Freshwater Forcing of AMOC Revisited

Feng He, Peter Clark

2022 US AMOC Science Team Meeting

04/27/22, WHOI

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It appears that the intuitive idea of freshwater (FW) forcing of AMOC has not been tested again the data,

mainly because

modern AMOC records are short, and the modern AMOC changes are still in hot🌶️ debate

Two of the biggest advantages of paleoclimate records are

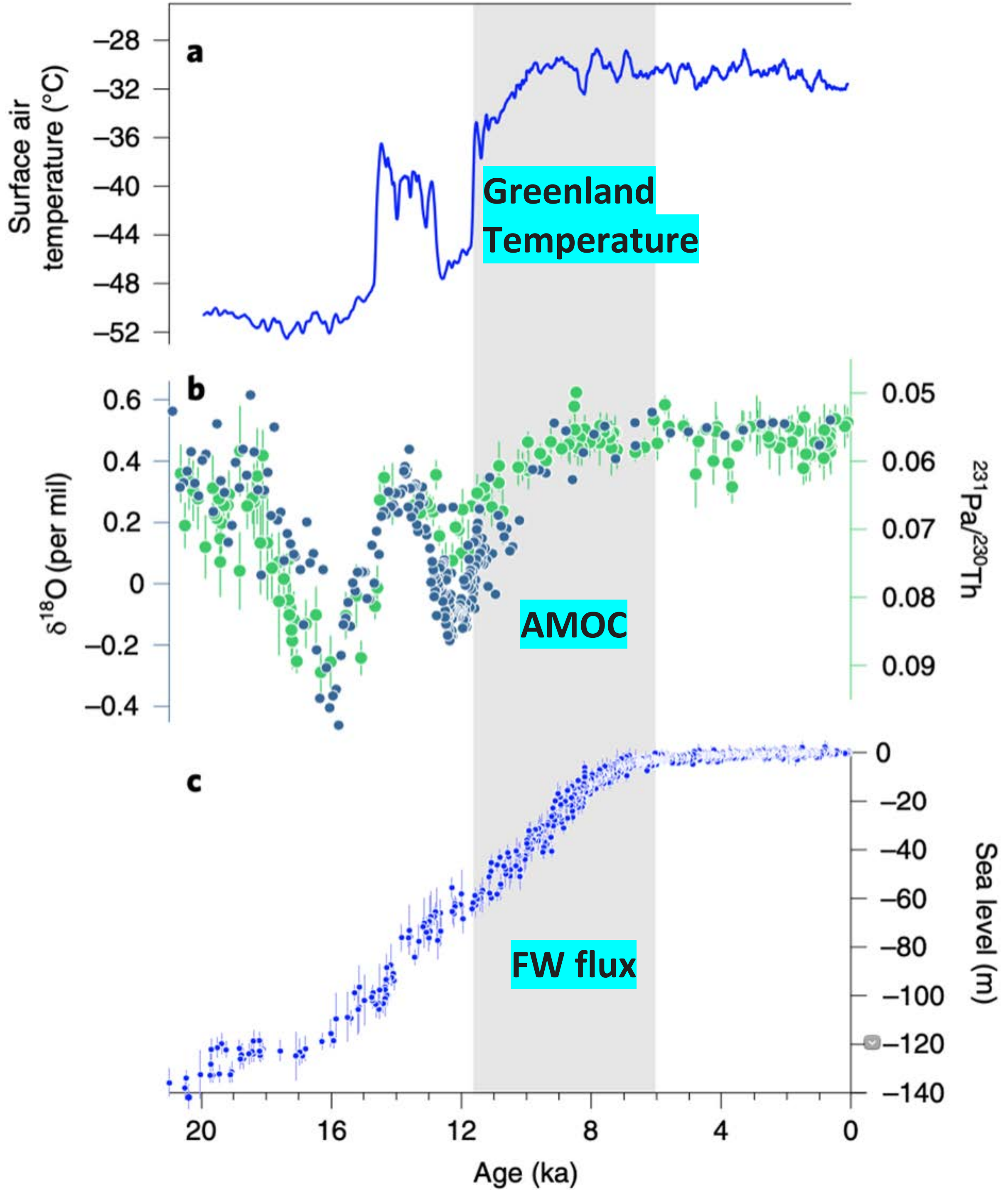
1. Long records
2. Large signals

Holocene Meltwater-AMOC Paradox

AMOC sensitivity to freshwater (FW) input change is shown to be muted

when FW fluxes (50m sea level equivalent) associated with the final Northern Hemisphere deglaciation (~5,700 years) are considered.

