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Variation of the scaling characteristics of temporal and spatial distribution of earthquakes in Caucasus

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HIGHLIGHTS

- Slow cycles in long-range correlations of earthquakes space and time distribution.
- Antiphase variations in long-range correlations in spatial and temporal domains.
- Decrease in temporal correlations occurs at increased seismic energy release.
- Increase in spatial correlations occurs at decreased seismic energy release.

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ABSTRACT

In the present study we investigated the character of variation of long-range correlations features in earthquakes' temporal and spatial distribution in Caucasus. Scaling exponents of data sets of interearthquakes time intervals (waiting times) and interearthquakes distances were calculated by method of Detrended Fluctuation Analysis (DFA). Scaling exponent values were calculated for time windows with consecutive 500 data as well as for 5 year long sliding windows.

It was shown that scaling exponents calculated for different windows vary in a wide range indicating variable behavior from antipersistent to persistent type. In the overwhelming majority of cases scaling exponents manifest persistent behavior both in the earthquakes time and spatial distributions. Close to 0.5 and antipersistent scaling exponents were obtained for the time periods when the strongest regional earthquakes occurred.

We observed slow trend in long-range correlation features variation for the considered time period.

1. Introduction

Despite the complexity of the Earth crust as dynamical system, there are some well known universal scaling relations that characterize different aspects of earthquakes distribution [1–4]. The interest to the investigation of scaling properties of seismic process has especially increased for the last decade. At present the results of multitude of theoretical researches and the analysis of field data on the scaling features of earthquake spatial temporal and energy distributions from different seismic regions with different tectonic regimes carried worldwide can be cited (e.g. Refs. [5–12], etc.).

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In general, an advantage of such analysis is that assessment of scaling characteristics of data sets provides valuable information about the strength of correlations or about the extent of the determinism/regularity in the considered process. In practice calculated scaling exponents become a kind of indexes for assessment of the degree of regularity of investigated complex process [13–15,8,16,17,10].

Analysis of the scaling features of seismic process shows clearly that earthquake generation in general does not follow patterns of random process. Exactly, well established clustering, at least in time and spatial domains, suggests that earthquakes are not independent and that seismicity is characterized by slowly decaying correlations (named long-range correlations), what is commonly exhibited by non-linear dynamical systems far from equilibrium [13,14]. Moreover, it was shown that in the temporal and spatial domains earthquake distribution may reveal some features of, close to low-dimensional, nonlinear structure, while in the energy domain (magnitude distribution) it is close to random-like high dimensional process [18,19]. Thus, according to present views, seismic process, in different of its domains (spatial, temporal, energetic) manifest different scaling properties or in other words is characterized by different extent of regularity [18,19,12,11,20,21].

In this work we studied scaling properties of the series of waiting times and distances between consecutive earthquakes in the earthquake catalogue of Caucasus and adjacent territories. Importance of such researches for Caucasus is obvious taking into consideration that Caucasus is seismically active zone and that in the last decades it was struck by strong earthquakes, such as Spitak 07.12. 1988 (M6.9), Racha 21.04.1991 (M6.9), Barisakho (M6.5) 23.11.1992, Racha 07.09. 2009 M6.1.

Present study is the continuation of our previous researches in which we already analyzed integral dynamical characteristics of seismic process in Caucasus for the whole available period of observations [19,22,12]. As it was already mentioned in those researches, for the entire period of observation, we showed that by the features of temporal and spatial distributions seismicity in Caucasus reveals features of the correlated, non-random process. At the same time, the character of variation of scaling properties for shorter time periods remains unclear.

In order to fill this gap, we aimed to analyze dynamical features of seismicity in Caucasus by assessing scaling characteristics of its time and space distribution for shorter time periods.

Thus the main focus of this research was the analysis of the character of variations of the scaling exponents of data sets of waiting times and interearthquake distances, calculated for smaller, comparing to whole catalogue time span, time periods. Such analysis should provide additional insight into the evolution of complexity and spatio-temporal structure of the seismicity in Caucasus.

2. Used data and methods of analysis

Data sets of waiting times and interearthquake distances for the period from 01.01.1960 to 31.12.2014 were extracted from the earthquake catalogues of M. Nodia Institute of Geophysics, Tbilisi State University and Institute of Earth Sciences of Ilia State University. Catalogue area includes the segment of the Mediterranean Alpine Belt, located between the still converging Eurasian and Africa-Arabian lithosphere plates and represents typical continent–continent collision zone. The information about area, covered by catalogue and the type of seismic network can be found in Refs. [23,24].

Analysis of the Gutenberg–Richter relationship for used catalogue showed that it can be considered as complete for $M \geq 2.2$. At the same time, taking into account the results of time completeness analysis (not shown here), $M \geq 3.0$ magnitude threshold has been used, when we considered the whole catalogue for the entire time of observation. This was done to avoid possible problems related to bad working conditions of seismic network of Caucasus in 90th, after collapse of USSR (see for details [24]). Original earthquake catalogue included 6684 $M \geq 3.0$ events. Next, in order to remove a bias due to the presence of aftershocks, we declustered the catalogue using the Reasenberg's algorithm (1985). From the declustered catalogue, containing 4757 events, we calculated sequences of waiting times or inter-earthquakes times (IET) in minutes, as well as inter-earthquakes distances (IED) in kilometers, used in the further analysis.

In this research long-range time-correlations in the investigated interevent time and distance data sets were assessed by the method of Detrended Fluctuation Analysis (DFA) [25,14]. Method of DFA permits the detection of long-range correlations embedded in a nonstationary time series through calculation of a quantitative parameter—DFA scaling exponent. Though some authors still question the efficiency of method, especially for short nonstationary data sets (e.g. Ref. [26]), generally this analysis technique is widely accepted and often used for different types of time series including geophysical data sets (e.g. Refs. [27,6,17,28–30]).

Being frequently used, the basics of DFA are well known and described in series of often cited articles, so we will just briefly stop on its main steps. At first given time series of N samples is integrated. After this the integrated time series is divided into boxes of length n, and in each box the polynomial local trend is calculated and removed. Then N/n mean squared residuals—Detrended Fluctuation Functions ($F(n)$), should be calculated for each box of size n.

$$F(n) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[Y(i) - Y_n(i)]^2}\,.$$

Since $F(n)$ increases with the box size n, in case of fractal or self-similar properties of analyzed data, a power-law behavior $F(n) \sim n^{\alpha}$ can be revealed. If a power law scaling exists, the $F(n)$ vs. n relationship, in double logarithmic fluctuation plot,