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Landform evolution at small scales – modified Flint’s law vs. hillslope diffusion

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The majority of the contemporary concepts in tectonic geomorphology is based on models of fluvial erosion where the erosion rate is a function of the channel slope S and the catchment size A. The widely used relationship originating from early work of Hack in the 1950s – often referred to as Flint’s law – assumes that the erosion rate is a function of the product SA^θ with $\theta \approx 0.5$. It typically holds for catchment sizes above about 5 km^2. However, some important features of landform evolution such as the height of peaks and the migration of drainage divides depends on the erosion at smaller catchment sizes.

The simplest way to account for the deviation from Flint’s law at small catchment sizes consists in modifying the functional dependence of the erosion rate on channel slope and catchment size. One version that was found to approximate the observed topography quite well uses the form $S(A^\theta + b^\theta)$ with a given value b. This approach is sometimes entitled debris flow regime. On the other hand, diffusive processes are known to become dominant over fluvial processes at small catchment sizes. Including diffusive processes into a landform evolution model fundamentally changes the type of the differential equation from hyperbolic to parabolic and thus also affects the properties of the solution.

In this study we investigate the effect of hillslope diffusion on topography with focus on the question how this effect can be quantified from digital elevation models. Numerical simulations show that the channel slope achieves a maximum value at a finite catchment size if hillslope diffusion is involved, while the channel slope continuously increases with decreasing catchment size for the modified version of Flint’s law of fluvial erosion. Topographic analyses of different regions indeed reveal a maximum in channel slope at a finite catchment size in low mountain ranges, while the effect is very weak or even not visible at all in high mountain ranges. This result suggests that hillslope diffusion is important at small scales at least in low mountain ranges. However, the shape of the slope vs. catchment size curve predicted from numerical simulations differs in detail from the curves obtained from digital elevation models, so that it is still a challenge to estimate the respective diffusivity from digital elevation models.