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Modeling rock avalanche propagation onto glaciers

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Rock-ice avalanches are rare but not uncommon in high-mountain regions. Rock slopes in permafrost conditions can experience slope instabilities, in particular in relation with permafrost degradation processes. Clusters of landslides, including rock falls and rock avalanches, are often triggered by seismic shaking and they are documented for more recent, historical earthquakes which involve large glacierized mountain walls.
Rock-ice avalanches range in volume from a few cubic meters to tens million of cubic meters.
When they occur in a glacial environment, rock avalanches are controlled by the presence of ice in the moving material and by the motion over the glacial basal surface. Melting of ice during propagation can reduce granular friction by fluidization effects and saturation of the basal landslide material; the friction can be further reduced through sliding over the glacier because of the lower shear resistance of ice.
This work focuses at evaluating the mobility of glacial debris avalanches for hazard analyses purposes by providing a set of calibrated cases. We model the propagation of several rock avalanches selected among well known historical events. The events were either triggered by Denali (2002) and the Anchorage (1964) earthquakes occurred in Alaska and have volumes ranging from 5 M m3 to 25 M m3.
We replicate the glacial rock avalanches using models which solve the depth averaged quasi-3D equation for motion using either (i) the Smoothed Particle Hydrodynamics (McDougall and Hungr 2004) and (ii) a finite element (Chen and Lee, 2000) methods in a Lagrangian reference frame. The codes allow for different rheological models and earth pressure yield criteria.
The post-event topographies are extracted from the ASTER satellite grid, with a cell size of 22 m. The pre-event topographies were reconstructed by modifying the original terrain data in the area interested by the detachment and the deposition outlined by available maps and morphological evidences (Shreve, 1966; Post, 1967; Jibson et al., 2006). The event reconstructions and the back analyses are based on the observations available from the literature. We test the performance of the Frictional and Voellmy rheologies and we define, for each rheology, a range of values for the parameters which best replicate the propagation of the ice-rock avalanches.
The Voellmy rheology best performs at replicating the landslide propagation with respect to the frictional one. The best fitting parameters obtained for ice-rock avalanches span in a narrow interval, and are lower than those typical of other rock and debris avalanches. As an example, the bulk basal friction angles (the sole parameter required in the frictional rheology) range within 6° and 12° whereas typical values for rock debris avalanches vary from 11° to 31°. Moreover, the best fitting values for the friction angle are inversely related to the event volumes.
The consistency of the back-analyzed parameters is encouraging for a possible use of the model in the perspective of hazard mapping. These parameters could be useful to predict the possible evolution of future events.