Project no.043386

TRIGS

TRIGGERING INSTABILITIES IN MATERIALS AND GEOSYSTEMS

Sixth Framework Programme (FP6) - STREP

New and Emerging Science and Technology Pathfinder Initiative (NEST)

Deliverable no. 2.2.1 *Deliverable title*

Report on the applicability of cellular automata models to geophysical phenomena

Due date of deliverable: 30th of June 2008
Actual submission date: 30th of June 2008

Start date of project:1st of January 2007 Duration:36 months

Organisation name of lead contractor for this deliverable:UJF
Diffusion Level: PU

Revision [1]

Deliverable 2.2.1 Report on the applicability of cellular automata models to geophysical phenomena

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Introduction

The cellular automata model of Bak et al. [1987] was first applied to earthquakes by Bak et al. [1989], in order to model the power-law distribution of earthquakes sizes. In addition, this model also reproduces clustering in time [Olami et al., 1992], though it does not quantitatively explains all properties of real seismicity [Helmstetter et al., 2004]. It was then applied to other natural phenomea, such as landslides [Noever 1993; Hergarten and Neugebauer 1998], snow avalanches [Faillettaz et al., 2004], or volcanic eruptures [Lahaie and Grasso, 1998]. Many studies during the last 15 years have used sandpile-like models to understand earthquake distribution in space, time and magnitude. These studies have complexified the model of Bak et al. [1989] to reproduce realistic seismicity, by introducing scale-invariant geometry [Huang et al, 1998], visco-elastic rheology [Hainzl et al., 1999], fluid flow [Yamashita, 1997], creep [Hainzl, 2004], stress-corrosion [Lee and Sornette, 2000], or rate-and-state friction laws [Dieterich, 1995; Ziv and Rubin, 2003]. Most of these models use long-range elastic interactions, rather than the nearest-neighbors interactions of Bak et al. [1987]. Several of these models reproduce most properties of seismicity. The limited quality of real seismicity data, and our limited knowledge of the Earth's crust rheology, does not allow us to distinguish these models.

Application to model geophysical phenomena

We have compared the distribution of event sizes and of inter-event times for geophysical phenomena (seismicity, snow avalanches, volcanic eruptions, and landslides catalogs) with simulations of the OFC sandpile model. For all datasets and simulations, we found that the inter-event time distribution follows a power-law decay at short times, and an exponential at larger time. This reflects temporal clustering at short times, that is probably due to triggering between events. Another interpretation for this law, in the case of volcanic eruptions or landslides, is that these events have been triggered by a time-dependent process. Landslides can be triggered by heavy rain, or freeze-thaw cycles, and both eruptions and landslides are sensitive to earthquakes. In contrast, automata models use a constant loading rate. All geophysical phenomena analysed (snow avalanches, rockfalls, eruptions, and seismicity) also have the same power-law distribution of event sizes as cellular automata.

Cellular automata such as the OFC or BTW models produce stationary avalanche activity. This is well adapted to model the seismicity or landslide activity at a large scale. But when studying a particular landslide, the activity (displacement or microseismicity) is often found to increase with time, up to macroscopic rupture. This behavior may be reproduced by models such as the Democratic Fiber Bundles models, or more complex models such as the one developped by [Amitrano and Helmstetter, 2006]. This type of models explains the power-law singularity of deformation and/or micro-seismicity that has been observed preceding landslide failure [Helmstetter et al, 2003 ; Amitrano et al., 2005]. These models also reproduce the change of the event size distribution, which can be fitted by a gamma law with a cut-off increasing as rupture approaches.

Publications

The statistics of volcanic eruptions, and their comparison with automata models, has been published in:

- Lemarchand N., J.-R. Grasso (2007), Interactions between earthquakes and volcano activity, Geophys. Res. Lett., 34, L24303, doi:10.1029/2007GL031438.

The analysis of landslides catalog and the comparison with automata models is part of a paper by Tatard et al. which should be submitted soon.

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