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Formation cause of thermal infrared high temperature belt along Honghe fault and its relation to earthquakes*

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Abstract

Aiming at two Dayao earthquakes with magnitude more than 6 occurred in 2003 in Yunnan Province, we analyzed and interpreted the NOAA satellite thermal infrared images of 1999, 2003 and 2004 in Chuandian region, and also calculated the annual variation of brightness temperature of the hot belt along Honghe fault to explore the formation cause of the high temperature belt and its relation to the earthquakes. The results show that the high temperature belt along Honghe fault is caused by geographic environment factors, such as water system and terrain. But the annual average brightness temperature of the belt in earthquake year of 2003 is clearly higher than that in no earthquake years of 1999 and 2004, this maybe indicates that the thermal activities of Honghe fault increase in earthquake years, and can cause the annual variation anomaly of brightness temperature. We can detect and monitor this thermal activities of Honghe fault before earthquake by analyzing and comparing the relative changes of thermal infrared brightness temperature of the hot belt in different years

Key words: **thermal infrared remote sensing**; **annual variation anomaly**; **earthquake precursor**; **fault activity**
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Introduction

The relation between satellite thermal infrared anomaly and earthquakes or fault activities has been studied for more than ten years. Many researchers contribute themselves to the research field and made some progress (Gorny *et al*, 1988; Andrew *et al*, 2002; WANG and QIANG, 1995; ZHENG *et al*, 1996; QIANG and DIAN, 1998). In recent years, with the rapid development of satellite remote sensing technique and its wide application to the field of seismology, more and more researchers are involved in this work and many relevant articles were published (ZHANG *et al*, 2002; DENG *et al*, 2003). However the impact of non-earthquake factors (weather, terrain *etc*) upon Earth surface thermal radiation is very complex, and the heat anomaly relevant to seismic or fault activity is submerged by strong background information, thus, it is still a bottle-neck problem how to effectively separate and remove the influences of non-earthquake factors and extract the thermal anomaly really caused by seismic or fault activities. The solution for the problem demands deeper study based on more earthquake cases.

The Chuandian region is a seismically active area, where strong earthquakes with magnitude

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more than 6.0 are frequent. Some learners have studied the relation of satellite thermal infrared anomaly to activities of strong earthquakes in the region. QIANG and DIAN (1998) researched Lijiang M_S=7.0 earthquake occurred on February 3 1996 in Yunnan Province, and found thermal infrared anomaly appeared along Honghe fault 53 days before the shock; DENG *et al* (2003) made a research on Yaoan M_S=6.5 earthquake occurred on January 15, 2000 in Yunnan Province, and also found warming anomaly along Honghe fault before the event. In 2003, another two earthquakes took place in Dayao, Yunnan Province. Aiming at these two events, the paper analyzed NOAA16 satellite images of Chuandian region in 1999, 2003 and 2004, and obtained some new results.

1 Studied area and data

There were two earthquakes occurred in Dayao, Yunnan Province in 2003, one was M_S=6.2 earthquake with epicenter of 101.2°E, 26°N on July 21, another was M_S=6.1 with epicenter of 101.3°E, 26°N on October 16. The epicenters of the two events are close to each other and both located in Chuandian tectonic block. There is no evident active fault being found on the ground about 60~70 km around the epicenters, also there is no historical earthquake record in this region. But outside this scope, there are many large active faults and strong earthquake records. In order to study the influences of this two earthquakes on satellite thermal infrared images, we interpreted and analyzed NOAA16/AVHRR satellite data in a region of 97°E~107°E, 22°N~33°N in 1999, 2003 and 2004 in the paper. To avoid the disturbance of sunshine and cloud, only cloudless images during nighttime were selected. Figure 1 gives the seismic tectonic background of studied area. Two solid circles in Figure 1 are epicenters of two Dayao earthquakes.

