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Determination of the Catchment Master Transit Time Distribution With Stable Water Isotopes

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Catchment-scale hydrologic response shows a wide range of temporal and spatial dynamics. Theoretically, it can be deconvolved into a sequence of impulse responses derived from the application of a specific (linear or non-linear) impulse response function (IRF) to every single precipitation input. In doing so, each IRF can be considered an independent transit time distribution (TTD) resulting from individual precipitation events. The shape of each event TTD is determined by a combination of catchment internal and external properties (topography, soil, climate), catchment states (terrestrial water storage), resulting flow paths (surface, subsurface) and the sequence of hydrologic forcing events (amount and timing of water and energy). Tracking a sequence of changing TTDs and combining the information that it provides into a single catchment response descriptor (the master transit time distribution (MTTD)) reveals valuable information about dominant flow paths and hydrologic partitioning at the catchment scale. The MTTD is created by superimposing all individual (input-weighted) TTDs and can serve as a catchment classification tool that incorporates catchment properties, storage states and flow paths. Since the exact shape of each individual TTD is unknown (as it depends on both internal and external catchment properties), we start out by tracking only one important descriptor of the TTD, its mean (mTT), while leaving other parameters constant. The mTT is often considered to be stationary and no generally applicable method exists that allows for the tracking of temporal variations of mTT, especially in catchments with large temporal variability in terrestrial water storage. We present a novel method to estimate varying mTT from stable isotope measurements. The approach is based on two principles. First, water leaving the catchment is a mixture of water with different transit times that entered the catchment at different locations. Therefore its final isotopic composition can be described by means of an IRF that lags and disperses the input impulse in time (creating slow and quick components). Second, the chemical variability of the outflow in relation to the chemical variability of the inflow decreases with time (due to more mixing with older water components). Using the transient chemical variability as a tool to calibrate the IRF model hands us the key to tracking variable mTT. Time series of $\delta 2$H in precipitation and stream water were recorded over a period of three years in a small semi-arid catchment in the Santa Catalina Mountains near Tucson, AZ (USA). The variability within a moving window of the observed $\delta 2$H time series in stream flow is reproduced with a dispersion IRF that uses the $\delta 2$H time series of precipitation as input. The model is calibrated for each time step by adjusting the mTT of the IRF (with shorter mTT producing higher variability and vice versa). The resulting time series of mTTs defines a specific TTD for each time step of the modeling period. With this information, a characteristic MTTD is produced for the catchment.