Forecasting Earthquakes in Qinghai-Tibet Plateau Using Rescaled Range Analysis

Linfeng Xu¹, Jiemin Chen¹, Zhixin Liu¹⁺, Yan Liu² and Jiawei Tian²

¹School of Life Science, Shaoxing University, Shaoxing 312000, Zhejiang, P. R. China
²School of Automation, University of Electronic Science and Technology of China, Chengdu 610054, Sichuan, P. R. China

*Corresponding author e-mail: liuzhixin@usx.edu.cn

Abstract. Fractal analysis provides a powerful method for studying complicated natural phenomena. This paper employs fractal analysis to study seismology based on the statistical fractal concept and provides a simple overview for analysing the temporal distribution and fractal characteristics of seismic activity. We delve into the self-shot fractal characteristics of seismic activity by using an analysis of the Rescaled Range scale invariance of seismic time and time interval sequences.

1. Introduction

In recent years, more and more attention has been paid to ecological issues [1-4], and seismic activity poses a huge threat to human life and property. Every earthquake is accompanied by huge losses. Research related to seismic activity. Describing the statistical characteristics of regional seismic activity through a catalog of earthquakes is one of the primary methods employed today to analyze seismic activity [5]. However, seismic activity is based on the instability of the Earth’s lithosphere [6] and is nonlinear [7]; the mechanisms involved in causing earthquakes are very complicated [7], the strength of an earthquake fluctuates significantly over time, and regions will alternate between being seismically active and stable [8]. Because earthquakes are complex [9], we need to determine some parameters that are used to describe its activity. For example, Kagan [8] used a coefficient of variation and proved that the establishment of the model [10,11] and the system [12,13], as well as the selection of the parameters [14-16] are very important to the experimental results.

Previous studies mostly are based on statistics [17]. The question at hand is whether we are able to make estimates of the variables that may occur in the future based on observations made in the past or over a short term. Or, in contrast, we can speculate the statements of a variable which will fluctuate in a short time based on the statistical characteristics of a long term variable [18]. This is a quiet question and its hazards when combined with spatial analysis [19-21]. With the deepening of machine learning [22-26] and the combination of statistics [27] and deep learning [28-30], seismic research has been further developed.

The Rescaled Range Analysis method uses time sequence analysis, and the Hurst exponent is the fractal dimension of standard deviation or range structure [31,32]. Hurst analyzed many complex natural phenomena, studying mostly on how the time sequence conforms to the self-affine fractal [33,34]. The smaller H becomes when < 0.5, the more regular the sequence becomes, and conversely a larger H > 0.5 indicates less regularity [35]. Using a different length of sliding time-window among
earthquakes, and studying their regularity, and extrapolating the future situation [36,37], can provide relatively conservative estimates of the nature of future events [38].

Based on the above theory, a relationship curve with a slope of 0.85 between frequency and magnitude is obtained which indicates that the earthquake time of the study area is of self-similarity and scale invariance. [39]. Then, we systematically analyzed seismic data of Qinghai-Tibet Plateau with magnitudes greater than 3.0 from 1900 to 2013(Figure 1). Furthermore, using Rescaled Range Analysis, we analyzed the earthquake frequency time series of the partitioned study area and 8 groups of earthquakes with magnitudes greater than 7, and extracted the variation characteristics of the value of H for these strong earthquakes [40,41].

Figure 1. The epicenter distribution when MS is greater than or equal 3 in the Qinghai-Tibet Plateau.

The Qinghai-Tibet Plateau zoning research area considered in this paper can be researched on the basis of their respective interactive characteristics. Searching for seismic activity characteristics at a small scale, thus avoiding the over-smoothness in identifying the overall characteristics when inspecting large areas.

2. Data analysis

2.1. Study area and data sources

The study area mainly including Sichuan, Yunnan, Qinghai and Tibet, is one of the most earthquake-active areas in China [42]. The strongest area where was interacted by collision and uplifting of Indian plate and Eurasian plate [43,44].

In addition, the heterogeneity of the regional stress field is indicated for the spatial distributions of differences among different sub-blocks. This area has been stricken by devastating earthquakes with high frequency (Wenchuan M8.0 in 2008, Yushu M7.1 in 2010, etc.), which caused severe damage and put an adverse impact on socioeconomic development [45]. It is worthwhile for us to put much attention and emphasis on this earthquake-stricken area all the time since the prediction system has not been satisfactory enough.

The data are from the China Earthquake Network Center and U.S to consider the effects of uneven data availability on our study [46,47]. We have studied all earthquake records with epicenters distributed in southwestern China (21–37°N, 78–110°E) from 1900 to 2013.

2.2. The processing and analysis of the seismic data

The K–K method was used to identify earthquakes that could be classified as aftershocks. This allowed us to delete aftershocks from the dataset. The aftershock can’t be completely remove, but we expect that the effects of short-term clustering are diminished [48]. Figures 2 provide frequency diagrams that show the data analysis before and after aftershocks were deleted.
The MC is an important parameter that we should estimate, which is based on the Wiemmer’s and Wyss’s method [49,50].

The G-R relationship method (FMD) was used in this paper to analyze the integrity of earthquake catalogues and to calculate the minimum integrity magnitude (Formula 1).

\[
\log N = a - bm
\]

Where \( m \) is earthquake magnitude, \( N \) is the earthquake magnitude, and \( a \) & \( b \) are constants.

