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Modeling a mountain basin sediment cascade

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Mountain basins are most sensitive to climate change because of the dependence of snow and ice melt processes, surface weathering and erosion on air temperature, combined with their rapid rainfall-runoff response. Consequently, sediment yield from mountain basins will also likely be related to climate variability. Constructing sediment budgets is the first step towards understanding the interaction of climate and earth-surface processes. Recently, mountain basin sediment transfer has been conceptualized as a sediment cascade in which, following erosion, sediment travels through multiple cycles of storage and remobilization before exiting the basin. However, few studies have extended this concept beyond the identification and quantification of individual processes and storage units. In this study we have developed a probabilistic sediment cascade model based on a sediment budget spanning more than 4 decades in the Illgraben, an active, debris-flow prone basin in the Swiss Alps. We use this model to investigate the role of thresholds and hydrological and sediment storage dynamics in the transformation of the observed probability distribution of slope failures into that of debris flows.

The sediment cascade model consists of a hydrological and sediment module, both of which are based on a spatially lumped storage reservoir representation of the involved physical processes. Water and sediment are generated and routed according to conceptual rules and thresholds which we define and calibrate based on observations. We run simulations with stochastic sediment input drawn from the power-law distribution of slope failures and observed climatic variables (precipitation and air temperature) at the daily resolution for the period 2000-2009, and investigate the outputs of the model in terms of (1) the probability distribution and (2) the timing of sediment discharge events compared to observed debris flows. The triggering of debris flows in our model is conditioned by the presence of runoff in the channel system. Our results show that it is both the availability of sediment in storage together with the dynamics of sediment supply from hillslopes into channels that determine the statistical distribution of debris flow volumes. We demonstrate how supply limitations in the channel reservoir decrease the volume of potentially large debris flows and result in a steepening of the power-law tail of the distribution of debris flow volumes.

Experiments with different sediment input procedures suggest that the stochastic sediment input is an important element in the realistic reproduction of sediment transfer dynamics and ultimately the probability distribution of sediment discharge. Future work will focus on using the sediment cascade model with a stochastic climate as opposed to observations, and studying the sensitivity to climate versus sediment input. This work is of significance in that it addresses the uncertainties involved in the reconstruction of climate change from sedimentary records.