Isolating the climate response to West Antarctic Ice Sheet loss and Northern Hemisphere vegetation changes of the mid-Pliocene

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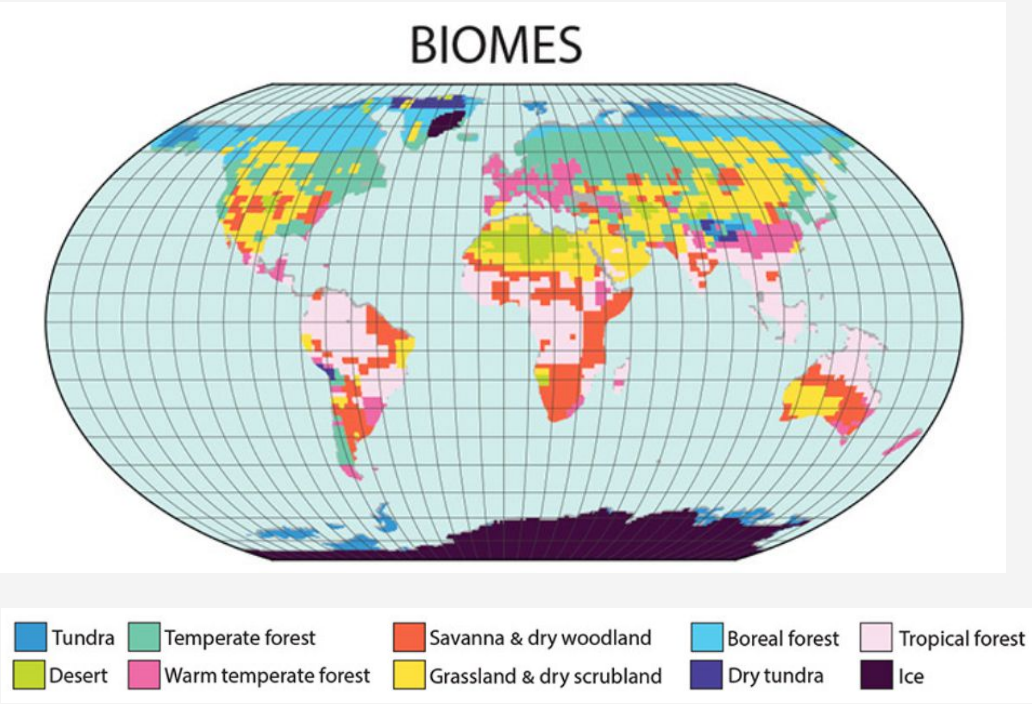
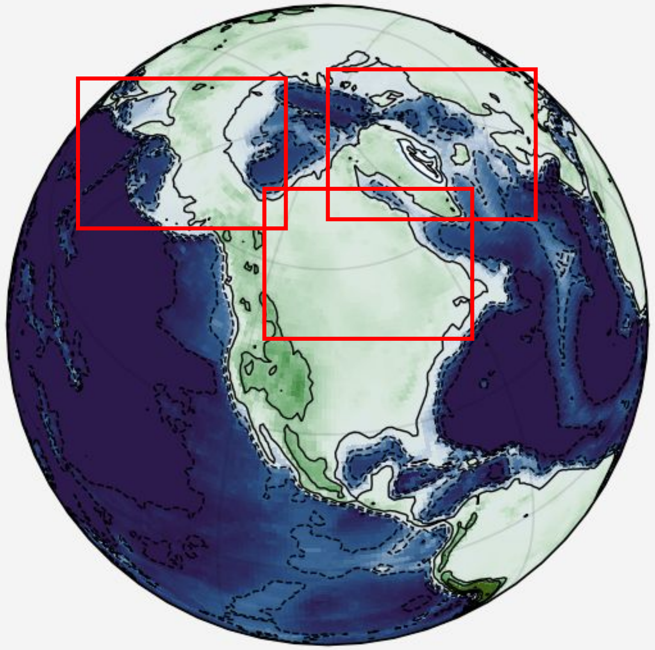
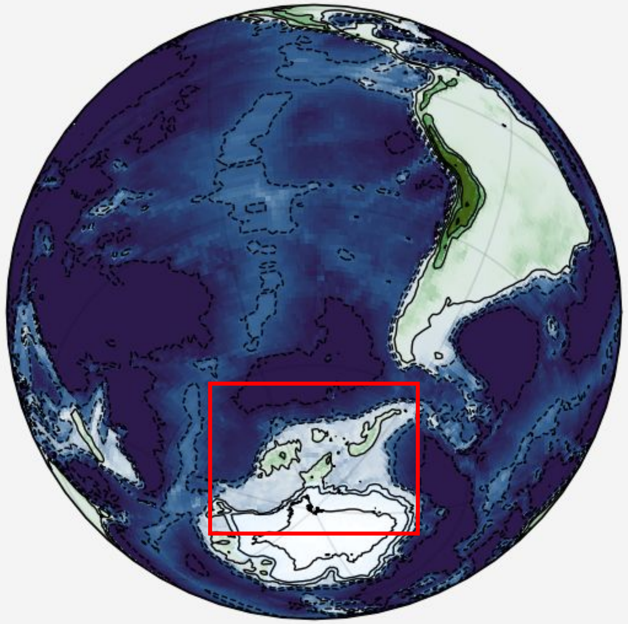
NSF | NCAR OPERATED BY UCAR

The mid-Pliocene (~3.3 Mya) has been widely used as an analogue for future warming



