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Understanding the Rapid Precipitation Response to CO_2 and Aerosol Forcing on a Regional Scale

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Regional precipitation change is one of the most uncertain aspects of climate change prediction, and can have major societal implications. On a global scale, precipitation is tightly constrained by the radiative cooling of the troposphere. As a result, precipitation exhibits a significant rapid adjustment in response to certain forcing agents, which is important for understanding long term climate change. However, the mechanisms which drive the spatial pattern of rapid adjustment are not well understood.

In this study we analyze the spatial pattern of rapid precipitation change using simulations with fixed sea surface temperature. Using data obtained from sixteen models participating in the Coupled Model Inter-comparison Project Phase 5 (CMIP5), we investigate the response to three different forcing scenarios; an abrupt quadrupling of CO_2, an increase in all aerosols, and an increase in sulphate aerosol from pre-industrial to present day levels. Analysis of the local atmospheric energy budget is used to understand the observed changes.

We find that the spatial pattern of rapid precipitation adjustment due to forcing is primarily driven by the rapid land surface response. As a result, the spatial pattern due to quadrupling CO_2 opposes that due to increased sulphate and increased all aerosols. Increasing CO_2 levels causes warming of the land surface, due to enhanced downwelling longwave radiation. This destabilizes the atmosphere by warming the lower troposphere, producing an overall shift of convection and precipitation to over land. The reverse is observed for increased sulphate and increased all aerosols. Changes in tropospheric cooling are important in determining the magnitude of regional precipitation change, thereby satisfying global energy budget constraints.

We find the spatial pattern of rapid precipitation change due to quadrupling CO_2 levels is robust between models. The most significant precipitation changes occur in the tropics, with significant increases occurring over central Africa, Southern Asia, the Maritime Continent and western South America, due to warmer land surface temperatures driving enhanced moist convection. Over the tropical oceans, reduced tropospheric cooling combined with a general shift of convection to over land, results in large reductions in precipitation. Over mid-latitude land regions a lack of moisture prevents enhanced convection, and reduced tropospheric cooling causes precipitation to decrease. These findings explain the mechanisms which drive the rapid precipitation response on regional scales, and demonstrate the importance of rapid land surface temperature changes.