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ORIGINAL PAPER

Thermal infrared anomalies as a precursor of strong earthquakes in the distant future

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Abstract Satellite thermal infrared images contain valuable earthquake precursor information. Past studies concluded that such information appeared only a few days or dozens of days before an earthquake would occur. In our study, though, we observed that the time intervals between the thermal infrared precursor and an earthquake's occurrence can be up to 10 years. An infrared image can also synchronously indicate the locations of additional future earthquakes with different epicenters within a region. The shape, area, intensity, and movement of thermal infrared anomaly areas are a combination of all the future strong earthquakes within a region. These distant future earthquakes are generally located near the edges, endpoints, or corners of the main structure, fine structures or periphery structures of a thermal infrared anomaly area and play a role in confining the anomaly area. There have not been any exceptions among the strong earthquakes we analyzed, which have included the 2011 Japan M_w 9 event, the 2010 Yushu M_S 7.1 event, the 2008 Wenchuan M_S 8 event, and many other strong events following the 2004 Sumatra M_S 9 event. Surprisingly, some of the earthquakes can outline an area of elevated temperature observed many months ago. If we can roughly locate these potential epicenters through the analysis of thermal infrared images and combining the analysis with other information, and then dynamically monitor them, it may be easier to observe the precursor of an earthquake and predict its occurrence.

Keywords Earthquake · Precursor · Distant future · Thermal infrared · Remote sensing

1 Introduction

Through satellite thermal infrared (TIR) images, some studies have already documented an extensive elevated temperature near epicenters that appear within dozens of days before the earthquakes occurs (Qiang et al. 1997a, 1999; Tronin et al. 2002; Tramutoli et al 2005; Genzano et al. 2007; Panda et al. 2007; Saraf et al. 2008; Rawat et al. 2011). The elevated

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temperature areas often appear in the form of ellipses with a size, location, intensity and structure that changes as time goes on. Yao (2007) noted that earthquake precursors are special changes of the whole physical and chemical regional field instead of only a few sites. A regional crust will not create only a single earthquake at a time, but will gestate all possible earthquakes at any given time. Namely, all sites meeting certain conditions will simultaneously deform and accumulate stress for their respective earthquakes, which may vary in velocity or power. The unborn earthquakes are at different development stages, with some close to maturity and almost ready to rupture, some at budding states, and others between the two states. In a region, sometimes the next strong earthquakes occur on the heels of a strong earthquake; and in other cases, the time interval between two strong earthquakes may be many years. An example of the former is the large earthquakes that occurred near Sumatra Island and to the east of Sumatra Island. A large number of strong earthquakes, including a M_S 8.7 event, occurred in this region closely following the M_S 9 Sumatra earthquake on December 26, 2004. An example of the latter is several large earthquakes that occurred near Yuanping in Shanxi Province, China. These three earthquake events were an M 7.5 on May 23, 512 at 38.9°N, 112.8°E, an M 7.25 on January 15, 1038 at 38.4°N, 112.9°E, and an M 7 on November 22, 1683 at 38.7°N, 112.7°E, separated by time intervals of about 526 and 645 years. We also noticed that the elevated temperature ellipses that appear dozens of days before an earthquake were usually not distributed around the future epicenter, but instead were located on one side of the epicenter varying distances apart. In addition, the longer axis of the elevated temperature ellipse did not usually follow the trace of the future causative fault. We thought that this phenomenon correlated with the process of gestating other earthquakes in this region in the more distant future. The structure, location and motion of the elevated temperature ellipses can all provide some evidence of the aforementioned cognition.

Yao and Qiang (2010) found that the same elevated temperature ellipses could synchronously reflect the developing process of the Wenchuan M_S 8.0 and the Yutian M_S 7.3 earthquake in China in 2008; both have a time interval of 52 days and an epicenter distance more than 2,000 km. This time interval, however, is shorter than many other examples and since the Wenchuan and the Yutian earthquakes are only a pair of events, the infrared relationship between both is easily observed. Whether calefactive ellipses can “visit” their unborn epicenters at the same time for more earthquakes that may occur at different times in the distant future in the whole region is a question with scientific value. If so, analyzing the static and dynamic structural features of the calefactive ellipses, documenting indicative information of earthquakes and then dynamically monitoring them have immeasurable significance for improving earthquake prediction. This article approaches the subject by analyzing TIR images and discussing applications to a number of typical strong earthquakes.

