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The material point method for simulating dense snow avalanches over complex real terrain

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Various dynamics models can reproduce the motion of avalanches from release to deposition. These models often simulate a conceptual avalanche, adopt depth-averaged approaches and do not resolve variations along flow depth direction, and thus have clear limitations. This study presents three-dimensional, full-scale modeling of dense snow avalanches performed using the complex real terrain of the Vallée de la Sionne avalanche test site in Switzerland. We use the material point method (MPM) and a large-strain elastoplastic constitutive law for snow based on a Modified Cam Clay model. In our simulations, various and transient avalanche flow regimes are simulated by setting distinct snow properties. Snow avalanches are investigated from release to deposition. Detailed simulation results include the initial failure patterns, the mechanical behavior during the flow, and the characteristics of the final avalanche deposits. More specifically in the release zone, we can observe brittle and ductile fractures depending on the defined snow properties. During the flow phase, we monitor the temporal and spatial variations of snow density in the avalanche. In particular, cohesionless granular flows, cohesive granular flows, and plug flows are associated with snow fracture, compaction, and expansion. Finally, we can observe the structure of the avalanche deposit surfaces which show distinguishable differences in terms of smoothness, granulation, and compacting shear planes. This new model can offer a quantitative analysis for studying avalanches in different regimes and provide a powerful tool for exploring the dynamics of full-scale avalanches on complex real terrain, with high physical detail.