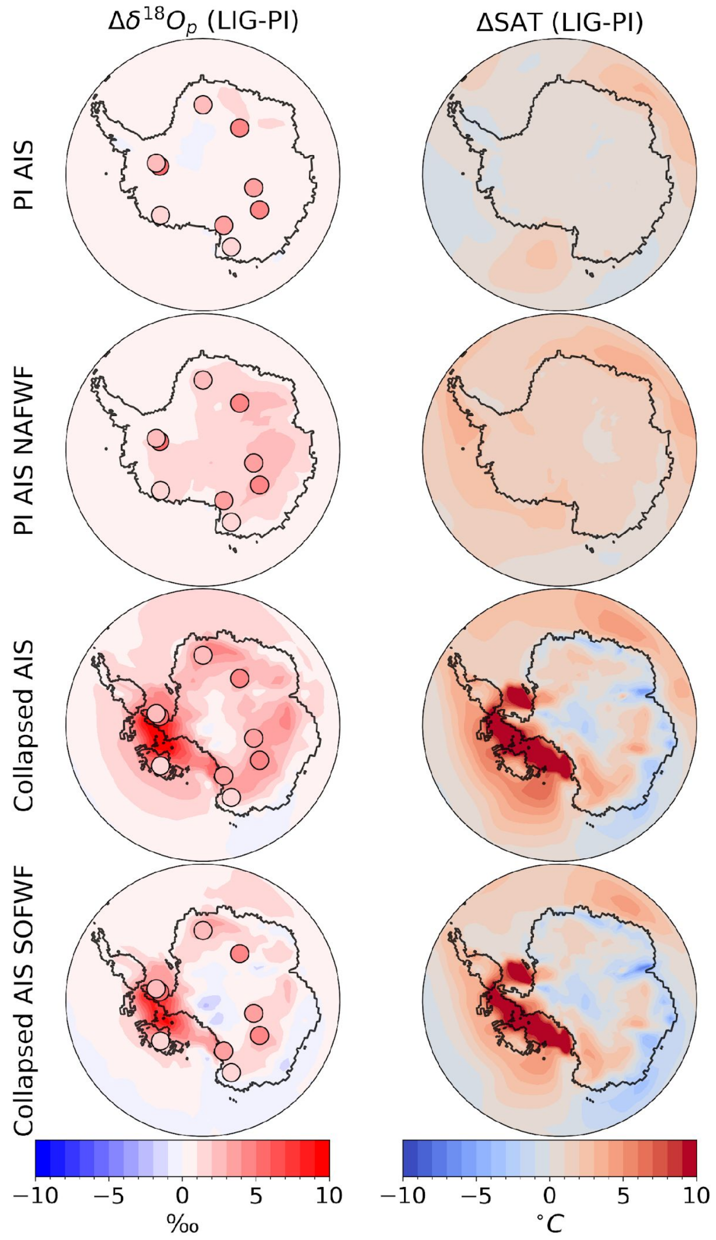
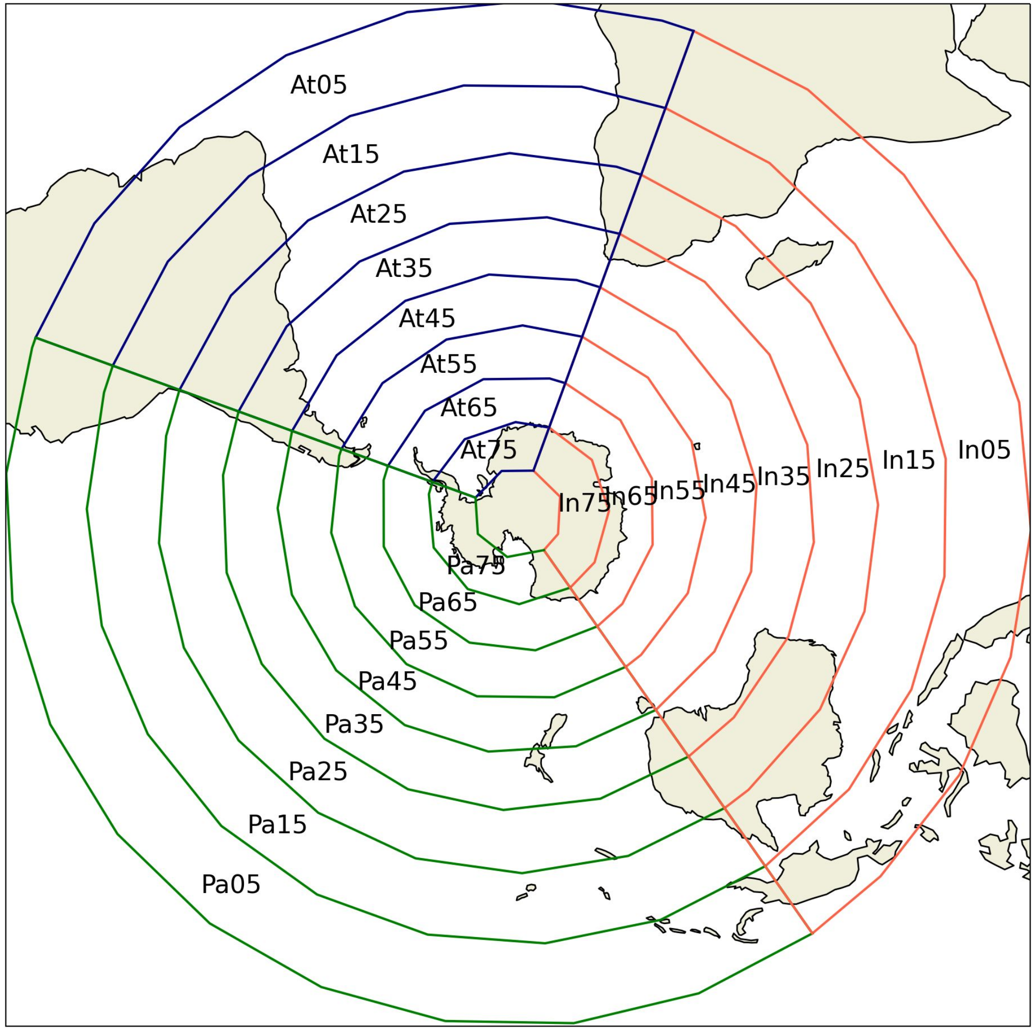
$\delta^{18}O$ increases with decreasing elevation





