# *Reviewer 1:*

**Point 1: Page 1 Line 25 in abstract – PPV, FDR, TPR and FNR are best added their full names.**

**Response 1:** The full names of PPV, FDR, TPR and FNR will be added.

**Change 1:** P1L24-This is the first time that the ability to predict earthquakes has been evaluated based on the positive predictive value (PPV), false discovery rate (FDR), true-positive rate (TPR) and false-negative rate (FNR).

**Point 2: Line 35-The "TIR" might be repeated with the "outgoing longwave satellite"**

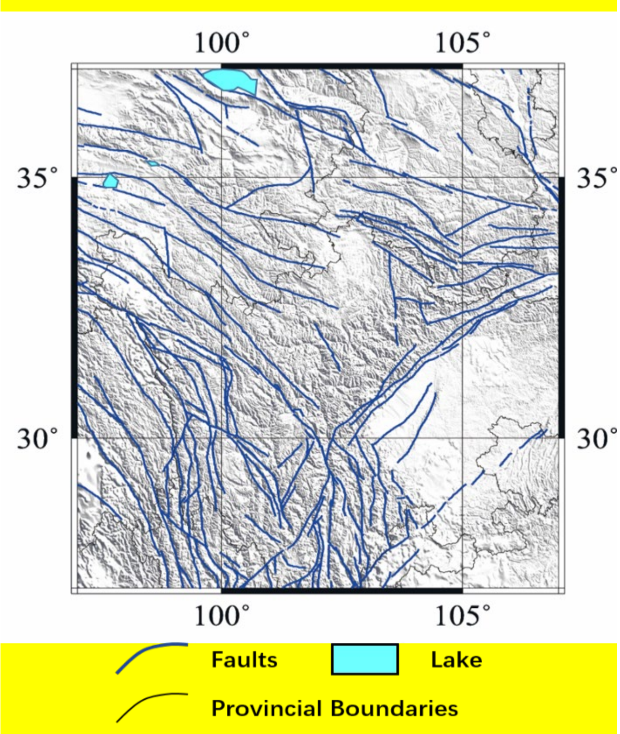
**Response 2:** "outgoing longwave" will be deleted.

**Change 2:** P2L7-Several studies have detected space-time anomalies in TIR satellite imagery,

**Point 3: Page 3 * Add the names of the main faults in Fig.1. An overall map of China and Sichuan could also be considered.**

**Response 3:** Because there are abundant faults in the study area, the figure will be in a mass and be confusing when the names of faults are added. Moreover, the names of faults are not necessary in our study.

**Change 3:**




**Point 4: There are three spatial resolutions -250m, 500m, 1000m of the MODIS data, which one was used in your paper? Line 32- How did you get this conclusion-"But earthquakes caused by ground subsidence, human factors and so on will not cause TIR anomalies"?**

**Response 4:** The spatial resolution of our data is 5600m. And the line 32 I have deleted it in the manuscript.

**Change 4:** P6L8-The LST data were retrieved at 5,600 m using the generalized split-window algorithm. In the day/night algorithm, daytime and nighttime LSTs are retrieved from pairs of day and night MODIS observations in seven TIR bands.

**Point 5: Page 6 * Maybe I did not understand the calculation process, but the right sides of the formula (11) and (12) are the same as the right sides of the formula (5) and (6). What's the purpose for repeating the same expression?**

**Response 5:** yes, they are the same. But, they have different meaning. In (5) and (6) the left of these formulas are the final calculated values used for finding the ALICE. And the (11) and (12) is an iterative process, the values will be changed with the iterative process, in other words, the A in formula (11) and (12) are different. But the formula and method are little bit confusing and hard to understand, so I changed the organization of method.

**Change 5:** P8L25

$$A(r,T) = A_1(r,t) * A_2(r,t) \quad (9)$$

$$V_{REF}(r,\tau,T) \equiv \frac{\sum_{\forall t \in T}[\Delta V(r,t) \cdot A(r,t)]}{\sum_{\forall t \in T} A(r,t)} \quad (10)$$

$$\sigma_{\Delta V}^2(r,\tau,T) \equiv \frac{\sum[\Delta V(r,t) \cdot A(r,t) - \mu_{\Delta V}(r,\tau)]^2}{\sum_{\forall t \in T} A(r,t)} \quad (11)$$

**Point 6: "In ELEFTHERIOU's study" should add the reference. Line 29- "one of 5) and 5)" is "one of 5) and 6)"?**

**Response 6:** the reference will be added. And the 5) and 5) will be corrected to 5) and 6)

**Change 6:** P9L18-The RETIRA $\otimes_{\Delta V}(r,\tau,T)$ > 2. In Eleftheriou's study, the threshold was set at 4 (Eleftheriou et al., 2016) ;

P10L5-but do not satisfy at least either 5) or 6),

**Point 7: Page 9 Line 3- Period A is from 2002.09 to 2007.12, is Period B also from 2002.09 to 2007.12? Line 9- I cannot find the brown rectangle.**

**Response 7:** Period B is 2008.01 to 2018.03, and in Page 9 Line 3, it should be "Period A" not "Period B", I will correct it. And in the fig, it is an orange rectangle, I will correct it.

**Change 7:** P12L3-Further evidence is presented in Table 1, where earthquakes of $M \geq 5.0$ that occurred during period A (from 2002.09 to 2007.12) are detailed.

P13L2-The orange rectangle represents the study area ($27^{\circ}N$ to $37^{\circ}N$, $97^{\circ}E$ to $107^{\circ}E$).

**Point 8: Page 12 Line 31- "Thermal anomalies are more likely to be extracted and TIR anomalies are more likely to correspond to earthquakes". Do you have a standard of the thermal anomaly? Just as the size and the amplitude of the anomaly.**

**Response 8:** the standard identification I have shown in chapter 3.3, these rules are quoted form "Long-Term RST analysis of anomalous TIR sequences in relation with earthquakes occurred in Greece in the period 2004-2013”.

**Change 8:** no changes.

**Point 9: There are 61 anomalies with period C, but 60 anomalies without period C because of the more cloud in period C in study area, however, little difference of clouds in Fig.7 and Fig.8 can be detected. Should you make the difference more obvious?**

**Response 9:** Sorry for my unclear expression. There is little difference between in the distribution of clouds, but what I want to show is the relationship between the earthquakes distribution and clouds distribution. In period C, many earthquakes happened in the position that always blocked by clouds.

**Change 9:** no changes.

**Point 10: Page 14 * In Fig.9, the percentage of PPV and TPR with magnitude _7.4 is 0, is there no TIR anomalies for these earthquakes? I have read some papers that there were TIR anomalies when Wenchuan 8.0 earthquake occurred. * In 4.3 The evaluation of earthquake prediction ability for RST and 5 Discussion, the description is complicated, can you simplified them slightly?**

**Response 10:** Yes I have also read some papers that indicate the TIR anomalies before Wenchuan earthquakes, but may use different data, different method and different identification rules for TIR anomalies. In this paper, I do not mean that there is no TIR anomalies before Wenchuan Earthquake, and I cannot give the results that there is or there is not a TIR anomaly corresponding to some earthquake. This article is only to evaluate and study whether the results extracted by RST with use of MODIS LST data are effective.

**Change 10:** no changes.

**Point 11: Page 16 Line 37- “the prediction ability of RST in Sichuan area is limited”. I think this sentence is too absolute. Many earthquakes occurred in Longmenshan fault in Sichuan area had been studied by scientists, and got some anomalies before or after**

**the earthquake. For example, Singh (2010) had found precursory signals using satellite and ground data associated with the Wenchuan earthquake of 12 May 2008. Zhang Yuan-sheng (2010) also detected the TBB anomalies before Wenchuan earthquake; and Zhang Xuan (2013) had analyzed the thermal infrared anomaly before the Lushan 7.0 earthquake. So, maybe the data was not suitable for this region, not simply because of the cloud. This should be descripted in the paper.**

**Response 11:** The expression in my paper is unclear. I did not negate the validity of Thermal Infrared for earthquake prediction studies, nor did I negate the validity of this method. I just want to say things based on the results, the prediction ability of RST method and MODIS data in Sichuan area is limited, it may be caused by weather, data, identification of TIR anomalies or others.

**Change 11:** P23L10-As such, the prediction potential of RST using MODIS LST data in the Sichuan area is limited. However, it doesn't indicate that the RST is not effective for earthquake prediction, on the contrary, many other cases prove that this method is very effective for extracting TIR anomalies. The low PPV and TPR may be caused by the limitation of RST, nature of MODIS LST data, special topographic and weather background of study area, or something else.

# *Reviewer 2:*

**Point 1: The paper needs to be rewritten in better English as it is incomprehensible in many cases, distracting from the authors' primary contribution. I suggest the authors substantially revise, through elimination of ancillary matters (reduce the extend of the text and try to eliminate any repetitions).**

**Response 1:** I have invited a native-speaker to help me polish the English and almost the whole paper have been modified.

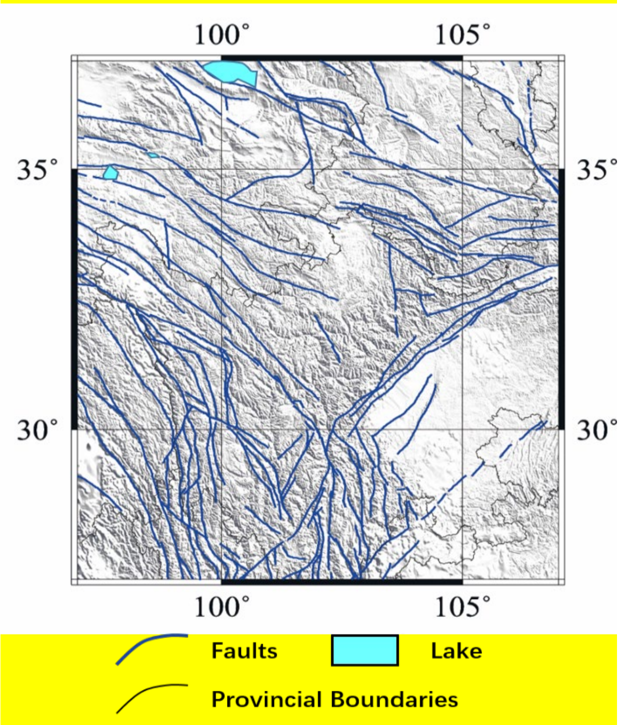
**Change 1:** English Polishing.

**Point 2: Fig.1: The faults cannot be well discriminated. You should change the color or the width of the symbol.**

**Response 2:** I will make Fig.1 more clearly.

**Change 2:**

P5 Fig.1




**Point 3: Page 3, last line: What do you mean with the word "scope"?**

**Response 3:** "scope" is the "range", I will modify the expression.

**Change 3:** P5L6- As shown in Fig.1, the range of the study area is $27^{\circ}N$ to $37^{\circ}N$, $97^{\circ}E$ to $107^{\circ}E$.

**Point 4: first line: The coordinates have been given in the previous page.**

**Response 4:** I will delete the repeated information.

**Change 4:** P4L20- In this paper, RST is applied to a mountainous area in China.

**Point 5: Page 3: You repeat the same information about the study area.**

**Response 5:** I will simplify the information about the study area.

**Change 5:** P5L4-L15

The southeastern Gansu province and its neighboring regions were selected as the study area, to assess the correlation between TIR anomalies and earthquakes from September 2002 to March 2018. As shown in Fig.1, the range of the study area is $27^{\circ}N\ to\ 37^{\circ}N$, $97^{\circ}E\ to\ 107^{\circ}E$. The study region is located at the intersection of Gansu, Qinghai, and Sichuan provinces; it also includes the intersection of the northern section of the north-south seismic belt and the Kuma seismic belt. Structures in this area are complex and strong earthquakes are frequent (Yang, Zhang et al., 2002). The area is on the eastern edge of the Tibetan Plateau, belonging to the upper part of the rhombic block in the southeast Gansu province. The Xian River fault, the Longmen Shan Fault, and the Anning River fault intersect here, and the structure is Y-shaped. This type of geomorphology is widely encountered in plate tectonics, and the Longmen Shan fault in the north-northeast direction becomes a steep slope in the southeast Sichuan Basin and an erosion plateau northwest of the study area.

**Point 6: Page 4, lines 30-35: I think it would be more helpful to give a distance radius.**

**Response 6:** It is a good advice, however in this paper the latitude and longitude will make it more easy to understand and memorize.

**Change 6:** no changes.

**Point 7: Page 4, line 42: Please give the year of Eleftheriou et al publication.**

**Response 7:** I will correct it.

**Change 7:** P6L1- The RST approach is based on multi-temporal analyses of historical satellite observational datasets acquired under similar observational conditions (Eleftheriou et al., 2016).

**Point 8: Page 6, lines 8-10: "And because the blizzard, forest fire and the large area of clouds usually cause the abnormal increase or decrease in LST with a magnitude that far bigger than the change caused by earthquakes."**

**Response 8:** This sentence is a repeated information, and the meaning of this sentence has been expressed separately in the preceding paper.

**Change 8:** This sentence has been deleted.

**Point 9: In your methodology section it is not clear whether you use RETIRA index or not. In the abstract you write: "In this paper, a refined RST data analysis and Robust Estimator of TIR Anomalies (RETIRA) index were used to extract the TIR anomalies from 2002 to 2018 in Sichuan 20 area with use of Moderate-resolution Imaging Spectro-radiometer (MODIS) LandSurface Temperature (LST)," but I cannot find any reference to RETIRA index in the main text.**

**Response 9:** I will add the reference of RETIRA.

**Change 9:** P9L3-The RETIRA (Robust Estimator of TIR Anomalies, Filizzola, 2004) must be computed,

**Point 10: I think that RST methodology must be re-written in order to become clear where the already known RST RETIRA methodology stops and how your refinements have been implemented.**

**Response 10:** Sorry for my inaccurate expression, I have not done a refinement for RST, and the RST methodology have been rewritten.

**Change 10:** P6 Chapter3.2

**Point 11: Page 6, lines 37-38: The sentence is : : :.strange???**

**Response 11:** I will correct it.

**Change 11:** P9L3-The RETIRA (Robust Estimator of TIR Anomalies, Filizzola, 2004) must be computed, and the bigger the absolute value is, the more evident the anomaly is. $\otimes_{\Delta V}(r,\tau,T)$ is the RETIRA of location r at time $\tau$, which belongs to the time series T.

**Point 12: Eleftheriou et al., 2016 applied the RST RETIRA index and not the ALICE index. As far as I know, these are two different indexes. In pages 6 and 7 you mention ALICE.**

**Response 12:** I have made a mistake, what I use in this paper is RETIRA and there is no ALICE, I will correct it.

**Change 12:** All the ALICE have been replaced by RETIRA

**Point 13: Page 7: The conditions need to be refined using better syntax.**

**Response 13:** The conditions have been modified.

**Change 13:**

P9L18

1) The RETIRA $\otimes_{\Delta V}(r,\tau,T)$ > 2. In Eleftheriou's study, the threshold was set at 4 (Eleftheriou et al., 2016) ; however, from a statistical perspective, when the value is greater than two times the standard deviation, it already falls within the abnormal category. In this study, therefore, the threshold is set at 2.
2) The $V(r,t)$ is not blocked by clouds or affected by other factors.
3) Spatial persistence: The TIR anomalies cluster together and are not isolated, being part of a group covering at least 150 $km^2$ within an area of $1° * 1°$ (400 pixels in the images).
4) Temporal persistence: At least one more TIR anomaly appears within 7 days after the first TIR anomaly.
5) The TIR anomalies appear 30 days before or 15 days after the $eq(r,t)$ (Eleftheriou et al., 2016) .
6) The shortest distance from a given point in the TIR anomalies group to the epicenter of $eq(r,t)$ is less than $R_D = 10^{0.43M}$.

**Point 14: Page 7, line 29: Please correct the sentence: one of 5) and 5) mean that there are TIR anomalies but no corresponding earthquake.**

**Response 14:** The sentence will be corrected.

**Change 14:** P10L6- but do not satisfy at least either 5) or 6),

**Point 15: Page 7, line 30: What do you mean? Please explain.**

**Response 15:** The sentence has been modified.

**Change 15:** P10L6- There are also cases wherein no TIR anomalies occur.

**Point 16: Page 8, first paragraph: Please refine your English or exclude this paragraph. In my opinion, Fig. 2 is enough. Fig. 3: Its caption needs refinement. I propose to move this fig and the first two paragraphs of page 10 in the STUDY AREA Section.**

**Response 16:** I will refine this paragraph, and thanks for your advice, but I think it is necessary to summarize the Fig.2. The caption of Fig.3 will be refined, and thanks for your advice, but the purpose of the Fig.3 is to show that many earthquakes are gathering in certain regions, and the Study area section focused on the distribution of faults and the geologic background.

**Change 16:**

P10L19- First, the temporal distribution shows that the seismicity from 2002 to 2018 was most active in 2008, and that it increased in frequency and violence from that time. The bottom of Fig. 2 indicates that there were 3,615 earthquakes in the study area($3.5 \leq M \leq 4$, 2,262; $4 \leq M \leq 5$, 1,124; $5 \leq M \leq 6$, 198; $6 \leq M \leq 7$, 26; and $7 \leq M \leq 8$, 5. Therefore, the study area is characterized by severe seismic activity. As may be seen from the upper part of Fig. 2, the average earthquake frequency during period A (from 2002.09 to 2007.12) was around 78. However, the total number of earthquakes in 2008 increased to 981 including the May 12 2008 Ms 8.0 Wenchuan Earthquake, the most serious earthquake in China in recent years. Although the frequency decreased substantially after 2008 (the average frequency during this period was 243), it remained much higher than it had been during period A. The temporal distribution indicates that seismic activity prior to 2008 had been relatively weak, but in 2008, the seismic activity was extremely intense and reached its peak. After 2008, seismicity in this area continued to maintain this intensity.

Fig. 2 The temporal distribution from 2002.09 to 2018.03 of earthquakes with $\mathrm{M} \geq 3.5$ in the study area, and the distribution of seismic frequency with earthquake magnitude.

Fig. 3 The spatial distribution of earthquakes in the study area. The orange rectangle represents the study area ($27^{\circ}N\ to\ 37^{\circ}N$, $97^{\circ}E\ to\ 107^{\circ}E$). Earthquakes beyond the parameters of the study area are shown because earthquakes close to the study area may also cause TIR anomalies within the study area.

**Point 17: Fig. 4: Please, rewrite the caption of the Figure.**

**Response 17:** The caption will be rewritten.

**Change 17:**

Fig .4 Two examples of the correlation between TIR anomalies and earthquakes: on the left is the TIR anomaly recorded on 2006.12.29 that corresponded to two earthquakes, and on the right is the TIR anomaly recorded on 2010.10.22 that did not correspond to earthquakes.