He and Clark, Nature Climate Change, 2022

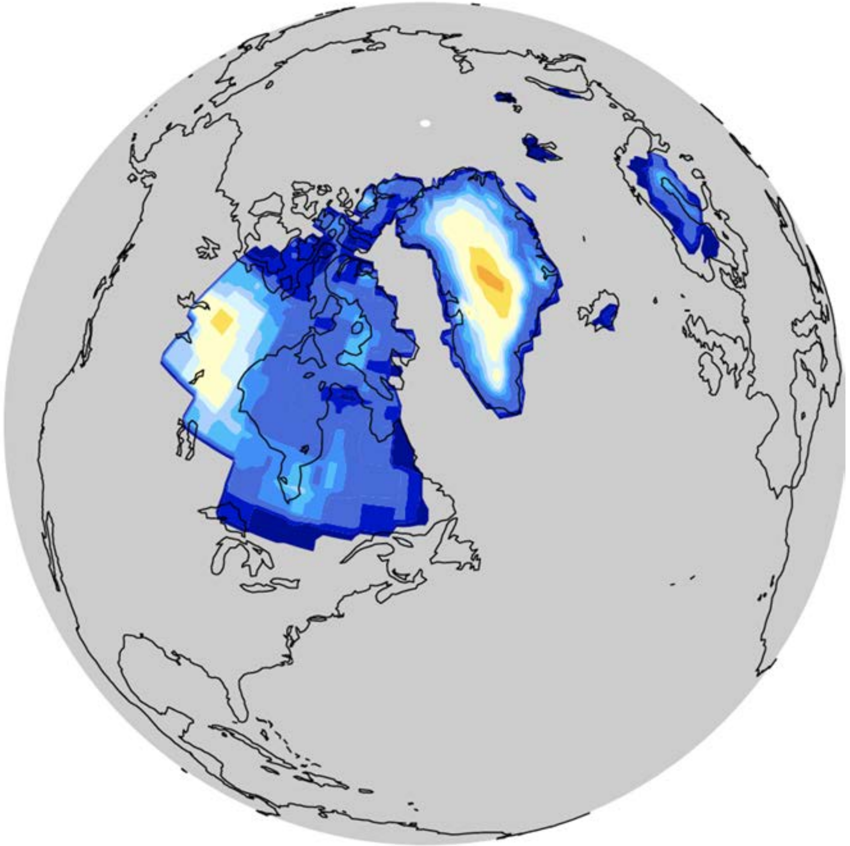


FW: 50m sea level rise in 5,700 years = 0.1 Sv

FW: Bering Strait opening = 0.08 Sv

Total FW flux into Arctic/North Atlantic Ocean in the early Holocene = 0.10-0.18 Sv

YD

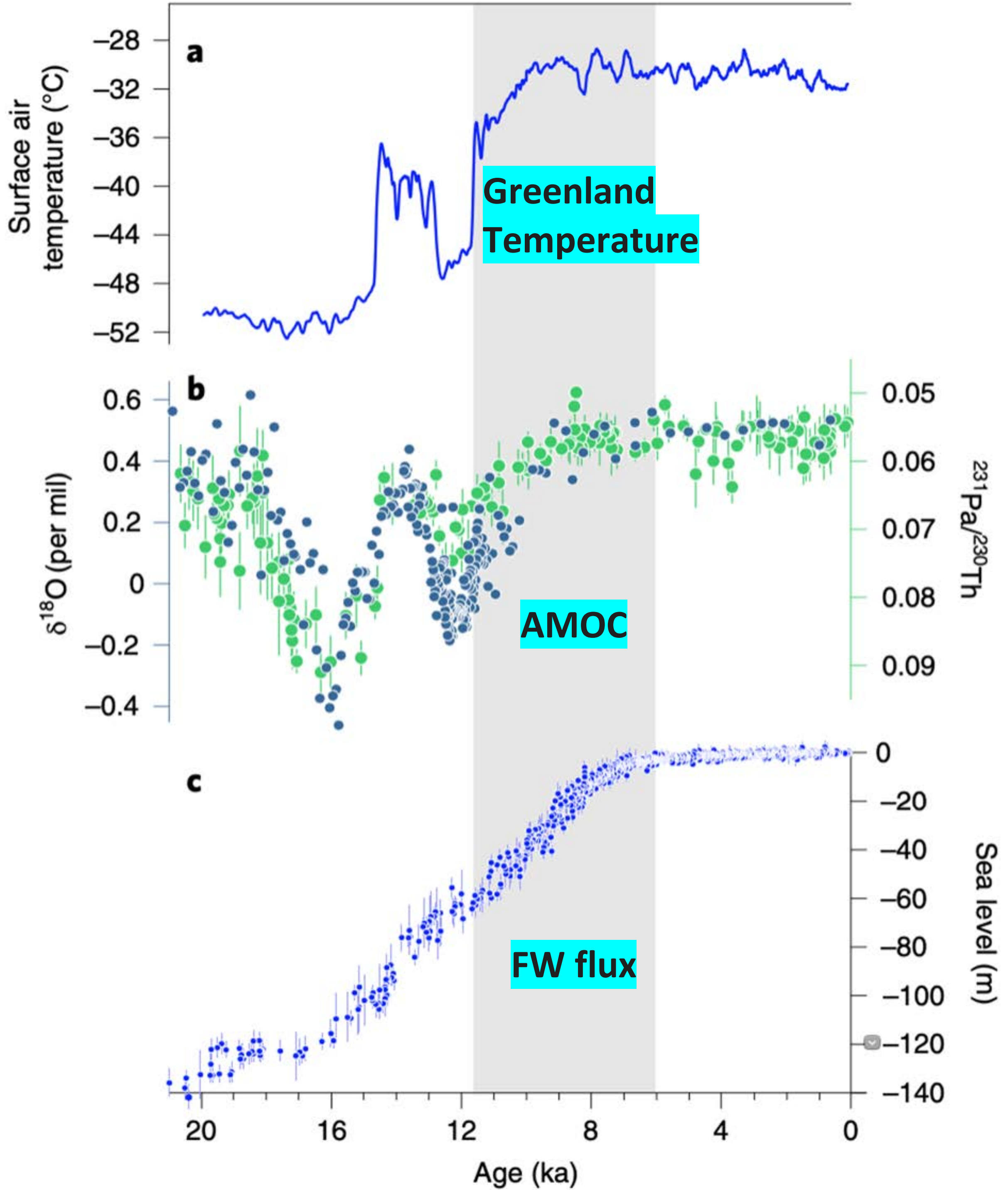


Holocene Meltwater-AMOC Paradox

AMOC sensitivity to freshwater (FW) input change is shown to be muted

when FW fluxes (50m sea level equivalent) associated with the final Northern Hemisphere deglaciation (~5,700 years) are considered.

