UNIVERSITY OF CALIFORNIA UCRIVERSIDE

2022 US AMOC Science Team Meeting

Deciphering the climate impacts of a weakened Atlantic Meridional Overturning Circulation during the 21st century

Wei Liu
University of California Riverside

Collaborate with Alexey Fedorov (Yale), Shang-Ping Xie (SIO/UCSD), Shineng Hu (Duke) and Xianglin Ren (UCR)

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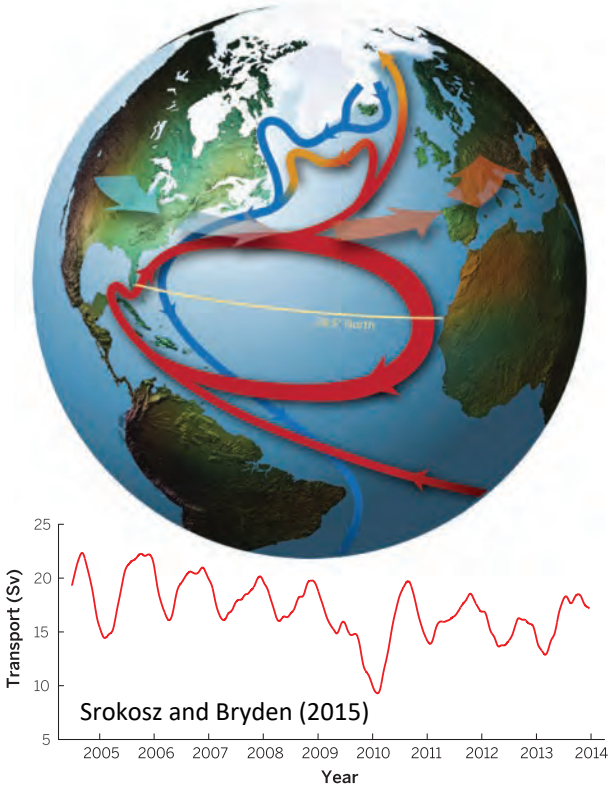
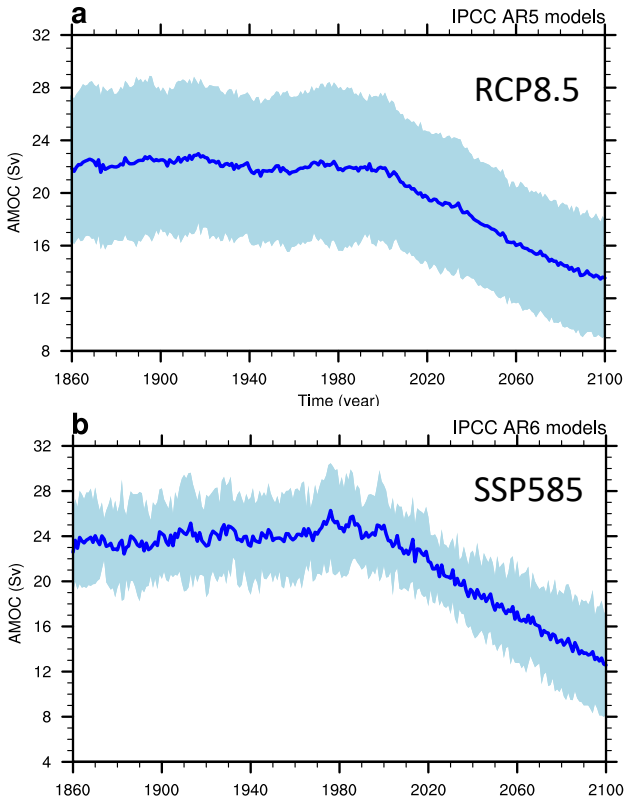
AMOC observation and projection

