Stronger Arctic Amplification Produced by Decreasing, not increasing, CO_2 Concentrations

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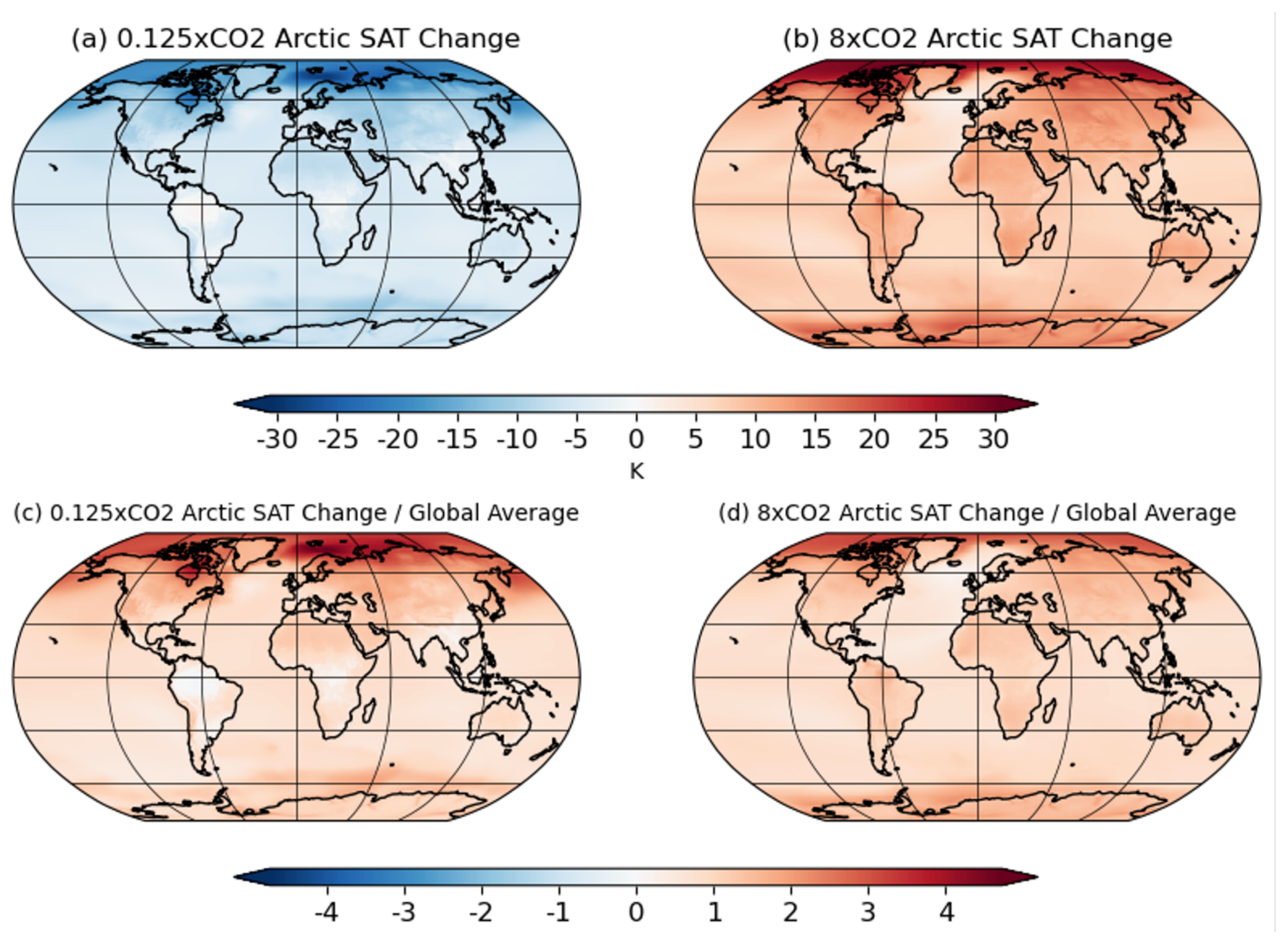
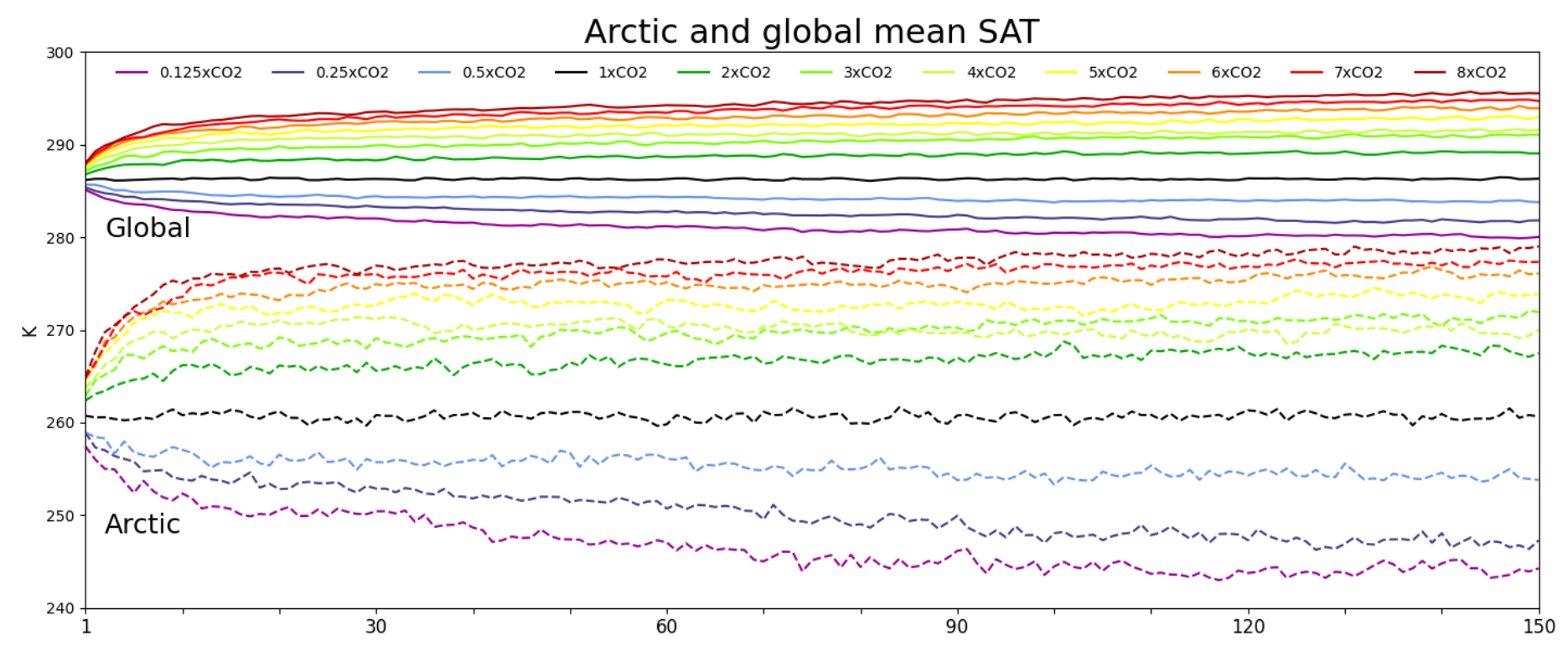
A. Arctic amplification (AA) in cooling & warming scenarios