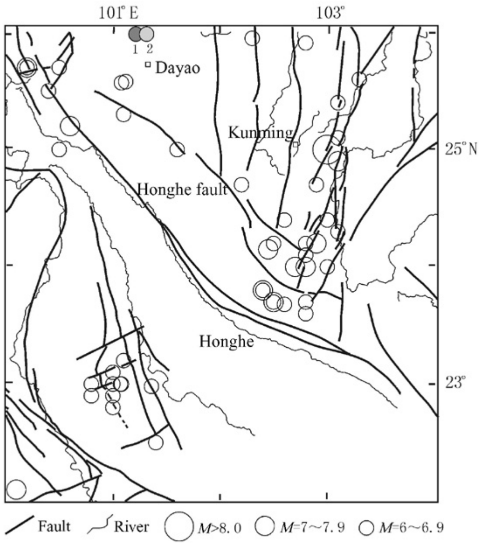

Figure 1 Tectonic background of the studied area (same region as Figure 2 and Figure 3)

The NOAA series Polar Orbiting Meteorological Satellites have been operated by the National Oceanic and Atmospheric Administration (NOAA) of the USA since the first one launched in the late seventies of last century. They fly on near circle orbit 870 km above the Earth surface *via* polar regions with flying period 102 min. It can supply images for each point of the Earth surface at least twice per day. Each satellite carries a multi-spectral optical-thermal sensor called the Advanced Very High Resolution Radiometer (AVHRR). By scanning 54° from nadir the instrument is able to provide a 2 700 km swath width with a spatial resolution of 1.1 km at nadir. The AVHRR data, recorded in five spectral bands, cover 0.58~12.5 μm wavelength region, which are respectively band 1 and band 2 in visible and near infrared (0.58~1.0 μm) suitable for detecting reflectivity of earth-atmosphere system; band 3 in middle infrared (3.55~3.93 μm) sensitive to high temperature and suitable for detecting anomalious heat features; band 4 and band 5 in thermal infrared (10.5~12.5 μm), reflecting thermal radiation of earth-atmosphere system in normal temperature (300 K or so) and providing plenty of data for studying thermal field of Earth surface with a data precision of 0.12 K. The retrieval of land temperature and sea temperature both uses band 4 and band 5.

2 Thermal image features along Honghe fault

2.1 Image features one month before and after earthquake

The paper first analyzed the thermal images one month before and after earthquake events. For the M_S=6.2 earthquake occurred on July, 21, there were few images available for analyzing thermal anomalies because of grievous disturbance of cloud during rainy period from June to August. For the M_S=6.1 earthquake occurred on October 16, there were lot of cloudless images which can be used to interpret and analyze. From the selected images of September 23, September 24 and September 26, a clear high temperature belt can be found. The belt spreads in the direction of northwest-southeast along Honghe fault, moreover, in the direction of northwest its width gets narrow, its brightness temperature gets low and dies away at about 25°N; in the direction of southeast, its width gets broad, its brightness temperature gets high and disappears at about 22°N. The temperature of the hot belt is higher 1~1.5° than background. (Figure 2a)

On the images of October 22, November 6 and November 8 after M_S=6.1 earthquake, the hot belt still existed, and its features such as spread direction, width and magnitude are all similar to that before the event (Figure 2b). In order to further find the varying process of the hot belt with time, all NOAA16 satellite thermal IR images in the whole year of 2003 were interpreted and analyzed. As a result, similar hot belts along Honghe fault have been observed on other cloud free thermal images besides those before and after shocks. This indicates that it is difficult to explain the relation between the hot belt and the two earthquakes only according to the thermal images of the year of 2003. It is necessary to analyze the satellite data of the years without earthquakes and compare the observed results with that of the year of 2003.