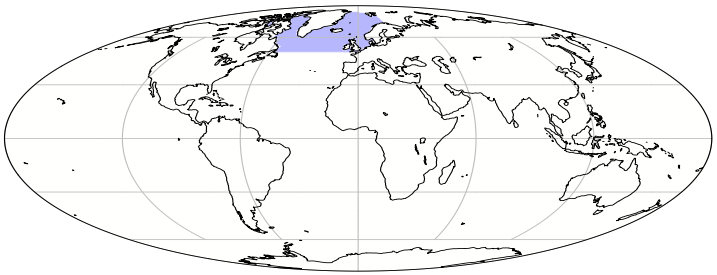




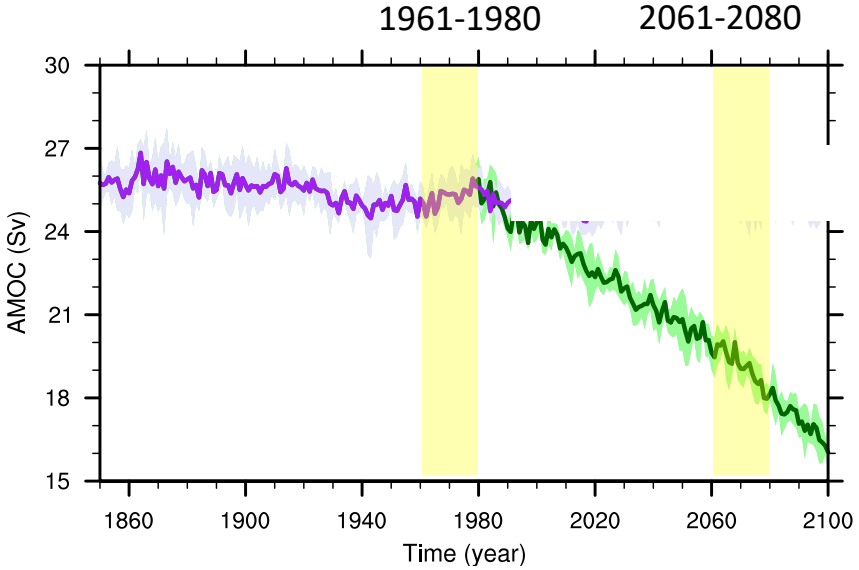
Scientific question:
What is the role of the AMOC in future climate change?

Problems: Under anthropogenic warming, this AMOC slow-down occurs along with variations in other parts of the climate system. Therefore, within a fully coupled climate system, it is difficult to separate the effect of AMOC slowdown on climate from the effects of other varying and interacting climate components.

CCSM4 sensitivity experiment



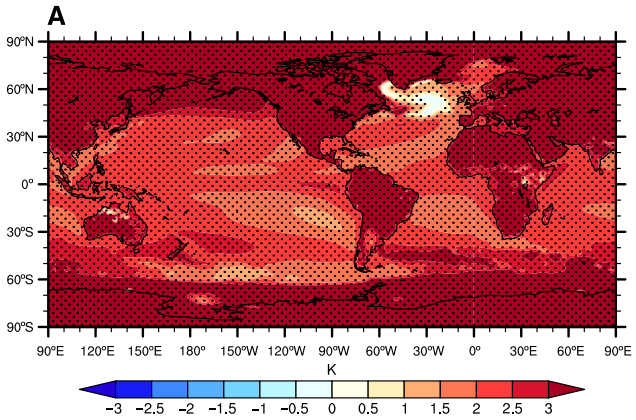
Freshwater removal from the subpolar North Atlantic covering deep water formation regions

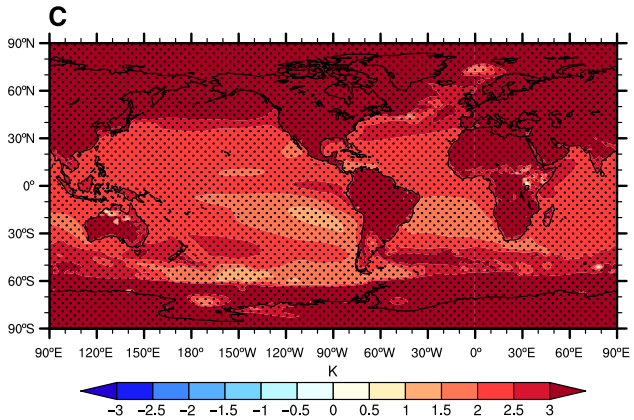


- CCSM4 is a fully coupled, broadly used IPCC AR5 climate model.
- We use CCSM4 historical + RCP 8.5 simulation, 5 ensemble members (< 1980, purple; > 1980, green)
- Sensitivity experiment (**since 1981, hist+RCP8.5 forcing but with fixed AMOC**, 1981-2100, purple), 5 ensemble members.

