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Physical interpretation of parameters in the gamma distribution: implications for time-variant transit time assessment in catchments.

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Transit time distributions (TTD) are being increasingly used as tools for exploring catchment hydrological function and a means of process conceptualization. Estimating the parameters of TTDs usually involves relating the temporally varying input concentration of a conservative tracer to the signal in the stream. To date, most studies have been confined to single sites or to a small number of nested catchments with short ($<$ 2 years) data collection periods. This may constrain the significance and transferability of findings as only a narrow range of the climatic variability in a spatially restricted area is captured. We used long-term ($>$ 10 years) data sets of ^{18}O and Cl^- from 38 catchments (ranging in size from 0.5 - 1600km^2), in 8 geomorphically and climatically distinct parts of the Scottish Highlands. The most appropriate TTD to model the tracer signals in streams using convolution integrals was the gamma distribution: The associated α and β parameters allow more flexibility to parsimoniously account for non-linearities in the system response than other distributions. The resulting mean transit times (MTT = $\alpha\beta$) ranged between 40 and 1500 days for the individual catchments. Multiple linear regression models suggested that catchment MTT is largely controlled by the proportion of responsive (i.e. overland flow generating) soil cover, drainage density and precipitation intensity (R^2 = 0.90). Although calibrated only for catchments of up to 35km^2, these controls also hold for catchments of up to 1600km^2 in other regions of the Scottish Highlands.

An additional inter-annual analysis of TTDs in 3 selected catchments illustrated the time-variant nature of TTDs and explored possible physical interpretations for α and β. The individual annual MTTs were much more variable than the MTT for the entire observation period. Using multiple precipitation indices, it was found that parameter β was systematically related to changes in climatic conditions and therefore controlling the temporal dynamics of MTTs. Consistent with previous analysis, it was shown that α varies spatially between catchments, rather than temporally, and that it appears to be influenced by aspects of catchment structure and organization that control the non-linearities in catchment hydrological response. This was illustrated by low α values ($\alpha < 0.5$) for catchments with predominantly responsive soils, which exhibit high degrees of non-linearity caused by rapid activation of preferential and overland flow paths, and higher values ($\alpha \geq 0.5$), for catchments with more freely draining soils, dominated by subsurface flows which move towards the theoretical response of a linear reservoir (α = 1). The relationship between β and precipitation characteristics was subsequently used to express β in a given catchment as a climate-related function to estimate time-variant TTDs, which should give more accurate characterization of the timing and magnitude of peak solute fluxes. In the wet, cool climatic conditions of the Scottish Highlands, the fluctuations in transit times from the time-variant TTD were shown to be roughly consistent with the variations of MTTs revealed by inter-annual analysis.