AMOC data:
Pa/Th: McManus et al., 2004, Lippold et al., 2019
Cross-strait $\delta^{18}O$ at the Florida Straits: Lynch-Stieglitz 2017

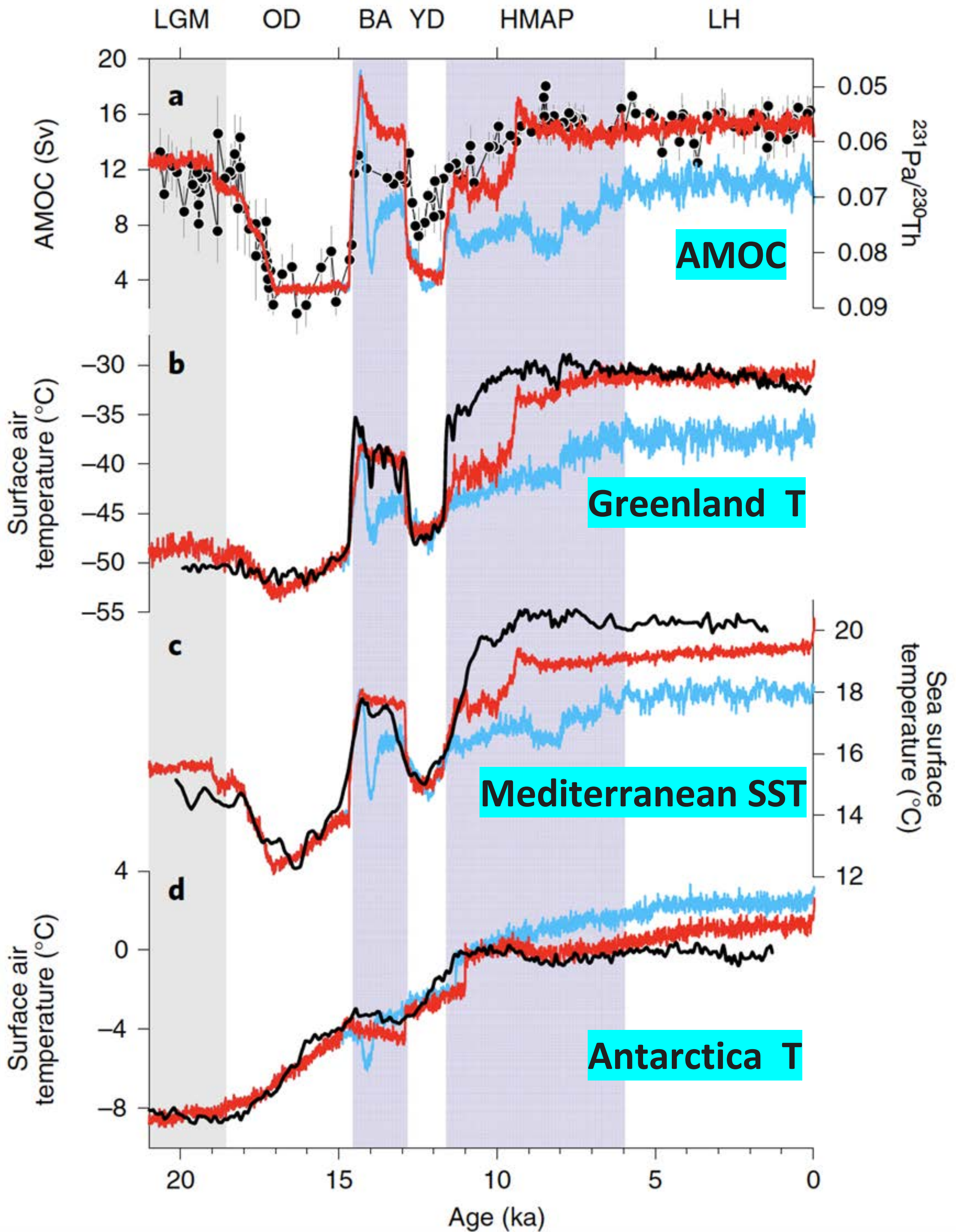


Two transient CCSM3 simulations of past 21,000 years with/without FW in the Holocene

For the simulation with known AMOC (proxy) data,

it's better prescribing AMOC than prescribing FW.