The vanished North Atlantic warming hole (NAWH)

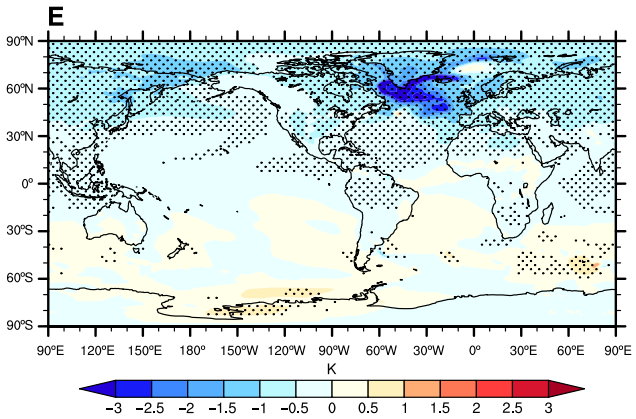
Weakened AMOC





Fixed AMOC

A-C The impact of the weakened AMOC



(2061-2080) – (1961-1980)

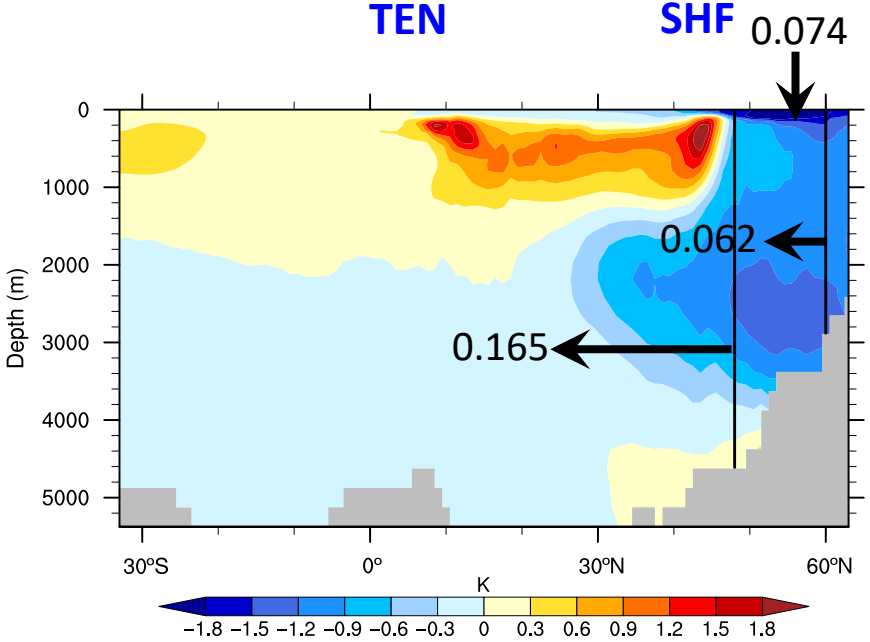
CCSM4 experiments shows that the weakened AMOC primarily accounts for the NAWH in the 21st century.

The physical mechanism

Heat budget analysis on the full-depth water column in 48-60°N in the North Atlantic

$$\iiint_V \left(\rho_0 C_p \frac{\partial \theta}{\partial t}\right) dv' = \iint_S (\mathrm{shf})\, ds' - \iiint_V \{\rho_0 C_p [\nabla \cdot (\mathbf{v}\theta)]\} dv' + \iiint_V (\mathrm{diff})\, dv'$$

