<u>Review of “A lattice grain model of hillslope evolution” by Tucker, McCoy and Hobley (*ESURF*)</u>

Short-summary:

The authors present a two-dimensional *reduced complexity* model of hillslope evolution called The Grain Hill Model. This model is based on the lattice-grain model introduced by Tucker et al. (2016), which is a continuous-time cellular automaton model with process-based rules governing the model dynamics and with parameters related to measurable physical quantities. The authors show how the Grain Hill Model is able to reproduce a range of common slope forms, from fully soil mantled to rocky and partially mantled. The hillslope morphologies that the model can reproduce include convex-upward soil mantled slopes, planar slopes, cliffs with basal ramparts, and hogback-like slope forms.

Furthermore, by adjusting the parameters of the model to describe two field-site hillslope examples, the authors show that the model is able to reproduce correctly the form and scale of the landforms.

Strengths:

- Overall the paper is interesting. A relatively simple model that is able to integrate very different time scales (short time scale associate to grain motion, intermediate time scale associate with disturbance events and a much larger time scale for slope evolution) and to reproduce a wide range of hillslope morphologies.
- The Grain Hill model is implemented in the Landlab modeling framework, which is open source.
- The authors provide good insights on the physical meaning of parameters and main mechanisms of landform evolution.
- Nice exploration of the parameter space showing some classical examples and providing physical insight as well.

Weaknesses:

The main criticism on the paper relates to the model description. The authors present The Grain Hill model in Section 2 (‘Model description’). This model builds on the previously introduced (slightly modified) CTS Lattice Grain model (Tucker et al., 2016) which is the main dynamical component of Grain Hill determining the movement of the grains on the hillslope. Although the authors have made some efforts to briefly describe this model component, I have found it insufficient. I am not claiming that the authors should provide all the details (again) of this model, since that description was the object of a previous publication, but given that the scope of the paper is introducing a new model for hillslope evolution (e.g. as indicated by the title), this paper should be sufficiently self-contained. What I mean is that the reader should have a good understanding of the functioning of the model (rules and dynamics) without the need of going back and forth between this manuscript and Tucker et al. (2016), which I have found myself doing quite often. Obviously, the technical implementation of the model rules (e.g., smart algorithms to rank times or how to take advantage of the Landlab’s grid architecture) can be omitted, since they are well described in the previous publication, and it is not detrimental to conveying the essence of the model.

In fact, even after going back and forth between this manuscript and Tucker et al. (2016), there are a few issues that remain unclear to me and should be addressed in the manuscript. So please see the following comments and questions:

- My understanding of the grain motion for the most basic grain dynamics of the model is as follows: **(1)** Disturbance is described as a Poisson process, assigning a state transition at a given time for every surface grain (random variable taken from an exponential distribution with parameter *d*), which forms a queue sorted by the transition times. **(2)** The "soonest transition" (change in the state of the corresponding grain) in the queue is executed, which may trigger future state transitions of neighboring grains. **(3)** The gravity and inelastic collision rules (Figure 4 and 5) would dictate the subsequent transitions and movements. I assume that the two latter processes (driven by gravity and collision) operate at smaller time scales. Is this so? If yes:
    - What is the time scale of the gravitational transitions illustrated in figure 5? is that time scale dictated by an additional parameter/rate *g* (not listed in this manuscript)? If yes:
        - is *g* a constant rate, and therefore all the grains transition exactly at time $1/g$ after being updated to their current state? or is *g* the rate that characterizes an exponentially distributed random variable τ, and each grain transitions after a (different) lag τ?
    - What is the time scale at which the inelastic collisions and movements illustrated in figure 4 take place? Same than the previous time scale, $1/g$? constant lag or stochastic random variable?