Adding water tags to our simulations

Tagging evaporative fluxes from specific regions allows us to track moisture sources and water isotope ratios from source to sink.



Water tags:

- Indian Ocean – 10° latitudinal steps (0-80°S)
- Pacific Ocean – 10° latitudinal steps (0-80°S)
- Atlantic Ocean – 10° latitudinal steps (0-80°S)
- Antarctic sourced moisture
- Southern Ocean sea ice sourced moisture

Moisture tagging is an extremely useful tool and should totally be added to CESM3. I know someone who would love to do that for a postdoc if y'all are hiring! 😉

Method for partitioning δ^{18}O signal

Following Hu et al., 2019:

$$\Delta(\delta^{18}O_P)_i = \Delta[condensation_i + rainout_i + source\ composition_i]\times\left(\frac{P_i}{P_{total}}\right) + source\ location_i$$

- $condensation_i = \left(\delta^{18}O_{P\,sink} - \delta^{18}O_{wv\,sink}\right)_i$
- $rainout_i = \left(\delta^{18}O_{wv\,sink} - \delta^{18}O_{wv\,source}\right)_i$
- $source\ composition_i = \left(\delta^{18}O_{wv\,source}\right)_i$
- $source\ location_i = \delta^{18}O_{P\,sink}\times\Delta\left(\frac{P_i}{P_{total}}\right)$

