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Analysis of Unlocking Process of Concave-convex Bodies in Wenchuan Earthquake Sequence Based on B-value Tomography

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Abstract: B-value mapping seems to have an abnormally low value before the main earthquake. When this gridding technique is applied to Wenchuan earthquake, Lushan earthquake and Jiuzhaigou earthquake of the Wenchuan earthquake sequence of Longmenshan fault, the characteristics of low B-value before the earthquake are not found. On the contrary, the anomalies of high B-value above 20km before Lushan earthquake and Jiuzhaigou earthquake are obvious in the shallow crust. Although Wenchuan earthquake had a strong shadow on Jiuzhaigou earthquake, there was an obvious area where B value increased between the two faults. After Jiuzhaigou earthquake, the area increased to 0.78. Combined with the Lushan earthquake, there is a funnel-shaped high-value area below 25km depth. The reasonable explanation is that the unlocking of deep stress and shallow seismic activity jointly promoted the Jiuzhaigou earthquake.

Keywords: Wenchuan earthquake sequence, B value, High value anomaly.

1. Introduction

The strong heterogeneity of faults or crust can be mapped by the change of frequency magnitude distribution (FMD) [1]. The representative parameter B is inversely proportional to the average magnitude, which describes the power-law attenuation of the occurrence frequency of earthquakes with the increase of magnitude. B value can be used as a sensitive measure of crustal stress change, and positive feedback has been obtained in the detection of magma sac in volcanic area [1] and the rupture of main shock concave-convex bodies such as Parkfiled [2].

The increase of B value is consistent with the activity of seismic activity, while the decrease of B value corresponds to the decrease of the proportion of large and small earthquakes, which is usually the representation of the main shock bump. Concave-convex bodies are usually associated with abnormally low B values ($b<0.6$) [3]. Concave-convex body is generally defined as a strong patch on a fault, surrounded by a weak coupling state with slightly strong seismic activity. The M8 Wenchuan earthquake on May 12th, 2008, the M7.2 Lushan earthquake on April 20th, 2013 and the M7.2 Jiuzhaigou earthquake on August 8th, 2017 on Huya fault on the west side of Longmenshan fault can be regarded as strong earthquake concavities. Using the gridding technology provided by Wiemer [2], the temporal and spatial changes of B value before and after two main earthquakes can be calculated, and the information about the fracture of concave-convex bodies can be given, which can provide some prediction reference for the occurrence of earthquakes.

2. Data

B-value is calculated by using the earthquake catalog data of Wenchuan earthquake sequence from February 4, 2000 to August 8, 2020 downloaded from China Seismological Network Center. The study area has a high seismic activity rate and a dense network of seismic observation stations, with an integrity magnitude of 1.1. The Lushan earthquake in 2013 happened to be located at the edge of the aftershock area of Wenchuan earthquake on the Longmenshan fault zone, and Jiuzhaigou earthquake was only 300km away from Lushan earthquake, which provided a good testing ground for determining the location of the main shock concave-convex body and stress transmission by using B value. The depth of earthquake catalog data is 0.1-49km, and the latitude and longitude range is 102.5-106 degrees east longitude and 29.5-34 degrees north latitude. As shown in figure 4.

3. Method

The frequency magnitude distribution formula describing the relationship between earthquake frequency and magnitude power law is as follows

$$\log_{10}N = a - bM \tag{1}$$

Where N is the cumulative number greater than the integrity magnitude m. Parameter a is the activity rate of large earthquakes, and b is the b value of the required solution, which is a measure of the magnitude ratio of earthquakes. The standard deviation can be solved by boostrap iteration [4]:

$$\delta b = 2.3b^2\sqrt{\frac{\sum_i (M_i-\langle M\rangle)}{n(n-1)}} \tag{2}$$

4. Result

The Wenchuan earthquake sequence is divided into three stages, and the influences of Wenchuan earthquake, Lushan earthquake and Jiuzhaigou earthquake on surrounding and adjacent faults are considered respectively, and the temporal and spatial distribution of B value is calculated.

4.1. B-value Characteristics of Wenchuan Earthquake

Figure 1 shows the spatial distribution of seismic activity in the aftershock area and adjacent faults caused by Wenchuan earthquake. We chose the data in this area to map the B value.

