The impacts of a weakened Atlantic Meridional Overturning Circulation on ENSO in a warmer climate

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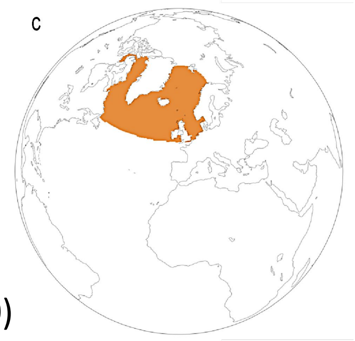
2023 CESM Workshop

Background and **Scientific Questions**

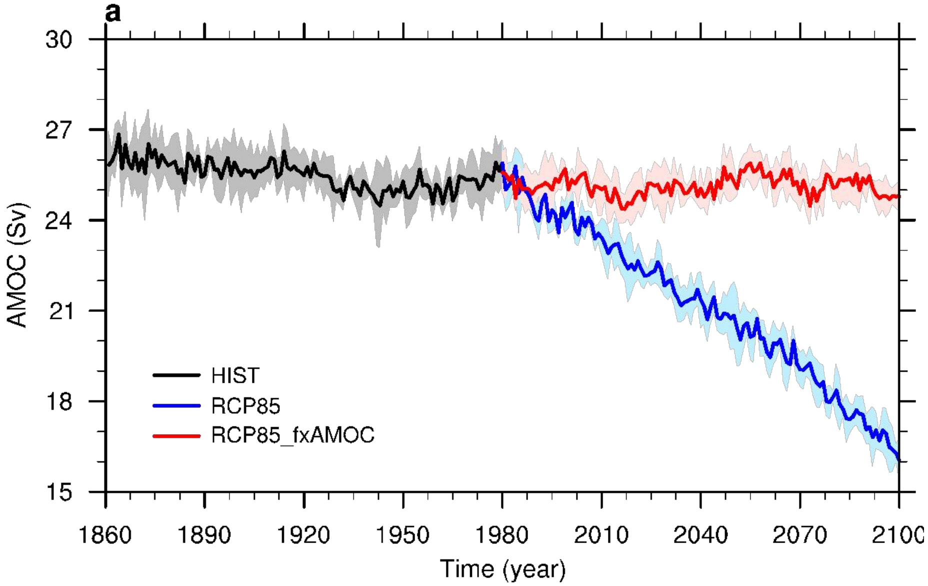
- The Atlantic Meridional Overturning Circulation (AMOC) and El Niño/Southern Oscillation (ENSO) are two crucial elements in the Earth's climate system.
- The AMOC is projected to slowdown in the 21st century, which could impact the global and regional climate, potentially including ENSO variability.
- Classical Freshwater hosing experiments (in the absence of anthropogenic global warming) show that a weakened/collapsed AMOC can enhance ENSO variability (Timmermann et al. 2007; Dong & Sutton 2007), cause an eastward shift of ENSO SST anomalies (Willianson et al. 2018) or reduce ENSO variability (Orihuela-Pinto et al. 2022).
- **The above AMOC impact on ENSO, however, are obtained from hosing experiments. The impacts of projected AMOC slowdown have not been explicitly assessed in the context of anthropogenic warming via fully coupled climate model experiments.**
- **It remains unclear how and to what extent the projected AMOC slowdown can affect future ENSO variability during the 21st century.**

CCSM4 experiments

- One-degree CCSM4, historical historical+RCP8.5 simulations, 5 ensemble members.
- Fixed AMOC experiment: branched from the year 1980 of the historical simulation and driven by the same historical and RCP8.5 forcings except that a small amount of freshwater is gradually removed from the subpolar North Atlantic and uniformly redistributed over rest of the global ocean (Liu et al. 2020), 5 ensemble members.