Core drivers of δ^{18}O change due to collapse

$$condensation_i = \left(\delta^{18}O_{P\,sink} - \delta^{18}O_{wv\,sink}\right)_i$$

$$rainout_i = \left(\delta^{18}O_{wv\,sink} - \delta^{18}O_{wv\,source}\right)_i$$

$$source\ composition_i = \left(\delta^{18}O_{wv\,source}\right)_i$$

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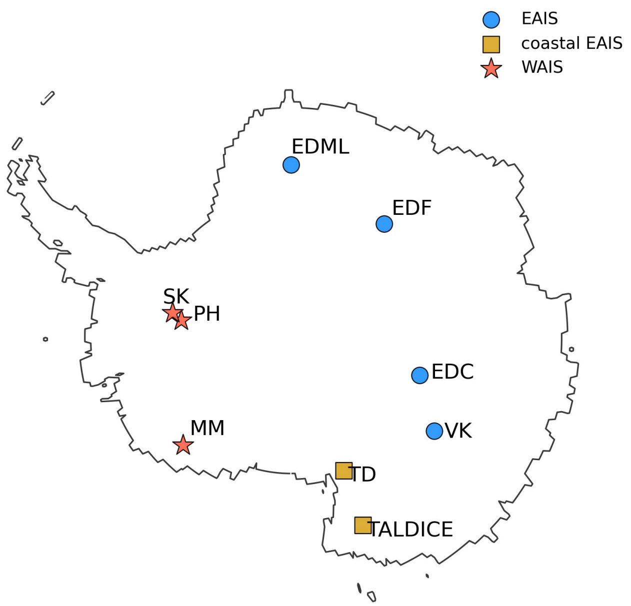

