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Comparative Analysis of Geophysical Flow Models: Voellmy, μ(I), and μ(R) Rheologies

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The experimental-based $\mu(I)$ rheology is now prevalent to describe the movement of gravitational mass flows. Though the $\mu(I)$ rheology has been successfully applied to the modelling of historical debris flows and rock avalanches, its physical implication is not fully understood. In this study, we re-formulate the $\mu(I)$ rheology as a Voellmy-type relationship, which is composed of a Coulomb friction term and a turbulent term. We find that different from the classic Voellmy rheology (ξ is a constant), the turbulent coefficient ξ in the $\mu(I)$ rheology is heavily dependent on the avalanche height and velocity, indicating the shear-thinning features. However, as $\mu(I)$ rheology is a pure function of velocity (for a constant height), the friction exhibits no change during the acceleration and deceleration stage. With this purpose, we introduce a newly proposed $\mu(R)$ rheology that relates the friction to the production and decay of fluctuation energy (granular temperature) R. Using one-dimensional block models, we show the equivalence of I and R, and elucidate why similar results of $\mu(I)$ and $\mu(R)$ rheologies are easily obtained. Ultimately, this comparative analysis offers valuable insights into improving geophysical flow models, enhancing our understanding of flow behavior's dependence on various factors and leading to more accurate assessments and mitigation of geophysical hazards.