The results are shown in Figure 1. The spatial B-value distribution shows that the northwest and southwest sides of Longmenshan fault have high B-values, which correspond to the middle of Huya fault where Jiuzhaigou earthquake in 2017 is located, indicating that the aftershocks of Wenchuan earthquake played a role in stress transmission for Jiuzhaigou earthquake. The southwest side is located in the aftershock area of Lushan earthquake. We segmented before and after the main earthquake in order to understand the trigger correlation between seismic activity in the whole region. This is different from Wiemer's concern about the low-value anomaly of concave-convex bodies before the main earthquake [2]. Visual inspection shows that there is no abnormally low B value in the slip area of Lushan earthquake fault, and the time B value also gives the same result. It shows that Wenchuan earthquake partially activated the small faults around Lushan concave-convex body.

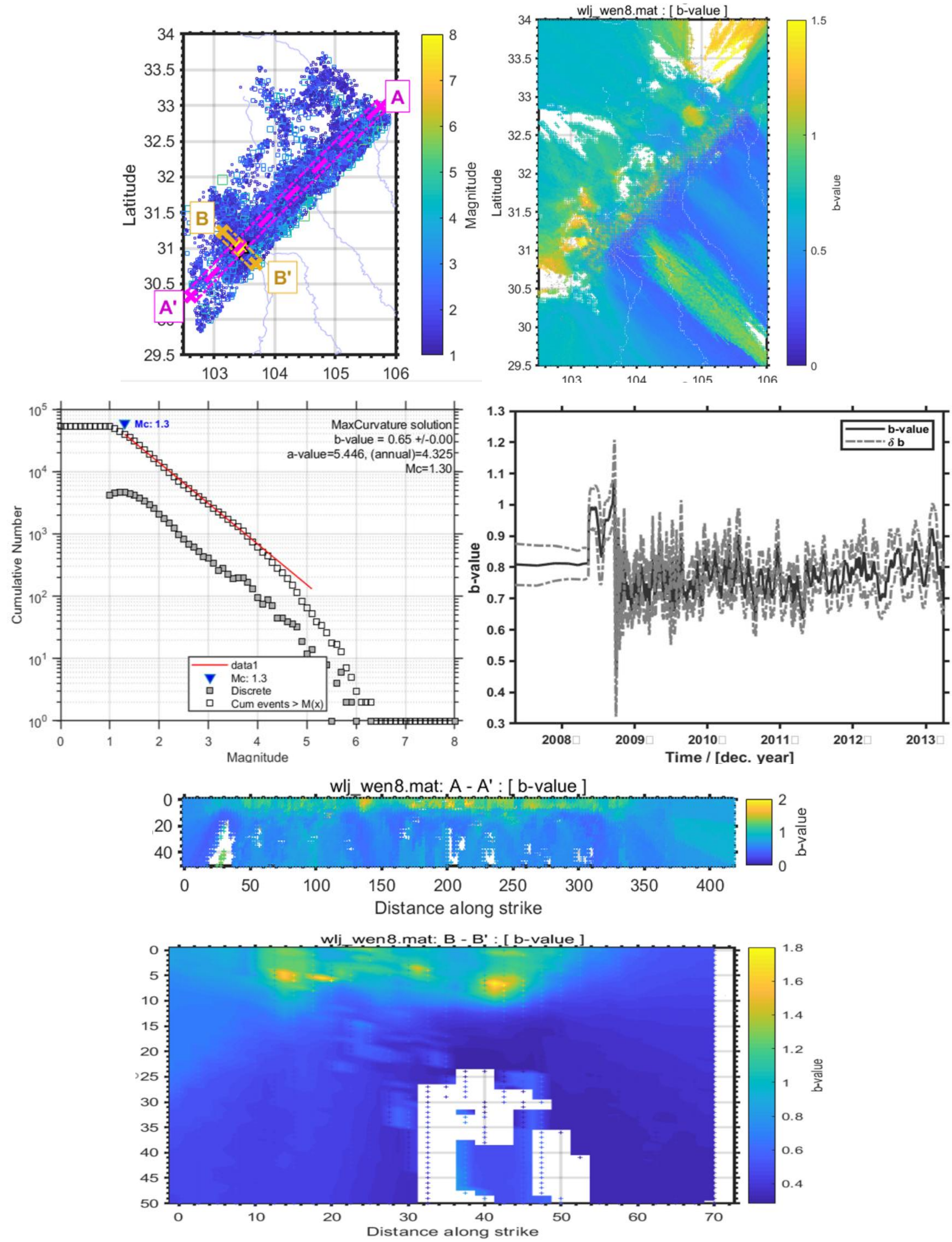

Figure 1. Temporal and spatial distribution characteristics of seismic activity caused by Wenchuan earthquake

