Upscaling from particle to catchment: marker-in-cell approaches to modelling soil erosion

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TITLE: Upscaling from Particle to Catchment: Marker-in-Cell Approaches to Modelling Soil Erosion

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ABSTRACT BODY: Most approaches to simulating soil erosion ignore the particle-based nature of movement, with processes occurring on a hillslope over a range of spatial and temporal scales. The continuum-based approaches commonly used lead to a number of problems. First, the models do not simulate explicitly the small-scale processes of sediment transport. The average behaviour of the particles contained within the cell is used to simulate sediment transport, but it is known that particles behave differently according to local conditions. Secondly, sediment-transport pathways do not follow the structure prescribed by a regular grid in a cell-based, continuum model. Thirdly, the spatial scale of the cells do not often relate to the real spatial scales of movement. Fourthly, the continuum approach ignores the non-linear nature by which some particles move much slower and others much faster than the mean rate.

In response, we have developed a marker-in-cell model to examine the spatial and temporal 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.

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 using experimental data from a rainfall-simulation experiment on an artificial hillslope. 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.

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