TEN SHF -ΔOHT D

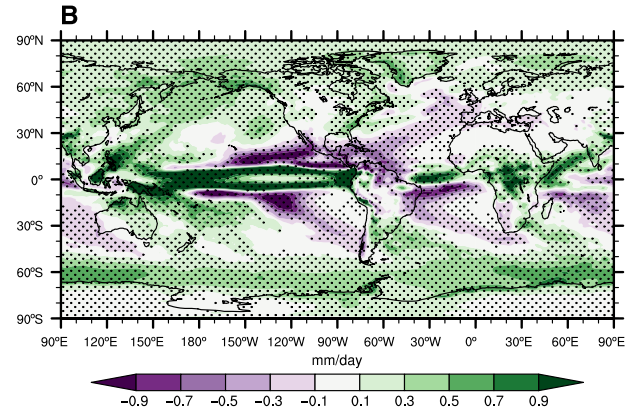


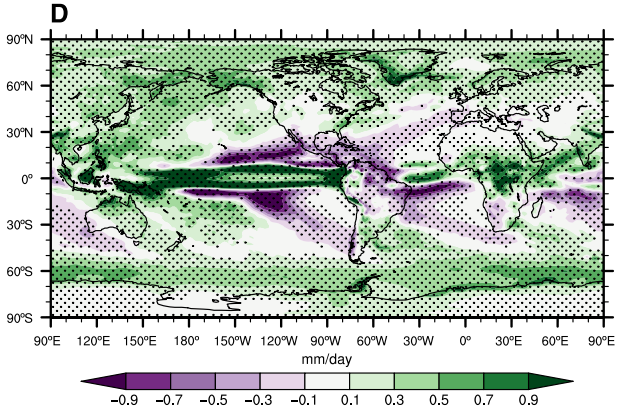
Heat budget term	Difference (PW)
TEN	-0.031
SHF	0.074
D	-0.002
-ΔOHT	-0.103
OHT(S)	-0.165
OHT(N)	-0.062
OHT_{Eul} (S)	-0.153
OHT_{ed+sub} (S)	-0.012
OHT_{ov}	-0.124
OHT_{az}	-0.029
OHT_{Eul} (N)	-0.079
OHT_{ed+sub} (N)	0.017

- The cooling is primarily caused by the reduced net meridional ocean heat transport, which is mainly due to the weakening of the AMOC.