2 Methodology

Geostationary meteorological satellites, such as FY-2, have a variety of sensors that can probe different wave bands. We are interested mainly in their 10–11 μm and 11.5–12.5 μm bands. The measured values in these bands are normalized into grayscale that are then divided into different grades. We give each grade a hue from red to blue. After this, we can calculate radiation temperature (T_R) base on the grayscale values and then use this temperature and the radiation coefficient of ground objects (ε) in the formula $T = a_0 \varepsilon T_R$ (a_0 is a coefficient) to both acquire and analyze actual ground temperature (T).

If we find anomalistic information of infrared radiation, then—excluding the possible effect of meteorological and other factors—we can determine whether or not it is a precursor anomaly coming from an earthquake's gestation. If there is such anomaly, we will analyze characteristics such as location, shape, magnitude, area, uniformity, structural relationship, movement, deformation, and change in temperature and area. Then we can analyze the possible relationship between the anomaly and the size, location, and occurrence time of potential strong earthquakes. Sometimes, warming—with no relationship to the season, time of day, topography, or weather—can be observed due to earthquakes. Since this earthquake warming has no relationship to the aforementioned factors that can cause temperature variation, scientists can easily differentiate between these two different causations.

In the past, we only paid close attention to the relationship between a single strong earthquake that was going to occur in the very near future (within a couple dozen of days) and the thermal infrared anomalies. Our primary surveillance and analysis began from initial thermal radiation anomalies with smaller temperature rise and smaller area. Then we would follow up the change of the anomalies in area, temperature, shape, movement direction, and velocity. Keeping the Quaternary tectonic system in mind, we would identify and analyze indicative marks or predictive signals of an impending earthquake. The warming areas move and their end destination usually coincides with the earthquake's epicenter; this is a very useful characteristic for analyzing the relationship between earthquakes and infrared anomalies.

In recent years, we have extended such analysis simultaneously to more or even all possible strong earthquakes within a region and also within a longer (more than 10 years) future period by paying attention to the relationship between images and earthquakes and the relationship between different earthquakes. Earthquake precursors often show only slight or discontinuous anomalies in radiation temperature. The movement of any infrared anomaly is complex; it is not entirely linear, onward, steady and coherent: sometimes it has backward or tortuous movement, sometime it stops. Therefore, we must pay attention to temperature variations at each time and space point according to the thermal infrared images that are collected daily and be prepared to adjust our analysis at any time.

3 The 2004 Sumatra M_S 9 earthquake and succedent strong earthquakes

A M_S 9 earthquake occurred in Sumatra (3.298°N, 95.779°E) on December 26, 2004 (UTC, used in the whole paper). Its rupture expanded toward the north-northwest, extending 1,200–1,300 km along the Andaman trough (Ammon et al. 2005). Some thought that succeeding strong earthquakes would migrate north-northwest along the rupture and the plate boundary. We speculated, though, that the succeeding strong earthquakes would transfer east. We analyzed infrared images from the FY-2b satellite and observed a large region with an elevated temperature prior to the Sumatra earthquake, with an anisomerous structure that was stronger in the east than in the west. In our view, the static and dynamic structures of a thermal infrared precursor field will be decided by all future earthquakes in different developmental stages at different sites in this region. Thermal infrared images are able to foreshadow earthquakes that will occur after many years. Close to a strong earthquake event, information on its possible occurrence time, location and magnitude will appear or intensify in the images.

On December 2, 2004, the extensive elevated temperature region located near the Sumatra earthquake can be divided into the western, the central, and the eastern areas. The eastern area was mainly located in 125°–155°E, 0°–20°N, striking NE. The western area was located in 71°–74°E, 11°–15°N, and was striking N-NW. Lastly, the central one was mainly located in 91°–99°E, 6°–17°N. The intensity of the elevated temperature regions increased from west to east (Fig. 1). The southern end of the central section pointed to the epicenter of the imminent M_S 9 great earthquake. But why did the eastern area have a higher temperature and an obviously larger area than the central one where the earthquake was about to occur? We presumed the eastern area was a region where other large earthquakes would occur in the near future. This conjecture was correct. Since 2005, many strong earthquakes occurred just on the edges of the regions with different elevated temperature in the eastern area, in particular, on the SW-W ends (Fig. 2).

