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A model for entrainment in avalanches and debris flows based on PIV measurements of viscous gravity currents

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A simple experiment, designed to investigate entrainment in geophysical free-surface flows such as avalanches and debris flows, was performed using a dam break of viscous fluid which travels over a rigid bed until meeting a shallow layer of the same fluid at rest; this represents an avalanche which begins entraining material along its path. Particle image velocimetry (PIV) on a streamwise section in the entrainment zone allowed the measurement of internal flow velocities and the observation of entrainment processes such as bed excavation. Image processing techniques were used to identify surface height and the current/substrate interface.

A model was derived for this system, starting from the viscous Navier-Stokes equations for conservation of mass and momentum in domains including entrainable material. The flow is shallow and there is a rigid base, b(x) below z=0, representing the beginning of an entrainable region (modelled by a hyperbolic tangent). The free-surface kinematic boundary condition was used to link surface height and flow velocity, thus removing the need for depth-averaging.

The derived equations are solved using a parabolic solver to obtain the surface height and velocity field throughout the flow and the velocities are used in a simple advection scheme, examining the progression of the current/substrate interface at the base of the dam-break.

The numerical predictions closely match the experimental observations. Sharp surface height gradients diffuse quickly upon entry into the entrainment zone and the flow front accelerates. The current sinks into the bed and downstream bed material is forced upwards as found in the laboratory. The rates that the current excavates the bed, both in the vertical and streamwise directions, follow the same power laws as observed, and the surface height and internal velocities are in agreement in the model and the experiments.