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Critical dynamics and scaling in hydrology

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In 1951 Harold Hurst discovered his famous power law in the auto-correlation of the Nile runoff. Ever since then, runoff time series of many rivers around the world have been shown to exhibit scale-invariance over large ranges in time. As an example of spatial scaling, we show that at least five moments of runoff distributions in the Mosel catchment follow power laws w.r.t. the sub-catchment's area.

This prevalence of spatio-temporal scale-invariance might lead to the hypothesis that, through some sort of self-organization, hydrological systems are poised close to a critical state that is entirely described by a set of scaling laws. These scaling laws should thus be amenable to relatively simple mathematical modeling without a detailed account of all the local hydrological processes that lead to their emergence.

Traditional hydrological modeling though largely ignores the existence of scaling laws. For instance, state-of-the art error models in hydrology are normal AR1 processes added on top of the Box-Cox transformed outputs of deterministic bucket models. These processes introduce both a volume and a time scale and thus manifestly break scale invariance. The 90 years of daily runoff measurements from the Meuse catchment allow us to study the statistics of residuals from traditional calibrated hydrological models. We demonstrate that the observed auto-correlation is in startling contrast to the assumed AR1 process, and resembles much more scale-invariant flicker noise. Furthermore, the residuals violate the assumed normality and are much more fat tailed.

We argue that using state-dependent rather than constant noise as well as colored rather than white noise might allow us to improve standard hydrological models towards respecting observed scaling laws, which seems to be important for the prediction of the statistics of extreme and rare events.