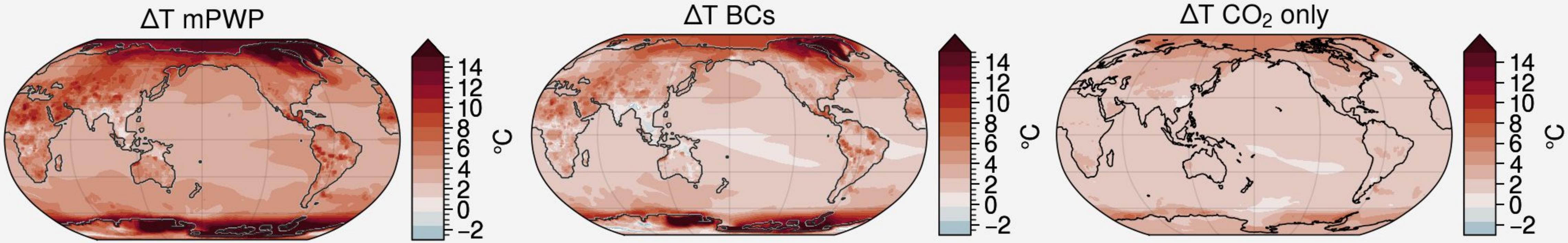
PRISM4 reconstruction of mid-Pliocene biomes (Dowsett et al. 2016)





PRISM4 reconstruction of mid-Pliocene topography (adapted from Dowsett et al. 2016)

These boundary conditions have been shown to have a large effect on global temperature in simulations of the Pliocene



$\overline{\Delta T} = 5.1°C$ $\overline{\Delta T} = 2.9°C$ $\overline{\Delta T} = 2.0°C$

In CESM2, boundary conditions contribute >1/2 of total global temperature change

Feng et al., *JAMES,* 2020
Dvorak et al., *Journal of Climate* 2025

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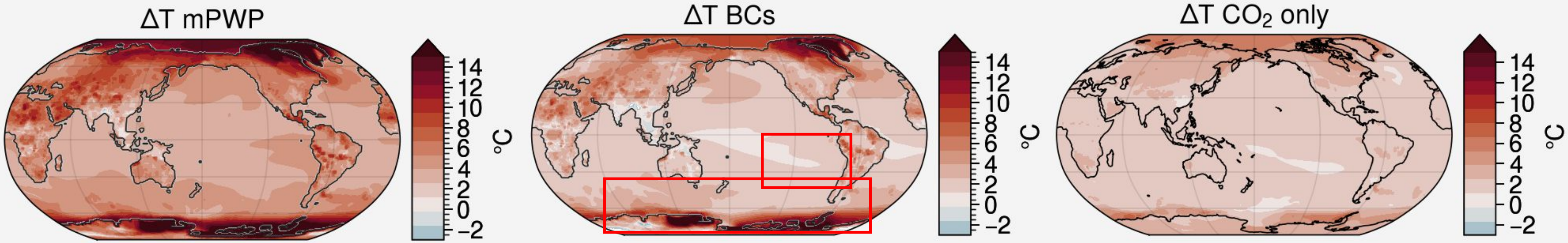

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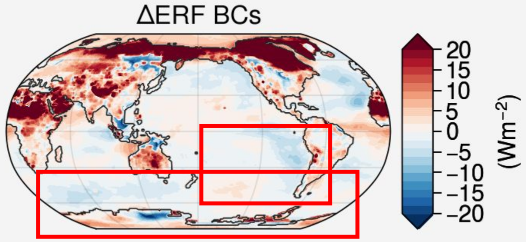
In CESM2, boundary conditions contribute >1/2 of total global temperature change

Despite comprising <1/2 of total forcing

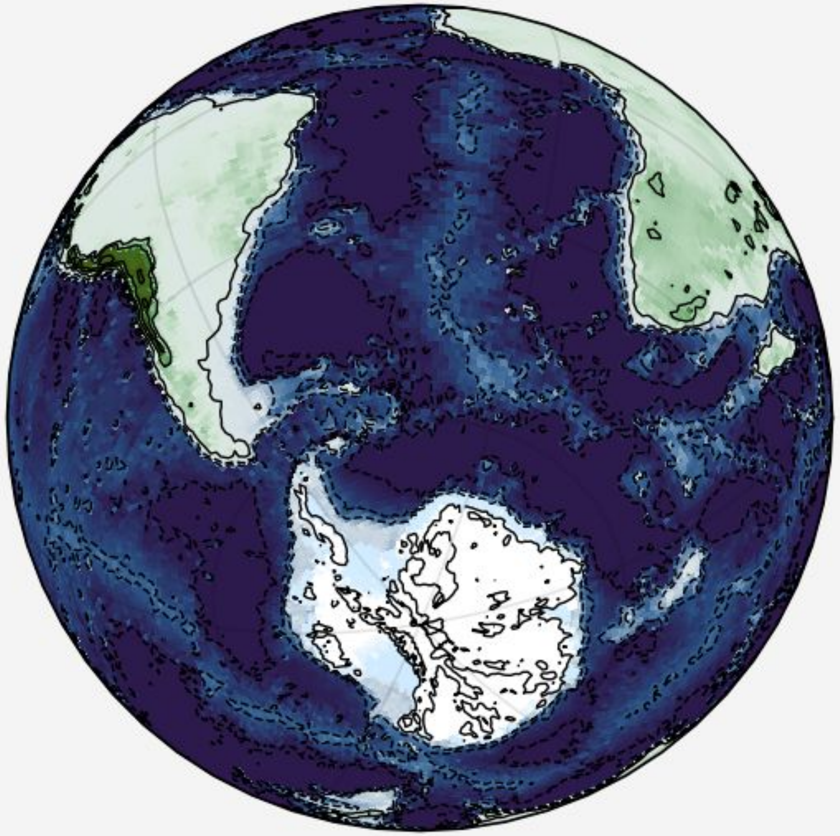


Southern Ocean & subtropical Pacific warming with little forcing

Feng et al., *JAMES*, 2020
Dvorak et al., *Journal of Climate* 2025

SST pattern prompts closer examination of effect of ice sheet loss on global ocean and climate

