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Towards an Improved Parameter-Free Entrainment Model for Snow Avalanches

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On physical grounds, the rate of bed entrainment in gravity mass flows should be determined by the properties of the bed material and the dynamical variables of the flow. Due to the complexity of the process, most entrainment formulas proposed in the literature contain some ad-hoc parameter not tied to measurable snow properties. Among the very few models without free parameters are the Eglit–Grigorian–Yakimov (EGY) model of frontal entrainment from the 1960s and two formulas for basal entrainment, one from the 1970s due to Grigorian and Ostroumov (GO) and one (IJ) implemented in NGI's flow code MoT-Voellmy. A common feature of these three approaches is their treating erosion as a shock and exploiting jump conditions for mass and momentum across the erosion front. The erosion or entrainment rate is determined by the difference between the avalanche-generated stress at the erosion front and the strength of the snow cover. The models differ with regard to how the shock is oriented and which momentum components are considered. The present contribution shows that each of the three models has some shortcomings: The EGY model is ambiguous if the avalanche pressure is too small to entrain the entire snow layer, the IJ model neglects normal stresses, and the GO model disregards shear stresses and acceleration of the eroded mass. As they stand, neither the GO nor the IJ model capture situations—observed experimentally by means of profiling radar—in which the snow cover is not eroded progressively but suddenly fails on a buried weak layer as the avalanche flows over it. We suggest a way to resolve the ambiguity in the EGY model and sketch a more comprehensive model combining all three approaches to capture gradual entrainment from the snow-cover surface together with erosion along a buried weak layer.