He and Clark, Nature Climate Change, 2022

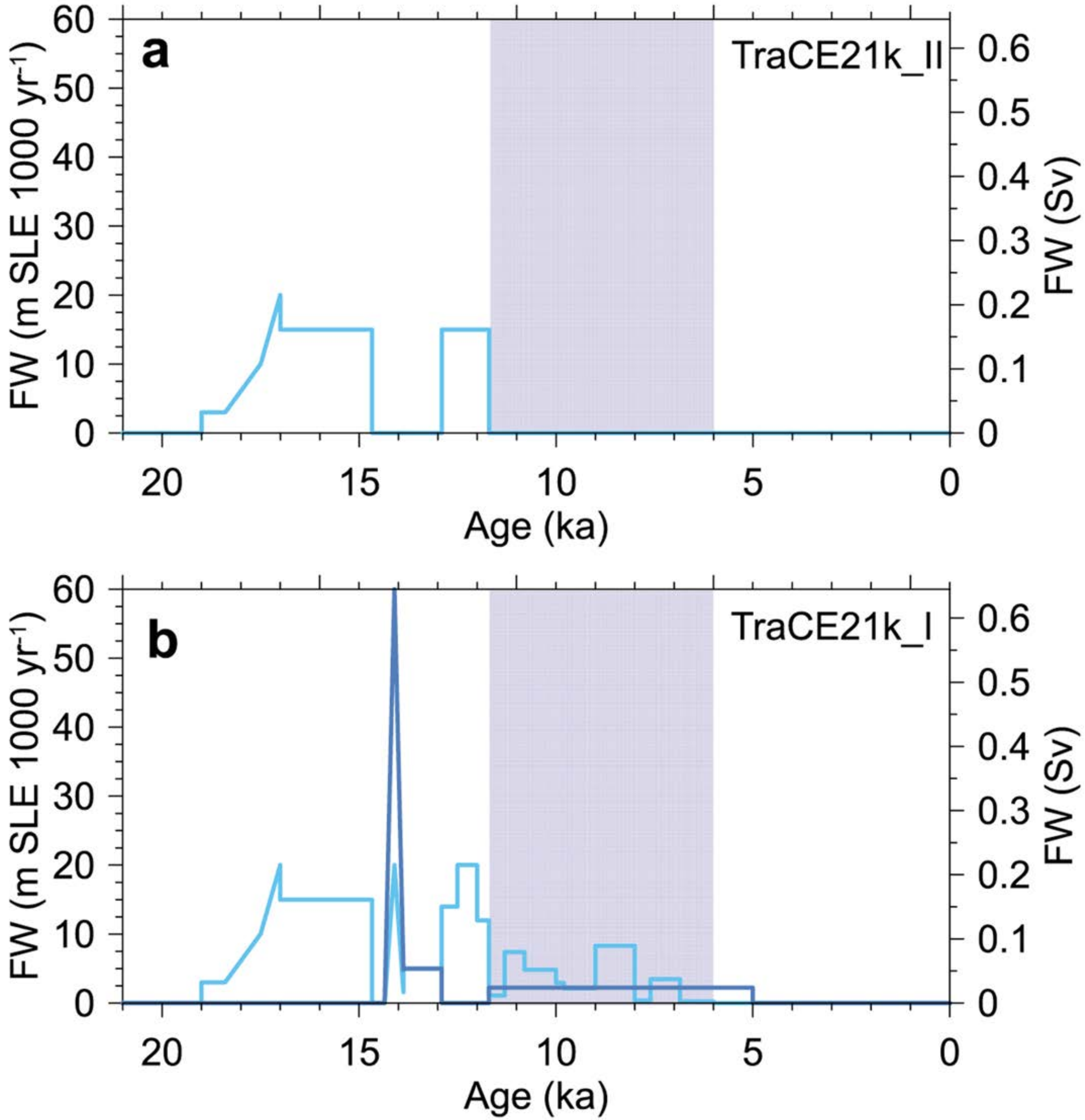


FW schemes

TraCE-21K-II: prescribing AMOC

Question I: can we prescribe AMOC in the model without using FW forcing?

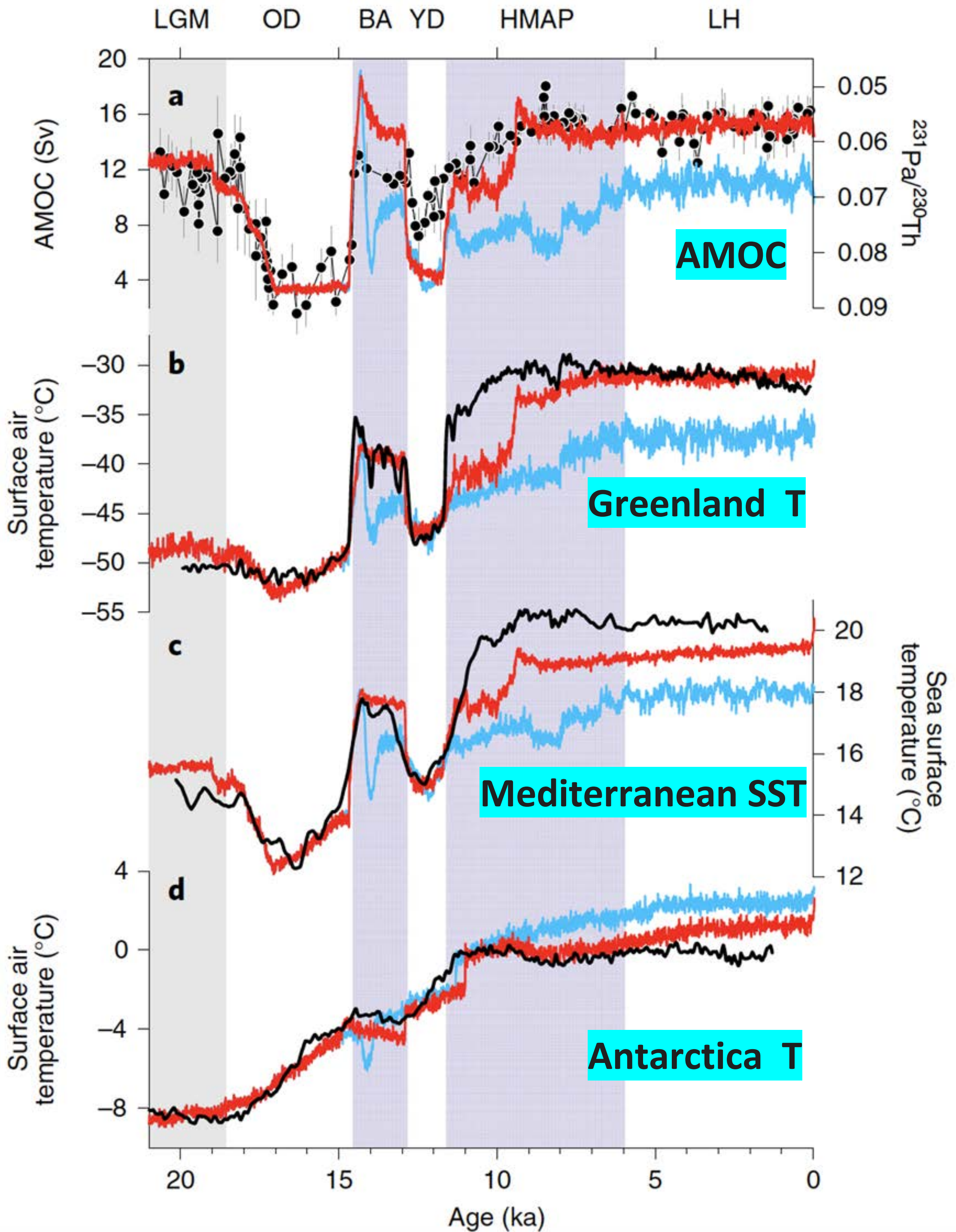
TraCE-21K-I: prescribing FW after BA warming