- Isolate the WAIS as a potential driver of mPWP warming
- Investigate the coupled climate response to those features that may be ***expected to occur in the long-term response to GHG changes***



ETOPO1 modern day bed topography + ice

nature climate change

Article https://doi.org/10.1038/s41558-

Unavoidable future increase in West Antarctic ice-shelf melting over the twenty-first century

Received: 13 April 2023

Kaitlin A. Naughten[1], Paul R. Holland[1] & Jan De Rydt[2]

Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica

Ian Joughin, Benjamin E. Smith, Brooke Medley

INSIGHTS | *PERSPECTIVES*

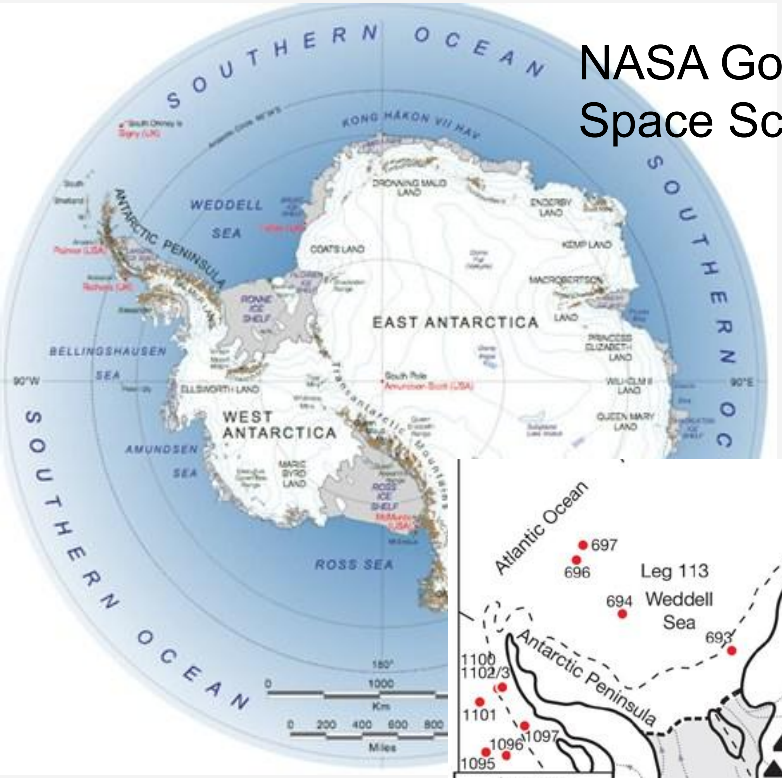
CLIMATE

Is ice sheet collapse in West Antarctica unstoppable?

Most climate scenarios paint a bleak future for the West Antarctic Ice Sheet

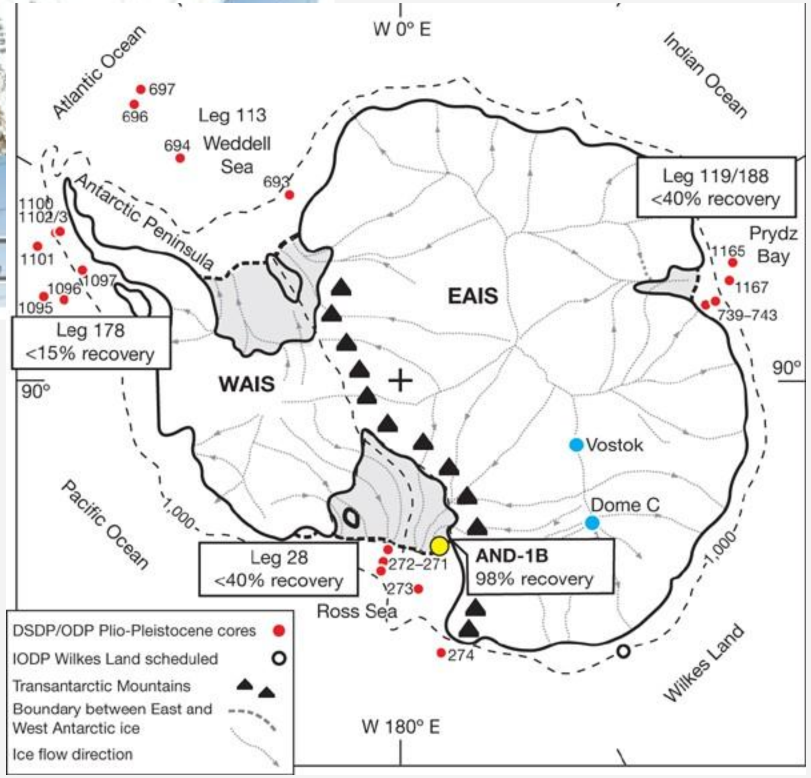
By **Christina Hulbe**

tribution to sea level, but the geometry and flow of the shelf affect the position of the