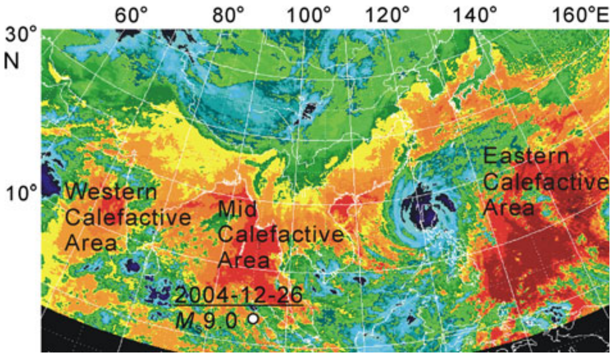

Fig. 1 The three elevated temperature areas that represent the infrared precursor of the 2004 Sumatra M_S 9 earthquake. From *purple* to *dark red*, *brown*, *yellow*, *green*, *light blue*, *dark blue* temperatures decrease step by step in the satellite images used in this paper

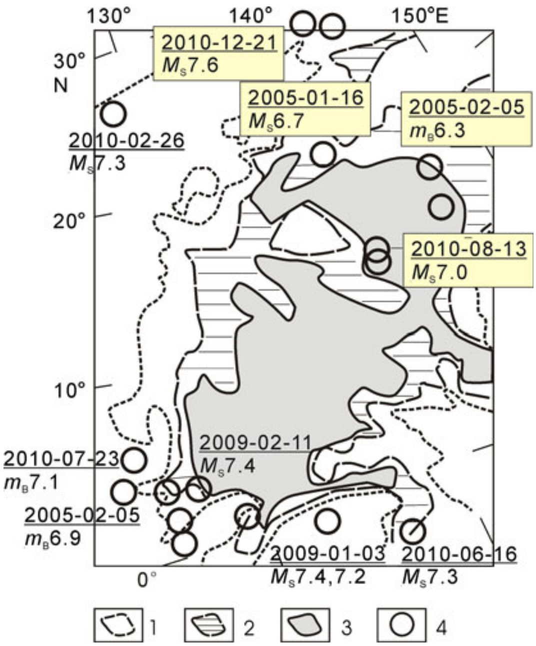

Fig. 2 The relationship between some events ($M > 6$) later than the Sumatra M_S 9 earthquake and the three levels elevated temperature area at 2004-12-02T14:30. *1* general elevated temperature area as earthquake's infrared precursor; *2* higher elevated temperature area; *3* the highest elevated temperature area in this figure; *4* epicenters (only part strong earthquakes)

Over time, the thermal infrared anomaly areas may "visit" areas where more future strong earthquakes may occur. The area and intensity of the three elevated temperature areas all increased on December 4, accompanying their deformation and movement. A lot of strong earthquakes occurred in the eastern area after the M_S 9 Earthquake, such as the Kyushu M_S 7.3 earthquake on March 20, 2005, the Taiwan M_S 7.4, 7.1 earthquake on December 26, 2006, …. The strong earthquakes were usually located at the edges, angle vertexes, or strip ends of the infrared calefactive areas (Fig. 3). Figure 3 displays only a few relevant earthquakes. In fact, the earthquakes have not stopped occurring near this location in recent years. Table 1 lists a part of strong earthquakes that occurred there from November, 2008 to December, 2010.

Although an anomalistic elevated temperature area may represent all sites gestating earthquakes in different developing stages within the whole region, an impending earthquake usually has special characteristics in thermal infrared images. It usually shows some special variations or movements of infrared anomaly, such as a tendency to trend toward the epicenter. The infrared images of the Sumatra M_S 9 earthquake show a typical earthquake precursor structure, which had special changes and movements approaching the epicenter a few days before the earthquake occurred. On the morning of December 20, the thermal infrared field degraded, decreasing gradually from more than 23 °C in the elevated temperature area and almost disappearing in the west area. At 14:30, however, the temperature in the central and the eastern area rapidly increased again, and the 23 °C calefactive zone (red) reached directly to the epicenter of the impending M_S 9 event (Fig. 4). This illustrates the special information of an impending strong earthquake in a thermal infrared field where more strong earthquakes may occur in the future. If all the indicative