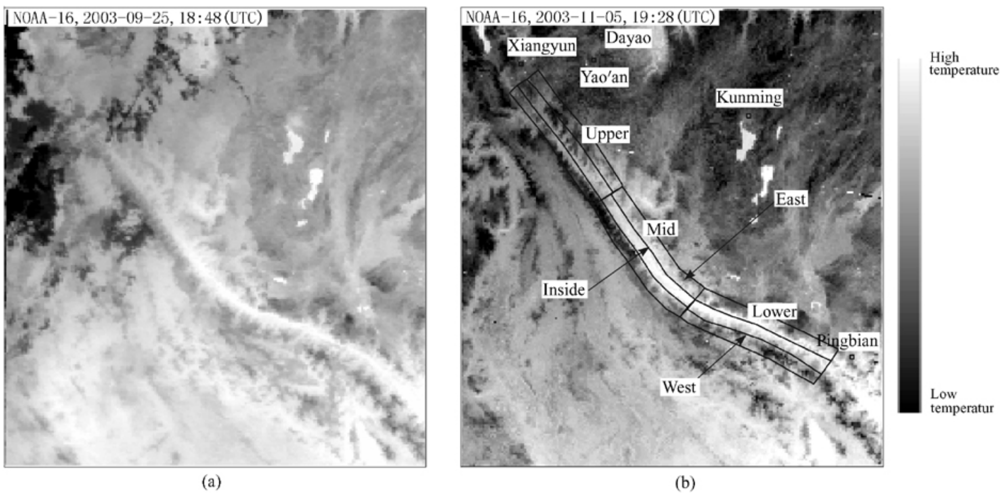

Figure 2 Thermal images around Honghe fault before and after M_S=6.1 earthquake during nighttime
(a) At 02h48min on September 26, 2003 before earthquake; (b) At 03h28min on November 6, 2003 after earthquake

2.2 Image features of no-earthquake years

The seismic activity in China is relatively steady in 1999 and 2004 compared with the year of

2003. There was no strong earthquake with magnitude above 6.0 occurring in Chinese mainland in 1999 and 2004. we made a comparison between thermal images of two years and that of 2003 so as to reveal the differences of the hot belts between the years with earthquake and the years without earthquakes. Therefore, all NOAA16 thermal images during nighttime of 1999 and 2004 were selected and processed. After Image processing including NOAA (AVHRR) thermal infrared images data extraction, calibration, radiation, atmospheric corrections and cloud eliminating, the IR brightness temperature image series displayed in pseudocolor and gray level are obtained. From these brightness temperature image series, it can be seen that a hot belt along Honghe fault, which is very similar to that of 2003 on position and features, presented on all cloudless images during nighttime (Figure 3). This result indicates that the hot belt along Honghe fault is a natural IR image feature or image structure caused by environment condition such as terrain and water system, instead of the thermal anomaly caused only by seismic activities.

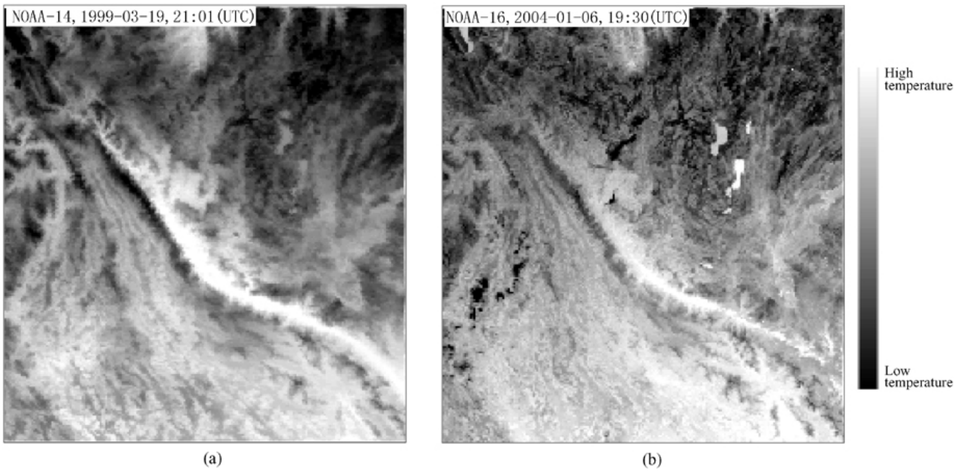

Figure 3 Brightness temperature images in 1999 and 2004
(a) At 05h11min on March 20, 1999; (b) At 03h30min on January 7, 2004

