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The importance of sediment network connectivity for assessing erosion rates using cosmogenic isotopes

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The estimation of time-averaged, catchment-wide erosion rates using cosmogenic nuclide concentrations in alluvial sediments is becoming increasingly commonplace in catchments of a wide range of sizes, and in a variety of climatic and tectonic settings. The underlying theory for the method assumes that river sediment collected at some point in a catchment gives an integrated estimate of the erosion rate in the entire catchment over a timescale determined by the isotope being used. Inverse 1-Dimensional numerical modelling is used here to apportion the accumulation of cosmogenically-derived nuclides between different phases in grain transport, namely: pre-detachment from bedrock; hillslope colluvium (both diffusive and landslide processes are modelled); and, alluvial. The model reconstructs the histories of individual sediment grains using a Monte Carlo approach. Data for model validation are provided by measurements of ^{10}Be in bedrock and alluvial samples from the Rio Torrente catchment, Spain. This is an active orogenic setting in which rates of uplift and erosion are rapid. Soils are thin ($<$1m) and shallow landslides dominate hillslope sediment movement in large parts of the catchment. The alluvial channel is very steep with a mixed bedrock-alluvial bed. Using boundary condition and parameter values from the site and/or literature relating to similar settings, the model predicts measured ^{10}Be concentrations reliably if a suitable estimate of the diffusive (creep) hillslope transport rate is used. Proportions of total isotope concentration measured at the catchment outlet vary, but typically over 85% of total isotope concentration is acquired during hillslope transport. This reflects the strong dependence of isotope production rate on altitude, and the efficient evacuation of sediment once it enters the river channels. Consequently, the processes of transfer of sediment from hillslopes to channels and from tributaries into the

main channel are critical as these provide storage areas during which nuclide concentration may accumulate or decay (depending on the duration and elevation of storage, whether a grain is buried or at the surface, and the half-life of the measured nuclide). The model assumes instantaneous hillslope-alluvial sediment transfer. The effect of delaying this exchange can be modelled by introducing an alluvial storage term to the model. This increases the proportion of isotope concentration acquired while grains are in the river channel only slightly in the Torrente. However, generalised modelling of larger catchments with increased fluvial storage shows that the residence time of grains at the hillslope-alluvial interface can account for much higher (up to 40% in some cases) proportions of total isotope concentration. When catchment-wide erosion rates are calculated from measured isotope concentrations, uncertainties increase rapidly as the duration of storage increases. Interpreting such erosion-rate estimates thus requires that storage and transfer processes are better understood. This reasoning applies equally to storage at river confluences, where tributary fans delay sediment throughput and lead to changes in isotope concentration that are not directly related to catchment erosion rates.