The application of R/S analysis for the earthquake prediction in Sichuan, China

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Abstract

Fractal is one of the powerful analysis for the study of complex natural phenomena. This paper employed fractal analysis in seismology based on the Statistical fractal concept and gave a simple overview to fractal characteristics of seismic activity in the spatio-temporal distribution. Analyzed by the R/S scale invariance of seismic time sequence and time interval sequence, this paper explored the self-shot fractal characteristics in the seismic activity.

Keywords: statistical fractal, earthquake, spatio-temporal distribution, R/S analysis method

1 Introduction

The research on the Seismic activity means the research on the overall time, space and the strength distribution feature of groups of Seismic activity. Using the catalog of earthquake to describe the statistical characteristics of regional seismic activity is one of the primary ways of today's research on seismic activity [1]. However, as a kind of instability phenomenon of the Earth's lithosphere which is nonlinear dynamical system, the mechanism of earthquake is very complicated, the strength of earthquake had a significant fluctuation over time and showed active and quiet alternating changes [2]. Because of its complexity, so we get a lot and Different aspects of the parameters those are using to describe the Earthquake activity, time change of seismic activity, the cluster of earthquake on time and space and Earthquake spatial concentration. Such as Kagan which uses the coefficient of variation CV to describe the statistical characteristics of the intervals of adjacent earthquake and describe the uniform or non-uniform of the process of earthquake quantitatively and so on [3-4].

Most of these studies are based on statistics, describe the feature such as the overall situation and fluctuations of the earthquake in a region with statistical features, such as average value, mean square error and so on [5]. The question now is whether we can make estimates to the situations may occur in the future of variables by the observation in the past or in a short time. Or on the contrary, speculate the situations may occur in a short time by the statistical characteristics of the long-time variable [6]. And this is significant in the analysis of seismic activity and seismic hazard.

R/S is a method of time series analysis which is derived by the self-affine fractal. Essentially, the Hurst exponent is the fractal dimension of standard deviation or basis structure[7-8]. Hurst analyzed many complex phenomena in nature, most of their time series conform to the self-affine fractal, and H>0.5, which means that complex phenomena in nature not only have randomness, but also a certain regularity [9]. They are long-range correlations in regularity of time. In other words, what happened later is not random, there is a certain relationship with what happened before, and reflects a certain regularity [10]. The value of H has an important physical meaning. The greater it declined from 0.5, the more regularity of the sequence, conversely the less [11]. Changing the length of time, and studying its regularity based on the relatively short time observation, and extrapolate the situation in the future, make a relatively conservative estimate for the future events. It can reflect the inner regularity of complex time series [12].

Based on the theory above, this paper proves that the scale invariance characteristics and the long-range correlation of seismic activity, to show that seismic activity time is not independent Poisson process, but the seismic activity later is affected by which in a previous time, so it is meaningful that we use R/S to study the regularity of the seismic time sequence [13]. Based on this, it is analyzed earthquakes in Sichuan since 1970 in a full time and systematically. At the same time, did an R/S analysis to groups of earthquake these are greater than or equal to magnitude 7 in Sichuan, China, to extract the variation characteristics of the value of H which is Hurst's dimension in the medium-strong earthquake [13-14].

This paper used R/S method to study the question that Hurst index and H values of seismic interval sequence in Sichuan change with time, to seek in the abnormal variation of the value of H before a medium-strong earthquake.

2 The principle and calculation steps of R/S method

R/S method was put forward in 1965 by Hurst. It is a way to analyze the time series. Its main principle is as follows [15].

