Analysis on the predicting significance of mid-strong earthquake swarms in Gansu and its surrounding areas

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Abstract. In order to obtain the accurate prediction efficiency of earthquake swarms in Gansu province, the statistics of minor-moderate earthquake swarms that have occurred in Gansu since 1980 are performed. The earthquake swarm parameters are calculated and the precursory earthquake swarms are extracted based on the criteria of distinguishing the abnormal earthquake swarm. The precursory swarms obtained were analyzed correspondingly with the earthquakes with M ≥ 5 in and around Gansu, and the prediction efficiency of them was evaluated. The accurate precursor index of the earthquake swarms in Gansu were summarized, which provided a judging basis for the seismic trending and made a certain contribution to earthquake prevention and disaster reduction.

1. Introduction
The characteristics of minor-moderate earthquake swarms are an important part of earthquake prediction research. The earthquake swarm activity in the Songpan-Pingwu area before the Minxian 6.6 earthquake indicates that the earthquake swarms may have certain short-term prediction efficiency to strong earthquakes in Gansu. The Luqu earthquake swarm in Gansu, which was formed from January 18 to March 28, 2019, was identified as a precursory earthquake swarm. 214 days later, the Xiahe 5.7 earthquake occurred within 100 km from the swarm, which further illustrates that swarms in Gansu may have certain indication for the prediction of the time, space and magnitude for future strong earthquakes. In addition, Gansu is located on the northeast edge of the Qinghai-Tibet Plateau with frequently strong earthquakes in China. The geological structure in the area is complex. The Alkin earthquake zone, Qilian earthquake zone, and north-south earthquake zone run through from northwest to southeast. The frequency of earthquakes and the earthquake swarms are relatively high, so the swarms may become one of the predictive indicators of earthquakes with M ≥ 5 in and around Gansu.

However, due to the different levels of earthquake activity in different regions, there is also some difference in the relationship between the earthquake swarms and mid-strong earthquakes around these earthquake swarms [1-2, 4-5, 9]. Therefore, it may be not feasible to apply a unified index for the swarm to predicting med-strong earthquakes. It is necessary to establish the prediction index system of the earthquake swarms to mid-strong earthquakes, which provides services for the tracking and predicting of earthquake situation. In this abstract, the earthquake swarms in Gansu after 1980 have been obtained, whose properties have been analyzed, and the time, space, and structural response relationship between the swarms and moderate-strong earthquakes was systematically studied. Then, the R-value of the swarms was calculated to evaluate prediction efficiency to strong earthquakes. Besides, the prediction
indexes of earthquake swarm is applicable to Gansu are refined to reduce the errors of subsequent mid-strong earthquake predictions and provide a basis for earthquake tracking.

2. Correlation analysis

2.1. Determination and prediction significance of the precursory earthquake swarm

According to Lu [6] and "The Guide to Earthquake Prediction Methods" [7], the criteria of judging earthquake swarms are as follows: ① the maximum daily frequency of The earthquake sequence is at least 3 times and the total number of it is 10 above times; ② the largest magnitude in the earthquake sequence is below ML5.2, the magnitude difference (ΔML) between the largest and the second-largest earthquake is less than 1.1; ③ Within 15 days before the start of the sequence and after the end of it, the earthquakes with ML ≥ 1.0 have not been recorded. In this case, the date of the first earthquake is the start of the swarm sequence, and the date of the last earthquake is the end of it. If small earthquakes are recorded continually for many days from the 16th day, the sequence is accumulated only when the frequency of the ML≥1.0 earthquake is greater than or equal to 3 times or the frequency of the ML≥2.0 earthquake is larger than 2 times on the 16th day. For the judgment of earthquake swarm properties, a quantitative analysis method is often used, which is, that the swarm parameters b, h, p, k, U, and F values are applied to judge precursory earthquake swarms. In 1997 [8], among the precursory swarms indexes summarized by Prediction and Prevention Department of State Seismological Bureau in Earthquake Prediction Methods, the single index is that one of the earthquake swarm parameters U> 0.5, K> 0.7, <0.55, b> 0.65, h <1.0 is true, and the comprehensive indexes is that one of the U-K, U- ρ, K- ρ , or U-K- ρ combinations composed of U> 0.5, K> 0.7, or ρ <0.55 is true. The comprehensive index is generally better than single index. Previous research have suggested that within 1-2 years after the end of the precursory earthquake swarm, M≥5.0 earthquakes may occur within 400-500 km near the swarm [3, 10, 12], which shows that the anomaly of the earthquake swarm can correspond to the strong earthquake at the maximum distance of 500km.

