Geophysical Research Abstracts
Vol. 14, EGU2012-6628-1, 2012
EGU General Assembly 2012

Scaling sediment dynamics on hillslopes using particle-based approaches

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The processes occurring on a hillslope act over a range of spatial and temporal scales. A common approach is to ignore the continuum of spatial scales and subdivide the space into patches, creating a cell-based model. This is a powerful and computationally efficient tool for simulating spatial patterns of erosion, but the method is not without its problems. First, the models do not simulate explicitly the small-scale processes of sediment transport. Sediment transport is dealt with using expressions which represent the average behaviour of the particles contained within the cell, but we know that they behave differently according to local conditions. Secondly, sediment-transport pathways do not follow the structure prescribed by a regular grid. Thirdly, the spatial scale of the cells do not often relate to the real spatial scales of movement.

In response, we have developed a marker-in-cell model to examine the spatial patterns of soil erosion, which allows particle-based approaches to be linked to more traditional cell-based approaches, and individual particle movement to be simulated. Markers (representing sediment particles), containing sediment-property information, are initially distributed on a cellular grid. A cellular model is used to set up the boundary conditions and determine the hydrology and hydraulics on the hillslope. The markers are then moved through the grid according to these properties. This technique combines the advantages of Eulerian and Lagrangian methods while avoiding the shortcomings of each (computational efficiency vs. accuracy). The model simulates all the processes of detachment and transport; raindrop detachment and transport, interrill erosion, concentrated erosion (bedload transport) and suspended sediment transport.

The model is tested using experimental data from a rainfall-simulation experiment on an artificial hillslope. We demonstrate that the model performs well in simulating the hydrology and spatio-temporal distribution of overland flow, and recreated the observed spatio-temporal patterns of soil erosion. Thus, we show that marker-in-cell models have the potential to model small-scale, granular processes explicitly and over a suitably large area to capture emergent, larger scale dynamics. The implications of this modelling approach are discussed in the context of the application to explicit representation of detachment, transport and depositional processes within models at large temporal and spatial scales, and the data needed to underpin them.