Using a Green's Function Approach to Diagnose the Pattern Effect in GFDL AM4 and CM4

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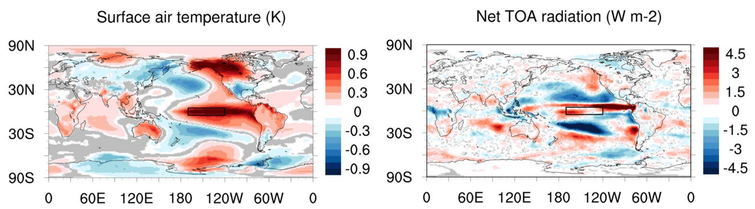
Introduction

Radiation is sensitive to the geographic patterns of surface temperature changes, which is referred to as the "pattern effect" (Stevens et al. 2016).

Difference in surface warming -> changes in atmospheric circulation-> changes in convection/clouds -> changes in radiation.



Maps of surface air temperature (left) and net TOA radiation (right) retrieved from the Amip-piForcing run regressed against the Niño 3.4 index.

The Green's function approach

To better understand the pattern effect, previous studies applied the Green's function (GF) approach to atmosphere-only simulations forced by patches of anomalous SSTs (e.g., Zhou et al. 2017, Dong et al. 2019).

The change of a variable X (e.g., net TOA radiation, surface air temperature, and so on) at a grid point i in response to perturbations in SST is computed as

$$\Delta X_i = \sum_{j=1}^{n} \frac{\partial X_i}{\partial SST_j} \Delta SST_j + \epsilon_X$$

$$\mathcal{J}_X = \begin{bmatrix} \frac{\partial X_1}{\partial SST_1} & \cdots & \frac{\partial X_1}{\partial SST_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial X_n}{\partial SST_1} & \cdots & \frac{\partial X_n}{\partial SST_n} \end{bmatrix}$$

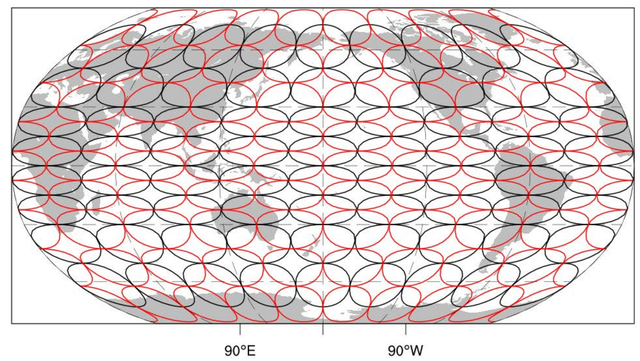
For the change at grid point $i = 1$:

$$\Delta X_1 = \begin{bmatrix} \frac{\partial X_1}{\partial SST_1} & \cdots & \frac{\partial X_1}{\partial SST_n} \end{bmatrix} \begin{bmatrix} \Delta SST_1 \\ \vdots \\ \Delta SST_n \end{bmatrix}$$

