

The Nonlinear Time Sequence Analysis in the Alpine-Himalayan Earthquake Zone

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Abstract. The characteristics of the earthquake activity in the Eurasian earthquake zone, which is the second largest earthquake zone in the world, was investigated by researchers. The earthquake activity of the Eurasian earthquake zone was analysed in various disciplines, such as earth dynamics, rock mechanics, geology and tectonics. The emergence of fractal theory provided a new direction in exploring the characteristics of the earthquake activity in the Eurasian earthquake zone. This study processed the data on the earthquake activity in the Eurasian earthquake zone by self-similarity method and scaled invariant feature test and used the rescaled range analysis method to analyse the nonlinear time series fractal characteristics of the earthquake activity in the Eurasian earthquake zone. Results show that the time series of earthquake activity in the study area is not an independent Poisson process, which exhibits the characteristics of scale invariance and long-range correlation. Approximately 80% of the H values of the earthquake activity iteratively increase and decrease for moderate earthquakes, which is mainly concentrated during the increasing stage. The time difference of the H value between the two-neighbouring earthquake shows that the H value fluctuates in the active earthquake region and is stationary in the relatively stable region. Strong earthquakes will likely occur in the next few years because the H value fluctuates.

1 Introduction

Research on earthquake activity is a comprehensive and interdisciplinary field, which involves knowledge from various fields, such as geophysics, earth dynamics, rock mechanics, geology, tectonics and geodesy [1-8]. Significant results are obtained in analyzing the earthquake activity in the Eurasian earthquake zone, such as the spatial distribution of the Eurasian Earthquake Research on the laws of earthquake activity [9-16]. Only a few studies are related to the characteristics of earthquake activity at the current stage of large-scale earthquake zones, such as the Eurasian earthquake zone [17-21]. Earthquake activity exhibits the characteristics of a complex system. Thus, using a large

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spatial scale to examine earthquake activity helps explore the characteristics of earthquake activity from the system perspective. Small-scale earthquake activity is generated based on the stress balance of the large-scale earthquake zone [22]. Therefore, investigating the characteristics of the earthquake activity of large spatial scales is necessary. This study focuses on the earthquake activity of large spatial areas to fill the gap in research.

The current study employs the rescaled range analysis (R/S) method to examine the earthquake activity in the Eurasian earthquake zone based on fractal theory. The invariance and long-range correlation of the earthquake activity in the Eurasian earthquake belt was verified using complete earthquake activity data. The study analyzed different kinds of earthquake activities by utilizing the R/S method to obtain the Hurst index. Different kinds of earthquake activities were analyzed by employing the full-time sliding method to determine the special properties of the earthquake activity in the Eurasian earthquake zone, vector of the plate movement, stress equilibrium and spatial distribution of the earthquake activity in the Eurasian earthquake zone. Only a few studies are related to the characteristics of earthquake activity at the current stage of large-scale earthquake zones, such as the Eurasian earthquake zone. Earthquake activity exhibits the characteristics of a complex system. Thus, using a large spatial scale to examine earthquake activity helps explore the characteristics of earthquake activity from the system perspective. Small-scale earthquake activity is generated due to the stress balance of the large-scale earthquake zone [22]. Therefore, investigating the characteristics of the earthquake activity of large spatial scales is necessary. This study focuses on the earthquake activity of large spatial areas to fill the gap in research.

The current study employs the rescaled range analysis (R/S) method to examine the earthquake activity in the Eurasian earthquake zone due to fractal theory. The invariance and long-range correlation of the earthquake activity in the Eurasian earthquake belt was verified using complete earthquake activity data. The study analyzed different kinds of earthquake activities by utilizing the R/S method to obtain the Hurst index. Different kinds of earthquake activities were analyzed by employing the full-time sliding method to determine the special properties of the earthquake activity in the Eurasian earthquake zone.

2 Previous study

Earthquake birthing is considered a nonlinear process [23], which indicates that earthquake attributes, are essentially heterogeneous and complex. Therefore, considering the nonlinear system in research is an innovative and effective method to examine earthquake activities which have nonlinear characteristics.

The R/S method is applied to process earthquake data. Yangming et al. [24] analyzed the earthquake activities at different magnitudes and spatial scales in the US by using this, Turkey, China and other locations and determined that the frequency time series of these earthquake activities exhibited a good R/S relationship; thus, the characteristics of earthquake activities were identified in the time series. Chen et al. [1] also employed the R/S method to assess the parameters of earthquake activity and determined that the H value declines significantly before earthquakes occur. To sum up, the H value is a good predictor of earthquakes.

3 Description, processing and analysis methods of data

3.1 R/S analysis method

In 1965, British hydrologist H. E. Hurst first proposed R/S theory, which is eventually called the R/S method [1]. The R/S method is employed to analyses research objects with time sequence properties, known as the ‘the analysis that changes the scale’. The indicator of the R/S is the Hurst index [25]. The Hurst index can be used in analyzing various complex and natural phenomena to obtain the time series characteristics of these phenomena [26]. The research objects of this method must possess a certain statistical regularity in different time series. The conclusions obtained from the entire timescale can be used in the timescale after a certain treatment, and the opposite can also be true, by which the similar characteristics between the parts and the whole can be obtained [27-31].