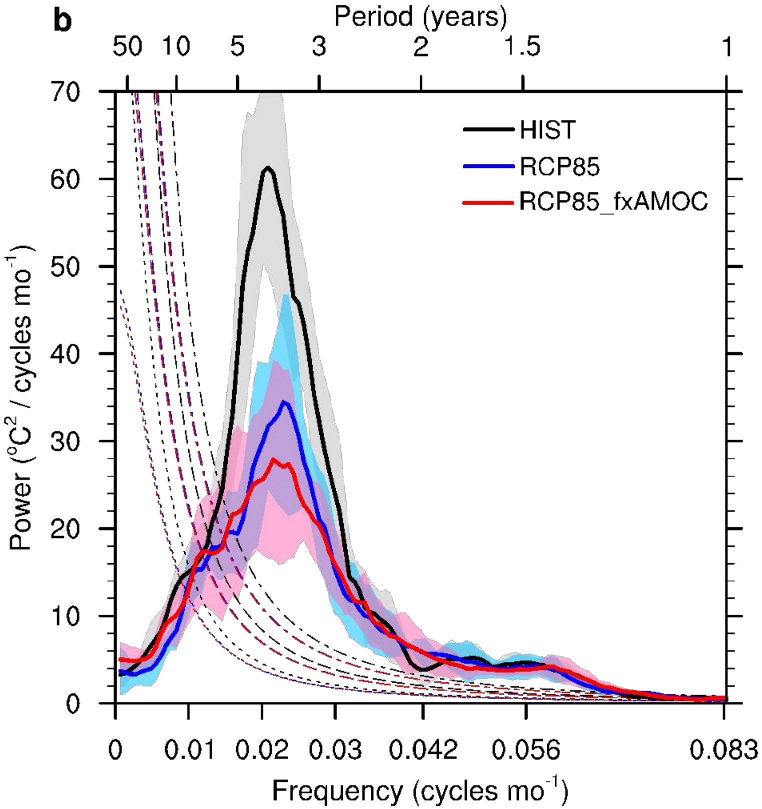


- HIST (1861-1980)
- RCP85 (1981-2100)
- RCP85_fxAMOC (1981-2100)



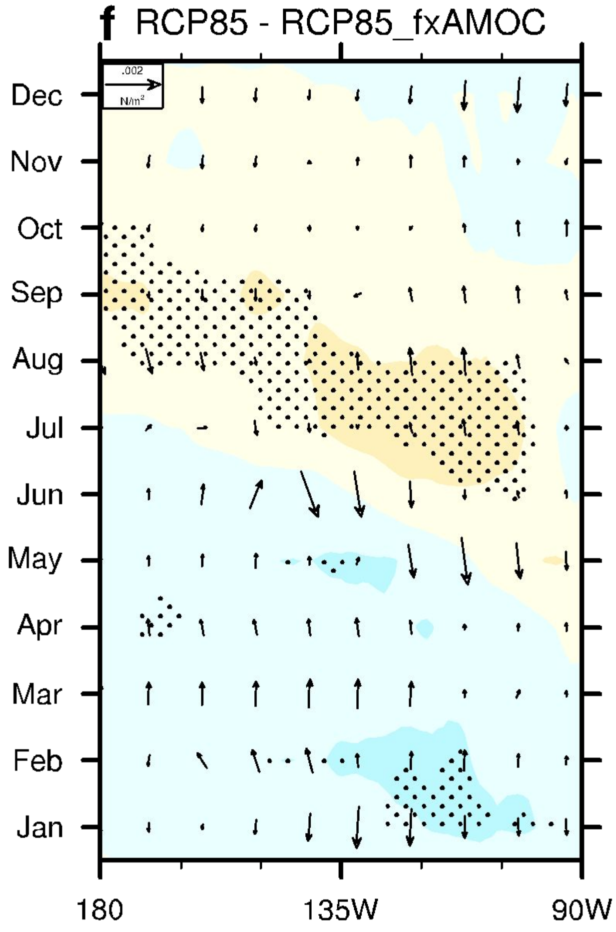
AMOC impacts on ENSO

- The projected anthropogenic warming shortens future ENSO period while the AMOC slowdown can make the ENSO period even shorter.
- The ensemble-mean magnitude of ENSO variability decreases over the twenty-first century under the RCP8.5 scenario, and such decrease might be even larger without the projected AMOC slowdown.



Physical mechanisms

- A weakened AMOC indeed acts to further reduce the SST annual cycle in the eastern equatorial Pacific relative to the simulated future state with an already weakened annual cycle.
- This result is consistent with those from Dong and Sutton (2007) and Timmermann et al. (2007), suggesting that a weakened annual cycle can lead to intensification of the ENSO amplitude and vice versa via the frequency entrainment mechanism (Chang et al. 1994; Liu 2002; Timmermann, Lorenz, An, Clement, & Xie 2007).