- My understanding is that when a grain (or aggregate) moves to occupy an empty cell (fluid), it keeps the same state of movement (arrow direction). Is that correct? If yes, can this give rise to grains that temporally float in the fluid (grain surrounded by six fluid cells)? (I think it depends on the previous questions about the characteristic time scales of gravitational and movement/collision transitions).
- How is the model initialized? For example, what is the geometry (flat?)? Do the lateral edges of the grid play a main role on the early evolution of the hillslope?
- How does the grid type (squares vs. hexagons) affect the results? It is stated in page 7 (lines 12-13) that the gravitational rule sets effectively the angle of repose to 30 degrees. Does the angle of repose strongly relate to the chosen hexagonal grid?
- I would really appreciate as a reader to have access to some videos (as supplemental information) of the evolution of the model, including the evolution of the hillslope as it approaches its steady state.
- Figure 3 is not very straightforward. Maybe it would be good to highlight the cell-pair affected by the transition/movement. With the current caption and text, it is confusing to see several arrows, but only one cell pair changing (this takes me back to my first questions about time scales). Also, I guess that this picture is not illustrative of the The Grain Hill model (otherwise some grains would be floating on the air/fluid). Maybe it would be more interesting to provide an example relevant to hillslopes.
- The authors illustrated in Figure 19 that the model is capable of reproducing realistic hillslope forms with parameters estimated from field data. However, it is not straightforward to evaluate the model performance in the absence of a direct comparison with the observations. I suggest that the authors can either (a) overlap Figure 19a,b with the profiles shown in Figure 2a,b to show that qualitatively the model is able to reproduce the form and height of those landforms, or (b) provide

a quantification of the fit of the observed profile with the model results. Regarding the determination of the parameters, it may also be helpful if the authors can comment on their assumption of δ=1 m, as they suggested that the soil depths typically range between 0.2 and 1.2 m which is almost an order of magnitude difference for the variation. Are the results sensitive to this parameter?

Minor points:

- Figure 7 looks disproportionally big in comparison with other figures (e.g. Figure 4 or 5).
- Please label the different panels of Figure 8 (e.g. a,b,…) to make easier their reference in the text.
- The authors state that Figure 9 shows the results of 125 model runs. It is not clear what those different runs are. From the figure, I can see 5x9 different combinations of λ and *d* so, do you run some cases twice and some case three times?
- Figure 19 caption: "State state models" --> "Steady state models".
- Given the scope of the paper and the number of figures, I am not sure if Figure 6 adds much to the explanation of the model.
- Please be consistent in terminology (e.g. mean gradient vs. slope gradient)

Other comments:

- The authors emphasize the simplicity of the model by pointing out the reduced number of parameters (3 in its simplest version). However, this kind of assessment is a little tricky when we refer to CA models, where the type and number of rules play a significant role in evaluating the simplicity of the model.
- For me it is a little contradictory using "continuous-time" and "Cellular Automaton" as descriptors of a model. Cellular automata were originally defined as discrete models both in time and space, as well as the state variable of each grid cell. Models with discrete space and state variables, but continuous time, sometimes are called Boolean Delay Equations (Figure 2 in Zaliapin et al. 2003).

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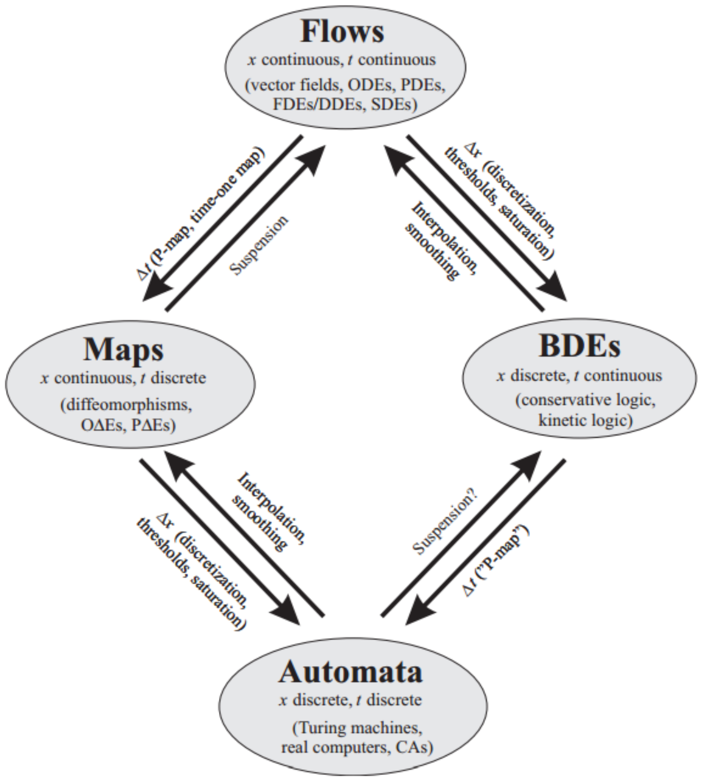

Reference:

I. Zaliapin, V. Keilis-Borok, and M. Ghil, A Boolean delay equation model of colliding cascades. Part I: Multiple seismic regimes, J. Stat. Phys. 111:815-837 (2003).