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Two-step method to extract seismic microwave radiation anomaly: Case study of M_S8.0 Wenchuan earthquake*

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Abstract The satellite remote sensing has become a promising technique for detecting earthquake and fault activities. But it is still very difficult to exactly extract the earthquake anomaly from the complicated remote sensing information. This paper presented a two-step method to extract the seismic microwave radiation anomaly related with earthquake, which could eliminate the stable influence of geography, terrain, coversphere and seasons, as well as the random influence of weather. Furthermore the two-step method was applied to analyze the anomaly of Wenchuan earthquake based on the data of AMSR-E. Microwave radiation anomalies were effectively detected related to the main shock and aftershocks. The extracted microwave radiation variation showed general features of three-stage: the positive radiation anomaly appeared around the epicenter in the first stage, quiet variation in the second stage, and abnormal area gradually moved to the epicenter in the third stage. After the main shock the microwave radiation anomalies distributed along the Longmenshan faults, and the epicenters of aftershocks were coincident with the anomaly area in space.

Key words: **Wenchuan earthquake; AMSR-E; microwave radiation; brightness temperature; anomaly extraction**

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1 Introduction

Since the year 2 000 many strong earthquakes have occurred, such as the M_S7.9 Sumatra earthquake on December 12, 2004 in Indonesia, the M_S8.0 Wenchuan earthquake on May 12, 2008 in China and the M_S7.3 Haiti earthquake on January 12, 2010. These earthquakes caused severe deaths and injuries. This situation urges seismologists to pay more attention to the earthquake prediction based on satellite remote sensing. Gorny et al. (1988) firstly used the remote sensing data (NOAA/AVHRR) to analyze seismic activity of middle Asia region, and preliminarily explored the idea to predict earthquake with thermal infrared remote sensing. Afterwards, Tronin (1996) systematically analyzed 10 000 infrared images (NOAA/AVHRR-2) of the same region, and verified the earthquake infrared anomaly phenomenon. In the meantime and then, some scholars also found there were thermal infrared anomaly phenomena before some moderate to strong earthquakes (Qiang et al., 1991; Arun and Swapnamita, 2005; Tramutoli et al., 2005). The reported increment of surface temperatures before earthquake reaches 2–4 °C, occasionally higher. Usually, the anomaly appears one month to several days before the earthquake. Several mechanisms or hypothesis have been put forward to interpret the reported temperature increase: (1) the diffuse CO_2 emanation from the Earth before earthquake causing a local greenhouse effect (Qiang et al., 1991), and a temperature increment due to the excitation of electric field (Tronin, 2002), (2) the rising fluids leading

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to the emanation of warm gases (Gorny et al., 1988), (3) the thermo-elastic effect and friction heat due to tectonic stress (Geng et al., 1998), (4) the near-ground air ionization due to enhanced radon emission, leading to the condensation of water vapor from the atmosphere and, hence, to the release of latent heat (Pulinets et al., 2006), and (5) the recombination of stress-activated positive hole in quartz-embedded rock resulting in infrared emission (Freund, 2003).

Recent studies have shown anomalous changes in water vapor over the surrounding land and oceanic regions around the epicentral region before and after the earthquake. The sudden increase in column water vapor in the atmosphere before the earthquake might be attributed to the increase in evaporation due to increase in surface latent heat flux (SLHF) (Dey and Singh, 2003).

After Wenchuan earthquake, Zhang et al. (2010) analyzed the thermal infrared anomaly during Wenchuan earthquake with the thermal infrared brightness temperature data from the FY-2C satellite. After processing the satellite data with wavelet transform and Fourier transform, the result showed the thermal infrared anomaly located in the Longmenshan fault zone and its southern region, and appear within April 25 to the end of May 2008.

Anyway, it is difficult to recognize the anomaly in cloudy conditions since the infrared radiation from the Earth's surface cannot pass through clouds and arrive to the satellite. Maeda and Takano (2009) used the satellite microwave data AMSR-E to analyze the microwave radiation anomaly during Wenchuan earthquake, and obtained some valuable results. However, to extract and to recognize the actual microwave anomaly is also difficult, and the analysis method for microwave anomaly is waiting for improvements. In this paper, we presented a new method to extract the microwave radiation anomaly from AMSR-E for Wenchuan earthquake.

