Geophysical Research Abstracts
Vol. 21, EGU2019-6481, 2019
EGU General Assembly 2019

Intensification of heavy precipitation events in continental-scale climate-change simulations with kilometer-scale resolution

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Climate models and observations show that heavy precipitation is intensifying with a warmer climate, and these changes are very often put in the context of theoretical expectations from the Clausius-Clapeyron relation. Observations, models, and theory suggest that the intensity of day-long events increases with this relation, i.e. at a rate of 6-7 % per degree warming, where the warming is with regard to (near-)surface temperatures. However, the intensification of heavy precipitation is very sensitive to the time period considered, the region and model investigated, and the analysis method employed. In particular, for short-term events, many studies show departures from the Clausius-Clapeyron scaling and exhibit increases at a faster (super-adiabatic) rate. These rapid increases of heavy precipitation events are of paramount importance to many climate adaptation measures, and the uncertainties and discrepancies between different studies represent a serious challenge to current-day applications. High-resolution simulations provide attractive prospects to deal with these important questions without the need of convective parameterization schemes.

Here we employ a high-resolution model at convection resolving resolution of 2.2 km over a pan-European domain and analyze the scaling of heavy precipitation intensity in response to climate warming over different regions. The analysis shows that in most regions the increase of heavy precipitation with near-surface temperature is around the Clausius-Clapeyron rate, except for the British Isles where it exceeds this rate for heavy daily and hourly precipitation by about a factor 2. We can reconcile these conflicting results by showing that for the British Isles the lower troposphere, which contains most of the moisture, warms faster than the surface, especially over oceans. Thus it can contain more moisture than expected from the increase in surface temperature, thereby leading to an above Clausius-Clapeyron increase in heavy precipitation when scaled with surface temperatures. These results indicate that the changes in surface precipitation are largely controlled by temperature changes in the lower troposphere, and not simply by changes in the surface temperature. With the current approach, we are able to reconcile conflicting results for time periods down to one hour, but many questions remain regarding shorter-term accumulation periods.