The Role of a Weakened AMOC in the Future Arctic Amplification

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Motivation & Background

Arctic amplification, notable for its intensified surface warming compared to the global average, has been a focal point in climate studies. Multiple factors, such as surface albedo feedback, Planck feedback, lapse-rate feedback, and atmosphere/ocean energy transports, contribute to this phenomenon. Of particular interest is the **Atlantic Meridional Overturning Circulation (AMOC)** and its intricate link to Arctic warming. Observations indicate a slowdown in the AMOC, while enhanced northern high-latitude ocean heat transport (OHT) into the Arctic has been noted. Understanding the AMOC's role in Arctic amplification remains pivotal.

Method

We aim to isolate and quantify the impact of a weakened AMOC on Arctic amplification using the fully coupled CCSM4 model under anthropogenic warming by the end of the 21st century.

RCP8.5 & freshwater removed from north of 50°N in the North Atlantic and the Labrador and Greenland, Iceland, and Norwegian Seas. (**Liu et al., 2020;** scan the QR code for more details on experiments)

Results

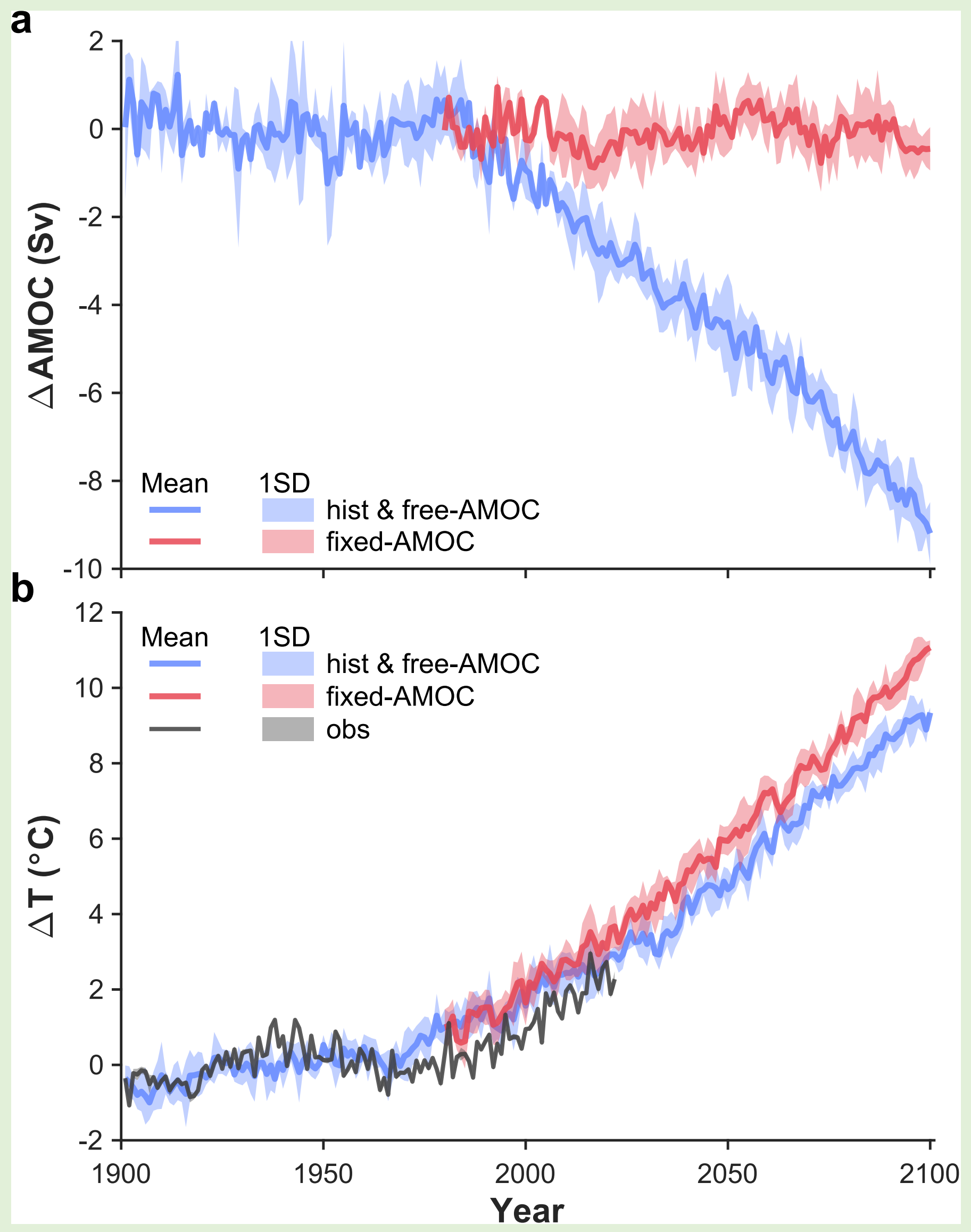

Figure 1: Changes in Annual mean AMOC strength and Arctic surface temperature anomalies with respect to the average over 1901-1980.

Warming trend between 1981-2100

- free-AMOC: 0.74°C decade^{-1}
- fixed-AMOC: 0.86°C decade^{-1}

Pronounced warming divergence post-2030s warming peaks in last two decades of the century (**Fig 1**).

Free vs. fixed-AMOC simulations comparison reveals ~2°C Arctic cooling during 2081-2100 and notably ~5°C cooling in North Atlantic near Greenland (**Fig 2**).

Weakened AMOC slows Arctic warming by 1.41°C, lowers Arctic amplification factor by 0.36, notably in DJF and MAM.

