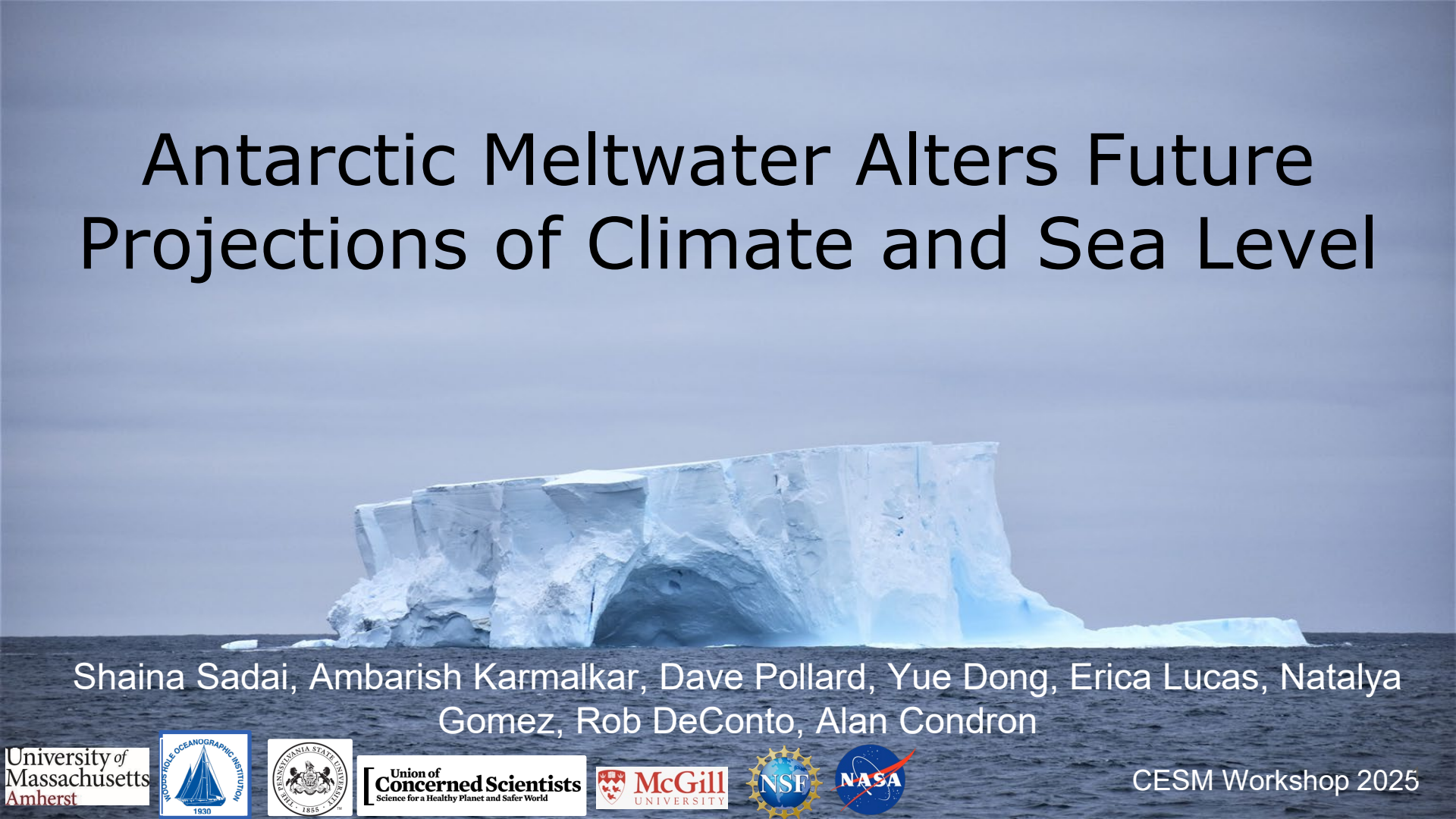
Antarctic Meltwater Alters Future Projections of Climate and Sea Level



Shaina Sadai, Ambarish Karmalkar, Dave Pollard, Yue Dong, Erica Lucas, Natalya Gomez, Rob DeConto, Alan Condron

CESM Workshop 2025

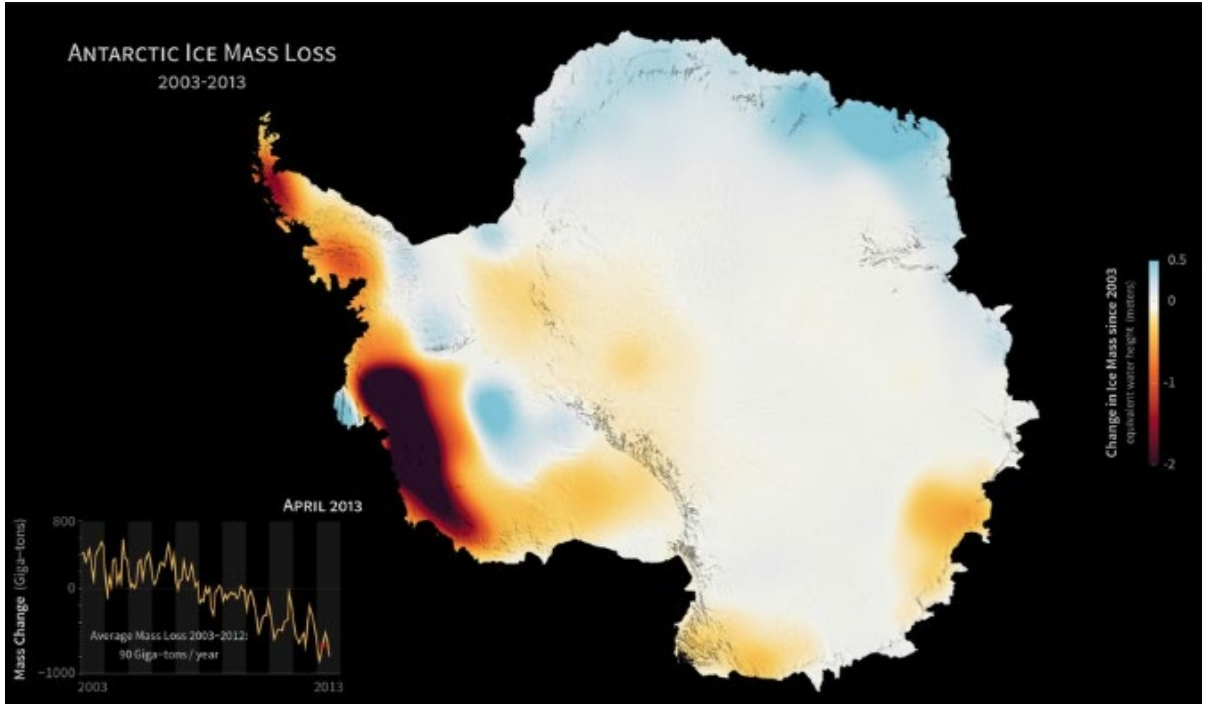
Modeling Antarctica's evolution and impacts

Importance

- Impact on local and global climate
- Driver of sea level
- Impacts to society

Challenges

- Marine based
- Hard to represent some dynamics
- Interactions and feedbacks to ocean, atmosphere, solid Earth

