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Investigating rainfall and catchment attributes promoting heavy-tailed distributions of river flows

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Heavy-tailed probability distributions of streamflow are frequently observed in river basins. They indicate sizable odds of extreme events in these catchments and thus signal the existence of enhanced hydrological perils. Notwithstanding their relevance for characterizing the hydrological hazard of river basins, identifying specific mechanisms which promote the emergence of heavy-tailed flow distributions has proved challenging due to the complex hydrological response of such dynamical systems exposed to highly variable rainfall inputs.

In this study we combine a continuous hydrological model grounded on the geomorphological theory of the hydrologic response with archetypical descriptions of the spatial and temporal distributions of rainfall inputs and catchment attributes to investigate physical mechanisms and stochastic features leading to the emergence of heavy tails.

In the model, soil moisture dynamics driven by the water balance in the root zone trigger superficial and subsurface runoff contributions, which are routed to the catchment outlet by means of a representation of transport by travel time distributions. The framework enables a parsimonious distributed description of hydrological processes, suitably considered with their stochastic character, and is thus fit for the goal of investigating manifold mechanisms promoting heavy-tailed streamflow distributions.

A set of archetypical spatial and temporal variabilities of rainfall inputs and catchment attributes (e.g., localized versus uniform rainfall in the catchment, lumped versus distributed catchment attributes, mainly upstream versus downstream source areas, high versus low rainfall frequency) are finally imposed in the model and their capability (or not) to affect the tail of the streamflow distribution is investigated.

The proposed framework provides a way to disentangle physical attributes of river catchments and stochastic properties of hydroclimatic variables which control the emergence of heavy-tailed streamflow distributions and thus identify the key drivers of the inherent hydrological hazard of river basins.