Tracking of Thermal Infrared Anomaly before One Strong Earthquake-In the Case of Ms6.2 Earthquake in Zadoi, Qinghai on October 17th, 2016

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Abstract. The detection and tracking process of thermal infrared anomaly before Ms6.2 earthquake in Zadoi, Qinghai on October 17th, 2016, are reviewed and analyzed; then the different characteristics of thermal infrared brightness temperature data before this earthquake is described in details. According to these characteristics, the tracking process of thermal anomaly is divided into four stages, respectively identification stage, pre-judgment stage, tracking and approaching stage and verification stage. The anomaly forms and turning signals focused in each stage can provide clear indication information for earthquake pre-judgment; finally, the prediction efficiency and technical issues of this method are illustrated and discussed.

1. Introduction
Thermal infrared remote sensing detects the thermal condition on the ground surface by measuring the infrared radiation of earth-atmosphere system, and we can utilize this thermal condition to capture the earthquake precursor information, which can predict the location and time of earthquake occurrence over Ms5.5 on a one-month to half-year scale. It is shown by tracking and analysis result of massive thermal infrared data that this method possesses excellent verification rate in short-term earthquake prediction [1-11]. After the Ms6.2 earthquake occurred in Zadoi, Qinghai on October 17th, 2016, we traced back the precursor indication and predicting conclusion proposed in pre-earthquake consultation work by applying thermal infrared brightness temperature data, and found that quite complete and typical precursor responses of earthquake thermal anomaly have been formed since September 7th, 2016, when the thermal anomaly related to Zadoi earthquake was proposed in the weekly consultation report. Based on this, on the foundation of thermal infrared anomaly images, the characteristics of thermal anomaly before Zadoi earthquake at different stages are described, and the indication role of anomaly forms in judgment of epicenter in thermal infrared temporal-spatial evolution process is analyzed, and then the prediction efficiency of this method and the technical issues remaining to be improved are discussed.

2. Data source and processing method
The basic data in this paper come from the infrared remote sensing brightness temperature products of China geostationary meteorological satellite FY-2C/E/G (from National Satellite Meteorological Center of China Meteorological Administration). FY-2 satellites are loaded with optional infrared and visible-light scanning radiator, and can provide observation data for at least 24 times every day. In addition, the effective observation range is between 60°N and 60°S, 45°E and 165°E. The earth
curvature and unstable factors in satellite orbits will cause the observation data not geometrically calibrated to distort. To avoid complex manual calibration, the geometrically calibrated and scaled data can be directly downloaded from National Satellite Meteorological Center. In everyday work, the one-hour average equivalent blackbody brightness temperature data provided by this center in standard format is mainly adopted. Considering the influence of sunlight radiation, the data from 1am to 5am (Beijing time) in mainland China and its neighboring areas is captured because the morning fog in basins and plains has not yet been formed in this period and the earth-atmosphere can basically reach an equilibrium point. In addition, the brightness temperature data obtained from FY remote sensing data network in selected period is in HDF format, which adopts stratified data structure storage and leads to large data file being generated every day. Faced with such massive data, we carry out channel separation and format transformation on original brightness temperature data. Then, window supplementation method is used for average processing and the processed daily brightness temperature data is supplemented into the original database.

Satellite thermal infrared remote sensing information reflect the integrated influence of ground-surface radiation, atmospheric radiation and remote sensing instrument parameters, which contain the changes of various periodical components, such as sun, cloud, rain, terrain and earthquake preparation. The earthquake thermal infrared anomaly signal is relatively weaker and tends to be submerged into these interference signals and background noises. How to suppress the interference and highlight the useful information is the key of our research. So we utilize the wavelet transformation method, which has been widely applied in digital signal processing in recent years, to separate the signals in different time scales[12-14]. The db8 wavelet basis in Daubechies wavelet system is used in wavelet transformation on brightness temperature data. Considering the different periods of above influential factors, the 7-order low-frequency wavelet component is abandoned to remove the influences from basic earth temperature field, annual temperature field and terrain; the interference from short-term meteorological factors, such as cloud, rain and cold-hot airflow, is removed by abandoning the 2-order high-frequency wavelet component; finally, the 2-order low-frequency component is used to deduct the 7-order low-frequency component to obtain the positive-negative thermal infrared brightness temperature data in the time domain. The earthquake short-impending anomaly information needed by the research is contained in this characteristic period range. Then, Fourier transformation is used to estimate the power spectrum of wavelet data in order to extract the advantageous frequency and amplitude we need in massive thermal infrared brightness temperature data. The specific calculation is as follows: considering that the duration of most earthquake infrared short-impending anomaly ranges between 10 days and 90 days, the window length n is set as 64 days in this paper, and m (m=1, 2, 3, 4, 5, m=1 in this paper) is the sliding window length, then calculates the power spectrum by Fourier transformation. Later, all the power spectra of each pixel is processed by relative amplitude, and the obtained time-frequency spatial data are applied for scanning over the whole time, space and frequency range, thus to analyze the characteristics of thermal anomaly before and after the earthquake[15-16].

