

Identification of Precursory Anomalies before Moderate-strong Earthquakes in Junction of Shanxi-Hebei-Inner Mongolia Area

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Abstract In this paper, we take the Junction of Shanxi-Hebei-Inner Mongolia area as study region using earthquake corresponding relevancy spectrum method (ECSR method) to identify comprehensive precursory anomalies before moderate-strong earthquake. On base of single-parameter relevancy spectrum database with target earthquake magnitude as Ms4.7 and initial earthquake magnitude as Ms1, we carry on multi-parameter analysis and find that result with time interval of 9 months and anomaly threshold with 0.40 times standard deviation has better prediction efficiency. Its anomaly corresponding rate and earthquake corresponding rate are 6/10 and 9/9 respectively.

1 Introduction and Method Brief

The Junction of Shanxi-Hebei-Inner Mongolia is a historical earthquake-prone area located at the intersection of Zhangjiakou-Bohai tectonic belt and Fenwei earthquake belt. There are more than 20 NNE right-lateral strike-slip and tensile tilt-slip faults. The area has been identified as a seismic hazard area for many years, so it is of great significance for the effective identification of seismic anomalies in this area. A lot of research indicate that different observed records and many seismic parameters deriving from earthquake catalogues may show different kinds of precursory anomaly before strong earthquakes. Many scholars have done lots of studies to explore different methods to extract and identify precursory anomaly before strong earthquakes based on mathematical statistics. Such as precursory recognition method of comprehensive information entropy [1], dynamic subordinate function method based on fuzzy mathematics[2], multipoint group slope and synthetic information flow method[3-4], normalized rate (slope) method[5]. Earthquake corresponding relevancy spectrum method (ECSR) was proposed by Wang Haitao et al. to identify comprehensive precursory anomaly before earthquakes and has been applied in many studies areas [6-14]. Here we will carry out precursory anomaly identification analysis with ECSR method.

The theory of ECSR method is as follows:

According to Wang Haitao et al.[6], for the observed time sequence x_1, x_2, \dots, x_n ($i=1, 2, \dots, n$), x_{\max} and x_{\min} are the maximum and minimum value, respectively. The mean and standard deviation can be obtained as follows:

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$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

$$\sigma = \sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 / (n-1)}, \quad (2)$$

On basis of formula (1) and (2), the value range distribution interval is defined as the following rule:

$$Dx_0 \in (\bar{x} - k\sigma, \bar{x} + k\sigma) \quad (3)$$

$$Dx_1 \in (\bar{x} + k\sigma, \bar{x} + 2k\sigma) \quad (4)$$

$$Dx_2 \in (\bar{x} + 2k\sigma, \bar{x} + 3k\sigma), \quad (5)$$

$$Dx_n \in (\bar{x} + nk\sigma, x_{\max}), \quad (6)$$

$$Dx_{-1} \in (\bar{x} - 2k\sigma, \bar{x} - k\sigma), \quad (7)$$

$$Dx_{-2} \in (\bar{x} - 3k\sigma, \bar{x} - 2k\sigma), \quad (8)$$

$$\dots, \quad Dx_{-n} \in (x_{\min}, \bar{x} - nk\sigma), \quad (9)$$

According to formula (3) to (9), we can obtain range spectrum curve by counting the frequency of observed data sequence that distributed in the corresponding range. The value k and n can be modified so as to make the range spectrum curve more similar with the normal distribution as possible. If the data sequence is stable, k should be small as 0.2 when data sequence is stable, k should be big as 0.3 or so when it fluctuates. The value n is between 6 and 10 usually.

Then we can calculate the earthquake corresponding relevancy spectrum (ECSR) in different time intervals by following steps. Firstly, determine target and initial earthquake magnitude according to seismic feature of study area. Secondly, count the number of observational

sequence distributing in different interval of Dx_m to Dx_m point-by-point and the number of earthquakes in different studied interval (unit: month). Then, count the data number corresponding with target earthquakes and all data number of corresponding range, and calculate the ratio of them (regarded as earthquake corresponding relevancy). So we can convert the time sequence of different seismic parameters j ($j = 1, 2, \dots, k$) into corresponding relevancy time sequence P_{ij} ($i = 1, 2, \dots, n$) according to the affiliation value range point-by-point. Then we can obtain the sliding average correlation of different seismic parameters of time interval t ($t = 3, 6, 12, 18$) (unit: month) by formula (10).

$$\bar{P}_{ij} = (P_{ij} + P_{(i+1)j} + \dots + P_{(i+t-1)j}) / t, \quad i = 1, 2, \dots, (n - t + 1) \quad (10)$$

We can get multi-point sliding extreme correlation sequence (M_{ij}) on base of \bar{P}_{ij} and the arithmetic average of M_j of different parameter.

