Characteristics of Thermal Infrared Anomalies during the Earthquakes in Wenchuan, Lushan in Ya’an and Jiuzhaigou

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Abstract: Satellite thermal infrared observation has advantages over other earthquake observation techniques. With MODIS remote-sensing images from the TERRA satellite, the thermal infrared brightness temperature difference variation rate was used to analyze the observation data prior to three Magnitude-7-and-above earthquakes along the fracture zone of Longmen Mountain, and the result showed that there were thermal infrared brightness temperature anomalies one to two months before these three Magnitude-7-and-above earthquakes, and the earthquakes took place along the boundaries of the area where the anomalies occurred. The observation data show that there have been five times of substantial anomalies in the study area, among which four times were correlated to earthquakes.

1. Introduction
In earthquake monitoring and forecasting, the satellite thermal infrared observation materials have advantages over other earthquake forecasting data as these materials cover wide ranges, feature high resolution and continuity, and are not subject to limitations of the geographic environment[1].

As remote-sensing satellite technology matures, earthquake monitoring and forecasting based on infrared remote-sensing data has made much progress. Many research achievements in this regard have been applied to earthquake forecasting, and have become an important tool for daily monitoring and forecasting. Some Chinese studies have proved that there was considerable thermal radiation amplification in the seismogenic zone before the earthquakes, and this amplification could be recognized by the long-wave radiation field strength and brightness temperature changes realized by satellite remote-sensing technology. As seismic thermal infrared recognition algorithms reach maturity and see broad adoption, the data source has developed from single images to multiple remote-sensing data, the analysis has been shifted from horizontal analysis to vertical analysis, and anomaly detection methods have developed at the same time. There are four major types of anomaly extraction methods: visual interpretation, anomaly extraction algorithms based on difference analysis, anomaly extraction algorithms based on signal analysis, and anomaly extraction algorithms based on background field analysis[2]. The objective of this research is to explore whether there were anomalies before strong earthquakes using the TERRA satellite MODIS remote-sensing infrared brightness temperature data. Therefore, using the mean difference-based anomaly extraction algorithm, this study analyzed the thermal infrared data prior to the earthquakes that hit Wenchuan, Lushan in Ya’an and Jiuzhaigou, and extracted considerable thermal infrared anomalies.
2. Data selection
The data used in this research were TERRA satellite MODIS remote-sensing data from 2004 to 2020, which consisted of 36 spectral channels, covering electromagnetic spectra within a range from 0.4 to 14 μm including visible light, near-infrared light, and far infrared light. Among the 36 channels, six detected physical quantity information that was radiation quantity from the earth surface, i.e., Channel 20, Channel 21, Channel 22, Channel 23, Channel 31 and Channel 32. Channels 20 and 21 presented similar morphology and showed good correlation to the ground temperature [3]. In the present work, the data obtained from Channel 21 were analyzed, covering the area of 100° ~115°E, and 30°~45°N, with a spatial resolution of 1 km.

3. Data processing and research method
Previous studies have employed different satellite remote-sensing thermal infrared data and different research methods to explore the thermal infrared anomalies before strong earthquakes, and nearly all the obtained anomalies were temperature rises [4-12]. Therefore, in this study, only abnormal information about temperature rises was extracted in this study.

The study areas of the present work were the areas of earthquakes that hit Wenchuan, Lushan in Ya’an, and Jiuzhaigou; the thermal infrared brightness temperature difference variation ratio was calculated before and after the earthquakes, and the anomalies were extracted.

The calculation of the difference variation ratio was calculated by the following steps. First, the difference between the present-day brightness temperature value and the value a quarter before was calculated (in the present study, one quarter comprised of 91 days); then, the minimum difference value in the quarter before the present day was calculated the variation of the present-day background value and the prior background value. By the same token, the difference value of each time point in the selected range of time was calculated to obtain the mean variation within the selected period of time (this mean value involved complete thermal infrared brightness and temperature background); the ratio of the present-day difference to the present-day mean value was calculated to obtain the difference variation ratio of thermal infrared brightness temperature. By connecting the difference variation ratio of all days in the selected period of time, we could obtain a temporal variation ratio curve (to highlight the anomalies, third power operations were performed on the thermal infrared brightness temperature difference variation ratio to plot the temporal curve). The correlations between the peaks of the curve and the seismic precursors were explored.

The calculation equations are

\[ \Delta B = \Delta B_i - \Delta B_{min} \]  
\[ \bar{B} = \frac{\Delta B_1 + \Delta B_2 + \Delta B_3 + \ldots + \Delta B_n}{n} \quad (n > 1) \]  
\[ Y = \frac{\Delta B}{\bar{B}} \]  

In Eq. (1), \( \Delta B_i \) refers to the quarter-on-quarter difference of thermal infrared brightness temperature, \( \Delta B_{min} \) refers to the minimum quarter-on-quarter difference prior to the present day, which is an unstable variable. In Eq. (2), \( \bar{B} \) is the mean value obtained as per \( \Delta B \), and \( n \) is the total number of days of the time series. According to Eqs. (1) and (2), the thermal infrared brightness temperature difference variation ratio \( Y \) could be obtained.