Arctic amplification (AA), referring to the phenomenon of amplified warming or cooling in the Arctic compared to the warming or cooling in the rest of the globe, occurs in abrupt increasing or decreasing CO_2 fully coupled ocean-atmosphere-sea-ice-land model experiments.

FIGURE 1. Global mean surface air temperature (SAT) changes to 1/8 (a) and 8 (b) times the concentrations of pre-industrial atmospheric CO_2 level. (c) and (d) are the corresponding factors dividing by global mean SATs.

FIGURE 2. Global and Arctic (60°N–90°N) mean surface air temperature (SAT)

B. AA factor & energy budget analysis

1. Identity Arctic amplification with a non-dimensional Arctic amplification factor (AAF):

$$AAF = \frac{\Delta SAT_{Arctic}}{\Delta SAT_{global}}$$

2. Consider the energy budget equation for the atmospheric column:

$$\Delta R + \Delta F - \Delta H_o = 0$$

3. Decompose the response of net downward radiation at the top of the atmosphere (TOA) into radiative feedbacks, using differences between the $nxCO_2$ run and the $1xCO_2$ run:

$$\Delta R = \Delta R_F + \Delta R_{PL} + \Delta R_{LR} + \Delta R_{AL} + \Delta R_{WV} + \Delta R_{CL}$$

$$\Delta T = -\frac{\Delta F}{\lambda_P} - \frac{\lambda_P' \Delta T}{\lambda_P} - \frac{\Sigma \lambda_i \Delta T}{\lambda_P} - \frac{\Delta AHT}{\lambda_P} - \frac{\Delta OHT}{\lambda_P} - \frac{\Delta H_o}{\lambda_P} - \frac{\Delta R_{res}}{\lambda_P}$$

C. AA is coupled to sea-ice and turbulent heat flux changes

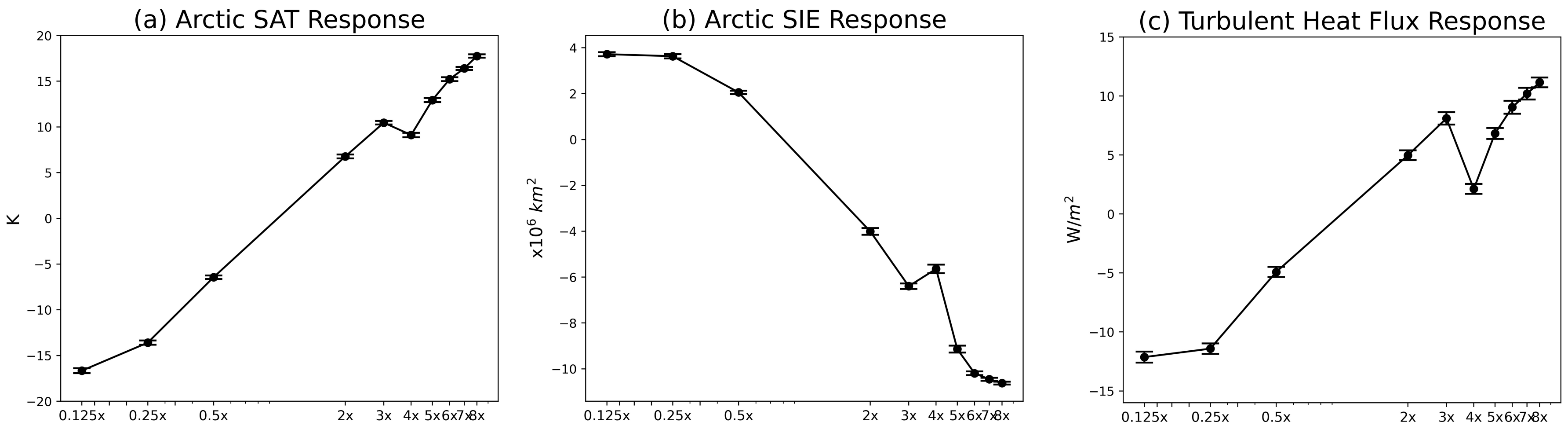
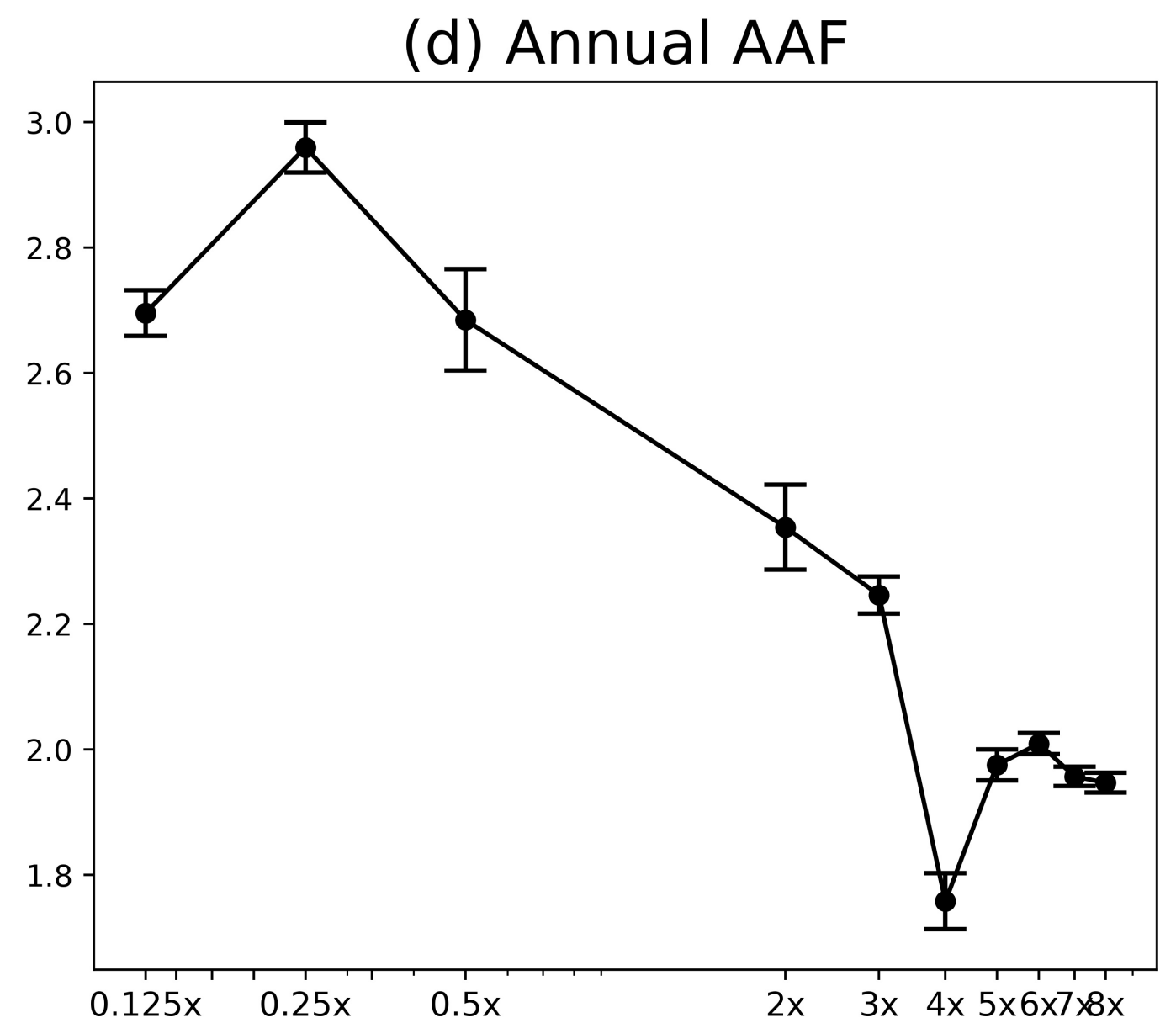


