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Calibrating max-stable models of rainfall extremes at multiple timescales

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Understanding the probabilistic behaviour of extreme rainfall events is critical for estimating the risk of flooding, leading to better design of infrastructure and management of flood events. The majority of engineering design is based on estimates of the probability of extreme rainfall known as the Intensity-Frequency-Duration relationship (IDF). IDF curves are estimated at each rain gauge and are subsequently interpolated for application to ungauged locations. The pointwise nature of IDF estimates leads to difficulties, especially at sub-daily timescales, due to the sparseness of sub-daily extreme rainfall data. As a result there is greater uncertainty and potential for bias when estimating sub-daily extreme rainfall. By using a model that incorporates dependence between spatial extremes as well as across multiple timescales, there is considerable potential to improve estimates of extreme rainfall.

The aim of this research is to develop max-stable models of extreme rainfall that have both spatial dependence as well as dependence across timescales. Max-stable processes are a direct extension of the univariate generalized extreme value (GEV) model into the spatial domain. Max-stable processes provide a general framework for modelling multivariate extremes with spatial dependence for just a single duration extreme rainfall. To achieve dependence across multiple timescales, Koutsoyiannis et al. (1998) proposed a mathematical framework which expresses the parameters as a function of timescale. This parameterization is important because it allows data to be incorporated from daily rainfall stations to improve estimates at sub-daily timescales. The approach therefore addresses the issue of sparseness for sub-daily stations by exploiting the denser network of daily stations.

A case study in the Hawkesbury-Nepean catchment near Sydney is used, having 82 daily gauges (>50 years) and 13 sub-daily gauges (>24 years) over a region of 300 km x 300 km area. The max-stable model incorporates spatial dependence by fitting parameters simultaneously, as well as considering covariates such as latitude, longitude and elevation. Models were fitted for the case of sub-daily gauges and daily gauges separately, and an additional model was fitted for the timescale-dependent case. A comparison of the model results for the sub-daily case and the timescale-dependent case shows significant improvement to the subdaily estimates due to the density of the daily network. The improvement in sub-daily estimates comes despite the fact that the daily data are at a much longer duration, and is due to a better representation of the spatial structure of the location and scale parameters for the GEV distribution. Some important considerations with this approach are (i) numerical issues related to the number of model parameters and locations, (ii) how to represent differences in the spatial structure with duration (for example, shorter duration extremes are less spatially dependent than longer durations) and (iii) the fact that extreme events in the subdaily record often come from the same events in the daily record (inferred from the timestamp), which induces dependence across durations. By adopting max-stable frameworks that explicitly incorporate spatial and temporal dependence it is possible to significantly improve the estimate of sub-daily extreme rainfall used in design situations.