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Hierarchical Bayesian modelling of hydrological extremes

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Hydrological time series are characterized by variability over a wide range of temporal scales. While lower frequency variability has been widely studied in hydrology, it is seldom explicitly accounted for in extreme value models. This limitation arises as a consequence of the limited data available for inference on extremes, and especially in the case of hydrological processes exhibiting relevant variability over yearly or longer time scales. Motivated by the statistical analysis of extreme rainfall, here we present a Bayesian hierarchical model developed for estimating the probability distribution of extreme values of intermittent random sequences. This method relaxes the asymptotic assumptions ordinarily employed in extreme value theory, and models the entire underlying parent distribution of the events. The hierarchical structure of the model explicitly separates the 'fast' time scale of event occurrence from a lower-frequency variability component, which is modeled through latent-level variables. In the case of rainfall, this latent level represents the inter-annual variability in the distributions of both of event magnitudes and in the frequency of their occurrence. Inference is conducted numerically by means of a Bayesian approach, thus allowing for the inclusion of relevant prior information, and leading to a fully probabilistic description for the quantities of practical interest, such as high return times quantiles. Here we test the proposed model by means of a simulation study, and include an application to rainfall data obtained from long instrumental records. Our results show that this approach I) leads to improved inference in the case of relatively short datasets, and II) can benefit from prior information on the physical processes involved in order to reduce estimation uncertainty. Moreover, we show that the presence of low frequency variability leads to statistical models characterized by heavier tails, thus underlining the importance of low frequency variability in determining the extreme-value statistical properties even in the case of stationary models. While the focus of our application in on rainfall extremes, the structure of the model is quite general and applications to other environmental variables are discussed.