Abstract

It is well known that climate sensitivity, defined as the global mean surface temperature change per unit radiative forcing, depends on the forcing agents (such as CO2, CH4, O3, aerosols, solar radiation, land cover change, etc.) to some extent. Previous studies have shown that agents producing larger forcing in high latitudes cause larger climate change compared to forcing agents that cause larger forcing in low latitudes. This thesis investigates the causes for this dependence of climate sensitivity on the meridional patterns of radiative forcing using a linear forcing-feedback framework. In this framework, we decompose the total feedback parameter as a sum of albedo, Planck, lapse rate, water vapor, and cloud feedbacks, and quantify the role of each of these feedbacks using the radiative kernel technique. We further provide process based mechanistic explanations for how these feedbacks enhance the climate response when forcing is imposed in high latitudes. For this work, we use the NCAR Community Atmospheric Model version 4 (CAM4) for performing several climate change simulations that are driven by idealized meridional distributions of radiative forcing.

The first part of the thesis shows that global mean surface warming caused by an increase in solar irradiance, which exhibits larger forcing in tropical regions than the high latitudes, is smaller than that caused by an increase in CO2, which induces a more uniformly distributed radiative forcing around the globe. The resulting difference in warming is primarily due to differences in lapse rate, water vapor, and cloud feedbacks, which together account for 65% of the difference in total feedback parameters between the two forcing agents. These findings are confirmed in the second part of this thesis by examining climate responses to three stylized simulations where solar radiative forcing is imposed in three different latitude belts (tropical, Antarctic, and Arctic). The third part examines climate response to interhemispheric differences in radiative forcing by increasing the solar constant separately in the northern and southern hemispheres. We find that radiative forcing in the southern hemisphere results in larger climate sensitivity due to larger shortwave cloud feedbacks. We investigated the impacts of these interhemispheric differences in radiative forcing on the tropical circulation, atmospheric heat transport, planetary albedo, and land/sea warming contrast.

Overall, this thesis enhances our understanding of climate feedbacks and their dependence on the meridional structures of radiative forcing, providing deeper insights into the physical science aspects of global climate change and the effects of potential solar radiation modification approaches.

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Journal Publications:

Harpreet Kaur, G. Bala and Ashwin Seshadri, 2023: Why is Climate Sensitivity for Solar Forcing Smaller than for an Equivalent CO2 Forcing? Journal of Climate, https://doi.org/10.1175/JCLI-D-21-0980.1

Harpreet Kaur, G. Bala and Ashwin Seshadri, 2024: Climate response to interhemispheric differences in radiative forcing governed by shortwave cloud feedbacks, Environmental Research: Climate, https://iopscience.iop.org/article/10.1088/2752-5295/ad8df6

Harpreet Kaur, G. Bala and Ashwin Seshadri, 2025: Why is climate sensitivity larger for radiative forcing imposed in polar latitudes than forcing imposed in tropical latitudes? Climate Dynamics (under revision)