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Analysis of relaxation temporal patterns in Greece through the RETAS model approach

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Abstract

The temporal decay of eight aftershock sequences in the area of Greece after 1975 was examined with main shocks magnitudes of $M_w \geq 6.6$. The analysis was done through the restricted epidemic type aftershock sequence (RETAS) stochastic model, which enables the possibility to recognize the prevailing clustering pattern of the relaxation process in the examined areas. In four of the cases the analysis selected the epidemic type aftershock sequence (ETAS) model to offer the most appropriate depiction of the aftershock temporal distribution which presumes that all shocks to the smallest ones in the sample can cause secondary aftershocks, while for the rest of the sequences triggering potential seems to have aftershocks above a certain magnitude threshold (RETAS model) and they are expected to induce secondary activity.

The models, developed on aftershock data, were also applied to forecast real seismicity after the conclusion of the aftershock sequences. For four out of eight cases, we obtained promising estimations of ensuing seismicity after the end of the sequences with models based only on aftershock data. Some features of the RETAS model simulation were also studied, like simulating magnitudes, revealing that it is reasonable to consider in the model the temporal behavior of the aftershocks' magnitudes as well. Stochastic modeling was also applied to estimate the duration of the relaxation process, assuming that the end of each sequence is marked by the divergence of real seismicity from the modified Omori formula (MOF) model, the latter known to represent pure aftershock activity. The obtained results give an indication that possibly low stressing rate results in longer duration of the relaxation process in a region.

Keywords: Aftershock sequence; Stochastic models; RETAS; ETAS; Relaxation process; Simulation

1. Introduction

Stochastic modeling has become a major tool in examining the clustering properties of earthquake occurrences. Former tendency of carrying out declustering algorithms that remove aftershocks from a catalog is now replaced by the application of a number of stochastic processes to fit the clustering behavior of a sequence. This allows making use of all available information in a seismic catalog and thus aftershock data can in many cases help in the detection of anomalous seismicity changes like quiescence or activation prior to a large earthquake (Matsu'ura, 1986; Zhao et al., 1989; Ogata et al., 2003; Ogata, 2005a,b; Drakatos, 2000). The great interest

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dedicated by many researchers of the aftershock activity to statistical methods is obviously linked to the vast possibilities, which they offer in studying and modeling the relaxation process. Among them, the most important are development of detailed temporal patterns, elaboration of adequate stochastic models of aftershock occurrences, detection of anomalous seismicity changes before strong aftershocks or before forthcoming main shocks, providing stochastic grounds for seismic hazard analysis etc.

One can find a number of point processes in the literature that concern aftershock clusters in time or both in space and time (Ogata, 1988, 1993, 1998; Kagan, 1991; Vere-Jones, 1992; Musmeci and Vere-Jones, 1992; Rathbun, 1993, 1994; Schoenberg, 1997; Console and Murru, 2001; Zhuang et al., 2002; Ogata et al., 2003; Console et al., 2003; Gospodinov and Rotondi, 2006). One of the first approaches to model the gradual decay of the aftershocks triggered by a strong earthquake is the so-called Omori law (Omori, 1894). Utsu (1970) transformed it into the modified Omori formula (MOF), which is most widely used up to now. It is grounded on the basic assumption that all the events in an aftershock sequence are triggered by the stress field change due to the main shock, follow a nonstationary Poisson process and there is no subclustering in the sequence. When we deal with more complex cases and especially when smaller aftershocks are considered, temporal clustering becomes apparent. Under such circumstances and particularly when we study some conspicuous secondary aftershock activities of large aftershocks, the single modified Omori formula cannot provide the best prediction of the rate decay as demonstrated in Guo and Ogata (1997).

These cascading complex features of aftershocks motivated Ogata (1988) to formulate the epidemic type aftershock sequence (ETAS) model, based on the idea of self-similarity and extending the capacity of generating secondary events to every aftershock of the sequence. The two models constitute limit cases, the MOF model with only one parent-event and the ETAS model in which every event shares in the generation of the subsequent ones. The vast variability of different geotectonic conditions and different temporal patterns of aftershock occurrences requires some intermediate cases to be considered and there is a range of triggering models, which stand between the MOF and ETAS (Vere-Jones, 1970; Vere-Jones and Davies, 1966; Ogata, 2001; Gospodinov and Rotondi, 2006). In their work on the restricted epidemic type aftershock sequence (RETAS) model Gospodinov and Rotondi (2006) examined a case in which, as in Ogata (2001), triggering capabilities possess events with magnitudes larger than or equal to a threshold, M_{th}. The RETAS model is similar to the ETAS one, but leaving a gap between the magnitude M_{th} of the triggering event and the magnitude cut-off M_0. The idea is borrowed by Bath's law (Bath, 1965, 1973), which affirms certain difference between main shock's magnitude and the one of the largest aftershock. By varying M_{th} one can examine all RETAS models between the MOF and the ETAS model on the basis of the Akaike Information Criterion (AIC; Akaike, 1974).

The purpose of this paper is to study stochastic features of the relaxation process after some strong earthquakes in Greece by the RETAS model approach. There are a number of papers which analyze aftershock occurrences in that area on the basis of the MOF model (Latoussakis et al., 1991; Drakatos and Latoussakis, 1996; Drakatos, 2000) but in our work we want to make use of the enhanced capacities of the RETAS model to identify the most adequate stochastic patterns of time clustering for the data. The model has the advantage to verify all its versions between the MOF and the ETAS model including them as limit cases. Our aim is also to test how well an aftershock occurrence model can forecast the seismicity rate after the sequence is over, examine some aspects of the RETAS model simulation and analyze its applicability to assess the relaxation duration. We expect to shed more light on whether different seismotectonic regimes may reflect in stochastic dissimilarity.

2. RETAS model formulation

Each stochastic model is developed after some basic physical assumptions. For the MOF it is regarded that the total relaxation process is controlled by the stress field changes caused by the main shock. The aftershocks are conditionally independent and follow a nonstationary Poisson process. The ETAS model (Ogata, 1988) assumes that every aftershock in a certain zone can trigger further shocks and the contribution of any previous earthquake to the occurrence rate density λ_j of the subsequent events can be decomposed into separate terms representing the time and magnitude distribution as

$$\lambda_j(t, m) = h(t - t_j|m_j) = k(m_j)g(t - t_j) \qquad (1)$$

Here $h(t - t_j|m_j)$ is the functional form of the rate density after the jth event, which depends on the elapsed time after this shock and on its magnitude. As Ogata (1988) suggested, this function is decomposable and the temporal decay rate follows the MOF $g(t) \propto (t+c)^{-p}$ while the functional form of $k(m_j)$ is chosen to be exponential on the basis of the linear correlation between the logarithm of the aftershock area and the main shock's magnitude, studied extensively by Utsu and Seki (1955). Hence, the