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The temporal series of the New Guinea 29 April 1996 aftershock sequence

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Abstract

The aim of our search is the analysis of aftershock temporal series following a mainshock with magnitude $M \geq 7.0$. Investigating aftershock behavior may find the key to explain better the mechanism of seismicity as a whole.

In particular, the purpose of this work is to highlight some methodological aspects related to the observation of possible anomalies in the temporal decay. The data concerning the temporal series, checked according to completeness criteria, come from the NEIC-USGS data bank. Here we carefully analyze the New Guinea 29 April 1996 seismic sequence.

The observed temporal series of the shocks per day can be considered as a sum of a deterministic contribution (the aftershock decay power law, $n(t) = K\cdot(t + c)^{-p} + K_1$) and of a stochastic contribution (the random fluctuations around a mean value represented by the above mentioned power law). If the decay can be modeled as a non-stationary Poissonian process where the intensity function is equal to $n(t) = K\cdot(t + c)^{-p} + K_1$, the number of aftershocks in a small time interval Δt is the mean value $n(t)\cdot\Delta t$, with a standard deviation $\sigma = \sqrt{n(t) \cdot \Delta t}$.

Keywords: New Guinea; Seismicity; Earthquake; Precursors

1. Introduction

About a third of the earthquakes detected all over the world are aftershocks, the distinguishing feature of which is clustering in space and time. Their temporal distribution often follows a regular trend, as first observed by Omori (1894). The aftershocks are very frequent immediately after the mainshock, but the frequency decreases rapidly, with a power law decay following, in general, the Omori law $n(t) = n_1\cdot t^{-p}$, where p, the decay parameter, is nearly 1 and n_1 is related to the number of shocks in the first day. The aftershocks tend principally to involve fault segments near the mainshock. The first earthquake increases the probability of following shocks by a triggering action.

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2. Aftershock temporal series: some theories and models

An earthquake big enough to cause damage will likely be followed by several aftershocks of considerable size in a short time span. Earthquakes located within a characteristic distance from the main event can be considered aftershocks. This distance is usually considered equal to one or two lengths of the fault segment related to the mainshock. There are some empirical relations that allow evaluating, in a more accurate way, the length of the zone fractured by the mainshock when the magnitude of this event is known. One of these relations was found by Utsu (1969) relating the fractured fault segment length L to the seismic event magnitude M:

$$\log_{10} L = 0.5 \cdot M - 1.8 \quad (1)$$

The main parameters of aftershock sequences are: the spatial distribution, the total number of the aftershocks and the temporal decay rate. Aftershocks are frequent immediately after the mainshock and decay, approximately, as the inverse of the elapsed time (Omori law). The magnitudes of the aftershocks generally follow the Gutenberg–Richter relation (Gutenberg and Richter, 1954):

$$\log_{10} N(M) = (a - b) \cdot M \quad (2)$$

where N is the number of shocks with magnitude equal or greater than M, while a and b are constants.

The most important results are those deriving from study of the aftershock activity temporal trend (Keilis-Borok and Kossobokov, 1990a,b). The sequence examined is described by the modified Omori formula (Utsu, 1961):

$$n(t) = K(t + c)^{-p}$$

where $n(t)$ is the frequency distribution and K, c and p are constants. The original Omori law (1894) was found empirically and considers $p = 1$ and $c = 0$. The number of events will rapidly decrease immediately after the mainshock, until it is lost within the background seismicity of the examined area. It is also observed that sometimes a large aftershock occurs in an area near to the mainshock rupture zone. This aftershock is, in turn, followed by its own aftershocks, called “secondary aftershocks”. Moreover, occasionally anomalous aftershock activity decreases or increases are observed. So the temporal decay is a matter of study since it gives information about the seismogenic process and the physical conditions of the “source” region.

From a comparison between the maximum likelihood fit and the temporal decay, Page (1968) states that if the fracture process can be considered stochastic then there will be random fluctuations of the experimental data (number of shocks) around the theoretical value predicted by the decay law. The number of aftershocks N in a small time interval Δt follows a Poissonian trend with a mean $n(t)\cdot\Delta t$ and a standard deviation $\sqrt{n(t) \cdot \Delta t}$.

The confidence interval, at about 99%, for N is given by:

$$[n \cdot \Delta t - 2.5 \cdot \sqrt{n \cdot \Delta t}; \quad n \cdot \Delta t + 2.5 \cdot \sqrt{n \cdot \Delta t}]$$

Matsu’ura (1986) plots the cumulative number of aftershocks versus the “frequency linearized time”, τ. In this way the fit of the Omori formula to the temporal features of the sequences is checked. The aim of her work is to point out the anomalies that can occur during an aftershock sequence. The frequency linearized time is defined as:

$$\tau = \int_0^t n(s)\,\mathrm{d}s$$

where the integral represents the cumulative number of aftershocks using the parameters estimated in $n(t) = K(t + c)^{-p}$. The cumulative number of aftershocks increases linearly with τ for sequences that are well represented by the modified Omori formula (Utsu, 1961). During the occurrence of a decay anomaly, i.e. a decrease or increase of activity, the cumulative number versus τ fluctuates around the straight line that represents the Omori formula for the period under study.

This anomalous change in the p-value of the modified Omori formula could give useful information about a likely large aftershock occurrence. Studying an aftershock sequence in real time, it would be possible to observe an anomaly immediately after its beginning, to notice the quiescence and recovery stages and then to evaluate the probability of a forthcoming large aftershock. From the epicentral distribution of the aftershocks during the recovery stage we can attempt to identify the area of the forthcoming aftershock.