3. Tracking of thermal infrared anomaly in Zadoi earthquake

3.1 Introduction to the earthquake event

According to the measurement from China Earthquake Networks, an Ms5.2 earthquake occurred in Zadoi County, Yushu State, Qinghai Province at 3:14pm on October 17th, 2016 (Beijing time). The epicenter coordinates are 32.8°N and 94.9°E, and the focal depth is 9km. This earthquake is located inside the Qiangtang Block, and the epicenter is near the Zadoi fault and about 35km from Zadoi County. In addition, this earthquake is strike slip-normal type. Over 1 month before the earthquake, clear and identifiable regional anomaly (red area in Fig.1) has been found in the daily thermal infrared tracking. To ensure the reliability of calculation results and highlight the range and intensity of anomaly response, we screen repeatedly and scan the local thermal infrared anomaly.
3.2 Tracking process of earthquake thermal infrared anomaly

This thermal infrared anomaly is reflected in 1st frequency band with high reliability in the statistical results of typical earthquake cases, and this frequency band has high sensitivity and responsive rate to the thermal anomaly in dry areas. According to the thermal anomaly area covered in Fig.1, we set the local scanning area as 22°~42°N and 85°~110°E, and four stages can be divided by an overview of thermal infrared anomaly tracking process before Ms6.2 Zadoi earthquake.

(1) Identification stage: this stage ranges from late August to early September in 2016. It is found by the processing and analysis of thermal infrared data in daily work that there is obvious thermal infrared anomaly within an area ranging among 22°~32°N and 85°~103°E (Fig.1). This anomaly demonstrates as a large-scaled and high-value red response area, mainly involving the region of Sichuan-Qinghai-Tibet border and mid-Yunnan. The anomaly distribution form demonstrates approximate isolated circle shape, and is basically similar to the thermal infrared anomaly forms and intensity in typical earthquake cases. Therefore, it is initially judged as a focus area which is in urgent need of tracking.

(2) Pre-judgment stage: this stage ranges from early September to mid September in 2016. It is found by the temporal-spatial evolution figure of local thermal infrared brightness temperature power spectrum (Fig.2) that since mid August, there has been large-scale thermal infrared temperature rising area in Sichuan-Qinghai-Tibet border, Sichuan-Yunnan-Tibet border and western Yunnan. In addition, this temperature rising area gradually expands towards different directions. By September 4th, the thermal anomaly area reaches its peak. In the meanwhile, the anomaly forms are evolved into typical Z-shaped distribution. It can be seen from the statistical results of previous earthquake cases that the crossing point position of cross-distributed thermal anomaly forms is where the earthquake will occur frequently. Therefore, it is initially judged that the cross point of Z-shaped distribution, namely the black circle in Fig.3, will be the special area of concern in the next work (above conditions have been exhibited and illustrated in daily consultation conference).

(3) Tracking and approaching stage: this stage is mainly concentrated in mid September to early October. In order to focus the anomaly evolution process, narrow down the possible earthquake occurrence area and determine the earthquake intensity, we also take the local thermal infrared anomaly evolution figure as major tracking object (Fig.4). It is shown that since mid September, this thermal temperature rising area has entered into quick attenuation period. With the attenuation accelerating, the attenuation speed in Sichuan-Qinghai-Tibet border compared to other anomaly areas is the highest. It is shown by massive statistical results of earthquake cases that the epicenter is mainly located in the transition area where the anomaly appears and then quickly disappears. Therefore, we
judge that the possible earthquake occurrence area can be narrowed down to Sichuan-Qinghai-Tibet border (the upper block circle in Fig.3). We carry out time-sequential analysis on the relative power spectrum of the whole anomaly temperature rising area and obtain the change of thermal infrared relative power spectrum in recent 4 years (as shown in Fig.5), which can contributes to judge the time and intensity of earthquakes occurrence in the future. In Fig.5, the anomaly tracking in this area has lasted for above 50 days, and the relative change rate has reached its peak of recent 4 years on August 26th, 2016. Based on the conclusion from previous earthquake cases that the falling stage of anomaly peak is the possible period of time during which the earthquake occurs easily, we can approach the possible occurrence time of the future earthquake. In the meanwhile, combined with the temperature rising area and relative change rate of peaks, we present an empirical potential earthquake magnitude: about $Ms_{6.0}$ (above conditions have been exhibited and illustrated in daily consultation conference).