Varying Hurst values have different meanings. $H > 0.5$ indicates that the research object is random and rules must be followed, which is long-range correlated in time, and vice versa. $H < 0.5$ denotes that the study object is mainly regular and less random [32]. The Hurst index can obtain by analyzing data in different short timescales to achieve the regularity of data in a timescale. Thus, the Hurst index can be used to predict the occurrence of an event.

3.2 Verify the scale invariance of earthquake activity

The Gutenberg–Richter (G–R) relationship pertains to the magnitude–frequency relationship. The G–R law is a typical example of fractal power law, which is used to analyses the regularity of earthquakes and verify the integrity of earthquake data [33,34]. The earthquake activity in the Eurasian earthquake zone was statistically analyzed to obtain the magnitude–frequency curves of earthquake data from 1900 to 2015, which were preprocessed in the study area (Figure 1).

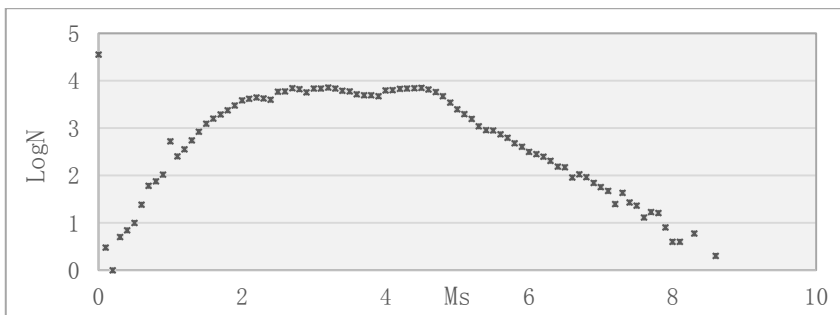


Fig. 1. Magnitude–frequency curves of the earthquake data in the Eurasian earthquake zone

Figure 1 shows that the G–R relationship is an exponential relationship, which can be applied to a broad range, i.e. from regional earthquakes to global earthquakes. The relationship shows that earthquake scaling invariance is established in a large range, which indicates that the entire Eurasian earthquake zone has scale invariance.

3.3 Verify the long-range correlation of earthquake activity

The pre-processed earthquake data in the Eurasian earthquake zone from 1900 to 2015 were analyzed dimensionally. The earthquake data with different spatial distributions and time series were examined from a different magnitude. Therefore, year was used as the unit to statistically analyze the frequency of different magnitudes of earthquake data. The statistical results were analyzed based on the Hurst index, and the analysis results in different scales of magnitude (Table 1) were obtained.

Table 1. H value of the Hurst index in the Eurasian earthquake zone

Earthquake magnitude Ms	H value
≥ 3.5	0.7704
≥ 4.0	0.5434
≥ 4.5	0.7574
≥ 5.0	0.7485
≥ 5.5	0.8006
≥ 6.0	0.6600
≥ 6.5	0.9621
≥ 7.0	0.8608

When the H value is less than 0.5, the earthquake time series contains more certainty factors and less random factors, and vice versa. The calculation results indicate that the H values of the different earthquake frequencies in the earthquake zone are > 0.5 , which denotes that the earthquake activity in the earthquake zone is not an independent Poisson process. By contrast, earthquake activities have long-range correlations, which show that previous incidents influence future incidents and that earthquake occurrences are both regular and random. This conclusion is consistent with that obtained by Roy P. N. S. [35]. Therefore, the R/S method is useful to analyze different magnitudes at various timescales in the earthquake zone.

4 Analysis of earthquake time series in the Eurasian earthquake zone using the R/S method

The amount of study data and the size of sliding windows significantly affect the accuracy and reliability of the H value. From the pre-processed data, the current study selects the earthquake activity data that meets the conditions of $M_s \geq 2.0$ and $M_s \geq 7.0$ from 1900 to 2015. The sliding window was set to two years, and a month was considered a sliding step [36-38]. Strong earthquakes in the earthquake zone were analyzed by using the R/S method. The characteristics of the H value during earthquake activity or before earthquake activity were identified.

Figure 2 shows that the average value of H is 0.5274, which is > 0.5 . This value indicates that the earthquake data have a long-range correlation. The actual H value fluctuates from the average value, and approximately half of the total values are higher than the average value. The H value of the earthquake zone changes with time and follows a certain law. The values of 105 datasets are less than 0.5, which account for 51% of the entire data. The values of 100 datasets are less than 0.5074, which account for 49% of the entire data. The values of 90 datasets are more than 0.55, which account for 43.6% of the entire data and indicates that the incidence of strong earthquakes is high. Approximately 87.68% of all the H values of the earthquake activity iteratively increase and decrease for moderate earthquakes, which are mainly concentrated during the increasing stage. The H

values declined on January 1911, June 1913, June 1914, December 1915, July 1917 and July 1918. During the remaining time period, a strong earthquake occurred within 10 months after a low H value was detected, and the time intervals of two low-value adjacent earthquakes are mainly three to five months. The earthquake activities in the earthquake zone increased and decreased, and the time points of earthquakes mainly occurred in the stage of increasing earthquake activity.