2 Two-step method

Usually the microwave radiation from the Earth's surface is mainly affected by surface temperature. However the surface temperature is affected by geography, terrain, coversphere, seasons, weather and so on. We take the influence of geography, terrain, coversphere and seasons as a constant because it less changes ideally in the same day of different years, and take the influence of weather as a random variable because the weather change is uncertain. The influence of seismic activities is the third variable. Ignoring the error of sensor and transmission process, the microwave radiation satellite detected could be expressed as

$$T(r,t) = T(p_r,t) + T(w_r,t) + \xi(r,t), \tag{1}$$

where r is the geographic position of a certain pixel. t is the satellite imaging time. $T(p_r,\, t)$ is the stable microwave radiation value caused by geography, terrain, coversphere and seasons. $T(w_r,\, t)$ is the random radiation value caused by weather. $\xi(r,\, t)$ is the seismic radiation value caused by seismic activity.

In order to extract seismic microwave radiation, $\xi(r,\, t)$, associated with earthquakes, it is needed to eliminate $T(p_r,\, t)$ and $T(w_r,\, t)$ from $T(r,\, t)$. The method could be divided into two steps so as to get rid of the influence of non-earthquake factors.

1) The first step is to eliminate the stable impacts of the geography, terrain, coversphere and seasons as in the following:

$$\overline{T(r)} = \frac{\sum\limits_{i=1}^{N} T(r,t_i)}{N}, \tag{2}$$

$$\Delta T(r,t_0) = T(r,t_0) - \overline{T(r)}, \tag{3}$$

where, $\overline{T(r)}$ is the average microwave brightness temperature of pixel r in the same day of non-earthquake years (in case of $M_S8.0$ Wenchuan earthquake it is 2003–2007) in the investigated area. i is the number of non-seismic years, N is the total amount of non-seismic years. t_i is a day of non-seismic year i, and t_0 is the same day in the earthquake year. $T(r,\, t_i)$ is the microwave brightness temperature of pixel r on the day t_i, $\overline{T(r)}$ is the mean value of all $T(r,\, t_i)$ in pixel r in the same day t_i of all non-earthquake years. $\Delta T(r,\, t_0)$ is the microwave brightness temperature of pixel r on the day t_0 of earthquake year subtracted by the mean value $\overline{T(r)}$.

2) The second step is to eliminate the random influence of weather condition. Suppose the weather conditions of the whole investigated area are the same, i.e. the brightness temperature variations of all pixels are commonly related to the same weather. We select the mean value of all corner-pixels located at the corners of the investigated area as the background value. Hence, the difference of the value in a pixel and the background value is calculated pixel by pixel. The following formulas are introduced.

$$\overline{\Delta T}(t_0) = \frac{\sum\limits_{j=1}^{n} \Delta T(r_j,t_0)}{n} \tag{4}$$

$$\Delta\Delta T(r,t_0) = \Delta T(r,t_0) - \overline{\Delta T}(t_0) \tag{5}$$

Here, $\overline{\Delta T}(t_0)$ is the background value taken from the corner-pixels of the investigated area. n is the number of corners of the investigated area. $\Delta\Delta T(r,\, t_0)$ is the differential value of each pixel with the background. Through above data processing with two steps, the stable influence of geography, terrain, coversphere and seasons and the random influence of weather can be eliminated. Thus we can proceed to analyze the seismic microwave brightness temperature anomaly before and after the earthquake.