AMOC impacts on rainfall projection

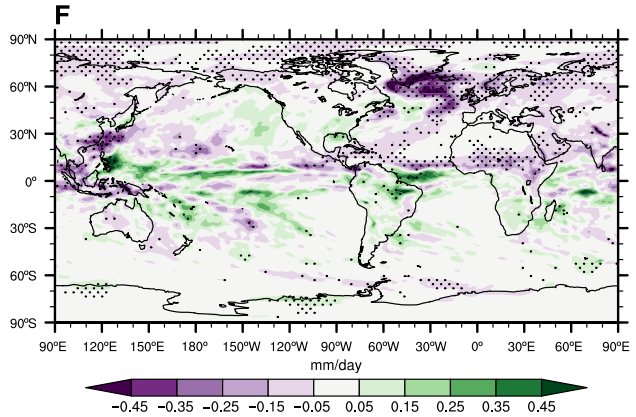
Weakened AMOC





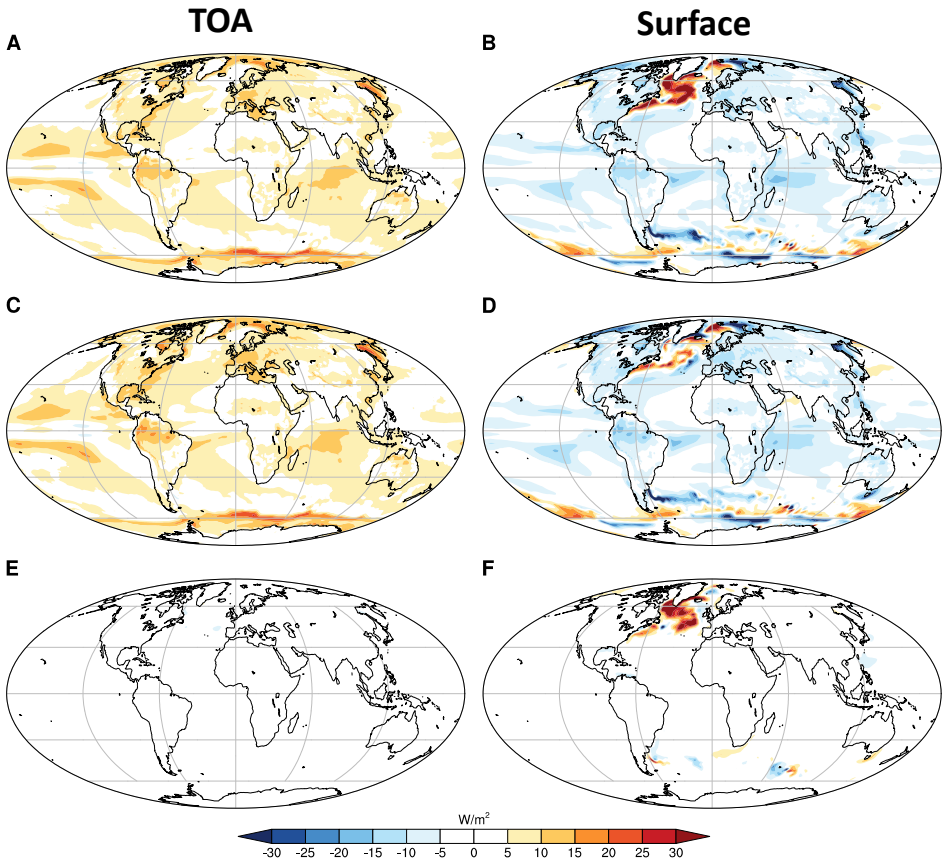
Fixed AMOC

B-D The impact of the weakened AMOC



- The weakened AMOC causes **reduced** precipitation over the NAWH region
- It also induces a **southward** shift of ITCZ, but not the leading mode of tropical precipitation projection.

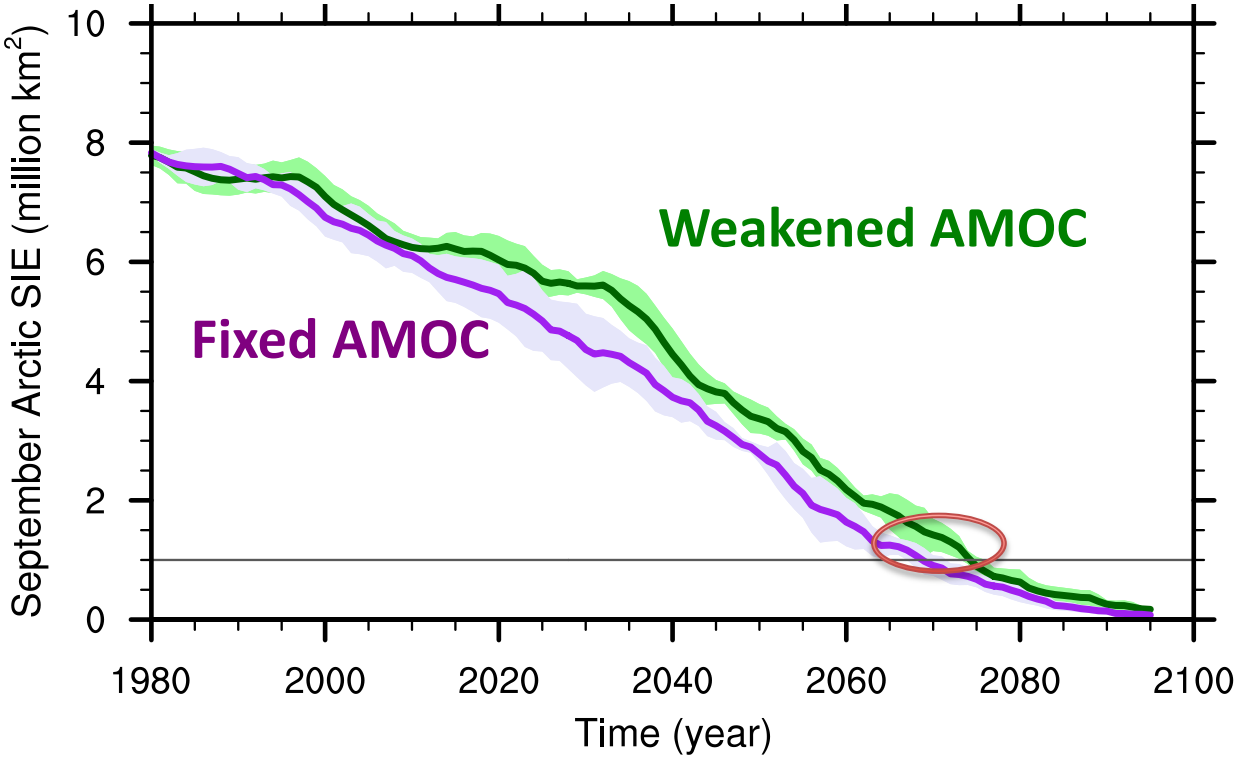
Energy fluxes at the TOA and surface



- Enhanced ocean heat uptake, primarily via turbulent heat fluxes, in the North Atlantic drives a northward cross-equatorial atmospheric energy transport, which explains the southward ITCZ shift.

