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Numerical simulations of wet snow avalanches: interplay between cohesion and friction

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Wet snow avalanches present distinctive features such as unusual trajectories, peculiar deposit shapes, and a rheological behavior displaying a combination of granular and pasty features depending on the actual snow liquid water content. Complex transitions between dry (cold) and wet (hot) flow regimes can also occur during a single avalanche flow. In an attempt to account for this complexity, we report on numerical simulations of avalanches using a frictional-cohesive rheology implemented in a depth-averaged shallow-flow model. Through extensive sensitivity studies on synthetic and real topographies, we show that cohesion plays a key role to enrich the physics of the simulated flows, and to represent realistic avalanche behaviors. First, when coupled to a proper treatment of the yielding criterion, cohesion provides a way to define objective stopping criteria for the flow, independently of the issues incurred by artificial diffusion of the numerical scheme. Second, and more importantly, the interplay between cohesion and friction gives raise to a variety of nontrivial physical effects affecting the dynamics of the avalanches and the morphology of the deposits. The relative weights of frictional and cohesive contributions to the overall stress are investigated as a function of space and time during the propagation, and related to the formation of specific features such as lateral levées, hydraulic jumps, etc. This study represents a first step towards robust avalanches simulations, spanning the wide range of possible flow regimes, through shallow-flow approaches. Future improvements involving more refined cohesion parameterizations will be discussed.