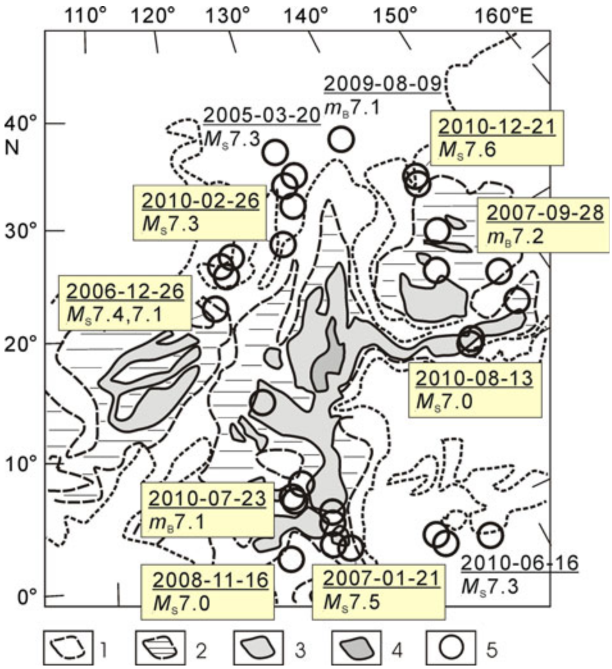

Fig. 3 The elevated temperature areas on December 4, 2004, indicating the locations of some strong earthquakes after the Sumatra M_S 9 event. *1* general elevated temperature area as earthquake's infrared precursor; *2* primary higher elevated temperature area; *3* moderate higher elevated temperature area, *4* the highest elevated temperature area in this figure; *5* epicenters

Table 1 $M \geq 6.8$ events in the scope of the Fig. 3 from November 16, 2008, to December 21, 2010

Date	Latitude/(°)	Longitude/(°)	Magnitude (M_S)	ETA
2008-11-16	1.12	122.45	7.0	2
2009-01-03	−0.4	132.90	7.4	1
2009-01-03	−1.43	133.80	7.2	1
2009-02-11	3.40	126.68	7.4	3
2009-07-13	24.09	122.23	6.8	1
2009-08-09	33.12	138.02	7.1 (m_B)	1
2009-08-17	23.45	123.81	6.9	1
2009-10-04	6.23	123.90	6.8 (m_B)	3
2009-10-30	28.75	130.54	6.8	1
2010-02-26	25.86	128.65	7.3	1
2010-06-16	−2.2	136.60	7.3	1
2010-07-23	5.98	123.86	7.1 (m_B)	3
2010-08-13	12.43	141.67	7.0	3
2010-12-21	27.06	143.30	7.6	1

The seismic parameters come from CSN's observation. ETA expresses the elevated temperature areas as earthquake's precursor on December 4, 2004 (shown in Fig. 3): 1 is general elevated temperature area, 2 is primary higher elevated temperature area, 3 is moderate higher elevated temperature area, and 4 is the highest elevated temperature area. All earthquakes in the table occurred at the edges, angle vertexes, or strip ends of ETA

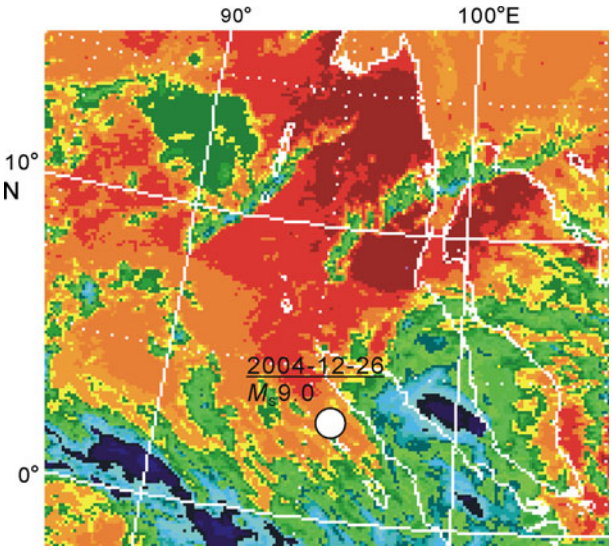

Fig. 4 The elevated temperature zone arriving at the epicenter of the Sumatra M_S 9 earthquake nearly 6 days in advance

image information, such as the extent of the elevated temperature, the degree of homogeneity, shape, and motion or variation, is combined, it is possible to predict an imminent strong earthquake.