3 Wenchuan earthquake being a case

A strong earthquake occurred in Wenchuan region of Sichuan province of China on May 12, 2008. We selected the data from AMSR-E sensor aboard the Aqua satellite to analyze the seismic microwave radiation anomaly. AMSR-E is composed of microwave radiometers at six-frequency bands (6.925, 10.65, 18.7, 23.8, 36.5 and 89.0 GHz). According to Maki et al. (2006) and Maeda and Takano (2009), it is suitable to use microwave radiation of frequencies 18.7 GHz to detect rock failures. So we selected microwave data of frequency 18.7 GHz and horizontal polarization to analyze the microwave anomaly before the earthquake. In the frequency 18.7 GHz the sensitivity of AMSR-E sensor is 0.6 K, mean spatial resolution is 21 km. The satellite imaging moment is about 01:30 (LT) every day, the investigation area covers between 28°–34° north geographic latitude and 100.4°–106.4° east geographic longitude, and the time range is from March 1 to June 30 between 2003 and 2008.

Figure 1 shows a typical image of microwave radiation in non-seismic years and in normal weather. We can see that in the non-seismic years the microwave radiation is mainly affected by local geography, terrain, and coversphere. The spatial distribution of microwave brightness temperature can be divided into three main zones. One is the Northwest plateau and its microwave brightness temperature is low due to its low surface temperature caused by the high altitude. Another is the Sichuan basin and its microwave brightness temperature is higher due to high surface temperature caused by the low altitude. The third is Longmenshan faults area and its microwave brightness temperature is also higher due to special geological structures and coverings. Besides, there are two low-microwave radiation parts respectively in the Northwest plateau and the Sichuan basin, and they are zones of abundant ice or water. Especially in the area around Yangtze river the microwave brightness temperature is very low, and the lowest brightness temperature is about 248 K.

According to formulas (2) and (3), we select the data from the year 2003 to 2007 as the background to eliminate the impacts of the geography, terrain, coversphere and seasons, and use the data of the year 2008 to do subtraction.

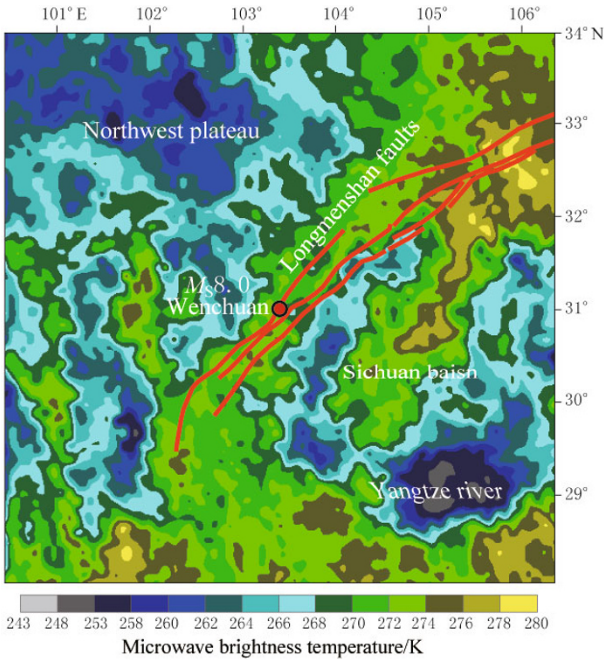

Figure 1 Typical image of microwave brightness temperature of the investigation area in no-seismic years and in normal weather. It represents the stable influence of terrain, coverings, season, latitude and altitude.

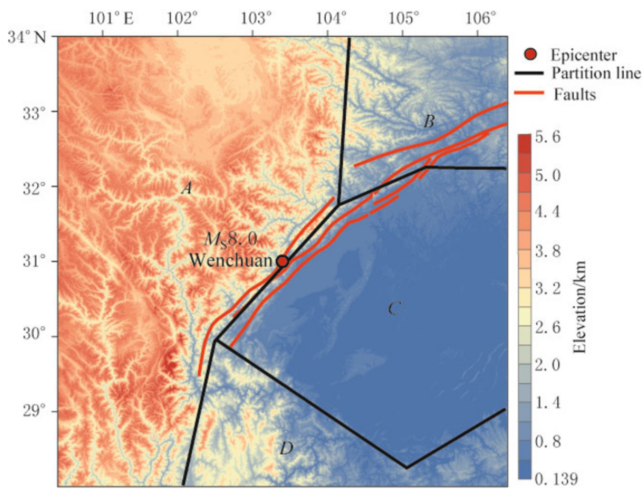

Figure 2 Digital elevation model and the divided areas of the investigated area.