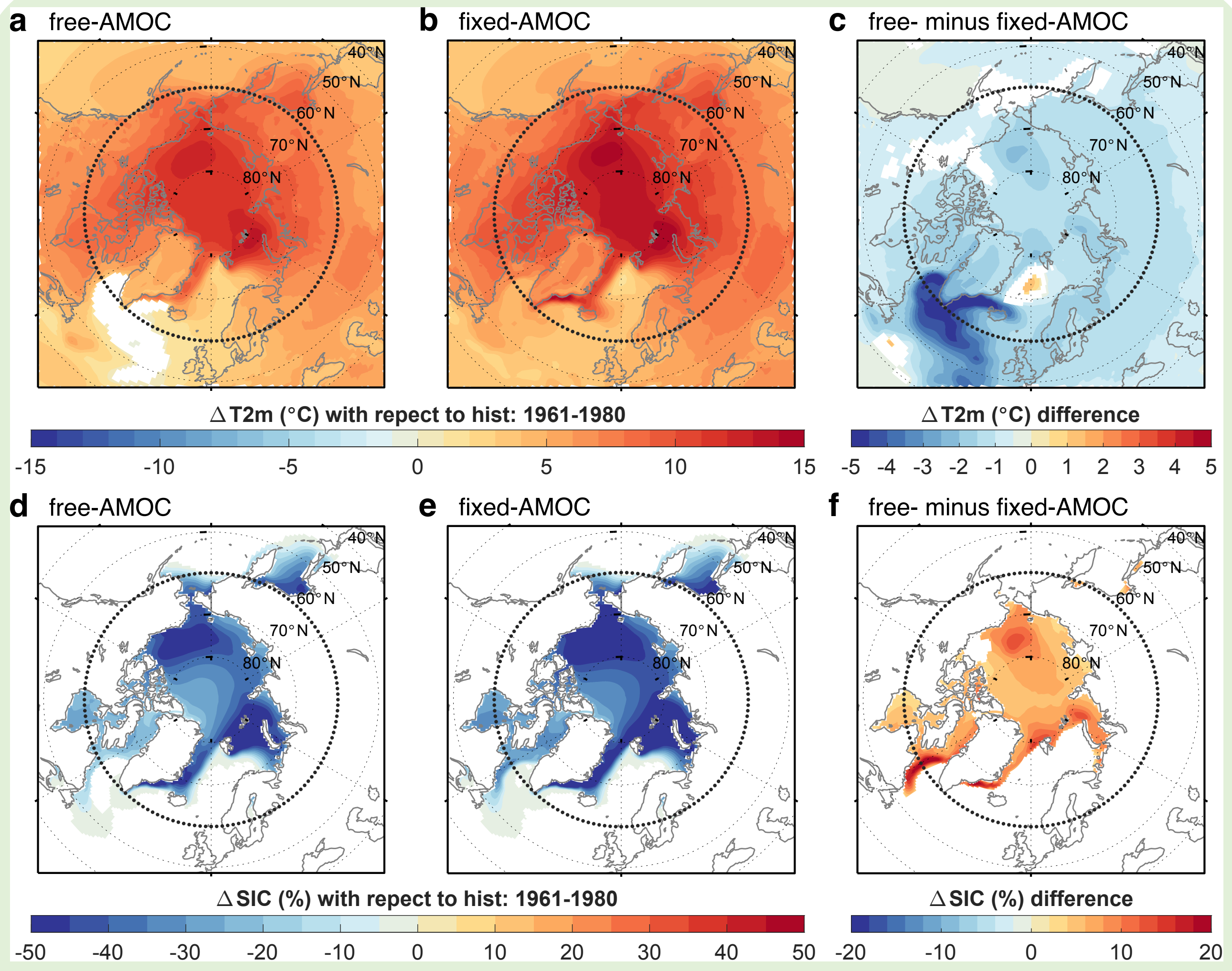

Figure 2: Projected changes in Arctic surface temperature and sea ice concentration, and the AMOC impact. (a-c) Annual mean surface temperature anomalies (relative to the average over 1961-1980) between 2081 and 2100. (d-f) Same as (a-c), but for sea ice concentration.

Partial Temperature Contribution

(2081-2100 compared to 1961-1980)

$$\Delta T_s = -\frac{\lambda'_{plk}\Delta\overline{T_s}}{\lambda_{plk}} - \frac{\sum_i \lambda_i \Delta\overline{T_s}}{\lambda_{plk}} - \frac{\Delta AET}{\lambda_{plk}} - \frac{\Delta OHU}{\lambda_{plk}} - \frac{\Delta R_{rd}}{\lambda_{plk}}$$