2.2. Technical ideas for the extraction of earthquake swa201rms prediction indexes

According to the judgment criteria of the earthquake swarm mentioned above, all earthquake swarms that have occurred in Gansu since 1980 are extracted. It was found that 90% of the swarms have more than 20 earthquakes. Considering the universality and commonality of earthquake swarms, only these earthquake swarms are analyzed and studied. The swarm parameters b, h, p, k, U, and F are calculated, and then the precursory earthquake swarms based on the precursory swarm indexes are extracted. Based on previous research results, and taking into account the different activity of the earthquake swarms in different regions and the strip-shaped characteristics of Gansu region, the correspondence and tectonic relationship of the precursory swarm extracted and medium-strong earthquakes which occurred within
400 km around the swarms in 1-2 years after the swarms were analyzed. Meanwhile, the R value proposed by Xu [11] was calculated to evaluate the efficiency of the precursory earthquake swarms. Under the premise to achieve efficiency, the specific technical ideas of abstracting the swarm prediction indexes are as follows:

2.3. Correspondence analysis between earthquake swarms and mid-strong earthquakes

### Table 1. Correspondence statistics of precursory earthquake swarms and mid-strong earthquakes

| No. | Duration          | Earthquake swarm | Total earthquakes | Maximum magnitude | Earthquake swarm type | Corresponding earthquake | Corresponding earthquake time | Interval from mid-strong earthquake (km) | Distance from mid-strong earthquake (km) | Tectonic relationship between the earthquake swarm and corresponding mid-strong earthquake |
|-----|------------------|------------------|-------------------|-------------------|------------------------|--------------------------|-------------------------------|------------------------------------------|-------------------------------------------|--------------------------------------------|
| 1   | 19890701~19900817 | Woven-Guang     | 65                | 4.8               | b-u-p                 | Hanxian-3                | 19900820                      | 9                                        | 15                                        | same structure                            |
| 2   | 19901101~19911121 | Sunan            | 13                | 4.7               | b-u-L-p               | Sunan-2                   | 19911220                      | 9                                        | 12                                        | same structure                            |
| 3   | 19910121~19920625 | Woven-Guang     | 71                | 3.5               | b-u-U                 | Dingxian-7               | 19920426                      | 305                                      | 245                                       | different structure                       |
| 4   | 19920921~19930620 | Jingta-Yongfeng | 32                | 4                 | U                    | Tianzhu-5                 | 19930102                      | 61                                        | 27                                        | same structure                            |
| 5   | 19930701~19940719 | Lanzhou-Yongfeng| 30                | 3.5               | b-U                 | Yalong-3                  | 19940122                      | 3                                        | 100                                       | same structure                            |
| 6   | 19950922~19950529 | Woven-Guang     | 94                | 3.6               | b-h-U                 | Tianzhu-4                 | 19950101                      | 3                                        | 95                                        | same structure                            |
| 7   | 19960121~19960207 | Guanzhong       | 36                | 3.1               | b-U                    |                          |                               |                                          |                                          |                                           |
| 8   | 19960901~19970510 | Luoyu           | 41                | 3.6               | b-u-p                 | Shaanxi-5                 | 19970122                      | 104                                      | 118                                       | different structure                       |
| 9   | 19980901~20000905 | Jingta-Baian    | 30                | 3.5               | b-h-U                 | Jingta-9                  | 20000606                      | 1                                        | 14                                        | same structure                            |
| 10  | 20010401~20100108 | Guanzhong       | 91                | 4.6               | U-b-h                 | Shaanxi-7                 | 20010717                      | 9                                        | 320                                       | different structure                       |
| 11  | 20010927~20011224 | Luoyu-Daxia     | 71                | 4.9               | b-h-p                 |                          |                               |                                          |                                          |                                           |
| 12  | 20011308~20030506 | Pingliang       | 108               | 3.1               | U-k-b-h                | Shaanxi-5                 | 20030113                      | 115                                      | 267                                       | different structure                       |
| 13  | 20030409~20050601 | Lianyuan        | 85                | 3.1               | b-h-p                 |                          |                               |                                          |                                          | same structure                            |
| 14  | 20040630~20040703 | Luoyu           | 50                | 4.5               | p-k-h                 |                          |                               |                                          |                                          |                                           |
| 15  | 20041334~20050105 | Poyang          | 20                | 2.6               | U-p                   |                          |                               |                                          |                                          |                                           |
| 16  | 20050530~20050908 | Poyang          | 50                | 3                 | U-p-b-h                |                          |                               |                                          |                                          |                                           |
| 17  | 20060619~20061222 | Pingliang       | 45                | 2.8               | U-k-b-h                |                          |                               |                                          |                                          |                                           |
| 18  | 20070610~20070413 | Huating-Pingliang| 45           | 2.8               | U-k-b-h                |                          |                               |                                          |                                          |                                           |