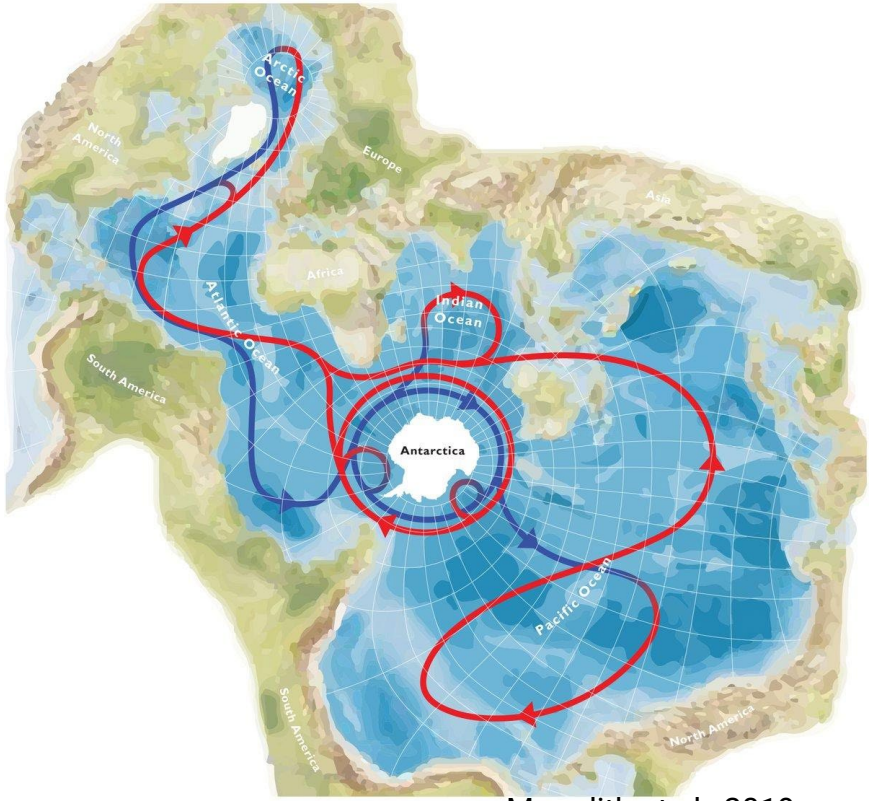


GRACE

Antarctica impacts global climate

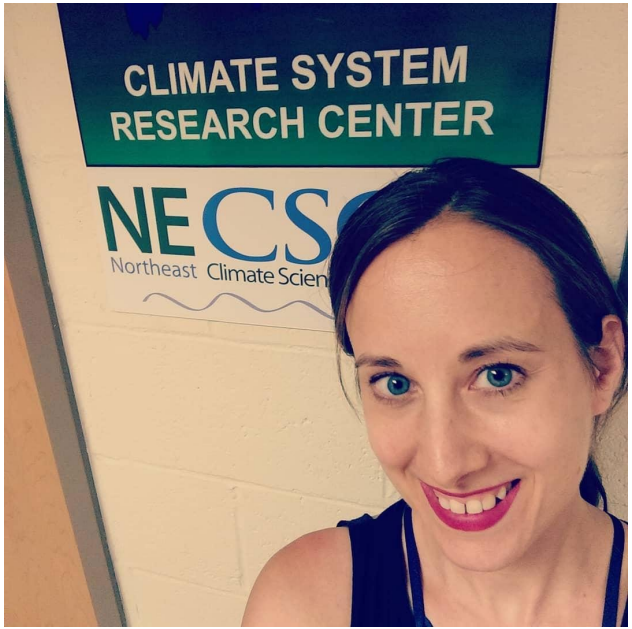
As efforts to integrate dynamic marine-based ice sheets into climate models continue, freshwater forcing experiments and ad-hoc coupling fills the gap

ex. Bronselaer et al., 2018; Golledge et al., 2019, Gorte et al., 2023, Park & Latif, 2019; Park et al., 2023; Purich & England, 2023; Sadai et al., 2020, Siahaan et al., 2023



Meredith et al., 2019

A storytelling approach



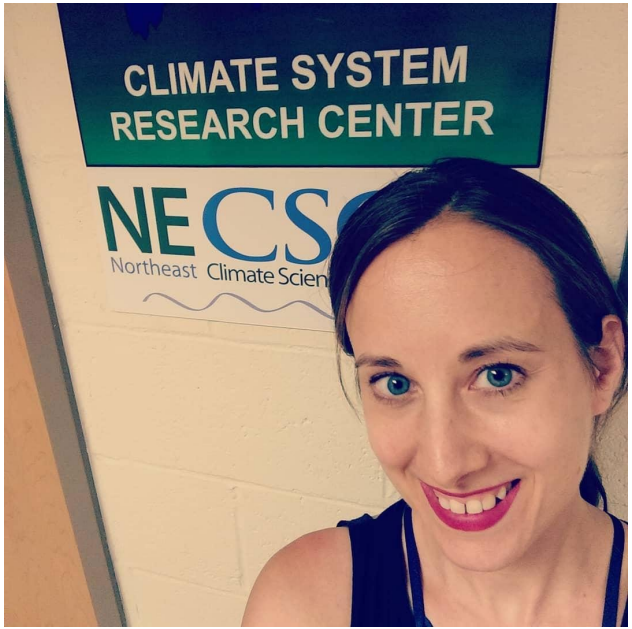
An image from the past, before the pandemic started, when people could see my face out in the world…

2015: Started my PhD

2016-2018: Running CESM1 meltwater experiments

Federal funding & support from NSF & NCAR was crucial

A storytelling approach



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2020: First dissertation chapter published!

Future climate response to Antarctic Ice Sheet melt caused by anthropogenic warming

SHAINA SADAI, ALAN CONDRON, ROBERT DECONTO, AND DAVID POLLARD Authors Info & Affiliations

Science is better with friends

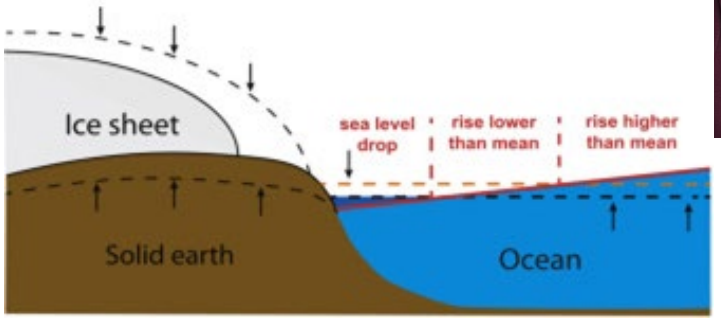
Research Letter | Open Access

Antarctic Ice-Sheet Meltwater Reduces Transient Warming and Climate Sensitivity Through the Sea-Surface Temperature Pattern Effect

