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Highly efficient methods to solve the Stream Power Law including sediment transport, local minima resolution and multi-direction flow

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Over the past few years we have continued the development of efficient methods and algorithms to model landscape evolution. The main purpose of our efforts is to obtain methods that can be inserted into an optimization (Bayesian) scheme to invert geological observations such as present-day landform, thermochronological and barometric data or sedimentary flux data, in order to obtain relevant constraints on local uplift rate, its evolution through time, as well as the value of model parameters. This often requires that hundreds of thousands to millions of forward model runs be performed to explore parameter space. This can only be achieved if the forward model run takes a few minutes of compute time, at most, to simulate tens of millions of years of landscape evolution at a spatial resolution that is relevant for the process being modeled (i.e., grid size or number of points used to discretize the model, n, of 1000×1000 or more). This is why we are currently developing methods that are implicit in time and thus allow for very large time step lengths ($10^4 - 10^6$ yrs), and are $O(n)$, i.e. where the number of operations increases linearly with n.

Here we will show improvements we have brought to the FastScape algorithm (Braun and Willett, 2013) previously developed to solve the Stream Power Law (SPL) implicitly and in $O(n)$ operations. These include (1) a new algorithm to include the theory of Davy and Lague (2009) concerning the effect of sediment transport and deposition in channels, (2) two new algorithms that find local minima and the geometry of the associated "lakes", the first being $O(n + N \log N)$ (N being the number of detected local minima) and the second $O(n)$, as well as several algorithms to drain water, and transport and deposit sediment across the lakes, and (3) a new algorithm to compute the drainage area and solve the SPL for distributed flow routing (i.e. Multiple Flow Direction instead of $D8$ or steepest descent flow direction). We have also added an efficient method to solve the equation governing diffusive hillslope transport that is implicit and $O(n)$, based on an ADI (Alternating Direction Implicit) algorithm. We are currently working on the development of an algorithm that improves accuracy when the SPL and the hillslope diffusion equation are solved sequentially.

Braun, J. and Willett, S.D., 2013. A very efficient, O(n), implicit and parallel method to solve the basic stream power law equation governing fluvial incision and landscape evolution. Geomorphology, 180-181, pp., 170-179.

Davy, P. And Lague, D., 2009. Fluvial erosion/transport equation of landscape evolution models revisited. Journal of Geophysical Research: Earth Surface, 114:2003-2012.