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Testing hypotheses of velocity and celerity at the catchment scale using ensemble hydrograph separation

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Making hydrological models more realistic requires both better physical understanding of their underlying processes, and more rigorous tests of the hypotheses that they embody. In the current model-testing paradigm, multiple interdependent hypotheses are combined to generate model predictions, which are then compared with observational time series that reflect multiple interdependent forcings. This approach is problematic in several respects. If the modeled time series does not match the observations, which of the model's many embedded hypotheses is falsified? Conversely, even if the model matches the data, how many of its underlying hypotheses could still be wrong, perhaps in offsetting ways? The essence of the problem is that if model simulations depend on many interacting hypotheses, and if observational data reflect many different environmental forcings, then comparisons of simulations against data will rarely be diagnostic tests of specific hypotheses in the model.

For this reason, I have long argued for a different approach to hypothesis testing, in which key signatures of behavior are extracted from both model and data before they are compared (Kirchner et al., 1996; Kirchner, 2006). This approach allows one to isolate the model/data comparison as much as possible from potentially confounding factors in both the model and the data.

One key signature of catchment behavior, which has challenged many hydrologic models, is the contrast between the relatively short timescales of hydrologic response to precipitation events, reflecting the celerity of hydraulic potentials, and the much longer timescales of water transport through the landscape, reflecting the velocity of water movement as tracked by passive tracers (Kirchner, 2003). Here I show how both the velocity and celerity of transport at the catchment scale can be quantified from hydrologic and isotopic time series. The conventional formula used for hydrograph separation can be converted into an equivalent linear regression equation that quantifies the fraction of current rainfall in streamflow across ensembles of precipitation events. These ensembles can be selected to represent different discharge ranges, different precipitation intensities, or different levels of antecedent moisture, thus quantifying how the fraction of "new water" in streamflow varies with forcings such as these. This approach can be generalized to determine the contributions of precipitation inputs to streamflow across a range of time lags. In this way the short-term tail of the transit time distribution can be directly quantified for an ensemble of precipitation events, for direct comparison with the unit hydrograph, which quantifies the distribution of hydraulic celerities. High-frequency tracer time series from several experimental catchments will be used to demonstrate how this approach can be used to generate distinctive signatures of catchment behavior for testing model hypotheses.

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