Yue Dong, Andrew G. Pauling, Shaina Sadai, Kyle C. Armour

Dr. Yue Dong

Dr. Gomez

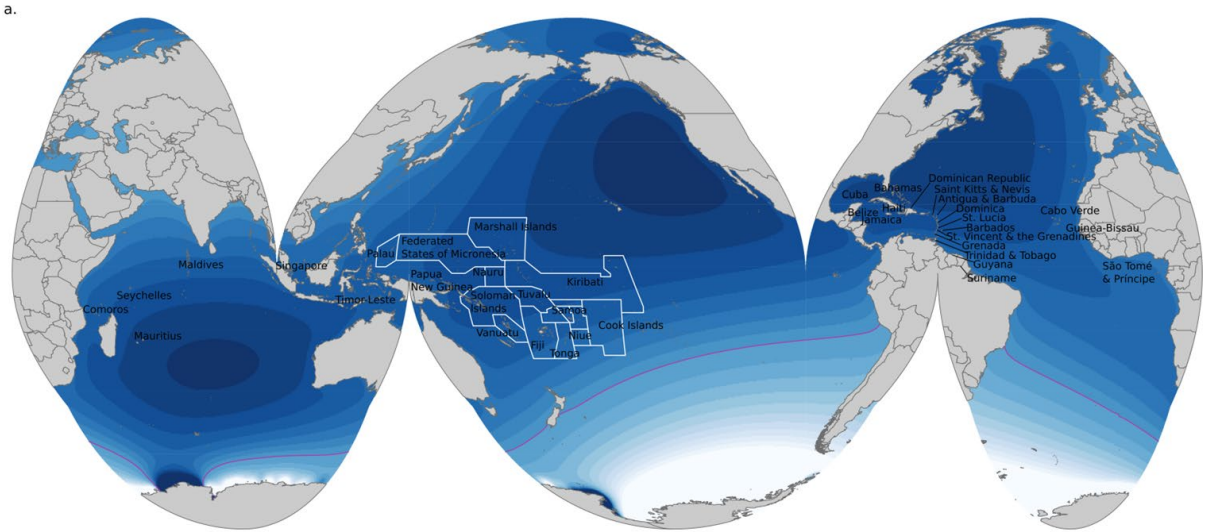


De Boer et al., 2017

A storytelling approach

2019-2021: Researched climate justice implications under UNFCCC of sea level rise & meltwater feedbacks on GMST

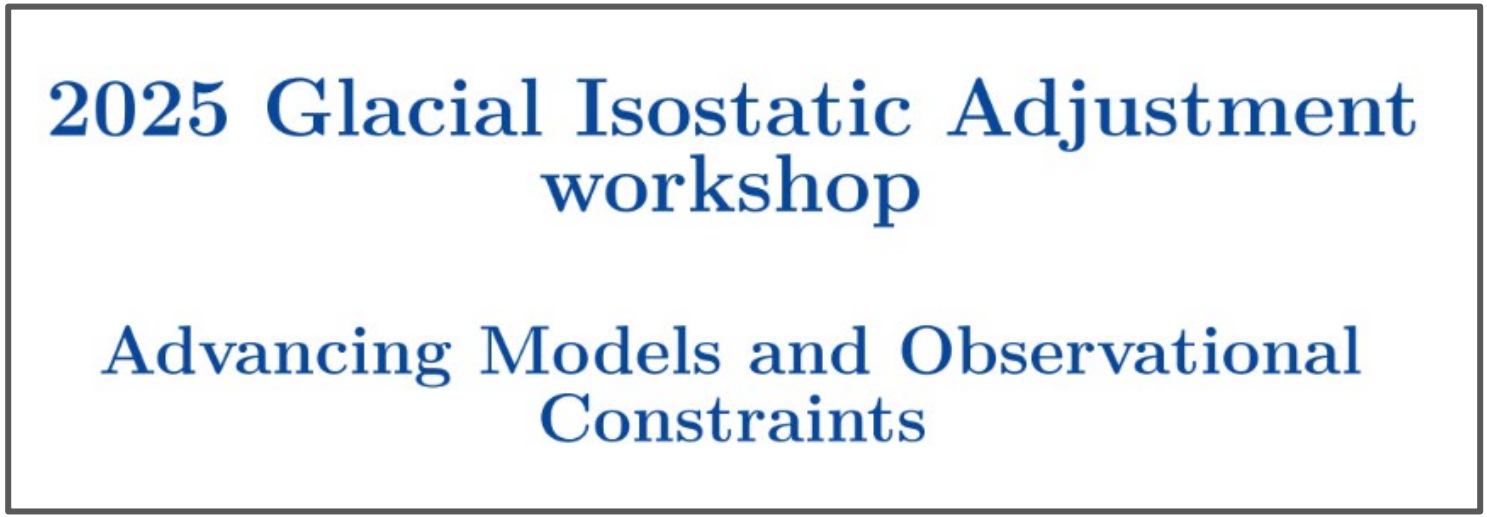
2022: chapter published



The Paris Agreement and Climate Justice: Inequitable Impacts of Sea Level Rise Associated With Temperature Targets

S. Sadai ✉, R. A. Spector, R. DeConto, N. Gomez

Advances!



Toward Modeling Glacial Isostatic Adjustment in the Community Earth System Model

K. Thayer-Calder[1], W. Lipscomb[1], G. Leguy[1], S. Zhong[2], T. Yuan[2], D. dePolo[2]

1- NSF National Center for Atmospheric Research, Boulder, Colorado 2- University of Colorado, Boulder

A storytelling approach

Photo by Max Wilhelm

2019: started coupling CESM and PSU3D for my last dissertation chapter

Had it successfully running in 2021, finished RCP8.5 and model validation for defense

2022: Graduated!

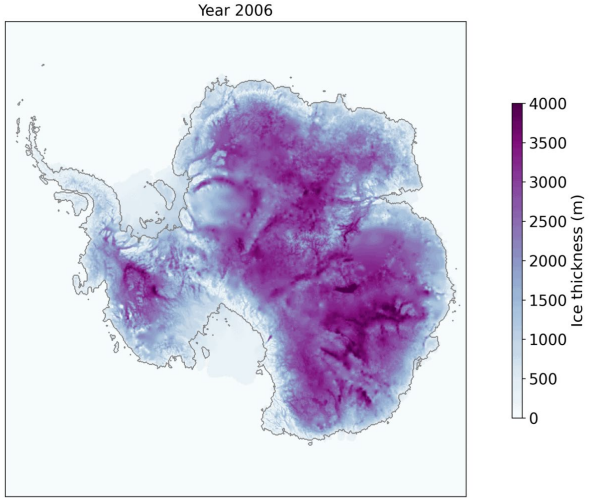
CESM1 + PSU-3D

- Community Earth System Model v 1
- Approx. 1° grid (110 km) resolution
- 60 vertical levels in ocean, 31 in atmosphere
- Ran with land ice model masked out

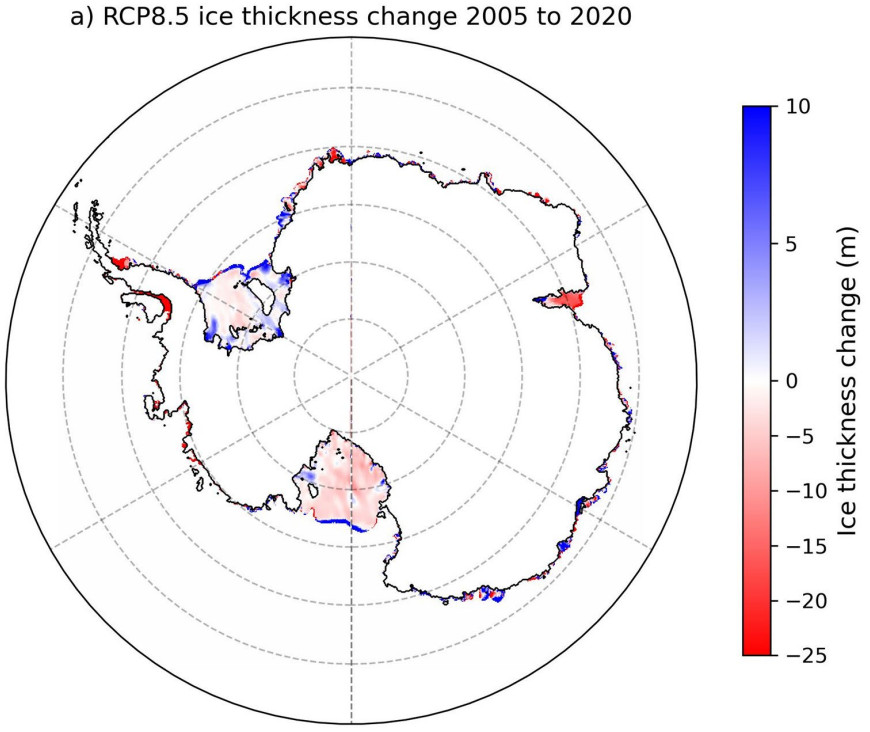
- Penn State University Ice Sheet Model
- Simulates basal melt, calving, surface melt, grounding line migration, and more
- Run at 10 km resolution

