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Exploring fluvial morphodynamics through scales

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Surface processes control mass transfer efficiency on Earth, responding to tectonic and climatic forcings. These forcings impact landscape dynamics across a wide range of temporal scales, from individual events (e.g., storms) to geological time spans (e.g., Cenozoic climate cooling). Bridging these temporal scales poses a significant challenge for Landscape Evolution Models (LEMs). While LEMs are conventionally employed to study the effects of climate or tectonics on landscape dynamics over geological time, numerical methods simulating short-term processes such as landslides, floods, erosion, and sediment transport struggle to be projected beyond a few hundred years.

In this contribution, we address this challenge by leveraging a recent model development—graphflood—that enables the computation of hydro-stationary water surfaces and discharge using a simplified shallow water approximation. This new model shows an order-of-magnitude improvement in speed over its predecessors, achieved through the efficiency of algorithms applied to directed acyclic graphs. Through testing induced subgraph dynamic traversals for initial calculations of a stationary state and employing GPU techniques to maintain the state to slower erosion and deposition processes, we demonstrate the potential for an additional order-of-magnitude reduction in computation time for fluvial dynamics. We also investigate how the computation of landslide runout using a shallow water approximation with a friction coefficient modified to account for velocity-weakening can be introduced within the same numerical framework.

First, we explore various sets of fluvial erosion and deposition laws (e.g., stream power, Meyer Peter Muller) to determine the minimal representation needed for fluvial morphodynamics and projecting them across scales at the lowest computational cost. We then perturb the system with landslides processes and observe the controls on its resilience to external forcings. Lateral dynamics (e.g., lateral erosion, deposition, interaction with valley walls) and the model's ability to capture different river states (e.g., high flow vs low flow, flood) emerge as crucial elements in understanding the complexity of river responses to climato-tectonic perturbations.