FIGURE 3. The response of the annual-mean (a) Arctic SAT, (b) Arctic sea-ice extent (SIE), and (c) turbulent heat flux, averaged over the last 30 years of the simulations. Error bars denote 95% confidence intervals calculated using Student's t-distribution.



- Annual SAT and turbulent heat flux are stronger as the CO_2 increase, while the weakening of the Atlantic meridional overturning circulation (AMOC) reduces heat transport into the Arctic in 4 x CO_2 experiment .

FIGURE 4. Annual-mean Arctic AAF defined as the ratio of the Arctic mean SAT response to the global mean SAT response, averaged over the last 30 years of the simulations. Error bars denote 95% confidence intervals calculated using Student's t-distribution.

F. Conclusions and Discussions

1. The main finding is that decreasing, rather than increasing, CO_2 concentrations produces stronger AA.
2. The sea-ice loss-turbulent heat fluxes-SAT feedback play an essential role in producing both cold and warm AAs.
3. The lapse-rate feedback plays a crucial role in cooling scenarios, whereas albedo feedback is the most important process in warming experiments.
4. Unlike the peaks of warm AA, which shift gradually from November to December or January as CO_2 increases, those of cold AA do not shift but are locked in the month of October. It is likely related to the climatological SIE minimum in September.
5. The lapse-rate feedback amplifies the AA seasonality response, but may not be the essential driver.