4 The shared infrared information of the 2008 Wenchuan M_S 8 and the 2010 Yushu M_S 7.1 earthquakes

The previously discussed close connection between the Wenchuan M_S 8.0 earthquake on May 12, 2008 and the Yutian M_S 7.3 earthquake on March 20, 2008 can be seen in the

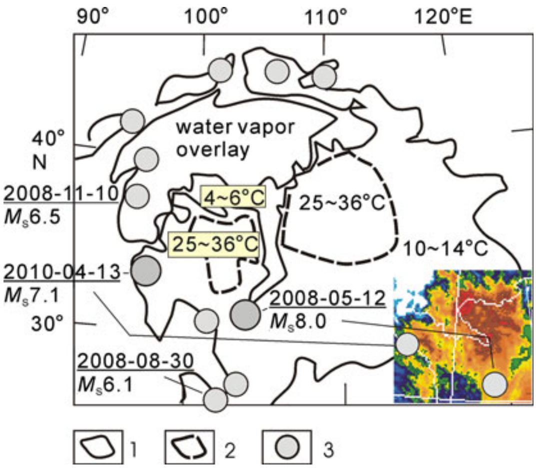

Fig. 5 The elevated temperature ellipse (2008-05-06) foreshadowing strong earthquakes in 2008 and in 2010. *1* general elevated temperature area as earthquake's infrared precursor; *2* core elevated temperature area; *3* epicenters

thermal infrared images (Yao and Qiang 2010). The interval of time between the two earthquakes is 52 days. In 2010, a M_S 7.1 earthquake occurred at Yushu (33.22°N, 96.59°E). We thought there was a large possibility that clues predicting this future earthquake may appear in earlier thermal infrared images. After analyzing the infrared images, we observed anomalies that suggest it. The 2010 Yushu M_S 7.1 earthquake was located just at a typical point reflecting earthquake preparation in the infrared image on May 6, 2008, which is one of the most representative images predicting the imminent Wenchuan M_S 8.0 earthquake (Fig. 5). Before, it is an unperceived phenomenon that thermal infrared images include such plentiful information indicating different future earthquakes over a long time interval. Moreover, the elevated temperature ellipse in the image also predicts a number of other earthquakes; such precursors of earthquakes in the distant future also exist in the more subtle structures of thermal infrared images. For example, the images (2008-03-03T6:00) that we used to analyze the 2008 Wenchuan 8.0 earthquake precursors included a secondary calefactive ellipse within the larger elevated temperature structure. The Yushu M_S 7.1 earthquake occurred on April 13, 2010, just on the edge of the elevated temperature ellipse. A subtle linear structure in the ellipse also hinted at the location of the earthquake (Fig. 6). The emergence of the thermal infrared ellipse began at least 2 years, 1 month and 10 days before the Yushu earthquake occurred.

5 The 2011 Japan M_w 9 earthquake

The Japan (38.1°N, 142.6°E) M_w 9.0 earthquake on March 11, 2011, again validated the aforementioned phenomenon and cognition. It was located at an angular vertex of the precursory calefactive region of the 2004 Sumatra M_S 9 earthquake (Fig. 7). The time interval between the Japan M_w 9.0 earthquake and the elevated temperature area (2004-12-17; Fig. 7) is 6 years, 2 months and 22 days.

6 The modes of infrared images indicating earthquakes in the distant future

How does a thermal infrared image indicate earthquakes in the distant future? Answering this question clearly has a great significance to better understand and apply the

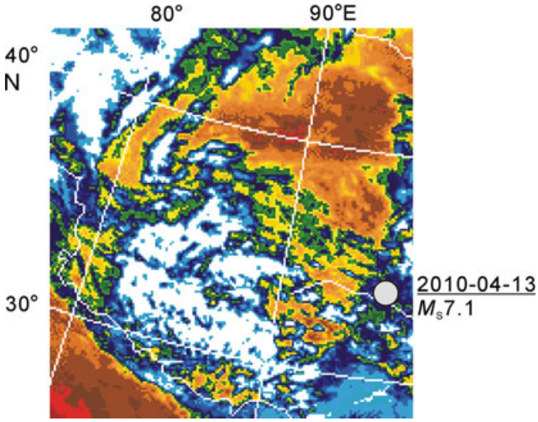

Fig. 6 The thermal infrared ellipse and subtler structures foreshadowing the 2010 Yushu 7.1 earthquake 771 days in advance

