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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Origin of the power-law exponent in the landslide frequency-size distribution" *by* Ahoura Jafarimanesh et al.

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Dear Professor Stefan Hergarten,

Thank you for your comments on the discussion paper by Jafarimanesh et al. (2018). Below is our three-part answer: (1) to clarify the role of the local terrain slope relative to the more complex factor of safety (FS) in the emergence of the power-law, (2) to show the role of soil thickness on the simulated frequency-size distribution, and (3) to respond to all other comments and questions.

1 Factor of safety versus constant slope threshold

#1) FS is indeed a function of the local slope θ if all other soil parameters are kept constant. We thus now test $20^\circ \leq \theta \leq 40^\circ$ as a possible interval of unstable slope thresh-

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olds, based on the 4 FS formulations and all other parameters kept within reasonable ranges. Figure A.1 shows the frequency-size distributions derived from the size of unstable areas, defined by $\theta \geq 20°$ (left) and $\theta \geq 40°$ (right). We see that the power-law behaviour is still observed (with median exponent α = 1.9-2.2 within the range of fluctuations observed for the percolation model based on FS). The impact of increasing the θ threshold is mainly a decrease in the overall number of landslides, since there is less soil (smaller area) made unstable in the process. Therefore, our conclusion holds; the power-law behaviour must emerge from the fractal topography since the θ spatial distribution is a direct consequence of it. However, it is preferable to consider the FS threshold in landslide modelling since it takes into account the other soil characteristics (refined model in which the θ threshold can change locally) and since FS is a standard in landslide hazard assessment. #2) This result is consistent with a percolation model in which a change of the threshold would only change the number of clusters observed and not their size distribution since a fractal is self-similar. We expect a similar result for real topography, which is also fractal (e.g., Mandelbrot, 1983). We did the test with some real topographies in Switzerland and found a similar power-law behaviour. The power-law would however disappear if the topography was smooth (see e.g., our original figure 2 where only one landslide footprint emerges). In the revised manuscript, we will therefore emphasize that the power-law already emerges if we use directly a θ threshold instead of FS but that in practice, FS should still be used as triggering value.

2 The role of soil thickness

#3) We originally used a constant h = 10 m in the pristine fractal topography so that the final soil depth distribution is realistic with 0 < h < 100 m. This distribution is shown in Figure A.2. We now additionally tested an initial h = 25 m, with results shown in Figure A.3. We observe a decrease in the power-law exponent α, controlled by more events in the tail. The same exercise on an FS-based percolation model shows only a general increase in the number of landslides and no change in α. This suggests that the propagation phase has indeed an impact on α, as suggested by the reviewer. We will therefore update our abstract and conclusion to mention that while the power-law behaviour indeed emerges from the topography via the initiation phase, the total amount of soil available in any given region will tend to decrease α by filling the distribution tail (leading to more greater landslides) via the propagation phase. We thank the reviewer for spotting the role of the initial h. It also means that the FS map can still be used as a proxy to landslide hazard but with the resulting α only giving an upper bound to the true α. We will add a new figure showing the respective role of h for different fractal dimensions.

#4) The statistics obtained in our study is observed over about two orders of magnitude (our original figure 4), which is similar to the one observed in Nature (our original figure 1). We believe that the concern of a rather narrow distribution and of small landslide sizes is due to a typo from our part. The unit of the x-axis is not "squared metre" but "number of cells" in the model. In our original figure 4, based on a grid of 78m resolution, we get 50 cells = 304,200 m2 (which makes our maximum median estimate consistent with the real observations of the figure 1). We apologize for this error and will correct it in the revised version.

