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Cellular Automata Models Applied to the Study of Landslide Dynamics

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Landslides are caused by complex processes controlled by the interaction of numerous factors. Increasing efforts are being made to understand the spatial and temporal evolution of this phenomenon, and the use of remote sensing data is making significant contributions in improving forecast.

This paper studies landslides seen as complex dynamic systems, in order to investigate their potential Self Organized Critical (SOC) behavior, and in particular, scale-invariant aspects of processes governing the spatial development of landslides and their temporal evolution, as well as the mechanisms involved in driving the system and keeping it in a critical state. For this purpose, we build Cellular Automata Models, which have been shown to be capable of reproducing the complexity of real world features using a small number of variables and simple rules, thus allowing for the reduction of the number of input parameters commonly used in the study of processes governing landslide evolution, such as those linked to the geomechanical properties of soils. This type of models has already been successfully applied in studying the dynamics of other natural hazards, such as earthquakes and forest fires.

The basic structure of the model is composed of three modules: (i) An initialization module, which defines the topographic surface at time zero as a grid of square cells, each described by an altitude value; the surface is acquired from real Digital Elevation Models (DEMs). (ii) A transition function, which defines the rules used by the model to update the state of the system at each iteration. The rules use a stability criterion based on the slope angle and introduce a variable describing the weakening of the material over time, caused for example by rainfall. The weakening brings some sites of the system out of equilibrium thus causing the triggering of landslides, which propagate within the system through local interactions between neighboring cells. By using different rates of weakening in space and in time it is possible to represent different rainfall scenarios and different physical responses of the material, which in the real world are the consequence of many factors, such as the geomechanical properties and the water content of soils. (iii) Finally, a driving rule, which allows the system to work continuously.

The analysis of the resulting space-time patterns shows that these models represent useful ways of investigating the SOC behavior of landslide dynamics. Geomorphological processes can thus be studied using altitude values as real input data, and comparing outcomes based on DEMs of different areas. This approach supports the study of areas for which detailed information is not available, and for which the investigation of landslide processes is usually problematic. Implications of model choices in terms of stability criteria, weakening rates, and space-time weakening patterns are identified by comparing the patterns produced by different sets of model parameters to those obtained from real datasets.