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Scale-invariant models for extreme rainfall: Application to Australian sites

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Abstract: Hydrological infrastructure design and management require understanding the occurrence of flood events. However, flow measurement sites are more limited than rain gauge sites. Extreme rainfall can be a feasible replacement of the flow measurement as the input for a frequency model of rainfall-induced floods. Rainfall intensity-duration-frequency (IDF) curves are the current standard approach for estimating extreme rainfall subject to the designed probability. Scale invariance is an important concept in rainfall frequency analysis, because rainfall process exhibits a multi-fractal nature. Scale invariance applied to extreme rainfall modelling can be conceptualised as the probability of extreme rainfall remaining the same under duration-change transformations (Veneziano and Lepore, 2017). A parsimonious scale-invariant rainfall model defines a family of durations IDF curves at various return periods. Two main contributions of this study are: (1) Scaling properties for Australian at-site data are assessed, ensuring the legitimacy of rainfall modelling based on scale invariance; and (2) A scale-invariant model developed in this study manifests more physically reasonable extreme rainfall estimates and simplification of model parameter estimation.

Menabde et al. (1999) derived a standardised scale-invariant (S-SI) rainfall IDF model based on the EV1 distribution. This model assumes that cumulative probability of a rainfall intensity can be preserved over durations d to d^*, where d^* is the duration corresponding to the standardised intensity i^*. We build on their work and employ master curve analysis for a more general scale-invariant rainfall IDF model (MS-SI). A master IDF curve is defined by pooling standardised intensities at all durations, followed by fitting a GEV distribution. By back transforming the master IDF curve, IDF curves for desired durations can be obtained. Benefits of MS-SI in extreme rainfall estimation includes: (1) Manifesting universal behaviour over duration; (2) Physically realistic behaviour of IDF curves namely avoidance of cross-over when extrapolating to low-probability events; and (3) Simplification of parameter estimation and reduction in parameter uncertainty.

Twelve Australian sites (and key neighbouring sites) representative of typical climate regimes ranging from tropical to temperate conditions are considered. Annual maximum rainfall intensity data is obtained from Australian Bureau of Meteorology, which contains 11 durations (5 min–72 hours) with usable records of up to 130 years. Scaling property assessment shows that observed intensity from all Australian sites presents significant scale invariance. Scale invariance is reflected by linear behaviour of statistical moments and 2 extreme value distribution parameters (location and spread) with respect to duration. Estimated GEV shape parameters for all individual durations match one of the GEV distribution types, whereas the uncertainty range of the shape parameter can cover values characteristic of more than one GEV distribution type. For each site, the uncertainty of shape parameter at a given duration can be substantial. The pooling of durations at a single site reduces the uncertainty. Further pooling across a region (main site and key neighbouring sites), further reduces parameter uncertainty, in agreement with the global shape parameter survey by Papalexiou and Koutsoyiannis (2013). The performance of the 2 scale-invariant models incorporating standardisation S-SI and MS-SI, is reported using goodness-of-fit metrics, as well as reliability diagrams.

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