**Point 18: Page 13, line 12: " : : :.is far from enough". I don't understand. Is it good? Is it Very good? or the opposite?**

**Response 18:** It is not good, and I will rewrite this sentence.

**Change 18:** P18L8- With the aim of evaluating the earthquake prediction potential of RST using MODIS LST data for the Sichuan area, the true-positive rate (TPR) of correspondence between TIR anomalies and earthquakes with M $\geq 4.0$ alone is insufficient. Therefore, four types of data are incorporated, with four types of ratio calculated as follows:

**Point 19: Section 4.3: (The evaluation of earthquake prediction ability for RST). It is very complicated. I think that you must make this section more attractive and easy to be read.**

**Response 19:** I will refine this section.

**Change 19:** Chapter 4.3.

**Point 20: Page 19: "Conclusions" and not "Conclusion".**

**Response 20:** It will be corrected.

**Change 20:** P26L9- Conclusions

**Point 21: And of course one simple question: Many researchers and among them Eleftheriou et al., use to call "thermal anomaly" the pixels with 4__Îd'(x,y) > 4. The fact that you selected a threshold equal to 2 instead of 4, makes the results comparable?**

**Response 21:** The criterion for determining TIR anomalies is relatively subjective, and there is no universal standard to judge whether there is TIR anomalies. For instance, $R_I$ values have been classified as 'anomalous' pixels for different threshold: >2.0, >2.5, >3.0 and >3.5(Tramutoli, Cuomo et al. 2005) ; $\geq 2.0$ and $\geq 3.0$ (Genzano, Aliano et al. 2007); $\geq 2.0$, $\geq 2.5$ and $\geq 3.0$ (Pergola, Aliano et al. 2010). In ELEFTHERIOU's study, the threshold was set to 4, however, from the point of view of mathematical statistics, when the value is greater than two times the standard deviation, it has already belonged to the abnormal category, so in this study, the threshold is set to 2.

Genzano, N., C. Aliano, C. Filizzola, N. Pergola and V. J. T. Tramutoli (2007). "A robust satellite technique for monitoring seismically active areas: The case of Bhuj–Gujarat earthquake."  431(1): 197-210.

Pergola, N., C. Aliano, I. Coviello and C. Filizzola (2010). "Using RST approach and EOS-MODIS radiances for monitoring seismically active regions: a study on the 6 April 2009 Abruzzo earthquake." Natural Hazards & Earth System Sciences 10(2): 239-249.

Tramutoli, V., V. Cuomo, C. Filizzola, N. Pergola and C. J. R. S. o. E. Pietrapertosa (2005). "Assessing the potential of thermal infrared satellite surveys for monitoring seismically active areas: The case of Kocaell (Izmit) earthquake, August 17, 1999."  96(3): 409-426.

**Change 21:** No changes.

# *Reviewer 3:*

Sincerely thanks for your suggestions and questions.
I do have learned a lot from your comments.

**Main comments 1,2: Whole paper needs to be rewritten in a better English. In particular some sections, like the paragraph 3.2 (RST methodology) or paragraph 5 (Discussion), are not clear and only after various readings the paper can be understood. The major part of citations should be revised, both in the form (sometime given name is used instead of surname like at line 6 of page 2) and in content (some wrong citations have been used or some important citations miss, as for RETIRA index).**

**Response for main comments 1,2:** The major part of citations should be revised, both in the form (sometime given name is used instead of surname like at line 6 of page 2) and in content (some wrong citations have been used or some important citations miss, as for RETIRA index).

I will rewrite my paper in English and invite a native speaker to help me polish it. And I will check my paper and revise the citations.

Changes for main comments 1,2: I have asked a professional English editing service to polish our manuscript. The citations have been revised .

**Main comments 3: To identify thermal anomalies possibly related to impending earthquakes, you used LST (Land Surface Temperature) products retrieved by the radiance collected by MODIS sensor on board of the polar satellites EOS/AQUA and EOS/TERRA.**
**Taking in mind that Authors who proposed the RST approach shown the advantages offered by the use of sensors onboard of geostationary platforms instead of sensor onboard of polar satellite packages (see the paper Filizzola, C., N. Pergola, C. Pietrapertosa, and V. Tramutoli (2004), Robust satellite techniques for seismically active areas monitoring: a sensitivity analysis on September 7, 1999 Athens's earthquake, Phys. Chem. Earth, 29(4–9), 517–527, doi:10.1016/j.pce.2003.11.019), since 2004 the major part of RST applications to thermal monitoring of seismogenic areas have been carried out using TIR satellite records acquired by sensors onboard of geostationary satellites (as also you have reported in the your paper). Now, my question is why you prefer to use EOS/MODIS data instead that TIR records collected by sensor on geostationary platforms (e.g. the Japanese MTSAT satellite)?**
**Moreover, LST (Land Surface Temperature) products have been take in account. LST products are very useful to reduce variability of atmospheric water vapor, but in the computation of LST several approximations are necessary (e.g. emissivity, total water vapour content, ecc.), which should produce errors (also of 4-5 K degree) in the satellite LST estimations. Taking in mind, that thermal anomalies possibly related to seismic activity are of low intensity, wrong LST estimation could mask and/or generate false anomalies. Have you an idea of the impact of this errors on the your analysis?**

**Response for main comments 3:** Firstly, we can compare the MODIS with other kinds of thermal infrared satellite receiving instruments (GMS-5 and AVHRR), in the following table some characteristics have been shown.

Table 1 The characteristics of three kinds of satellite thermal infrared data receiving instruments.

| Parameter | GMS-5 | AVHRR | MODIS |
|---|---|---|---|
| Spatial resolution/km | 5 | 1 | 1 |
| Bit | 8 | 10 | 12 |

| | | | |
|---|---|---|---|
| Bands | 4 | 5 | 36 |
| Thermal Infrared Bands | 2 | 3 | 6 |
| Band Width | | 100 | 20 |
| Scan method | Line-scanning | Line-scanning | CCD-scanning |
| SNR | | 9~20 | >=500 |

From the table, it can be concluded that MODIS outperforms other sensors in terms of spatial resolution, data accuracy and Thermal infrared bands. Moreover, it can provide global daily nighttime data which is also suitable for TIR anomalies extraction.

Secondly, some researchers have published papers about the TIR anomalies before earthquakes with use of MODIS LST data or other LST data. D. Ouzounov found evidence for a thermal anomaly LST pattern that is apparently related to pre-seismic activity with use of MODIS LST data(Ouzounov and Freund 2004). And that is a strong evidence to prove that the MODIS LST is also can be used for TIR anomalies study. Moreover, other researchers have also conducted the studies with t MODIS LST data(Choudhury 2005, Panda, Choudhury et al. 2007, Pergola, Aliano et al. 2010). So, I think that MODIS LST data is also suitable for this study.

In this paper, the structure is intact, and to compare different data extraction TIR anomalies is not the purpose, which can be conducted in the coming research.

**Main comments 4: Earthquake catalogue (China Seismic Information; http://www.csi.ac.cn/) used to verify possible correlation with TIR anomalies is inaccessible. Please provide a correct URL. Anyway, consulting a different seismic catalogue, i.e. UGSG catalogue (https://earthquake.usgs.gov/earthquakes/search/), using a similar criteria (M≥3.5; Depth >0; region from 25°N to 40°N and from 95°E to 110°E; time since August 1, 2002 up to April 15, 2018) I found 2369 earthquakes, respect to 3615 seismic events reported in the your paper. A comparable numbers of seismic events, i.e. 3828, is obtained when the USGS catalogue is**

**consulted starting by 1965. Have you use seismic data from 2002 or from 1965? In the first case (i.e. 2002) how you explain this difference (2369 vs 3615)? In the second case (i.e. 1965), because MODIS data are available since 2002, how is possible found some relations among TIR anomalies and earthquakes (before 2002)? In this last case, please provide a correct analysis.**

**Response for main comments 4:** http://www.csi.ac.cn is the Chinese Official website to publish the Earthquake information. And I am sorry for that I cannot get on this website either and I do not know why. And I refer to another website China Earthquake Datacenter (http://data.earthquake.cn), and the earthquake catalog is the same as before. I can attach my seismic catalog in the attachment. The catalog obtained from USGS is different from China, especially for the earthquakes with M<5.0. This is because the nearer to the epicenter, the more abundant and accurate information the stations can get, so the earthquake catalog provided by Chinese officials is more suitable for this study than USGS.

**Main comments 5: About the performed correlation analysis among the appearances of TIR anomalies and earthquake occurrences, you should be in mind that working in the optical band, a wide presence of meteorological clouds, as well as the lack of satellite data, do not allow to give continuity to the observations, which is necessary to identify possible TIR anomalies or to fully appreciate a possible space–time persistence of previously occurred TIR anomalies, producing in this way a possible overestimation of missed events. Please, consider this suggestion and provide a more convincing analysis. As consequence also your conclusions should be reconsidered.**

**Response for main comments 5:** A wide presence of meteorological clouds, lack of satellite data surely will influence the TPR or FNR. However, I think we should not to remove the earthquakes influenced by clouds or lack of data. I think this analysis is a simulated forecast, the prediction ability is to evaluate how many earthquakes can or cannot be predicted with this method and data. Surely, earthquakes are unable to be predicted when there is large wide of clouds, but in other words, this is also a great limitation and defect of the RST method or Thermal Infrared data, and how to solve these problems is the key to enhance the ability of earthquake prediction. Some earthquakes cannot be predicted by this method is the truth, we should not to avoid or remove them, on the contrary, the earthquakes correspond to no TIR anomalies should be counted in missed rate. But the high missing rate does not mean that the RST or MODIS data are not valid for earthquake prediction study, it reflects some limitations of this method and data in other aspects.

**Point 1: Page 1 - Lines 18-19; In the abstract, you announced that a refined RST data analysis and Robust Estimator of TIR Anomalies (RETIRA) index were used, but in the text I have not read any new improvements to the RST methodology, if not those reported in Eleftheriou et al. (2016). Otherwise please explain better the refinements made to the RST technique. Moreover, add the reference of RETIRA index.**

**Response 1:** sorry for that, there is no refinement for the RST, but the statistical method, I add PPV, FDR and FNR to evaluate the earthquakes prediction ability. And I will add reference.

**Change 1:**

P9L3-The RETIRA (Robust Estimator of TIR Anomalies, Filizzola, 2004) must be computed

**Point 2: P1 - L25; Please provide the complete name of PPV, FDR, TPR and FNR.**

**Response 2:** I will add the full name of PPV, FDR, TPR and FNR.

**Change 2:** P1L24- This is the first time that the ability to predict earthquakes has been evaluated based on the positive predictive value (PPV), false discovery rate (FDR), true-positive rate (TPR) and false-negative rate (FNR).

**Point 3: P1 - L26; The sentence "the prediction ability of RST in Sichuan area is limited" is**

**too strong!**

**Response 3:** I will change the sentence. “The prediction ability of RST with use of MODIS in Sichuan area is limited.”

**Change 3:** P1L26- The statistical results indicate that the prediction potential of RST with use of MODIS is limited with regard to the Sichuan region.

**Point 4: P4 - L34-36; I not understand the sense of this sentence "Moreover, Tronin indicated that the anomaly was sensitive to crustal 1000kmearthquakes with a magnitude more than 4.7 and for distance of up to 1000km" in this position.**

**Response 4:** That is the reason why I choose earthquakes with M>=3.5, because those earthquakes have covered the earthquakes with M>=4.7.

**Change 4:** No changes.

**Point 5: P5 - L14-24; Cloudy pixel, as well as pixels declared as edge clouds, should be exclude before the computation of $\Delta V(r,t)$ otherwise effects due to cloudiness are not removed and false TIR anomalies could be generate.**

**Response 5:** yes, I have eliminated the cloudy pixels and the edge clouds. And this have also been presented in this paper.

**Change 5:** No changes.

**Point 6: P5 - L25-31; How you identify the extreme weather events (e.g. blizzard)?**

**Response 6:** two ways. 1. The kσ-clipping processing can eliminate some influence of extreme weather. 2. By using satellite cloud map, wind direction map and meteorological knowledge, the meteorological data in this area are analyzed. For example, there is wide blizzard in this area from Jan. 2008 to Mar. 2008. And these works have been completed in the pre-processing and construction of background field, so this is a repeated information, I will delete it.

**Change 6:** This sentence has been deleted.

**Point 7: P6 - L9-13; The reference Saraf et al. (2009) is correct? I not found no mention about effects of cloudy pixels on ΔV in this publication.**

**Response 7:** Accepted, I have given the wrong reference, I will correct it.

**Change 7:** P7L28- As demonstrated by Aliano et al. and Genzano et al., the spatial distribution of clouds over a thermal heterogeneous scene can significantly change the value of $\Delta V$ in the cloud-free pixels(Aliano et al., 2008; Genzano et al., 2009).

**Point 8: P6 - L13-20; Cold spatial average effect as reported in Aliano et al. (2009), Genzano et al. (2010) and Eleftheriou et al. (2016) could affect the whole TIR scene. Rightly you have take in account this effect, but in opposite way of Genzano at al. (2015) or Eleftheriou et al. (2016) you work at pixel level instead of whole scene level. In this way, the above mentioned effect could be not removed in the computation of reference fields.**

**Response 8:** Maybe I have expressed it right, in this paper, when the cloudy fraction of the land portion of the scene is >80%, all the pixels in this scene will be removed from the calculation of background field.

**Change 8:** No changes.

**Point 9: P6 - L32-35; The sentence "This process should be paid more attention, because in the past papers, this process is always ignored." is wrong. In all applications of RST approach, kσ-clipping method (always applied) guarantee to remove outlier (i.e. extreme events) from the computation of reference fields. Please, consider to rewrite better the sentence.**

**Response 9:** I will delete this sentence.

**Change 9:** This sentence has been deleted.

**Point 10: P6-P7 (Change detection step); Although you have announced the computation of ALICE index, the index reported in the equation 13 should be the RETIRA index (correct equation can be found in Filizzola et al. 2004; Tramutoli et al. 2005). Please, correct it.**

**Response 10:** I have made a mistake, I used the RETIRA in this paper not the ALICE.

**Change 10:** All the ALICE have been replaced by RETIRA.

**Point 11: P7 L9-23; The criteria used to identify TIR anomalies are the same introduced for the first time in Genzano et al. (2015) and in Eleftheriou et al. (2016) in order to indentify Significant Sequences of TIR Anomalies (SSTAs). Please consider to call it in similar way, mentioning these two publications. Moreover, starting from a mathematical point of view you have consider to set a threshold K equal 2, if you have a normal distribution (Gaussian) a 2 times the standard deviation could be sufficient to identify anomalies. In addition, RETIRA index (as well as ALICE index) give the possibility to evaluate in term of SIgnal-Noise ratio (S/N) the intensity of anomalies (see Tramutoli at al. 2001 or Tramutoli et al. 2005 for more details). Please, take in mind this suggestions when choose threshold k.**

**Response 11:** Thanks for your advice, however, I think the expressions in my paper are also OK, and they are also clear - TIR anomalies, TIR anomalies correspond to no earthquakes.

**Change 11:** No changes.

**Point 12: P9 L3; Period B is the same of period A (i.e. from2002.09 and 2007.12)?**

**Response 12:** Period B is from 2008.01 to 2018.03, I will correct it.

**Change 12:**

P12L2-Further evidence is presented in Table 1, where earthquakes of $M \geq 5.0$ that occurred during period A (from 2002.09 to 2007.12) are detailed. There were 229 earthquakes of $M \geq 5.0$, while the total number during period A was 24, which accounted for 10.48% overall; the duration of period A accounted for 33.87% of the total timeframe (i.e., period A + period B). Moreover, there were no earthquakes of $M \geq 6.5$ during period A, but there were 14 earthquakes of $M \geq 6.5$ during period B (from 2008.01 to 2018.03). All of this evidence indicates that seismic activity during period B was significantly more violent and frequent.

**Point 13: P10 Fig.4; Figure shown are not a good example of TIR anomalies possibly associated to earthquakes. In the example on the right part (TIR map of 2010/10/22) earthquakes seems not satisfy the rules announced in chapter 3.3. Moreover, to show the whole sequence of TIR anomalies, not only one day with TIR anomalies, could help the reader to better understand the concept of Significant Sequence of TIR Anomalies.**

**Response 13:** I am sorry that I have made a mistake, right of the Fig.4 is the instance that TIR anomaly do not correspond to earthquakes.

**Change 13:**

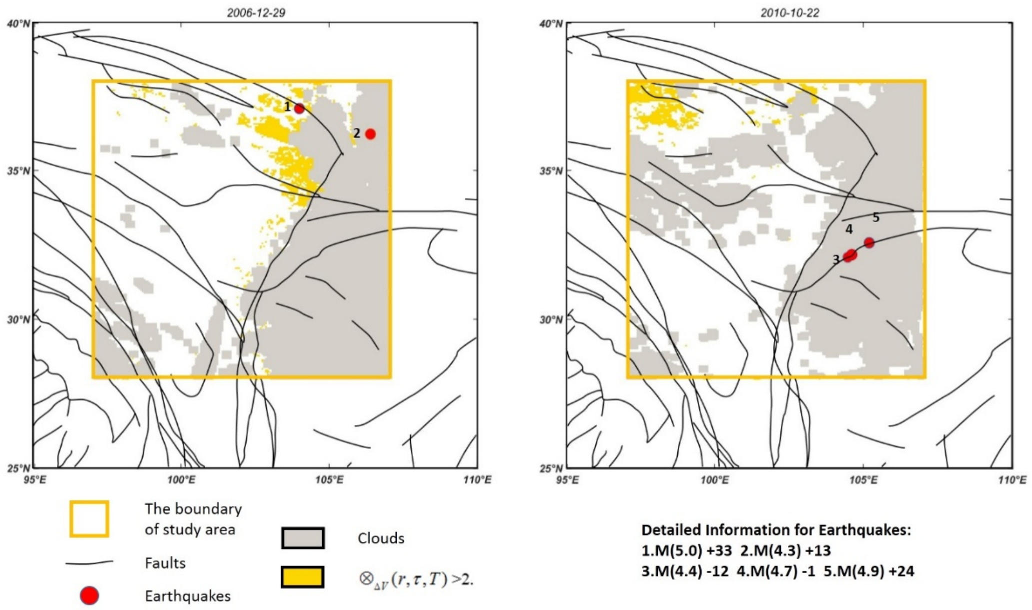



Fig .4 Two examples of the correlation between TIR anomalies and earthquakes: on the left is the TIR anomaly recorded on 2006.12.29 that corresponded to two earthquakes, and on the right is the TIR anomaly recorded on 2010.10.22 that did not correspond to earthquakes.

