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Challenges in the predictive simulation of cascading landslide processes

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History has shown that cascading landslides, such as the debris avalanches from Huascarán in 1962 and 1970, the Kolka-Karmadon rock-ice-avalanche in 2002, or the rock avalanche-debris flow event of Bondo in 2017, can be very destructive due to their high energies, velocities and volumes. They can lead to large numbers of fatalities, huge material damage, and disruption of critical infrastructure.

Cascading landslides are a specific class of multi-hazard events in which one type of motion transforms into another or an initial, primary movement triggers a secondary process. High-mountain areas are particularly prone to this type of landslides due to their dynamic, rapidly changing environments and their high relief. For example, an initial rock fall can reach snow or ice masses and transform into a rock-snow- or rock-ice-avalanche, or into a debris flow. Physically-based numerical modelling is often used for the attempt to predict such events as a basis for the design of risk management strategies such as early warning systems. However, we identify at least two specific types of challenges making accurate and reliable predictions highly difficult:

- (a) The dynamic behaviour of such process chains, especially in the transition phase, is not yet fully understood. Existing models are either developed for (i) fall or (ii) flow processes. Whereas substantial progress has been made in previous years in the integrated simulation of flow-type movements, no software which fully and directly considers the transformation of fall to flow processes is known to the authors. Therefore, it is not yet possible to simulate fall-flow sequences of cascading landslide events with one single tool. Model chains have to be used instead, which have a limited capacity for appropriately representing the transition phase between the two types of processes.
- (b) Limited knowledge on the initial conditions and input parameters represents another severe limitation. Model input relies on available information on previous events and on certain characteristics of the (possible) release and impact area. Obviously, the quality of the data set is significantly influencing the model results. Whereas the scientific community is far away from exact predictions of landslide impact, an important objective should consist in better constraining the definition of possible scenarios to be considered for hazard and risk

management.

For the reasons highlighted, it remains highly challenging to adequately predict the impact areas, energies, and travel times of cascading landslides in space and time. Nevertheless, stakeholders require such predictions for decisions on sustainable hazard and risk management strategies. Therefore, the aims of this study are (i) to evaluate possibilities to appropriately combine models for fall and flow processes and (ii) to examine data acquisition methods for the model input. Furthermore, (iii) appropriate strategies to present and to communicate simulation results need to be discussed.