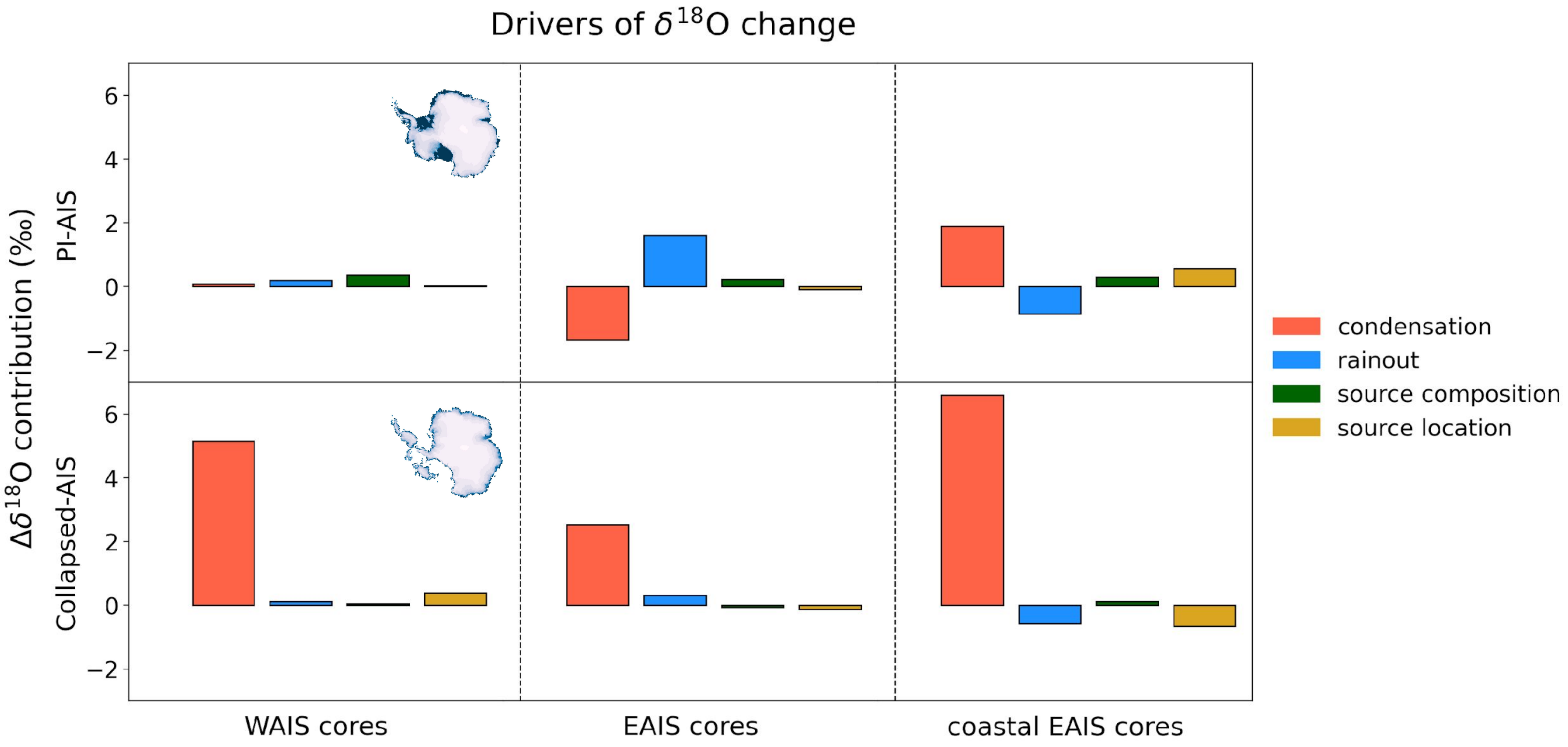

Core drivers of $\delta^{18}O$ change due to collapse

$$condensation_i = \left(\delta^{18}O_{P\,sink} - \delta^{18}O_{wv\,sink}\right)_i$$

$$rainout_i = \left(\delta^{18}O_{wv\,sink} - \delta^{18}O_{wv\,source}\right)_i$$

$$source\ composition_i = \left(\delta^{18}O_{wv\,source}\right)_i$$

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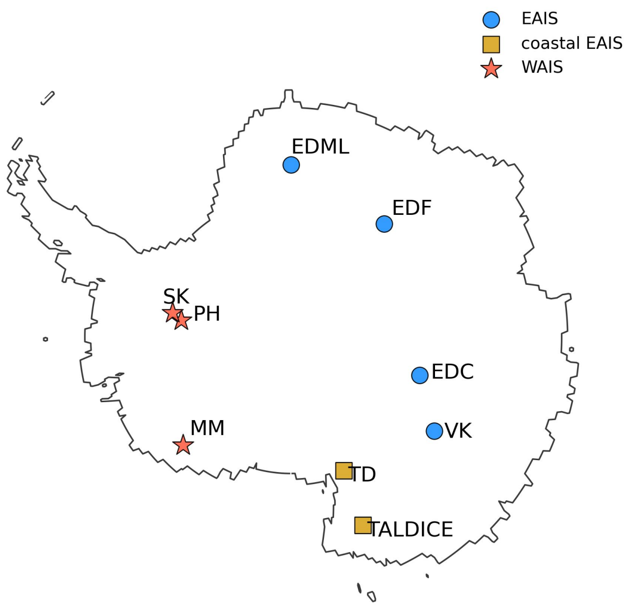