**Point 14: P11 Fig.5; As reported in the caption "The cells in the blue rectangle mean that this day is affected by a large area of clouds, ...", now, some days with TIR anomalies belonging to several sequences of TIR anomalies (i.e. 2, 10, 27, 32, 35, 36, 37, 45, 50, 58, 59) are affected by a wide cloudy coverage, all this lets thinks that TIR anomalies due to meteorological effects are not removed from the analysis (as suggested in Eleftheriou et al., 2016).**

**Response 14:** Thanks for your advice, yes I have made a mistake, and I have corrected all the related results, figs and analysis.

**Change 14:**

Fig.5, Fig.6, Table2, Fig.9, Table3, Table4, Fig.10 and Fig.11 have been redone. And all the related contents in text have been corrected.

**Point 15: P12 L21-33. Rightly, you are reported that cloudy coverage could prevent to observe with continuity the presence of TIR anomalies, this is a intrinsically limitation of satellite technologies which work in the optical band, and not of RST methodology. Please revise your sentences.**

**Response 15:** As what I have mentioned at the beginning of the reply, I will revise the sentence.

**Change 15:**

P23L10-As such, the prediction potential of RST using MODIS LST data in the Sichuan area is limited. However, it doesn't indicate that the RST is not effective for earthquake prediction, on the contrary, many other cases prove that this method is very effective for extracting TIR anomalies. The low PPV and TPR may be caused by the limitation of RST, nature of MODIS LST data, special topographic and weather background of study area, or something else.

**Point 16: P13-16 Paragraph 4.3 (The evaluation of earthquake prediction ability for RST); The performed analysis not have any sense if carried out in this way. Mainly, the analysis on the rate of earthquakes which correspond ("TPR") or not ("FNR") to TIR anomalies it is very complicated to perform, because gaps in observations, due to the lack of satellite data or to a wide presence of meteorological clouds make impossible to give a continuity to the observations, which is necessary to identify possible TIR anomalies or to fully appreciate a possible space–time persistence of previously occurred TIR anomalies, as consequences the relation one to one (earthquake-TIR anomalies) that you are looking is corrupted by this limitation. Anyway, before to comment the results of a some kind of sensitivity analysis this circumstance should be announced.**

**Response 16:** As what I have explained at the beginning of the reply, this is simulated earthquake prediction, the limited prediction ability may be caused by lack of data, clouds cover, method itself, the characteristics of the data, the limitation of RST or other things. No matter what is reason that makes some certain earthquakes cannot be predicted, some of earthquakes haven't been correlated with TIR anomalies is the truth, so they have to be counted in the missing rate. Our paper is not to study why these earthquakes are not corresponding to TIR anomalies, but just evaluate the prediction ability.

Another thing I want to explain that, in this study, earthquakes and TIR anomalies are not one-to-one but many-to-many.

Choudhury, S. J. I. J. o. R. S. (2005). "Cover: Satellite detects surface thermal anomalies associated with the Algerian earthquakes of May 2003." **26**(13): 2705-2713.

Ouzounov, D. and F. Freund (2004). "Mid-infrared emission prior to strong earthquakes analyzed by remote sensing data." Advances in Space Research **33**(3): 268-273.

Panda, S. K., S. Choudhury, A. K. Saraf and J. D. J. I. J. o. R. S. Das (2007). "MODIS land surface temperature data detects thermal anomaly preceding 8 October 2005 Kashmir earthquake." **28**(20): 4587-4596.

Pergola, N., C. Aliano, I. Coviello and C. Filizzola (2010). "Using RST approach and EOS-MODIS radiances for monitoring seismically active regions: a study on the 6 April 2009 Abruzzo earthquake." Natural Hazards & Earth System Sciences **10**(2): 239-249.

# A Statistical Analysis of TIR Anomalies ~~extracted~~Extracted by RST in Relation ~~with~~to an Earthquake in the Sichuan Area ~~with Use of~~using MODIS LST Data

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**Abstract:** ~~There is a long history for research~~Research in the field of earthquake prediction has a long history, but ~~weakness~~the inadequacies of traditional approaches to the study of seismic ~~hazard~~threats have ~~been more and more~~become increasingly evident. Remote sensing and earth observation technology, ~~which is a new~~an emerging method that can ~~instantly acquire a large area of abnormal information caused by earthquakes, is~~ rapidly capture information concerning anomalies associated with seismic activity across a wide geographic area, has for some time been believed to be the key to ~~the breakthrough of~~overcoming the bottleneck in ~~the study of~~ earthquake prediction~~. A~~ studies. However, a multi-parametric ~~approach seems, instead,~~method appears to be the most promising approach ~~in order to increase~~for increasing the reliability and precision of short-term seismic hazard ~~forecast~~forecasting, and ~~Thermal Infrared~~thermal infrared (TIR) ~~anomaly is an~~ anomalies are important ~~part of the~~ earthquake precursors. ~~Though many scientists~~While several studies have ~~studied~~investigated the correlation among TIR anomalies identified by the ~~Robust Satellite Techniques~~robust satellite techniques (RST) methodology and single ~~earthquake, there is~~earthquakes, few ~~study to extract the~~studies have extracted TIR anomalies ~~in~~over a long period ~~and~~within a large study area. Moreover, ~~a~~ statistical ~~analysis of TIR anomalies in relation with earthquake is needed~~analyses are required to determine whether ~~there is the existence of~~ TIR anomalies ~~before earthquake~~are precursors to earthquakes. In this paper, ~~a refined~~ RST data analysis and the Robust Estimator of TIR Anomalies (RETIRA) index were used to extract the TIR anomalies from 2002 to 2018 in the Sichuan ~~area with use of~~region using Moderate~~-resolution~~ Resolution Imaging ~~Spectro-radiometer~~Spectroradiometer (MODIS)

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~~Land Surface Temperature~~land surface temperature (LST~~), and~~) data, while the earthquake catalog ~~were also~~was used to ~~study~~ascertain the correlation between TIR anomalies and earthquake occurrences~~ of earthquake.~~. Most ~~of the thermal infrared~~TIR anomalies ~~correspond~~corresponded to earthquakes, and statistical methods ~~are~~were used to ~~prove that there is a~~ verify the correlation between the extracted ~~thermal infrared~~TIR anomalies and earthquakes. ~~And this~~This is the first time ~~to evaluate earthquakes prediction~~that the ability ~~with use of~~ to predict earthquakes has been evaluated based on the positive predictive value (PPV~~,~~), false discovery rate (FDR~~,~~), true-positive rate (TPR) and false-negative rate (FNR~~, the~~). The statistical ~~result shows~~results indicate that the prediction ~~ability~~potential of RST with use of MODIS ~~in~~is limited with regard to the Sichuan ~~area is limited~~region.

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Key Words: Thermal ~~Infrared Anomalies, Land Surface Temperature~~infrared anomalies, land surface temperature, MODIS, ~~Earthquake~~earthquake

## 1. Introduction

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~~There are numerous observations of~~ Changes in the surface temperature ~~changes~~ of the earth's crust prior to ~~Earth's crust~~ the occurrence of earthquakes have been attested to by numerous observations (Tronin~~, Hayakawa~~ et al., 2002). ~~Nowadays,~~ Thermal ~~Infrared Remote Sensing~~infrared (TIR) remote sensing has ~~taken to be~~recently emerged as a ~~new method~~promising technique for detecting seismic precursors~~ detecting~~. Anomalous ~~thermal infrared~~ TIR emissions have been ~~widely~~ detected by satellite sensors ~~before~~prior to the occurrence of major earthquakes (Piroddi~~, Ranieri~~ et al., 2014). Several studies ~~discovered~~have detected space-time anomalies in TIR ~~and outgoing longwave radiation (OLR)~~ satellite imagery, ranging from weeks to days~~,~~ both before and after earthquakes (Wang, 1984~~,~~; Gorny~~, Salman~~ et al., 1988~~,~~; Qiang~~, Xu~~ et al., 1991~~,~~; Tronin, 1996~~,~~; Tramutoli~~, Bello~~ et al., 2001~~,~~; Ouzounov and Freund, 2004~~,~~; Tramutoli~~, Corrado~~ et al., 2015). ~~Identification~~The investigation of ~~thermal infrared (~~TIR~~)~~ signals as seismic precursors ~~as pre-seismic signal~~ has gained ~~support over world, especially~~traction worldwide, particularly in Russia, China, India, the United States, and Italy, ~~and~~while Saraf et al. observed ~~such~~similar short-term anomalies ~~around~~in the epicentral ~~region for~~regions of earthquakes in India, Algeria, Iran, China, Pakistan and Indonesia ~~through~~ using National Oceanic and Atmospheric

Administration Advanced Very High Resolution Radiometer (NOAA-AVHRR~~,~~), Terra/Aqua-Moderate Resolution Imaging Spectroradiometer (MODIS) and passive microwave Defense Meteorological Satellite Program Special Sensor Microwave/Imager (DMSP-SSM/I) satellite data~~ and call them~~, applying the term 'transient TIR ~~anomalies~~anomalies' (Saraf~~, Rawat~~ et al., 2009).

There ~~is~~are few ~~data analysis~~analytical techniques that can isolate residual TIR variations~~,~~ potentially associated with earthquake occurrence~~,~~ from ~~the~~ TIR signals of normal variability ~~of TIR signal due~~attributable to other causes (Tramutoli~~, Cuomo~~ et al., 2005).~~ But, more than~~ However, in over 10 years (since 2001) of ~~application of~~applying the general ~~Robust Satellite Techniques~~robust satellite techniques (RST) (Tramutoli, 1998~~,~~; Valerio, 2005~~,~~; Tramutoli, 2007) methodology to the investigation of this issue, ~~have shown~~ the ~~ability~~potential of this approach ~~to discriminate~~for discriminating anomalous TIR signals ~~possibly~~potentially associated with seismic activity from normal fluctuations ~~of~~in Earth's thermal ~~emission~~emissions related to other causes (e.g., meteorological~~)~~), independent of ~~the earthquake occurrences~~seismic activity, has been verified (Eleftheriou~~, Filizzola~~ et al., 2016). RST is based on the Robust AVHRR ~~techniques~~Technique (RAT), which ~~is proposed~~was developed for environmental monitoring ~~with the use of~~using NOAA/AVHRR observations (Tramutoli, 1998). ~~And since then~~Since that time, most ~~of the announced RAT~~ reported applications of RAT have demonstrated ~~their~~the technique's reliability ~~as well their~~ and exportability ~~on~~for different satellite sensors and geographic areas, ~~so~~and RAT has evolved into RST (Tramutoli, 2007). RST ~~contains~~comprises two main steps: the first ~~RST requirement~~ is ~~the~~ characterization of behavior ~~in~~under normal conditions; and the second ~~step~~ is ~~the~~ establishment of the change~~-~~-detection criteria ~~which~~that should be specified for each ~~considered~~class of phenomenon ~~class~~considered, and ~~chosen~~for the selected technology ~~as well as for~~and the time and place of the observation (Tramutoli, 2007).

~~With use of~~ Several studies have used RST~~, many researchers have extracted TIR anomalies (in the following all the TIR anomalies refer~~ to ~~the thermal infrared anomalies extracted by RST) in different earthquakes,~~extract and ~~have analyzed~~analyze the space-time distribution of TIR anomalies~~.~~ (henceforth, all TIR anomalies mentioned were extracted using RST) relating to different earthquakes. Using MODIS land surface temperature (LST) data, Pergola et al. studied the 6 April 2009 Abruzzo earthquake and found that spatially extended and time~~-~~-persistent TIR

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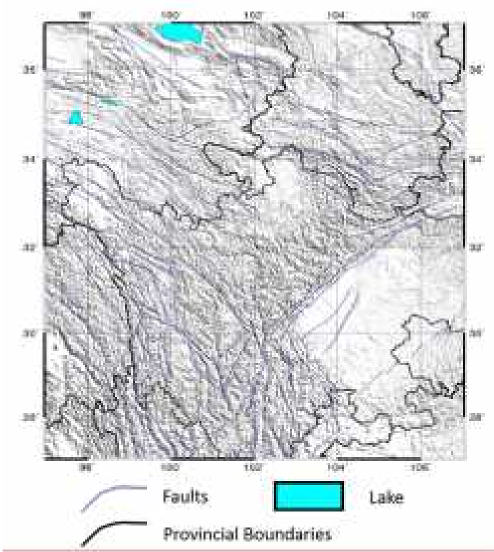
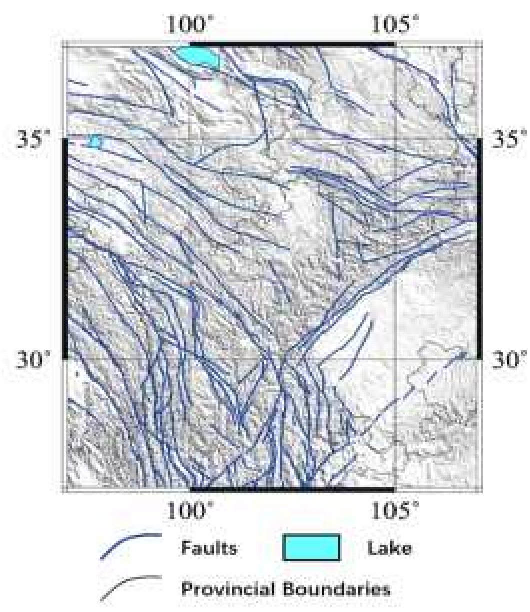
~~Nowadays, some~~Several researchers have ~~done a~~conducted long-term statistical ~~analysis~~analyses to determine the ~~correspondence~~correlation between TIR anomalies and earthquakes. Genzano et al. used ~~data of~~ GMS-5/VISSR TIR measurements to ~~study~~investigate earthquakes with M~~>~~ > 4 that occurred in a wide area ~~around~~surrounding Taiwan, ~~in~~during the month of September from 1995 to 2002~~, and~~; the false~~-~~-positive rate (FPR) remained at zero when ~~the~~ earthquakes with M~~>~~ > 4 or ~~M>~~4.5 were considered, and the ~~false positive rate~~FPR remained ~~less than~~under 6% when ~~the~~a threshold of M > 5 ~~is~~was applied (Genzano, Filizzola et al., 2015). Tramutoli et al. studied ~~the~~ earthquakes with M~~>~~ > 4~~.0~~ in ~~Italy~~the southern Apennines in Italy's Po plain from July 2012 to June 2013 and ~~the testing area was Italian southern Apennines, Po Plain, they~~ found that the ~~false positive rate~~FPR was ~~lesser~~less than 33~~%~~%, while the missing rate ~~is up to~~was as high as 67~~%~~% (Tramutoli, Corrado et al., 2015). Eleftheriou et al. studied ~~the~~ earthquakes that occurred in Greece ~~in period~~between 2004~~-~~ and 2013 ~~with use of~~using TIR images acquired ~~by~~with MSG/SEVIRI, and found that more than 93% of all identified TIR anomalies occurred in the prefixed space-time window around the time and location of ~~occurrence of~~ earthquakes ~~(~~with M~~>~~ > 4~~) and the~~, with an overall ~~false positive rate is <~~FPR < 7~~%~~% (Eleftheriou, Filizzola et al., 2016). It seems that RST is an ~~effect method to extract~~effective means of extracting TIR anomalies ~~before~~ that occur as precursors to earthquakes, but ~~there is~~ no such study ~~for~~has hitherto been conducted on the Chinese mainland ~~of China~~.

~~However, some researchers~~Several studies, however, have ~~proved~~proven that some ~~single~~individual earthquake results are unreliable. Some so-called TIR anomalies are caused by ~~weather~~meteorological anomalies~~, which~~ that are ~~not related~~unrelated to earthquakes. ~~An instance is that~~For example, Matthew et al. studied the Gujarat (India) earthquake of 2001, and ~~he~~ found that ~~the~~ previous ~~study~~studies, which had indicated ~~there was~~ the presence of TIR anomalies ~~before~~prior to the earthquake, ~~was not reliable.~~were unreliable. They concluded that there was no robust evidence for the existence of LST anomalies prior to the 2001 Gujarat earthquake, and that cloud ~~covering~~cover was ~~one~~a possible cause ~~for~~of the anomalies (Blackett~~, Wooster~~ et al., 2011). ~~So, a~~As such, rigorous ~~rule~~statistical analyses of ~~thermal~~ TIR ~~anomaly judgement and~~anomalies over long ~~period statistical analysis~~periods are necessary.

In this paper, RST ~~will be~~is applied ~~for the~~to a mountainous area in China ~~(27°N – 37°N, 97°E – 107°E) to study a mountainous area of China. The long)~~. Long-term analysis (from ~~Sep~~Sept. 2002 to Mar. 2018) ~~will conform~~is used to verify the ~~correspondence~~correlation between TIR anomalies and earthquakes. Based on the statistical results, the earthquake prediction ~~ability~~potential of RST will be evaluated ~~in this paper~~.

2. Study area

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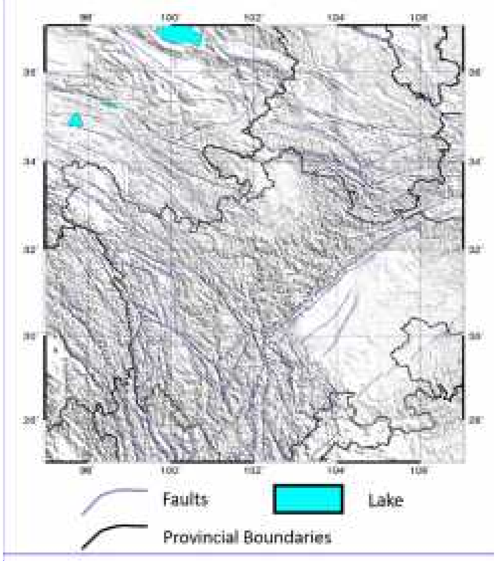


Fig.1 The distribution of faults in East-Southern Gansu province and its ~~neighbor~~neighboring regions.

~~East-southern~~The southeastern Gansu province and its ~~neighbor~~neighboring regions ~~are~~were selected ~~to~~as the study area, to assess the correlation ~~of~~between TIR anomalies and earthquakes from ~~Sep.~~September 2002 to ~~Mar.~~March 2018. As ~~it is~~ shown in Fig.1, the ~~scope~~ range of the study area is $27^{\circ}N$ to $37^{\circ}N$, $97^{\circ}E$ to $107^{\circ}E$. The study region is located at the ~~junction~~intersection of Gansu, Qinghai, and Sichuan~~,~~ provinces; it ~~is~~ also includes the intersection of the ~~North~~northern section of ~~North-South~~the north-south seismic belt and the Kuma seismic belt~~, moreover, structures~~. Structures in this area are complex and strong earthquakes are frequent (Yang, Zhang et al., 2002). The area is on the eastern edge of ~~Tibet~~the Tibetan Plateau, belonging to the upper part of the rhombic block in the ~~eastern-southern~~southeast Gansu province. The Xian River fault, the Longmen Shan Fault, and the Anning River fault ~~are connected~~intersect here, and the ~~shape of the~~ structure is ~~like a 'Y'~~Y-shaped. This ~~kind~~type of geomorphology ~~contains abundant~~is widely encountered in plate tectonics, and the Longmen Shan fault in the north-northeast direction ~~of NNE~~ becomes ~~the~~a steep slope ~~of~~in the ~~Southeast~~southeast Sichuan Basin and ~~the~~an erosion plateau ~~in the~~ northwest of the study area.

