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Direct comparison of bedload transport in flume experiments and numerical simulations

Eric Deal (1), Qiong Zhang (2), Jeremy Venditti (3), Ken Kamrin (2), and Taylor Perron (1)

(1) Department of Earth, Atmospheric and Planetary Science, MIT, Cambridge, Massachusetts 02139, USA, (2) Department of Mechanical Engineering, MIT, Cambridge, Massachusetts 02139, USA, (3) Department of Geography, SFU, Burnaby, V5A 1S6, Canada.

Empirical sediment transport models have common characteristics suggestive of the underlying physics, but mechanistic explanations for these characteristics are lacking due to an incomplete understanding of the fundamental physical mechanisms involved. In order to improve our understanding of channel-scale sediment entrainment and transport we are studying the detailed mechanics of fluid-grain interactions using a combination of laboratory flume experiments, advanced numerical simulations, and granular mechanics theory.

Hydrodynamic interactions on the scale of several grains can be key to sediment transport problems, therefore it is desirable to explicitly model such interactions. However, simulating particle-fluid interactions explicitly is both challenging and computationally demanding. To achieve this, we developed a numerical simulation based on a discrete-particle plus Lattice-Boltzmann fluid method (LBM-DEM). This method tracks discrete particles interacting with each other through contact laws while mechanically coupled to a dynamic interstitial fluid, and is particularly well suited to moving boundary value problems such as ours. However, to identify gaps and issues with our understanding of the relevant physics, such simulations must be tested.

To provide a quantitative, real-world benchmark, we performed a series of carefully instrumented laboratory flume experiments observing bed-load transport of spherical grains in a simple channel geometry over a wide range of flow conditions from the threshold of motion to near-suspension. Using high-speed cameras coupled with computer-vision based particle tracking, we tracked the majority of grains in the grain bed and water column, with track paths stretching over several hop-lengths. Flow fields are also observed using particle image velocimetry (PIV) and we further apply particle tracking to images from the PIV camera, providing simultaneous observations of grain and fluid motion. Taken together, these observations allow us to compare grain-scale physical phenomena in our experiments with our numerical simulations in detail.

We have set up our simulations with boundary conditions and parameters chosen to reproduce the experimental setup. This facilitates direct comparisons with our laboratory measurements of grain and fluid motion. We discuss the ability of these simulations to emulate our experiments, the benefits of which are twofold: where the simulations work well, we use them to observe grain-scale dynamics that would be difficult or impossible to measure in a laboratory setting or in the field. But we also learn from situations in which the experiments and simulations diverge, leading to improvements in both the simulations and our understanding of how fluid-grain interactions influence sediment transport.