Response of hourly precipitation extremes to temperature and moisture perturbations: results from a mesoscale model.

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1. The Clausius-Clapeyron relation and precipitation extremes

Observations of extreme (sub-)hourly precipitation at mid-latitudes show a large dependency on the dew point temperature often close to 14% per degree, which is 2 times the dependency of the specific humidity on dew point temperature as given by the Clausius–Clapeyron (CC) relation (e.g. Lenderink et al. 2011). In literature, it is argued that this 2CC scaling is linked to the response of convective precipitation to temperature and moisture increases (Moseley et al. 2013; Loriaux et al. 2013).

2. Modeling setup and analysis

By simulating a selection of 11 cases over the Netherlands characterized by intense showers, we investigate this hypothesis in the non-hydrostatic weather prediction model Harmonie at a resolution of 2.5 km. First, for each case a reference simulation representing present-day climate conditions is performed. Then, the experiments are repeated using perturbations of the atmospheric profiles of temperature and humidity: (i) using an idealized approach with a warmer (colder) atmosphere, uniform with height, assuming constant relative humidity, and (ii) using changes in temperature and humidity derived from a long climate change simulation at 2 degrees global warming. The climate perturbation reveals a warming that is non-uniform with height. In general, the warming near the tropopause is largest, indicating a small increase in stability of the atmosphere. Also, the warming near the surface is ~0.5 °C larger than the global average temperature rise of 2 °C, and the relative humidity near the surface decreases with a few percent.

Here, we will discuss the sensitivity of precipitation extremes to local dew point temperature changes; see Lenderink et al. (2011) for why the dew point temperature is used. All perturbations have a difference in the local dew point temperature compared to the reference of approximately 2 degrees.

3. Results of one case

Results of one case (based on 11 August 2004) are shown in Figure 1, for both the reference experiment and the plus 2 degrees idealized warming experiment. It is shown that the broad features of the accumulated precipitation field are in both experiments very similar. Yet, the warmer experiment shows considerably higher precipitation amounts, in particular for the southern part of the domain. Likewise, the experiment with a 2 degree colder atmosphere reveals a decrease in precipitation amounts.

Results obtained with the climate perturbation are generally close to results of the plus 2 degrees idealized perturbation for areas with high precipitation amounts. However, the areas with lighter precipitation show a decrease for the climate perturbation, whereas in the idealized plus 2 degrees perturbation they generally reveal an increase. Apparently, this is due to the decrease in relative humidity for the climate perturbation.

The other 10 cases give comparable results. Except for one case, all cases show an increase in precipitation amounts with temperature, although the actual increase varies from experiment to experiment.

Figure 1. Daily precipitation sum for the reference experiment (upper panel) and the future experiment (lower panel) under a idealized two degree uniform warming and unchanged relative humidity perturbation.
4. Changes in hourly precipitation extremes

Next, we look at changes in the statistics of hourly precipitation extremes. We pooled all data from all grid boxes, all hours and all 11 cases together, and computed precipitation amounts for different values of the Probability of Exceedance (PoE).

Results as shown in Figure 2 reveal a remarked increase in precipitation extremes with (dew point) temperature derived from comparing different set of perturbed experiments to the reference experiment. For the most extreme events (right side of the plot) hourly precipitation increase with more than 10 % per degree rise in dew point temperature. The sensitivity to the temperature perturbation is rather constant with PoE for the two uniform perturbation experiments, but shows a remarked dependency on the PoE for the climate perturbation; that is, less extreme events show smaller increases.

Figure 2. Change in extreme precipitation for different values of the Probability of Exceedance (PoE) with respect to the reference simulation. Changes are normalized per degree rise in dew point temperature. Colors are: red, derived from +2 °C perturbation; blue derived from -2 °C; black, derived from -2 and +2 °C perturbations; green, derived from climate perturbation.

Results for the individual cases separately display different sensitivities of hourly precipitation extremes to the perturbations, with values between 7 and 17 % per degree derived from the uniform perturbation (combined sensitivity from the -2 and +2 °C perturbations), and 0 and 15 % per degree for the climate perturbation. Considering the statistics of individual events it appears that for some events a positive temperature perturbation does not results in considerable increase in precipitation intensity, suggesting a possible limit on precipitation intensity. We note that the same cases do show a considerable reduction in precipitation intensity with the -2°C perturbation. On the other hand, the poor statistics of these individual runs, and the chaotic behavior of the atmosphere in convective conditions, may play a role as well.

5. Conclusion

We simulated a selection of 11 cases with extreme convective precipitation under present-day climate conditions and modified colder and warmer climate conditions with a mesoscale model (Harmonie). This model explicitly resolves the largest convective motions, in contrast to regional (and global) climate model in which convection is parameterized. In general, a considerable increase of hourly precipitation extremes – in the tail of the distribution averaging to 10-14 % per degree – was found. This is larger than expected based on moisture availability, predicting an increase of 6-7 % per degree. Yet, also the differences between the results of the cases were substantial. This, and the suggestion of a possible limit of the increase of precipitation intensity with temperature, needs to be investigated further.

References