3 The annual variation of brightness temperature along Honghe fault

As mentioned above, the hot belt along Honghe fault appeared on the thermal images of both year with earthquakes and years without earthquakes. But this still cannot exclude the possibilities of that the hot belt is related to two Dayao earthquakes occurred in 2003 and the thermal activities of Honghe fault strengthened in 2003. Actually, the thermal anomalies caused by seismic activities are a part of relative change of surface brightness temperature. This variation is mixed into complex heat radiation information coming from Earth surface, moreover, it may be very small compared with the temperature variations caused by other intrinsic factors, especially by meteorological factor. So it is not likely large enough to bring clear anomalies, which can be interpreted, directly on thermal IR images. However, it would be possible to discover the IR anomalies and their varying trend by calculating and comparing the temperature values of same region in different years. Based on this idea, the annual variations of the brightness temperature around Honghe fault in the years of 1999, 2003 and 2004 are calculated as follows to reveal the diversity among different years.

3.1 The statistic methods of brightness temperature

We divided the hot belt into three segments along the direction of its extending, respectively called the upper, the middle and the lower segment; each one is 130 km long; and divided the hot belt into three strips across its extending direction, respectively called the west side, the inside and the east side, each one is 10 km wide (Figure 2b). Then the temperature values of each pixel were extracted and the average values for each 130 km×10 km region were calculated. In order to improve the reliability of statistical result, only cloud free images during nighttime were selected for statistics. It should be noted that the special climate and terrain of Chuandian region result in persistent cloud covering over sky, which is one of the main obstacles to infrared observation and monitoring from the space. Although NOAA16 provides at least one AVHRR image of Chuandian region each night, we only acquire about one cloud free image suitable for analysis a week in the periods from January to April and from September to December. Unluckily, there were few images to be used in the period from May to August.

3.2 The statistic results of brightness temperature

The statistic results described above indicate the brightness temperatures of the hot belt along Honghe fault basically changed in similar trend in the three year, that is to say, in the direction across the hot belt, the temperature of the inside is higher than that of the other two sides, and the east side is higher than the west side a bit. In the belt′s extending direction, the temperature in middle segment is higher than that of the upper and lower, and the lower is higher than the upper

