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Unravelling the evolution and avulsion mechanisms of debris-flow fans

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Debris flows are water-laden masses of soil and fragmented rock that rush down mountainsides and spill out onto valley floors and alluvial fans, where they can devastate people and property. Expansion of human population into mountainous regions and the effects of global warming have increased the hazardous effects of debris flows over the last decades. Debris-flow channel avulsions (channel shifts) are critical to debris-flow fan evolution and hazard mitigation, because avulsions distribute debris flows and associated hazards through space and time. However, both the long-term evolution of debris-flow fans and their avulsion process are poorly understood. We aim to unravel the spatio-temporal patterns of debris-flow fan evolution and their avulsion mechanisms and tendency.

Here we present a combined analysis of laboratory experiments; field data (repeat topographic analyses and dendrogeomorphological and lichenometrical reconstructions from debris-flow fans in Japan, USA, Switserland and France) and numerical modelling, identifying the main drivers of avulsion on debris-flow fans and their associated spatio-temporal evolution. We show that there are two main processes driving avulsions on debris-flow fans operating at two distinct timescales. (1) Channel plugs locally block channels forcing subsequent flows to avulse and follow alternative flow paths. The frequent but stochastic nature of channel-plug formation leads to a partly unpredictable avulsion and spatial depositional patterns on timescales of a few events. (2) Nevertheless, over timescales of tens of events the average locus of debris-flow deposition is observed to gradually shift towards the topographically lower parts of a fan, highlighting the importance of topographic compensation in the avulsion process on debris-flow fans.

We further show that the magnitude-frequency distribution of the debris flows feeding a fan strongly affects the spatio-temporal patterns of deposition. Our results have strong implications for hazard mitigation and may help in timely identifying potential channel avulsions and future flow path prediction.