3. Data and method



**Comment [张1]:** Because there are abundant faults in the study area, the figure will be in a mass and be confusing when the names of faults are added. Moreover, the names of faults are not necessary in our study.

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3.1 Data introduction

MODIS data ~~is~~are used to calculate the TIR anomalies, and the earthquake information ~~got~~used for statistical analysis was provided by China Earthquake Datacenter (http://data.earthquake.cn)~~obtained from the China Seismic Information (http://www.csi.ac.cn/) is used for statistical study in this paper./~~).

The MODIS instrument is ~~operating~~used on both the Terra and Aqua ~~Spacecrafts~~spacecrafts. It has a ~~viewing~~ swath width of ~~2330~~2,330 km and views the Earth's entire surface ~~of the Earth~~ every ~~one~~1 to ~~two~~2 days. Its detectors measure 36 spectral bands between 0.405 and 14.385 µm, and it ~~acquires~~can acquire data at three spatial resolutions~~ — 250m, 500m, 1000m~~: 250, 500, and 1,000 m. In this study, nighttime MODIS ~~Land Surface Temperature~~LST daily data (MYD11C1) ~~is~~are used ~~for the extraction of~~to extract TIR anomalies. Because ~~LSTs~~LST data are susceptible to solar radiation during the daytime, ~~the~~ nighttime data ~~is~~are selected for use. The ~~LSTs~~LST data ~~is~~were retrieved at ~~5600m by~~5,600 m using the generalized split-window algorithm. In the day/night algorithm, daytime and nighttime LSTs are retrieved from pairs of day and night MODIS observations in seven TIR bands. Moreover, the daily nighttime ~~Cloud Mask~~cloud mask data (MYD35L2) ~~is~~are used ~~for excluding~~to exclude the LST data covered by the cloud. The ~~resolution~~resolutions of ~~Cloud Mask~~the cloud mask data ~~is 250m~~are 250 and ~~1000m~~1,000 m, so the resolution ~~have to~~must be downscaled to correspond with the LST data.

~~The China Seismic Information has recorded~~ ~~a total of 898,035 earthquakes of whole~~across China since~~1965. The total number of the recorded earthquakes is 898035. Earthquake~~ since 1965. Earthquakes caused by block movement and crust compression ~~is a kind~~represent an extreme type of ~~severe~~ geological movement~~,~~; earthquakes are ~~the~~ instantaneous bursts of accumulated energy, and they may ~~lead to large area~~result in the presence of TIR anomalies~~. The earthquake happens out of~~ across a large area. Earthquake occurrences within the study area will also cause ~~the~~ TIR anomalies ~~near the~~close to its boundaries~~ in study area, so~~; therefore, for the ~~previous analysis, the~~ earthquakes ~~happened in~~that occurred within the area 25°N–40°N, 95°E–110°E will also be ~~used~~analyzed to ~~study~~examine the TIR anomalies ~~in~~at 27°N–37°N, 97°E–107°E. ~~But~~However, earthquakes ~~caused by~~attributed to ground subsidence~~, human~~ and anthropogenic factors ~~and so on will~~are not ~~cause~~ associated with TIR anomalies, ~~so the~~and therefore earthquakes ~~with~~where depth~~=~~ = 0 ~~should be~~are excluded~~. Moreover,~~ from analysis. Tronin ~~indicated~~et al.

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**Comment [张2]:** I can attach my seismic catalog in the attachment. The catalog obtained from USGS is different from China, especially for the earthquakes with M<5.0. This is because the nearer to the epicenter, the more abundant and accurate information the stations can get, so the earthquake catalog provided by Chinese officials is more suitable for this study than USGS.

observed that ~~the anomaly was~~anomalies were sensitive to crustal earthquakes with a magnitude of more than 4.7 and ~~for~~over a distance of up to ~~1000km~~1,000 km (Tronin~~, Hayakawa~~ et al., 2002). ~~So~~Therefore, we ~~select the earthquake with~~selected earthquakes of $M \geq 3.5$ and depth $> 0$ ~~happened in~~that occurred within the area of $25^{\circ}N$ to $40^{\circ}N$, $95^{\circ}E$ to $110^{\circ}E$ for ~~study~~analysis, and after screening, ~~the~~a total ~~number~~ of 3,615 earthquakes satisfied these conditions ~~is 3615~~.

### 3.2 RST Methodology

The RST approach is based on ~~a~~ multi-temporal ~~analysis~~analyses of historical ~~data set of~~ satellite ~~observations~~observational datasets acquired ~~in~~under similar observational conditions (Eleftheriou~~, Filizzola~~ et al., 2016). ~~Because~~Since the surface environment is relatively constant, ~~the location of~~ high~~-~~- and low-temperature ~~and low temperature is~~ locations are also relatively ~~steady. Along with the change of~~consistent. Over time, the infrared brightness temperature will change, ~~but it changes in slow speed~~albeit very gradually and in small ~~scale~~increments with obvious seasonal characteristics. ~~Put aside influence~~Aside from the influences of meteorological factors and earthquake ~~thermal infrared anomaly~~TIR anomalies, the brightness temperature ~~in~~within the same area and during the same time period ~~of the year has strong~~exhibits robust stability and regularity. ~~So~~Therefore, the basic ~~theory of~~principle that guides RST is that the background field is constructed to extract the thermal anomalies, and the mean and variance of the ~~land surface temperature~~LST are used to ~~measure~~evaluate the degree of ~~thermal infrared anomalies~~TIR anomaly.

This method consists of three main steps, ~~it is~~ as follows:

- Pre-processing

RST is used to construct a reference, which is ~~regarded~~considered to be ~~at~~in a normal state under no influence from other factors, and to measure and extract the anomalies at the corresponding time. $V(r,t)$ ~~is~~are LST data in location *r* at time *t*. ~~So~~Therefore, the first step is to eliminate the data affected by clouds, and to remove outliers.

➢ To eliminate the ~~influence~~effect of day~~-~~-to~~-~~-day climatological changes or ~~season~~seasonal time drifts, ~~a~~ pre-processing ~~will be conducted for~~is applied to the daily LST data:

$$\Delta V(r,t) = V(r,t) - V(t) \qquad (1)$$



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Where ~~ ~~$\Delta V(r,t)$ is the difference between the value of LST ~~value~~ acquired at time $t$ in location $r$ and its spatial average, $V(t)$, computed ~~on~~in the investigated area considering only those pixels belonging to the same class~~, while~~; in this study area, all ~~the~~ pixels belong to the land class.

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- ~~To build~~The cloud-~~-~~mask ~~with use of Cloud Mask~~is constructed using cloud mask data (MYD35L2). ~~In order to be sure~~ To ensure that only cloud-free radiances contribute to the computation of the reference fields~~,~~ (RFs), not only those pixels but also the 24 ~~ones~~pixels in ~~a~~the surrounding 5~~× 5 box around it (very often~~ × 5 area (frequently belonging to cloud edges) ~~have been~~are excluded ~~by~~from the following RFs computations ~~of reference fields~~(Eleftheriou~~, Filizzola~~ et al., 2016).

$$A_1(r,t) = \begin{cases} 0, i\ \ the\ k\ \ \ r\ w\ \ a\ \ \ b\ c\ \ \ a\ tt\ \ t \\ 1, o\ her \end{cases} \quad (2)$$

- ~~To build an~~An outlier-mask is constructed.

This step is to determine the outliers, and these values should be excluded from the construction of the background field and the extraction of TIR anomalies.~~Apart from the influence of clouds, there are still many~~several ~~other factors will change the~~affect ~~LST, for instance, the~~including ~~extreme weather (blizzard, foehn~~e.g., blizzards or the Foehn ~~effect and so on), human's~~), human ~~activity, and forest fire~~fires. ~~These factors will lead to rapid and dramatic changes in large area~~across a wide range ~~of LST data. And these~~These ~~anomalies should be excluded from the construction of~~ the ~~background filed~~field ~~and the extraction of TIR anomalies.~~

$$A_2(r,t,\tau) = \delta_1(r,t,\tau) * \delta_2(r,t,\tau) * \delta_3(r,t,\tau)$$

(3)~~$A_2(r,t) = \begin{cases} 0, i\ \ the\ d\ \ \ a\ k\ \ \ r\ a\ ti\ \ t\ w\ \ a\ o, \\ 1, o\ her \end{cases}$ (3)~~

As it is shown in eq. (3), $\delta_1, \delta_2, \delta_3$ are three kinds of data that should be excluded from the construction of backfields. As demonstrated by Aliano et al. and Genzano et al., the spatial distribution of clouds over a thermal heterogeneous scene can significantly change the value of $\Delta V$ in the cloud-free pixels(Aliano et al., 2008; Genzano et al., 2009~~ #10~~). The large cloud cover area will introduce a cold spatial average effect to the computation of the RFs, so that when $V(r,t) <$ ~~$\mu_V$~~$\mu_V - 2 * \sigma_V$ (here, $\mu_V$ is the temporal average and the $\sigma_V$ is its

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$$\delta_1(\mathrm{r,t,\tau}) = \begin{cases} 0, i\ \ V(r,t) - \mu_V(r,t,T) < -2 * \sigma_V(r,t,t), t < \tau \\ 1, o\ \ he \end{cases} \quad (4)$$

Moreover, even where no cold spatial average effect is produced, extended cloud coverage can determine the *V(t)* values and the values of the considered signal $\Delta V(r,t)$, scarcely representative of the actual conditions of cloud-free pixels, so that when the cloudy fraction of the land portion of the scene is $> 80\%$, all pixels must be excluded from the computation of the RFs (Eleftheriou et al., 2016).

$$\delta_2(\mathrm{r,t,\tau}) = \begin{cases} 0, i\ \ c \quad f \quad o\ \ l \quad p \quad o\ \ s \quad i\ \ > 80\% \\ 1, o\ \ he \end{cases} \quad (5)$$

$\delta_3$ is used to remove the outliers (where k ≥ 2), and its expression is as follows:

$$\delta_3(\mathrm{r,t,\tau}) = \begin{cases} 1, i\ \ |V(r,t) - \mu_V(r,t,T)| < k\sigma_V(r,t,t) \\ 0, o\ \ he \end{cases} \quad (6)$$

$\delta(r,t,t) = \cancel{\delta_1}\delta_1(r,t,t) * \delta_2(r,t,t) * \delta_3(r,t,t)$ computed using an iterative $k\sigma$-clipping technique, which begins by computing $\delta(r,t,t)$ based on the first determination of $\mu_V\cancel{(r,t,T)}(r,t,T)$ and $\sigma_V^2(r,t,T)$, and continues by updating their values using only space-time locations with $\delta(r,t,t) = 1$, as follows:

$$\mu'^2_{\Delta V}(r,t,T) \equiv \frac{\sum_{\forall t \in T}[\Delta V(r,t) \cdot A(r,t)]}{\sum_{\forall t \in T} A(r,t)} \quad (7)$$

$$\sigma'^2_{\Delta V}(r,t,T) \equiv \frac{\sum[\Delta V(r,t) \cdot A(r,t) - \mu_{\Delta V}(r,\tau)]^2}{\sum_{\forall t \in T} A(r,t)} \quad (8)$$

The process should be iterated until no further exclusions are determined, using the latest determination of $\delta$ (Tramutoli, 1998). And the final result of $\delta$ is the $A_1$ what we want. ~~The detailed steps for calculating $A_2$ will be shown in next step are detailed below.~~

- Computing Reference Fields ~~(RF)~~

  - The $\mu_{\Delta V}(r,t,\Delta T)$ is the mean of location *r* for time series *T*. The variance $\sigma^2_{\Delta V}(r,t,T)$ is applied at time $t$ using homogeneous historical records collected under the temporal constraint $t \in T$ *(t < τ)* ~~The $\mu_{\Delta V}(r,t,\Delta T)$ is the mean of location *r* for time series *T* and. The variance $\sigma^2_{\Delta V}(r,t,T)$ is applied at the time $t$, by using homogeneous historical records collected under the temporal constraint t ∈ T in the past (t< ≤ τ),~~ and the $V_R$ $(r,t,\Delta T)$ is the background field.

$$\mathrm{A(r,T)} = \mathrm{A_1(r,t)} * \mathrm{A_2(r,t)} \cancel{\mathrm{A(r,T)} = \mathrm{A_1(r,t)} * \mathrm{A_2(r,t)} * \mathrm{A_3(r,t)}} \quad (\cancel{4}9)$$

$$V_R \quad (r,t,T) \equiv \frac{\sum_{\forall t \in T}[\Delta V(r,t) \cdot A(r,t)]}{\sum_{\forall t \in T} A(r,t)} \quad (\cancel{5}10)$$

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$$\sigma_{\Delta V}^{2}(r, \iota, T) \equiv \frac{\sum[\Delta V(r,t)\cdot A(r,t)-\mu_{\Delta V}(r,\tau)]^{2}}{\sum_{\forall t\in T} A(r,t)} \qquad (611)$$

➢ To compute the The outlier-mask, and is then constructed; this method is aimeddesigned to eliminate the abnormal significant data caused by the non-seismic factors. FirstThe first step is to find reference fieldsthe RFs of minima $V_{min}(r,\iota,T)$ and maxima $V_{max}(r,\iota,T)$ to be used at the time τ.

$$\Delta V_{min}(r,\tau,T) \equiv \min\{\Delta V(r,t_1),\cdots,\Delta V(r,t_N)\}\ \forall t \in T, A(r,T) = 1 \qquad (7)$$

$$\Delta V_{max}(r,\tau,T) \equiv \mathrm{MAX}\{\Delta V(r,t_1),\cdots,\Delta V(r,t_N)\}\ \forall t \in T, A(r,T) = 1 \qquad (8)$$

Wherewhere a modified outlier-mask $A_s(r,t) = A(r,T)\cdot\delta(r,t,\tau)$ havehas been introduced in order to avoid contributions from accidental minima or maxima. And because the blizzard, since blizzards, forest firefires, and the large areaareas of cloudscloud cover usually cause the abnormal increaseincreases or decreasedecreases in LST with a magnitude that far bigger thanexceeds the changechanges caused by earthquakes. These data should not be included forin the calculation of reference fieldthe RF. As showndemonstrated by ALIANOAliano et al. and GENZANOGenzano et al., the spatial distribution of clouds, over a thermal heterogeneous scene, can significantly change the value of $\Delta V$ in the cloud-free pixels (Saraf, Rawat et al., 2009). The large cloud cover area of clouds will bringintroduce a cold spatial average effect to the computation of reference fieldsthe RFs, so that when $V(r,t) < \mu_V\mu_V - 2*\sigma_V$ (here, $\mu_V$ is the temporal average and the $\sigma_V$ is its standard), the value of these pixels pixels' values will be excluded (Eleftheriou, Filizzola et al., 2016). Moreover, even if not producing awhere no cold spatial average effect, an is produced, extended cloud coverage can determine values ofthe V(t) values and thenthe values of the considered signal $\Delta V(r,t)$, scarcely representative of the actual conditions of cloud-free pixels, so that when the cloudy fraction of the land portion of the scene is $> 80\%$, then all the pixels have tomust be excluded from the computation of reference fieldsthe RFs (Eleftheriou, Filizzola et al., 2016).

The termterms $\delta_1(r,t,\tau)$ a $\delta_2(r,t,\tau)$ are defined by the expression:

$$\delta_1(r,t,\tau) = \begin{cases} 0, i\ V(r,t) - \mu_V(r,\iota,T) < -2*\sigma_V(r,t,\tau) \\ 1, o\ he \end{cases} \qquad (9)$$

$$\delta_2(r,t,\tau) = \begin{cases} 0, i\ c\ f\ o\ l\ p\ o\ s\ i > 80\% \\ 1, o\ he \end{cases} \qquad (10)$$

For $\delta_2$ is used to remove the outliers caused by the forest fire orfires, blizzards and, or other factors, $\delta_2$ is used to remove them (with (where k >=≥ 2,; in this study the, k is set to beat 4), and



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~~its expression is as follows:~~

$$\cancel{\delta_{\varepsilon}(r,t,\tau)=\begin{cases}1, \text{ if } |V(r,t)-\mu_V(r,\tau,T)|<k\sigma_V(r,t,\tau)\\ 0, \text{ otherwise}\end{cases}}$$

~~$\delta(r,t,\tau)=\delta_{\varepsilon}\delta_{\varepsilon}(r,t,\tau)*\delta_{\varepsilon}(r,t,\tau)*\delta_{\varepsilon}(r,t,\tau)$ computed by using an iterative $k\sigma$-clipping technique, which starts~~begins ~~by computing $\delta(r,t,\tau)$~~ based ~~on the base of the first determination of $\mu_V(r,\tau,T)(r,\tau,T)$ and $\sigma_V^2(r,\tau,T)$,~~ and ~~continues by updating their values by using only space/~~-~~time locations with $\delta(r,t,\tau)=1$, as follows:~~

$$\cancel{\mu^{*2}_{\Delta V}(r,\tau,T)\equiv\frac{\sum_{\forall\tau\in T}[\Delta V(r,t)\cdot\delta(r,t)]}{\sum_{\forall\tau\in T}\delta(r,t)}} \quad \cancel{(11)}$$

$$\cancel{\sigma^{*2}_{\Delta V}(r,\tau,T)\equiv\frac{\sum[\Delta V(r,t)\cdot\delta(r,t)-\mu_{\Delta V}(r,\tau)]^2}{\sum_{\forall\tau\in T}\delta(r,t)}} \quad \cancel{(12)}$$

~~The process should be iterated until no further exclusions, are determined by the use of,~~ using the ~~latest determination of $\delta$ (Tramutoli, 1998).This process should be paid~~afforded ~~more attention, becauseas~~ it has been overlooked in the past papers, ~~this process is always ignored~~previous ~~studies.~~

- ~~Change-detection~~ step

- Change-detection

  - ~~To compute the~~The RETIRA (Robust Estimator of TIR Anomalies, Filizzola, 2004) ~~Absolutely Local Index of change~~Change of the Environment (ALICE),) must be computed, and the bigger the absolute value is, the more ~~obvious~~evident the anomaly is. $\otimes_{\Delta V}(r,{}^2,T)$ is the ~~ALICE~~RETIRA of location *r* at time $t$, which ~~is belonged~~belongs to the time series *T*.

$$\otimes_{\Delta V}(r,{}^2,T)=\frac{[\Delta V(r,{}^2)-V_{REF}(r,{}^2,T)]}{\pm_{\Delta V}(r,{}^2,T)} \qquad (~~13~~12)$$

  - ~~To determine whether the~~Whether $\otimes_{\Delta V}(r,{}^2,T)$ is affected by cloud~~. In~~ should be determined. From the results, it ~~can be~~may easily be concluded that some ~~area in certain time~~areas will lack ~~of~~ data at certain times, and for these ~~situations we have to implement~~scenarios a special value ~~to inform~~must be implemented to indicate that ~~this~~these data ~~is~~are affected by clouds and ~~it~~ should ~~not~~ be ~~analyzed in~~excluded from the

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~~following part~~ensuing analyses.

