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Probabilistic avalanche run-out analysis in complex terrain

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The initial and boundary conditions as well as the model parameters that are needed to calculate the run-out of snow avalanches with dynamic models are uncertain both due to model deficiencies and the stochastic nature of meteorological conditions. This translates on the one hand into an (often underestimated) uncertainty in the predictions of snow avalanche run-out from a seemingly deterministic calculation. On the other hand the extent of the hazard zone depends strongly on the frequency of the simulated event. For practical reasons, the epistemic uncertainties are usually ignored in practical hazard mapping, and the dependence on the assumed event frequency is approximated by using distinct sets of model parameters and (typically) fracture depth.

Methods for probabilistic calculation of avalanche run-out were developed at least 20 years ago, but have rarely been applied in practice, apparently for two reasons: The first is the required computational resources, which typically is 1000–10,000 times higher than in the conventional approach. The second reason is that neither legislation nor administrative routines are adept at handling uncertainty – avalanche hazard is categorized into a small number of zones, whose boundaries are required to be infinitely thin lines. However, in the same period the concept of risk has begun to take hold even in legislation and administration and has led to a need for a partly probabilistic approach to avalanche simulation. Moreover, Monte Carlo simulations with 1D dynamical models have become easily feasible thanks to powerful computers with parallel processing capability.

In this paper, we demonstrate that probabilistic run-out analysis can also be carried out routinely in complex terrain, where at least a depth-averaged model in two horizontal dimensions is required to capture the spatial variability of avalanche hazard. To this end, we extended MoT-Voellmy, a fast first-order finite-difference code of the Voellmy type, to allow for Monte Carlo simulations with a choice of probability distribution functions for the fracture depth, the shear strength of the entrainable new-snow layer and the two dimensionless friction parameters. The case studies demonstrate directly the extent of variation due to uncertainty in the model calibration and the influence of entrainment. We compare the dependence of the run-out distance on the avalanche return period with the predictions of the purely topographic-statistical alpha-beta model. The most important open problem is our lack of knowledge about the correlations between the stochastic parameters.