D. Feedback analysis: lapse-rate feedback in cooling scenario

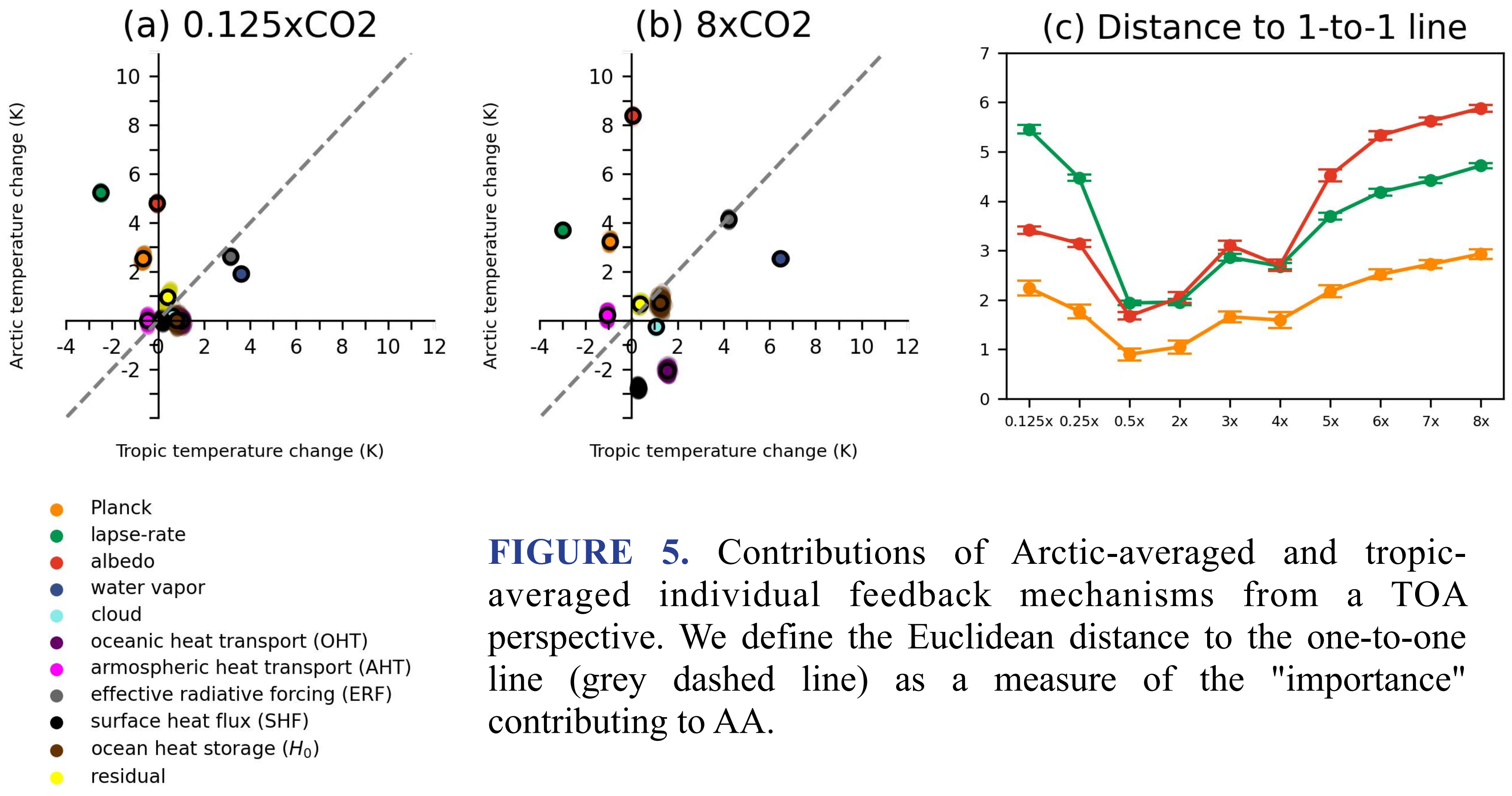


FIGURE 5. Contributions of Arctic-averaged and tropic-averaged individual feedback mechanisms from a TOA perspective. We define the Euclidean distance to the one-to-one line (grey dashed line) as a measure of the "importance" contributing to AA.