On the left side of the upper panel is the seismic activity on the Longmenshan fault zone, the yellow star is the Wenchuan earthquake, and the dashed box is the section of the Longmenshan fault zone along the Wenchuan earthquake. On the right is the calculated space b value. The distribution of frequency magnitude is given on the left side of the middle panel, and the change of B value with time is on the right side. The following two panels give the depth distribution characteristics of B value along fault section and vertical fault section respectively.

4.2. Influence of Lushan Earthquake on Aftershock Zone and Surrounding Faults

Lushan earthquake is located in the south of Wenchuan earthquake, and its contribution to the surrounding faults mainly reflects the increase of B value in the north and west of Longmenshan fault in space, which seems to have contributed to the occurrence of Jiuzhaigou earthquake, as shown in Figure 2.

The results of B-value of depth profile show that the northwest side of the fault has an unusually high B-value, ranging from 1 to 1.5, and it is concentrated above 20 km, and there is also a funnel-shaped high B-value below 25km, which forms stratification at 25 km, indicating that the clusters are mostly concentrated in the shallow crust, but the stress in the deep part has also decreased or shifted to the northwest. The occurrence of Jiuzhaigou earthquake may be encouraged by the unlocking of seismic activity in the shallow and slightly deep parts of the crust. Before Jiuzhaigou earthquake, there was no abnormal low value of B value.