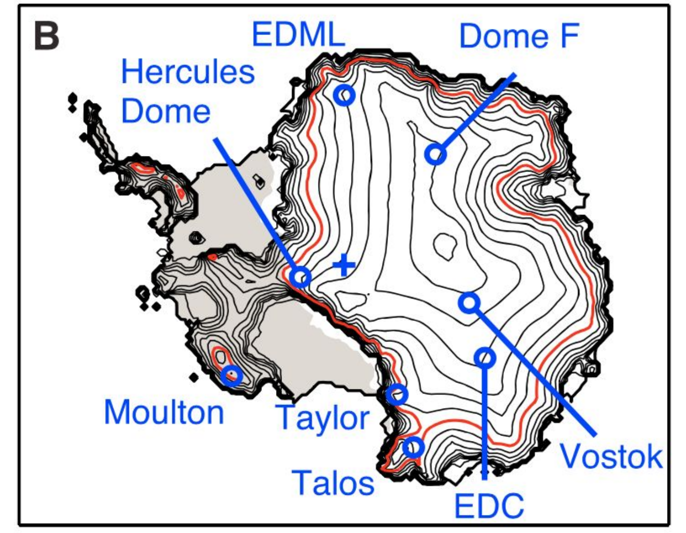
NASA Goddard Institute for Space Sciences

Paleogeographic evidence suggests that the WAIS retreated in periods of moderate warmth

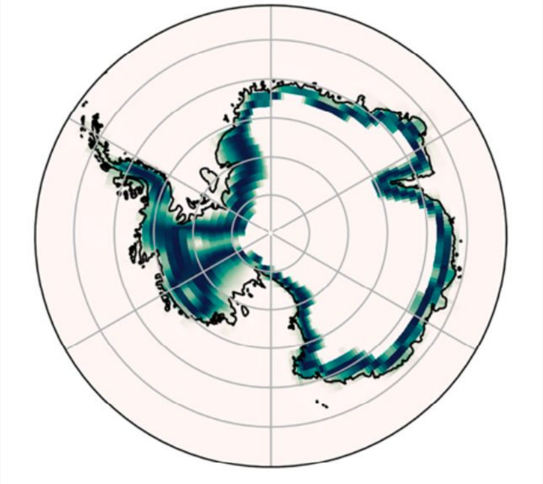


Ocean drilling program locations used to infer ice sheet extent in the Pliocene (Naish et al., *Nature*, 2009)

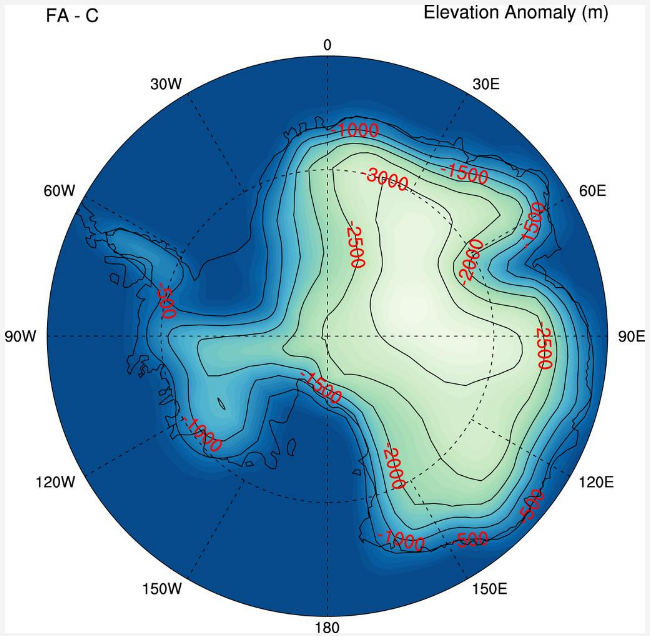
Most studies examining the climate response to WAIS loss have modeled only the topographic change:



Topography prescribed in Steig et al., *GRL,* 2015



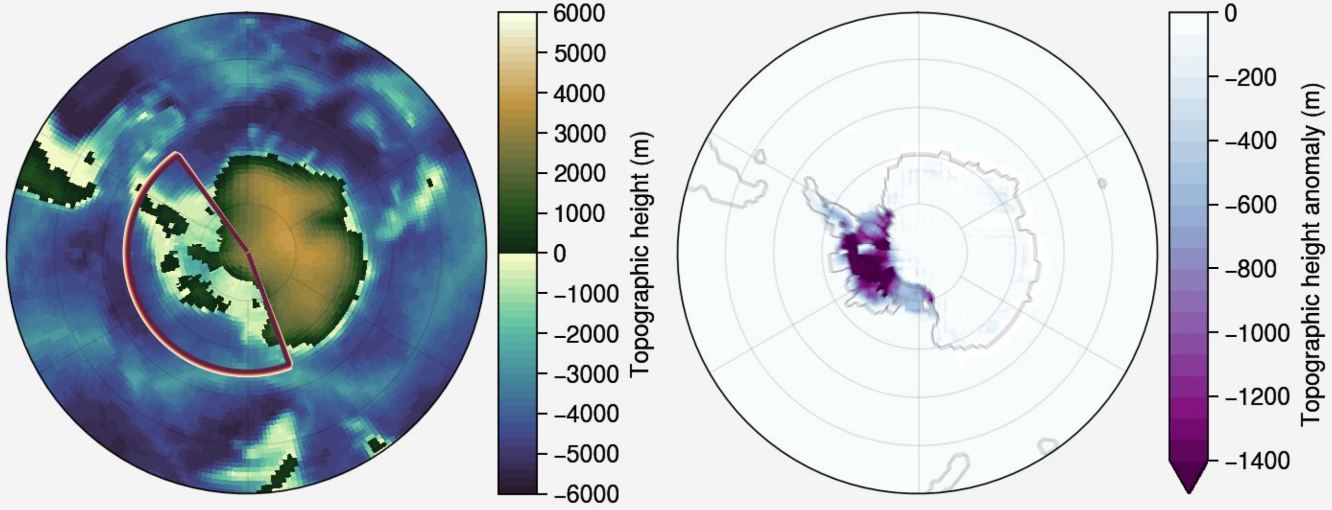
Topography anomaly prescribed in slab ocean simulations Pauling et al., *Journal of Climate,* 2023



