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Modeling river erosion and knickpoint propagation using a lagrangian description: numerical benefits and implications for river profiles

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Landscape evolution models generally solve for the time variation of elevation due to erosional processes on a fixed grid. This Eulerian description offers a tractable approach, despite leading to unnecessary dependency to slope, and in turn to numerical diffusion, when solving for the specific stream power incision model, e.g. with a slope exponent equal to 1. Indeed, under this condition, the stream power model reduces to a linear kinematic wave equation with a wave celerity independent of the local slope (Whitham, 1974; Whipple & Tucker, 1999). Using a Lagrangian description and solving for the horizontal advection of the topography due to erosion enables to develop a simple finite difference numerical scheme fully independent of local slope. This scheme presents numerous benefits over Eulerian descriptions, including the absence of numerical diffusion, unconditional stability and the possibility to track geomorphological features and slope instabilities such as knickpoints. We exploit the latter to track co-seismic knickpoints in simulations where uplift history is computed from a statistical model of earthquakes (Turcotte et al., 2007; Leonard 2010). This model results in spatial and temporal distributions of earthquakes that are consistent with Gutenberg-Richter frequency-magnitude scaling, a modified Båth's law, Omori's law in space and time (Turcotte et al., 2007) and earthquake dimension scaling laws (Leonard 2010). Motivated by recent results from sandbox experiments (Baynes, 2016), we then introduce a dependency of knickpoint celerity to knickpoint height, that is initially here equals to co-seismic displacement. This model authorizes the merging of successive and colliding knickpoints due to different celerities. We use this model to investigate the role of knickpoint height and temporal distribution and of the dependency of their celerity to height on the shape of river profiles. This model leads to river profiles with concavities deviating from predicted ones and to particular morphologies, including river profile characterized by a succession of knickzones separated by flat zones. We then discuss these implications in the light of natural river profiles.

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