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A multifractal framework to evaluate extreme rainfall trends across scales under a changing climate

Stergios Emmanouil[1], Andreas Langousis[2], Efthymios I. Nikolopoulos[3], and **Emmanouil N. Anagnostou**[1]
[1]Department of Civil and Environmental Engineering, University of Connecticut, Storrs, Connecticut, United States (manos@uconn.edu)
[2]Department of Civil Engineering, University of Patras, Patras, Greece
[3]Department of Mechanical and Civil Engineering, Florida Institute of Technology, Melbourne, Florida, United States

The accurate quantification of hydroclimatic risk requires detailed knowledge on the spatiotemporal characteristics of extreme rainfall. In engineering design, Intensity-Duration-Frequency (IDF) curves are fundamental tools that encompass information on rare precipitation events over a wide range of characteristic temporal scales and exceedance probability levels. Inspired by physical evidence and laws of thermodynamics, researchers widely suggest that the rapidly changing climate instigates more frequent and intense precipitation-related natural hazards. Based on the foregoing implication, current protection standards may be systematically threatened in the upcoming years. Under this non-stationary setting, several IDF estimation approaches have been proposed that allow for distribution parameter estimates to vary (in most cases linearly) with time. Yet, the introduction of additional model parameters increases the estimation uncertainty of rainfall intensity quantiles, especially for rare events. As a potential solution to limitations related to non-stationarity, Emmanouil et al. (2022) proposed an elaborate parametric approach founded on multifractal (MF) scaling arguments (see Langousis et al., 2009), which assumes that the statistical structure of rainfall at interannual scales can be approximated by sequential realizations of a stationary multifractal process with parameters that vary slowly across (not within) realizations. The suggested framework is particularly robust when describing the intensity and frequency of extreme rain rates from small precipitation samples (i.e., down to 2 years; see Emmanouil et al., 2020) and, therefore, it can be effectively applied to adequately short sequential segments of data, allowing for climatic variations to be revealed. Given the above, we attempt to expand the analysis of Emmanouil et al. (2022) toward evaluating the effects of future climate pathways on extreme rainfall, under a wide spectrum of topographical and climatological conditions. To do so, we derive IDF curves based on statistically downscaled estimates of multiple climate model outputs (e.g., Mearns et al., 2017) that cover a 120-year period (i.e., from 1979 to 2099) over the Contiguous United States (CONUS). The yielded outcomes for both historical data and climate model hindcasts exhibit that, on average, extreme rainfall displays similar trends over the study domain. However, it is shown that the dependence structure and variability of rare precipitation events vary significantly across data sources, and should be scrupulously delineated when assessing how existing risk considerations could actually be affected.

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