Geophysical Research Abstracts
Vol. 18, EGU2016-5525, 2016
EGU General Assembly 2016

Basal entrainment by Newtonian gravity-driven flows

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Gravity-driven flows can erode the bed along which they descend and increase their mass by a factor of 10 or more. This process is called basal entrainment. Although documented by field observations and laboratory experiments, it remains poorly understood. We look into this issue by studying eroding dam-break waves. More specifically we would like to determine what happens when a viscous gravity-driven flow generated by releasing a fixed volume of incompressible Newtonian fluid encounters a stationary erodible layer (composed of fluid with the same density and viscosity).

Models based on depth-averaged mass and momentum balance equations deal with bed-flow interfaces as shock waves. In contrast, we use an approach involving the long-wave approximation of the Navier-Stokes equations (lubrication theory), and in this context, bed-flow interfaces are acceleration waves that move quickly across thin stationary layers. The incoming flow digs down into the bed, pushing up downstream material, thus advancing the flow front. Extending the method used by Huppert [J. Fluid Mech. 121, 43–58 (1982)] for modelling viscous dam-break waves, we end up with a nonlinear diffusion equation for the flow depth, which is solved numerically.
Theory is compared with experimental results. Excellent agreement is found in the limit of low Reynolds numbers (i.e. for flow Reynolds numbers lower than 20) for the front position over time and flow depth profile.

The Newtonian model has sometimes been used to describe the flow behaviour of natural materials such as snow and debris suspensions, but the majority of existing approaches rely on more elaborate constitutive equations. So there is no direct application of the results presented here to real flow conditions. Yet, our study sheds light on the mechanisms involved in basal entrainment. We provide evidence that the whole layer of loose material is entrained quickly once the flow makes contact with the erodible layer. As this process occurs on very short times, we can consider that the whole layer underneath the incoming flow is mobilized instantaneously.