TraCE-21K-II: prescribing AMOC

Summary: both the model and data support that FW forcing of AMOC is muted.

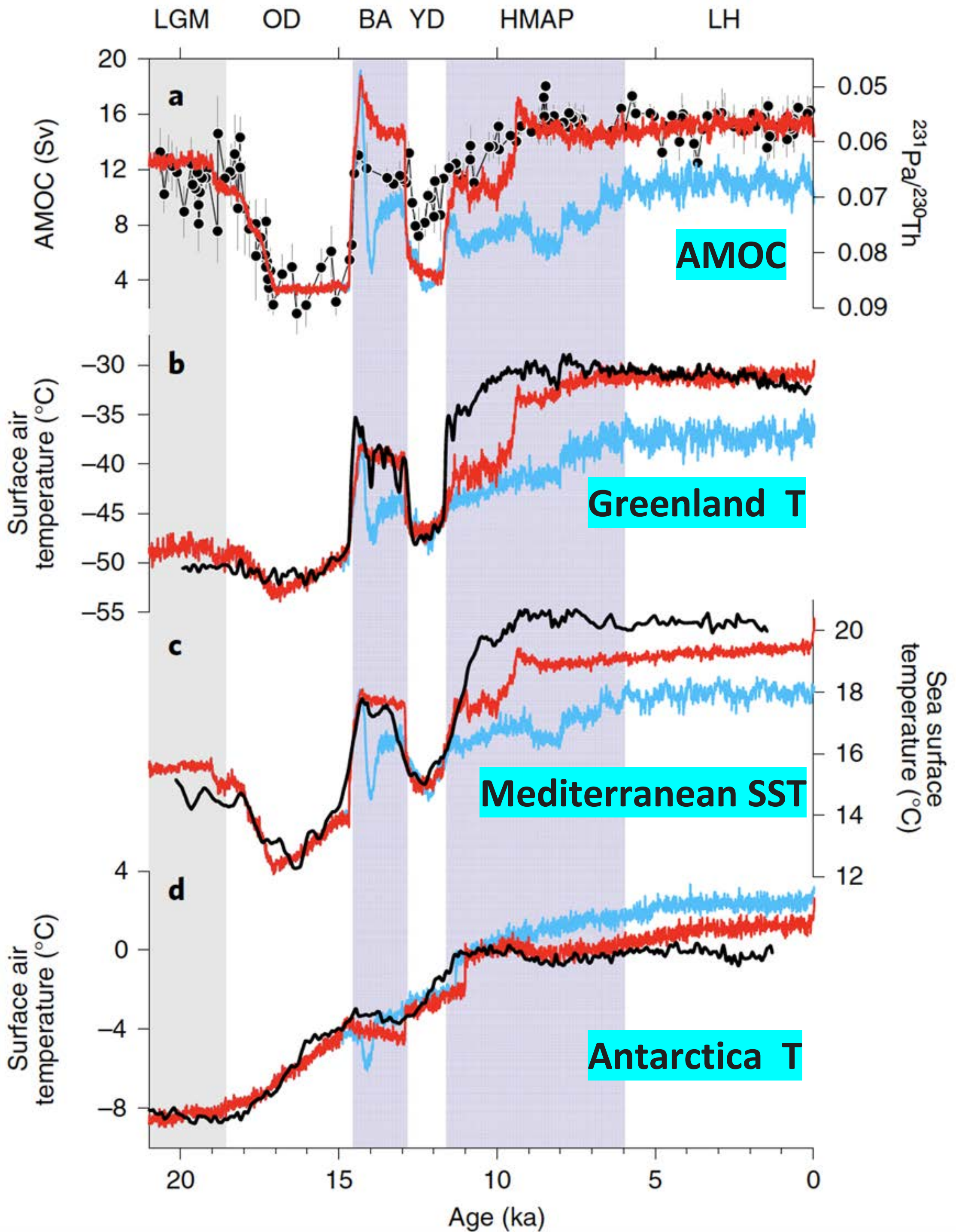
TraCE-21K-I: prescribing FW after BA warming



TraCE-21K-II: prescribing AMOC

Question II: both the model and data support that FW forcing of AMOC is muted, but what is causing the bias of high sensitivity of AMOC to FW in the model?

