Physical Mechanisms of the Precipitation Changes in the Subtropics and Extratropics

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1. Introduction

The subtropical and extratropical precipitation changes are characterized by a “dry-get-dryer and wet-get-wetter” pattern (Fig. 1). The conventional wisdom is that these changes are mainly driven by the increase in moisture in a warming climate. In this study, however, we show that the subtropical precipitation decline is not a thermodynamic response. This is supported by the fact that the subtropical precipitation decline is independent of the global mean (SST) warming, which dominates the increase in moisture.

Instead, the subtropical precipitation decline is primarily driven by the radiative forcing and the fast adjustments in land surface and SST patterns. On the other hand, the extratropical precipitation increase is characteristic of a thermodynamic response.

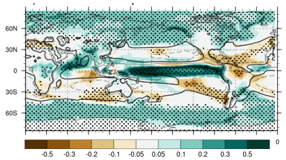

Fig. 1. CMIP5 Ensemble mean annual mean precipitation change (mm/day/K) from the 1pctCO2 simulation. Contour: annual mean P-E climatology. Stippling: regions where at least 8 (out of 9) models agree on the sign of change.

2. CO_2 VS mean warming VS pattern of warming

We first decompose the total changes in the subtropical and extratropical precipitation into mechanisms that are driven individually by the direct CO_2 forcing, the mean SST warming and the pattern of SST warming. This decomposition is achieved by AGCM simulations in which only a single forcing agent is specified. As shown in Fig. 2, the direct CO_2 forcing decreases precipitation in all subtropical basins and the pattern of SST change also suppresses precipitation in the subtropical Pacific and Atlantic Ocean. In contrast, the mean SST warming has little impact on the subtropical precipitation decline but dominates the extratropical precipitation increase.

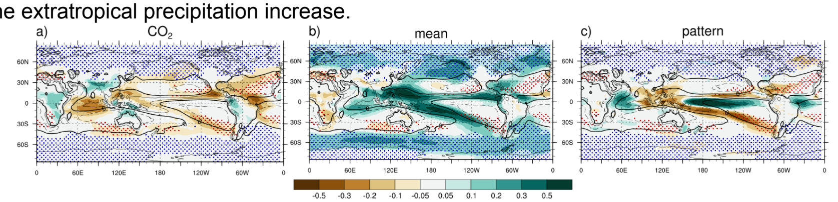

Fig. 2. CMIP5 Ensemble mean annual mean precipitation change (mm/day/K) from the AGCM simulations with single forcing agents. Contour: annual mean P-E climatology. Stippling: robust subtropical precipitation decline (red) and robust extratropical precipitation increase (blue).

3. Insensitivity to the mean SST warming

Here we calculate the total change of precipitation in the robust subtropical and extratropical zones by each individual forcing. It is clear that the mean SST warming does not contribute to the subtropical precipitation decline but dominates the extratropical precipitation increase. In the subtropical drying zones, the “dry-get-dryer” effect is almost entirely cancelled out by the increase in evaporation.

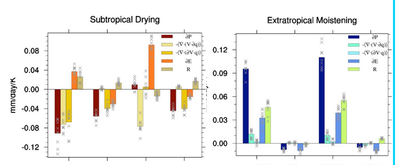

Fig. 3. Precipitation changes in the robust subtropical (left) and extratropical (right) zones (stippling in Fig. 2). Also shown is the moisture contribution by the thermodynamic, dynamic, evaporation and eddy transport.

4. Fast response VS slow response

The insensitivity to the mean SST warming indicates that the subtropical precipitation decline may have a much shorter timescale compared to the extratropical precipitation increase. In the experiment of abrupt CO_2 quadrupling, the subtropical precipitation decline forms immediately before the SST has warmed, whereas the extratropical precipitation increases slowly following the mean SST warming (Figs. 4 & 5). This further indicates that the subtropical precipitation decline is not caused by the “dry-get-dryer” mechanism.

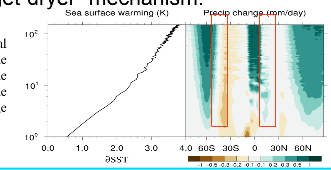

Fig. 4. Time evolution of the tropical mean SST (left) and changes in the zonal mean precipitation (right) in the abrupt4xCO2 simulation. Units for the precipitation change and SST change are mm/day and K, respectively.

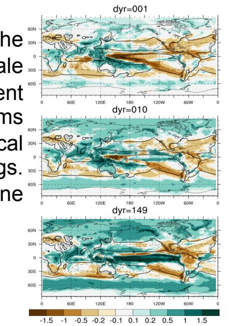

Fig. 5. Ensemble mean precipitation changes 1, 10 and 149 years after the initial forcing. Contour: climatological P-E.

5. Role of land-sea warming contrast

In both the CO_2-only AGCM simulation and the start of the abrupt $4xCO_2$ simulation, the land warms more than the ocean. Coincidentally, the precipitation decline in Fig. 2a is largely over ocean, whereas the land sees an increase in precipitation. Is the precipitation decline caused by the direct CO_2 radiative forcing or the land-sea warming contrast? Here, we use the aqua-planet simulation to answer this question.

The subtropical precipitation also decreases in the aqua-planet simulation but rather weakly (Fig. 6). In the AGCM simulation, the precipitation decline is primarily associated with a weakening in convection (Fig. 3). However, there is very little change in convection in the aqua-planet simulation. Therefore, land-sea warming contrast should play an important role.

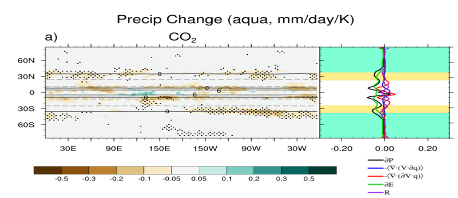

Figure 6. Precipitation changes from the CO2 only aqua-planet simulation, superimposed on the climatological P – E (contour). Stippling indicates robustness. The line plots on the right shows the zonal mean values of the terms in Fig. 3. The yellow shading indicates the subtropical drying belts where the zonal mean precipitation change is negative in aqua-planet simulation with both CO2 increase and mean SST warming.

6. Conclusion

Our results show that the subtropical precipitation decline is independent of the mean SST warming. This disproves the conventional wisdom that the subtropical precipitation decline is a “dry-get-dryer” response to the increase in moisture. On the other hand, the extratropical precipitation increase is characteristic of a thermodynamic response. Due to the insensitivity to the mean SST warming, the subtropical precipitation decline is a much faster response than the extratropical precipitation increase and forms immediately in the abrupt CO_2 quadrupling simulation.