The Role of Atlantic Meridional Overturning Circulation Stability in Shaping Arctic Amplification

Reed Fitzpatrick[1], Wei Liu[1]

[1]Department of Earth & Planetary Sciences, University of California, Riverside

rfitz010@ucr.edu

Background

Arctic amplification is defined by **accelerated warming in the Arctic relative to the rest of the globe** and is driven by several factors, many of which are related to AMOC stability. While **models project a moderate but stable AMOC slowdown, observational freshwater budget analysis suggests increasing instability since the early 20th century**, raising the risk of abrupt shifts. This study aims to investigate the role of AMOC stability under increased greenhouse gas radiative forcing in shaping Arctic amplification, particularly when accounting for model biases.

Methodology

Adjusting for Model Bias

To test model bias, we use the output from two parallel experiments based on NCAR CCSM3. The first version representing the **control run** (CTL) **was adopted from a 200-year simulation of a 1990 scenario**. While the second version corresponds to the CTL but is a **bias-adjusted run** (ADJ) **via surface flux corrections of temperature and salinity toward observations** using a seasonal cycle of expected heat and freshwater fluxes. These added artificial heat and freshwater fluxes **eliminate most temperature and salinity biases at the surface**, which potentially improves the formation of the NADW and the simulation of the AMV.

After running each of these simulations**, two parallel double CO_2 experiments** were conducted ($CTLCO_2$ and $ADJCO_2$). In model year 201, the atmospheric CO_2 concentration is **doubled instantaneously from the 1990 level and left fixed**. In this experiment, the meltwater discharge from the Greenland ice sheet is not included to simulate the behavior of the AMOC entirely under radiative forcing due to the increase in CO_2.

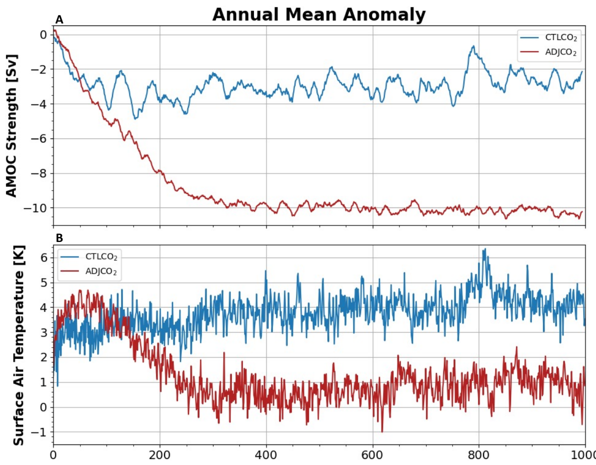

Fig 1 | Annual mean of AMOC strength (**A**) and Arctic (60° N - 90° N) surface air temperature (**B**) anomalies of $CTLCO_2$ - CTL (blue) and $ADJCO_2$ - ADJ (red).

Results

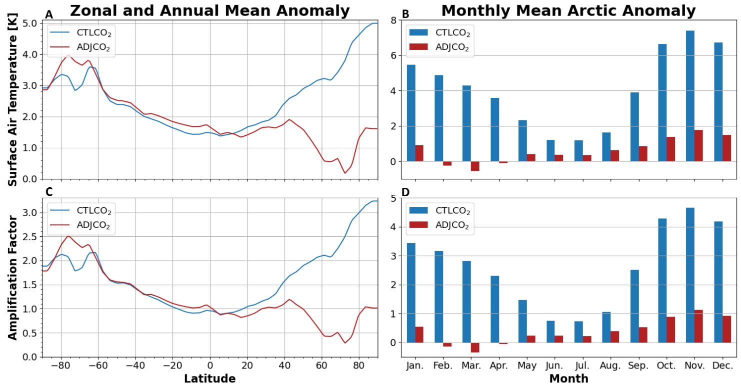

Fig 2 | Zonal and annual mean (left) and Arctic-averaged (60° N - 90° N) monthly mean (right) of surface air temperature (**A**, **B**) and amplification factor (**C**, **D**) anomalies for $CTLCO_2$ - CTL (blue) and $ADJCO_2$ - ADJ (red). The amplification factor is defined as the ratio of temperature changes between each latitude and the tropics (30° S - 30° N).

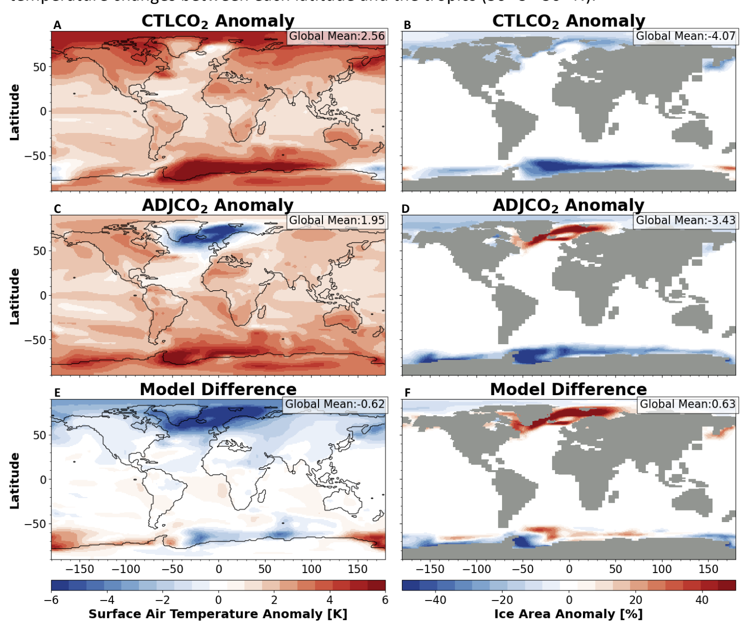

Fig 3 | Annual mean of surface air temperature (**A**, **C**, **E**) and ice area (**B**, **D**, **F**) anomalies where (**A**, **B**) is $CTLCO_2$ - CTL, (**C**, **D**) is $ADJCO_2$ - ADJ and (**E**, **F**) is the model difference between the $ADJCO_2$ and $CTLCO_2$ anomalies.

Conclusion

Impact of Model Bias

- When **correcting for model bias** ($ADJCO_2$), the **AMOC** is shown to **collapse**, whereas the **uncorrected model** ($CTLCO_2$) shows only an **AMOC weakening**
- **AMOC collapse** reduces the northward transport of heat, **slowing Arctic warming by approximately 3 K**.
- This is accompanied by a **more pronounced North Atlantic warming hole** and an **increase in Arctic sea ice area**, not observed in AMOC weakening.

Implications

- A **collapsed AMOC** is reflective of a **cooler Northern Hemisphere** and a **warmer Southern Hemisphere**.
- This temperature imbalance induced by an AMOC collapse **reduces Arctic Amplification** even though global temperatures continue to increase.
- These factors are closely **tied to seasonal timescales**, with their influence on **Arctic amplification varying throughout the year**, especially in an AMOC collapse.

Next Steps

- Further investigate how **rising emissions** could **trigger** an **AMOC collapse** and **affect the ocean-atmosphere energy balance** and **climate sensitivity**.
- The flux-adjusted experiments explore possible AMOC responses rather than a definitive solution which **highlights the need for physically improved models**.
- Compare results with similar CMIP6 experiments to **identify potential intermodel biases**.

References

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