Submitted Abstract

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Abstract

Erosion significantly affects the dynamics of gravity-driven mass flows and may lead to the formation of roll waves and/or erosion-deposition waves. Such wave phenomena can lead to severe flow variations and large flow depth, which have been one of the key concerns in many artificial and natural mass flows. Compared to roll waves which have moving material between the wave crests, erosion-deposition waves have completely stationary regions between individual crests. Although frequently observed from experiments and field events, roll waves, erosion-deposition waves and their transitions are challenging to be modelled under real-scale conditions involving complicated terrain and flow dynamics. Here, we study various erosion and entrainment behaviors as well as wave phenomena in snow avalanches using the material point method (MPM), finite strain elastoplasticity and critical state soil mechanics. With varied snow properties, distinct erosion patterns are obtained and analyzed with the mass change rate. When there is significant eroded and entrained mass, properties of released snow and erodible bed snow have clear correlations with the eroded mass, but not with the entrained mass, disclosing the difference in erosion and entrainment. Both enhanced and inhibited avalanche mobilities due to erosion and entrainment are captured under different conditions of snow properties and lengths of release and erodible zones. Furthermore, a snow avalanche at Vallée de la Sionne (VdlS) in Switzerland is modelled with consideration of bed erosion. The properties of the simulated snow are firstly calibrated with the deposition depth of the VdlS avalanche measured with a laser scanner. The dynamic behaviour of the avalanche is then analysed in terms of the different waves, the flow depth evolution at a fixed location, as well as the temporal and spatial evolution of the flow velocity. It is observed that both roll waves and erosion-deposition waves are naturally captured from the simulated avalanche. The flow depth evolution from the simulation shows satisfactory agreement with the field data measured with FMCW radar. The model is also able to recover the spatial evolution of the wave activity from release to deposit, which was measured in the field experiment using a radar. With both the numerical and field investigations, this study offers new perspectives on wave behaviour and provides a validated numerical approach for exploring waves in granular flows like snow avalanches. It may also stimulate the development of advanced erosion and entrainment models for large-scale avalanches.