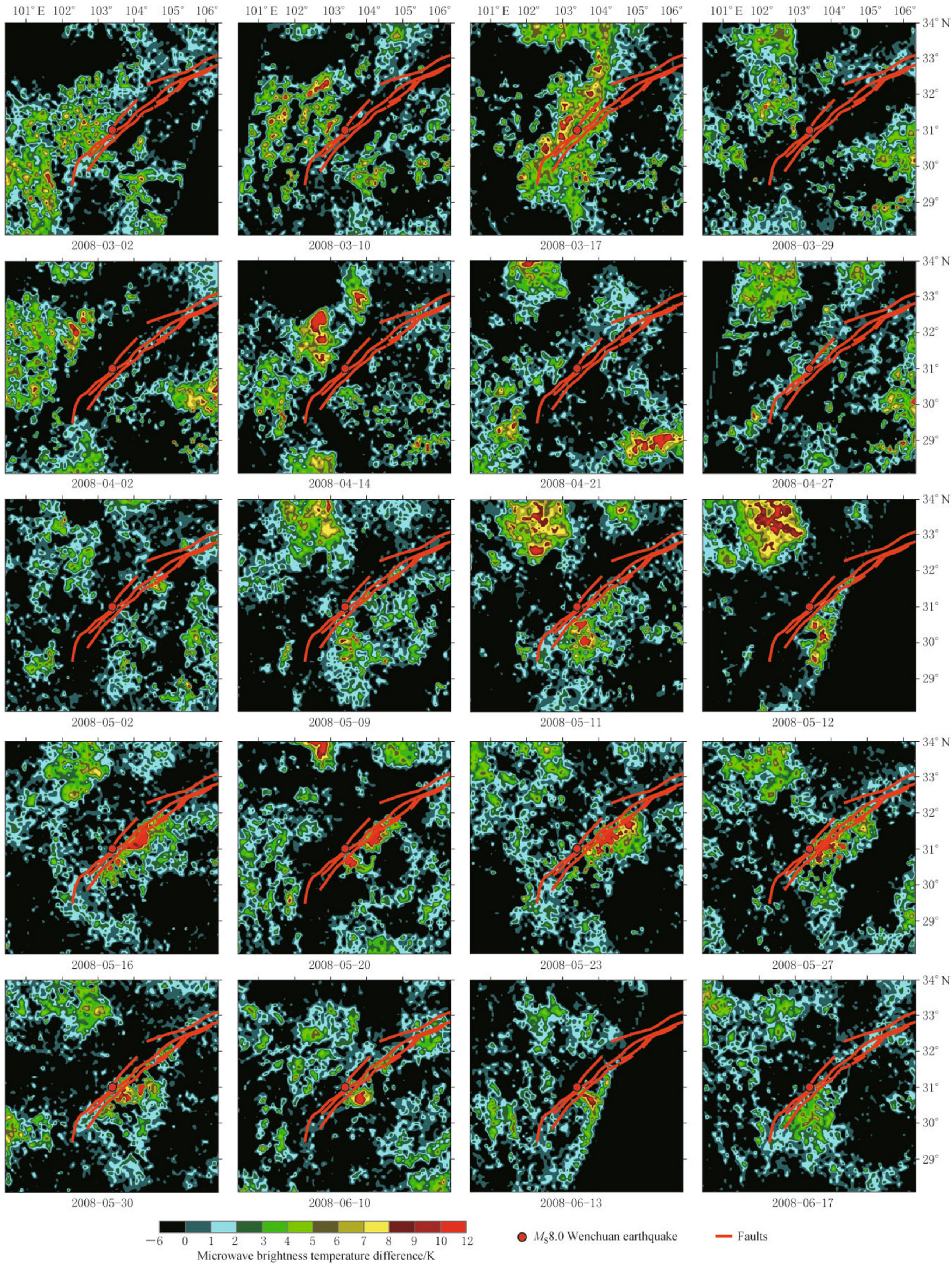

Figure 3 Microwave radiation anomaly developing before and after the Wenchuan earthquake on May 12, 2008.