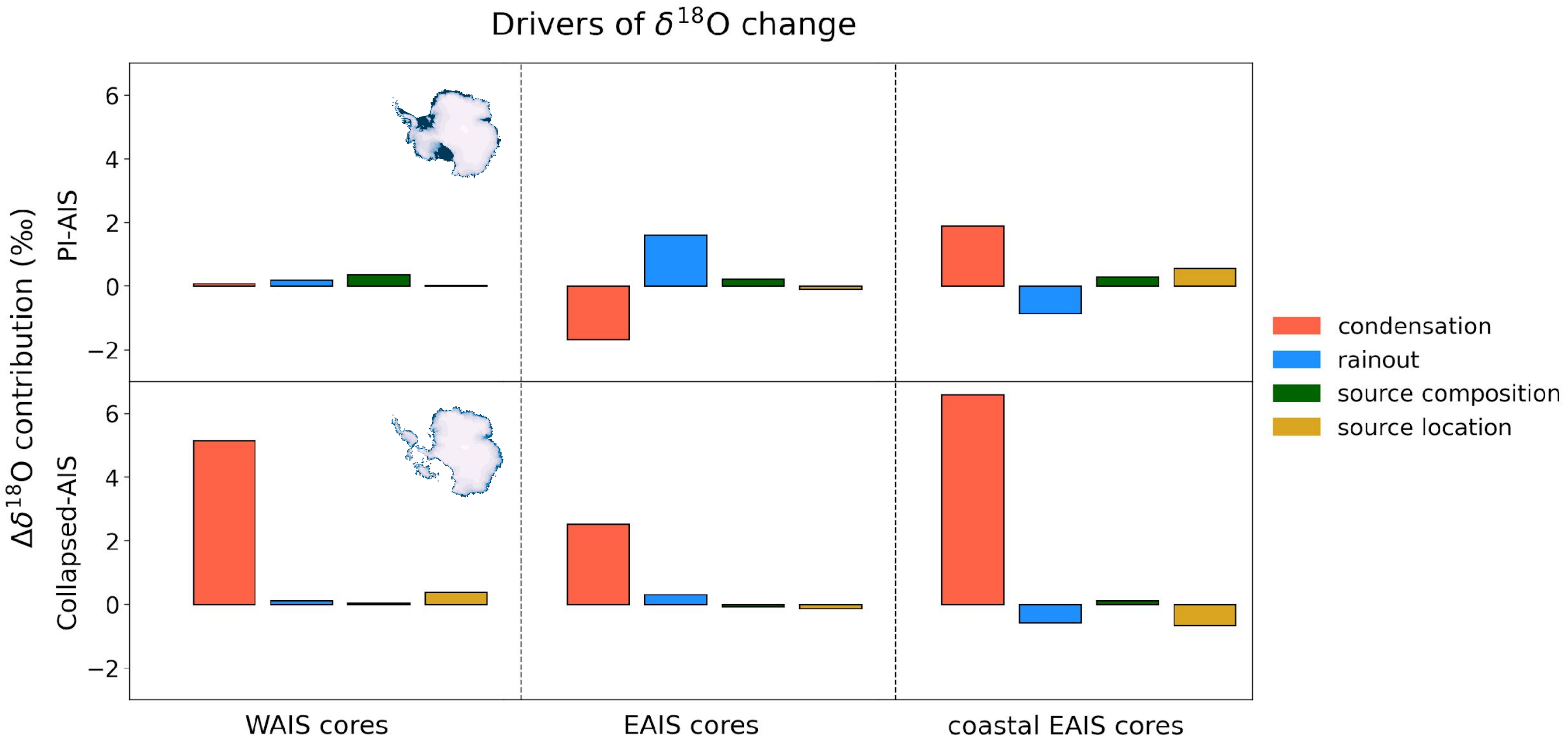

1. Condensation dominates $\delta^{18}O$ change in collapsed WAIS case
2. Aggregate impact of other drivers of $\delta^{18}O$ change is small

Thanks for listening! Questions? Feedback?

Recap:

1. A fully collapsed WAIS reproduces peak $\delta^{18}O$ best during the LIG
2. Collapsing the ice sheet drives regional warming, increasing condensation temperatures and enriching $\delta^{18}O$
3. Changing moisture sources and trajectories also contribute to $\delta^{18}O$ enrichment, especially over West Antarctica and peripheral East Antarctica. Could be evident in d-excess records.

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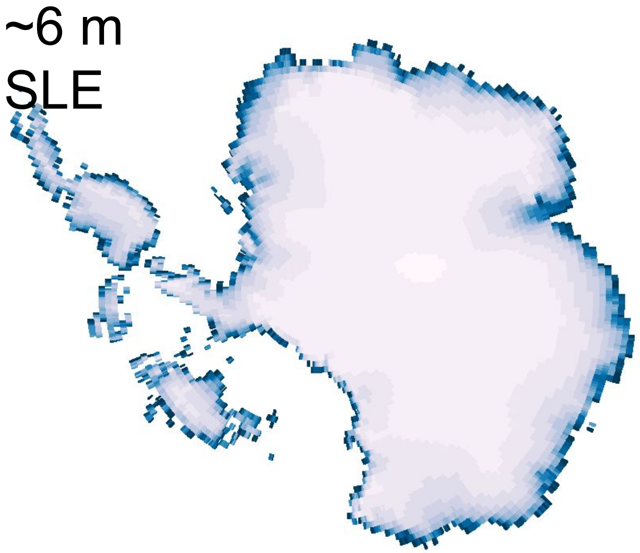

Fully collapsed West Antarctic Ice Sheet 127,000 years ago

This work is funded by NSF. The simulations are run on the Derecho supercomputer, which is sponsored and maintained by NSF.