SST pattern

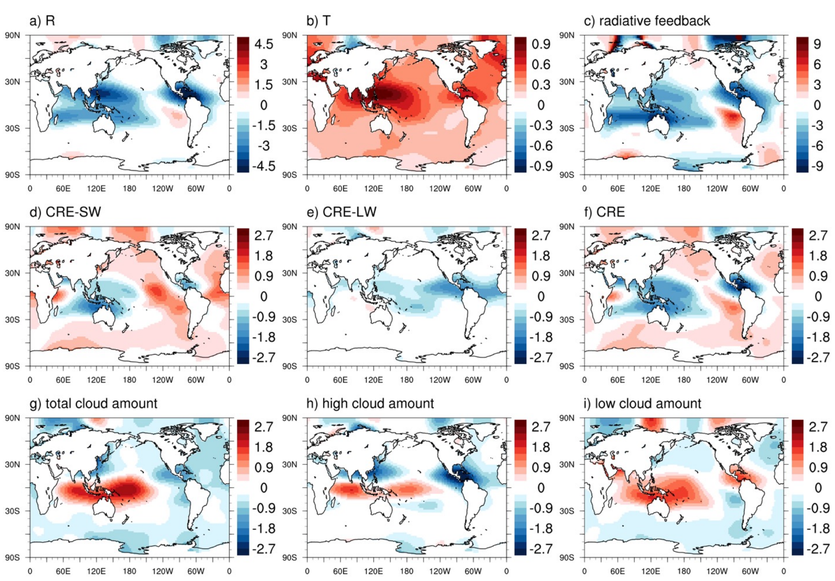
Experiment

The Geophysical Fluid Dynamics Laboratory (GFDL) AM4 model (Zhao et al. 2018a, 2018b) is used to conduct perturbation experiments forced by patches of anomalous SST.

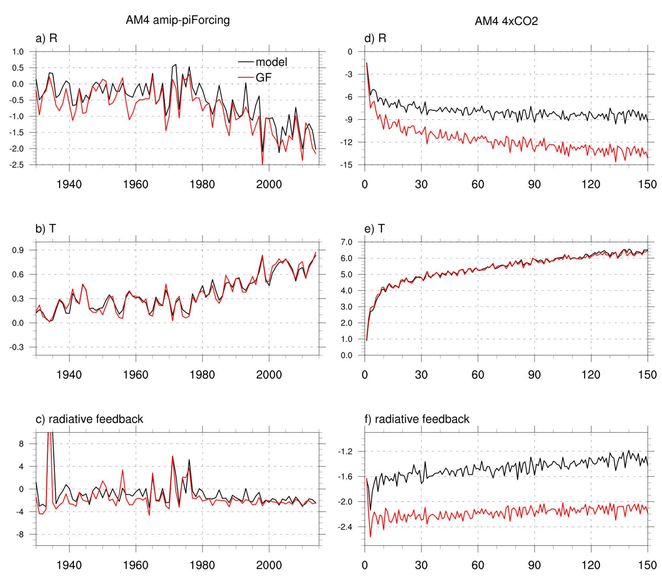


Geographic locations of SST patches used in this study. Contours show half-amplitude of the patches (e.g., contours are +2.0K when the parameter A is set as +4.0K).

Global-mean results



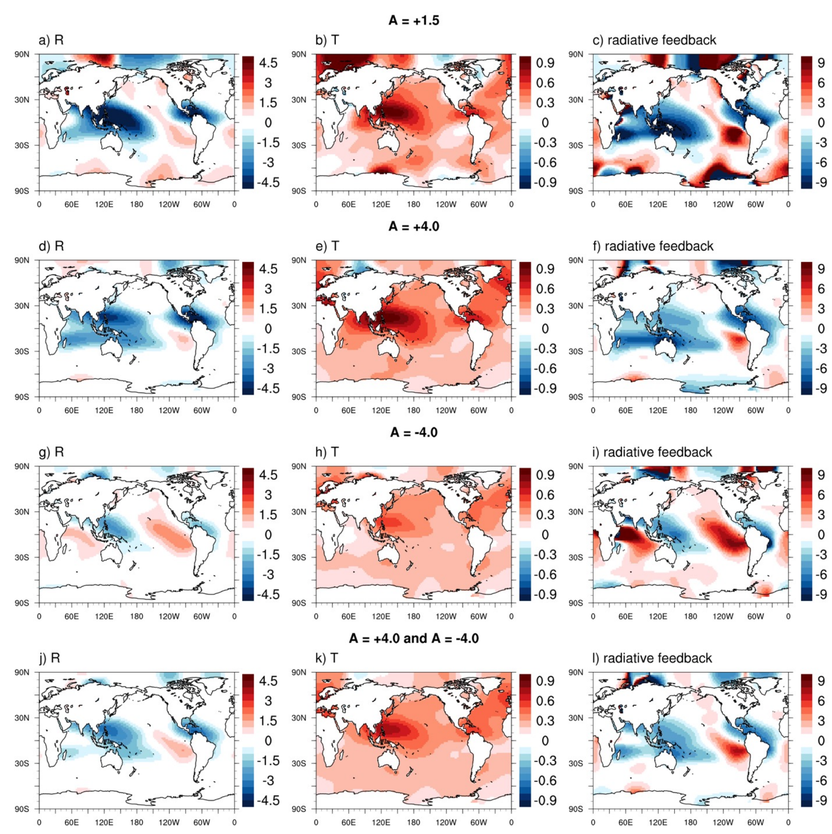
Maps of global-annual-mean changes in response to 1-degree local SST warming at each ocean grid point (values are normalized by actual physical area of each grid box). Note that the unit for (a), (d), (e) and (f) is $\times 10^{-8}$ W m^{-2} per unit local SST warming per square km, for (b) is $\times 10^{-8}$ K per unit local SST warming per square km, for (c) is W m^{-2} per 1 degree Kelvin global-mean surface air temperature warming (actual physical area has been canceled out), for (g)-(i) is $\times 10^{-8}$ percent per unit local SST warming per square km.



