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Modelling stratigraphic grain size response to changing rainfall frequency and magnitude in threshold landscapes

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Quantifying landscape sensitivity to climate change remains a key challenge in the Earth Sciences. Spatial and temporal grain size trends in stratigraphy are one way to decode past changes in environmental boundary conditions. In principle, the calibre and distribution of grain sizes present in a stratigraphy should reflect past discharge conditions. In the geological record we can use climate proxies to estimate the average rainfall conditions over the long term, but can we assume that grain size trends in stratigraphy are the integrative property of mean rainfall conditions? Intrinsic landscape thresholds may filter out lower magnitude rainfall events, thus limiting the types of water discharges sufficient to do work on the landscape. Such landscapes may only transport material during large, threshold-exceeding discharge events, complicating the interpretation of grain size trends in the field. We hypothesise that for threshold systems the stratigraphic record may preferentially record low frequency, high magnitude events that differ significantly from average conditions.

We explore the potential for changing rainfall magnitude and frequency to alter grain size trends in stratigraphic architecture using a 1D catchment-basin model with sediment erosion and deposition governed by a single advection-diffusion equation. Our model linearly couples sediment transport and initial grain size to a spatially uniform 'effective' rainfall, calculated from synthetic rainfall distributions and landscape thresholds. The downstream propagation of initial grain size in our basins is calculated using a self-similar fining model as a function of sediment volume and profile of depositional whilst the generation of accommodation space is kept fixed.

Synthetic rainfall distributions in the model are produced from thousand year simulations of weather station rainfall PDFs across Inyo County, California, as these capture a wide range of arid to semi-arid rainfall distributions. We measure the magnitude and proportion of rainfall events above a given threshold for each distribution to produce different effective rainfall values where average rainfall may otherwise be the constant over the thousand-year simulation.

Our model shows that for threshold landscapes the variability of rainfall intensity can strongly influence stratigraphic architecture both as a function of the sediment volume and grain sizes deposited in the basin. We show these insights provide a new means to interpret trends in sediment calibre observed on alluvial fan surfaces in the hyper arid and climate-sensitive Death Valley, where changes in GCM-derived average annual rainfall from the LGM to the present Holocene conditions appear insufficient to produce the pronounced changes in grain size observed in the field.

In general, our model highlights why it is imperative to consider the shape of past rainfall distributions to appropriately interpret grain size trends in climate-sensitive and threshold-controlled sediment routing systems.