Meltwater quantities

Air & ocean temperature, Precipitation



Model validation



Check if it works well by matching to observations (2005-2018):

1. Calving and basal melt rates around on the full ice sheet
2. Basal melt rates at specific locations
3. Total annual change in mass and GMSLR contribution
4. Spatial patterns of ice thickness change

A storytelling approach

2023: built out the collaboration for the paper:

Goal: Combine CESM + PSU3D simulations with GIA & sea level modeling and radiative feedback analysis

Wrestled through RCP4.5 simulation during Cheyenne decommissioning!

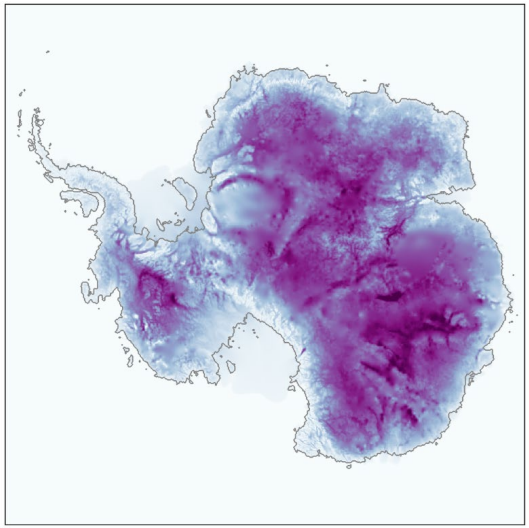
1 **Antarctic meltwater alters future projections of climate and sea level**

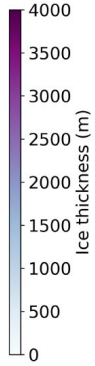
2 Shaina Sadai*[1,2,3], Ambarish Karmalkar[4], David Pollard[2], Yue Dong[5], Erica Lucas[6], Natalya

3 Gomez[6], Robert DeConto[2], Alan Condron[7]

Ice sheet + Climate + GIA models + Radiative Analysis

- Each model year CESM1 and PSU3D exchange information
- Offline coupling to a 3D viscoelastic Earth structure to account for GIA and spatial sea level change (Latychev et al. 2005)
- Radiative feedback analysis





Meltwater quantities

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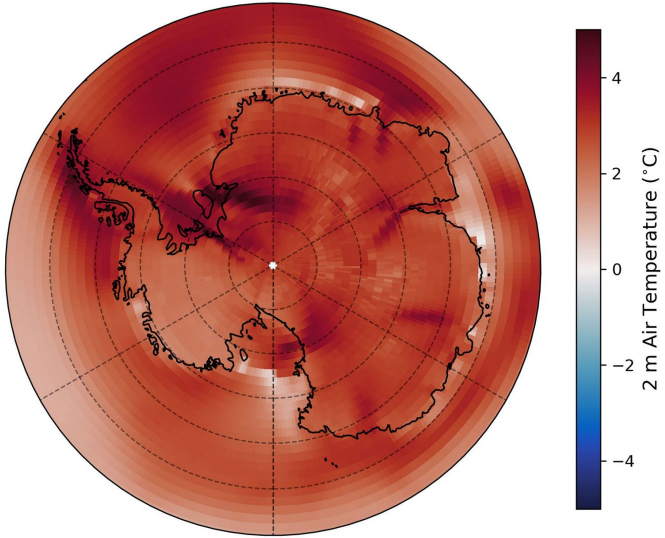
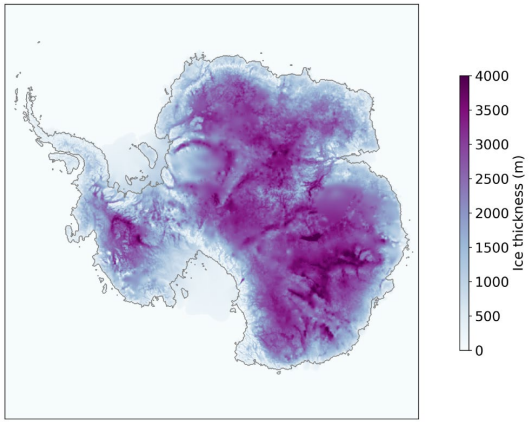


Additional coupling details

- Surface level meltwater forcing as liquid and solid fields predicted by PSU3D (spatially variable, annually evolving)
- Bias corrected ocean temps from POP2 extrapolated under floating shelves in PSU3D, single average value per shelf each year
- Temp & precip are lapse rate corrected in PSU3D as ice sheet surface evolves
- Single ensemble member per emissions scenario (RCP8.5 & 4.5) due to computational constraints; observationally constrained



