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On the dynamic nature of hydrological similarity

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The increasing diversity and resolution of spatially distributed data on terrestrial systems greatly enhances the potential of hydrological modeling. Optimal and parsimonious use of these data sources implies, however, that we better understand a) which system characteristics exert primary controls on hydrological dynamics and b) to what level of detail do those characteristics need to be represented in a model.

In this study we develop and test an approach to explore these questions that draws upon information theoretic and thermodynamic reasoning, using spatially distributed topographic information as a straightforward example. Specifically, we subdivide a meso-scale catchment into 105 hillslopes and represent each by a two dimensional numerical hillslope model. These hillslope models differ exclusively with respect to topography related parameters derived from a digital elevation model; the remaining setup and meteorological forcing for each are identical. We analyze the degree of similarity of simulated discharge and storage among the hillslopes as a function of time by examining the Shannon information entropy. We furthermore derive a 'compressed' catchment model by clustering the hillslope models into functional groups of similar runoff generation using normalized mutual information as a distance measure.

Our results reveal that, within our given model environment, only a portion of the entire amount of topographic information stored within a digital elevation model is relevant for the simulation of distributed runoff and storage dynamics. This manifests through a possible compression of the model ensemble from the entire set of 105 hillslopes to only 6 hillslopes, each representing a different 'functional group', which leads to no substantial loss in model performance. Importantly, we find that the concept of hydrological similarity is not necessarily time-invariant. On the contrary, the Shannon entropy as measure for diversity in the simulation ensemble shows a distinct annual pattern, with periods of highly redundant simulations, reflecting coherent and organized dynamics, and periods where hillslopes operate in distinctly different ways.

We conclude that the proposed approach provides a powerful framework for understanding and diagnosing how and when process organization and functional similarity of hydrological systems emerges in time. Our approach is neither restricted to the model, nor to model targets or the data source we selected in this study. Overall, we propose that the concepts of hydrological systems acting similarly (and thus giving rise to redundancy) or displaying unique functionality (and thus being irreplaceable) are not mutually exclusive. They are in fact of complementary nature, and systems operate by gradually changing to different levels of organization in time.