SPATIOTEMPORAL CLUSTERING IN SIMPLE EARTHQUAKE FAULT SYSTEMS

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While understanding the dynamics of seismic activity is fundamental to the investigation of the earthquake process, detailed studies of the earthquake fault system are difficult because the underlying dynamics of the system are not observable. In addition, the fact that nonlinear earthquake dynamics are coupled across a broad range of spatial and temporal scales, combined with the occurrence of rare, extreme events and the associated patterns in seismic data, means that computational simulations are critical to our understanding of the dynamics of the earthquake systems.

Simple models of statistical fracture have been employed effectively to test many of the typical assumptions and effective parameters inherent in the complicated dynamics of the earthquake fault system and their relative variability. These models have been employed with remarkable success to advance our understanding of the statistical properties of earthquakes. Burridge and Knopoff (1967) introduced a one-dimensional (1D) system of spring and blocks to study the role of friction along a fault in the propagation of an earthquake. Later Rundle and Brown (1991) presented a version with frictional sliding using the Mohr-Coulomb friction law that ignored inertial effects. Olami, Feder and Christensen (1992) generalized Bak, Tang and Wiesenfeld (1987) sand-pile model and introduced a lattice version of the continuous, nonconservative cellular automata model (OFC) to investigate SOC behavior in earthquakes. However, most of these models included only short-range stress transfer. None incorporated spatial heterogeneity into these earthquake-like fault models.

Real earthquake fault systems are not composed of identical homogenous materials. The variety of materials with different physical properties, such as frictional strength under pressure, can cause a variety of behaviors. Inhomogeneities in the form of stress-relieving micro-cracks have been incorporated into long-range OFC models (Dominguez et al., 2013; Serino et al., 2011), resulting in a better understanding of GR scaling. In addition, inhomogeneities have been introduced into fully elastic models resulting in either power-law statistics of event sizes or a separate distribution of events combined with large, system size events (Fisher et al., 1997). However, to date, none of these approaches have been able to reproduce both the temporal clustering and the complete magnitude-frequency distribution scaling regime that are primary features of natural seismicity and a critical component in the assessment of earthquake hazard.

In order to study a system with some aspects of spatial heterogeneities, we established a simple, long-range cellular automata model for earthquake fault systems based on the OFC model that incorporates a fixed percentage of stronger sites, or 'asperity cells', into the lattice. These asperity sites are significantly stronger than the surrounding lattice sites but eventually rupture when the applied stress reaches their higher threshold stress.

The introduction of these spatial heterogeneities results in a rich array of spatial and temporal clustering in the model, including large, recurrent events with foreshock and aftershock sequences and accelerating seismic moment release and mimics those seen in natural fault systems along with GR scaling (Figure 1).

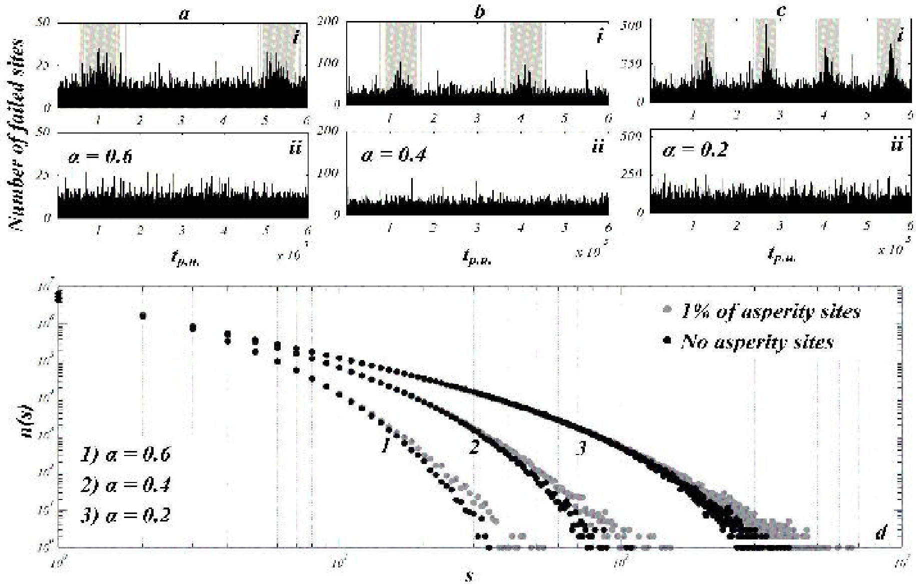

Figure 1. Time series of events during a period of $6*10^5$ pu for three different values of stress dissipation parameters (a) α = 0.6, (b) α = 0.4 and (c) α = 0.2; (i) are results for the model with 1% asperities (shaded background are those steps in which an asperity site breaks); (ii) are results for the homogeneous model. (d) Comparison between the distribution of events for two different scenarios (with and without 1% of spatially random distributed asperity sites) for three values of stress dissipation parameter and 10^7 plate updates

This work also demonstrates that it is possible to link the underlying physical properties to the measurable parameters of the spatial and temporal patterns observed in natural seismicity, such as the Omori exponent, stress drop or inter-event time. If spatial heterogeneity is important to the spatiotemporal behavior of earthquake sequences, and affects earthquake return period and precursory activity such as foreshocks, then it should be possible to link stress dissipation and the asperity distribution to the duration of foreshock-aftershock sequences and inter-event times, potentially allowing us to improve their predictability. The fact that the precursory patterns in earthquake fault networks are controlled by these spatial heterogeneities provides a new paradigm with which to investigate and quantify the relationship between fault structure, spatiotemporal clustering, and earthquake predictability.

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