Computational modeling of snow avalanche dynamics using the material point method

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Abstract

Snow avalanches cause significant fatalities and profound economic losses every year in cold and mountainous regions like the Alps. Numerical approaches can offer unparalleled and underpinning insights into the mechanics of snow avalanches, and can provide efficient analyses for avalanche mitigation. In this study, we investigate the dynamic behavior of snow avalanches using the material point method (MPM) and an elastoplastic constitutive law for porous cohesive materials. By virtue of the hybrid Eulerian-Lagrangian nature of MPM, processes involving large deformations, collisions and fractures, like snow avalanches, can be well handled. Meanwhile, the elastoplastic model enables us to recover the mixed-mode failure of snow, including tensile, shear and compressive failure. The MPM modeling is firstly calibrated and verified with simulations of real snow avalanches, in terms of avalanche front evolution, flow path, and density of avalanche deposit. We then investigate snow avalanche dynamics and flow regime transitions by systematically examining key mechanical factors including snow properties and slope geometry. Four flow regimes of snow avalanches reported from real observations are identified, and unique flow features are characterized. The MPM approach serves as a novel and promising pathway towards quantitative analysis of real-scale snow avalanches in complex terrain.