Singh et al. *Journal of Climate,* 2016

Isolating the climate response to a loss of the WAIS in the context of the mid-Pliocene requires a bathymetric change too

I investigate this in a single-forcing CESM2 simulation, where only the WAIS is changed (removed in both height and ocean extent)



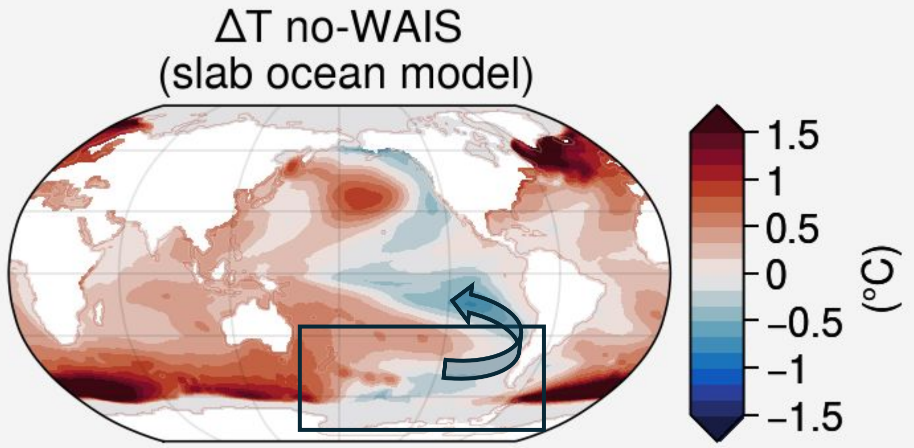
CESM2
Atmosphere: CAM6, finite volume 1x1 degree resolution grid
Ocean: POP2, 1x1 degree displaced pole grid with enhanced resolution in the tropics

Complete loss of the WAIS initiates Southern Ocean warming

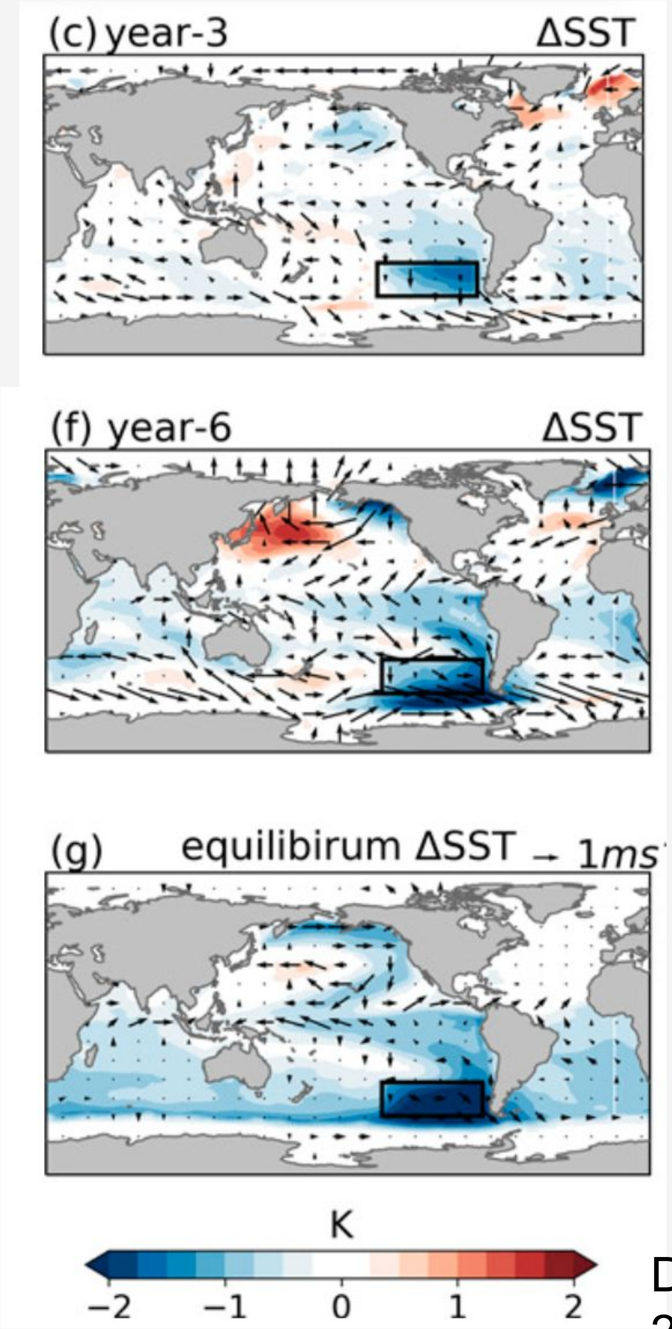
Topographic change results in locally cyclonic wind anomaly + strengthening of subtropical Pacific westerlies

Subtropical cooling gives way to warming as simulation equilibrates and SO warms

Complete loss of the WAIS initiates Southern Ocean warming – through ocean dynamical response



Slab ocean model (atmospheric response only) shows Pacific sector Southern Ocean + subtropical Pacific cooling



