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Entraining avalanches on slopes: results from experiments using PIV on viscoplastic gravity currents

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In order to conduct experiments simulating entrainment by avalanches on slopes, it was necessary to select a material which could act as both a stationary entrainable layer, mimicking undisturbed mud or snow, and a flowing mass, representing the flowing avalanche. Carbopol Ultrez 10, a viscoplastic "micro-gel" exhibiting a yield stress does just that: it remains plastic on a slope until an avalanche arrives and increases the shear within, reducing the viscosity in some or all of the material which may begin to flow as a fluid.
Carbopol is transparent and easily seeded with fluorescent tracking micro-particles, without significantly changing the material rheology. We take advantage of its properties to perform Particle Imaging Velocimetry (PIV) on an idealized avalanche, which flows into an entrainment zone where it interacts with a layer of stationary bed material. The internal velocity field is obtained for the flow as it passes over the loose material, showing the entrainment mechanisms active at different slope angles.
At the shallowest slope the avalanche is slower and mobilizes the bed almost entirely, causing it to slip along the base and buckle downstream of the front. At steeper slopes the avalanche shears the bed, yet appears to glide over it more easily with a smaller effect downstream. Increasing the concentration of the Carbopol and thus increasing the apparent yield stress leads to more destruction of the bed layer by the avalanche.
Three flow phases are identified, beginning with a "rolling phase" where the avalanche has minimal effect on the bed and seems to roll onto it as the front moves forward, then a "gliding phase" where the deposited fluid is pushed downwards and glides downstream, shearing the bed material. Finally, on the shallower slopes and at higher Carbopol concentration, the avalanche digs down to the rigid base, and completely displaces the bed material downstream, with its front riding atop an entirely mobilized plug-flow layer.