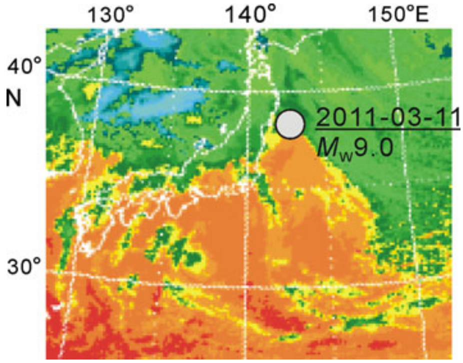

Fig. 7 The thermal infrared structure indicating the location of the 2011 Japan 9.0 earthquake 2,275 days in advance

corresponding method, observe the future earthquakes' gestation processes, analyze possible occurrence times, locations and magnitudes of future earthquakes, and heighten the level of earthquake predictions from long term to imminent scales. To develop a good understanding of the thermal infrared anomalies, we analyzed lots of thermal infrared images and found that all the regional future strong earthquakes participate in forming elevated temperature configuration with boundary restrictions. For example, the premonitory thermal infrared field of the 2004 Sumatra 9.0 earthquake repeatedly reached the epicenter of the 2008 Wenchuan 8.0 earthquake, with each instance containing at least three different spatial arrangements. In the first one, the Wenchuan epicenter was located at a corner of the main elevated temperature area as the precursor of the Sumatra 9.0 earthquake (Fig. 8a); the second mode was related to the micro-structures of the elevated temperature image, and the Wenchuan epicenter was located at the end of a local elevated temperature strip (Fig. 8b); in the third mode, the epicenter was located on the outer edge of the border zone of the main elevated temperature area (Fig. 8c). Although a border zone has a lower elevated temperature than its main calefactive field, it is still a part of the thermal infrared structure as an earthquake's precursor. Moreover, perhaps the border zone is a special location for earthquakes in the distant future. After all, there is a longer time interval of about 3 years and 5 months between the 2008 Wenchuan 8.0 earthquake and the thermal infrared images we used in this analysis. The phenomenon that earthquakes in the distant future are situated on the outer edge of an infrared border zone with lower elevated temperature is observed in other earthquake cases as well. For example, the thermal

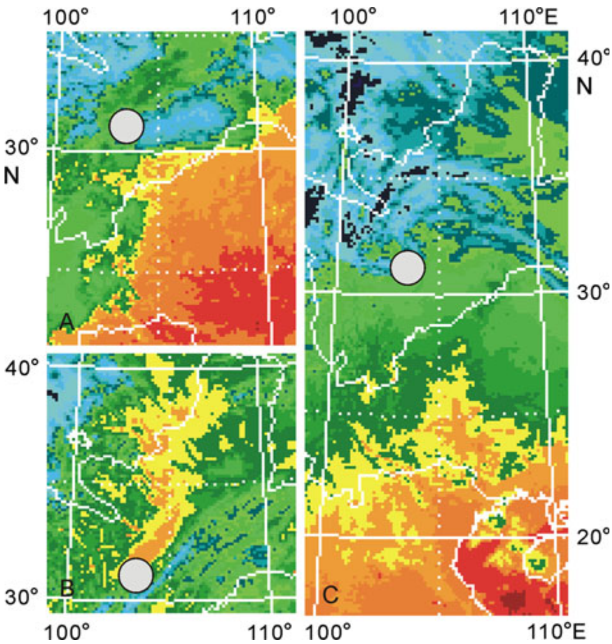

Fig. 8 The thermal infrared images indicating the 2008 Wenchuan earthquake in three modes 1,239–1,249 days in advance. **a** The thermal infrared image at 2004-12-10T8:00, **b** The thermal infrared image at 2004-12-17T7:00, **c** The thermal infrared image at 2004-12-20T14:00; the white circle is the epicenter of the 2008 Wenchuan M_S 8.0 Earthquake

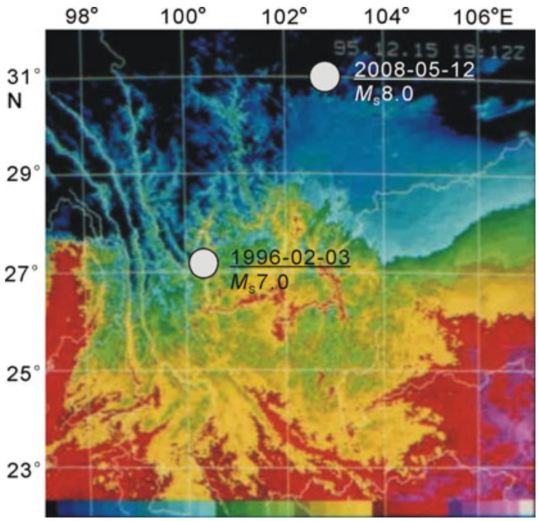

Fig. 9 The thermal infrared images indicating the 2008 Wenchuan earthquake 4,532 days in advance. The temperature in the color code *bar* steadily increases from the *left* (*dark blue*) to the *right* (*white*)

infrared image on December 15, 1995, clearly indicated the location of the unformed 2008 Wenchuan 8.0 earthquake that would occur about 12.5 years later. The Wenchuan epicenter was located just on the outer edge of such an infrared border zone and around a corner where earthquakes more easily occur (Fig. 9).