Figure 2. Thermal anomaly evolution before $Ms_{6.2}$ Zadoi earthquake

Figure 3. Delineation of thermal anomaly focuses area.
Figure 4. Thermal anomaly evolution before Ms6.2 Zadoi earthquake

Figure 5. Time-sequential curve of thermal infrared anomaly before Ms6.2 Zadoi earthquake

(4) Verification stage: this stage ranges from early October to the date of earthquake occurrence. In this stage, almost all the infrared temperature rising phenomena in the thermal anomaly area have disappeared, and the anomaly has gone through weak-strong-weak evolution process. Based on the development process of anomaly forms, identified characteristics and anomaly turning signals, we speculate that the earthquake occurrence time is gradually approaching. Until 3:14pm on October 17th, 2017, 52 days after the relative power spectrum of brightness temperature reached its peak, an Ms6.2 earthquake occurred in Zadoi, Qinghai, and the epicenter was right near the upper black circle in Fig.3 (denoted by ★ in Fig.3), which is basically complying with our focus area. Apart from temporal and spatial correspondence, the intensity of this earthquake is basically close to the magnitude we predicted in approaching stage. Therefore, we believe that the thermal infrared anomaly in this long period can be completely attributed to Ms6.2 Zadoi earthquake, and the work of short-impending tracking based on thermal infrared brightness data has produced good reflecting earthquake efficiency in this earthquake case.

4. Conclusion and discussion
In this paper, the earthquake tracking and prediction are carried out by analyzing the thermal infrared remote sensing data. The possible earthquake occurrence regions are found by landmark turning
signals in the evolution figure of thermal infrared anomaly. Then, the possible earthquake occurrence period of time and magnitude are determined further by the time sequential curve. It can be seen from this tracking process that the relative power spectrum of thermal infrared data amplified obviously before the Zadoi Ms6.2 earthquake, and this anomaly is reflected in the frequency band with high reliability. Above two points are the major judgment criteria and foundation for anomaly tracking process.

Through the thermal infrared anomaly evolution figure before Zadoi earthquake, we find that a large-scale thermal infrared anomaly area was showed up in the southeast of earthquake fault belt about 50 days before the earthquake. Contemporarily, we have provided relevant description of anomaly drawings and delineation of focus area in the weekly consultation work. Later, its anomaly form showed typical expanding and immigrating process. About one and a half month before the earthquake, the thermal anomaly area increased to maximum and then entered quick shrinking and recovering period. In the time domain, this thermal anomaly temperature rising phenomenon occurred about 2 months before the earthquake, and the earthquake occurred after the anomaly reached its peak; in the spatial domain, this thermal anomaly form which had experienced a process of initial appearance, accelerated development and final gradual attenuation, demonstrated a typical Z-shaped distribution, and the epicenter was right near the cross point of this Z-shaped distribution; in the intensity domain, the judgment on the earthquake magnitude was empirical, by comprehensively considering the temperature rising area and relative change rate of peak, the predicted earthquake magnitude is very close to the actual magnitude. Through the above analysis, it can be found that the thermal anomaly tracking effect related to Zadoi Ms6.2 earthquake is obvious and significant.

The current research on earthquake prediction and forecasting in China is still in its exploration stage, when we carry out a great deal of work on theoretical model establishment and earthquake case summary. Although massive long-term precursor observation work has been done across a wide range in multiple channels, the most destructive earthquakes occur in areas with relatively weaker earthquake monitoring capability. In other words, the continuous monitoring on various physical parameters in earthquake source region is lacking, and the precursor observation data cannot form an organic system and thus the relevant data cannot be analyzed and compared effectively. The infrared brightness temperature data of geostationary satellite can provide large-scale, quick and stable ground surface information due to their temporal consistency and spatial comparability, so it enjoys obvious advantages in the research of earthquake temporal-spatial characteristics. Currently the judgment of earthquakes based on thermal infrared temporal-spatial parameters is empirical. The prediction reliability on earthquake occurrence time and location is high, and the judgment on these two key elements is the emphasis in the whole tracking process. In Zadoi earthquake, the extraction of time and location elements, especially the precise delineation in location judgment, is obtained by common indicators from typical earthquake cases. On the issue of magnitude judgment, because of the complexity of multiple factors, such as geological environment, atmospheric environment, et al, the earthquake magnitude is not positively proportional to the size of thermal infrared anomaly area. In addition, although there is temporal-spatial correlation between earthquake activity and thermal infrared anomaly, it is still difficult to relate the anomaly to the seismogenic mechanism theoretically. So in the future short-impending tracking work, how to extract information truly related to earthquake precursor from complex thermal anomaly images, distinguish the thermal radiation anomaly characteristics in different regions and geological environments, and propose judgment suggestions and indicators which contain specific indicating information, will be the issue for us to research and explore deeply.

5. Acknowledgments
This work is financially supported by Earthquake Tracking Project of China Earthquake Administration (2017010413), and thanks to National Satellite Meteorological Center of China Meteorological Administration for provision of geostationary satellite data.
6. References

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