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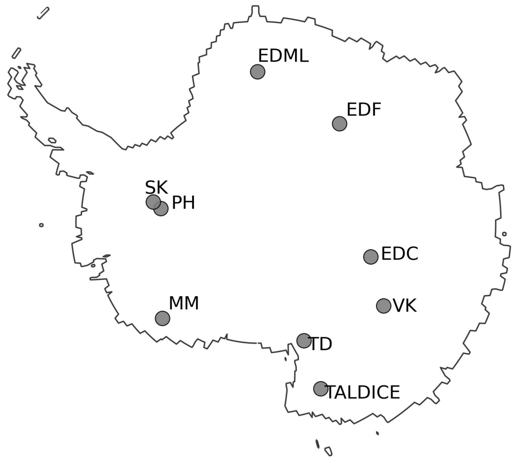
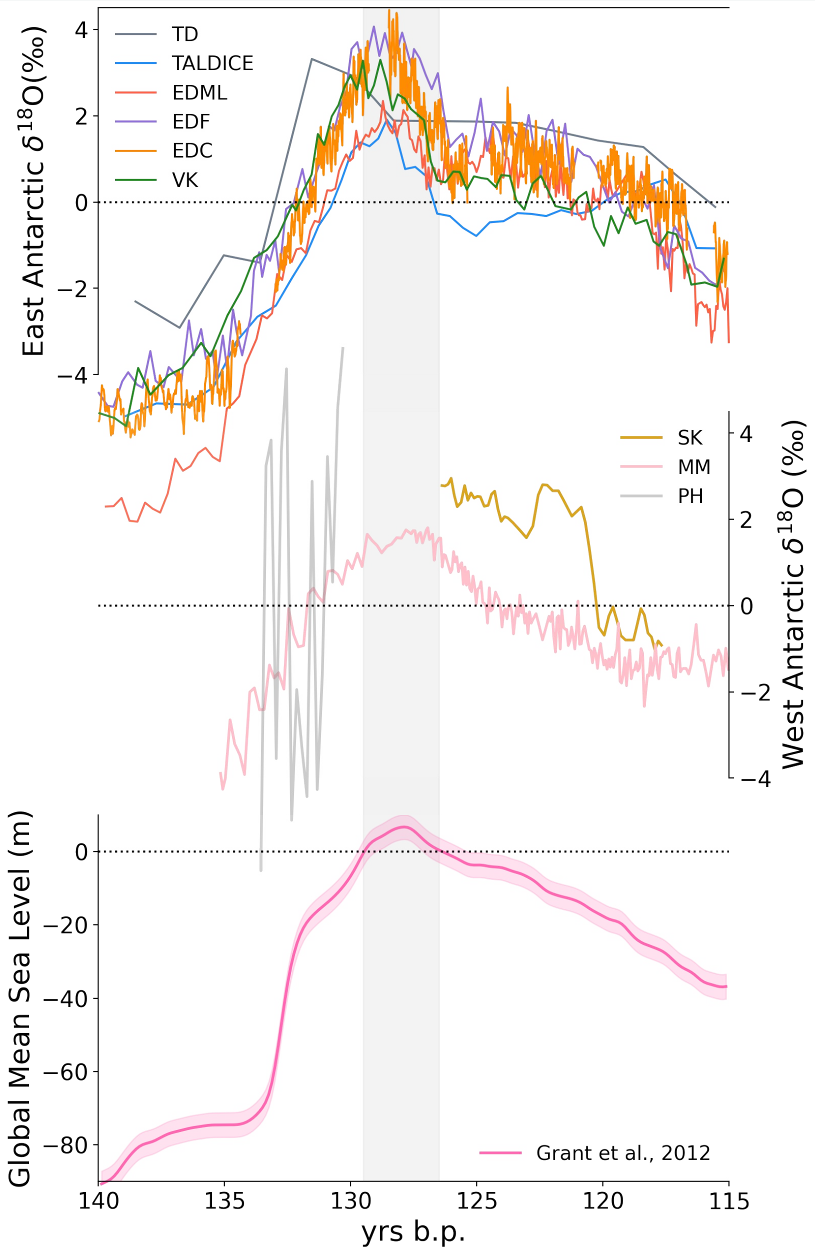
Antarctic ice core records from the LIG