Meltwater quantities

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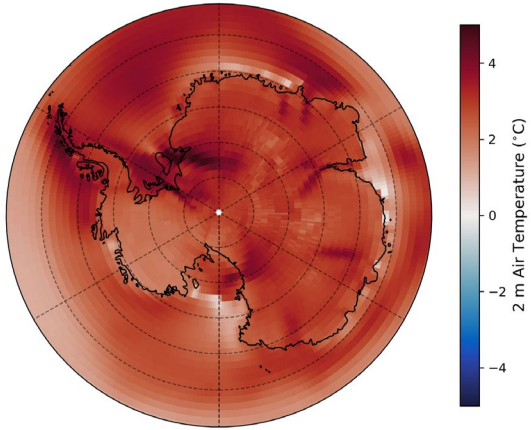
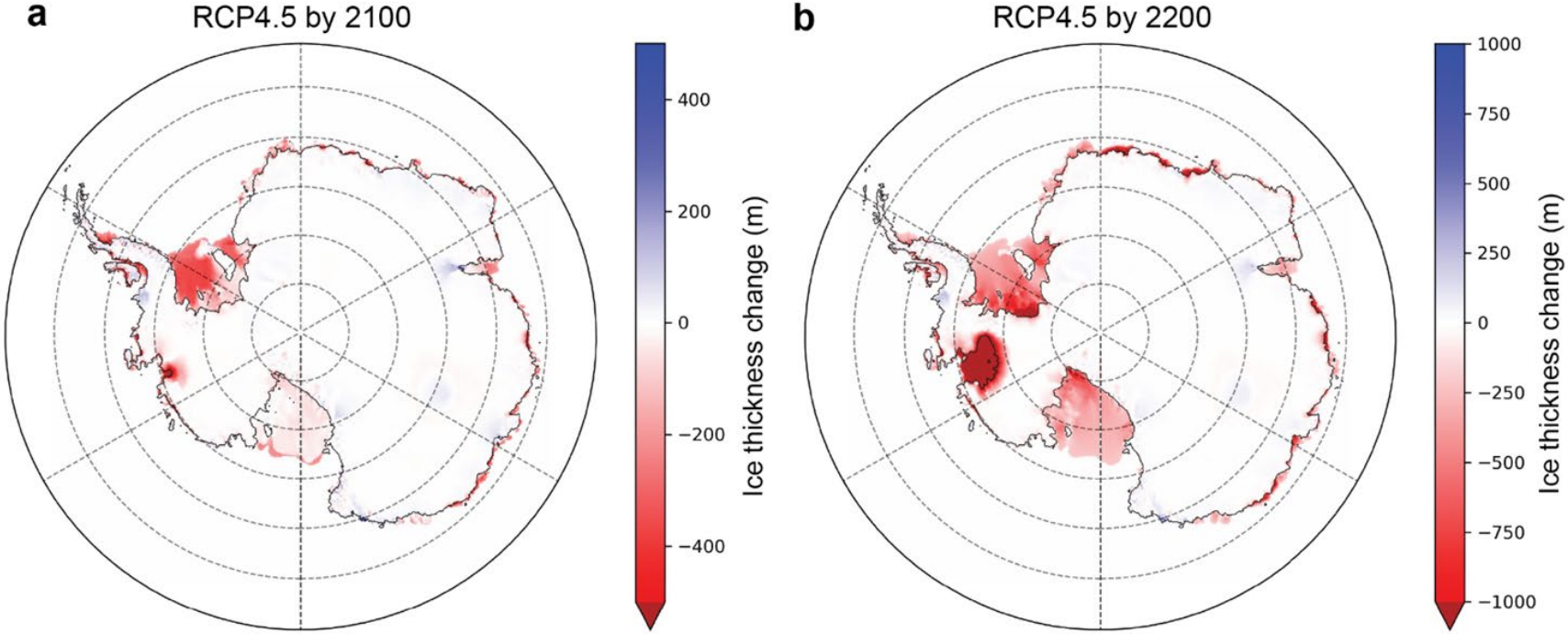
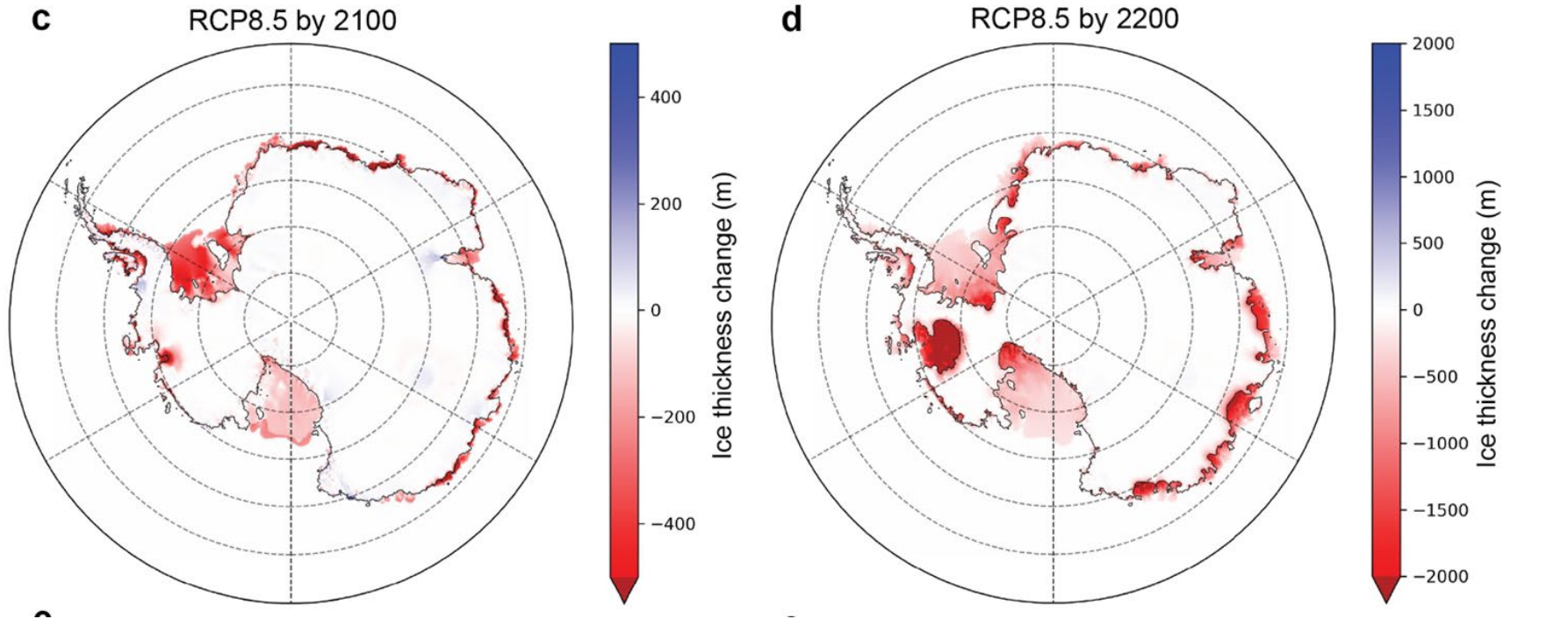