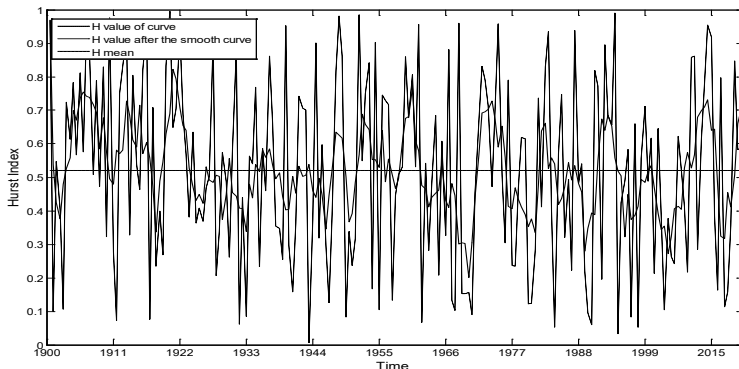


Fig. 2. Time course curve of the H value with $M_s \geq 2.0$ in the Eurasian earthquake zone

The results shown in figure 3 indicate that the mean value of H is 0.5036, which is greater than 0.5. This result indicates that earthquakes of this magnitude have a long-range autocorrelation. Overall, the H value of earthquakes in this magnitude fluctuates around the mean. However, the majority of these values are near the mean, and 82.22% of earthquakes have H values that tend to increase and decrease, gain a low value and increase again and then increase again. Except for the data on January 1905, September 1921 and April 1961, whose occurrence time declined, as many as 201 earthquakes were followed by a moderate–strong earthquake three months after a low H value was detected. The time intervals of the two low values of adjacent earthquakes are mainly five to seven months. Among the H values of the 204 earthquakes whose M_s is greater than 7.0, 107 account for approximately 52% of the total number with H value greater than 0.5, 109 account for 53% of the total number with H value less than 0.5036, and 89 account for approximately 43.6% of the total number with H value greater than 0.55. The results show that earthquakes of this magnitude have a long-range autocorrelation.

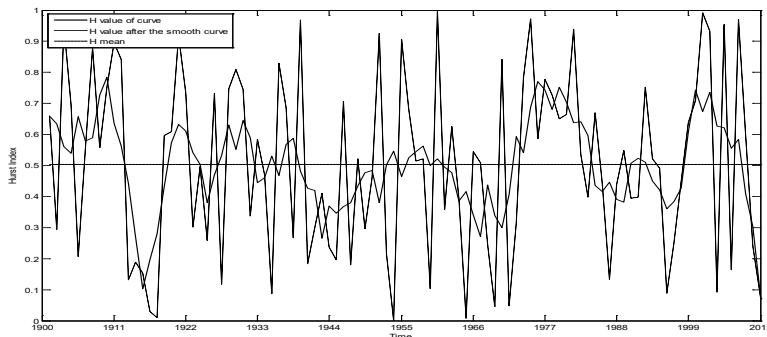


Fig. 3. Time course curve of the H value with $M_s \geq 7.0$ in the Eurasian earthquake zone

5 Analysis and discussion

The results of the analysis, which employed the R/S method on the pre-processed earthquake data of the Eurasian earthquake zone from 1900 to 2015, indicate that:

(1) The earthquake activities in the Eurasian earthquake zone exhibit self-similarity and are scale invariant. G–R relationship was used for analysis and testing to prove that the earthquake activity in this zone is not an independent Poisson process in the timescale. Current earthquake activities are influenced by past earthquake activities, which indicates that the Eurasian earthquake zone is scale invariant.

(2) The H value has strong correlation in the time series. The H values of all different earthquake frequencies in the earthquake zone are greater than 0.5. This result indicates that the earthquake occurrences in the Eurasian earthquake zone are both regular and random, which denote that the earthquake activity in the earthquake zone has a long-range correlation.

(3) By employing the R/S method, the H values of all the earthquake activities in the Eurasian earthquake zone are greater than 0.5. The values increase then decrease, incur a low value then increase again, and most are in process of increasing again. These findings indicate that the Eurasian earthquake zone is an active earthquake region.

(4) The H value fluctuates before a major earthquake. When the H value of $M_s \geq 7.0$ earthquakes becomes observably abnormal, most of the earthquake activities in the Eurasian earthquake zone are followed by an earthquake in three years because of the low H value. This result indicates that the earthquake occurrences in this zone are closely related to the geological structure and geographical conditions of the earthquake zone. The outcome also shows that the development and occurrence of earthquakes are complex, and various factors influence these processes. The frequent and abrupt increase or decrease of the H value warrants further research because these data indicate that an earthquake occurrence will likely occur in the next several years.

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