6 East Antarctic Ice Cores
(enriched 2-4 ‰)

3 West Antarctic Ice Cores
(enriched 2-5? ‰)

Synchronous with peak in global mean sea level





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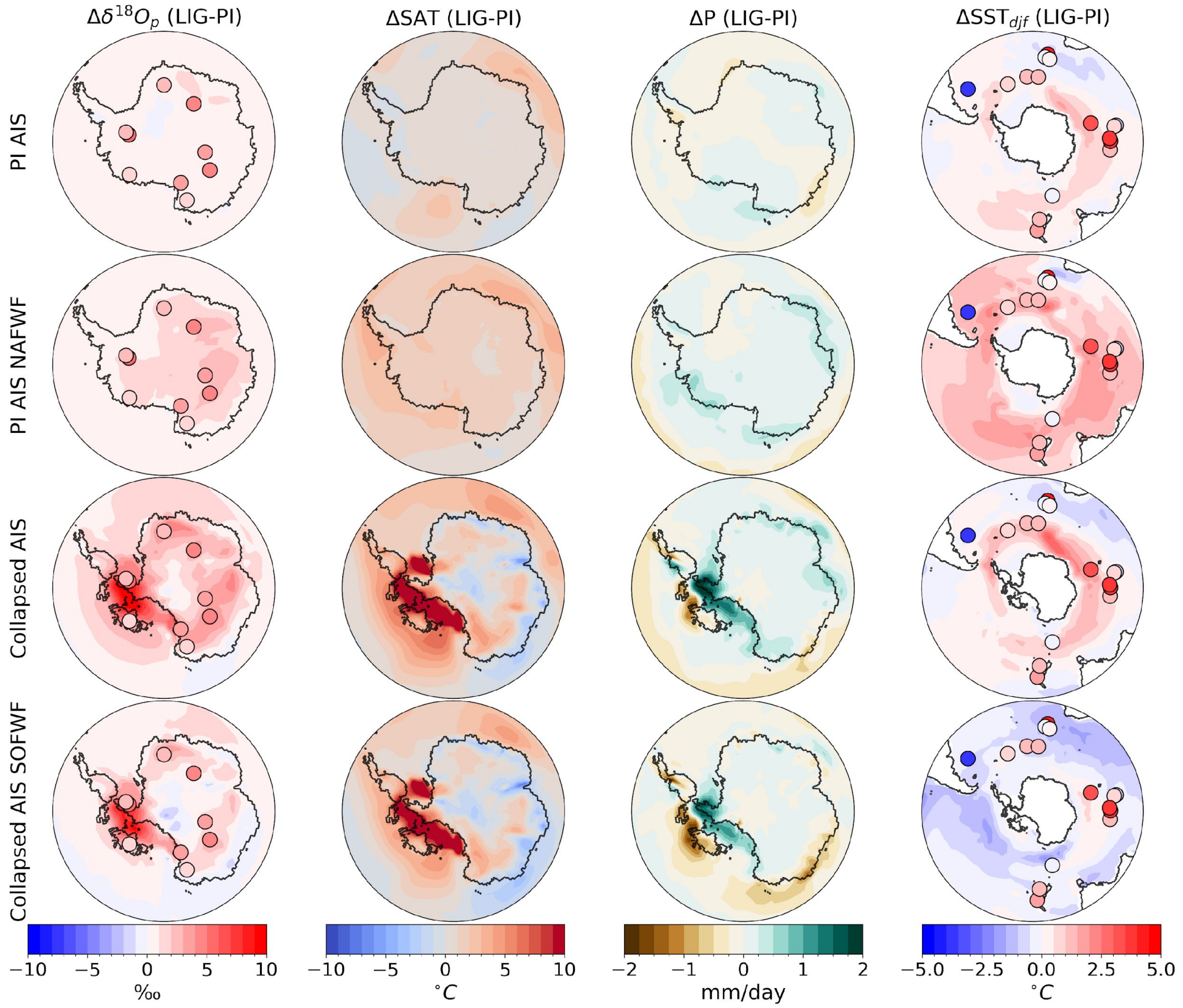
2. Reduced ice sheet regional warming more local precipitation enriched δ^{18}O

