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A new surface-process model for landscape evolution at a mountain belt scale

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We present a new surface process model designed for modeling surface erosion and mass transport at an orogenic scale. Modeling surface processes at a large-scale is difficult because surface geomorphic processes are frequently described at the scale of a few meters, and such resolution cannot be represented in orogen-scale models operating over hundreds of square kilometers. We circumvent this problem by implementing a hybrid numerical – analytical model. Like many previous models, the model is based on a numerical fluvial network represented by a series of nodes linked by model rivers in a descending network, with fluvial incision and sediment transport defined by laws operating on this network. However we only represent the largest rivers in the landscape by nodes in this model. Low-order rivers and water divides between large rivers are determined from analytical solutions assuming steady-state conditions with respect to the local river channel. The analytical solution includes the same fluvial incision law as the large rivers and a channel head with a specified size and mean slope. This permits a precise representation of the position of water divides between river basins. This is a key characteristic in landscape evolution as divide migration provides a positive feedback between river incision and a consequent increase in drainage area. The analytical solution also provides an explicit criterion for river capture, which occurs once a water divide migrates to its neighboring channel. This algorithm avoids the artificial network organization that often results from meshing and remeshing algorithms in numerical models.

We demonstrate the use of this model with several simple examples including uniform uplift of a block, simultaneous uplift and shortening of a block, and a model involving strike slip faulting. We find a strong dependence on initial condition, but also a surprisingly strong dependence on channel head height parameters. Low channel heads, as expected, lead to more fluvial capture, but with low initial relief initial and a small channel-head height, runaway capture is common, with a few rivers capturing much of the available drainage area. With larger channel-head relief, lateral capture of rivers is less common, resulting in evenly spaced river basins. Basin spacing ratios matching those observed in nature are obtained for specific channel head parameters. These models thus demonstrate the mixed control on basin characteristics by antecedent river networks and channel-head parameters, which control the mobility of drainage basin water divides.