4. Result analysis

4.1. Thermal infrared brightness temperature difference variation ratio anomalies in the Wenchuan Magnitude-8 Earthquake
On May 12th, 200, a Magnitude-8 earthquake occurred in Wenchuan, Sichuan province, China, with the epicenter at 31.0° N and 103.4° E, along the fracture zone of Longmen Mountain. The aforementioned
algorithm was employed to calculate the original brightness temperature data to obtain the difference variation ratio anomalies on the temporal and spatial dimensions. As Figure 1 shows, there were considerable anomalies in the thermal infrared brightness temperature difference variation ratio before the Wenchuan Earthquake. The anomalies emerged in February 2008, and reached a peak on May 11\textsuperscript{th}, the maximum anomaly in the past four years. The earthquake took place on May 12\textsuperscript{th}, after which the anomalies began to disappear, and the anomalies lasted for about four months. Considerable thermal infrared brightness temperature variation ratio anomalies have occurred from the end of Wenchuan Earthquake to the late 2020.

![Figure 1. Temporal curve of difference variation ratio of Wenchuan Earthquake](image)

4.2. Thermal infrared brightness temperature difference variation ratio anomalies for Magnitude-7 Earthquake in Lushan of Ya’an

On 20\textsuperscript{th} April, 2013, a magnitude-7 earthquake took place in Lushan, Ya’an, Sichuan, with the epicenter at 30.3° N, 103.0° E. There were significant anomalies in the thermal infrared brightness temperature difference variation ratio before the Ya’an Earthquake, as shown in Figure 3. The anomalies started in

![Figure 2. Spatial superposed map of variation ratios of Wenchuan Earthquake](image)
March 2013, reached the peak on 26th March, began to disappear in early April, the earthquake took place on 20th April, and the anomalies lasted about one month. From March to April, 2014, anomalies larger than those before the Ya’an Earthquake again occurred, and on 22nd November, 2014, a Magnitude-6.3 earthquake struck Kangding City (30.27° N, 101.68° E) in Sichuan, China.

4.3. Thermal infrared brightness temperature difference variation ratio anomalies for the Magnitude-7 Jiuzhaigou Earthquake

On 8th August 2017, a Magnitude-7 earthquake struck Jiuzhaigou, Sichuan, with the epicenter at 33.20° N, 103.82° E. As Figure 5 shows, there were significant anomalies in the thermal infrared brightness temperature difference variation ratio before the Jiuzhaigou Earthquake. From February to July, 2017, there were two large anomalies, and the anomalies reached the peak on 10th August; the earthquake struck the city on 8th August, and the anomalies gradually disappeared. In February 2020, there was again a large anomaly, but no earthquakes had occurred as of the end of 2020.
Figure 5. Temporal curve of difference variation ratios for Jiuzhaigou Earthquake

Figure 6. Spatial superposed map of difference variation ratios for Jiuzhaigou Earthquake

Figure 6 shows the superposed map of thermal infrared brightness temperature anomalies in Jiuzhaigou from 1st January, 2016 to 31st December, 2017, and the black dot in the figure represents the epicenter of Jiuzhaigou 7 magnitude earthquake. As the figure shows, the anomalies occurred in areas to the southeast of the epicenter, which areas of anomalies were marked dark grey and black.

5. Conclusions and discussion

5.1. Conclusions
In this study, the anomalies in the thermal infrared difference variation ratios before the earthquakes in Wenchuan and Jiuzhaigou were analyzed. The findings are as follows.

1) The difference anomaly extraction algorithm has good performance in extracting low-frequency background information, which provides a solid foundation for extraction of thermal infrared anomalies during earthquakes;

2) There were large-range anomalies before the earthquakes hit Wenchuan, Lushan in Ya’an, and Jiuzhaigou;

3) The epicenters of the earthquakes in Wenchuan, Lushan of Ya’an and Jiuzhaigou are situated along the boundaries of areas with the largest variation ratios of thermal infrared differences.

4) As shown in the temporal curves of anomalies (Figures 1, 3 and 5), there was one large anomaly before the Wenchuan Earthquake, but no anomalies occurred later; there was a larger anomaly after the earthquake hit Lushan, Ya’an, followed by a magnitude 6.3 earthquake in Kangding, but the magnitude was smaller than that in Ya’an, and but the anomaly was significantly stronger than that before Ya’an
Earthquake. Guo and Zhang et al. insisted that the thermal anomalies were reflected by the scope of the area with anomalies; they had no clear correlations to the magnitude of the earthquake, but were correlated to the geological and metrological conditions, which required further studies [13]. There was one large anomaly after Jiuzhaigou Earthquake, but no earthquakes followed. Experts argued that the thermal infrared anomalies could only indicate anomalies in the normal background values of ground temperatures during the period of anomalies, but the temperature changes were not caused by the earthquake. Therefore, false earthquake anomalies are inevitable in analysis of seismic thermal anomalies.

5.2. Discussion
The anomalies in the thermal infrared variation ratio extracted from three magnitudes 7 and above earthquakes are significant, but the extracted results are far from enough to support forecast of earthquakes. To accurately forecast the area and time of earthquakes, it is necessary to identify not only the development trend of thermal anomalies, but other short-impending information like the fractures and thermal infrared anomalies in the area of earthquakes, so that the earthquake precursors can be identified [15].

As the congestion and development of strong earthquakes cover large areas and feature a long recurrence period [3]. In this study, however, the data were extracted from a small area, and data of larger areas and more instances of earthquakes are required to achieve more convincing results.

Acknowledgments
This work is supported by the Qihang & Chuangxin Foundation of the Shaanxi Earthquake Agency(QC202002) and Key Laboratory of Earthquake Engineering and Engineering Vibration, Institute of Engineering Mechanics, China Earthquake Administration(2019EEEEVL0101).

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