The global-annual-mean response for net TOA radiation (a, d), surface air temperature (b, e), and radiative feedback (c, f) retrieved from the AM4 Amip-piForcing run (a-c) and the AM4 4xCO2 run. The black lines are model outputs while the red lines are values reconstructed by the GF.

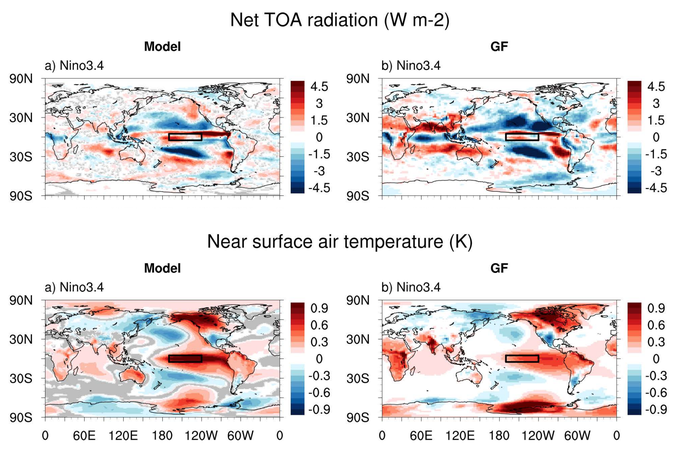
- **The GF overestimates the magnitude of radiative cooling and radiative feedback for the AM4 4xCO2 simulations.**

Sensitivity to the amplitude and sign of the SST perturbation



- **Nonlinearity does exist in AM4.**

Regional responses



Considering SST patterns associated with the ENSO:

- **Overall, the GF can reproduce the model-simulated regional responses.**
- **Surface air temperature is better reproduced by the GF, compared to net TOA radiation.**
- **Noticeable biases are found over land.**

Conclusion

- **For the Amip-piForcing run, the GF can reproduce model-simulated responses at both global and regional scales.**
- **The derived GF is sensitive to the amplitude and sign of the SST perturbation.**
- **More research is required to understand the discrepancy between model-simulated responses and the GF reconstructed ones, especially for atmosphere-only simulations forced by relatively uniform warming patterns.**

Reference

- Dong, Y., Proistosescu, C., Armour, K. C., & Battisti, D. S. (2019). Attributing historical and future evolution of radiative feedbacks to regional warming patterns using a Green's function approach: The preeminence of the western Pacific. *Journal of Climate.*
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- Zhou, C., Zelinka, M. D., & Klein, S. A. (2017). Analyzing the dependence of global cloud feedback on the spatial pattern of sea surface temperature change with a Green's function approach. *JAMES.*