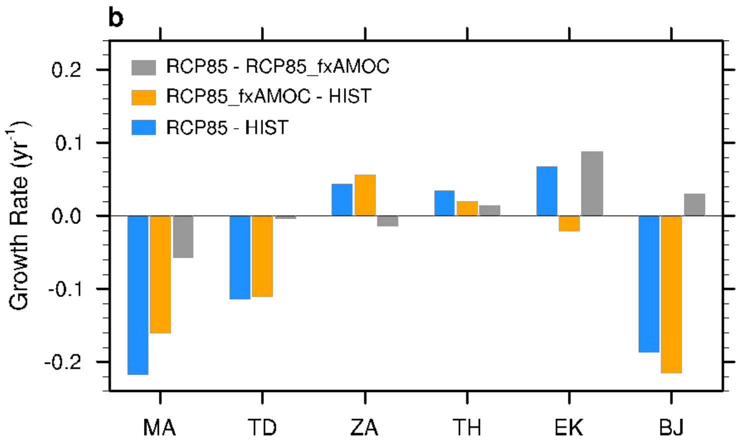


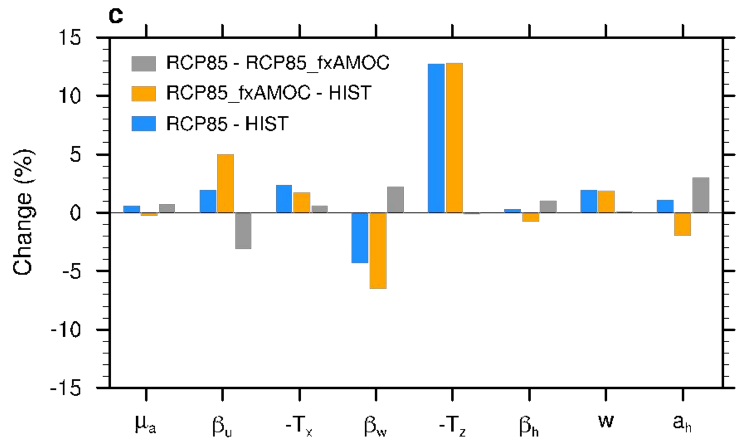
Bjerknes (BJ) stability index analysis

$$BJ = -\alpha_s - \alpha_{MA} + \mu_a\beta_u\langle -\overline{T}_x\rangle + \mu_a\beta_w\langle -\overline{T}_z\rangle + \mu_a\beta_h\left\langle \frac{\overline{w}}{H_1}\right\rangle a_h$$

TD MA ZA EK TH

- TD: thermodynamic damping; MA: mean advection feedback; ZA: zonal advection feedback; EK: Ekman upwelling feedback; TH: thermocline feedback
- If the AMOC stayed constant after the 1980s, the total BJ index would increase, which is consistent with the strengthening of ENSO variability from the RCP85_fxAMOC to RCP85 simulation.
- This relative increase in the BJ index is mainly caused by stronger positive Ekman upwelling feedback, which results from enhanced atmospheric wind stress response to SST anomalies (μ_a) and enhanced oceanic upwelling response to equatorial wind stress anomalies (β_w).