3 Response to the other comments

p1, l23: We will change "weathering as a trigger" to "weathering as a long-term driving force" in the revised manuscript.

p2, l21-22: We will now describe the work of Pelletier et al. (1997) as follows (same as original in italics): "Pelletier et al. (1997) retrieved α from a percolation model controlled by a threshold shear stress dependent on the terrain slope and on other physical parameters (such as cohesion, internal friction angle, etc.), which is therefore similar to the FS threshold approach. However, the origin of the power-law is difficult to assess there since the authors combined two fractal processes, the topography (to compute the slope angle) and the soil moisture (to compute the soil parameters). That study also only considered the area of the landslide initiation phase, not the landslide

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itself (i.e., no propagation phase)." Our results are roughly similar to Pelletier et al. (1997), as already noted p6 (lines 9-10, 15-16), but by including the landslide SOC-like process, we were able to clarify the origin of α, which is the main novelty of our work. Also, while both used a fractal topography, we used a random uniform distribution of soil parameters instead of a fractal one. This will be clarified.

p5, l1: It is possible that a few cells remain unstable with a soil element jumping between cells in an infinite loop. Therefore, we fixed a break defined as the iteration at which the number of unstable cells has remained constant over the previous 3 iterations (this number is close to zero and is often equal to zero, i.e., full grid stable after a relatively small number of iterations). This will be clarified in the revised manuscript.

p5, l28: We will correct α to αcum as we indeed have αcum = 1.5 αv - which is what we used before applying αnon-cum=αcum+1, as in Guzzetti et al. (2002).

We will provide the FS parameters in Table 1 of the revised version.

Figure 1: We will reformat the three plots to stretch them in the x-direction

Figure 2: This figure illustrates that the propagation of a landslide, which follows a SOC-like behaviour, does not necessarily leads to a power-law behaviour (since only one landslide footprint is created). This is already explained p5, l6-10. This allows to decouple the roles of the fractal topography and of the cellular automaton. This will be clarified in the text.

Figure 4: The parameter 'm' was originally used in the FS equation in an earlier version of the manuscript as the percentage of a slope that is saturated. In the latest version, we updated the FS equations and therefore removed the explanation about 'm' from the original manuscript. We will update Figure 4 in the revised version of the manuscript to remove this legacy parameter.

References:

Guzzetti, F., Malamud, B. D., Turcotte, D. L., and Reichenbach, P.: Power-law correlations of landslide areas in Central Italy, Earth Planet. Sci. Lett., 195, 169–183, doi: 10.1016/S0012-821X(01)00589-1, 2002 Jafarimanesh, A., Mignan, A., and Danciu, L.: Origin of the power-law exponent in the landslide frequency-size distribution, Nat. Hazards Earth Syst. Sci. Discuss., doi: 10.5194/nhess-2018-167, 2018 Mandelbrot, B. B.: The Fractal Geometry of Nature, Macmillan, New York, 1983

Figures

Figure A.1. Role of different unstable slope θ thresholds on the landslide frequency-size distribution. The power-law behaviour still emerges from the θ spatial distribution, which depends directly on the fractal topography.

Figure A.2. Distribution of soil thickness h after the erosion step of the LSgCA, applied to a fractal topography with initial constant h = 10 m.

Figure A.3. Role of total soil available represented by different initial soil thicknesses h = 10 or 25 m. More material yields more larger landslides via the LSgCA propagation phase, not observed for h = 10 m (nor by the initiation phase for h = 25 m).

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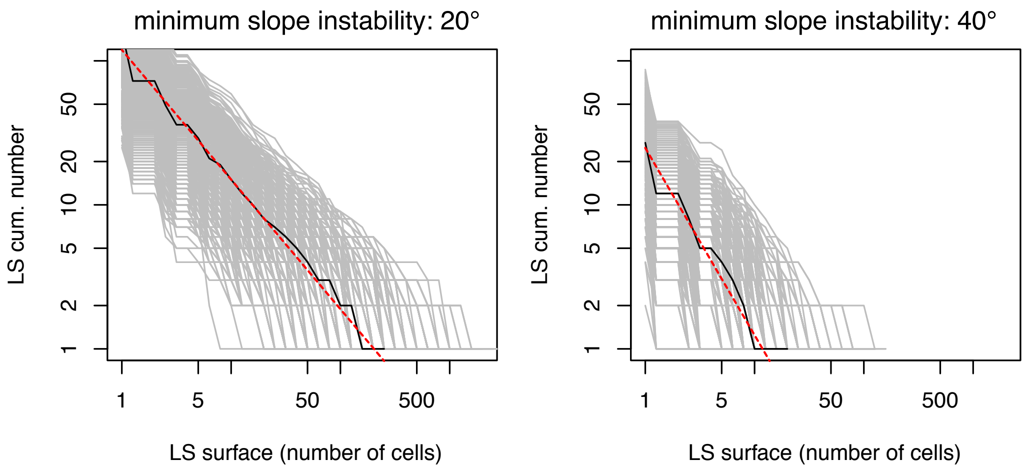
minimum slope instability: 20°
minimum slope instability: 40°
LS cum. number
1
2
5
10
20
50
1
5
50
500
LS surface (number of cells)

Fig. 1.