Consider a time increment $\{\xi(t)\}$, here $\{\xi(t)\} = B(t) - B(t-1)$, $B(t)$ is the observed value of time t(t = 1,2,……). To any positive integer τ , define the mean sequence:

$$\langle \xi \rangle_t = \frac{1}{\tau}\sum_{t=1}^{\tau}\xi(t) . \quad (1)$$

In the formula $\tau = 1,2,...$, which means the lag time. $X(t)$ means the cumulative deviation:

$$X(\mathrm{t},\tau) = \sum_{t=1}^{\tau}\left(\xi(t) - \langle \xi \rangle_\tau\right), 1 \le t \le \tau . \quad (2)$$

So define range $R(\tau)$:

$$R(\tau) = \max_{1\le t\le \tau}[X(t,\tau)] - \min_{1\le t\le \tau}[X(t,\tau)], \tau = 1,2... \quad (3)$$

Define standard deviation $S(\tau)$:

$$S(\tau) = \left\{\frac{1}{\tau}\sum_{t=1}^{\tau}(\varepsilon(t) - \langle \varepsilon \rangle_\tau)^2\right\}^{\frac{1}{2}}, 1 \le T \le \tau . \quad (4)$$

The ratio of range and standard deviation is $R(\tau)/\mathrm{S}(\tau)$, which can be thought of as R/S . After analyzed the statistical law of R/S , Hurst found the following relationship:

$$R/S \propto (\tau/2)^H . \quad (5)$$

Taking the logarithm of formula (5), we can get:

$$Lg(R/S) \propto HLg(\tau/2) . \quad (6)$$

We can see that $Lg(R/S)$ is directly proportional to $Lg(\tau/2)$. According to the relationship, there are $n(n > 2)$ values of $Lg(R/S)$ and $Lg(\tau/2)$ could be used to curve fitting. The slope of the linear which was got by curve fitting is Hurst index H.

3 Seismic data selection and processing

3.1 THE RANGE OF SEISMIC DATA

This paper used the earthquake directory which is offered by these two earthquake site CENC (The China earthquake networks center) [16] and USGS (The U.S. geological survey) [17] to proofread the earthquake catalogue of mainland China, and delete duplicates, supplement the missing item, to study the earthquake what the magnitude of earthquake is huge in Sichuan from 1900 to 2013. Using the K - K method to remove the handle of aftershocks for the data of seismic network and the USGS data.

3.2 THE INTEGRITY ANALYSIS OF THE SEISMIC DATA

The Regional seismic network in China was built in 1950s, the regional seismic network which has the small earthquake monitoring function was established in 1970s. So we have a lot of seismic data now. But in fact, the earthquake monitoring ability is different in different regions of China, After 1970 the earthquake is edited by the seismological bureau of Municipalities directly under the central government, autonomous regions and provincial, establish the earthquake catalog database. Earthquake catalog is the basal data of analysis of the seismic activity, is the precondition of the research on the rules of seismic activity, and is the indispensable data to study the dynamics of lithosphere. Because of the different level of development in various areas, there are many differences in earthquake monitoring ability, and earthquake catalogue which was written is limited, so the seismic record in the data of middle-strong earthquakes might be incomplete. So we need to consider its impacts to our study. In order to avoid the effect to the results by the lack of seismic data, we must attach great importance to the integrity of seismic data. The integrity of Seismic data refers to begin with a certain level of the earthquake, the earthquake can be observed above and be recorded completely.

MC is the important parameters, which is used to represent the smallest integrity of historical earthquake catalog. There are a lot of sources of seismic data, and those need to be screened. Because if we choose a higher minimum magnitude, that would miss a lot of useful data for the experiment. However, if we choose a low minimum magnitude, historical earthquake catalog may not be complete any more, and that would affect the result of the experiment. So in order to make full use of historical earthquake data, we need to give the distribution of time domain, the airspace to ensure the earthquake catalogue is complete and keep the useful information do not be missed. Especially for the research of different time scale and different spatial distribution.