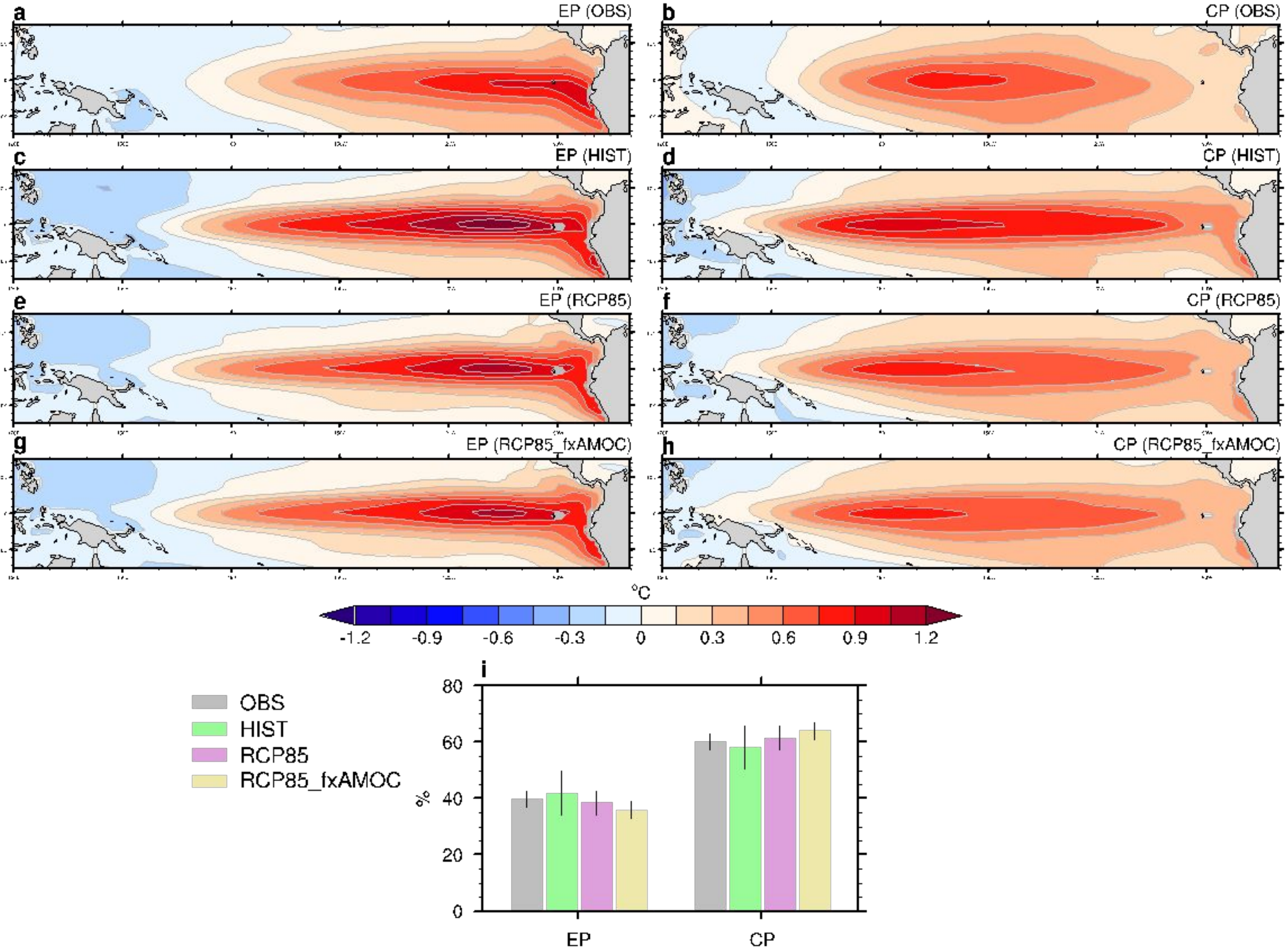


Conclusion

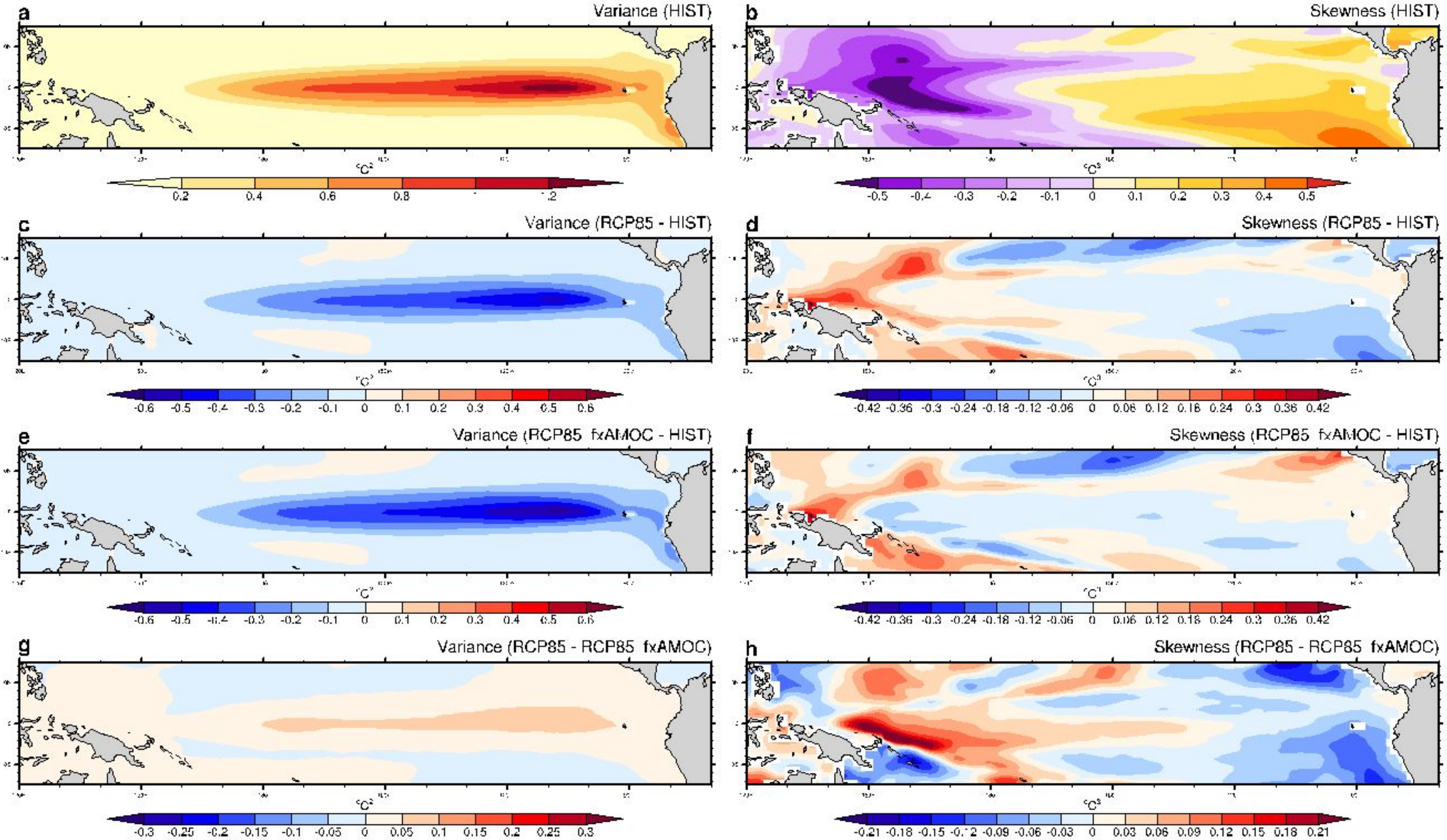
- We quantify the impacts of the AMOC on the ENSO under anthropogenic warming by comparing climate change model simulations with declining and fixed strengths of the overturning. After the 1980s, a weakened AMOC is shown to reduce the strength of SST annual cycle in the eastern equatorial Pacific and induce anomalous cross-equatorial northerly winds there, which strengthens ENSO variability by about 11%.
- Our analysis of the Bjerknes stability index reveals that this intensification of ENSO results mainly from enhanced Ekman upwelling feedback due to amplified atmospheric wind response to SST anomalies and oceanic upwelling response to equatorial wind stress anomalies.
- We also find that the weakened AMOC also promotes the occurrence of Central Pacific El Niño events and reduces ENSO skewness. These AMOC impacts on ENSO magnitude and complexity throughout the twenty-first century are however smaller than ENSO variations expected from internal climate variability.

Thank you!

Liu, W., Duarte Cavalcante Pinto, D., Fedorov, A., & Zhu, J. (2023).
