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Non-local rheology of stony debris flow propagating over a cohesionless sediment bed

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Velocity profiles of gravel-water mixtures observed in flume experiments often exhibit a double-slope behavior, with a lower narrower region where the velocity increases slowly, and an upper wider region often exhibiting a nearly linear behavior. Even though the flow can be classified within the grain-inertia regime, the overall profile seems to not conform to the power law (with exponent 1.5) distribution obtained by integrating along the normal to the flow the dispersive stresses envisaged by Bagnold (1954) in his pioneer work. Note that this formulation neglects the contribution to the velocity profile of the quasi-static (frictional) stresses that tend to dominate close to an erodible sediment bottom.
The present work investigates the possibility to find out a uniformly valid distribution of shear stress from the bottom to the flow surface. To this aim we follow a heuristic coherence length approach (GDR-MIDI, 2004) similar to the mixing length procedure commonly used to study the atmospheric boundary layer over canopy (see, e.g., Harmann and Finnegan, 2007).
A database built on 64 systematic debris flow experiments is used to disclose the general features of velocity profiles that establish within the body of almost steady water-sediment flows and the dependence of transport sediment volumetric concentration on the relevant parameters. The almost steady water-sediment flows considered in the study were generated by releasing a prescribed water discharge on a saturated layer of sediment (specifically, 3 mm gravel, 6 mm gravel, and 3 mm glass spheres) initially placed in a 10 m long and 0.2 m wide laboratory flume.
The analysis clearly indicates that stony debris flow conditions characterized the experiments. The mixing length does not result constant, as required by a Bagnold-like profile, but varies gradually, from zero at the flow surface, to a finite value near the erodible bottom. We discuss this structure in terms of shear stress distribution along the normal to the flow, with particular attention to the role played by frictional stresses near to the movable bed over which the debris flow propagates.