The Southern Ocean-tropical Pacific connection

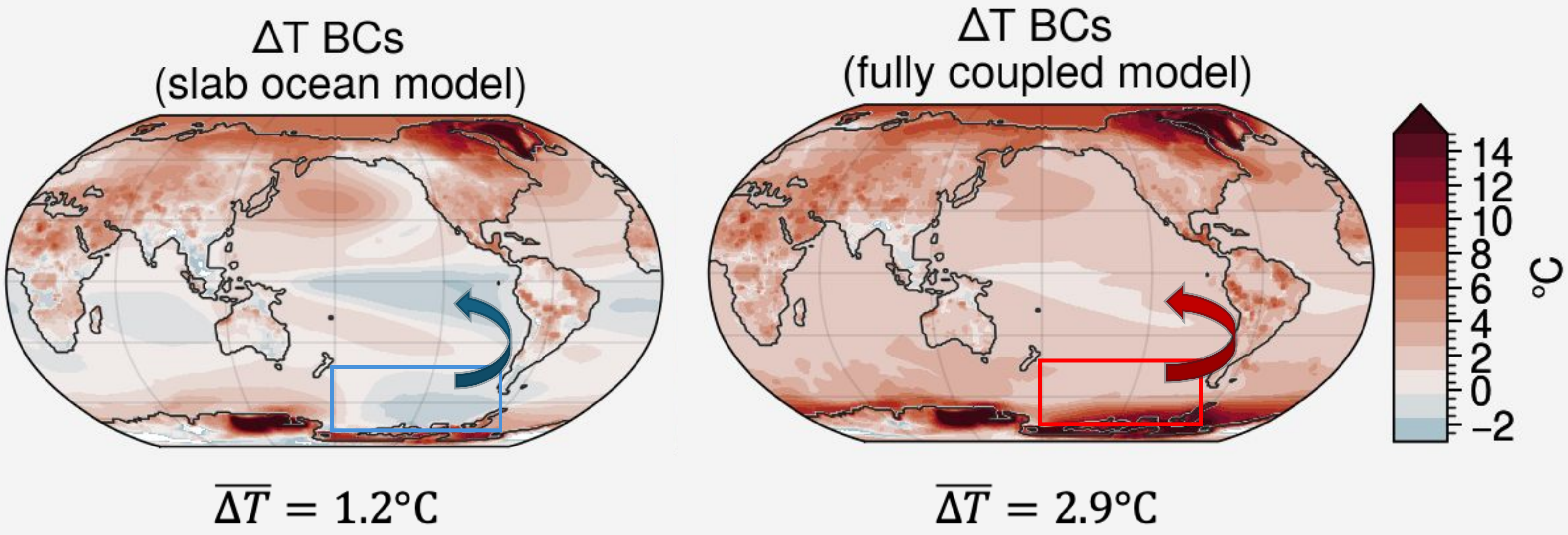
Negative heat flux convergence anomaly (cooling) in East Pacific Southern Ocean leads to tropical Pacific cooling through:

Advection of cool SSTs by mean winds toward the equatorial Pacific enhanced trade winds enhanced evaporation enhanced cooling…
(wind-evaporation-SST feedback)

Dong et al., *Journal of Climate,* 2022

The Southern Ocean-tropical Pacific connection

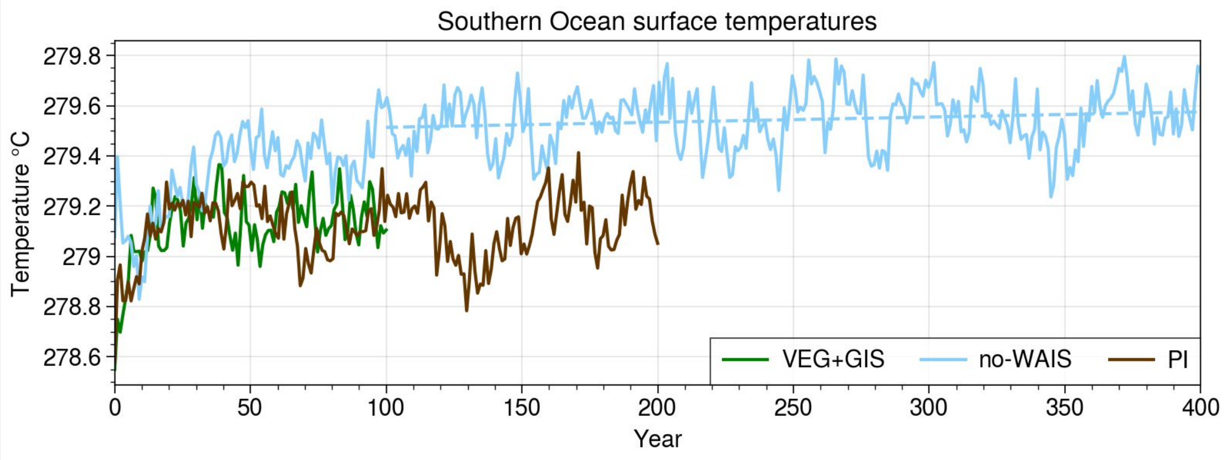
Wind-evaporation-SST feedback + subtropical cloud changes enhance the SST signature, reducing global temperature in the SOM and increasing it in the FCM

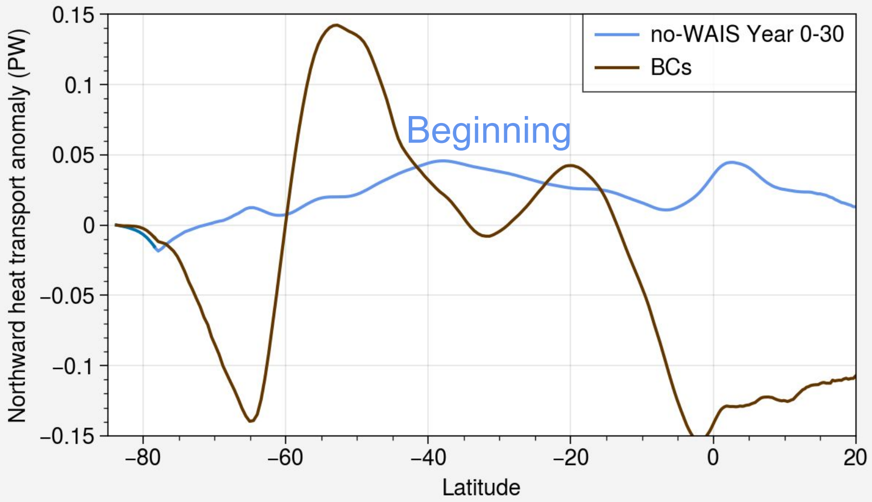


(No ocean dynamical feedback)

