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Multi-step Development and Evaluation of Calibration-free Hydrological Models

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The concept of "dominant processes" suggests that simplification is the key for an effective/efficient way to model hydrological systems. However, the use of calibration-based hydrological models can lead to incorrect interpretation of the significance of some processes, which can translate into an incorrect interpretation of interaction of water flows with biochemical cycles. We argue that dominant processes can be identified through the use of 1) calibration-free hydrological models that simulate the physics of hydrological systems, and 2) model evaluation at across multiple scales. In this work we systematically build calibration-free hydrological models by increasing model-complexity and evaluating performance. The goal is for all parameterizations in the model to be observable data-based or prescribed a priori. We illustrate this concept using a case study for river basins in Iowa during the Iowa 2008 extreme flood events. The simplest model applied is the Geomorphological Unit Hydrograph with time variable rainfall. We add complexities (incrementally) to flow propagation dynamics in the river network, spatio-temporal variability of rainfall and runoff generation, hillslope morphology and functioning, and soil dynamics. The results are evaluated across a large range of spatial scales. We find a close agreement, indicating that the approach successfully captured dominant processes. In addition, we show that predictions made by the spatially distributed model, such as time of arrival of peak flows at different locations in the river network, can become additional diagnostic tools for model validation.