Ice sheet under relatively low emissions



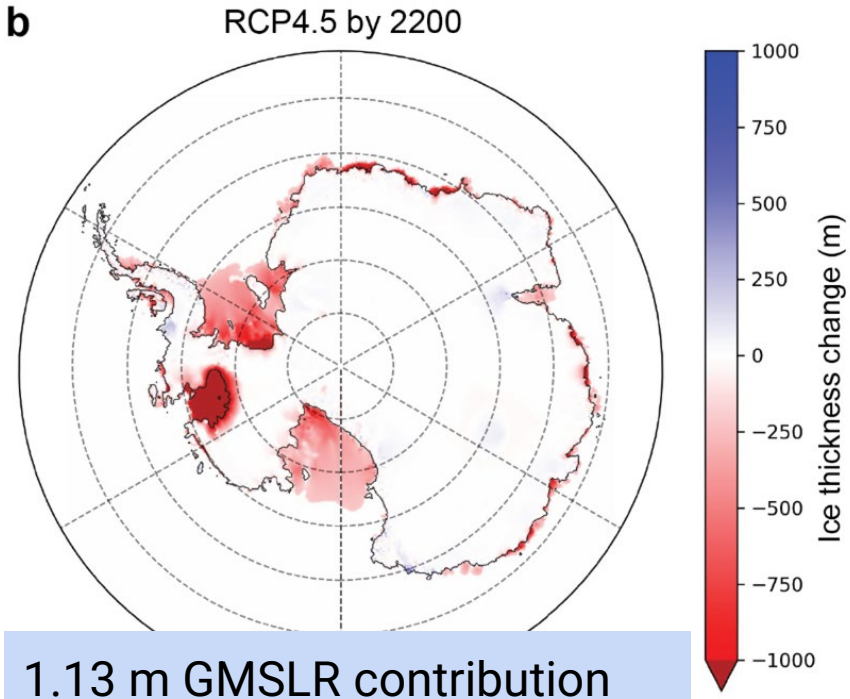
Sadai et al., under review

Ice sheet under high emissions

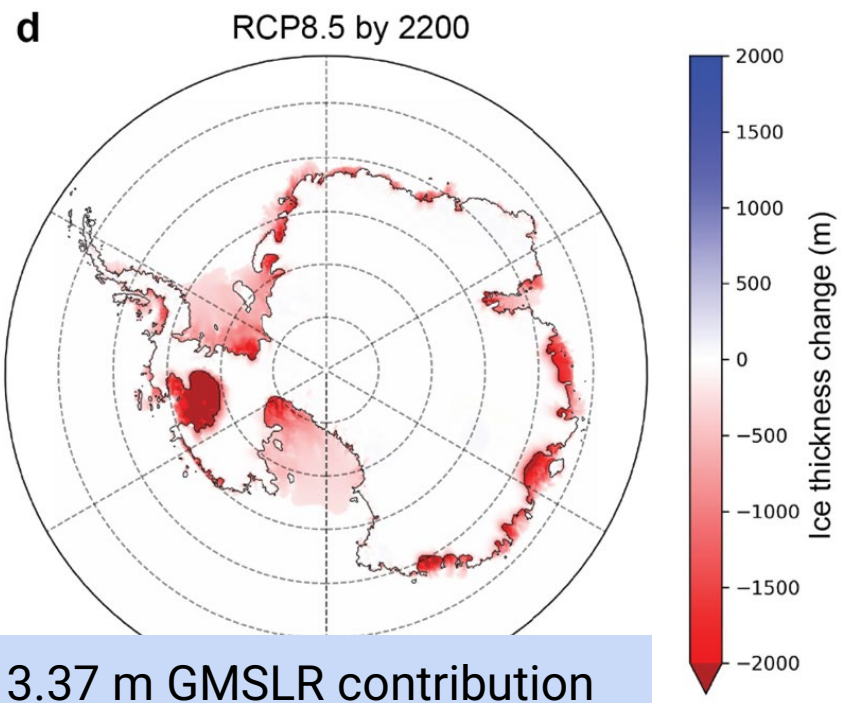


Sadai et al., under review

Ice sheet under low vs high emissions at 2200



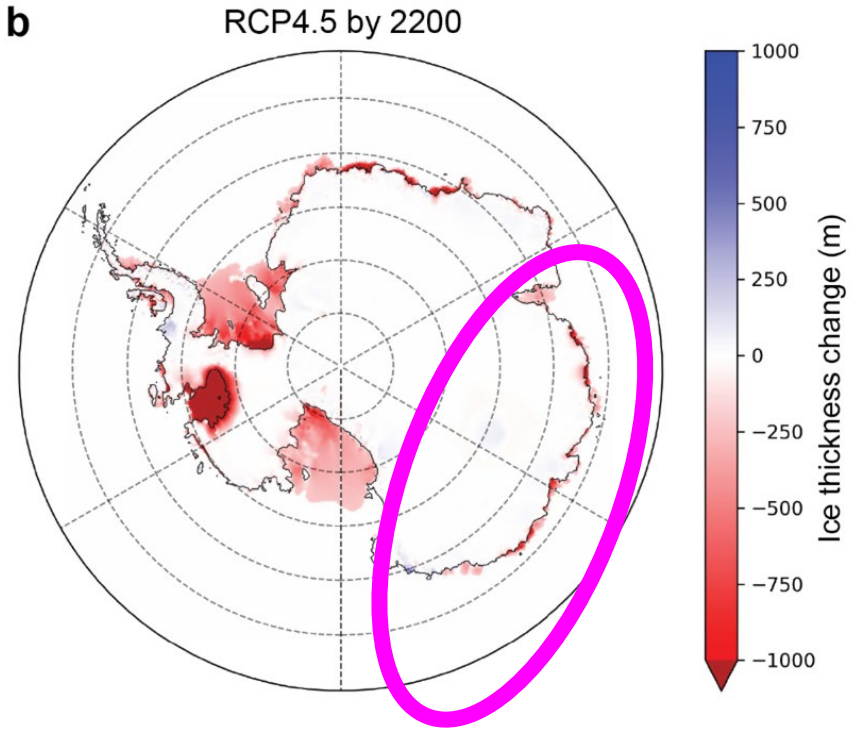
1.13 m GMSLR contribution

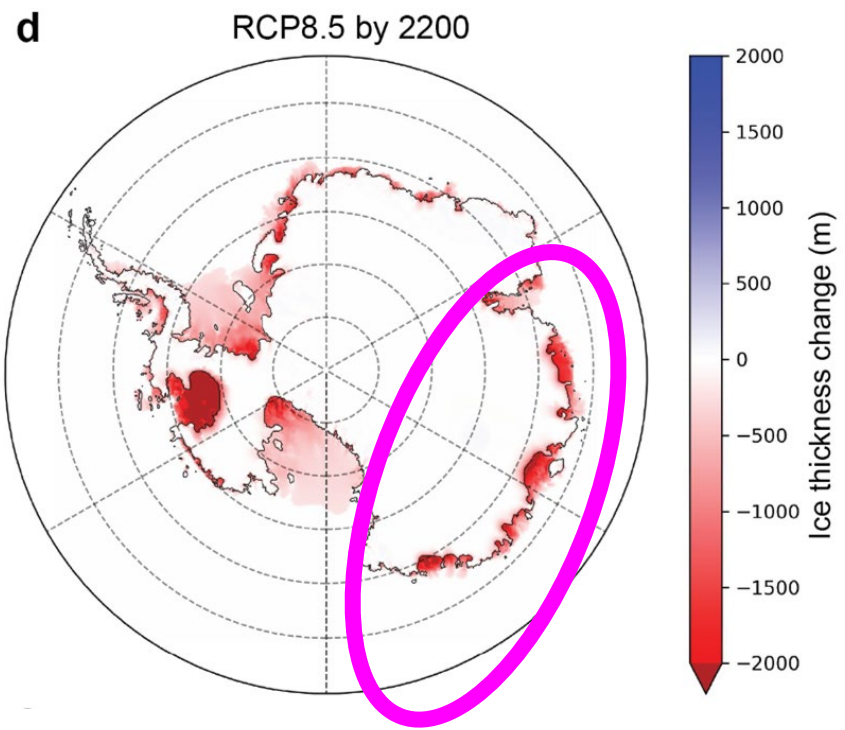


3.37 m GMSLR contribution

Sadai et al., under review

Ice sheet under low vs high emissions at 2200





Sadai et al., under review

