Form process relations and multi-process landscape evolution models

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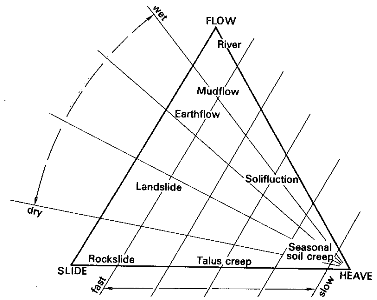
Form-process relations help and hurt...

Geomorphic processes have traditionally been defined through the landforms that they are deemed to have created. This approach has been hugely successful in helping to understand dynamics of landforms in this and other worlds. However, as we move towards conceptual and calculation frameworks in which the interactions between multiple (non-linear) processes create virtual landscapes, we find that landforms are in fact created by interactions between multiple processes. That places doubt on the way in which we defined the original processes.



Kirkby and Watson's classification of mass movement processes (1972, p 100)

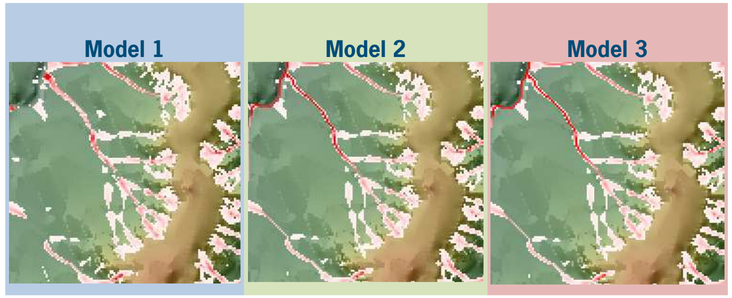
A better definition of processes would clarify the exact conditions (e.g. which slope, wetness, vegetation, material properties), under which geomorphic activity would be termed a certain "process" , and thereby also clarify the positions of transitions to other processes. Our present, incomplete definition of processes is illustrated in the figure on the left (and many others like it), which shows an overview of mass movement processes without information on transitions. Defining process boundaries would be an important step towards better landscape evolution models.

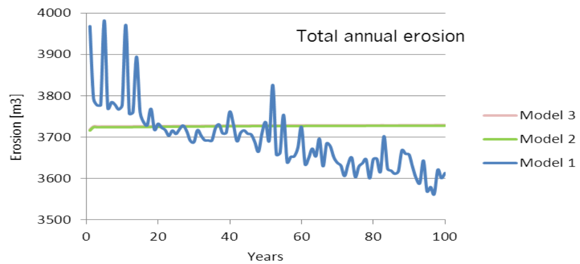
A model experiment to illustrate the hurt

The incomplete definition of geomorphic processes means that we expect landscape evolution models to make wrong predictions because processes in the current definition may unconsciously describe geomorphic activity twice or not at all (other sources of errors exist). In addition, there is likely to be a negative effect of transition itself, because equations on either side of the transition are different. To estimate the importance of these currently unsolvable problems, we attempted to mimic them. We used three model versions: one model with a formulation of erosion and deposition with a gradual transition of erosion parameters from sheet flow through rill flow to gully and fluvial systems – one model with a clear break in erosion parameters between low-flow and high-flow environments – and one model with a clear break in erosion parameters, but with process overlap between the low-flow and high-flow environments. The two latter models were calibrated to the default output of the first model after 100 years, and optimal parameter values time were compared. (C = transport capacity, Q = waterflow, Λ = tangent of slope).

Model 1: One process	Model 2: Two processes, correct transitions	Model 3: Two processes, wrong transitions
$C = Q^m \cdot \Lambda^n$	$C = Q^1 \cdot \Lambda^1$ for $Q < 700$	$C = Q^1 \cdot \Lambda^1$ for $Q < 800$
with m, n changing gradually with Q	$C = Q^{2.5} \cdot \Lambda^2$ for $Q >= 700$	$C = Q^{2.5} \cdot \Lambda^2$ for $Q >= 600$

First results





Even when calibrated to produce the same total sediment output from our test catchment, the models predict significantly different patterns and timeseries of sediment redistribution. Two striking observations:

- Model 1, which has the most gradual transition from low-flow to high-flow environments, produces a very variable timeseries of annual erosion, whereas the other two models do not.
- Models 2 and 3 produce very (but not completely) similar patterns and timeseries, even though their process descriptions differ substantially.

This suggests that the effect of subdividing the continuum of geomorphic activity into distinct processes is large.

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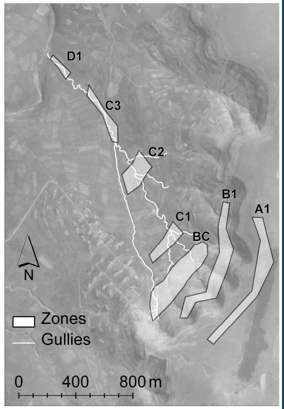
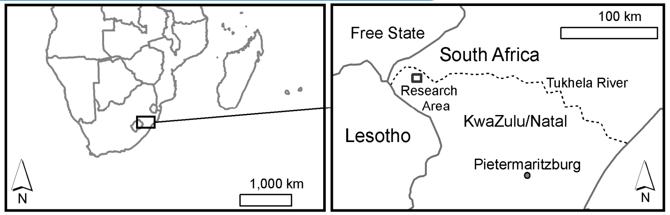
Uncertainty analysis setup

We measured how three levels of uncertainty in calibrated model parameters affected the significance of the difference between predictions for stable and changed climate. Monte Carlo analysis was used. We randomly drew sets of model parameters from their joint probability distributions (assuming three levels of uncertainty: 10%, 20% and 50% of the initial value) and ran the model with each of these sets for both climate scenarios. T-tests were used to calculate probabilities that stable and changing climate model outputs are equal).



Case study



Okhombe valley in South Africa was the case study area. LAPSUS had previously been calibrated to simulate 50-ka BP to present landscape evolution in this valley (Temme and Veldkamp, 2009). Changed climate predictions for the next thousand years were global year 3000 predictions scaled with regional year 2100 predictions. Temperature in Okhombe in the year 3000 was predicted 5 °C higher, rainfall was predicted about 250 mm higher.