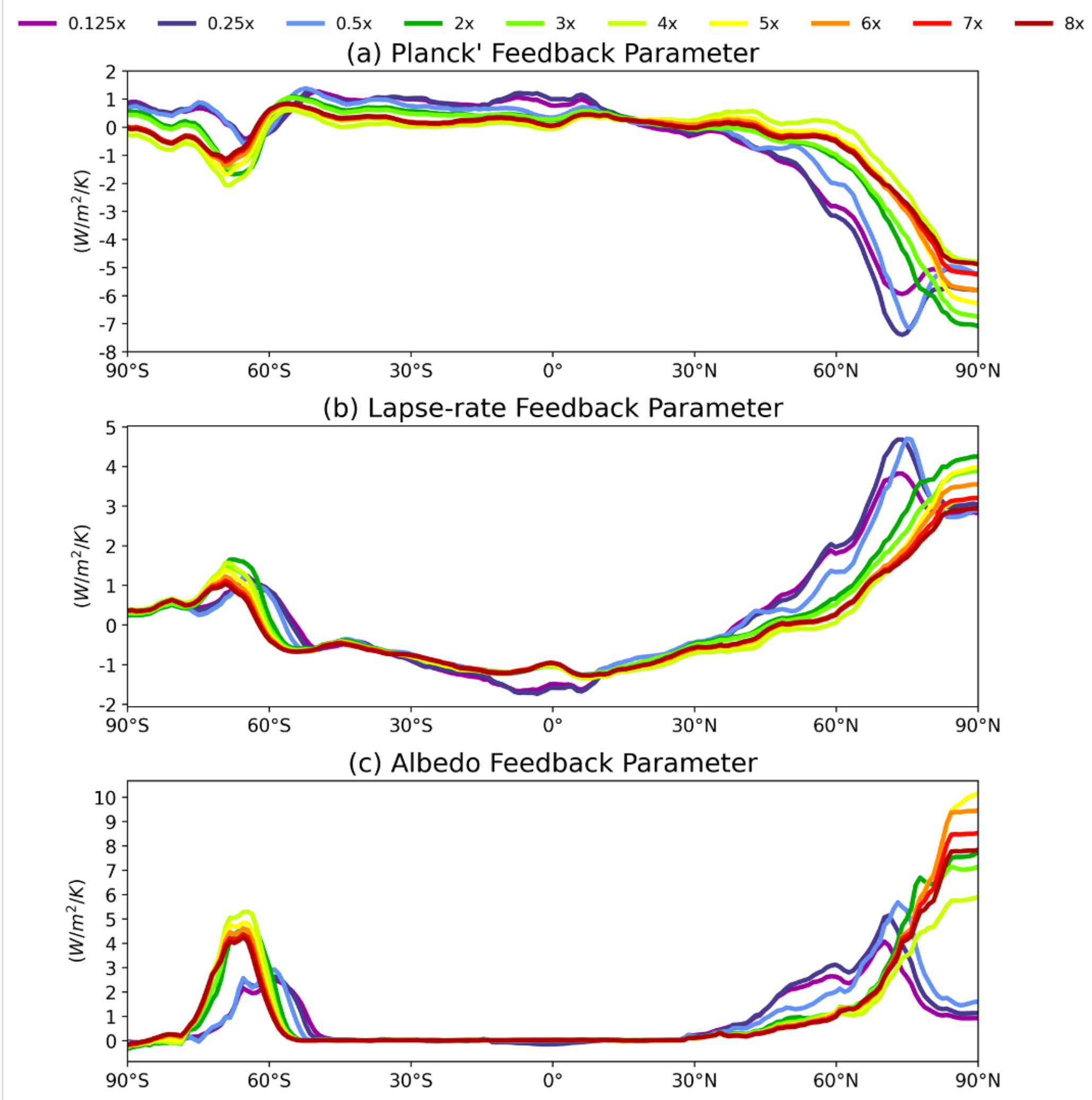


FIGURE 6. Latitudinal distributions of (a) Plank' feedback parameter, (b) lapse-rate feedback parameter, and (c) albedo feedback parameter.

