The Impact of SST Biases on Projections of Anthropogenic Climate Change: A Greater Role for Atmosphere-only Models?

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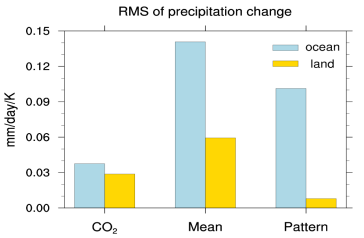
1. Introduction

CGCMs are traditionally chosen over AGCMs for projections of anthropogenic climate change, despite AGCMs' superior computational efficiency. This choice assumes that the incorporation of the ocean model improves the simulation by allowing for the dynamic prediction of SST. However, coupling often results in large systematic biases in SSTs, which also impacts the projected changes. Here, we show that an accurate SST climatology is more critical than the spatial pattern of SST change for the simulation of anthropogenic climate change over land. These results advocate for a greater application of AGCM simulations or flux-adjusted CGCMs to improve regional climate projections.

2. Insensitivity to the Pattern of SST Change

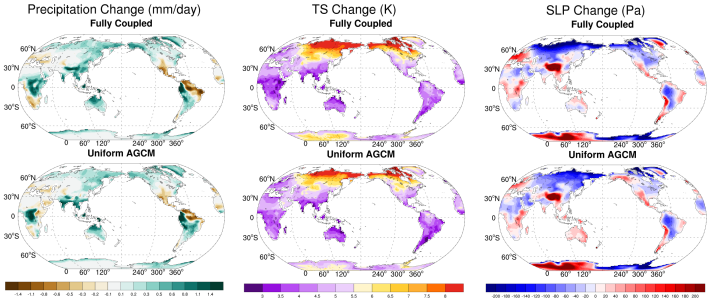
We assess the influence of the pattern of SST change on land climate change by comparing the relative impacts of direct CO_2 forcing, mean SST warming and pattern of SST change in the CMIP5 models. Although the pattern of SST change is very important over ocean, it is the least impactful over land. The magnitude of land precipitation change caused by the pattern of SST change is less than 20% of that due to the mean SST warming.



Ensemble mean RMS of precipitation change from the CO2 only, mean warming only and pattern of warming only simulations. Internal precipitation variability is removed from the total RMS.

3. Reproducing Land Climate Change with a "Uniform AGCM"

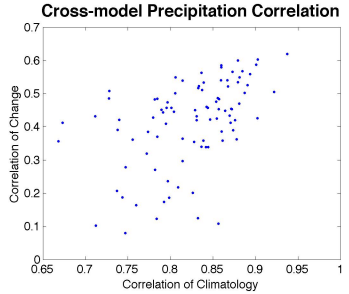
We use the CESM model to demonstrate that the anthropogenic climate change over land can be well simulated by AGCMs that are only forced with a uniform SST warming and increasing CO_2. The spatial structure of land climate change in the fully coupled and the uniform AGCM simulations is very similar. These results further suggest that the simulation of a structured SST change should not be a priority for the projection of land climate change and that CGCMs may be less advantageous than the computationally more efficient AGCMs.



Changes from the fully coupled (top) and uniform AGCM (bottom) simulations. Both simulations are run with the CESM (CAM4) model. The spatial correlation between the fully coupled and the uniform AGCM simulations is 0.82, 0.95 and 0.89 for changes in precipitation, surface temperature and SLP, respectively.

4. Impact of Climatological Biases

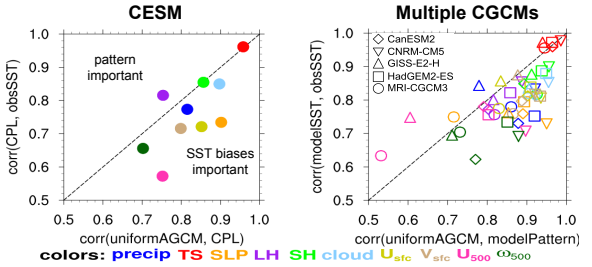
Models' climatological biases should have a great impact on the simulation of climate change since many spatial structures of anthropogenic climate change are positioned relative to the structures of the climatology. Here, we use the CMIP5 CGCMs to calculate the cross-model correlation of CGCMs' simulations of precipitation climatology and the corresponding projections of precipitation change. Overall, models that have more similar precipitation climatology have more similar precipitation change. Therefore, it is important to have an accurate climatology for the prediction of climate change.



Scatter plot of cross-model spatial correlation of global precipitation climatology versus the corresponding spatial correlation of the change in precipitation. The positive correlation indicates that a higher degree of similarity in precipitation climatology generally leads to a higher degree of similarity in projected change in precipitation.

5. Relative Importance of Climatological SST Biases and Pattern of SST Change

Because the climatology of most atmospheric variables largely depends on the underlying SST, the correction of SST biases should substantially improve climate projections. Here, we examine the relative importance of climatological SST compared to the pattern of SST change by comparing AGCM simulations with different climatological SSTs against those with different patterns of SST change. When the climatological SST is altered (y axis), a low correlation against the simulation with observed climatological SST indicates a large impact from the climatological SST biases. Likewise, when the pattern of SST change is altered (x axis), a low correlation against the Uniform AGCM indicates a large impact from the pattern of SST change. Because the data points are primarily below the diagonal line, it is more important to have an accurate climatological SST than a structured SST change.



Scatter plots of spatial correlation between simulations with different SST climatology versus simulations with different patterns of SST change. In the left panel, the y-axis represents the spatial correlation between the coupled CESM and the uncoupled CESM simulation with the observed SST climatology and the same SST changes, and the x-axis represents the spatial correlation between the coupled CESM and the "Uniform AGCM" simulation. The right panel shows in a similar fashion except for using SST climatologies (x) and patterns of SST change (y) from various CGCMs (indicated by markers). The spatial correlation is calculated for changes over land.

6. Conclusion

Our results suggest that the incorporation of the ocean model for simulating the structure of SST change is inessential and can actually degrade regional projections by introducing biases in the climatological SST. To improve projections, we may use high-resolution AGCMs combined with the observed SST and the current knowledge of SST changes.