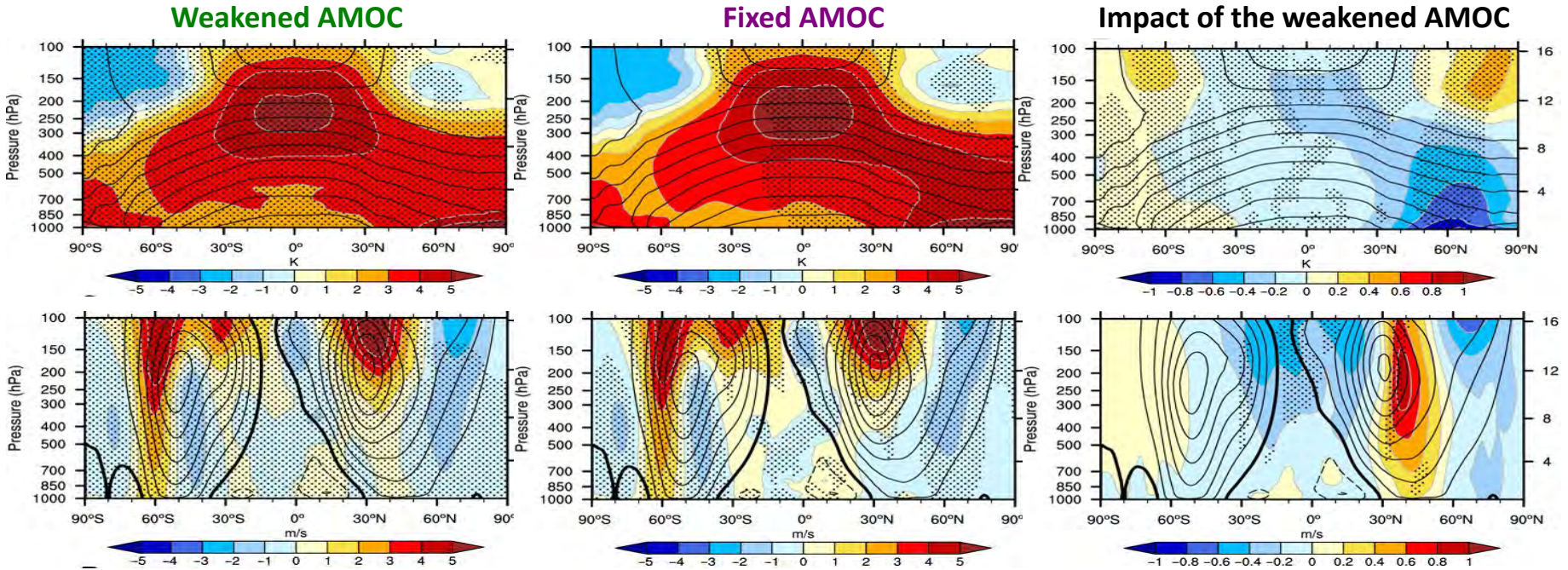
- This enhanced ocean heat uptake acts to damp the anomalous SST cooling in the North Atlantic, i.e., a negative feedback.

