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Tracking sediment across eroding landscapes: numerical modelling of probability density functions of detrital terrestrial cosmogenic nuclide concentrations

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Cosmogenic nuclide concentrations (CNCs) in alluvial sediments are now routinely being used to estimate time- and space-averaged catchment erosion rates. Assessing the validity and meaningfulness of these estimates, however, requires a much better understanding of the interconnections between tectonics, geomorphic processes and the probability distribution of CNCs in the sediments leaving a catchment. Each individual sediment grain has a unique history as it is eroded from the parent material, transported via a wide range of hillslope processes into the fluvial network and through this network to the point of deposition. Grains can accumulate cosmogenic nuclides prior to their detachment and throughout all the stages of transport and storage if they are not deeply buried or shielded. Different histories of exhumation, transport and storage lead to different distributions of CNCs in the sediment leaving an area and, therefore, the probability density function (PDF) of CNCs in sediments provides a signature of the tectonic and/or climatic setting(s) of the sediment's source area.

A version of the SIBERIA surface process model (SPM) with sediment tracking and cosmogenic nuclide accumulation modelling capabilities is used here for assessing the CNCs to be expected under different geomorphic scenarios, thereby providing a sounder theoretical base for the empirical, field-based measurements. The PDF of CNCs is predicted by forward modelling, using the high performance computing capabilities of a Monte Carlo production facility, the elevation histories of a very large

number of ‘parcels’ of sediment as their parent rock comes to the Earth’s surface and the sediment is eroded and moved through a catchment. For every model time step the SPM produces an instance of the modelled terrain by updating the elevation value of each domain node according to a sediment mass balance equation. A nuclide production rate is calculated for each of the nodes of every terrain instance as a function of the node’s latitude, elevation and degree of topographic shielding. This production rate and the time a given sediment parcel spends at every node that it passes on its route downstream determines that sediment parcel’s final nuclide concentration.

Data for model validation will be provided by measurements of cosmogenic ^{21}Ne concentrations in $16 - 22$ mm diameter quartzite clasts ($n \approx 60$) that have been collected from a ≈ 200 m reach of the Gaub river, Namibia, along with measurements of cosmogenic ^{10}Be concentrations in 14 amalgamated fluvial sediment samples collected from the outlets of the Gaub’s tributaries. The study area is characterised by the existence of two morphologically distinct regions: an upper, higher elevation ($\bar{z} \approx 1900$ m), low relief region, and a lower presenting a zone of very high relief that ends in a small low elevation ($\bar{z} \approx 1000$ m), low relief zone. As suggested by the $process \rightarrow form$ causality and confirmed by results from an earlier 2D GIS-based implementation of this model, the presence of these two morphologically distinct areas results in complex TCN PDFs that are ideally suited to illustrating the usefulness of the modelling work attempted by this project.