Natural hazards and self-organized criticality

Stefan Hergarten
Institute of Earth Sciences, KFU Graz
http://hergarten.at

Hazard and risk analyses of natural hazards are mostly based on their so-called frequency-magnitude relations. The frequency-magnitude relation of a certain phenomenon (such as earthquakes, landslides, tsunamis etc.) is a function P(s) which quantifies the mean number of events per time in a certain region as a function of the event size s. The latter may be an arbitrary measure of event size such as the Richter magnitude in case of earthquakes, the affected area in case of landslides or the maximum wave height in case of tsunamis.

Several natural hazards turned tour to have at least qualitatively similar frequency-magnitude relations, namely power-law distributions where P(s) decays with some negative power of the event size: $P(s) \sim s^{-b}$. Earthquakes are the most prominent example, but there is growing evidence that landslides, rockfalls, forest fires and volcanic eruptions follow similar distributions. Compared to other statistical distributions such as Gaussian or exponential distributions, power-law distributions have a heavy tail, which means that large events occur quite frequently in case of power-law distributed hazards. However, the exponents b vary strongly. The lowest values are found for forest fires and rockfalls, so that these phenomena are more dominated by large events than, e.g., earthquakes, landslides and volcanic eruptions.

The search for a unifying concept to explain the occurrence of power-law distributions in these apparently different phenomena is still going on. The theoretical framework of self-organized criticality (SOC) may be the most promising candidate. The basic concept was introduced by Per Bak and his coworkers more than 25 years ago. With the help of computer simulations they were able to show that some simple systems evolve ("self-organize") towards a state with critical properties, i.e., where power-law distributed events occur.

There have been attempts to apply the ideas of SOC to a variety of phenomena. However, SOC has been recognized in very few, rather simple computer models so far. In case of earthquakes, discrete mechanical models consisting of blocks connected by elastic springs have proven to be quite successful even quantitatively. Among the established SOC models there is a model for forest fires, too, although it overestimates the number of large fires. Rockfalls might be described by the original model of Per Bak and his coworkers, also called "sandpile model". The relationship of landslides to SOC is still unclear on a quantitative level as none of the established SOC model reproduces the observed low number of large landslides. Finally, the question whether volcanic eruptions can be interpreted in terms of SOC is completely open.