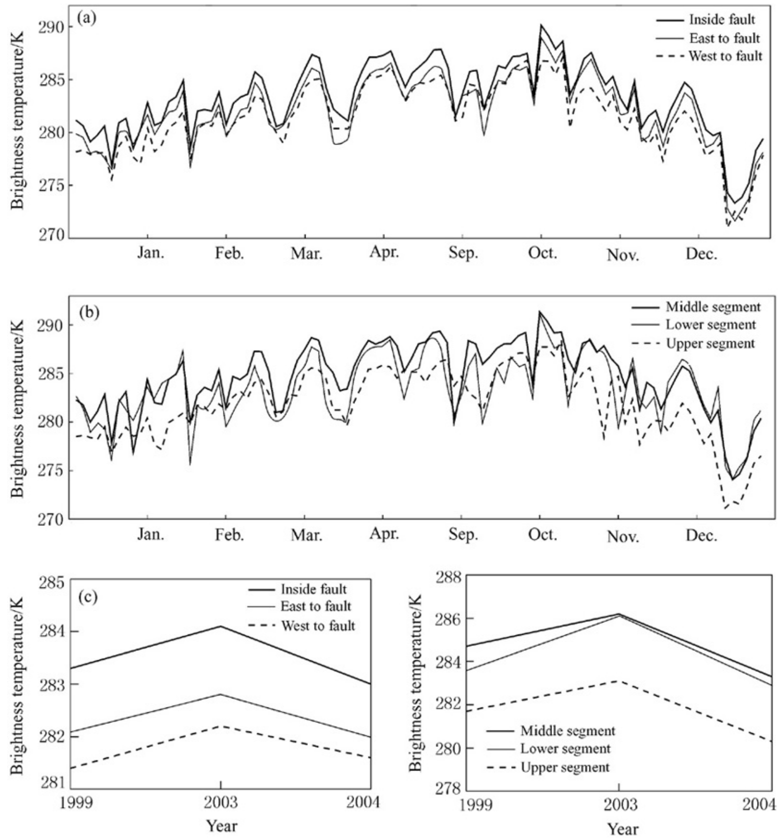

Figure 4 The brightness temperature annual variations of the hot belt along Honghe fault
(a) Comparison of the inside and the outside hot belt; (b) Comparison of the upper, the middle and the lower; (c) Comparison of average brightness temperature in 1999, 2003 and 2004

(Figure 4a and 4b). But the average temperature value inside the hot belt in the year of 2003 is obviously higher than that of the years of 1999 and 2004 about 1 K (Figure 4c). This higher temperature in the year of 2003 maybe related to the Dayao earthquakes occurred in this year.

4 Formation causes of the hot belt and its relation to earthquakes

4.1 Cause of formation of the hot belt

The Earth surface infrared brightness temperature is mainly affected by terrain and weather. Relatively, the change of terrain is slow, which mostly controls the spatial distribution of brightness temperature. In general, the ground isotherm is parallel to the contour lines of terrain, but the values are negatively related to each other. However, the variation of weather is very complex. The weather primarily influences the temporal process of infrared brightness temperature variation. The water system such as lakes and rivers show clear high temperature signs in nighttime images because of water′s high thermal inertia. From Figure 1, it can be seen that the Honghe fault just stretches along the valley of Honghe river, therefore it presents as a hot belt in nighttime images. Figure 5a and 5b show the terrain profiles along and across the hot belt respectively. It clearly showed that along the belt, terrain elevation decreases gradually from the upper to the lower, across the belt the valley is deep and the west side of the valley is higher than east side in terrain. Comparing these terrain features with the brightness temperature variation trend, it is clear that the hot belt along Honghe fault is a natural thermal infrared image characteristics contributed from environment condition.

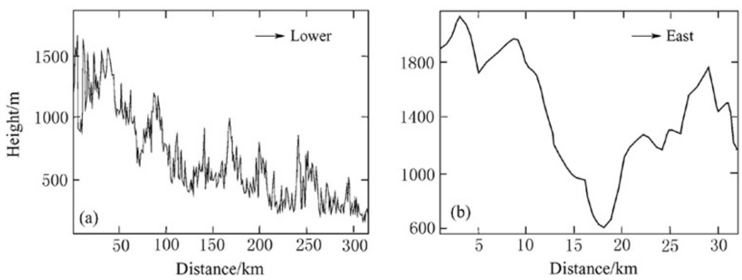

Figure 5 The terrain sections around Honghe fault
(a) Along Honghe fault (upper to lower); (b) Across Honghe fault (west to east)

4.2 Relation to Dayao earthquakes

Although the hot belt along Honghe fault is caused by environment condition such as terrain and river, the fact that its average temperature in the year of 2003 is higher than that in the years of 1999 and 2004 maybe imply that the hot belt is still related to the earthquakes occurred in 2003. It is possible that thermal activity of Honghe fault increased and caused the temperature going up because of the two events in 2003. In addition, it should be noted the brightness temperature of the middle segment is always higher than the lower segment in three years despite of the lower segment with low elevation and low latitude, this result is not accordant to common situation. This maybe indicates that the activities of Honghe fault differ in each segment. According to the result of active tectonic study (XIANG *et al*, 2000), the horizontal slipping velocity of Honghe fault is 0.5 mm/a in the middle segment, but in the lower segment it is only 0.05 mm/a. These parameters told us the middle segment′s activities are surely stronger than that of lower segment, which corresponded to the result of brightness temperature variation. In conclusion, we think the hot belt along Honghe fault still related to seismic activities although itself is caused by environment condition and is not the precursor anomalies. The high annual temperature variation and temperature variation difference in each segment may be the reflection of seismic activities and fault activities. Of course, we should compare annual temperature variations of different years to discover the temperature variation differences.