### 3.3 Identification of TIR anomalies

After the calculation of $\otimes_{\Delta V}(r,{}^{2},T)$ ~~K(r, τ, T)~~, the next step is to ~~determine whether it is~~identify the TIR anomalies and ~~to~~ correlate ~~the TIR anomalies~~them with ~~earthquakes~~earthquake occurrences. In this paper, ~~the~~a $\otimes_{\Delta V}(r,{}^{2},T)$ ~~K(r, τ, T) bigger than~~that exceeds the threshold ~~means that there is a~~ indicates the presence of a TIR anomaly~~, moreover, other~~; further conditions will be applied to ~~conform~~confirm the correlation ~~between the TIR anomalies and earthquakes~~. For $\otimes_{\Delta V}(r,{}^{2},T)$ ~~K(r, τ, T)~~ and $e(r,t)$, only ~~these~~in those cases ~~obey~~where the following conditions~~,~~ are satisfied can it be concluded that the TIR anomaly is related to $e(r,t)$:

1) The ~~ALICE~~RETIRA $\otimes_{\Delta V}(r,{}^{2},T) > 2$. In ~~ELEFTHERIOU'~~sEleftheriou's study, the threshold was set ~~to~~at 4 (Eleftheriou et al., 2016) ~~,~~; however, from ~~the point of view of mathematical statistics~~a statistical perspective, when the value is greater than two times the standard deviation, it ~~has~~ already ~~belonged to~~falls within the abnormal category~~, so in~~. In this study, therefore, the threshold is set ~~to~~at 2.
2) The $V(r,t)$ is ~~surely~~ not ~~be~~ blocked by clouds or affected by other factors.
3) Spatial persistence: The TIR anomalies ~~are gathering~~cluster together~~,~~ and ~~they~~ are not isolated, being part of a group covering at least 150 $k^{2}$ within an area of $1° * 1°$ (400 pixels in the images).
4) Temporal persistence ~~There are at~~: At least one more TIR anomaly ~~appearing~~appears within 7 days after the first TIR anomaly ~~in 7 days~~.
5) The TIR anomalies ~~appears~~appear 30 days before or 15 days after the $e(r,t)$ (Eleftheriou~~, Filizzola~~ et al., 2016) .
6) The shortest distance ~~for one~~from a given point in the TIR anomalies group to the epicenter of $e(r,t)$ is less than $R_D = 10^{L.4\,M}$.

~~The cases that~~Where the TIR anomalies satisfy conditions 1), 2), 3) and 4~~)~~), but do not satisfy at least ~~one of~~either 5) ~~and 5) mean that there are~~ or 6), TIR anomalies ~~but~~are present with no corresponding earthquake. ~~And other kinds of~~There are also cases ~~are of~~wherein no TIR anomalies

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occur.

## 4. Results and analysis

A comprehensive statistical analysis and the TIR extraction results are ~~shown~~detailed in this chapter. In chapter 4.1, a statistical analysis is conducted to ~~describe to~~ascertain the basic seismological conditions in the study area~~. And~~, while the statistical results for the correlation between earthquakes and TIR anomalies are ~~shown~~presented and analyzed in chapter 4.2. Finally, an analysis of the earthquake prediction ~~ability for~~potential of RST ~~will be shown~~is presented in chapter 4.3.

### 4.1 ~~A basic statistical~~Statistical analysis ~~for earthquakes~~of earthquake activity in the study area

~~Before studying~~Prior to investigating the correlation between TIR anomalies and earthquakes, a simple analysis ~~for~~of the temporal and spatial ~~characteristic~~characteristics of the earthquakes is ~~conducted~~required.

~~Firstly~~First, the temporal distribution shows that the seismicity ~~in 2008 is the most active~~ from 2002 to 2018 was most active in 2008, and ~~the seismicity after 2008 is obviously more frequent~~ that it increased in frequency and ~~violent than it before 2008~~violence from that time. The bottom of Fig. 2 indicates that there ~~are 3615~~were 3,615 earthquakes in the study area~~,~~ ($3.5 \le M \le 4$ ~~is 2262,~~, 2,262; $4 \le M \le 5$ ~~is 1124,~~, 1,124; $5 \le M \le 6$ ~~is~~, 198~~,~~; $6 \le M \le 7$ ~~is~~, 26; and $7 \le M \le 8$ ~~is~~, 5. ~~So~~Therefore, the study area is ~~a region with~~characterized by severe ~~earthquake~~seismic activity. ~~And, as it is shown in~~As may be seen from the upper part of Fig. 2, the average earthquake frequency ~~in~~during period A (from 2002.09 to 2007.12) ~~is about~~was around 78. ~~But~~However, the total number of earthquakes in 2008 ~~increases~~increased to 981 including the May 12 2008 ~~Ms8~~Ms 8.0 Wenchuan Earthquake, ~~which is~~ the most serious ~~earthquakes~~earthquake in China in recent years. ~~Though,~~Although the frequency ~~decreases a lot~~decreased substantially after 2008 (the average frequency ~~in~~during this period ~~is~~was 243), it ~~is still~~remained much higher than ~~the frequency in~~it had been during period A. The temporal distribution ~~tells~~indicates that ~~the~~ seismic activity ~~before~~prior to 2008 ~~is~~had been relatively weak, but in 2008, the seismic activity ~~is~~was extremely intense and reached ~~the~~its peak~~ value, after~~. After 2008~~ the~~, seismicity in this area ~~still maintains a relatively strong state~~continued to maintain this intensity.

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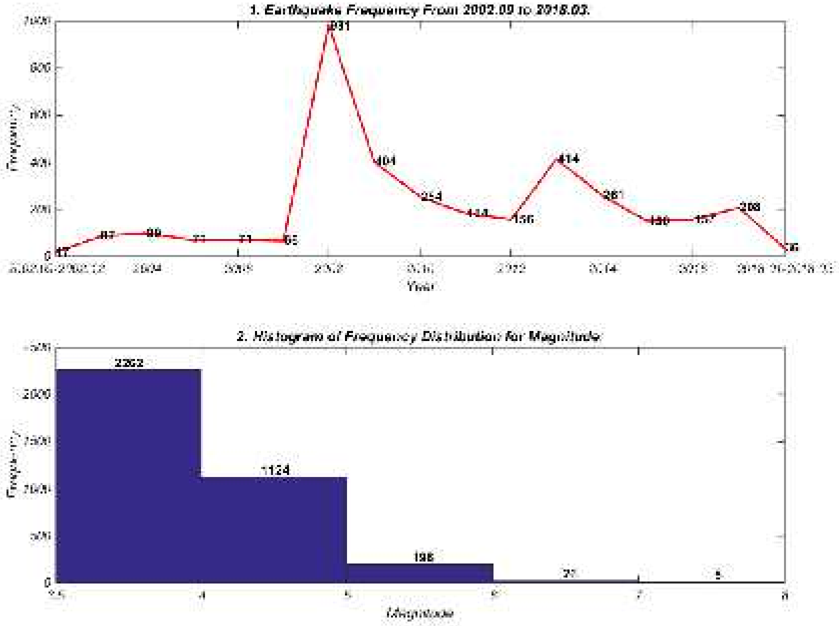


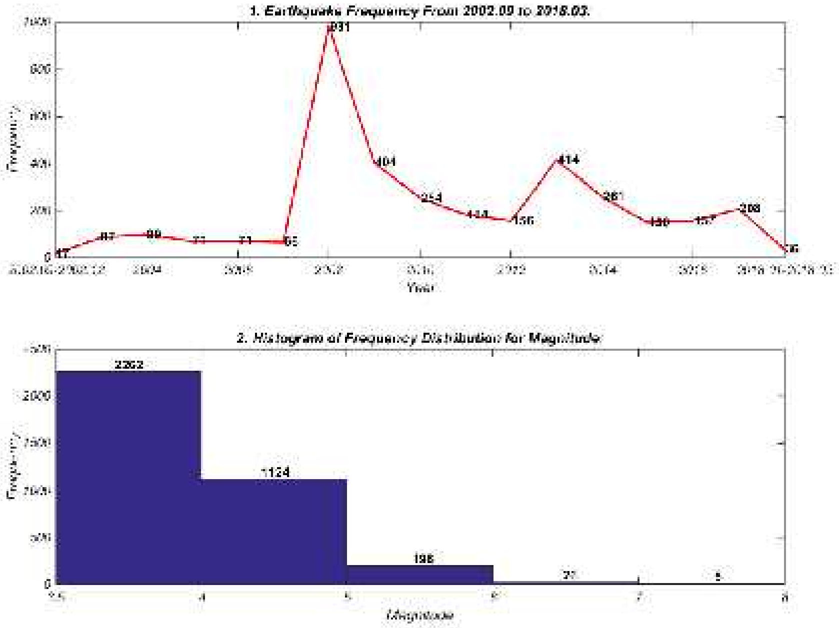


Fig. 2 The temporal distribution from 2002.09- to 2018.03 of earthquakes with $M \geq 3.5$ in the study area, and the distribution of seismic frequency ~~along~~ with ~~the~~earthquake magnitude ~~of the earthquakes.~~.

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Table~~.~~ 1 ~~The catalog~~Catalog of earthquakes with $M \geq 5.0$ ~~before year~~prior to 2008~~.~~

| Date | Latitude\°N | Longitude\°E | Depth\km | Magnitude |
|---|---|---|---|---|
| **2003.07.21** | 25.95 | 101.23 | 6 | 6.4 |
| **2003.10.16** | 25.92 | 101.30 | 5 | 6.2 |
| **2003.10.25** | 38.35 | 100.93 | 13 | 6.1 |
| **2003.08.18** | 29.57 | 95.60 | 33 | 6 |
| **2003.10.25** | 38.32 | 100.97 | 10 | 6 |
| **2006.07.19** | 33.03 | 96.35 | 30 | 5.9 |
| **2002.12.14** | 39.82 | 97.33 | 22 | 5.8 |
| **2005.08.05** | 26.55 | 103.15 | 21 | 5.6 |
| **2006.03.30** | 35.50 | 95.40 | 18 | 5.6 |
| **2003.11.13** | 34.75 | 103.93 | 10 | 5.5 |
| **2006.07.22** | 28.02 | 104.13 | 9 | 5.5 |
| **2006.08.25** | 28.03 | 104.01 | 7 | 5.5 |
| **2006.06.21** | 33.07 | 104.90 | 15 | 5.4 |
| **2006.07.18** | 33.07 | 96.28 | 20 | 5.4 |
| **2007.07.22** | 38.35 | 101.30 | 19 | 5.3 |
| **2004.09.07** | 34.73 | 103.92 | 19 | 5.2 |
| **2005.09.05** | 27.18 | 103.72 | 10 | 5.2 |
| **2003.08.21** | 27.42 | 101.27 | 5 | 5.1 |
| **2003.10.17** | 25.97 | 101.27 | 7 | 5.1 |
| **2003.11.01** | 25.93 | 101.22 | 3 | 5.1 |
| **2004.11.27** | 25.17 | 98.02 | 12 | 5 |
| **2005.01.05** | 32.28 | 101.55 | 5 | 5 |
| **2005.03.15** | 25.07 | 99.08 | 2 | 5 |
| **2006.07.23** | 33.03 | 96.05 | 30 | 5 |

~~And another~~Further evidence is ~~shown~~presented in ~~the~~ Table~~.~~ 1, ~~we have counted the earthquake with~~where earthquakes of $M \geq 5.0$ ~~in~~that occurred during period ~~B~~ A (from

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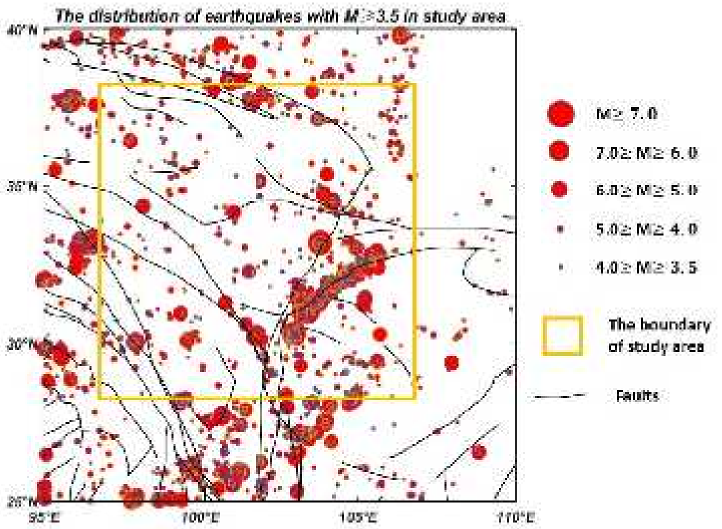
200~~2.09~~2.09 ~~and~~to 20~~07.12~~07.12~~).~~) are detailed. There ~~are~~were 229 earthquakes ~~with~~of $M \geq 5.0$, ~~but~~while the total number ~~in~~during period A ~~is~~was 24, which ~~is~~ accounted for 10.48~~%, while~~% overall; the duration of period A ~~is~~ accounted for 33.87% of the total ~~time (~~timeframe (i.e., period A + period B). Moreover, there ~~is~~were no earthquakes ~~with~~of $M \geq 6.5$ ~~in~~during period A, but there ~~are~~were 14 earthquakes ~~with~~of $M \geq 6.5$ ~~in~~during period B (from 2008.01 to 2018.03). All ~~these~~of this evidence ~~tell us~~indicates that ~~the~~ seismic activity ~~in~~during period B ~~is much~~ was significantly more violent and frequent.



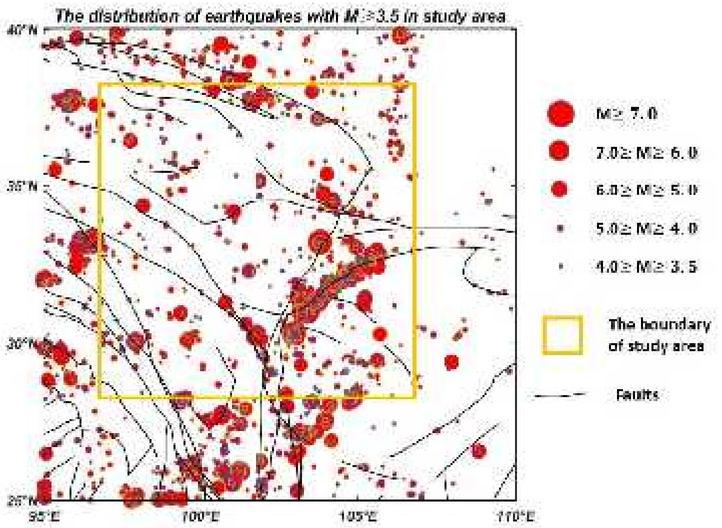



Fig. 3 ~~the~~The spatial distribution of earthquakes in the study area~~, and the~~. The ~~brown~~ orange rectangle ~~refers to~~represents the study area (27°N to 37°N, 97°E to 107°E). ~~The reason showing~~Earthquakes beyond the ~~earthquakes out~~parameters of the study area ~~is that the~~ are shown because earthquakes ~~closed~~close to the study area may also cause ~~thermal infrared (~~TIR ~~)~~ anomalies ~~in~~within the study area.

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~~Fig.~~Figure 3 shows the spatial distribution of earthquakes~~. The result indicates that the earthquakes mainly gather~~ within the study area. The results indicate that seismic events are clustered primarily in the west and center of the study area (25°N to 40°N,95°E to 110°E) ~~where~~which are mountainous ~~and the~~regions. The earthquakes are mainly aggregated along faults, ~~while the~~with a much sparser spatial distribution in the east and in the Sichuan Basin~~ is much more sparse~~. There is a clustering phenomenon centered on earthquakes ~~with~~of M ≥ 6, ~~the reason is that~~ since earthquakes usually occur ~~in faults~~along the fault lines of active geological movements.

The purpose ~~to study~~of investigating the temporal and spatial ~~characteristic~~characteristics of earthquakes is ~~for~~to acquire a general understanding of the seismic activities ~~in~~within the study area. ~~But there~~There is another important reason, however, which is to avoid ~~the large~~significant accumulation of earthquakes ~~in~~within a short ~~time and~~timeframe, and concentrated within a small area, ~~and~~with the result that ~~will lead to~~ the same TIR anomaly corresponds to ~~too many~~numerous earthquakes~~,~~; this phenomenon ~~will~~ excessively ~~increase~~distorts the statistical results ~~in the latter part. It is found that there are about~~presented above. Around 233 earthquakes were observed to occur after the ~~12th~~ May 12 2008 ~~Ms8~~Ms 8.0 Wenchuan earthquake, ~~and the~~in locations ~~of these earthquakes are~~ close to the epicenter of Wenchuan ~~earthquake~~event. In chapter 4.2, the statistical analysis will be divided into two ~~part,~~sections: one ~~is~~dealing with the earthquakes ~~in~~that occurred during period C (from 2008.04 to 2008.07), and the other ~~is without the~~dealing with those that occurred outside of period C.

## 4.2 ~~The statistical~~Statistical analysis ~~for~~of the correlation between TIR anomalies and earthquakes

In this section, ~~the~~ TIR anomalies are extracted and a statistical analysis ~~aiming at studying~~of the correlation between TIR anomalies and earthquakes ~~with~~of M ≥ 4 is ~~also been~~ conducted.

~~The way to judge~~Evaluation of the TIR anomalies ~~is~~conforms strictly ~~conformed~~to the ~~rules mentioned~~guidelines detailed in chapter 3.3.