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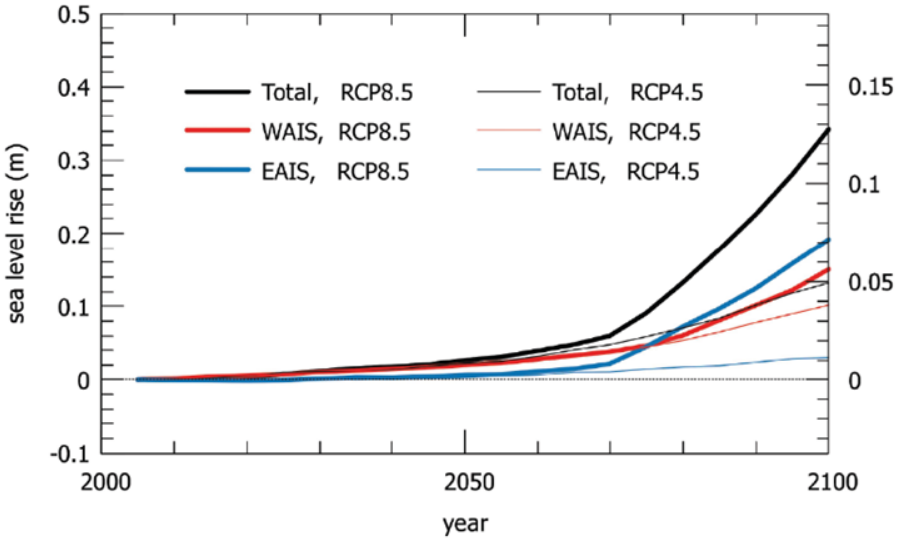
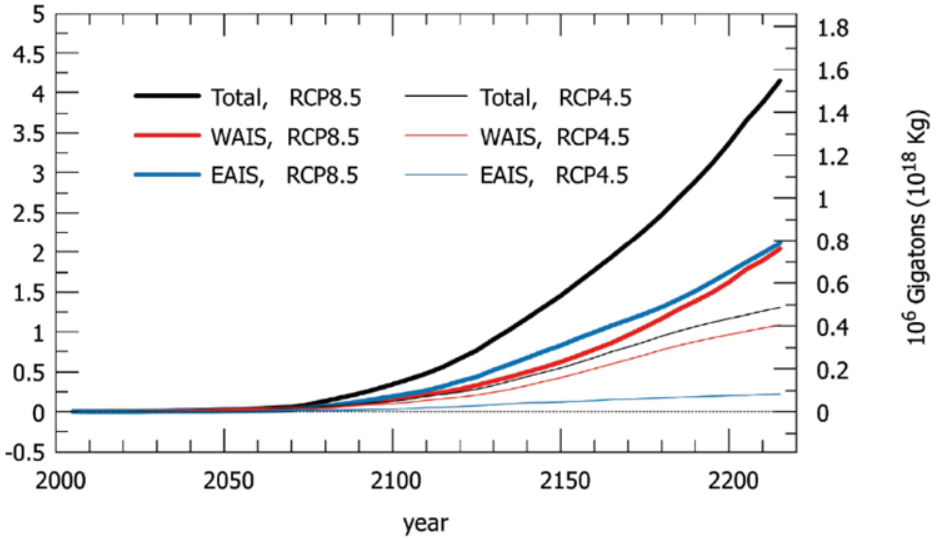




One-way MW forcing delayed ice sheet mass loss (DeConto et al., 2021); coupling further delayed ice sheet mass loss

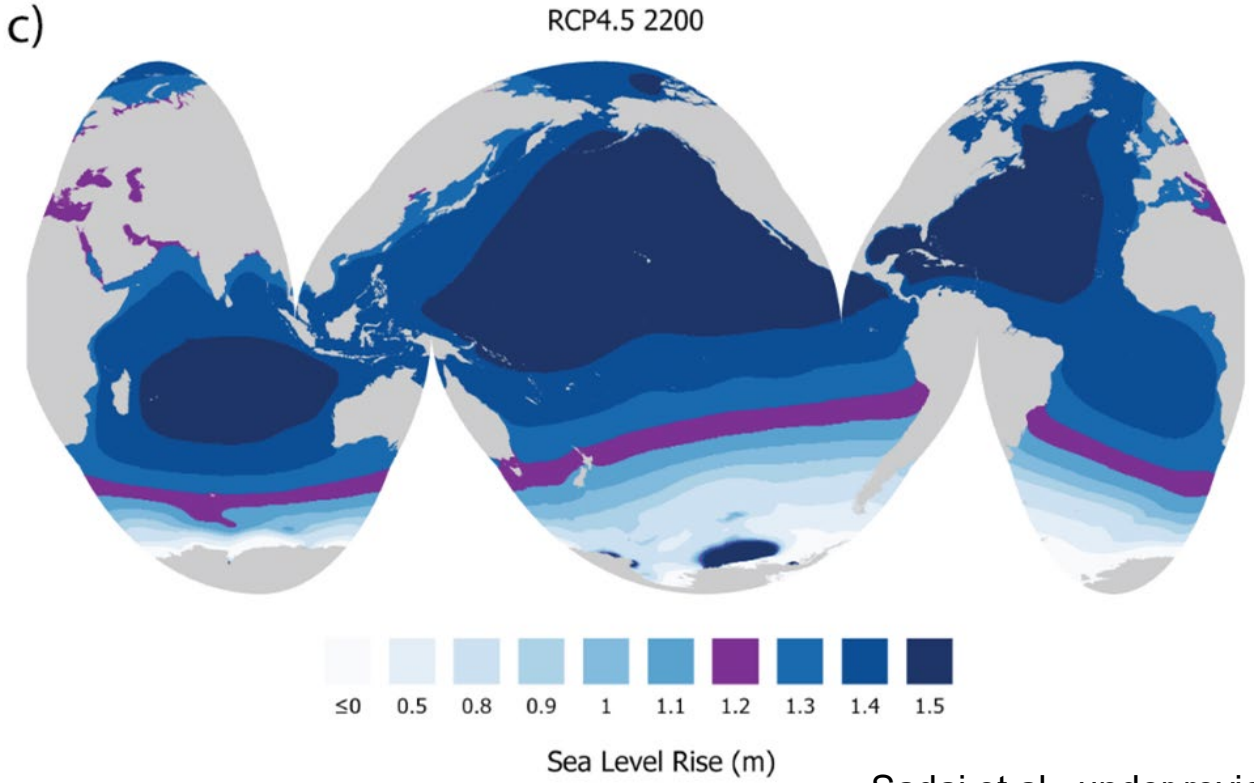
In line with Park et al., 2021, but not Siahaan et al., 2022 which found sea level fall (RCP8.5 at 2100)

Sadai et al., under review

Spatial sea level under low emissions

Antarctic sea level fingerprint

0.3 m higher regional sea level in some places as compared to Antarctica's GMSL contribution

