Geodesy and Geodynamics 2014,5(2):1-8

http://www.jgg09.com
Doi:10.3724/SP.J.1246.2014.02001

Compositional change of seismic event sequences in focal zones during preparation of strong earthquakes

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Abstract: The change of the structure of seismic event sequences in focal area in preparation period of strong earthquakes has been studied. Findings show that weak earthquake clustering in time increases in earlier stage of forming of focal area. However, spatial clustering of seismic events rises at the latest stage.
Key words: seismicity structure; focus of earthquake; seismic regime; earthquake forecast

1 Introduction

A study of the dynamic patterns of the location and time structure of a sequence of seismic events occurring in the preparation field of a large earthquake is of theoretical and practical importance for understanding the physical processes occurring in the focal area, creating an adequate theory of earthquake preparation, and forecasting seismic activity periods. It was shown that the spatial field structures of earthquake epicenters of large seismically active regions have similar, hierarchical character and that the fractal dimension of this field is less than 2[1-3]. It was noted that the fractal dimension of acoustic impulses leading to the destruction of rocks changes as the moment of the main gap is approached[4]. These changes are connected to demonstration of a number of predictive signs in acoustic emission mode (quiescence and activation).

Under natural conditions it can be expected that at times during large earthquake preparation the structure of seismic event sequences should change.

Studies of the focal areas of large earthquakes suffers from the problem of small statistics, since representative earthquakes falling in the area of their preparation are usually <500. Application of the theory of fractal sets can help to overcome this difficulty. Herein we propose a simple and effective method to allow us to trace the dynamics of the seismicity of focal zones. Using this method to study the seismic structure of focal zones of earthquakes allows us to learn about the evolutionary stages of the seismically active area during earthquake preparation.

Received: 2014-02-01; Accepted: 2014-04-10
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2 Research methods

We consider representative seismic events of large ($M>5$) earthquakes occurring in the preparation field for long enough term (25-30 years). From these events, with a shift in one event, we formed a sequence of samples consisting of a fixed number of earthquakes. Thus, the event scale is used but not the time scale. We analyze the characteristics of the sample reflecting the degree of unevenness of development of seismicity in the spatial region and time, as well as the dynamical changes of these characteristics as the main shock is approached.

For each sample we use a pair of numbers (R_{gr}, T_{gr}), where R_{gr} and T_{gr} are certain measures reflecting the degree of density of earthquakes in space and time, respectively. The maximum concentration of events in the space and time area has corresponding R_{gr} and T_{gr} values equal to 1, and an even distribution corresponds to R_{gr} and T_{gr} values of 0. We will consider four extreme cases, defining a place for studying the sample within the unit square (Fig. 1):

- Earthquakes are located in regular intervals in space and in time: (0,0).
- Sample earthquakes are localized in space but are distributed in time at regular intervals: (1,0).
- Earthquakes are distributed in the spatial area evenly but are clustered in time: (0,1).
- Earthquakes are localized in both space and time: (1,1).

The sequence of samples describes the tendency of change within the unit square that we tried to trace. The relevancy of the numerical modeling to real physical processes in many respects depends on the credibility of the input parameters. These include the spatial size of the area, the size of a unit cell into which this area is broken, the time interval during which we can neglect features of earthquake distribution, the volume of the individual sample, and the metrics referring the given set to this or that point of space (R_{gr}, T_{gr}). We will review these parameters in detail.

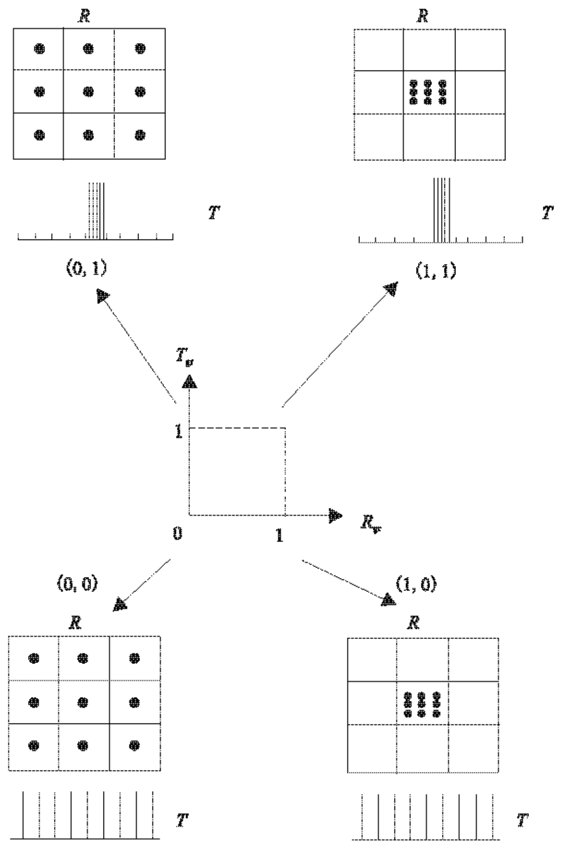

Figure 1 Variety of space and time groupings of earthquakes. (There are four extreme cases, defining a place for the studying the sample in the frame of a unit square. R: concentration of earthquake in space; T: concentration of earthquake in time)

The highest level of clustering of earthquakes in both time and space in natural conditions is observed during aftershock activity. Therefore it is natural to consider what exact character of grouping corresponds to position (1,1) in the square (R_{gr}, T_{gr}). This circumstance in many respects defines a choice of modeling parameters. We take as a unit cell of space the area equal to the aftershock distribution area, which can be identified with the seismic focal area to a first approximation, and as a unit interval of time the time interval coinciding with the average duration of aftershocks. The ratio between earthquake magnitude and the space-time area of aftershocks has been obtained by a number of authors[5-6]. The time intervals characterizing the average duration of aftershocks for earthquakes of various magnitudes have been taken[7]. We set the number of elements in a unit sample to be close to the average number of aftershocks for earthquakes of the studied magnitude. To calculate the number of aftershocks we recognized that, as a rule, the energy of the main shock surpasses that of the maximal aftershock by one or two orders of magnitude, and that all sets of aftershocks accurately fit into the diagram of earthquake frequency within practically the same angular factor, as well as exhibit similar background seismicity[8].

The choice of spatial area is divided into unit cells, based on fundamental rules of the kinetic theory of the durability of solids[9] according to which interaction of cracks occurs at certain concentrations. According to the failure concentration criterion, avalanche growth comes when average distance between ruptures is 3–5 times exceeding length of these ruptures.

Approximately the same size spatial areas can be found by proceeding from Ulomov's cell model of the primary inter-epicentral distances estimation between earthquakes of similar magnitudes. According to Ulomov's model the ratio of the linear sizes of the preparation area to the size of the formed rupture is equal to 3.6[8].

The concepts of earthquake density in space and time or their dispersion are closely related to questions of space and time metrics for a stream of seismic