Set j for different seismic parameters ($j = 1, 2, \dots, k$), w for sliding window length (unit: month), then

$$M_{ij} = \max \{ \bar{P}_{ij}, \bar{P}_{(i+1)j}, \dots, \bar{P}_{(i+w-1)j} \}, \quad i = 1, 2, \dots, n - w + 1 \quad (11)$$

$$M_j = (M_{1j}, M_{2j}, \dots, M_{(n-w+1)j}), \quad j = 1, 2, \dots, k \quad (12)$$

Sliding extreme average correlation of multi-parameters can be obtained as follow,

$$P_c = \sum_{j=1}^k M_j / k \quad (13)$$

2 Data Preparation

According to the geological structure and seismic activity characteristics of Junction of Shanxi-Hebei-Inner Mongolia Area, we determine the study area range is between 39.0°-42.0°N and 111.5°-116.0°E (see Fig.1). In this paper, we take small earthquake catalogue since January 1970 to March 2019 provided by China's Earthquake Network Center as data. Analysis of minimum magnitude completeness of the capital area by Wu minjie et al [15] shows that the minimum integrity magnitude of the whole area reached its highest value in 1986 and the minimum integrity magnitude can be controlled below ML2.0 since 1990. On base of ECRS method criteria, we select Ms4.7 as the target earthquake magnitude and Ms1 as initial earthquake magnitude.

Considering the accuracy and completeness of data, we delete aftershocks of earthquake catalogue by K-K method before time scan calculation. Here we calculate time sequence of seven seismic parameters such as η value, b value, seismic hazard D , earthquake defect \bar{M} , seismic intensity factor M_f , seismic frequency N and seismic modulation ratio R_m , which are the original data for the further calculation.

Then, the earthquake corresponding relevancy spectrum database of each seismic parameter in Junction of Shanxi-Hebei-Mongolia area is established by using the ECRS method proposed by Wang Haitao et al. Here the studying database is from 1970 to 2017 and the extrapolating prediction period is from 2018 to March 2019. We can go to quantitative identification and extraction of comprehensive anomalies before moderate-strong earthquakes by retrospective earthquake example analysis.

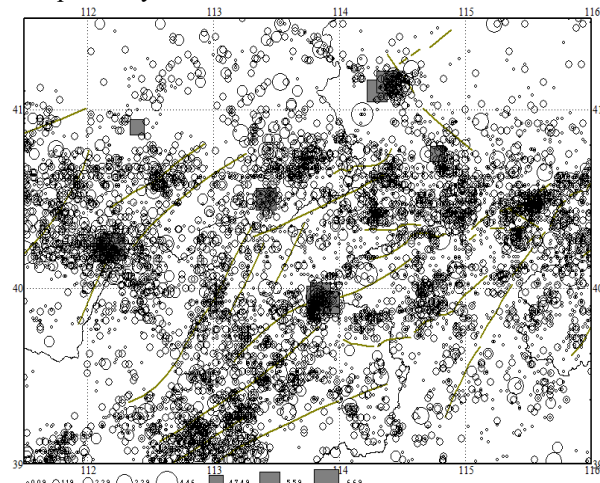


Fig.1 Earthquake ($\geq Ms1$) distribution of Junction of Shanxi-Hebei-Inner Mongolia Area since 1970 to March 2019 (square represent target earthquakes)

3. Calculation results

According to theory and criteria above, we get earthquake corresponding relevancy spectrum of each single parameter of Junction of Shanxi-Hebei-Inner Mongolia Area in different time intervals. And we calculate sliding extreme average correlation of multi-parameters on base of single-parameter results in corresponding time intervals. Due to the limitation of space, here we only give the final results of multi-parameters with time interval of 9 months, 12 months and 18 months (see Fig.2, Fig.3 and Fig.4).

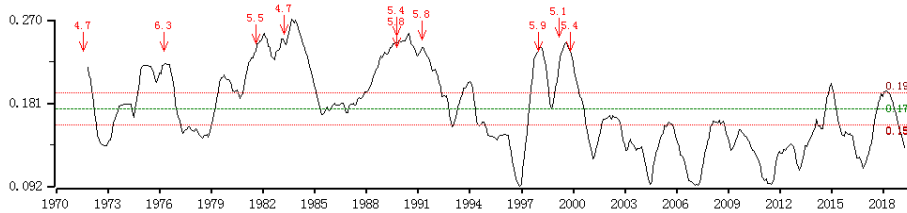


Fig.2 Multi-parameter sliding extreme average relevancy curve of 9-month interval of Junction of Shanxi-Hebei-Inner Mongolia Area