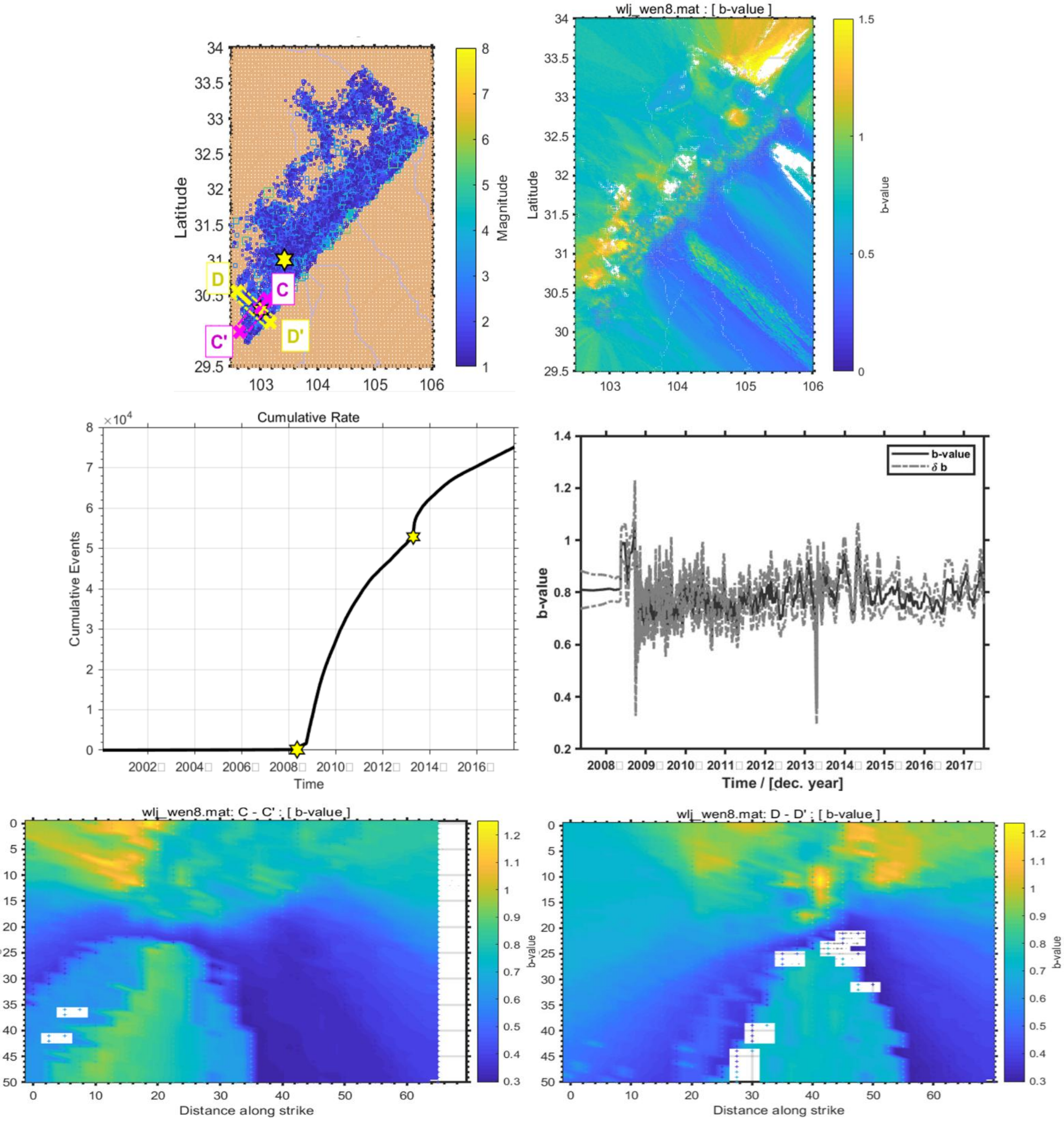

Figure 2. Temporal and spatial distribution characteristics of seismic activity caused by Lushan earthquake

On the left side of the upper panel is the seismic activity on the Longmenshan fault zone, the yellow star is Wenchuan earthquake and Lushan earthquake, and the dashed box is the section of the Longmenshan fault zone along the Wenchuan earthquake. On the right is the calculated space b value. The number of cumulative earthquakes is given on the left side of the middle panel, and the change of B value with time is on the right side. The following two panels give the depth distribution characteristics of B value along fault section and vertical fault section respectively.