Because with the development of social economy, the number of seismic stations are increasing and the monitor ability improved constantly. Which makes the minimum magnitude (MC) of historical earthquake catalog is in constant change with time. Usually the later the time, the smaller the value of MC is, that is to say, the more complete the seismic data is. At the same time, because of unbalanced development of various regions and the uneven of the base station facilities, which makes MC have some differences in spatial distribution, for example the difference at the edge of the seismic network and seismic network covering area is very obvious. All in all, MC not only changes with time, but also exist differences in the spatial distribution.

This paper selected the earthquake catalogues from 1900 to 2013 in Sichuan as the research object, so analyzed the minimum magnitude of the earthquake catalogue in time domain in the study of the region at the following content and gives the main earthquake activity area and the integrity in time and space distribution.

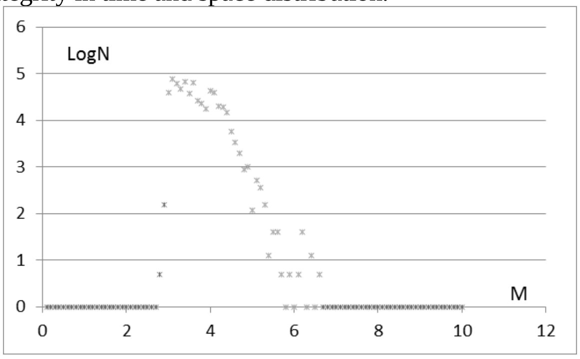

FIGURE 1 The magnitude-frequency diagram from 1900-2013

The method this paper used to analyze the earthquake catalogue integrity is the G R relationship (FMD), calculate the minimum integrity magnitude as shown in Formula 7:

$$LogN = a - bm, \qquad (7)$$

where N is a number of earthquake magnitude file or the cumulative sum of the earthquakes which above a certain magnitude m, a & b are constant. In the result diagram and the magnitude – frequency diagram which was calculated by the method, the number of small earthquake magnitude is in decline, we think that this is due to the earthquake catalogue is not complete.

The process of using magnitude - frequency relation to estimate the integrity minimum magnitude of seismic data as follows: first will begin the earthquake from 0, Level 1 as the step length increasing, until 10.0, get each file number of earthquake magnitude, make earthquake - frequency chart, as shown in figure 1; And then take out different lower limit Mi to fit by the formula (7), as shown in figure 2 to figure 4, the results show that the fitting residual error R is generally decreasing with the increase of Mi, it reduced to the minimum until Mi = Mc, and then increase along with the increase of Mi. Finally fitting results statistical figure as shown in figure 5, abscissa means the minimum magnitude, ordinate means the residual error R, the results showed that from 1900 to 2013 the minimum integrity is $Ms = 2.8$. Choosing the earth-quake catalogue at the lower magnitude limit $Ms = 2.8$ or above the limit from 1900 to 2013 is reasonable.

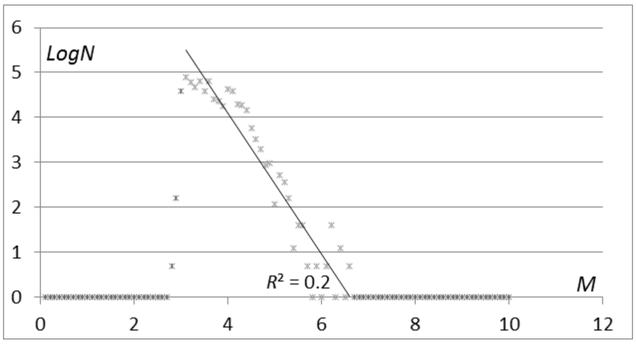

FIGURE 2 The magnitude-frequency chart from 1900-2013 (Ms=2.5)