Loss of WAIS shows trend toward Southern Ocean warming through enhanced high latitude ocean heat transport

Gradual warming of Southern Ocean is consistent with millennial scale adjustment





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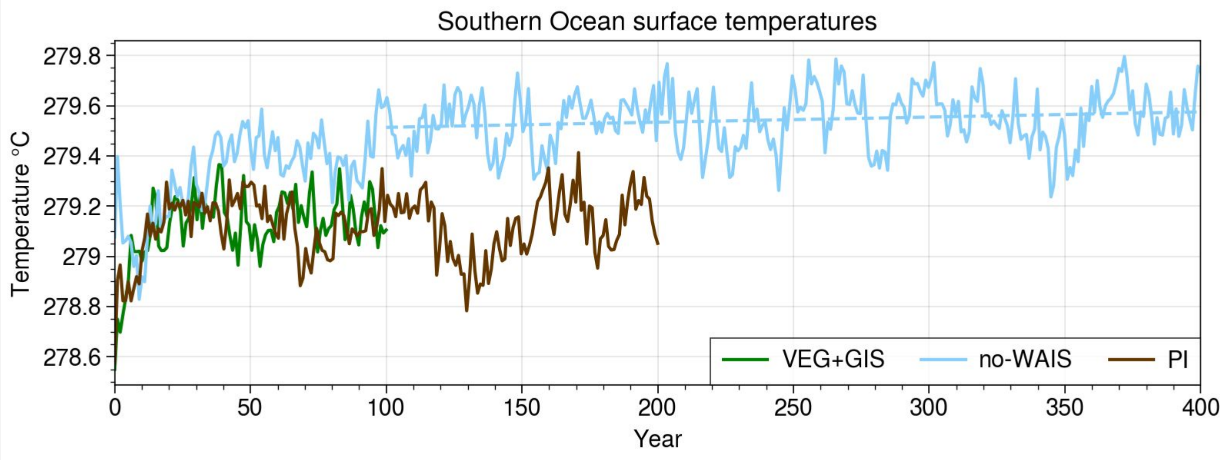

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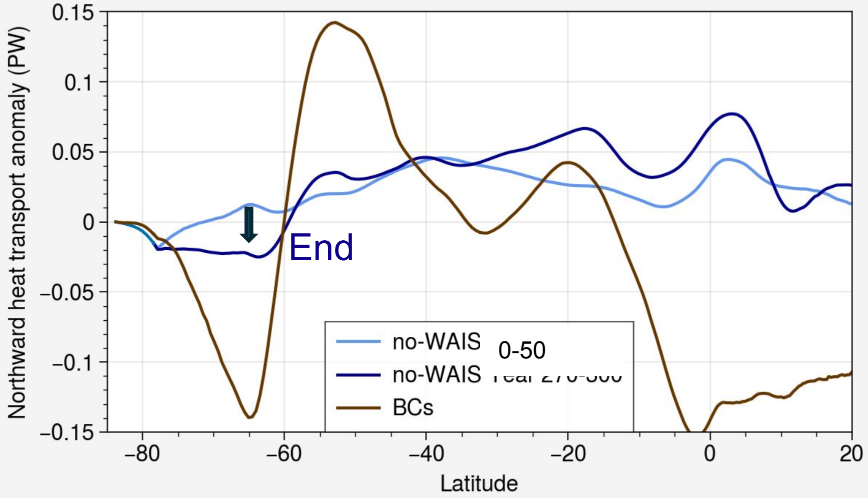
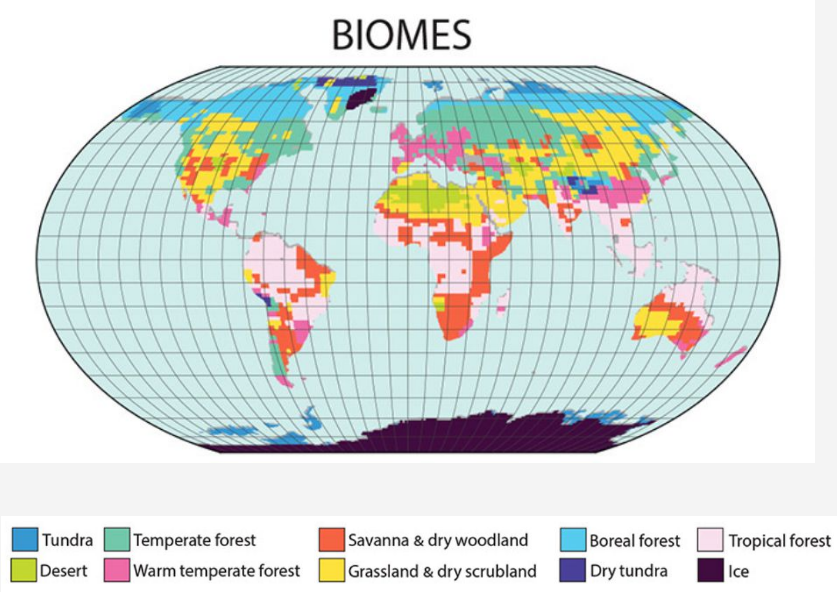


Vegetation and GIS changes caused a lot of northern hemisphere forcing!



