Interevent times within aftershock sequences as a reflection of different processes

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Abstract: We have looked into the interevent time distribution of aftershock sequences from different tectonic regimes with the aim of gaining information on the aftershock process. To this end we looked at some well defined aftershock sequences from Alaska, New Zealand and Mexico and proceeded to identify the distribution patterns of interevent times (also called waiting times) in both time and space. Several results emanate from this exercise. In most cases, more than one coherent process can be discerned with those acting following the main process, occurring surprisingly not in the volume surrounding the main rupture volume but rather within it.

1. Introduction

The aftershock process has been the subject of many studies throughout the history of seismological research (for a review see for example Utsu, 1995; Gross, 2003). Anyone who has been exposed to earthquakes is familiar with the notion that a sequence of (usually) smaller events follow the occurrence of a medium to large event. Intuition tells us that they most occur due to the perturbation introduced by the main rupture. However, the questions about why and where they take place are far from settled. In the most simplistic models, the main dislocation produces regions of increased stress in neighboring volumes where other events can be expected to occur. Other models attempt to explain the temporal characteristics of aftershocks as a hierarchical structure in which each aftershock can produce its own aftershock sequence.

However, careful examination of the decay rate of aftershocks at different regions around the world for similar size main shocks, by means of, for example, the number of aftershock of a prescribed magnitude (Singh and Suarez, 1988) or by the p-value in Omori’s law (Wiemer and Katsumata, 1999) clearly show differences that can not be attributed to a single process and highlight the importance of the tectonic regime.

Based on recent studies which looked at the probability distribution of interevent times of earthquakes occurring in a region, some authors have proposed a single universal scaling law which can account for the observed distributions appealing to self organized criticality as the inherent process (Bak et al. 2002). Based partly on their observations they claim that there is no inherent difference between mainshocks, foreshocks or aftershocks. These results, however, when examined in detail, may stem from the combination of events from different tectonic regimes which preclude any conclusion related to the individual earthquake process.

In this work we have analyzed the interevent time distribution of events belonging to well defined aftershock sequences from different regions, with the objective of identifying possible different processes within each sequence and their causes.

2. Data and method

Our data comes from selected seismicity catalogs from Alaska, New Zealand and Mexico which have been the focus of detailed studies regarding their homogeneity and completeness. Using those time intervals for which the best quality data is available, we extracted aftershock sequences by means of temporal and spatial associations. We looked at events with magnitude larger than 6.5 occurring in the upper crust since these are the most efficient with regards to aftershock generation.
Our selection criteria also helps avoid problems related to depth artifacts introduced in the locations. For each main shock a spatial criterium is employed following the relation for the maximum distance of expected aftershocks with respect to magnitude proposed by Kagan (2002). With this first set, a temporal criterium is used based on the rate of events following the main shock. Cumulative number of events Vs. time curves are used to select times of significant changes in seismicity rate. The interevent time distributions are then analyzed as a function of time and as a set of normal scores.

3. Discussion

Different patterns can be clearly discerned for some of the sequences analyzed while others show an apparent single process. In Figure 1 we show the temporal characteristics of interevent times for an aftershock sequence in Alaska for different magnitude cut-offs. Figure 2 shows the distribution of normal scores as a function of magnitude. In Figure 1 we can see different trends which appear to act at certain times after the mainshock.

Fig. 1 Temporal behavior or interevent times for an aftershock sequence in Alaska

Another key point to note from the curves in Figure 1 is that the different trends are easier to see in the smaller events than in the larger ones, although this may be due to the limited amount of larger events. The data in Figure 2, on the other hand, show an apparent single regime dominating the process.
Fig. 2 Frequency of occurrence of normalized interevent times for the Alaska aftershock sequence in Figure 1.

As another example, the aftershock sequence shown in Figure 3 corresponds to a mainshock which occurred in the South Island of New Zealand where again several trends can be discerned.

Fig. 3 Temporal behavior or interevent times for an aftershock sequence in the South Island of New Zealand

The normalized scores, again do not show any particular change in tendency, as seen in Figure 4.

Fig. 4 Frequency of occurrence of normalized interevent times for the New Zealand aftershock sequence of Figure 3.

The location of the separate sequences is shown in the following maps where it is apparent the spatial dependence of every set.
4. Conclusion

The analysis of interevent time distribution of aftershock sequences reveal that different processes start to act following the main shock. These processes can be due to stress concentrations incurred by both the main shock and other aftershocks in the vicinity. The location of events belonging to a particular process indicate the spatial dependence of the process which in turn can be traced to stress shadows.

Normalized scores do not reflect such differences which can be the reason why previous studies call for a single universal behavior in the interevent time properties.

5. Acknowledgement

This work was carried out with support from UNAM’s grant IN122602.

6. References