TraCE-21K-I: prescribing FW after BA warming



It's not due to model resolution

Meltwater routing and the Younger Dryas

Alan Condron[a,1] and Peter Winsor[b]

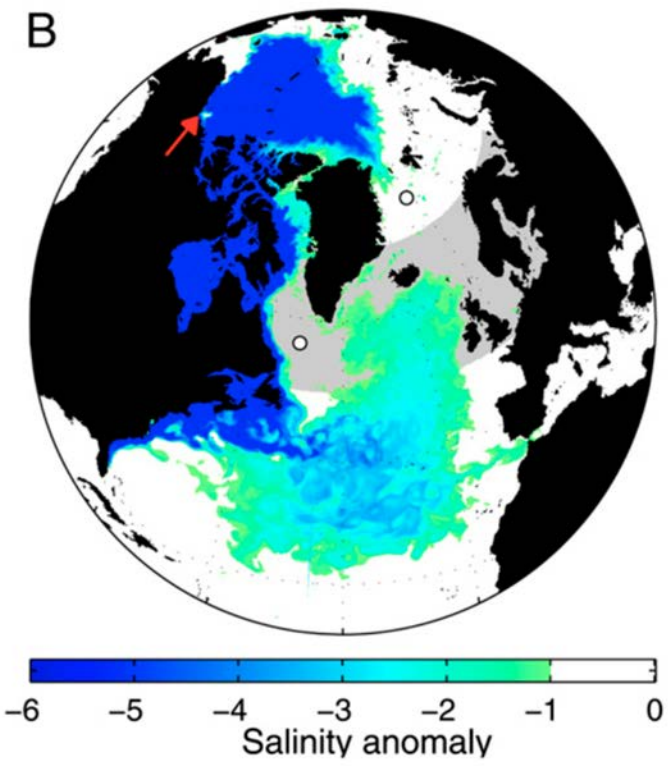
[a]Climate System Research Center, Department of Geosciences, University of Massachusetts, Amherst, MA 01003; and [b]Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Fairbanks, AK 99775

Edited by James P. Kennett, University of California, Santa Barbara, CA, and approved September 27, 2012 (received for review May 2, 2012)

Here we determine the potential of these two meltwater routes to weaken the AMOC by using a state-of-the-art, high-resolution (1/6°, ~18 km), global coupled ocean sea-ice circulation model [Massachusetts Institute of Technology general circulation model, MITgcm (14); see *Methods*]. This model captures the circulation

Table 1. The impact of meltwater from the St. Lawrence River and the Mackenzie River on deep convection and deep ocean circulation

Experiment	LS convection	GS convection	DSOW* (Sv)	AMOC*,† (Sv)	Northward heat transport*,† (PW)
Control	183	225	–3.0	17.0	1.25
Gulf of St. Lawrence	167 (–9%)	204 (–9%)	–2.1 (–30%)	14.6 (–14%)	1.09 (–13%)
Mackenzie (open)	131 (–28%)	85 (–62%)	–1.4 (–53%)	12.4 (–27%)	0.96 (–23%)
Mackenzie (closed)	67 (–63%)	52 (–77%)	–0.9 (–70%)	11.5 (–32%)	0.89 (–29%)



It's not due to model resolution

Climate Dynamics (2020) 55:1711–1732
https://doi.org/10.1007/s00382-020-05345-9

Impact of ocean resolution and mean state on the rate of AMOC weakening

L. C. Jackson[1] · M. J. Roberts[1] · H. T. Hewitt[1] · D. Iovino[2] · T. Koenigk[3] · V. L. Meccia[4] · C. D. Roberts[5] · Y. Ruprich-Robert[6] · R. A. Wood[1]

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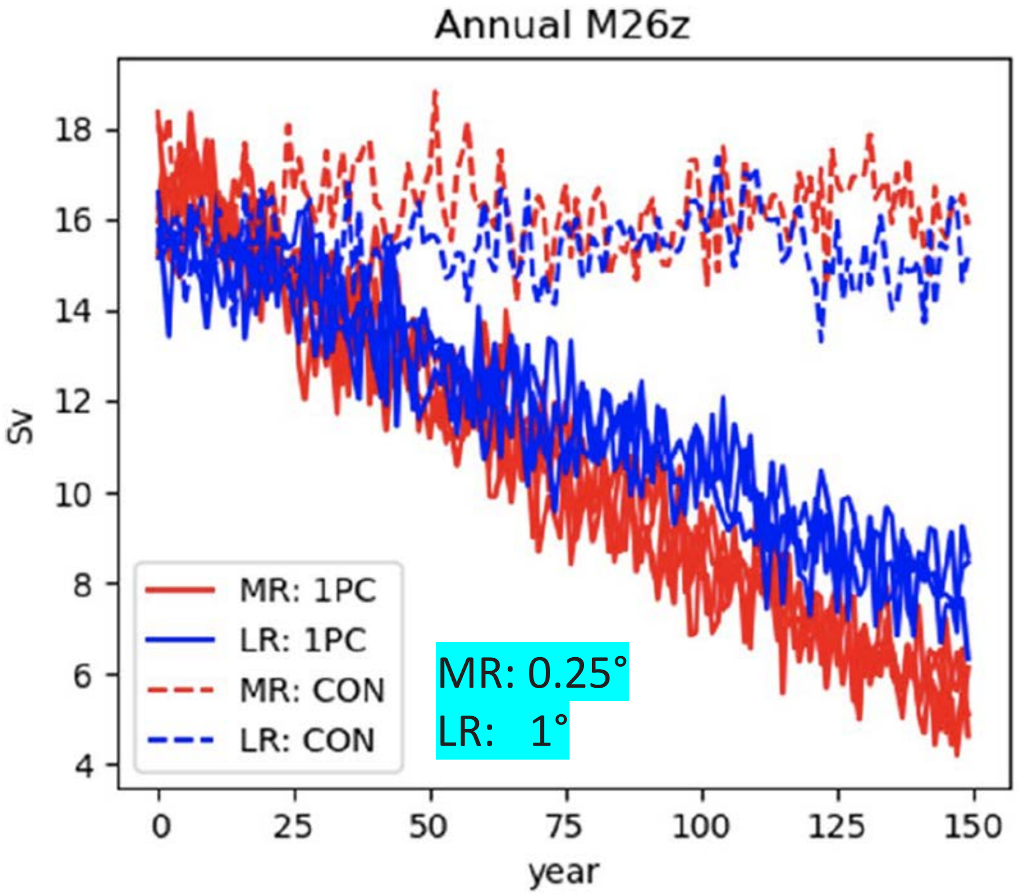
greater dense water formation there. Although there is some improvement of the higher resolution models over the lower resolution models in terms of the mean state, both still have biases and it is not clear which biases are the most important for influencing the AMOC strength and response to increasing CO_2 .

