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Is there a timescale where the Clausius-Clapeyron relation describes precipitation rate changes?

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One basic physical principle that has been broadly discussed in the literature in connection with precipitation rate changes is the Clausius-Clapeyron relation. This relation describes an increase in the atmosphere's moisture holding capacity of about seven percent for a temperature rise by one degree Kelvin. However, the temperature dependence and scaling of precipitation intensity distributions across timescales has so far not been presented in a comprehensive way. Precipitation events that persist throughout different timescales can lead to substantially different effects such as local flooding, erosion and traffic disruptions on short scales to large-scale flooding and water damage on longer scales. We present a fundamental study based on observational precipitation data at the high temporal resolution of five minutes from six stations in Germany. We obtain scaling relations of the probability distributions of precipitation intensity with temperature and timescale. Each station record contains an approximately 30 year-long timeseries of data.

By producing a cascade of averaging intervals, we track the behavior of precipitation intensity from the instantaneous to the daily resolution. While the high intensity-distribution of the shortest timescale displays a strict integer power-law tail, it acquires a more elaborate scaling when temperatures are distinguished or when precipitation and dry periods are mixed at longer averaging intervals. The coefficient of increase with temperature is a continuously and strongly varying function of temperature and of percentile and does not show an abrupt increase as noted previously. Conversely, when considering precipitation events, we find that the temperature dependence is reduced when the amount – not the intensity - of total precipitation produced by events is considered. As temperature increases, event duration decreases and reduces the accumulated precipitation yield. We caution that the Clausius-Clapeyron relation may not provide an accurate estimate of the temperature dependence of precipitation at any temporal resolution.

These results are contrasted with a further study where we investigate daily climate model and observational data for all of Europe – hence spatial dependency is now considered. In winter, a general increase in precipitation intensity with increasing temperature is indeed observed while in summer we find a decrease in the precipitation intensity. We interpret these findings by making use of model results where we can distinguish separate precipitation types and investigate the moisture content in the atmosphere. In winter, at the daily scale the Clausius-Clapeyron relationship indeed appears to set an upper limit to the increase in the large-scale precipitation with increasing temperature. Conversely, in summer the available moisture, and not the atmosphere's capacity to hold this moisture, may be the dominant factor for the large-scale precipitation.

We comment on the implication of our results for changes in the hydrological cycle and precipitation extremes under a changing climate.