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A statistical learning approach to extract information from hydrologic tracer timeseries

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Hydrologic tracer timeseries data (e.g. of stable water isotopes in rainfall and streamflow) have often been analyzed by extracting summary metrics (like the mean transit time) that provide some information about the storage and turnover of water in a watershed, but are laden with ad hoc, implicit, and questionable assumptions. Consequently, inferences about water age and runoff generation processes may be artifacts of the methods, rather than true implications of the tracer data. Potentially more reliable metrics have been suggested recently (e.g. the 'young water fraction') but these do not make full use of the information content of the data. The StorAge Selection (SAS) approach relaxes the common (highly questionable) assumption of steady-state flow, and thus allows the full time-variability of the transit time distribution to be captured. However until now its application has required ad hoc functional forms and relationships to be chosen for the underlying SAS function and its time-variability. This introduces artifacts that can skew estimates of the volume and sensitivity of water turnover rates within the catchment, inhibit inference of complex or multi-modal distributions, and is a subjective complication that presents a barrier to use of the approach.

Is it possible to make extract information about catchment water storage, turnover, and transit times without imposing ad-hoc assumptions, and instead allow the data to guide us? Can we obtain a clearer view of how these systems retain and release water of different ages at different rates, and vary how they do so over time? Can doing so allow us to better test hypotheses, tell richer stories about transport in dynamic hydrologic systems?

Three recent advances toward doing so have recently been developed. The first is to unify the analysis of flux quantity and age (or water celerity and velocity) in the form of an 'age-ranked storage-discharge relationship'. This relationship captures how the discharge of water of different ages changes when there is a change in the overall discharge. It thus provides a clearer view of the catchment mechanics driving streamflow generation and thus discharge age dynamics.

The second is Multiresolution Estimation of StorAge Selection (MESAS), a non-parametric statistical learning method for determining this relationship. This method avoids the need to specify a functional form – instead the shape of the function is iteratively determined from a coarse to a fine resolution, up to a limit at which the capacity of the data to meaningfully constrain the form is maximized.

The third is the development of computational techniques to accelerate the statistical learning implementation using an explicit Jacobian formulation and GPU acceleration.