5 Conclusions

The technique of satellite thermal infrared remote sensing provides a new observational method for studying earthquakes. Detecting seismic and fault activities by this technique is a promising research subject. Based on analyzing NOAA satellite data of three years of Chuandian region, the paper achieved following preliminary conclusions:

1) The hot belt along Honghe fault appeared not only in the images before earthquakes, but also in all cloudless nighttime images, So it is natural image feature caused by environment conditions instead of the precursor thermal infrared anomalies.

2) The average brightness temperature of the hot belt in the years with earthquakes is higher than that in the years without earthquakes, so it is necessary to utilize satellite data of several years (at least three years) and compare relative activities of the belt in different years for detecting this temperature variation differences.

3) Fault activities exists diversity in different segments, the thermal infrared radiation along a fault maybe differs in different segments. So it is possible to provide evidence for fault subsection by calculating and comparing brightness temperature variations in different segments of a fault in several years.

4) The results of this paper indicate the veracity and reliability of earthquake anomalies are related to the time scope of used satellite data. For a same earthquake case, different authors maybe derives different results because of their data different in spatial and temporal scope. Some anomalies seem to be connected with a certain earthquake in a short period, but in a long period (at least one year), they are actually reflection of a certain meteorological phenomenon. So it is necessary to analyze satellite data in different time scale for extracting real precursor anomalies and eliminating the disturbance of non-earthquake factors.

References

Andrew A, Tronin, Hayakawa M *et al*. 2002. Thermal IR satellite data application to earthquake research in Japan and China [J]. *Journal of Geodynamics*, **33**(2002) 519~534.

DENG Zhi-hui, WANG Yu, CHEN Mei-hua *et al*. 2003. Satellite infrared anomaly of several strong earthquakes in China mainland [J]. *Seismology and Geology*, **25**(2): 327~337 (in Chinese).

Gorny V I, Salman A G, Tronin A A *et al*. 1988. The Earth outgoing IR radiation as an indicator of seismic activity [A]. *Proceeding of the Academy of Science of the USSR* [C], 67~69, 301

QIANG Zu-ji and DIAN Chang-gong. 1998. Satellite infrared brightness temperature anomaly—earthquake imminent precursor [J]. *Science in China* (D), **28**(6): 564~573 (in Chinese).

WANG Hong-tao and QIANG Zu-ji. 1995. Research on earthquake prediction using satellite thermal infrared anomaly [J]. *Advance in Earth Sciences*, **10**(6): 537~541 (in Chinese).

XIANG Hong-fa, GUO Shun-min, XU Xi-wei *et al*. 2000. Active block division and present-day motion features of the south region of Sichuan-Yunnan province [J]. *Seismolgy and Geology*, **22**(3): 253~264 (in Chinese).

ZHANG Yuan-sheng, SHEN Wen-rong, XU Hui. 2002. Satellite thermal infrared anomaly before the Xinjiang-Qinghai border M_S8.1 earthquake [J]. *North Western Seismological Journal*, **24**(1): 1~6 (in Chinese).

ZHENG Lan-zhe, QIANG Zu-ji, DIAN Chang-gong. 1996. Practice and research on short-term-impending earthquake predication by interpreting satellite thermal infrared anomaly image [J]. *Earth Science—Journal of China University of Geosciences*, **21**(6): 665~668 (in Chinese).