Delayed Arctic summer ice-free time



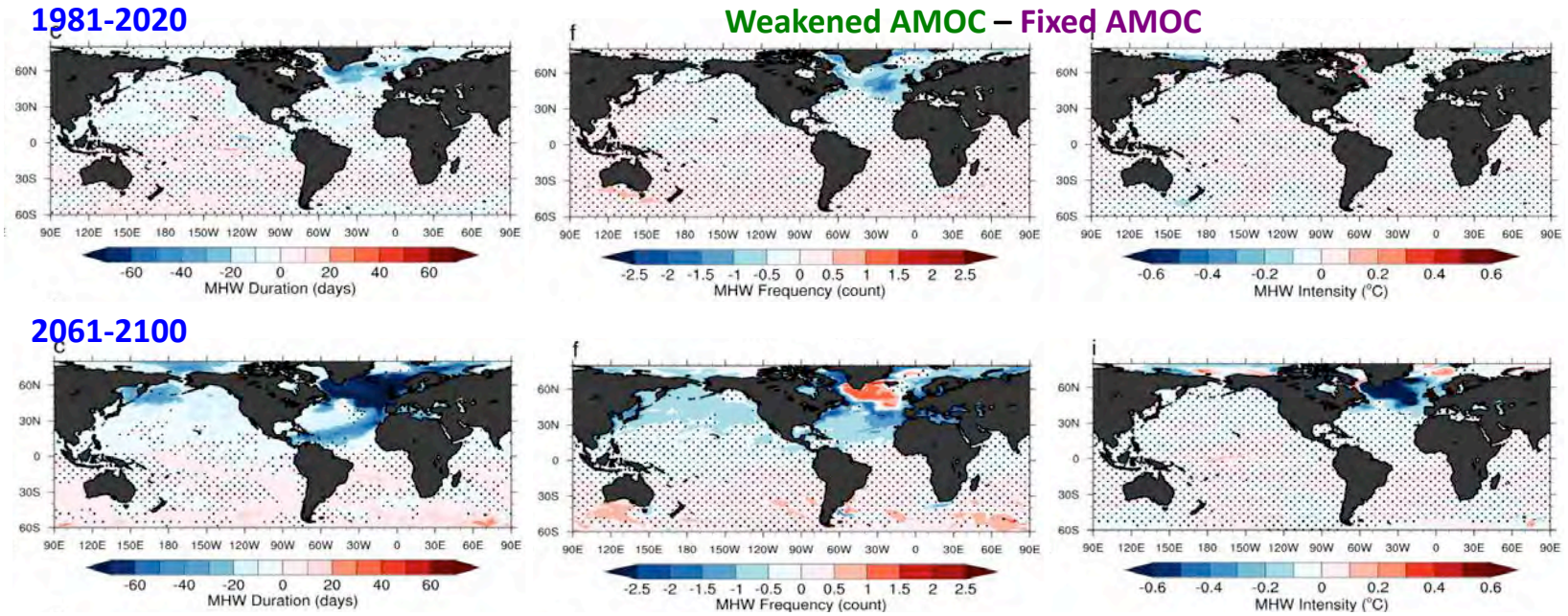
Summer Arctic ice-free time is delayed by 6 years due to the weakened AMOC.

AMOC impacts in atmospheric circulation



- The zonally averaged zonal wind response to the AMOC slowdown displaces the Northern Hemisphere westerly jets poleward during boreal winter.

AMOC impacts on global marine heatwaves (MHWs)



- AMOC impacts on MHWs are insignificant during 1981-2020 except the NAWH but become significant in the North Atlantic and North Pacific by 2100.
- The NAWH region would reach a near-permanent MHW state over 2061-2100 without a slowdown of the AMOC.

Conclusion

- The projected AMOC slowdown causes the NAWH to the south of Greenland, along with local reduced precipitation and enhanced ocean heat uptake.
- The weakened AMOC explains a reduction in Arctic sea ice loss in all seasons and, in particular, a delay by about 6 years of the emergence of an ice-free Arctic in boreal summer.
- In the troposphere, a weakened AMOC causes an anomalous cooling band stretching from the lower levels in high latitudes to the upper levels in the tropics and displaces the Northern Hemisphere midlatitude jets poleward.
- The AMOC slowdown will have significant impacts on MHWs in the North Atlantic and North Pacific by 2100. The NAWH region would reach a near-permanent MHW state over 2061-2100 without a slowdown of the AMOC.

Thank you!

Liu, W., Fedorov, A.V., Xie, S.-P. and Hu, S., 2020. Climate impacts of a weakened Atlantic Meridional Overturning Circulation in a warming climate. *Sci. Adv.*, *6*, eaaz4876.

Ren, X. and Liu, W., 2021. The role of a weakened Atlantic meridional overturning circulation in modulating marine heatwaves in a warming climate. *Geophys. Rese. Lett.*, 48, e2021GL095941.