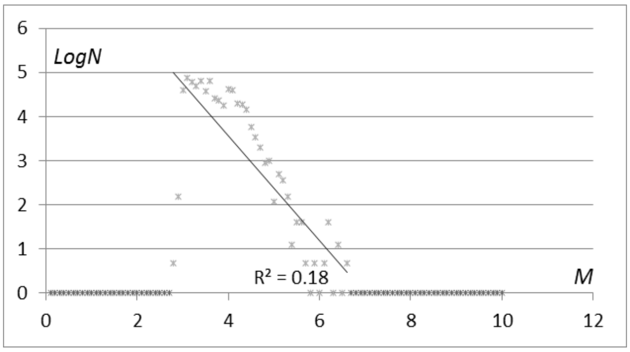

FIGURE 3 the magnitude-frequency chart from 1900-2013 (Ms=2.8)

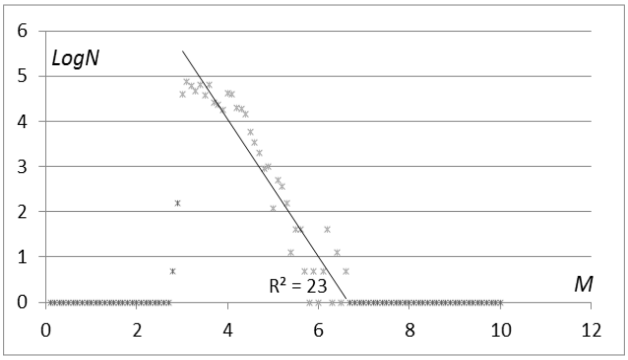

FIGURE 4 The magnitude-frequency chart from 1900-2013 (Ms=3.9)

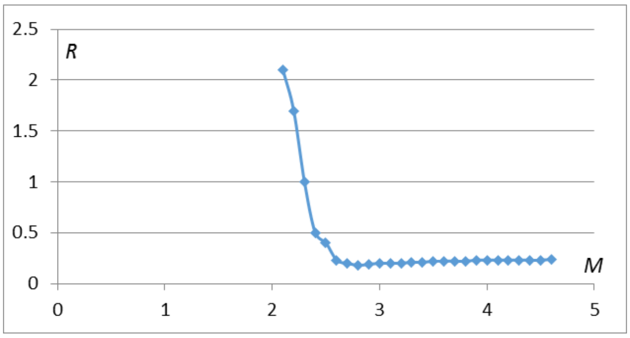

FIGURE 5 The sample of FMD method to estimate minimum integrity magnitude

4 The calculation results and analysis

In the R/S study of Earthquake sequence, such as Liu, C. used the method of non-integer order differential and integral calculus considering the integrity of earthquake catalogue and determination of the minimum magnitude [18], we research the earthquake which is more than 3 and from 1990 to 2013. We chose the frequency parameters values fitting.

The main factors influencing the value calculation precision and credibility are the size of the sample size and the reasonable selection of window. When maximum window size and the sample size is large, then get a high precision on H and the abnormal of H is highly reliable. When maximum window size and the sample size is small, then the credibility of abnormal of H's value is relatively low. So we improve accuracy by long zoom window in practical work. Considering the calculation accuracy of H, and to the considerations of precursor recognition even the substantiality of earthquake prediction, in computing, choose the window size as two years in the R/S analysis of the frequency is suitable.

Do the R/S analysis to the data of Sichuan region (latitude 26.0661-34.3203°N, longitude 97.3661-108.5329° E) from January 1990 to June 2013 a total of 20 years. Using two years as the length of time window to count years and setting a month as sliding step. Processing the data by taking 12 groups as a sliding step. The result of the calculation are shown in table 1, the time process curve of H is shown in figure 6, among them, the dotted line is the actual value of the slide. Because the value of H is affected by the man-made factors of the study area and time window, we set H's sliding step length as 5 and take its average, to reduce the influence of noise. Which used solid line to express.

