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Exploring the causes of rare extreme precipitation events

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Whereas trends of precipitation changes in general are disparate, an increase of extreme intensities of short precipitation events (daily to sub-hourly scale) with increasing temperatures seems unambiguous (e.g. Trenberth et al., Clim. Res. 47, 123-138, 2011; Berg et al., Nat. Clim. Change 13, 181-185, 2013; Kendon et al., Nat. Clim. Change 4, 570-576, 2014). In probability density functions (PDFs) of observed precipitation intensities that are frequently used in science and practice, high magnitude ("extreme") low frequency ("rare") precipitation events naturally appear at the tails of PDFs.

Due to the factual data scarcity, rare extreme events ("REEs") are difficult to come by with statistical analyses. Amongst studies of extreme precipitation, statistical work nevertheless makes a major contribution to the research field. Usually as a first step, a threshold is defined to classify extreme events out of a sample (statistical extreme events, "SEEs"), where methods are affected by the sample size. Such thresholds can be described user-defined or constructed. Subsequently, a PDF is sought, fit and applied (e.g. Yilmaz et al., Hydrol. Earth Syst. Sci. 18, 4065-4076, 2014;, Papalexiou et al., Hydrol. Earth Syst. Sci. 17, 851-862, 2013). While these studies respond to the needs of engeneering practice in e.g. infrastructure design, or trend analysis of precipitation in climate studies, they a) have to ignore REEs because of practical or statistical/data limitations (i.e. left out as "residual risk") and b) tell us little about the underlying processes of the climate and weather system causing REEs.

We define REEs in contrast to SEEs as to be of such occurrence that they cannot be sufficiently described nor predicted by means of a regular or fat-tailed PDF. We introduce a working hypothesis assuming that REEs are conditioned and caused by a conjunction of specific circumstances on different scales. We differentiate spatio-temporal circumstances of large-scale/long-term and regional/seasonal preconditioning that combine with specific local/short-term event conditions.

In this initial study, we primarily examine precipitation records of daily to sub-hourly (10min) resolution of the ZAMG (National Weather Service of Austria) meteorological station network over the climate-sensitive southern Alpine region for the extended summer season (MJJAS). Precipitation events exceeding the 98th percentile threshold of commonly accepted PDFs are seen as to be potential REEs and are subject to deeper analysis to test our working hypothesis. For each event, the preconditioning is evaluated making use of extended climate and weather data (atmospheric analyses, synoptic observations), complemented by available extreme event reports from ZAMG. This approach overcomes limits of data-sparse statistics by systematically exploring the processes and uncertainties of REEs on a per-event basis. We find that identifying specific patterns of REE preconditioning and actual event conditions helps to understand extreme precipitation uncertainties and delivers also valuable information for evaluating climate model simulations.