| 19  | 20080534~20080501 | Woven-Guang     | 77                | 3.8               | U-b-h                 | Ananzhu-3                 | 20080601                      | 349                                      | 358                                       | different structure                       |
| 20  | 20080501~20080110 | Woven-Guang     | 105               | 3.6               | U-k-b-h                |                          |                               | 98                                      | 391                                       | different structure                       |
| 21  | 20090315~20090313 | Sunan           | 43                | 3                 | U-b-h                 |                          |                               |                                          |                                          |                                           |
| 22  | 20090919~20090911 | Guanzhong       | 34                | 3.5               | h                    |                          |                               |                                          |                                          |                                           |
| 23  | 20090925~20091129 | Sunan           | 31                | 3.1               | U-b-h                 |                          |                               |                                          |                                          |                                           |
| 24  | 20100125~20100208 | Jingta-Baian    | 43                | 2.6               | U-k-b-h                |                          |                               |                                          |                                          |                                           |
| 25  | 20100828~20100911 | Guanzhong       | 54                | 2.5               | U-b-h                 |                          |                               |                                          |                                          |                                           |
| 26  | 20100903~20100928 | Guanzhong       | 54                | 4.5               | p-k-b                 |                          |                               |                                          |                                          |                                           |
| 27  | 20100927~20100925 | Jinta           | 43                | 2.8               | p-k-b                 |                          |                               |                                          |                                          |                                           |
| 28  | 20101213~20101203 | Sunan-Warui     | 103               | 3                 | U-k-b-b                |                          |                               |                                          |                                          |                                           |
| 29  | 20110123~20110103 | Sunan-Warui     | 103               | 3                 | U-k-b-b                |                          |                               |                                          |                                          |                                           |
| 30  | 20120123~20120106 | Yushu-Pinghu    | 288               | 2.6               | U-k-b-b                |                          |                               |                                          |                                          |                                           |
| 31  | 20130125~20130225 | Jingta          | 105               | 2.4               | U-k-b-h                | Shaanxi-5                 | 20130122                      | 361                                      | 329                                       | same structure                            |
| 32  | 20130405~20130611 | Anhui            | 34                | 3.5               | p-b-h                 |                          |                               |                                          |                                          |                                           |
| 33  | 20121224~20130106 | Sunan           | 38                | 2.4               | U-k-b                | Huaian-2                  | 20130605                      | 29                                        | 360                                       | same structure                            |
| 34  | 20140222~20140310 | Tuanhe          | 175               | 4.0               | p-b-b                 |                          |                               |                                          |                                          |                                           |
| 35  | 20160101~20160109 | Linan           | 54                | 4.5               | p-b                |                          |                               |                                          |                                          |                                           |
| 36  | 20160101~20160121 | Tuanhe          | 24                | 2.6               | U-p-b-b                | Ananzhu-3                 | 20160121                      | 209                                      | 124                                       | different structure                       |
| 37  | 20170102~20170115 | Tuanhe          | 22                | 3.4               | b-h                  |                          |                               |                                          |                                          |                                           |
| 38  | 20180101~20180129 | Luoyu           | 72                | 3.6               | p-b                   | Shaanxi-7                 | 20180126                      | 214                                      | 96                                        | same structure                            |
Using the above technical ideas, the corresponding statistical results between precursory earthquake swarms and mid-strong earthquakes are shown in Table 1. The earthquake swarms marked with pink in the table are the ones who are correspond to the mid-strong earthquakes in east-southern Gansu, and those marked with blue are the ones who are not correspond to mid-strong earthquakes in east-southern Gansu. In table 1, only 18 of the 38 precursory earthquake swarms since 1980 have been correspond to mid-strong earthquakes, and the corresponding rate between the earthquake swarm events and mid-strong earthquakes occurred from 2004 to 2011 is very poor; 12 of the 18 earthquake swarms which correspond to mid-strong earthquakes have the same seismic tectonic zone as the corresponding mid-strong earthquakes, and the remaining 6 earthquake swarms are located adjacent to the corresponding mid-strong earthquakes. The rate of the earthquake swarm in east-southern Gansu correspond to a mid-strong earthquakes is 5/8. For the whole Gansu, the corresponding rate between earthquake swarms and mid-strong earthquakes has averaged about 47% (18/38); the proportion of predicted time for mid-strong earthquakes in 6 months after the end of the earthquake swarm is 13/18, and the proportion of predicted time for mid-strong earthquake in the 6-12 months after the end of the swarm is 5/18. The proportion of predicted locations for mid-strong earthquakes which may be in a range of 300 km from the swarm is 14/18.