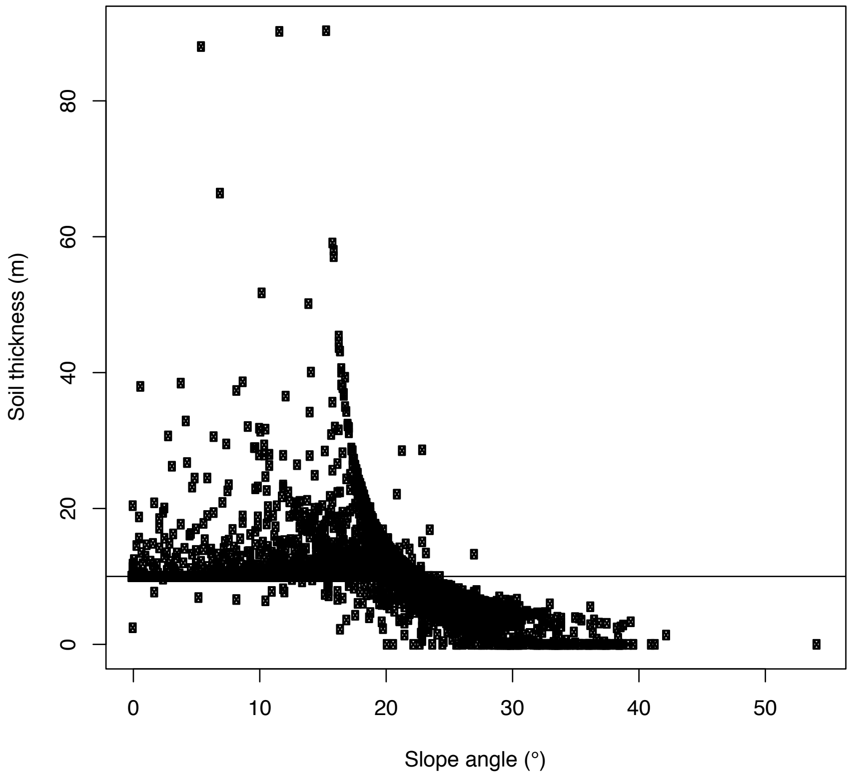

Fig. 2.

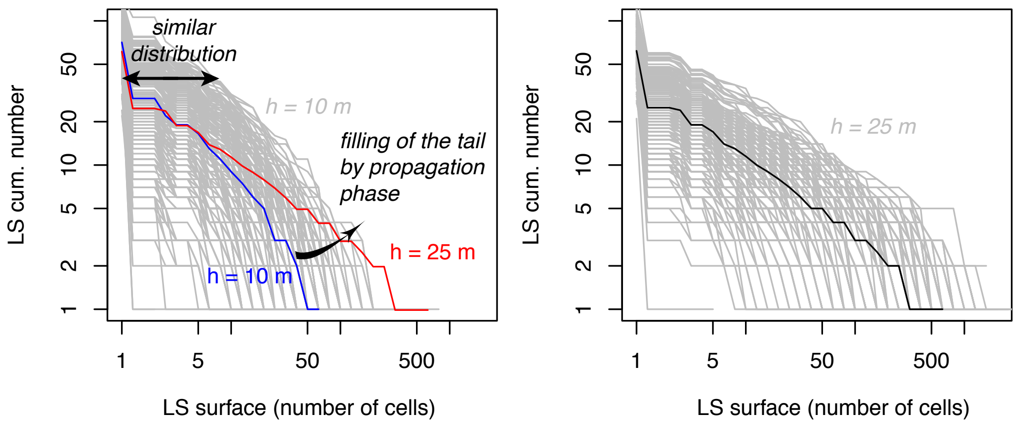

Fig. 3.

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