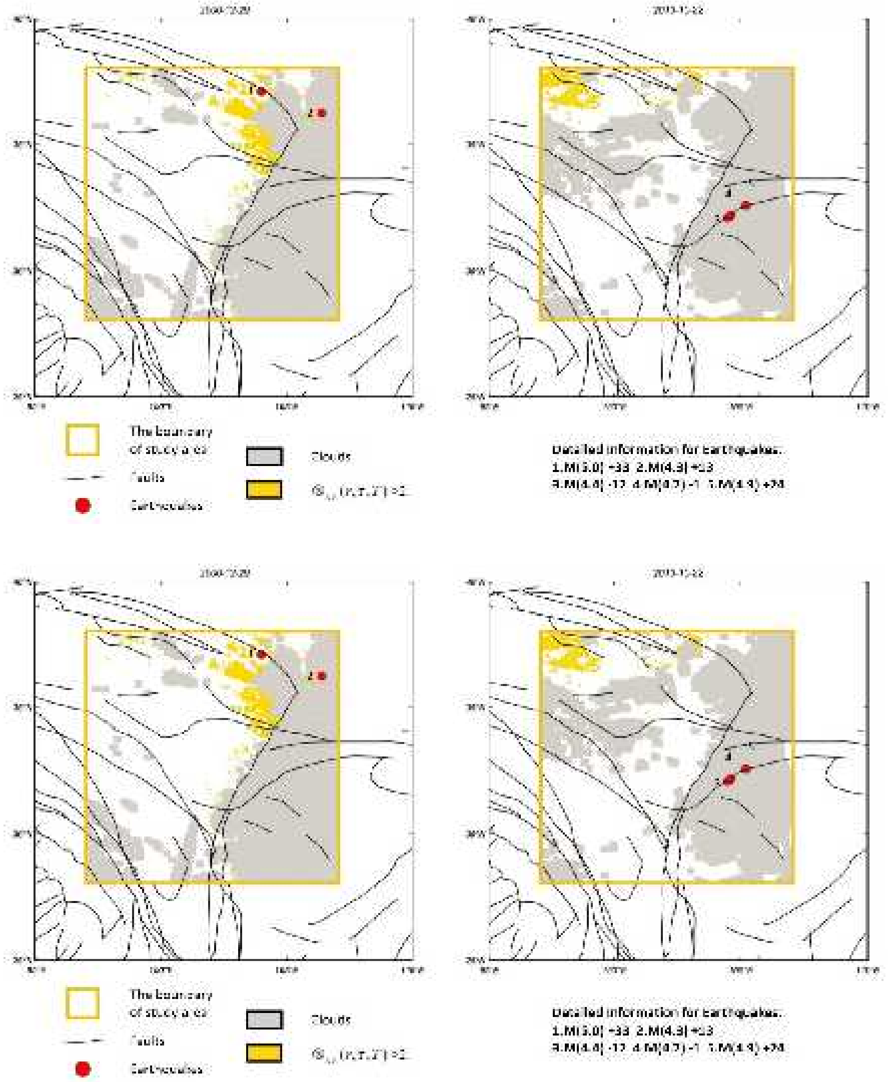

Fig. 4 Two ~~instance for~~examples of the correlation between TIR anomalies and earthquakes~~, and~~: on the left is the TIR anomaly ~~in~~recorded on 2006.12.29 ~~corresponding~~that corresponded to two earthquakes~~,~~ and on the right is the TIR anomaly ~~in~~recorded on 2010~~-~~.10~~-~~.22 ~~corresponding~~that did not correspondе~~d~~ to ~~three~~ earthquakes.

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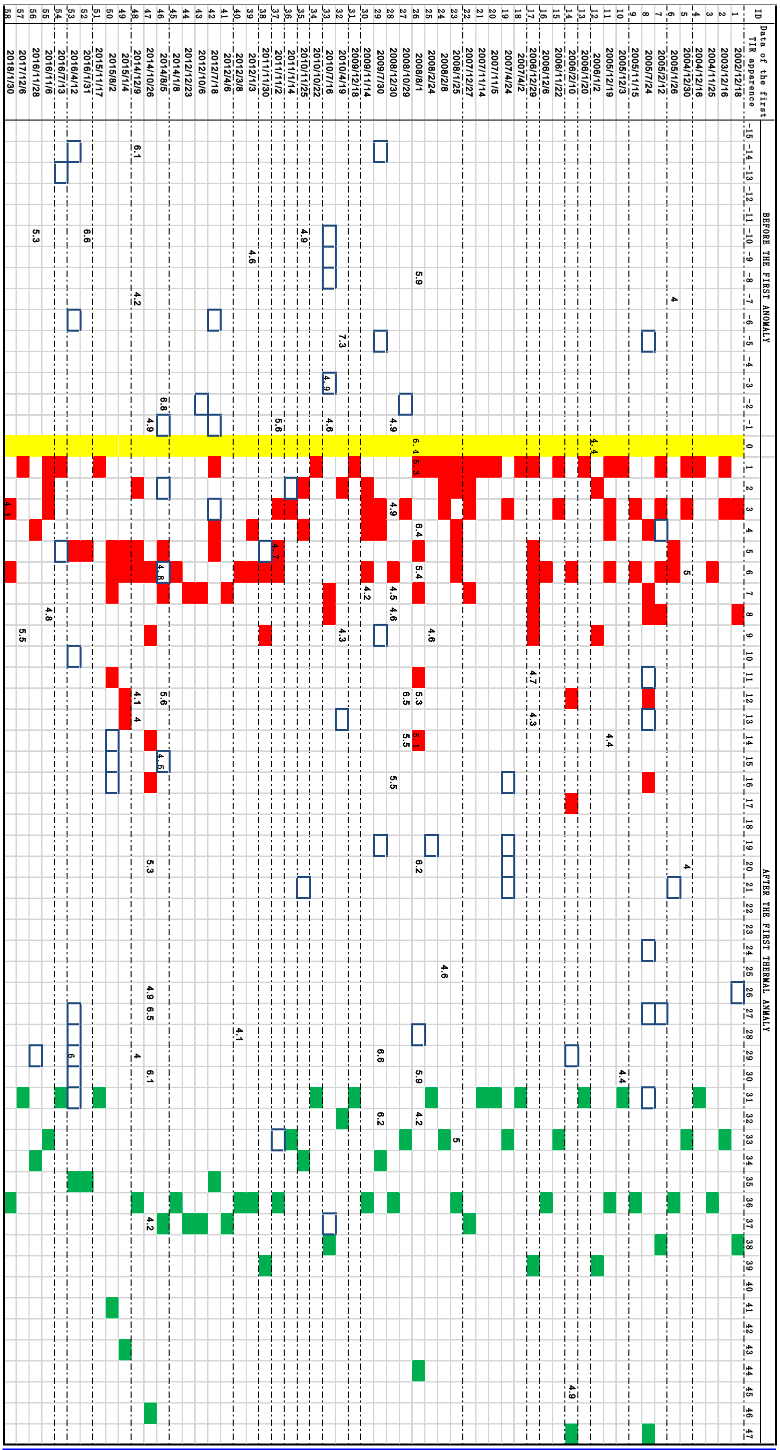
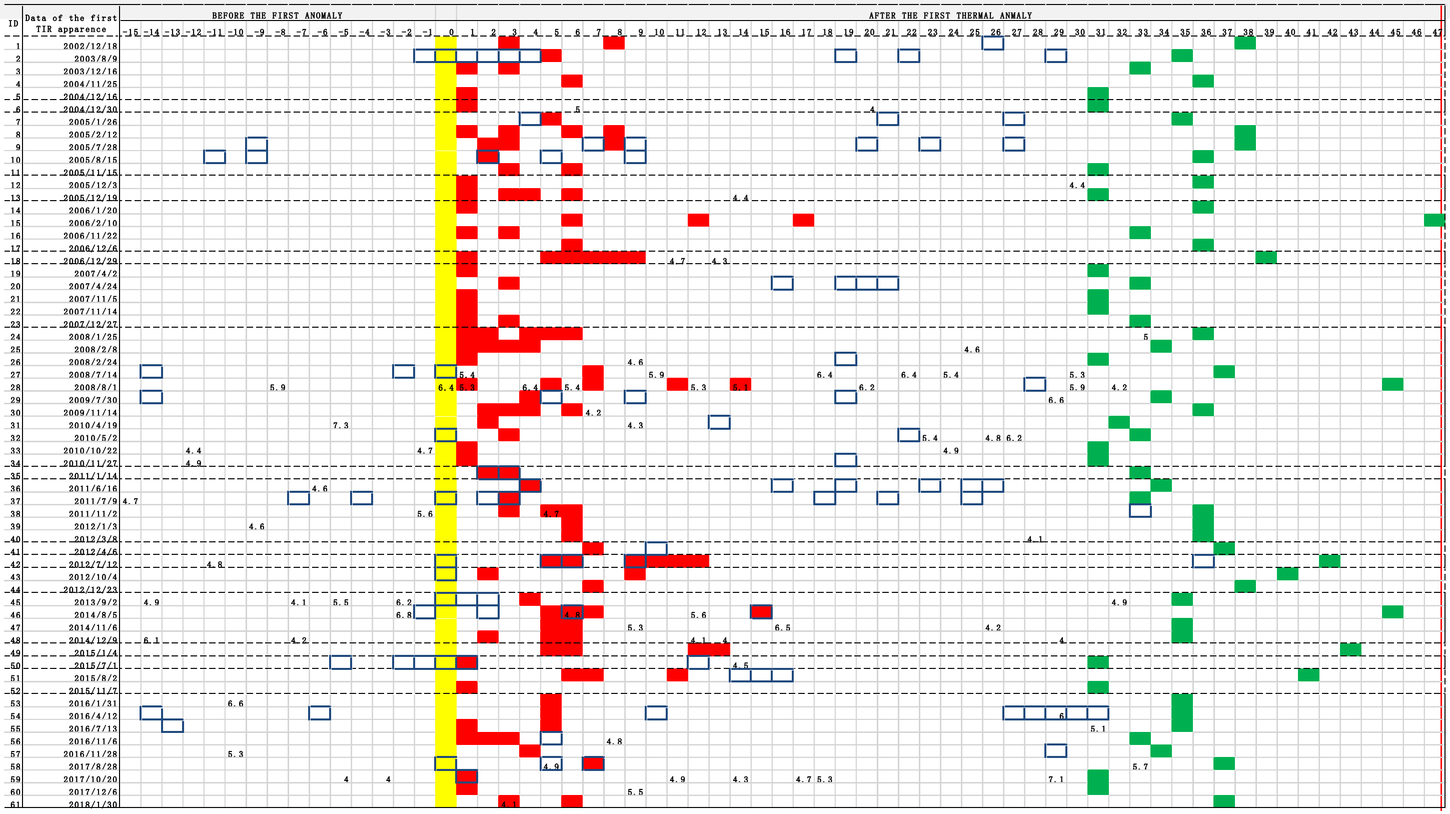
As ~~they are~~ shown in ~~the~~ Fig. 4, the TIR anomalies are extracted ~~by the~~using RST and the identification rules are applied to determine the correlation between TIR anomalies and earthquakes. After


ID
Data of the first TIR apparence
BEFORE THE FIRST ANOMALY
AFTER THE FIRST THERMAL ANOMALY



~~Fig.5 Correlation analysis among TIR anomalies and earthquakes with $M \geq 4.0$ in Sichuan area from Sep. 2002 to Mar. 2018. All 61 TIR anomalies are identified, and per row corresponds to one TIR anomaly. The first day of the TIR anomaly is shown in yellow, while the red cells are the following persistence. The cells in the blue rectangle mean that this day is affected by a large area of clouds, and the green cell is the final limitation for each anomaly. Cells with numbers indicate days of occurrence, and magnitude, of seismic events. The rows in the dotted box mean that there is no earthquakes corresponding to this TIR anomaly.~~

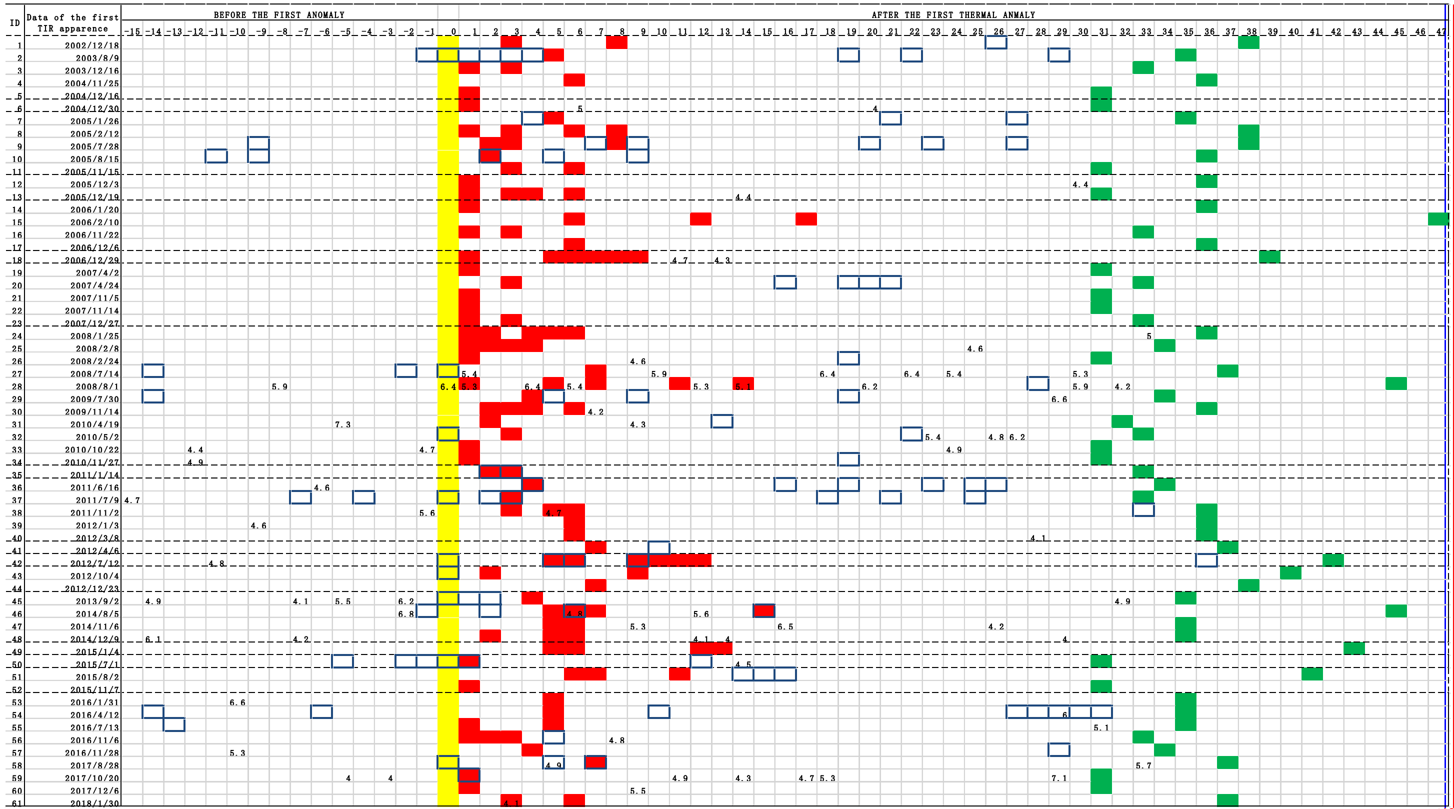



Fig. 5 Correlation analysis among TIR anomalies and earthquakes with magnitude bigger than 4.0 in the Sichuan area from September 2002 to March 2018. All 61 TIR anomalies are identified, and each row corresponds to one TIR anomaly. The first day of the TIR anomaly is shown in yellow, while the red cells denote the ensuing persistence. The cells in the blue rectangle indicate that this day is affected by a large area of cloud cover, and the green cell is the final limitation for each anomaly. Cells with numbers indicate days of occurrence, and magnitude, of seismic events. The rows in the dotted box mean that there is no earthquake corresponding to this TIR anomaly.

extraction, the total number of TIR anomalies is ~~61~~ 58 and the correlation ~~result is shown~~results are presented in ~~the~~ Fig. 5. Considering the examples reported in Fig. 4, which are summarized in ~~row~~rows ~~18~~ 17 and ~~33~~34, the cells in yellow corresponding to the first day of TIR anomaly are 2006-12-29 and 2010-10-22, respectively. It ~~can~~may be concluded ~~from the~~based on Fig. 5 that ~~35~~ 30 TIR anomalies correspond to earthquakes, while the other ~~26~~ 28 ~~do not, which are (~~(rows ~~1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 14, 15, 16, 17, 19, 20, 21, 22, 23, 35, 41, 43, 44,49, 51 and 52~~1, 2, 3, 4, 7, 8, 9, 13, 15, 16, 18, 19, 20, 21, 22, 31, 34, 36, 38, 41, 42, 43, 44, 45, 49, 50, 51 and 54) ~~)~~ do not. The correlation rate is 5~~7.4~~1.7%. ~~And as it is shown in~~It may be seen from Fig. 6 that most TIR anomalies appear ~~before~~as precursors to earthquakes.

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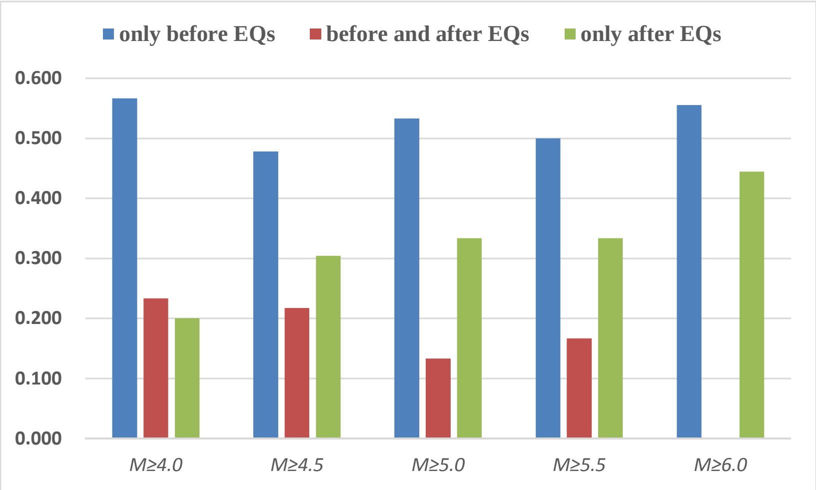


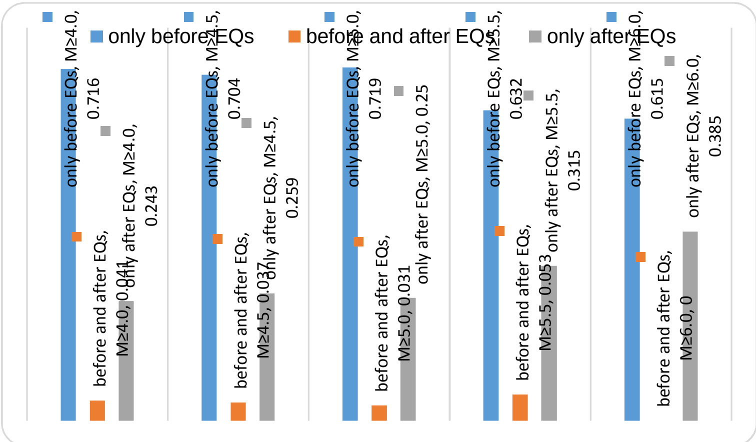

Fig. 6 Distribution of TIR anomalies with respect to ~~the earthquakes occurrence~~earthquake occurrences for different ~~class~~classes of magnitude.

