EGU21-5337, updated on 16 Jan 2022
https://doi.org/10.5194/egusphere-egu21-5337
EGU General Assembly 2021

Formation of dry granular fronts and watery tails indebris flows

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Dry granular fronts and watery tails often develop in debris flows, but their formation mechanisms are still poorly understood. Dry bouldery debris flow fronts are often attributed to particle-size segregation, but idealized experimental mixtures of fluid and mono-disperse grains also exhibit the formation of dry fronts. This motivates the development of a new depth-averaged model that treats grain-water mixtures as a buoyancy and Darcy drag coupled multiphase medium. This system is able to describe the temporal and spatial evolution of the grain and water depths as well as the associated grain and water depth-averaged velocities. It considers the layered development of the flow and incorporates a shear velocity profile into the model, instead of the standard plug flow assumption that is employed by almost all debris-flow models. By revisiting Davies' moving bed flume experiments, it is shown that, in the under-saturated region, shear results in the surface layer of dry grains moving faster than the bulk and they are preferentially transported to the flow front to develop a dry snout. Conversely, in the over-saturated region, the flow thickness is sufficiently small that the water friction is stronger than the friction acting on the grains. As a result, the surface grains can move faster than the water and leave it behind. This novel theory provides a rational framework that describes the complete longitudinal profile of debris flows from the dry granular front to the pure watery tail without the need to consider particle-size segregation.