4.3. Influence of Jiuzhaigou Earthquake on Aftershock Zone and Its Surrounding Faults

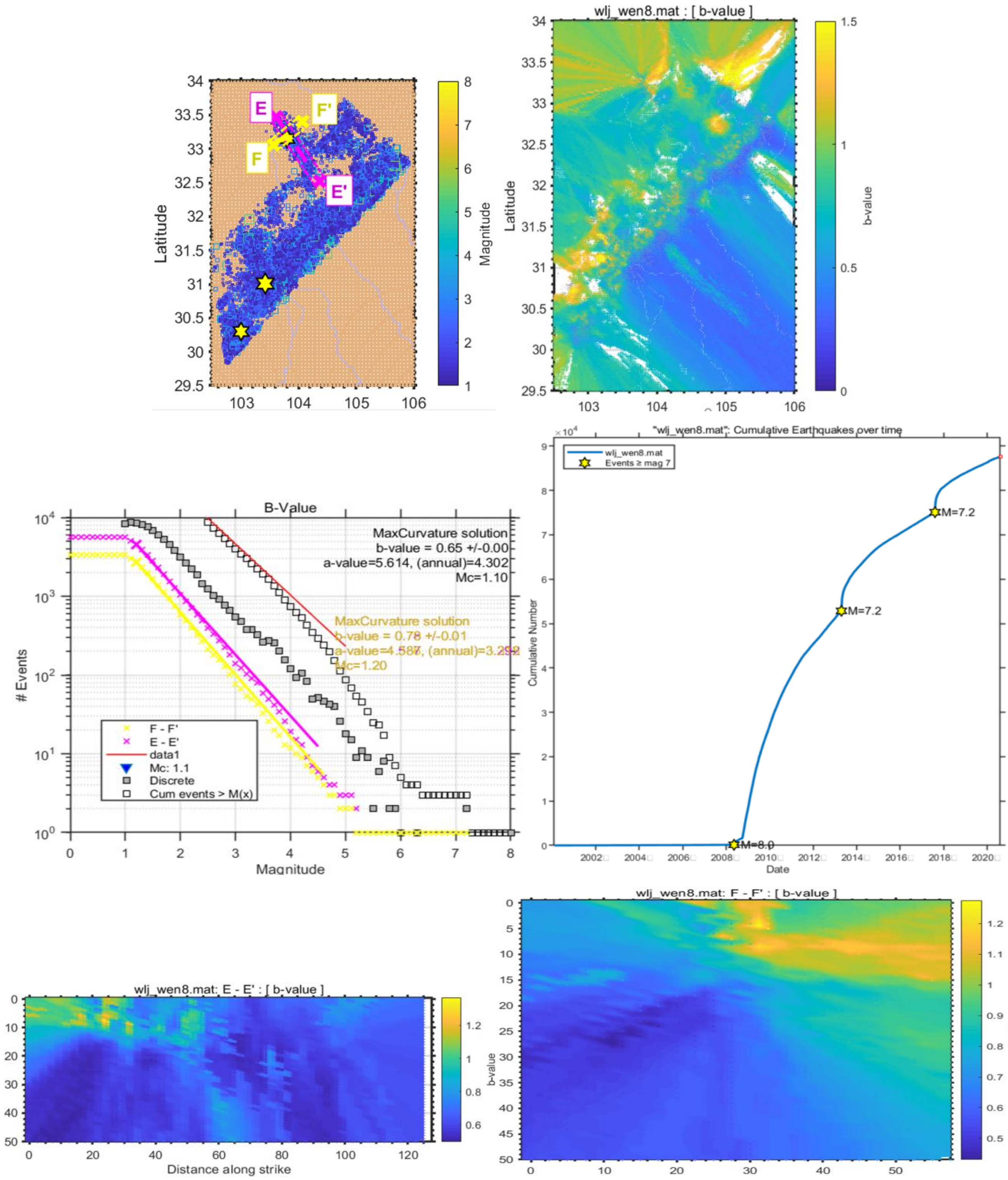

Figure 3. Temporal and spatial distribution characteristics of seismic activity caused by Jiuzhaigou earthquake

After Jiuzhaigou earthquake, the B value between Longmenshan fault and Huya fault increased, and almost all of them entered a relatively high B value state, reaching 0.78. The cumulative slope of Lushan earthquake and Jiuzhaigou earthquake is similar, but slightly weaker than Wenchuan earthquake. The depth profile of B value shows the connection between Jiuzhaigou earthquake and Wenchuan earthquake, and the high B value between the two faults is unusually obvious. The B value below 20km depth is also around 0.8, and small earthquakes are active.

On the left side of the upper panel is the seismic activity on Longmenshan fault zone and Huya fault zone on the west side, and the three yellow stars are Wenchuan earthquake, Lushan earthquake and Jiuzhaigou earthquake. The dashed box is the section of the fault along the Jiuzhaigou earthquake; On the right is the calculated space b value. The distribution of frequency magnitude is given on the left side of the middle panel, and the change of cumulative number with time is on the right side. The following two panels give the depth distribution characteristics of B value along fault section and vertical fault section respectively.

5. Conclusion and Discussion

The occurrence of Wenchuan earthquake and Lushan earthquake caused abnormally high B value on the fault and its surroundings. Previous studies have reported the obvious low-value anomaly of B value before the main earthquake, which corresponds to the rupture of concave-convex body [5]. In this study, we don't pay special attention to the characteristics of B-value anomalies before earthquakes, but consider the possible promotion of one main earthquake to another, which is characterized by high B-value regions. Concave-convex bodies have fractal characteristics [6], and the approximate double relationship between fractal dimension D and b value shows that if b value reaches 1-1.5, the fractal dimension is 2-3, that is, earthquakes are distributed in nearly three-dimensional space. From the above analysis, the earthquake has a high B-value anomaly with a depth of more than 20km on the west side of Wenchuan earthquake, and the Lushan earthquake has a high-value anomaly with a flaw shape below 25km in addition to the shallow high-value anomaly, it can be considered that Wenchuan earthquake has transmitted some stress to the western end of the fault in the deep, which is adjacent to Huya fault where Jiuzhaigou earthquake occurred in 2017, so it is reasonable to think that Wenchuan earthquake has promoted Jiuzhaigou earthquake, and the anomalies added between the two faults after Jiuzhaigou earthquake indicate the deep connection between the two faults. Although related studies have pointed out that the Wenchuan earthquake has caused a strong stress shadow on Jiuzhaigou [7], our analysis results prove that the simultaneous transmission of deep and shallow stresses may have played an opposite role in promoting Jiuzhaigou earthquake. The enhancement of B value shows that the number of small earthquakes increases, the fractal dimension increases and the crack propagation intensifies, which can give a reasonable explanation that Jiuzhaigou earthquake was triggered by Wenchuan earthquake, and Lushan earthquake also provided a certain weakening effect on small faults around its source, thus invading Jiuzhaigou earthquake concave-convex body.

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