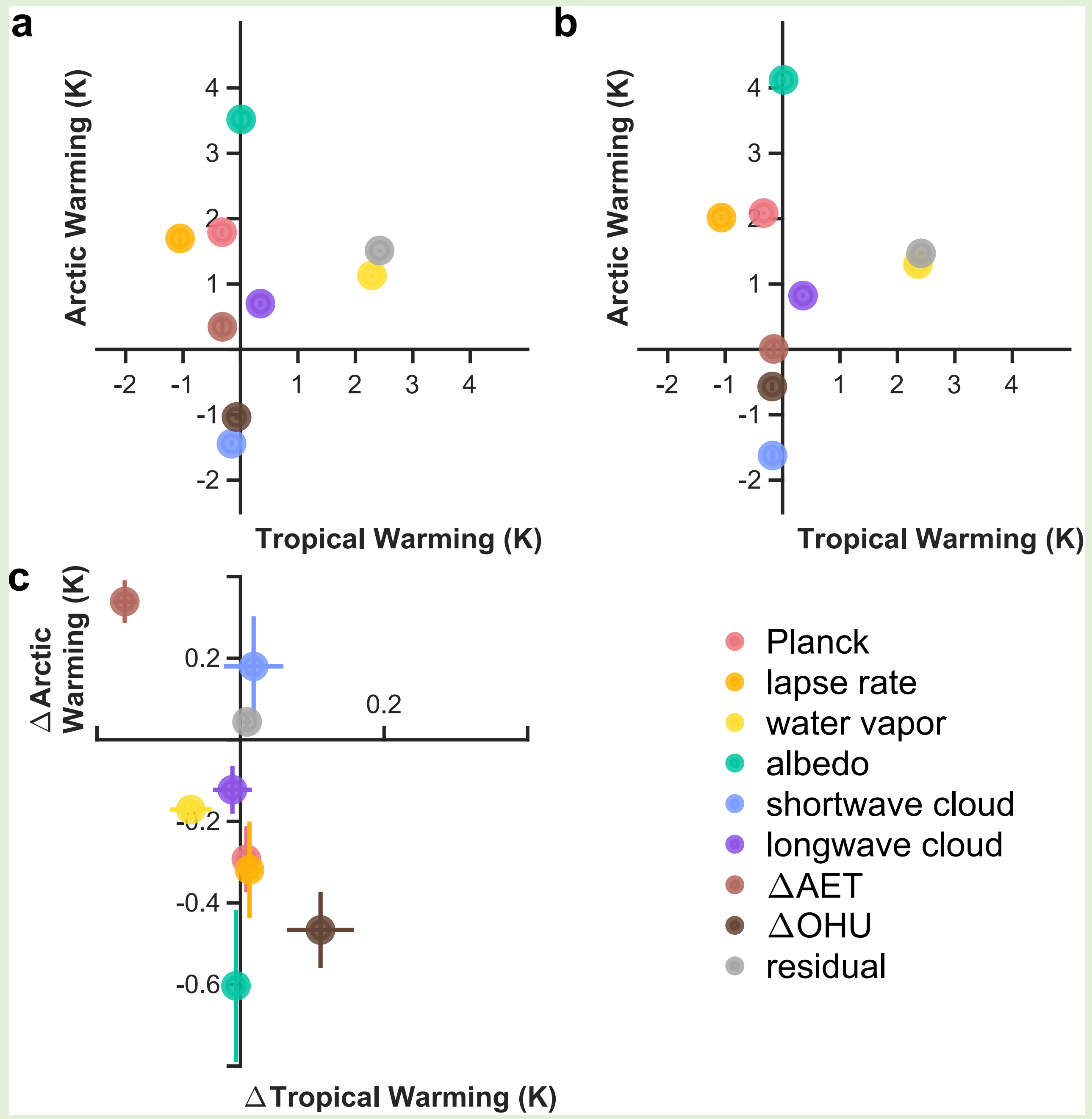

Figure 3: Contributions of radiative feedback, atmospheric energy transport (AET), and ocean heat uptake (OHU) to Arctic amplification, and the AMOC impact. Partial surface temperature changes for the Arctic (60°N-90°N) compared to the tropics (30°S-30°N) during 2081-2100 compared to 1961-1980

Weakened AMOC could lessen the Arctic warming during 2081-2100 via

Surface albedo feedback:
~43% (-0.60 K)
Ocean heat uptake:
~33% (-0.47 K)
Planck & lapse-rate feedback:
~43% (-0.61 K)
Water vapor feedback:
~12% (-0.17 K)

And slightly enhance the Arctic warming via

Cloud feedback:
~4% (0.06 K);
which is mostly contributed from the shortwave cloud feedback (13%; 0.18 K)
Atmospheric energy transport:
~23% (0.34 K)

Ocean heat budget

AMOC slowdown

- → OHT divergence
- → Whole-depth water cooling (**Fig 5a**)
- → Promote ocean heat uptake (**Fig 5b**)
- → Diminished heat storage (**Fig 5c**) and lessened sea ice loss (**Fig 2f**)
- → Outweighs convergence of atmospheric energy transport (**Fig 3c & Fig 5f**)