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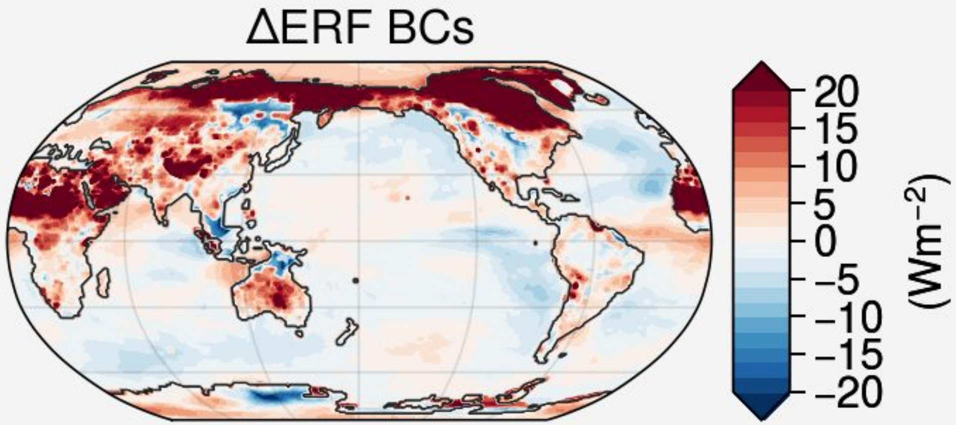


Asymmetrical forcing leads to net southward atmospheric energy transport

NH forcing □ NH TOA energy surplus

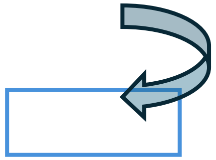
Requires net southward cross-equatorial energy transport □ northward shift of the ITCZ □ enhancement of equatorial winds

no-WAIS (fully coupled)

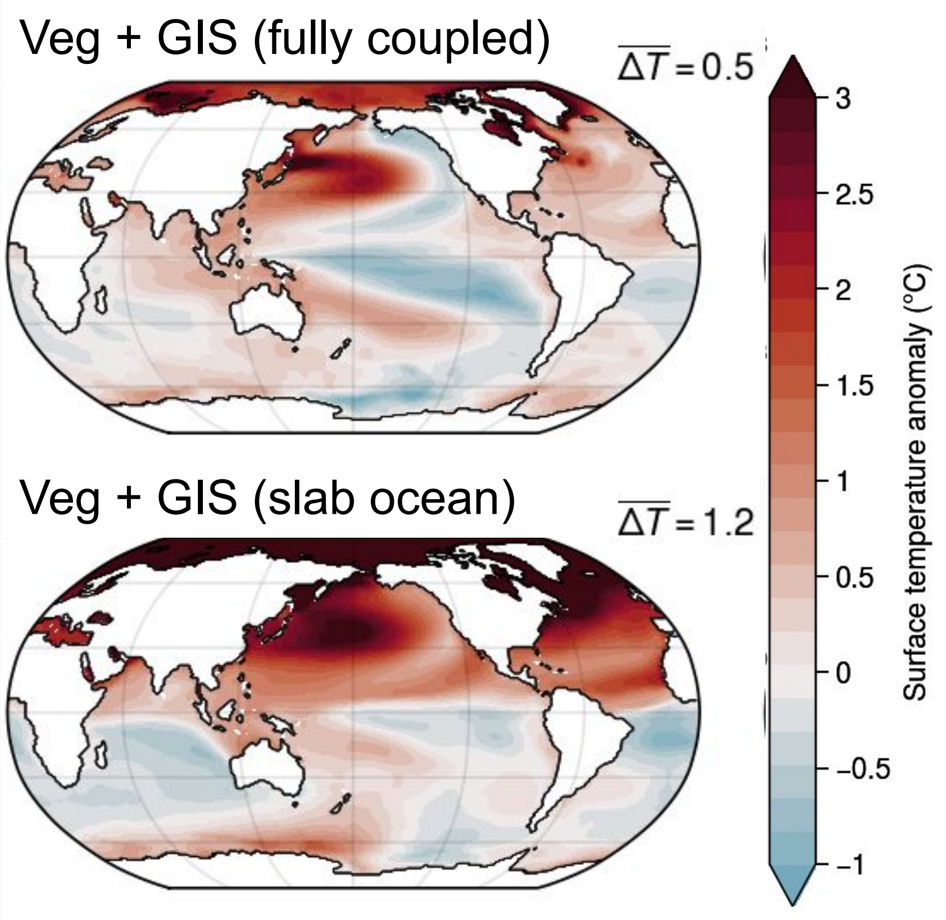
Veg + GIS (fully coupled)

This is enhanced through the WES feedback, resulting in tropical cooling response

Southern Ocean also cools (Rossby wave train mechanism)



Ocean dynamical feedback reduces global warming in response to NH forcing



In response to northern hemisphere forcing, changes in ocean heat transport damp global warming by moving excess heat away from the NH.

Equatorial cooling may also be enhanced through the Bjerknes feedback.

Concluding points

1. Southern Ocean warming in response to boundary conditions of the mPWP in CESM2 suggests important role for WAIS loss on climate
2. Single forcing WAIS experiments reveal potential for slow Southern Ocean, and subtropical Pacific, warming as ocean heat transport evolves
3. Vegetation and GIS changes cannot explain mPWP Southern and Pacific Ocean sea surface warming; opposite is found, driven largely by atmospheric processes