HadGEM3-GC3.1



It's still not due to model resolution

Geophysical Research Letters

RESEARCH LETTER

10.1029/2019GL086075

CMIP6 Models Predict Significant 21st Century Decline of the Atlantic Meridional Overturning Circulation

W. Weijer[1], W. Cheng[2,3], O. A. Garuba[4], A. Hu[5], and B. T. Nadiga[1]

Key Points:

and 21st century AMOC decline. Constraining this relationship with RAPID observations suggests that the AMOC might decline between 6 and 8 Sv (34–45%) by 2100. A smaller group of models projects much less AMOC weakening of only up to 30%.

with high-resolution models. Here we note that the few models that submitted simulations at higher resolutions (CNRM-CM6, MPI-ESM1-2, and HadGEM3-GC31) do not stand out from the rest of the ensemble, consistent with the conclusion from Winton et al. (2014) that spatial resolution in itself does not impact AMOC sensitivity to radiative forcing.

Implications of HMAP for future projections

nature climate change

ARTICLES

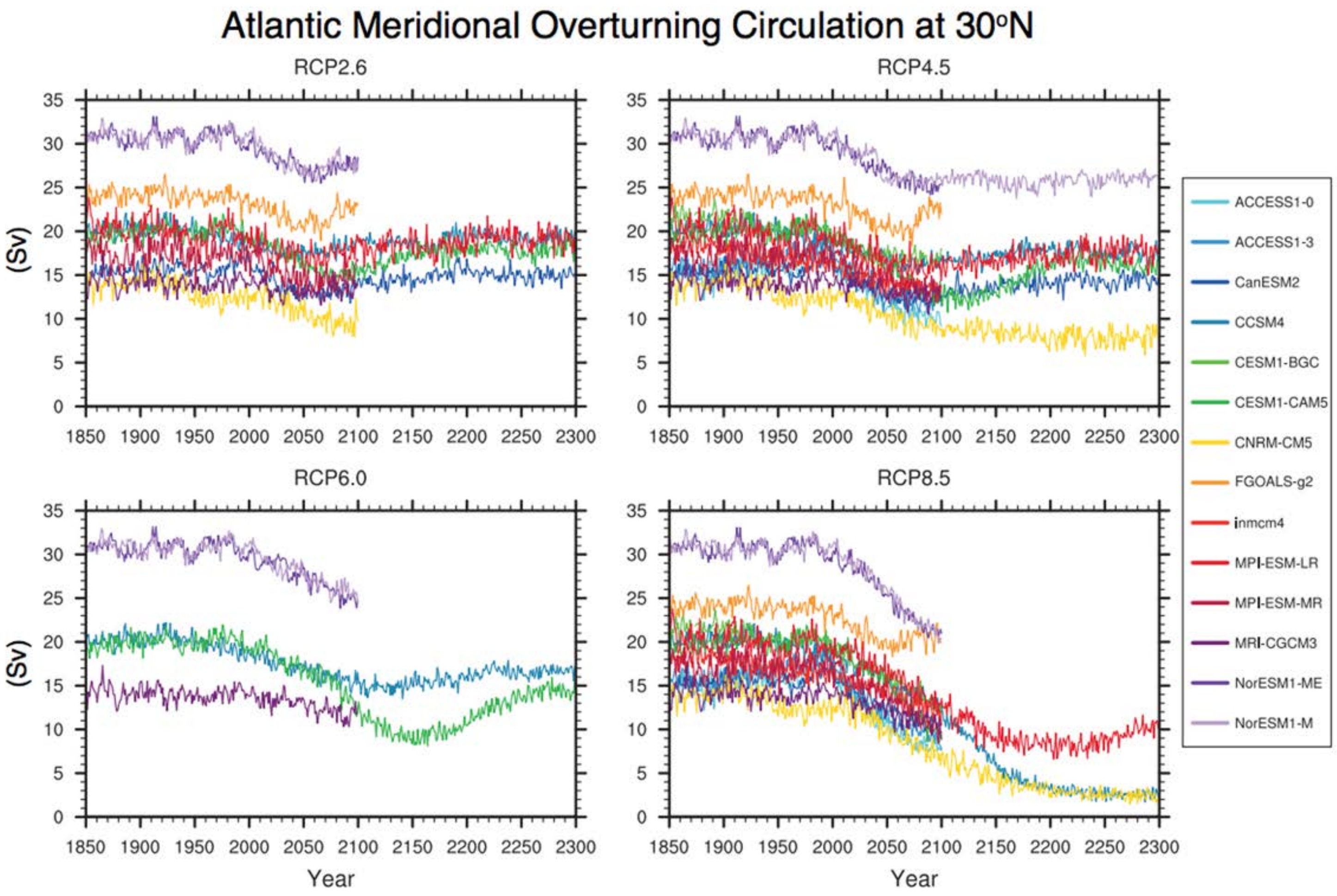
https://doi.org/10.1038/s41558-022-01328-2

