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A multi-grain reduced-complexity model for step formation and stability in steep streams

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We present a multi-grain particle-based reduced-complexity model for the simulation of the formation and stability of step-pool morphology by specifically considering the granular interactions between sediment and river bed leading to entrainment and deposition of grains. The model CAST2 (Cellular Automaton Sediment Transport), based on the uniform-size model of Saletti et al. [2016], contains phenomenological parameterizations of sediment supply, bed load transport, particle entrainment and deposition, and granular interactions in a cellular-automaton space. CAST2 simulates the effect of different grain sizes by considering two types of particles: fine grains, which can be mobilized by any flow, and coarse grains, whose mobility is flow-dependent.

The model has been applied to test the effect of granular forces on step formation and stability in step-pool channels, as hypothesized in the jammed-state framework by Church and Zimmermann [2007]. The jamming of particles in motion and their enhanced stability on the bed are modelled explicitely: in this way steps are effectively generated during high-flow periods and they are stable during low flows when sediment supply is small. Moreover, model results are used to show which are the fundamental processes required to produce and maintain steps in steep streams and these findings are consistent with field observations. Finally the effect of flood frequency on step density is investigated by means of long stochastic simulations with repeated flood events. Model results show that systems with high flood frequency are characterized by greater step density, due to the dominance of step-forming conditions.

Our results show the potential of reduced-complexity models as learning tools to gain new insight into the complex feedbacks and poorly understood processes characterizing rapidly changing geomorphic systems like step-pool streams, pointing out the importance of granular effects on the formation and stability of the step-pool morphology.

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