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Sediment cascade modelling for stochastic torrential sediment transfers forecasting in a changing alpine climate

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Alpine ephemeral streams act as links between high altitude erosional processes, slope movements and valley-floor fluvial systems or fan storage. Anticipating future mass wasting from these systems is crucial for hazard mitigation measures. Torrential activity is highly stochastic, with punctual transfers separating long periods of calm, during which the system evolves internally and recharges. Changes can originate from diffuse (rock faces, sheet erosion of bared moraines), concentrated external sources (rock glacier front, slope instabilities) or internal transfers (bed incision or aggradation).

The proposed sediment cascade model takes into account those different processes and calculates sediment transfer from the slope to the channel reaches, and then propagates sediments downstream. The two controlling parameters are precipitation series (generated from existing rain gauge data using Gumbel and Extreme Probability Distribution functions) and temperature (generated from local meteorological stations data and IPCC scenarios). Snow accumulation and melting, and thus runoff can then be determined for each subsystem, to account for different altitudes and expositions.

External stocks and sediment sources have each a specific response to temperature and precipitation. For instance, production from rock faces is dependent on frost-thaw cycles, in addition to precipitations. On the other hand, landslide velocity, and thus sediment production is linked to precipitations over longer periods of time. Finally, rock glaciers react to long-term temperature trends, but are also prone to sudden release of material during extreme rain events. All those modules feed the main sediment cascade model, constructed around homogeneous torrent reaches, to and from which sediments are transported by debris flows and bedload transport events. These events are determined using a runoff/erosion curve, with a threshold determining the occurrence of debris flows in the system. If a debris flow is triggered, it propagates downstream and changes volume, depending on direction shift (lateral deposits), changes in bed slope (deposition or erosion) and debris flow volume (bulking).

The model is applied to various torrential systems on which the model can be calibrated. The random sequence of precipitation events, annual variations in temperature, climate change affecting temperatures and/or precipitation produce a general trend in sediment production for a given torrential system. The results and sensibility analysis showcase the importance of mass wasting processes above streams, as well as the crucial role of rain-melt events in the spring and summer for alpine streams. The model correctly reproduces observed threshold behaviour of the stream system by external forcing, and stock exhaustion following an increase in extreme precipitation events.

The model results, especially the size/frequency distribution of debris flow volumes are crucial to maintain mitigation measures such as retention dams, and give clues for future sediment cascade modelling.