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Understanding Projections of Increased Convective Precipitation Intensity

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Many modeling studies predict that there will be more intense precipitation events in the future as the climate warms under greenhouse gas forcing. A theoretical understanding of this change is founded in the behavior of the Clausius–Clapeyron equation, which relates a 1K increase in surface temperature with a 7% increase in the saturation mixing ratio, along with model simulations which predict that relative humidity remains fairly constant as the climate warms. Here we compare the results from climate model simulations over the U.S. with this theoretical prediction.

The analysis shows the extent to which the theoretical prediction applies to the complex climate system, and we investigate the physics of the departures from theory for the convective component of rainfall. In regional model simulations of the mid-21st century, changes in convective precipitation rates are regionally and seasonally dependent. In the spring, there are up to 20% increases over most of the central and eastern U.S. These increases exceed the predictions of the Clausius–Clapeyron relation. In the summer, rainfall rates decrease up to 25% in the Midwest and increase up to 15% in the Northeast. Predictions are up to 14% (-4%) greater (smaller) than the model in Midwest (Northeast) in JJA. Predictions from the Clausius–Clapeyron relation are based on the assumption that the surface is fully saturated. Surface temperatures increase everywhere in the future although increases are greater in the Midwest (up to 3K) than in the Northeast (up to 1.4K). An analysis of the moist static energy balance reveals that the primary reason for the differences between the simulation and the theoretical prediction is related to soil moisture distributions. When there is adequate soil moisture for unrestricted evaporation, increases in convective rainfall intensities agree roughly with – or exceed – the theoretical prediction. When the soil is dry, warming leads to enhanced dry convection but there is no precipitation increase associated with the increase in convection. In this case, the theoretical prediction based on the Clausius–Clapeyron equation fails.

Keywords: precipitation, rainfall, Clausius-Clapeyron