- The lapse-rate feedback is the main process in generating AA in cooling scenarios, while the albedo feedback in the warming scenarios.
- Such asymmetric responses to warming and cooling CO_2 forcings by be related different spatial structures of these processes, as well as their sensitivity to CO_2 forcings.

E. Lapse-rate feedback explains most seasonality migration

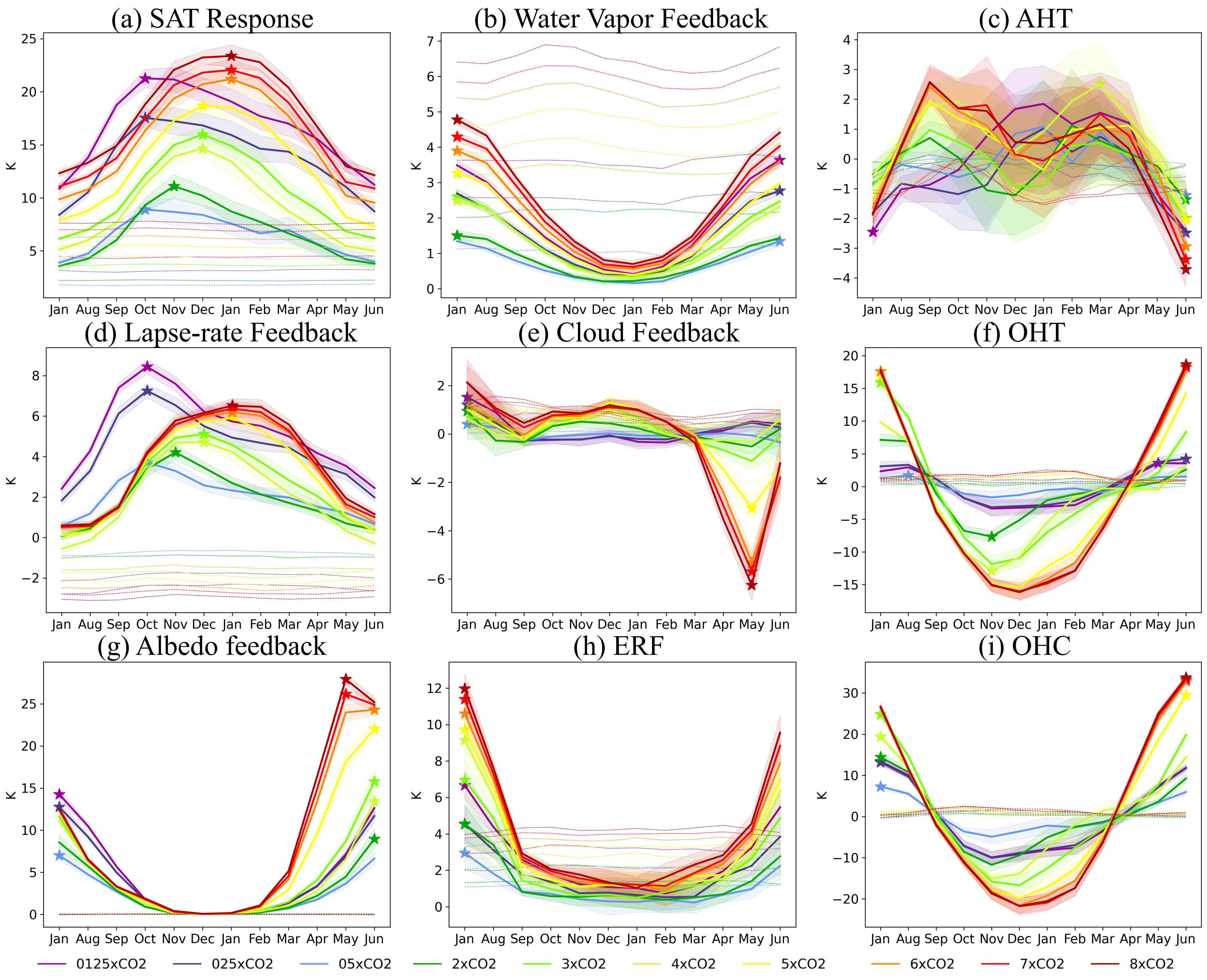


FIGURE 7. Arctic-averaged (solid line) and global-averaged (dashed line) seasonal evolution of (a) SAT response, (b) water vapor feedback, (c) AHT, (d) lapse-rate feedback, (e) cloud feedback, (f) OHT, (g) albedo feedback, (h) ERF, and (i) OHC.