The impacts of a weakened Atlantic Meridional Overturning Circulation on ENSO in a warmer climate.
Geophysical Research Letters, *50*, e2023GL103025. https://doi.org/10.1029/2023GL103025



a
EP (OBS)
b
CP (OBS)
c
EP (HIST)
d
CP (HIST)
e
EP (RCP85)
f
CP (RCP85)
g
EP (RCP85_fxAMOC)
h
CP (RCP85_fxAMOC)
°C
-1.2
-0.9
-0.6
-0.3
0
0.3
0.6
0.9
1.2
i
OBS
HIST
RCP85
RCP85_fxAMOC
%
80
60
40
20
0
EP
CP



a
Variance (HIST)
°C²
0.2 0.4 0.6 0.8 1 1.2
b
Skewness (HIST)
°C³
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5
c
Variance (RCP85 - HIST)
°C²
-0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6
d
Skewness (RCP85 - HIST)
°C³
-0.42 -0.36 -0.3 -0.24 -0.18 -0.12 -0.06 0 0.06 0.12 0.18 0.24 0.3 0.36 0.42
e
Variance (RCP85 fxAMOC - HIST)
°C²
-0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6
f
Skewness (RCP85 fxAMOC - HIST)
°C³
-0.42 -0.36 -0.3 -0.24 -0.18 -0.12 -0.06 0 0.06 0.12 0.18 0.24 0.3 0.36 0.42
g
Variance (RCP85 - RCP85 fxAMOC)
°C²
-0.3 -0.25 -0.2 -0.15 -0.1 -0.05 0 0.05 0.1 0.15 0.2 0.25 0.3
h
Skewness (RCP85 - RCP85 fxAMOC)
°C³
-0.21 -0.18 -0.15 -0.12 -0.09 -0.06 -0.03 0 0.03 0.06 0.09 0.12 0.15 0.18 0.21