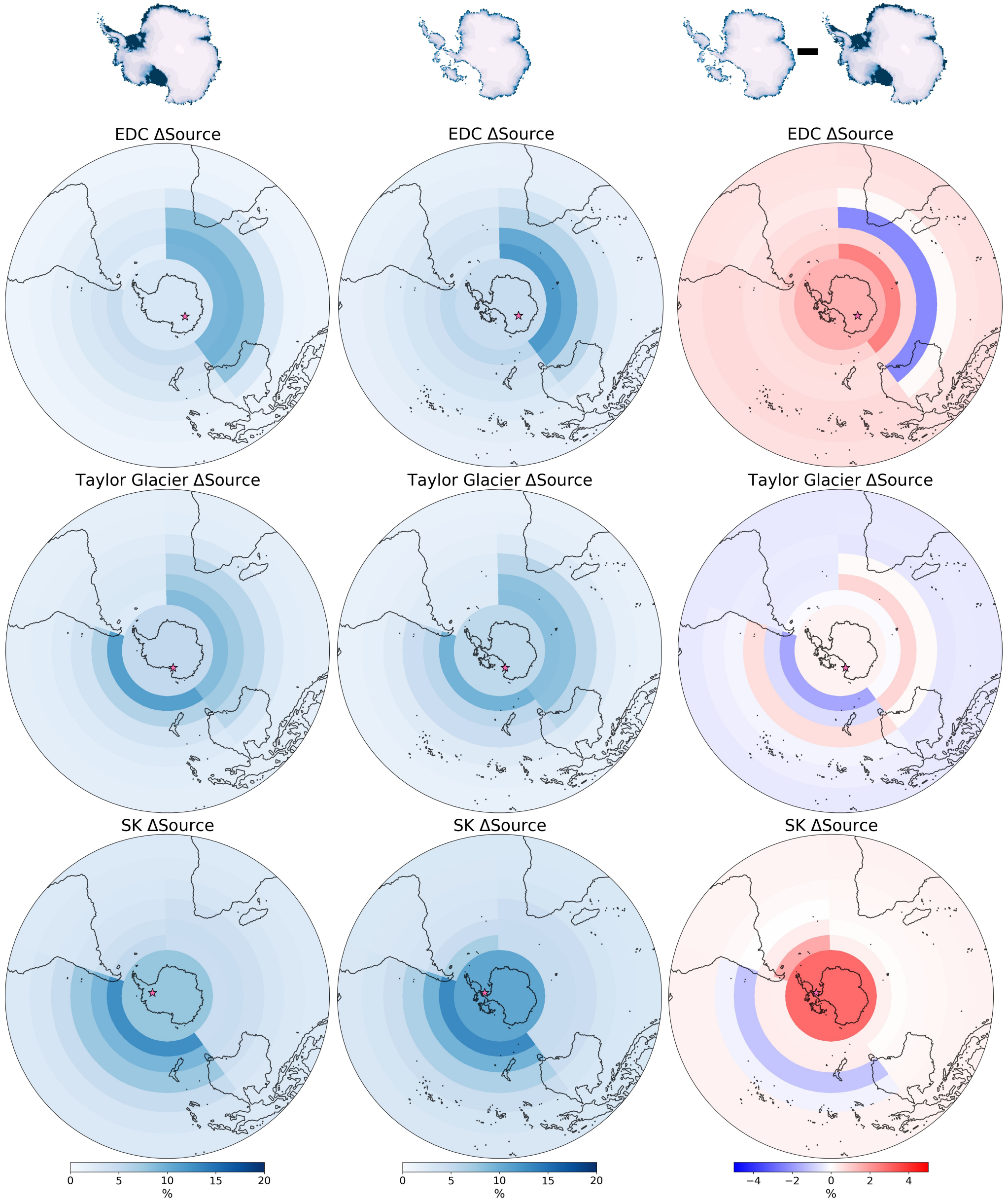


Antarctic moisture source change

Tracking the % contribution of moisture to 3 sample ice cores:

- Epica Dome C (EDC) - EAIS
- Skytrain Ice Rise (SK) - WAIS
- Taylor Glacier – coastal EAIS

1. EDC and SK experience a southward shift in moisture source



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1. EDC and SK experience a southward shift in moisture source
2. Taylor Glacier sees more northward moisture source.

Potentially due to an increase in coastal easterly wind strength.

Could be evident in d-excess records!