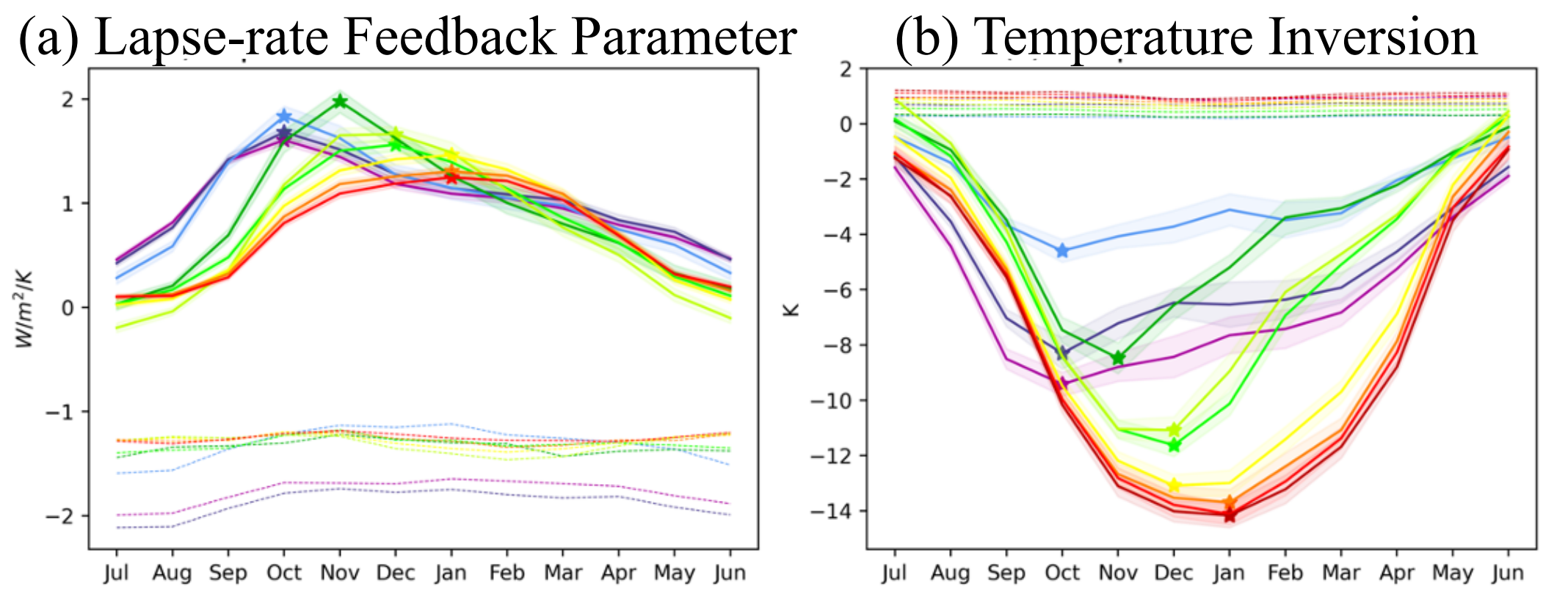


FIGURE 8. Arctic-averaged (solid line) and global-averaged (dashed line) seasonal evolution of (a) lapse-rate feedback parameter and (b) temperature inversion, defined as the difference between the air temperature at 850 hPa and 1000 hPa.

- Only the lapse-rate feedback shows consistent seasonality responses as those of the Arctic SAT and AAF.
- In cooling scenarios, a more pronounced temperature difference exists between the lower and upper troposphere.
- Stronger Planck feedback presents different latitudinal distribution in high-latitudes in the cooling and warming scenarios.

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