From the spatial distribution of the precursory earthquake swarms and corresponding mid-strong earthquakes (Figure 2), the earthquake swarms are mostly concentrated in the Wuwei-Baiyin region. The earthquake swarms in mid-west section of Qilian earthquake zone cannot effectively correspond to mid-strong earthquakes. The earthquake swarms which can correspond to mid-strong earthquakes are mainly located in the east of longitude 99°. The mid-strong earthquakes that occurred within 6 months after the earthquake swarms were mainly distributed in Gansu province. Meanwhile, those that occurred more than 6 months after the earthquake swarms were distributed along the direction of east-north. The corresponding mid-strong earthquakes in east-southern Gansu occurred mainly within 6 months after the precursory earthquake swarm.

![Figure 2. Effect diagram after dividing of the model in Figure 1](image)

According to the formula of R value scoring proposed by Xu [11], the prediction efficiency of the precursory earthquake swarms in Gansu region was evaluated to get the R value of -0.34 which is compared with the R0 value of 0.09 in Northwest China. The result of comparison is obviously R < R0,
which indicates that the earthquake swarms in Gansu may not have the prediction efficiency. However, the prediction efficiency of those swarms in east-southern Gansu was alone evaluated, and the R value score obtained is 0.36, then R > R0, which illustrates that the prediction efficiency of the precursory earthquake swarms in the southeast Gansu is better. In other words, the swarms in the southeast Gansu has more predictive significance for mid-strong earthquakes.

3. Conclusions
Thought the corresponding statistical analysis between the precursory earthquake swarms obtained and the mid-strong earthquakes within 400km around the earthquake swarms since 1980 and R-value calculation of the swarms, it concludes that the precursory earthquake swarms in Gansu region may not have the efficiency of predicting mid-strong earthquakes, but those in the southeast Gansu have good effectiveness to predict mid-strong earthquakes. Moreover, the prediction time of these earthquake swarms in this area for mid-strong earthquakes is generally within one year after the end of them, but the dominant prediction time of them is within 6 months. The dominant predictive locations of them for mid-strong earthquakes are within 300km from them, and they very likely in the same tectonic zone as the precursory earthquake swarms. The prediction probability of them for mid-strong earthquakes is 63% (5/8). These index systems can provide a strong judgment basis for tracking mid-strong earthquakes in Gansu.

This paper only analyzed systematically the time, space, intensity, and structure relationship between the earthquake swarms and the corresponding earthquakes, and extracted the prediction indexes of the earthquake swarms for mid-strong earthquakes to determine the reliability of predicting mid-strong earthquakes by using the earthquake swarms in Gansu. However, the response relationship between the earthquake swarms wide-distributed and the historical strong earthquakes in and around Gansu has not been analyzed from the perspectives of the spatial clustering distribution and time evolution processes, and retrospective analysis of the earthquake swarms before the strong earthquake has not been carried out, which will be the focus of the next work.

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