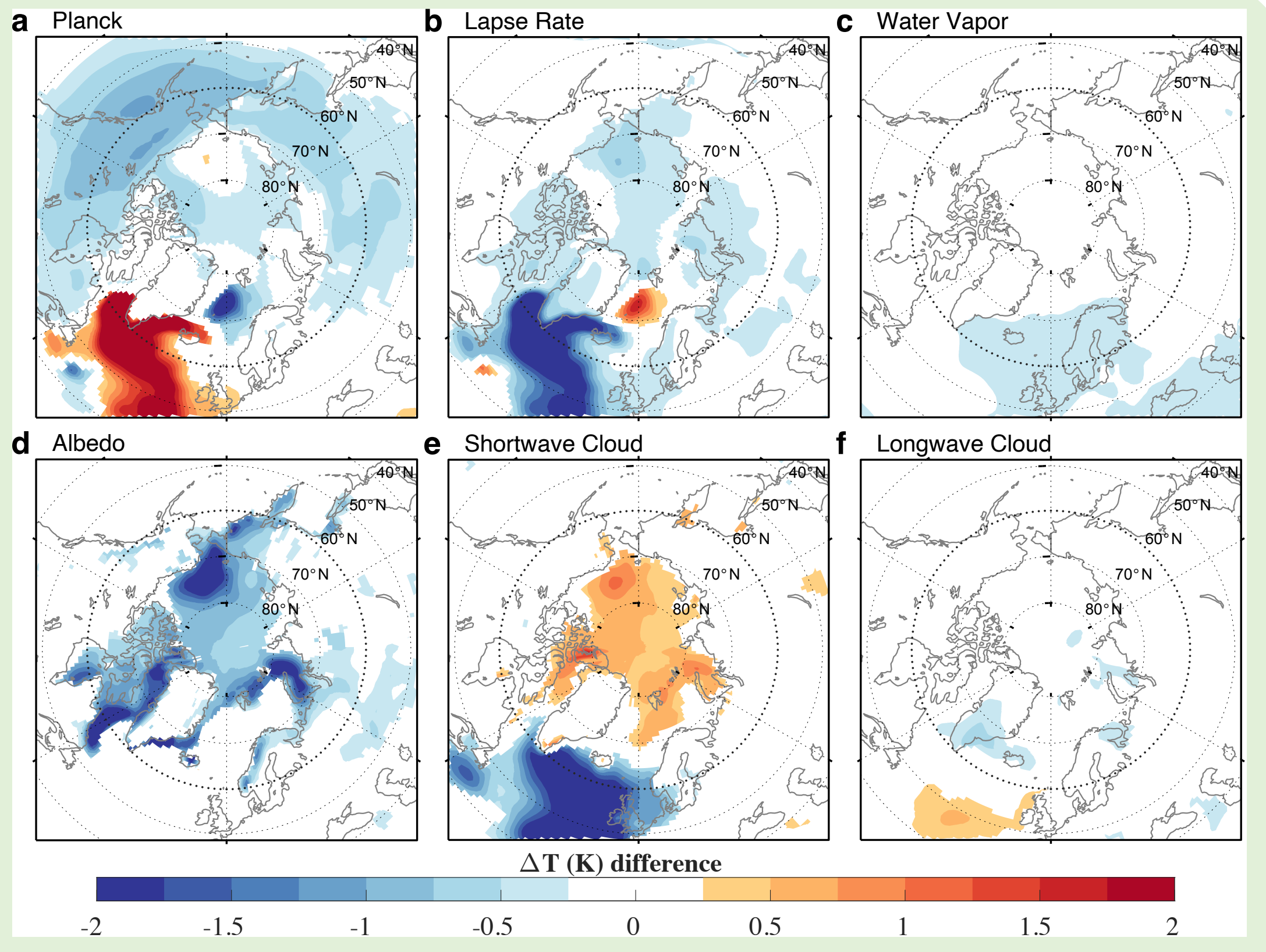

Figure 4: AMOC impacts on partial temperature contributions from radiative feedback. (a-f) Annual and ensemble mean partial temperature contribution differences between the free- and fixed-AMOC simulations (free minus fixed, color shading in K)