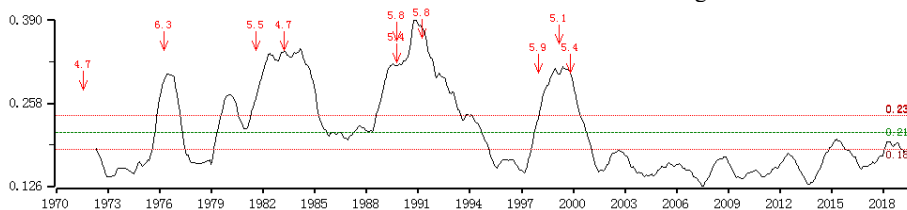


Fig.3 Multi-parameter sliding extreme average relevancy curve of 12-month interval of Junction of Shanxi-Hebei-Inner Mongolia Area

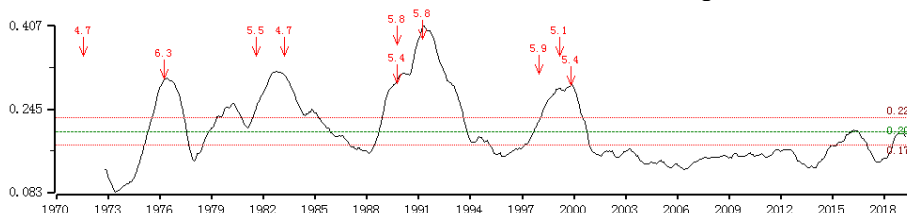


Fig.4 Multi-parameter sliding extreme average relevancy curve of 18-month interval of Junction of Shanxi-Hebei-Inner Mongolia Area

During the calculation of above, We choose the proper parameter k and n by checking the range spectrum structure. And seismic parameters whose value range curve is more similar to the normal distribution were selected to participate in further calculation. We can see from Fig.2 to Fig.4, there appear high-value anomalies before most moderate-strong target earthquakes.

Here we take two indexes of anomaly corresponding proportion (number of anomalies corresponding to the target earthquake / total number of anomalies) and the earthquake corresponding proportion (number of target earthquakes with anomalies before the earthquake/ total target earthquakes) to describe the predictive efficiency of ECRS method. By comparing the results of different time intervals, we find the multi-parameters earthquake corresponding relevancy spectrum of 9-month has better predictive effectiveness than others with 0.40 times standard deviation as anomaly threshold. We regard the target earthquakes occurred in two months as a set, so there are 9 sets earthquakes and 10 high-value anomalies in total. The anomaly corresponding proportion and earthquake corresponding proportion of 9 time-interval are 6/10 (60%) and 9/9 (100%) respectively

4. Conclusions and discussions

Extraction and identification of precursory anomaly using ECRS method applied in Junction of Shanxi-Hebei-Inner Mongolia Area is the key work this paper. According to the analysis results, we can get some following conclusions.

Earthquake corresponding relevancy spectrum method is an effective identification method of earthquake precursory anomaly by retrospective case research and test. There are obvious high-value anomalies before most of the moderate-strong earthquakes in Junction of Shanxi-Hebei-Inner Mongolia Area, so we can carry out earthquake anomaly determination with ECRS method in study area.

Different seismic parameters could show different abnormal forms such as starting time, peak value, end time and so on before moderate-strong earthquakes. Multi-parameter corresponding relevancy spectrum shows more significant anomalies than that of single parameter. So in order to highlight the precursory anomalies of moderate-short period before earthquakes, we can calculate the multi-parameters earthquake corresponding relevancy spectrum on basis of single-parameter of that.

We use ECRS method to extract and identify precursory anomaly before moderate-strong earthquakes since 1970 to March 2019 of Junction of Shanxi-Hebei-Inner Mongolia Area with target earthquakes magnitude of Ms4.7. Different target earthquake magnitudes can lead to different results of predictive effectiveness.

Analysis results of different time intervals are a little different in precursory anomaly identification, so we should choose the better one by testing several different intervals. Study on Junction of Shanxi-Hebei-Inner Mongolia Area shows that multi-parameter earthquake corresponding relevancy spectrum with 9-month interval has higher prediction efficiency with anomaly corresponding proportion and earthquake corresponding

proportion is 6/10 and 9/9 respectively. It indicates that the ECRS method can identify middle-short term comprehensive precursory anomalies in the study area.

Anomaly threshold is also a key factor to evaluate the predictive effectiveness. Here we take 0.45 times standard deviation as anomaly threshold, but it may be different from others researchers so that leads to different anomaly corresponding proportion and earthquake corresponding proportion.

Although we have achieved good precursory anomaly identification efficiency, there still have some misstatements and omissions and could be affected by subjective factors to some extent.

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