7 Discussion

Earthquakes have long gestation processes, so they should also have long-term precursors. The earthquake precursor anomalies studied in the past, though, usually appear a short time before the earthquake occurred. For example, a transient change of the electric field of the earth appears many hours before an earthquake (Varotsos and Alexopoulosa 1984). Georesistivities, telluric-currents or geomagnetism may show anomalies ranging from several days to several months prior to earthquakes (Myachkin et al. 1972; Ding et al. 2004; Qian et al. 2009). Some precursors appear even earlier, such as earth deformations, crustal strains, gravity anomalies that occur a few months to several years before earthquakes (Wang and Jiang 1997; Qian et al. 1997; Che and Fan 1999). The high gradient zone of a vertical deformation can be seen as far in advance as 15 years before an earthquake (Wang and Jiang 1997); Mescherikov (1968) concluded that accelerated crustal movements in seismic regions were observed 10–15 years before some earthquakes.

The elevated temperature fields before earthquakes are related to the crustal stress and the micro-fractures along the zone of increasing stress (Qiang et al. 1997b; Freund 2002). As the micro-cracks' continuously generate, infrared radiation is produced synchronously, too. The more micro-fractures that appears, the more obvious the infrared radiations and temperature change (Dong et al. 2001). Micro-fractures, however, mainly appear a short time before earthquakes occur. The micro-fracture waves accompanying the micro-fractures generally generate about 1–10 days before a main break (Zhao and Zhang 2009).

Although this mechanism is difficult to explain, we are confident as observed a definitive relationship between thermal infrared anomalies and strong earthquakes in the distant future. The calefactive anomaly area before an impending strong earthquake arrives at the epicenters of some distant future strong earthquakes but does not span them. We believe such a phenomenon is not a mere coincidence because there is not any exception among all strong earthquakes we analyzed.

Thermal infrared anomalies are usually located on one side of a future strong earthquake. This observation is difficult to explain if the regional crust serves in only the earthquake's preparation. If the regional crust only prepared a single earthquake, then the elevated temperature area would be distributed around the epicenter. Rock fracture experiments also concluded that shear fractures occurred along a thermal infrared high-temperature bond (Geng et al. 1998). In fact, on the contrary, if a thermal infrared area with higher elevated temperature has an unformed epicenter as its center, it is generally not a precursor of the earthquake. Only the elevated temperature area that is restricted by an unformed earthquake has a direct relationship with the event.

Moreover, many of calefactive fields prior to strong earthquakes are not in the shape of strips and are not consistent with the locations of the causative faults. They are able to rapidly appear, disappear, intensify, weaken, or deform. Their locations also constantly change and are able to move from one side of an epicenter to another side (Yao and Qiang 2010). This observation is not a characteristic of a single rock fracture process; physical deformations and micro-fractures in the crust prior to an earthquake cannot quickly transfer from one region to another. One rational explanation is that the static and dynamic structures of a thermal infrared anomaly area are determined not only by an impending earthquake, but also by all other earthquakes that will occur in the region within some period of time in future. The sites in different earthquake-pregnant stages in a region are the boundary constraint points of an anomaly calefactive area.

For example, near the time of the 2008 Yutian M_S 7.3 earthquake, the stress thermal ellipse transferred from the original NW–W side of the impending Wenchuan M_S 8.0

