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Shape-based models of landscape evolution

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Two models stand out in quantitative geomorphology: the diffusion model for hill-slopes and the stream power model for fluvial erosion. Though highly debated and often criticized for over-simplifying surface processes, these two models have provided some of the most powerful tools in geomorphology, including river long-profile analysis, steepness index, chi analysis, and equlibrium hill-slope profiles. More recently these models have been applied together as a diffusion-advection equation yielding other important advances, such as an understanding of the spacing of first order channels in simple landscapes. A powerful aspects of both models is their simplicity, as they depend solely on the characteristics of the surface describing the landscape and a rate coefficient. As a result, these models are easily calibrated to real landscapes, manipulated for theoretical treatments, or applied in landscape evolution models. One of the most interesting features of the stream power model in particular is the dependence on both local conditions, quantified by slope, as well as non-local conditions, quantified by contributing catchment area. This non-locality is the source of much of the richness observed in the model behaviour, but it is also challenging to deal with both numerically and theoretically. In particular, contributing area cannot currently be cast in terms of standard mathematical forms, preventing the application of modern mathematical tools.

We revive and expand an old approach to provide a second constraint on contributing area based on the conservation of mass. This allows us to rewrite models such as the stream power model or the diffusion-advection model as PDEs without explicit dependence on contributing area. One of the most exciting aspects of this is these models are in terms of local derivatives of landscape shape only. As a result of this, we show that for equilibrium landscapes, it should be possible to determine erosion rate at all points on the landscape from local derivatives of topography only. The application of the technique may provide new ways of generating hypotheses to compare model to real landscapes, and opens landscape evolution equations to the study using established methods in differential function analysis.