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Power law tails in streamflow extremes: effect of precipitation and basin properties

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Heavy tailed distributions which are not exponentially bounded often provide best fits to the maxima in streamflow time series. The strength of the fat tail can be approximated by a power law decay function with a characteristic exponent α which captures the relative frequency of occurrence of extreme events: as the exponent decreases extreme events become more likely. Although extreme value theory provides limiting distributions which exhibit approximately heavy tails it does not explain the physical origin of the characteristic exponent. It is expected that the value of α should to some degree be related to the precipitation distribution or to basin and river network properties which govern the rainfall-runoff transformation, or both. The strength of these relations could explain the dominant processes that lead to flood extremes and their statistical predictability. In this paper we explore these questions on a dataset from Switzerland.

The dataset consist of daily streamflow and precipitation records for 55 river basins in Switzerland with average record length $\sim$40 years. The study basins cover a range of sizes (14–905 km^2) in the forelands and Swiss Alps (mean altitude 473–2710 m) with different precipitation totals (mean annual precipitation 345–2423 mm). The mountainous environment also means that a wide range of soil depth, rock cover, glacierized area, mean basin gradient and drainage density are covered. All of these basin properties were used in our analysis as predictors of the rainfall-runoff transformation.

In a first step the existence of power law tails in concurrent records of daily streamflow and precipitation was examined by estimating the exponent α with the maximum likelihood method on a seasonal basis. It was found that α was generally higher for streamflow (mean $\alpha = 5$) than for precipitation (mean $\alpha = 4.3$) extremes and also much more variable. There are also indications of seasonal differences with lowest values of α in the autumn and winter months for streamflow but with little difference for precipitation. This is indicative of a more organized runoff regime in those seasons with fewer outliers. Furthermore, although the power law was the best fit to precipitation extremes in all cases on an annual basis, this was not the case for streamflow where in 25% of the cases exponential-like tails provided a better fit. In a second step the basin-related dependencies of the exponent α were examined. It was found that the correlation between α for streamflow and precipitation was statistically insignificant for all seasons. On the other hand basin properties provided much stronger relationships with streamflow α, most notably mean station altitude and gradient (positive correlation) and soil depth (negative correlation) in all seasons. Glacier coverage was also positively correlated with α in all seasons expect winter which indicates that glaciers on the average tend to dampen flood extremes by reducing the rapid runoff generating area during heavy storms. Overall our results show that power law scaling is more evident in precipitation than in streamflow extremes and that the scaling regime of runoff maxima is more significantly related to basin properties than to precipitation.