The frequency–magnitude diagram for the Qinghai-Tibet Plateau and data set, namely for 1900 to 2013, are presented in Fig. 3(a), which is equal to \( MC = 2.8 \) (Fig. 3(b)). Therefore, choosing the earthquake catalogue above the limit \( MC = 2.8 \) from 1900 - 2013 is equitable.

2.3. Rescaled Range Analysis method and results

The Rescaled Range Analysis method is used to analyze the time sequence. Define range:

\[
R(\tau) = \max_{1 \leq s \leq T} [X(t, \tau)] - \min_{1 \leq s \leq T} [X(t, \tau)], \tau = 1, 2, ...
\]
Where

Define the standard deviation:

Then we found:

3. Results

3.1. Temporal variations of Hurst for moderately strong earthquakes

We collect time series of H values (earthquakes with MS ≥ 5 in Sichuan province) which shows that the values of 90% of the H measurements were lower than the mean value (0.4353). For 77.78% of the time when large earthquakes occurred during the recovery of the down-low-recovery process of H, H was not in a declining stage except during December 1994 and October 2011. The remains are expected to experience a strong earthquake within three years. The region of 5–12 months is now in the recovery stage of the down-low-recovery process, so the chance of a strong earthquake occurring is relatively high in the near future.

We collect time series of H values (19 groups) and relevant information of the MS ≥ 5 earthquakes in Yunnan region. The estimates of H of earthquake in Yunnan region are presented in Fig.5. Nearly 70% groups (13 of 19 groups) had an H below 0.5. Nine groups had an H below the average value 0.45 and closed to 50%. Six groups had an H above 0.5. Four groups with an H were above 0.55 and 67% of these groups were associated with strong earthquakes.

With the exception of four groups of earthquakes (those occurring in December 1992, June 2007, June 2012, and September 2012) that occurred during the high-decline stage, the remains occurred during the low-recovery stage. Therefore, in 3 years from the low to the recovery stages, strong earthquakes are more likely to occur. The anomaly was concentrated during a period of 11–12 months. Currently, the change of a strong earthquake in the future is the highest in the recovery stage during the down-low-recovery process.

![Figure 5. The H-time curve of earthquakes in Yunnan area](image)

We collect time series of H values and relevant information of the MS ≥ 5 earthquakes in Tibet region. The H curve in Figure 6 shows that 37 groups of earthquakes occurred in Tibet with MS ≥ 6.0. Of those, 26 groups (close to 70% of all 37 groups) had an H lower than 0.5, 11 groups larger than 0.5, 7 groups larger than 0.55. Except for these 6 groups of earthquakes (which occurred in September 2008, October 2008, July 2009, September 2009, March 2010 and April 2010), the remains occurred during the low-recovery stage and in a year when a strong earthquake occurred. Before a strong earthquake occurred, 80% of all measures of H may show the anomaly features of the decline-low-recovery process. An abnormal concentration time is 4 to 8 months. We could know that a declining stage of decline-low-recovery will occur in the future based on Figure 6. Therefore, the chance of a strong earthquake occurring in Tibet is very small.
3.2. **Temporal variations of Hurst for strong earthquakes**

Figure 7 shows the Rescaled Range Analysis curve of H in south western China for strong earthquakes, while we select the earthquake catalogue for south western China and the corresponding values of Hurst’s H when MS ≥ 7.

![Figure 6. The H-time curve of earthquakes in Tibet region](image)

![Figure 7. The H-time curve of earthquakes in Southwest of China.](image)

4. **Discussion and conclusions**

In this study of seismic activity, we discussed the seismic activity by analyzing the temporal and spatial distribution characteristics of earthquakes, and determined a regularity of earthquake occurrence. By analyzing the values of H, we came to the following conclusions.

1. We used a sliding Rescaled Range Analysis to determine the frequency of the seismic time sequence. 80% earthquakes showed obvious precursor anomalies which had uniform morphological characteristics. The values of H characteristically exhibited a series of decline-low-recovery process cycles. The earthquakes occurred when the value of H was in the declining and recovery stages.

2. No relationship was observed among the durations of the anomalies, specifically, the lowest value, the descending range and the total time from the lowest value to earthquake occurrence. Although the earthquake magnitude varied across the study area, the precursor anomalies before a strong earthquake occurred almost always were of the same magnitude. However, no low value anomalies were associated with the two 5.0 magnitude earthquakes in the Sichuan area. These situations might be related to geological structure [51, 52], or other factors.

3. According to the value of H of the time interval, we can see that the reliability of H is high in active seismic areas, such as Tibet and southwestern China, and the anomaly is very visible.

4. We selected 66 groups of earthquakes with M ≥ 5.0 occurred in Sichuan, Yunnan and Tibet. These exhibited anomalies with decline-low-recovery cycles. Over 70% occurred in the recovery stage. With results in our region, an earthquake typically occurred when the value of H increases from the lowest point within three years. A rapid increase in H from a low value is a short-term precursor which is deserved being noticed. If this situation is met, an earthquake may be coming.

5. For Sichuan and Yunnan, the possibility of a strong earthquake is greater. The possibility of the occurrence of strong earthquake in Tibet is relatively small.
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