Then we carry out the second step to get the differential value pixel by pixel and day by day according to formulas (4) and (5) to search for seismic changes. Because the whole investigation is not on the same weather condition due to the influence of larger difference in elevation (see Figure 2), we subdivide the whole investigated area into four less areas: A, B, C, D. The second step is carried out for every area. The results are shown with typical differential-value images in Figure 3.

From Figure 3 we found that the microwave radiation developing before and after Wenchuan earthquake on May 12, 2008 had the following characteristics:

1) From March 2, 2008 to April 26, 2008 the high microwave radiation appeared in the northwest of Longmenshan faults and the south margin of the Sichuan basin. On April 14, 2008 the highest microwave brightness temperature increment reached 11 K. While the microwave brightness temperature in Sichuan basin stayed in lower value in this period.

2) From April 27, 2008 to May 10, 2008 the microwave radiation in whole area was lower, and the microwave brightness temperature variation in the entire area was less than 3 K, which indicates that the microwave radiation was in a quiet period.

3) On May 11, 2008 a high microwave radiation area suddenly appeared southeast near the epicenter, and it was strengthened on May 12, 2008.

4) After the main shock the high microwave radiation anomaly distributed along the Longmenshan faults. Figure 4 shows the epicenters of aftershocks ($M_S \geq 5.0$) and the mean image of microwave radiation anomaly from May 12 to May 30 in 2008; it is found that the epicenters of aftershocks are coincident with the anomaly area in space. From May 30, 2008 the anomalies began to weaken. However, there was a sudden increase on June 10, 2008 and on June 13, 2008, respectively, which should be related to the strong aftershocks happened on June 9, 2008 (M_S5.0) and on June 11, 2008 (M_S5.0), respectively.

5) From June 17, 2008, the microwave radiation anomaly began to weaken and disappeared finally.

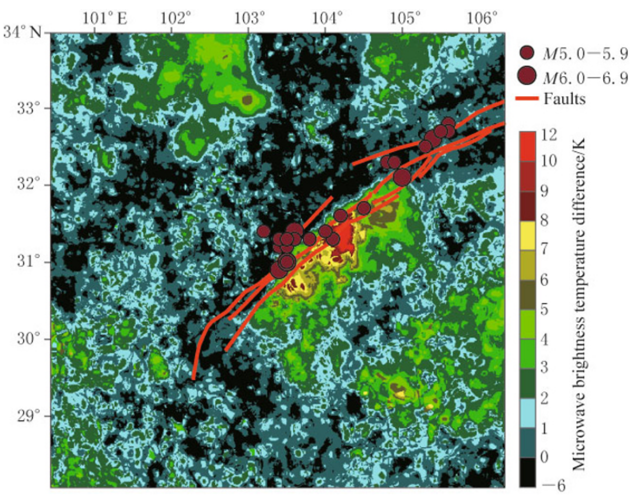

Figure 4 Spatial comparison of aftershock epicenters and microwave radiation anomaly after May 12, 2008.

4 Conclusions

This paper reached the following conclusions:

1) A two-step method was developed to extract the seismic microwave radiation anomalies from AMSR-E satellite remote sensing data related to earthquake. The method could eliminate the stable influence of geography, terrain, coversphere and seasons, as well as the random influence of weather.

2) With M_S8.0 Wenchuan earthquake on May 12, 2008 being a case, it was proved that the two-step method could extract effectively seismic microwave radiation anomalies. The largest increment of microwave brightness temperature was up to 12 K, and the microwave radiation anomalies related to Wenchuan earthquake have general features of three stages, i.e., the positive radiation anomaly appeared around the epicenter in the first stage, quiet variation in the second stage and abnormal area gradually moved to the epicenter in the third stage. After the main shock the microwave radiation anomalies distributed along the Longmenshan faults, and the epicenters of aftershocks were coincident with the anomaly area in space.

Besides, we suppose that the microwave radiation anomalies emerged near the epicenter on May 11, 2008, then it should have been a valuable information for the precursor of M_S8.0 Wenchuan earthquake on May 12, 2008.

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