Freshwater forcing of the Atlantic Meridional Overturning Circulation revisited

Feng He[1] ✉ and Peter U. Clark[2,3]

Freshwater (FW) forcing is widely identified as the dominant mechanism causing reductions of the Atlantic Meridional Overturning Circulation (AMOC), a climate tipping point that led to past abrupt millennial-scale climate changes. However, the AMOC response to FW forcing has not been rigorously assessed due to the lack of long-term AMOC observations and uncertainties of sea-level rise and ice-sheet melt needed to infer past FW forcing. Here we show a muted AMOC response to FW forcing (~50 m sea-level rise from the final deglaciation of Northern Hemisphere ice sheets) in the early-to-middle Holocene ~11,700–6,000 years ago. Including this muted AMOC response in a transient simulation of the Holocene with an ocean–atmosphere climate model improves the agreement between simulated and proxy temperatures of the past 21,000 years. This demonstrates that the AMOC may not be as sensitive to FW fluxes and Arctic freshening as is currently projected for the end of the twenty-first century.

Are CMIP-projected AMOC declines in 2100 partly 😔or predominantly😰 due to Arctic sea ice melting?



Collins et al. (2013).

Are CMIP-projected AMOC declines in 2100 partly 😔 or predominantly 😰 due to Arctic sea ice melting?

CMIP5

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 1206–1211

Implications of Arctic sea ice changes for North Atlantic deep convection and the meridional overturning circulation in CCSM4-CMIP5 simulations

Alexandra Jahn[1] and Marika M. Holland[1]

Received 27 November 2012; revised 9 January 2013; accepted 21 January 2013; published 26 March 2013.

CO_2 forcing. This weakening of the overturning is caused by a reduction or shut down of North Atlantic (NA) deep convection due to a surface freshening. In the Labrador Sea, the surface freshening is caused by strongly increased liquid freshwater exports from the Arctic, which are largely due to the decrease in the Arctic sea ice cover. In the strongest

CMIP6

UiO : Department of Geosciences
University of Oslo

US CLIVAR

Surface freshening in Subpolar North Atlantic is weakening Overturning Circulation

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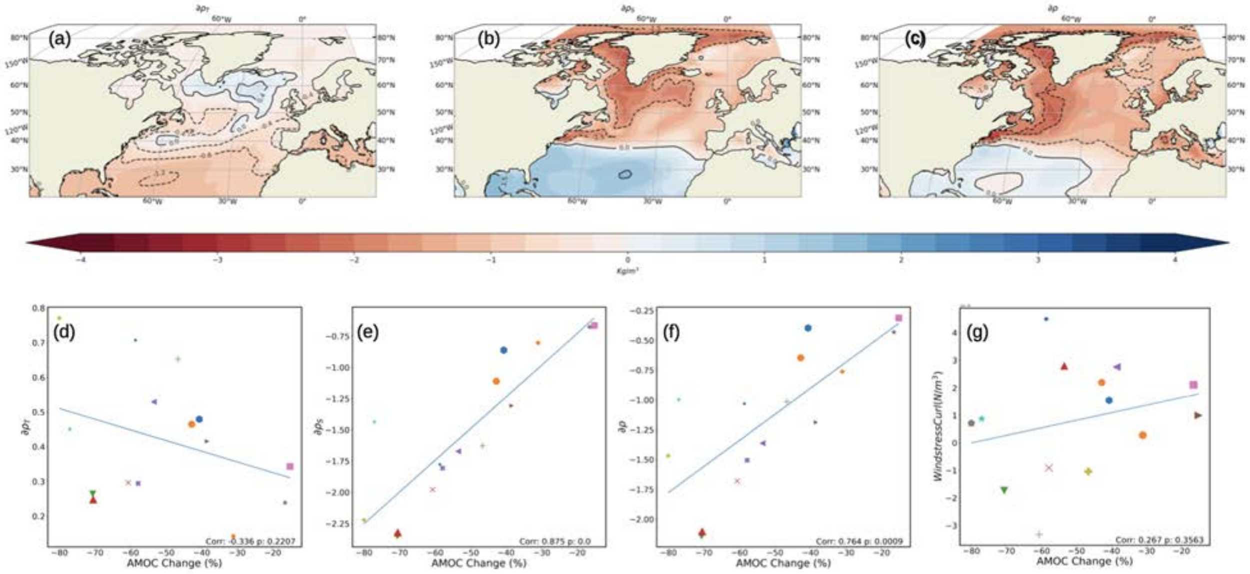
1. Section for Meteorology and Ocean Science, University of Oslo, Norway; 2. Norwegian Meteorological Institute, Oslo, Norway; 3. Department of Physics and Technology, UiT The Arctic University of Norway, Tromsø, Norway

Abstract. *We examine Atlantic Meridional Overturning Circulation (AMOC) changes in the quadrupled CO_2 experiments conducted under the CMIP6 program. The results suggest that AMOC weakens in response to freshwater input in the subpolar gyre, due primarily to sea ice melt. The resulting freshwater flows south along the eastern coast of North America and then eastward, north of the Gulf Stream. This weakens the density gradient across the North Atlantic Current, decreasing the associated vertical shear and consequently the transport. As such, the inflow to the northern downwelling regions is cut off.*



How to address HMAP in AMOC modeling?

Following the CO_2 protocol below:

1. **prescribe CO_2 for climate simulations of the past and future**

2. **treat any predicted CO_2 changes from carbon cycle models with caution**

How to address HMAP in AMOC modeling?

If you are concerned with HMAP

1. **prescribe AMOC for climate simulations of the past and future**
2. **treat any predicted AMOC changes from climate models with caution**

Thank you!

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