Geophysical Research Abstracts
Vol. 16, EGU2014-13593, 2014
EGU General Assembly 2014

A three dimensional two-phase debris flow model: Reduction to one free model parameter by linking rheology to grain size distribution and water content

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Attempts to model debris flow material either as a granular or as a viscous matter can not account for the wide range of debris flow processes, leading to the development of two-phase models with one phase accounting for the fluid and the other for the grains. Within this group of models, depth-averaged approaches are wide-spread, but since the rheology of true material is sensitive to pressure and shear gradient, three dimensional simulations are necessary to predict flows in complex geometries. Phase interaction can be modelled by solving the Navier-Stokes equation system for each phase and linking the phases with drag force models. However, this is a numerically expensive way that introduces a number of free parameters because too little is known about drag of non-spherical grains in non-Newtonian fluids. The approach proposed here solves one phase-averaged Navier-stokes equation system by applying the Volume of Fluid method, while still allowing to account for the sensitivity of the local rheology to pressure and shear in dependency to phase concentrations. One phase with a Herschel-Bulkley rheology represents the interstitial fluid and can mix with a second phase with the Coulomb-viscoplastic rheology of Pudasaini (Birte et al. 2013) that represents the gravel. A third phase is kept separate and represents the air.

This setup allows modelling key properties of debris flow processes like run out or impact in high detail. By linking the Herschel Bulkley parameters to water content, clay mineral proportion and grain size distribution (Kaitna et al. 2007, Yu et al. 2013), and the parameters of the Coulomb-viscoplastic rheology to the angle of repose of the gravel, a reduction to one free model parameter was achieved.

The resulting model is tested with laboratory experiments for its capability to reproduce the sensitivity of debris flow material to water content and channel curvature. Existing large scale flume experiments are used to corroborate the model and demonstrate its sensitivity to smooth or rough channel bed conditions, and a simulation of a large scale debris flow breaker is presented to show its applicability for practical problems.