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A Cellular Automata Model for the Study of Landslides

Luisa Liucci (1), Cristian Suteanu (2), and Laura Melelli (1)

(1) Department of Physics and Geology, University of Perugia, Italy (Luisa.Liucci.LL@gmail.com; Laura.Melelli@unipg.it), (2) Department of Geography & Environmental Studies and Department of Environmental Science, Saint Mary's University, NS, Canada (Cristian.Suteanu@smu.ca)

Power-law scaling has been observed in the frequency distribution of landslide sizes in many regions of the world, for landslides triggered by different factors, and in both multi-temporal and post-event datasets, thus indicating the universal character of this property of landslides and suggesting that the same mechanisms drive the dynamics of mass wasting processes.

The reasons for the scaling behavior of landslide sizes are widely debated, since their understanding would improve our knowledge of the spatial and temporal evolution of this phenomenon. Self-Organized Critical (SOC) dynamics and the key role of topography have been suggested as possible explanations. The scaling exponent of the landslide size-frequency distribution defines the probability of landslide magnitudes and it thus represents an important parameter for hazard assessment. Therefore, another - still unanswered - important question concerns the factors on which its value depends.

This paper investigates these issues using a Cellular Automata (CA) model. The CA uses a real topographic surface acquired from a Digital Elevation Model to represent the initial state of the system, where the states of cells are defined in terms of altitude. The stability criterion is based on the slope gradient. The system is driven to instability through a temporal decrease of the stability condition of cells, which may be thought of as representing the temporal weakening of soil caused by factors like rainfall. A transition rule defines the way in which instabilities lead to discharge from unstable cells to the neighboring cells, deciding upon the landslide direction and the quantity of mass involved. Both the direction and the transferred mass depend on the local topographic features.

The scaling properties of the area-frequency distributions of the resulting landslide series are investigated for several rates of weakening and for different time windows, in order to explore the response of the system to model parameters, and its temporal behavior. Results show that the model reproduces the scaling behavior of real landslide areas; while the value of the scaling exponent is stable over time, it linearly decreases with increasing rate of weakening. This suggests that it is the intensity of the triggering mechanism rather than its duration that affects the probability of landslide magnitudes.

A quantitative relationship between the scaling exponent of the area frequency distribution of the generated landslides, on one hand, and the changes regarding the topographic surface affected by landslides, on the other hand, is established. The fact that a similar behavior could be observed in real systems may have useful implications in the context of landslide hazard assessment.

These results support the hypotheses that landslides are driven by SOC dynamics, and that topography plays a key role in the scaling properties of their size distribution.