However, as ~~it has been~~ mentioned in section 4.1~~ that~~, period C may be associated with a significant increase in the total number of TIR anomalies and the correlation rate~~ a lot. So~~. As such, the experiment was also performed without period C~~ is also been conducted~~, and the number of TIR anomalies is ~~60~~still 58, while the correlation rate is 5~~6.7~~1.7%, both of which are ~~roughly~~ the same as the former result. Theoretically, ~~in period C,~~ the high earthquake frequency ~~of earthquakes is high~~ and ~~the magnitude of earthquakes is large, which~~magnitudes of period C should generate ~~a lot of~~numerous TIR anomalies and ~~have good correspondences~~correlate strongly with earthquakes. ~~But there is~~However, only ~~one~~a single TIR anomaly corresponding to ~~5~~five earthquakes~~, Fig.~~ was observed. Figure 7 may indicate the reason~~. It indicates that~~ for this: earthquakes ~~are gathering in~~cluster along several faults, but the spatial ~~location~~locations of these faults are always blocked by ~~the clouds, and the~~cloud cover with a percentage ~~is bigger than~~ in excess of 90%. With the ~~long time and~~lengthy persistence of cloud coverage over a large area~~ of clouds blocking~~, the TIR anomalies caused by ~~the~~ earthquakes ~~in~~during period C ~~may~~ cannot be extracted ~~by~~using RST.

~~For a more comprehensive~~Comprehensive analysis ~~for~~of Fig. 5~~,~~ reveals that there are ~~23~~22 TIR anomalies in period A~~ with,~~ ~~19~~15 ~~corresponding~~of which do not correspond to ~~no~~ earthquakes, while ~~there are~~of 3~~8~~6 TIR anomalies in period B~~ with,~~ ~~only seven corresponding~~ ~~7~~13 do not correspond to ~~no~~ earthquakes and the correlation rate reaches ~~82~~63.9~~%~~%, which is ~~much~~significantly higher than 5~~7~~1.7%. ~~Fig.~~Figures 2 and ~~Fig.~~8 ~~can explain~~illustrate this phenomenon~~,~~: in period A, the ~~magnitudes of~~ earthquake intensity magnitudes are small, the frequency is low, and ~~nearly~~almost half of ~~the earthquake occurs~~all earthquakes occur in the cloudy region, or ~~its~~ adjacent ~~area, so the earthquakes are~~ to it; therefore, it is difficult to ~~correspond to~~ determine any correspondence between the earthquakes and the extracted anomalies, and some ~~potential~~ anomalies may have not been extracted ~~because of clouds. As for~~owing to the cloud cover. Regarding the results ~~in~~from period B, the frequency and ~~magnitude~~magnitudes of earthquakes in ~~the~~ sparsely ~~clouds~~clouded areas ~~increase a lot, thermal anomalies are more likely to be extracted and~~ are significantly increased, so that TIR anomalies are more likely to be extracted and more likely to correspond to earthquakes.

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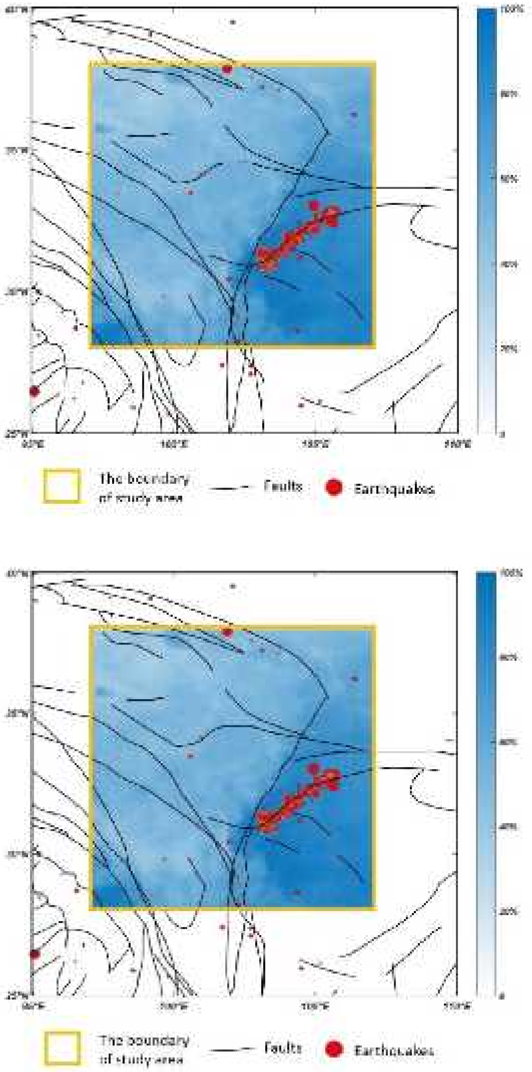


Fig. 7 The distribution of earthquakes ~~in period C~~ and the frequency of each pixel ~~being~~ blocked by cloud cover in period C~~, and the~~; higher values ~~mean~~indicate that the pixels are more ~~frequent~~frequently blocked by clouds.

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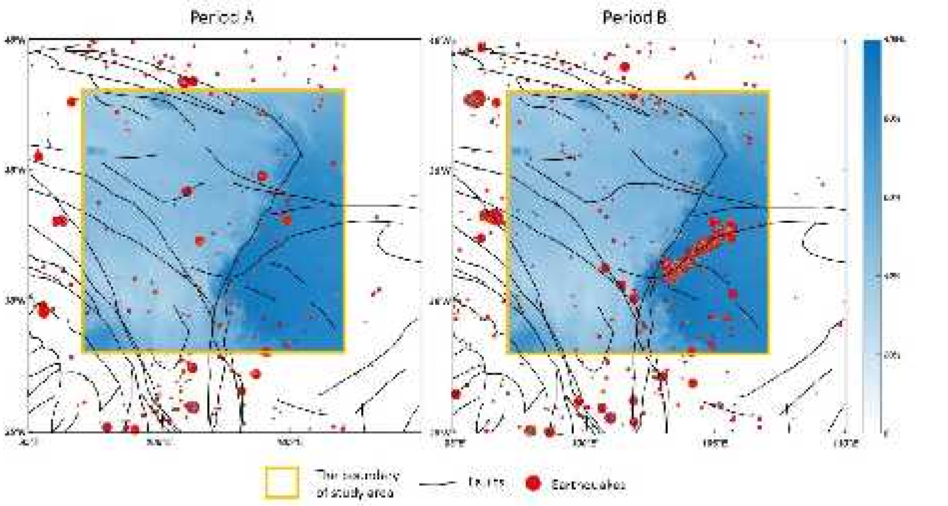


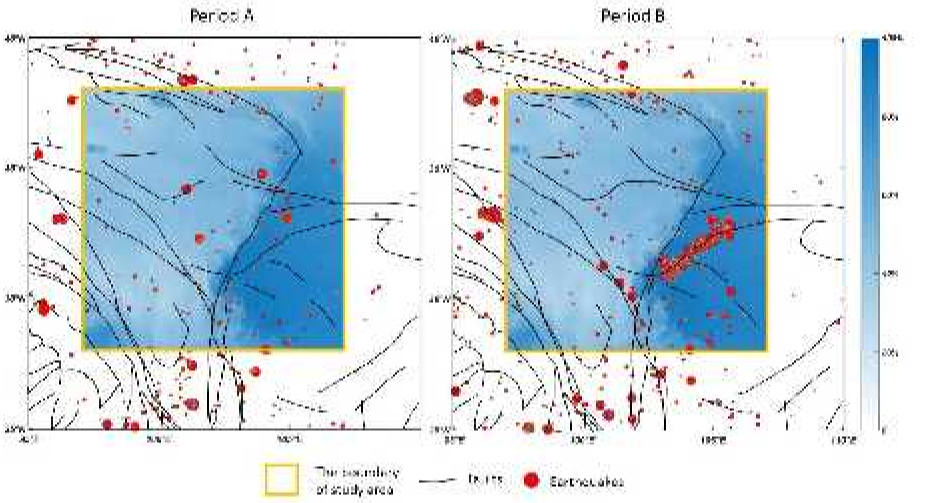


Fig.8 The distribution of earthquakes in ~~period~~periods A~~,~~ and B and the frequency of each pixel being blocked by cloud cover in period C~~, and the~~; higher values ~~mean~~indicate that the pixels are more ~~frequent~~frequently blocked by clouds.

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4.3 ~~The evaluation~~Evaluation of the earthquake prediction ~~ability for~~potential of RST using MODIS LST data in Sichuan area

~~Aiming at~~ With the aim of evaluating the earthquake prediction ~~ability~~potential of RST using MODIS LST data ~~in~~for the Sichuan area, ~~only~~ the true~~-~~ positive rate ~~for~~(TPR) of correspondence between TIR anomalies and earthquakes with M ≥ 4.0 ~~is far from enough. So~~alone is insufficient. Therefore, four types of data are ~~counted and~~ incorporated, with four types of ~~rate are~~ratio calculated as follows:

TP1: True~~ Positive~~-positive 1, the total number of TIR anomalies ~~corresponding~~that correspond to earthquakes.

FP: False~~ Positive~~-positive, the total number of TIR anomalies ~~corresponding~~that do not correspond to ~~no~~any earthquakes.

TP2: True~~ Positive~~-positive 2, the total number of earthquakes ~~corresponding~~that correspond to TIR anomalies.

FN: False~~ Negative~~-negative, the total number of earthquakes ~~corresponding~~that do not correspond to ~~no~~any TIR anomalies.

Positive predictive value (PPV~~:~~): The ~~rate~~ratio of TIR anomalies ~~which~~that correspond to earthquakes to the total number of TIR anomalies.

~~FPR:~~False discovery rate (FDR): The ~~rate~~ratio of TIR anomalies ~~which~~that do not correspond to ~~no~~any earthquakes to the total number of TIR anomalies.

TPR: The ~~rate~~ratio of earthquakes ~~which~~that correspond to TIR anomalies to the total ~~earthquakes.~~

~~FNR: The rate~~number of earthquakes~~ which correspond to no TIR anomalies to the total~~.

FNR: The ratio of earthquakes that do not correspond to any TIR anomalies to the total number of earthquakes.

**Table~~.~~ 2 ~~The statistical result~~Statistical results of earthquakes with M ≥ 5.0**

| | TP1 | FP | TP2 | FN |
| --- | --- | --- | --- | --- |
| M ≥ 5.0 | ~~19~~15 | ~~42~~43 | ~~32~~27 | ~~218~~223 |
| | PPV: ~~31.1~~25.9% TP1/(TP1+FP) | | TPR: ~~12~~10.8% TP2/(TP2+FN) | |
| | FDR: ~~68.9~~74.1% FP/(TP1+FP) | | FNR: ~~87~~89.2% | FN/(TP2+FN) |

For a more accurate understanding of the ~~8~~eight parameters, an example is ~~shown~~presented in Table 2. The example ~~studies~~considered the earthquakes ~~with~~of M ≥ 5.0, and ~~result indicates~~the results indicate that ~~there are 61~~58 (TP1+FP) TIR anomalies ~~appearing in study~~ appeared over the

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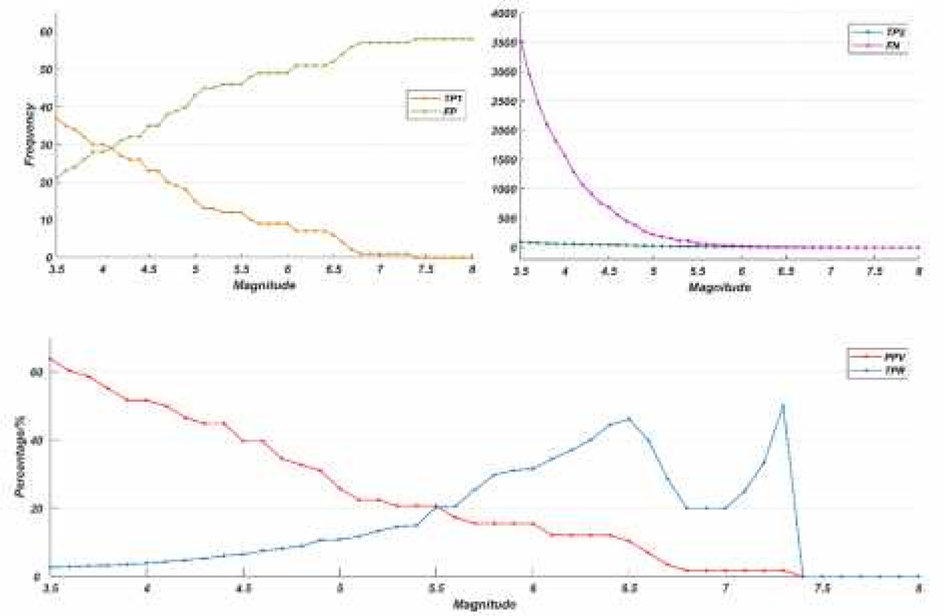
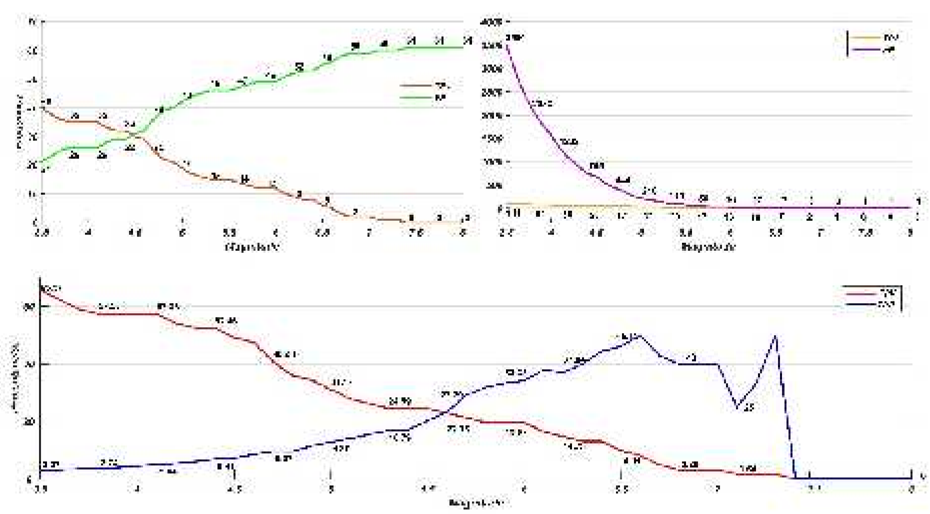
duration of the study period, and ~~19~~ 15 (TP1) of ~~them~~these correspond to earthquakes while the other ~~42~~ 43 (FP) do not; as such, the probability of exact correspondence between ~~the~~ TIR anomalies and earthquakes is ~~31.1~~25.9% (PPV~~)~~), while the probability of no correspondence is ~~68.9~~74.1% (~~FPR~~FDR). Moreover, ~~there are~~ 250 (TP2+FN) earthquakes ~~with~~of $M \geq 5.0$ were recorded in the study area~~, and~~; ~~32~~ 27 (TP2) of ~~them~~these correspond to TIR anomalies~~,~~ while the other ~~218~~ 223 (FN) ~~correspond to no TIR anomalies~~do not; as such, the probability of exact correspondence between the earthquakes and TIR anomalies is ~~12~~10.8% (TPR) while the probability of no correspondence is ~~87~~89.2% (FNR). We have calculated the earthquakes with $M \geq m$ (m~~={~~ = {3.5, 3.6, 3.7,…,7.8, 7.9, 8.0~~}). And both~~}), and the experiments are conducted both with and without period C~~ are calculated, the~~. The results show that ~~they are roughly the same~~these do not differ significantly, so in this section~~, we~~ only ~~discuss~~ the ~~result with~~results including period C are discussed.





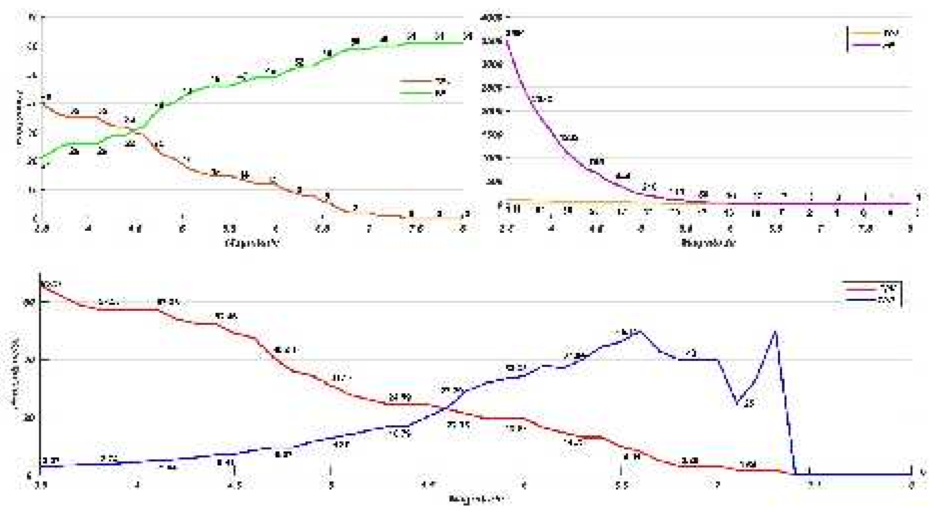


Fig. 9 The statistical ~~result~~results of earthquakes including ~~the~~ period C (from 2008.04 to 2008.07), and the ~~curve~~curves TP1, FP, TP2, FN, PPV and TPR~~ are corresponding~~, which correspond to the ~~example~~examples presented in Table 2.