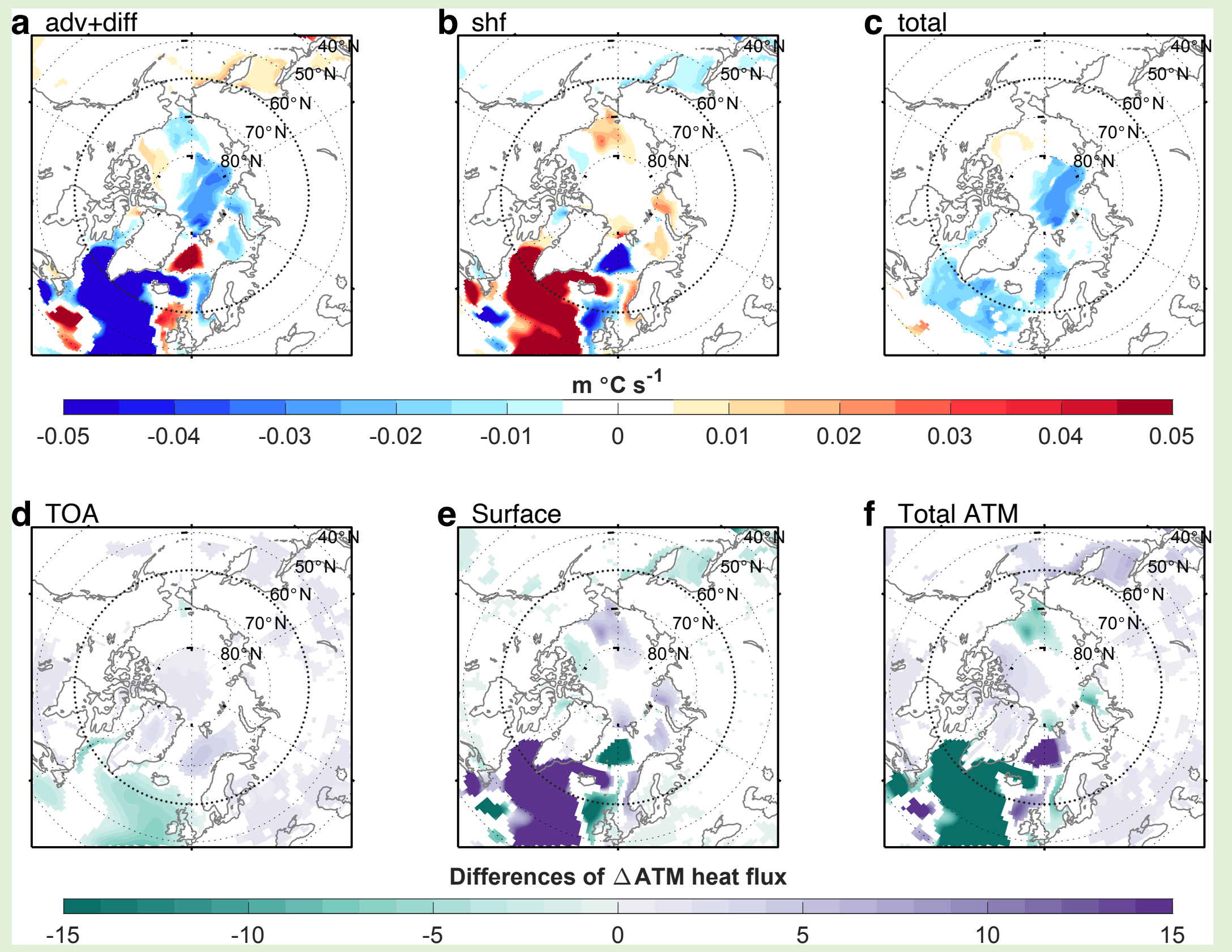

Figure 5: AMOC impacts on annual mean ocean temperature tendencies and atmospheric energy transport convergence. (a-c) Annual and ensemble mean ocean temperature tendency differences (free minus fixed) during 2081-2100 (d-f) Annual and ensemble mean differences for (d) TOA and (e) surface energy fluxes, and (f) whole-column atmospheric energy transport convergence (d minus e)

Summary

Comparing CCSM4 free- and fixed-AMOC simulations under RCP8.5, we find weakened AMOC reduces Arctic surface warming. By the end of 21st century, pronounced cooling (~5°C) occurs in the Atlantic sector, linked to reduced Arctic sea ice loss and surface albedo feedback (~43%). AMOC-driven ocean heat uptake and temperature feedback also contribute to surface cooling.

Acknowledgement

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