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Regional trends in short-duration precipitation extremes: a flexible multivariate monotone quantile regression approach

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Estimating historical trends in short-duration rainfall extremes at regional and local scales is challenging due to low signal-to-noise ratios and the limited availability of homogenized observational data. In addition to being of scientific interest, trends in rainfall extremes are of practical importance, as their presence calls into question the stationarity assumptions that underpin traditional engineering and infrastructure design practice. Even with these fundamental challenges, increasingly complex questions are being asked about time series of extremes. For instance, users may not only want to know whether or not rainfall extremes have changed over time, they may also want information on the modulation of trends by large-scale climate modes or on the nonstationarity of trends (e.g., identifying hiatus periods or periods of accelerating positive trends).

Efforts have thus been devoted to the development and application of more robust and powerful statistical estimators for regional and local scale trends. While a standard nonparametric method like the regional Mann-Kendall test, which tests for the presence of monotonic trends (i.e. strictly non-decreasing or non-increasing changes), makes fewer assumptions than parametric methods and pools information from stations within a region, it is not designed to visualize detected trends, include information from covariates, or answer questions about the rate of change in trends. As a remedy, monotone quantile regression (MQR) has been developed as a nonparametric alternative that can be used to estimate a common monotonic trend in extremes at multiple stations. Quantile regression makes efficient use of data by directly estimating conditional quantiles based on information from all rainfall data in a region, i.e. without having to precompute the sample quantiles. The MQR method is also flexible and can be used to visualize and analyze the nonlinearity of the detected trend. However, it is fundamentally a univariate technique, and cannot incorporate information from additional covariates, for example ENSO state or physiographic controls on extreme rainfall within a region.

Here, the univariate MQR model is extended to allow the use of multiple covariates. Multivariate monotone quantile regression (MMQR) is based on a single hidden-layer feedforward network with the quantile regression error function and partial monotonicity constraints. The MMQR model is demonstrated via Monte Carlo simulations and the estimation and visualization of regional trends in moderate rainfall extremes based on homogenized sub-daily precipitation data at stations in Canada.