TABLE 1 time series values of the earthquake in Sichuan province

Date	Time	Latitude	Longitude	Depth	MS	Time sliding H
2013/04/20	02:47.5	30.3	102.99	17	7	0.3553
2013/01/18	42:50.1	30.95	99.4	15	5.5	0.3737
2011/10/31	58:15.0	32.6	105.3	6	5.2	0.4353
2009/06/29	03:51.5	31.46	103.96	24	5.5	0.5109
2008/05/12	27:59.5	31.01	103.42	14	8.0	0.3852
2001/02/23	09:21.8	29.55	101.14	24	6	0.4049
1998/11/19	38:13.8	27.27	101.03	33	6.1	0.2963
1996/12/21	39:39.9	30.56	99.51	10	5.6	0.3054
1996/02/28	22:01.6	29.13	104.73	32	5.4	0.3807
1994/12/29	58:29.7	29.11	103.83	32	5.6	0.4148

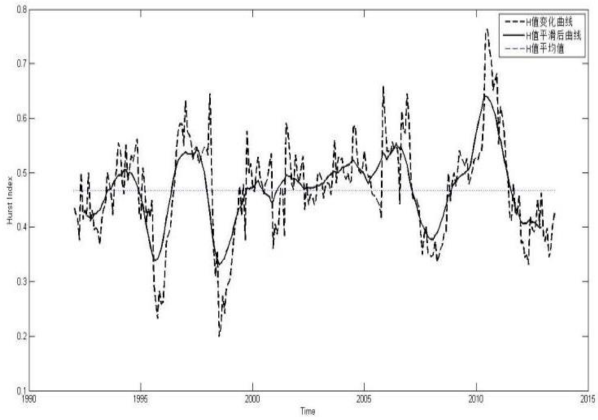

FIGURE 6 The time process curve of the H of earthquake in Sichuan area

The result shows that 90% of H are lower than the average value which is 0.4353, the H of 77.78% of big earthquake are in the process of recovery of down - low-recovery stage. H isn't on decline phase except the December 1994 and October 2011. The rest 8 groups of earthquake are all had an earthquake in 36 months. Abnormal interval sequence is concentrated in the 5 to 12 months. Which is in the process of recovery of down - low- recovery stage in the future, these are more likely happened in the middle-huge earthquake.

5 Conclusion

The study of the seismicity means that first analyze the earthquake of a certain magnitude interval in time and space distribution characteristics, then discuss its physical meaning, and then make a scientific summary for the law of earthquake. As a kind of nonlinear time series analysis method, seismic activity R/S method is applied to sliding Hurst index H value, mainly based on the earthquake catalog data for research. Through this paper we can get the following conclusions.

(1) Under the smooth background, in the steady background, took sliding R/S analysis of frequency time series of the earthquakes in the area above magnitude 3 since 1990.80% of earthquakes showed prominent or morphological characteristics is uniform precursory anomaly. Abnormal morphology is value of H which was begin with normal, but then down-low-recovery. The earthquakes occurred in the value of H on the decline and the process from low basis to rise.

(2) The unusual duration and the lowest value, the decrease and the low value to the occurrence time and total time have no relationship. Although the earthquake in the study area size is different, but the abnormal form before the earthquake almost show a same order of magnitude. The abnormal process of the 8 magnitude earthquake is clear. Such as the abnormal of H in Wenchuan 8.0 magnitude earthquake in 2008. However there are no abnormal low value in two 5.0 magnitude earthquakes in Sichuan area. These might related to tectonic characteristics, characteristic of medium and the earthquake location and other factors. Which also reflects the complexity of the occurrence of earthquakes. And these may also be related to the limitations of the method.

(3) According to the time interval value H, you can see that seismically active areas where is the reliability of H is high, the value of H stable value in the normal background relatively, so that is extremely clear and reliable.

(4) The research of time interval and frequency sequence in Sichuan. For the relatively concentrated area of earthquakes: the earthquake which is greater than 5.0, are in abnormal down-low-recovery, but the earthquake occurred in the recovery stage were more than 70%. And according to the results of the research region by the lowest earthquake occurred in the process of abnormal, H began to rise within three years. Among them the advantage of frequency sequence time rallied for a minimum of 4 to 7 months and 4 to 8 months, the time interval sequence is concentrated in two closed period: 4-12 months or 11-12 months. The quickly picked up of H from low value is a short-term precursor worth noting. If H value appears this change, there would be a risk of earthquake in the coming months.

