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Time-dependent free-surface viscoplastic flows down steep slopes; experimental results

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The objective of this work was to increase our understanding of gravity-driven geophysical flows by developping a new platform to simulate avalanches of fluid in the laboratory.

To simulate flow avalanches in the laboratory, we created a unique experimental setup consisting of a metallic frame supporting a reservoir, an inclined aluminum plane, and a horizontal run-out zone. At 6-m long, 1.8-m wide, and 3.5-m high, the structure is probably the largest laboratory setup of its kind in the world. In a dam-break experiment, up to 120 liters of fluid can be released from the reservoir down the 4-m long inclined plane. We precisely control initial and boundary conditions.

Compared to true avalanches, we are able to fully control the initial and boundary conditions, the nature of the flowing material (e.g., rheological properties), and the flow geometry. We can also measure all what is needed to test the efficiency and reliability of governing equations worked out for describing highly complex, non-equilibrium, nonlinear flows.

To measure the free-surface profile, a novel imaging system consisting of a high-speed digital camera coupled to a synchronized micro-mirror projector was developed. The camera records how regular patterns projected onto the surface are deformed when the free surface moves. We developed algorithms to post-process the image data, determine the spreading rate, and generate whole-field 3-dimensional shape measurements of the free-surface profile. We compute the phase of the projected pattern, unwrap the phase, and then apply a calibration matrix to extract the flow thickness from the unwrapped phase.

56 different flow configurations, with a wide range of inclinations, were finally tested with Newtonian and viscoplastic fluids. For each test, the evolution of the free surface was recorded in 3 dimensions. Different flow regimes were observed, which depend on: the plane inclination, the setup geometry, the volume, and characteristics of the fluid. Partial agreements were found between theoretical models and our results.