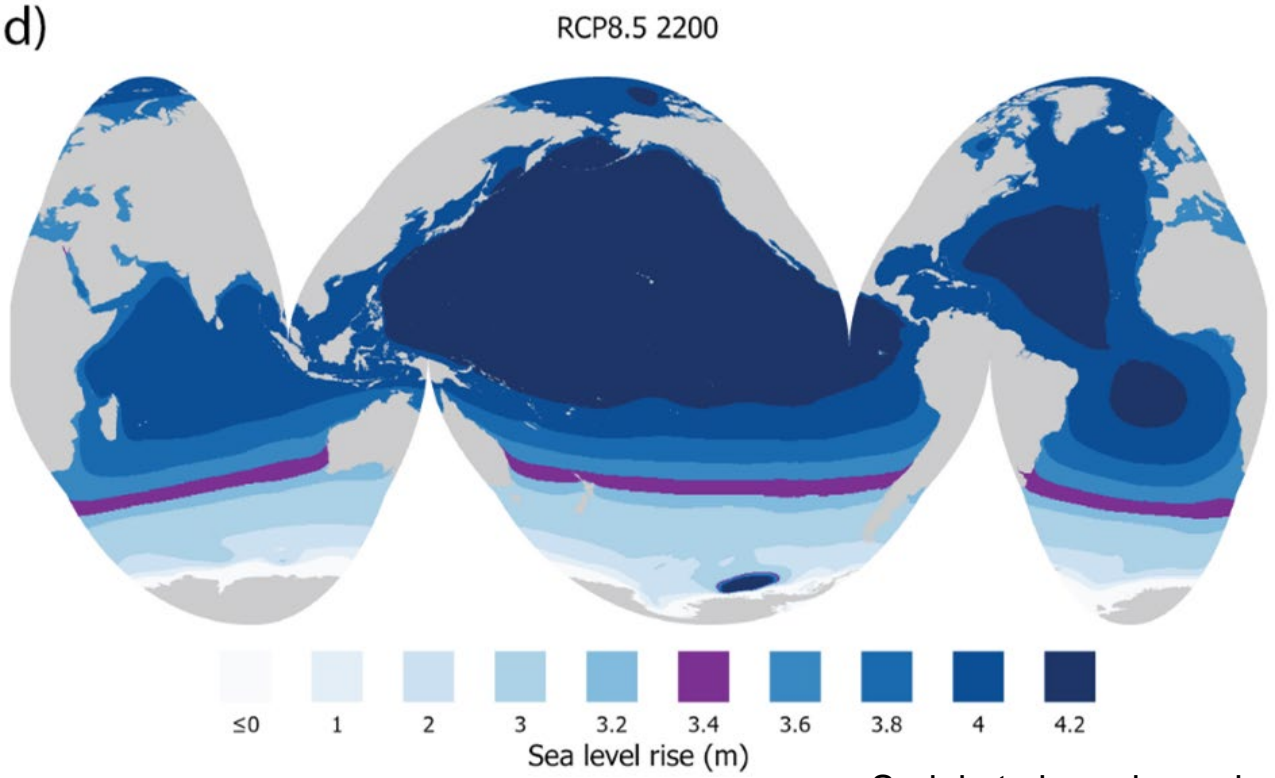


Sadai et al., under review

Spatial sea level under high emissions

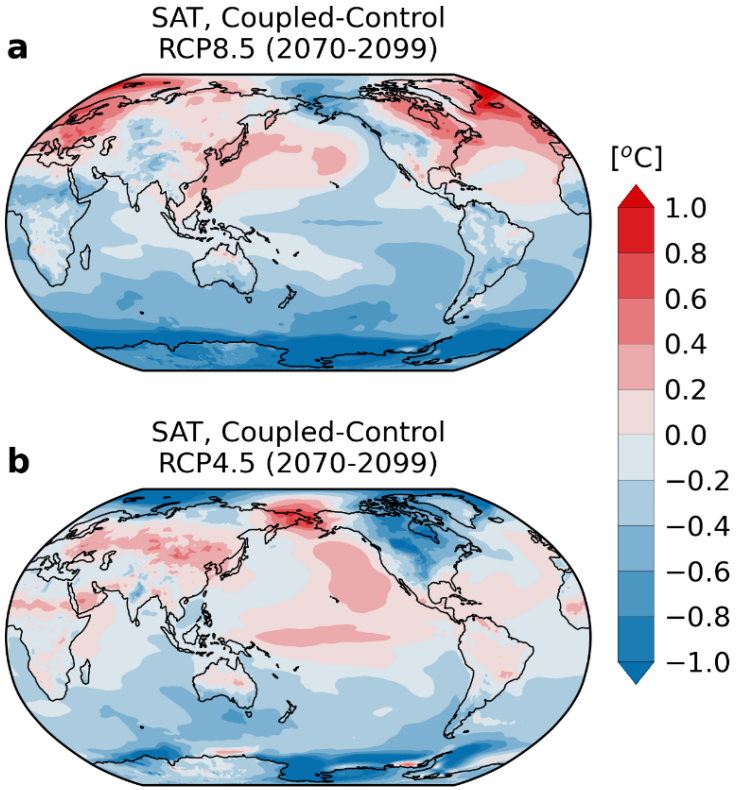
0.9 m higher regional sea level

Different spatial pattern from higher EAIS mass loss



Sadai et al., under review

Climate model air temperature response



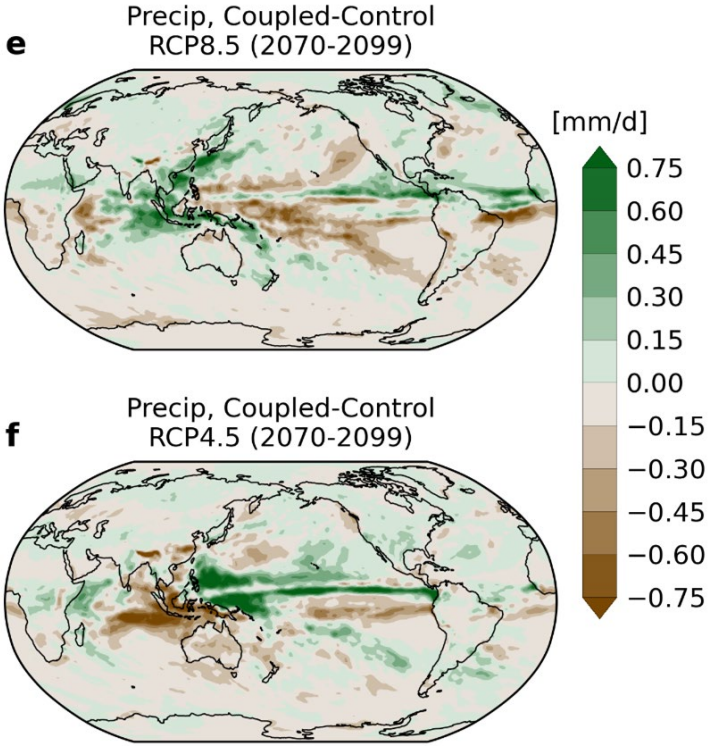
Delayed GMST rise, ~0.3°C lower than control at 2100

But bipolar effect with cooling south & warming north

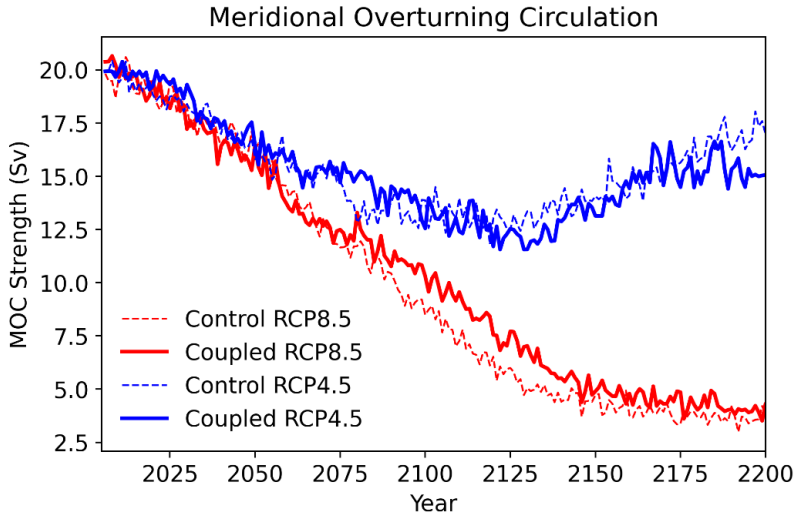
Causes:
More efficient deep ocean heat storage from increased stratification
Lower effective climate sensitivity from surface cooling & teleconnections

Sadai et al., under review & Dong et al., 2022

Precipitation and heat transport



Northern Hemisphere: warmer & wetter
Southern Hemisphere: cooler & drier
Delayed AMOC slowing (RCP8.5)



Sadai et al., under review

A storytelling approach

Jan. 2024: submitted paper to peer review

3 desk rejections in 4 months

2025: still not published…currently in 3rd round of peer review

Conclusions

- Using climate + ice sheet + GIA and sea level models we can better study interactions in the Earth system
- We find large EAIS contributions to GMSLR under high emissions.
- Ad-hoc coupling shows potential Earth system responses as work to incorporate dynamic marine-based ice sheets and GIA models into ESMs continues

Thank you!

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On the job market!