(5) To Sichuan, the possibility of the occurrence of earthquakes is relatively large.

References

[1] Li J, Chen Y 2001 Rescaled range (R/S) analysis on seismic activity parameters *ACTA Seismologica Sinica* **14**(2) 148-55

[2] Kawamura M, Wu Yh, Kudo T, Chen Cc 2014 A statistical feature of anomalous seismic activity prior to large shallow earthquakes in Japan revealed by the pattern informatics method *Natural Hazards and Earth System Science* **14**(4) 849-59

[3] Chen C, Lee Y T, Chang Y F 2008 A relationship between Hurst exponents of slip and waiting time data of earthquakes *Physica A Statistical Mechanics and its Applications* **387**(18) 4643-8

[4] Xu Y, Burton P W. 2006 Time varying seismicity in Greece: Hurst's analysis and Monte Carlo simulation applied to a new earthquake catalogue for Greece *Tectonophysics* **423**(1-4) 125-36

[5] Wheeler R L, Mueller C S 2001 Central US earthquake catalog for hazard maps of Memphis Tennessee *Engineering Geology* **62** 19-29

[6] Yao Q L 2003 A fuzzy method for evaluating the influences of some geological factors on earthquake disaster risk *Seismology and Geology* **2** 245-59

[7] Enescu B, Ito K, Radulian M, Popescu E, Bazacliu O 2005 Multifractal and Chaotic Analysis of Vrancea (Romania) Intermediate-depth Earthquakes: Investigation of the Temporal Distribution of Events *Pure and Applied Geophysics* **162**(2) 249-71

[8] Rong Y M, Wang Q, Ding X, Huang Q H 2012 Non-uniform scaling behavior in Ultra-Low-Frequency (ULF) geomagnetic signals possibly associated with the 2011 M9 Tohoku earthquake *Chinese Journal Geophysics* **55**(11) 3709-17

[9] Silva P G, Goy J L, Zazo C, Bardaji T 2003 Fault-generated mountain fronts in southeast Spain: geomorphologic assessment of tectonic and seismic activity *Geomorphology* **50** 203-25

[10] Gao H, Zhu Y, Han M, Dou M, Li J 2009 Research on deformation characteristics of Weihe basin *Journal of Geodesy and Geodynamics* **29**(3) 60-6

[11] Han W, Jiang G 2004 Study on distribution characteristics of strong earthquakes in Sichuan-Yunnan area and their geological tectonic background *ACTA Seismologica Sinica* **26**(2) 211-22

[12] Bassingthwaighte J B, Raymond G M. 1994 Evaluating rescaled range analysis for time series *Annals of Biomedical Engineering* **22** 432-44

[13] Shao H, Du C, Liu Z, Sun Y, Xia C 2004 Multi-scale analysis of earthquake activity in Chinese mainland *ACTA Seismologica Sinica* **26**(1) 102-5

[14] Omori S, Komabayashi T, Maruyama S 2004 Dehydration and earthquakes in the subducting slab: empirical link in intermediate and deep seismic zones *Physics of the Earth and Planetary Interiors* **146**(1-2) 297-311

[15] Meng X, Zhao P 1991 Fractal method for statistical analysis geological data *Journal of China University of Geosciences* **2**(1) 111-6

[16] CENC. Available from: http://www.csndmc.ac.cn/newweb/data.htm

[17] USGS. Available from: http://earthquake.usgs.gov/earthquakes/

[18] Liu C, Zhang J, Liu Y 1995 Time-space scanning of seismic time interval fractals for the large north China region by R/S analytical method *Earthquake* **4** 372-8

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