earthquake to its SE–E side (Yao and Qiang 2010). The SE–E side must have some earthquake-pregnant sites where it maybe did not appear obvious precursors then. As of 2010 September, many $M \geq 5$ earthquakes occurred on the edges of the main neonatal elevated temperature area especially around the SE–E end. These earthquakes surprisingly outlined the elevated temperature area appearing many months ago (Fig. 10). The thermal infrared ellipse on the west side of the Wenchuan epicenter had been steadily decreasing and nearly disappeared (Fig. 10); the neonatal elevated temperature area on the east side split into two offshoots, respectively, stretching east and east-southeast. The main part of the entire neonatal elevated temperature area was shaped like a rectangle, with edges and corners that were outlined by future earthquakes that would occur much later than the calefactive area's formation. In fact, the neonatal elevated temperature area was also forming an ellipse. In the front of the main ellipse area, near the SE–E end, there were fine arc structures that had been forming and developing. A M_S 7.2 earthquake occurred at the Ryukyu Islands (25.86°N, 128.65°E) along one of the fine arcs on February 26, 2010. The fine arcs intersected at the SE-E end of the ellipse long axis where some earthquakes have occurred in the recent past, such as a M_S 6.8 event at the Ryukyu Islands (28.75°N, 130.54°E) on October 30, 2009. The branch structure was two triangles (Fig. 10); the epicenter of the Wenchuan 8.0 earthquake is their shared vertex. The north triangle had a M_S 4.8 earthquake at the northwest vertex on January 24, 2010; around its east vertex, fourteen M_S 4.7–6.8 earthquakes occurred between August 28, 2009, and August 10, 2010. The south triangle six M_S 4.9–6.3 earthquakes occur on its southwest vertex between July 9, 2009, and August 29, 2010, and forty-nine M_S 4.4–6.9 earthquakes occur around its east-southeast vertex between June 28, 2009, and September 27, 2010. Figure 10 only displays a few representative earthquakes to demonstrate the relationship. The time interval between a M_S 5.2 earthquake at the SE-E vertex and the observation of the elevated temperature area is 2 years, 5 months, and 21 days. We predict that more earthquakes will occur near the locations of the calefactive ellipse or two triangles.

Thermal infrared anomalies are able to indicate an estimated location of the epicenter of earthquakes at different times in the future. Through dynamically monitoring and analyzing these possible earthquake-pregnant sites that have been preliminarily identified from current infrared images and others, we can gradually discover and interpret the predicting information of the seismic locations, magnitudes, and occurrence times. Because some earthquake-pregnant sites or precursor growing sites have a long time between the formation of a nearby calefactive ellipses and the earthquakes' occurrence, much of the information from monitoring can contribute to correct recognition and analysis of the

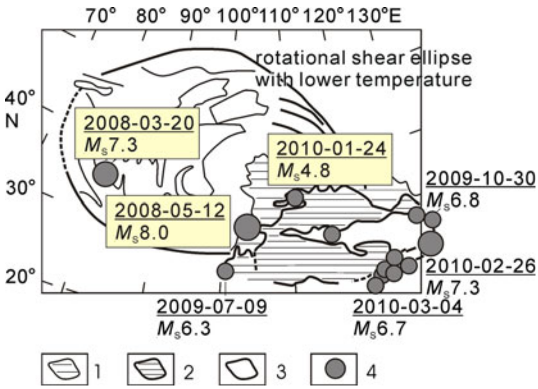

Fig. 10 The stress thermal rotational shear ellipse on April 6, 2008, its evolution and structural relationship with the Wenchuan 8.0 and later earthquakes. *1* general elevated temperature area; *2* higher elevated temperature area; *3* rotational shear ellipse; *4* epicenters

earthquake precursor. Moreover, the smaller tracing range enables researchers to focus their attention on every earthquake precursor characteristics and monitor their changes.

8 Conclusion

(1) The thermal infrared anomaly areas that appear dozens of days before a strong earthquake are a product of the earthquake preparation and are created by the common stress and deformation field of future strong earthquakes in different development stages at different locations in the region.
(2) Thermal infrared anomaly images contain precursor information not only from an impending strong earthquake, but also from earthquakes that will occur in the more distant future. We observed the precursor of two large earthquakes in the same thermal infrared image; one earthquake would occur more than decade later and the other earthquake only dozens of days after the appearance of the thermal infrared anomaly.
(3) Future earthquakes with different maturity are generally located at the edges, corners, and ends of an isolated elevated temperature area; they likely played a role in restricting the elevated temperature structure.
(4) If an earthquake occurs in the rather distant future, its epicenter may be located at the outer edge of the marginal zone with lower elevated temperature of an infrared anomaly area.
(5) An earthquake that will occur within dozens of days may have a stress thermal field with special static and dynamic structural features, which are reflected in the infrared images. Information predicting an imminent strong earthquake can be extracted from features observed in an infrared image, with some contribution from future earthquakes.
(6) The significance of our work is to provide a new direction for the prediction of strong earthquakes in a region in the following few years. Through dynamically monitoring the possible earthquake sites that were preliminarily identified through infrared images, we can observe indicative signs of the future earthquakes' locations, occurrence times and magnitudes, and enhance the reliability of earthquake prediction.

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