**Table~~.~~ ~~2~~ 3 ~~The detailed~~Detailed results of earthquakes including ~~the~~ period C (from 2008.04 to 2008.07~~).~~)**

| M | TP1 | FP | TP2 | FN | PPV | ~~FPR~~FDR | TPR | FNR |
|---|---|---|---|---|---|---|---|---|
| 3.5 | 37~~40~~ | 21~~21~~ | 97~~111~~ | 3518~~3504~~ | 0.638 ~~0.656~~ | 0.362 ~~0.344~~ | 0.027 ~~0.031~~ | 0.973 ~~0.969~~ |
| 3.6 | 35~~38~~ | 23~~23~~ | 87~~100~~ | 2946~~2933~~ | 0.603 ~~0.623~~ | 0.397 | 0.029 | 0.971 |

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|---|---|---|---|---|---|---|---|---|
| | | | | | | ~~0.377~~ | ~~0.033~~ | ~~0.967~~ |
| 3.7 | 34~~36~~ | 24~~25~~ | 79~~90~~ | 2465~~2454~~ | | 0.414 | 0.031 | 0.969 |
| | | | | | 0.586 ~~0.590~~ | ~~0.410~~ | ~~0.035~~ | ~~0.965~~ |
| 3.8 | 32~~35~~ | 26~~26~~ | 70~~81~~ | 2094~~2083~~ | | 0.448 | 0.032 | 0.968 |
| | | | | | 0.552 ~~0.574~~ | ~~0.426~~ | ~~0.037~~ | ~~0.963~~ |
| 3.9 | 30~~35~~ | 28~~26~~ | 66~~76~~ | 1817~~1807~~ | | 0.483 | 0.035 | 0.965 |
| | | | | | 0.517 ~~0.574~~ | ~~0.426~~ | ~~0.040~~ | ~~0.960~~ |
| 4 | 30~~35~~ | 28~~26~~ | 63~~74~~ | 1574~~1563~~ | | 0.483 | 0.038 | 0.962 |
| | | | | | 0.517 ~~0.574~~ | ~~0.426~~ | ~~0.045~~ | ~~0.955~~ |
| 4.1 | 29~~35~~ | 29~~26~~ | 59~~68~~ | 1291~~1282~~ | | 0.500 | 0.044 | 0.956 |
| | | | | | 0.500 ~~0.574~~ | ~~0.426~~ | ~~0.050~~ | ~~0.950~~ |
| 4.2 | 27~~33~~ | 31~~28~~ | 54~~62~~ | 1076~~1068~~ | | 0.534 | 0.048 | 0.952 |
| | | | | | 0.466 ~~0.541~~ | ~~0.459~~ | ~~0.055~~ | ~~0.945~~ |
| 4.3 | 26~~32~~ | 32~~29~~ | 51~~59~~ | 917~~909~~ | | 0.552 | 0.053 | 0.947 |
| | | | | | 0.448 ~~0.525~~ | ~~0.475~~ | ~~0.061~~ | ~~0.939~~ |
| 4.4 | 26~~32~~ | 32~~29~~ | 49~~56~~ | 762~~755~~ | | 0.552 | 0.060 | 0.940 |
| | | | | | 0.448 ~~0.525~~ | ~~0.475~~ | ~~0.069~~ | ~~0.931~~ |
| 4.5 | 23~~30~~ | 35~~31~~ | 48~~54~~ | 691~~685~~ | | 0.603 | 0.065 | 0.935 |
| | | | | | 0.397 ~~0.492~~ | ~~0.508~~ | ~~0.073~~ | ~~0.927~~ |
| 4.6 | 23~~29~~ | 35~~32~~ | 45~~51~~ | 556~~550~~ | | 0.603 | 0.075 | 0.925 |
| | | | | | 0.397 ~~0.475~~ | ~~0.525~~ | ~~0.085~~ | ~~0.915~~ |
| 4.7 | 20~~25~~ | 38~~36~~ | 40~~47~~ | 451~~444~~ | | 0.655 | 0.081 | 0.919 |
| | | | | | 0.345 ~~0.410~~ | ~~0.590~~ | ~~0.096~~ | ~~0.904~~ |
| 4.8 | 19~~22~~ | 39~~39~~ | 37~~40~~ | 382~~379~~ | | 0.672 | 0.088 | 0.912 |
| | | | | | 0.328 ~~0.361~~ | ~~0.639~~ | ~~0.095~~ | ~~0.905~~ |
| 4.9 | 18~~21~~ | 40~~40~~ | 33~~36~~ | 279~~276~~ | | 0.690 | 0.106 | 0.894 |
| | | | | | 0.310 ~~0.344~~ | ~~0.656~~ | ~~0.115~~ | ~~0.885~~ |
| 5 | 15~~19~~ | 43~~42~~ | 27~~32~~ | 223~~218~~ | | 0.741 | 0.108 | 0.892 |
| | | | | | 0.259 ~~0.311~~ | ~~0.689~~ | ~~0.128~~ | ~~0.872~~ |

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|---|---|---|---|---|---|---|---|---|
| 5.1 | 13~~17~~ | 45~~44~~ | 25~~30~~ | 188~~183~~ | 0.224 ~~0.279~~ | 0.776 ~~0.721~~ | 0.117 ~~0.141~~ | 0.883 ~~0.859~~ |
| 5.2 | 13~~16~~ | 45~~45~~ | 24~~28~~ | 156~~152~~ | 0.224 ~~0.262~~ | 0.776 ~~0.738~~ | 0.133 ~~0.156~~ | 0.867 ~~0.844~~ |
| 5.3 | 12~~16~~ | 46~~45~~ | 20~~27~~ | 117~~127~~ | 0.207 ~~0.262~~ | 0.793 ~~0.738~~ | 0.146 ~~0.175~~ | 0.854 ~~0.825~~ |
| 5.4 | 12~~15~~ | 46~~46~~ | 20~~23~~ | 114~~111~~ | 0.207 ~~0.246~~ | 0.793 ~~0.754~~ | 0.149 ~~0.172~~ | 0.851 ~~0.828~~ |
| 5.5 | 12~~15~~ | 46~~46~~ | 19~~19~~ | 75~~75~~ | 0.207 ~~0.246~~ | 0.793 ~~0.754~~ | 0.202 ~~0.202~~ | 0.798 ~~0.798~~ |
| 5.6 | 10~~14~~ | 48~~47~~ | 15~~17~~ | 58~~56~~ | 0.172 ~~0.230~~ | 0.828 ~~0.770~~ | 0.205 ~~0.233~~ | 0.795 ~~0.767~~ |
| 5.7 | 9~~13~~ | 49~~48~~ | 14~~16~~ | 41~~39~~ | 0.155 ~~0.213~~ | 0.845 ~~0.787~~ | 0.255 ~~0.291~~ | 0.745 ~~0.709~~ |
| 5.8 | 9~~12~~ | 49~~49~~ | 14~~15~~ | 33~~32~~ | 0.155 ~~0.197~~ | 0.845 ~~0.803~~ | 0.298 ~~0.319~~ | 0.702 ~~0.681~~ |
| 5.9 | 9~~12~~ | 49~~49~~ | 14~~15~~ | 31~~30~~ | 0.155 ~~0.197~~ | 0.845 ~~0.803~~ | 0.311 ~~0.333~~ | 0.689 ~~0.667~~ |
| 6 | 9~~12~~ | 49~~49~~ | 12~~13~~ | 26~~25~~ | 0.155 ~~0.197~~ | 0.845 ~~0.803~~ | 0.316 ~~0.342~~ | 0.684 ~~0.658~~ |
| 6.1 | 7~~10~~ | 51~~51~~ | 10~~11~~ | 19~~18~~ | 0.121 ~~0.164~~ | 0.879 ~~0.836~~ | 0.345 ~~0.379~~ | 0.655 ~~0.621~~ |
| 6.2 | 7~~9~~ | 51~~52~~ | 10~~10~~ | 17~~17~~ | 0.121 ~~0.148~~ | 0.879 ~~0.852~~ | 0.370 ~~0.370~~ | 0.630 ~~0.630~~ |
| 6.3 | 7~~8~~ | 51~~53~~ | 8~~8~~ | 12~~12~~ | 0.121 ~~0.131~~ | 0.879 ~~0.869~~ | 0.400 ~~0.400~~ | 0.600 ~~0.600~~ |
| 6.4 | 7~~8~~ | 51~~53~~ | 8~~8~~ | 10~~10~~ | 0.121 ~~0.131~~ | 0.879 ~~0.869~~ | 0.444 ~~0.444~~ | 0.556 ~~0.556~~ |
| 6.5 | 6~~6~~ | 52~~55~~ | 6~~6~~ | 7~~7~~ | 0.103 ~~0.098~~ | 0.897 | 0.462 | 0.538 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 0.902 | 0.462 | 0.538 |
| 6.6 | 45 | 5456 | 45 | 65 | | 0.931 | 0.400 | 0.600 |
| | | | | | 0.069 0.082 | 0.918 | 0.500 | 0.500 |
| 6.7 | 23 | 5658 | 23 | 54 | | 0.966 | 0.286 | 0.714 |
| | | | | | 0.034 0.049 | 0.951 | 0.429 | 0.571 |
| 6.8 | 12 | 5759 | 12 | 43 | | 0.983 | 0.200 | 0.800 |
| | | | | | 0.017 0.033 | 0.967 | 0.400 | 0.600 |
| 6.9 | 12 | 5759 | 12 | 43 | | 0.983 | 0.200 | 0.800 |
| | | | | | 0.017 0.033 | 0.967 | 0.400 | 0.600 |
| 7 | 12 | 5759 | 12 | 43 | | 0.983 | 0.200 | 0.800 |
| | | | | | 0.017 0.033 | 0.967 | 0.400 | 0.600 |
| 7.1 | 11 | 5760 | 11 | 33 | | 0.983 | 0.250 | 0.750 |
| | | | | | 0.017 0.017 | 0.983 | 0.250 | 0.750 |
| 7.2 | 11 | 5760 | 11 | 22 | | 0.983 | 0.333 | 0.667 |
| | | | | | 0.017 0.017 | 0.983 | 0.333 | 0.667 |
| 7.3 | 11 | 5760 | 11 | 11 | | 0.983 | 0.500 | 0.500 |
| | | | | | 0.017 0.017 | 0983 | 0.500 | 0.500 |
| 7.4 | 00 | 5861 | 00 | 11 | | 1.000 | 0.000 | 1.000 |
| | | | | | 0.000 0.000 | 1.000 | 0.000 | 1.000 |
| 7.5 | 00 | 5861 | 00 | 11 | | 1.000 | 0.000 | 1.000 |
| | | | | | 0.000 0.000 | 1.000 | 0.000 | 1.000 |
| 7.6 | 00 | 5861 | 00 | 11 | | 1.000 | 0.000 | 1.000 |
| | | | | | 0.000 0.000 | 1.000 | 0.000 | 1.000 |
| 7.7 | 00 | 5861 | 00 | 11 | | 1.000 | 0.000 | 1.000 |
| | | | | | 0.000 0.000 | 1.000 | 0.000 | 1.000 |
| 7.8 | 00 | 5861 | 00 | 11 | | 1.000 | 0.000 | 1.000 |
| | | | | | 0.000 0.000 | 1.000 | 0.000 | 1.000 |
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| 8 | 0~~0~~ | 58~~61~~ | 0~~0~~ | 1~~1~~ | | 1.000 | 0.000 | 1.000 |
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As ~~it is shown in~~ may be seen from Fig~~.~~ 9, PPV declines as the magnitude increases, while FP ~~obviously increases, this~~is also clearly seen to increase. This phenomenon indicates that with ~~the increase of the~~increased magnitude, the number of TIR anomalies ~~corresponding~~that correspond to the earthquakes decreases. TPR and FN can be seen to decrease steadily~~, because~~ as the total number of earthquake samples ~~is decreasing~~decreases.

~~But, what needs more~~The ratios (PPV and TPR) demand closer attention~~ is the rates (PPV, TPR). Firstly~~, however. First, a general perceptual analysis ~~shows~~reveals that PPV decreases steadily ~~with the increasing of~~as M increases, while TPR ~~is increasing~~ increases when ~~M~~ M≤ 6.5 and M=6.8~7.3 ≤ 6.6 and M = 7.2, 7.3~~,~~; the maximum ~~of~~ TPR is 50% when M= = ~~6.6 and~~ 7.3, and ~~the~~ TPR decreases when M=6.5~6.8 = 6.7~7.1. When M is 3.5 and 4.0, PPV is ~~65~~63.~~8~~6% and ~~57~~51.~~4~~7%, ~~it means~~respectively, indicating that when ~~there is~~ a TIR anomaly ~~appearing~~is evident, there is a ~~possibility of~~ 6~~5~~3.~~8~~6% (~~57~~51.~~4~~7%) possibility that earthquakes ~~with~~of M~~⩾~~ ≥ 3.5 (4.0) will ~~happen~~occur. When ~~the~~ M is 5, 6, or 7, ~~the E~~ PPV is ~~31.1~~25.9%, 1~~5.5~~9.7%, 1.7~~3.3~~%, and these are much lower than the PPV of M= = 3.5 and 4.0. It ~~is~~may be concluded from the change ~~of~~in the PPV curve that where ~~there is~~ a TIR anomaly is present, there will be a more than 50% possibility of an earthquake with M ≥3.5 (4.0) in the study area. ~~However, this~~ It does not ~~mean~~necessarily follow, however, that when there is a TIR anomaly, there will be strong earthquakes with M~~⩾~~ ≥ 5.0 in the study area. On the contrary, the probability ~~of~~that earthquakes ~~with~~of high magnitude ~~is still not high~~will occur remains low.

The TPR curve ~~of TPR tells~~indicates the probability ~~of a~~that an associated TIR anomaly will be present when earthquakes occur. When M =3.5 the TPR is ~~3.1~~2.7%, and ~~with the increasing of M~~as M increases, TPR increases steadily, ~~but~~although it ~~keeps in a~~remains low ~~state~~ when M □ [3.5, 5.4] and the TPR ~~are~~is lower than 20%. The results show that ~~the~~ lower-magnitude earthquakes ~~with low magnitude have~~ are relatively ~~low possibility~~ less likely (less than 20%) to correspond to TIR anomalies, ~~however, the~~while earthquakes ~~with~~of M~~⩾~~ ≥ 6.0, which are very destructive, have a ~~relative high~~relatively high likelihood of corresponding. High correspondence~~.~~ ~~The high correspondence is of great significance~~ is particularly significant with regard to



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earthquake prediction~~. It tells us that a considerable number of the~~: it indicates that destructive ~~earthquake is~~earthquakes are considerably more likely to be ~~predicted by~~predictable ~~using this method~~in this case.

According to ~~two~~both sets of results, ~~it can be concluded~~we may conclude that~~,~~ when a TIR anomaly ~~occurs~~is present, there is a 5~~7.3~~1.7% possibility ~~of~~that an earthquake ~~with~~of M~~⩾~~ ≥ 4.0 will occur, and ~~when there is a strong earthquake with~~in the case of earthquakes of M~~⩾~~ ≥ 6.0 occurs, more than ~~1/3 of the earthquakes~~ one third correspond to ~~thermal~~ TIR anomalies. Most TIR anomalies correspond to ~~the~~ earthquakes ~~with~~of M~~⩾~~ ≥ 4.0~~, however~~. However, when M~~⩾~~ ≥ 6.0, the PPV is relatively low, ~~and that means the~~resulting in a higher false alarm rate for strong earthquakes~~ is high. For~~. TPR~~, it is increasing~~ increases with ~~the~~ magnitude, and when M~~=~~ = ~~6.6 and~~ 7.3, it is 50%. It ~~can~~may be concluded ~~from~~based on the TPR curve ~~TPR~~ that the greater ~~the~~an earthquake's magnitude~~ of an earthquake is~~, the more ~~likely it is to be predicted by~~effective this method~~. But, in fact~~ is likely to be in predicting it. However, the PPV and TPR are low, or ~~in other words~~ the ~~FPR~~FDR and FNR, which are negative ~~for~~with regard to the ~~prediction ability~~predictive potential of RST, are ~~really~~ high. ~~All in all~~Overall, the false alarm rate for M~~⩾~~ ≥ 4.0 is 4~~2.6~~8.3%, ~~with the increasing of M the FPR will become higher,~~ and ~~the~~as M increases so too does FDR. The missing rate for M~~⩾~~ ≥ 4.0 is 96.2%, and it seems that when M~~<~~ < 5.5, there is no obvious correlation between TIR anomalies and earthquakes~~, though~~; nevertheless, TPR ~~will~~tends to increase when M ~~is becoming bigger, while the~~increases, though its maximum ~~of TPR is still~~remains at 50%, which is also an ~~unsatisfied~~unsatisfactory value. ~~So~~As such, the prediction ~~ability~~potential of RST using MODIS LST data ~~–~~in the Sichuan area is limited. However, it doesn't indicate that the RST is not effective for earthquake prediction, on the contrary, many other cases prove that this method is very effective for extracting TIR anomalies. The low PPV and TPR may be caused by the limitation of RST, nature of MODIS LST data, special topographic and weather background of study area, or something else.

## 5. Discussion

To compare ~~the~~these results with ~~the~~those from previous similar studies, ~~the summary~~a summaries of ~~the~~ four ~~similar~~such studies ~~is shown~~are presented in Table~~.~~ 3. It is ~~obvious~~evident that PPV ~~of this paper~~ is relatively lower in this study than in the others, so it is important to verify

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its actual added value in comparison with a random alarm function (see, for ~~instance~~example, Eleftheriou et al., 2016). The detailed method is ~~accessible~~available in chapter 3.4 of ~~(Eleftheriou, Filizzola et al., 2016),~~Eleftheriou et al. (2016), and the result is ~~shown~~presented in Fig. 10. When M ≥ 3.5, the point is at the upper ~~part~~extreme of the random guess, ~~which means~~ with the result that there is no obvious correlation between TIR anomalies and earthquakes with M ≥ 3.5~~, it seems that it is of a casual~~ ; rather, the correlation appears to be casual. When M ≥ 4.0 and M≥ 4.5, both of these ~~two~~ points are still very close to the line, ~~but it is~~though at the lower part, ~~and that means~~meaning that a non-casual correlation is actually ~~exists~~present among the extracted TIR anomalies and earthquakes (M ≥ 4.0 and ≥ 4.5). However, the correlation is not strong. The result in this ~~paper~~study is different from ~~Eleftheriou's study,~~that achieved by Eleftheriou: in her study, ~~there is a much more obvious and~~the strong correlation between the TIR anomalies and earthquakes~~. The cause~~ is much more evident. This may be attributable to the fact that, as ~~it being~~ shown in Fig. 8, the east and southeast corner of the study area is ~~always~~consistently blocked by ~~the~~ clouds, ~~and total~~ i.e., for over 90% of the time~~ taken up is over 90%, at the same time there are many~~. Several earthquakes ~~happening~~also occur in this area, ~~and these~~ but insufficient data prevents correlation between the earthquakes ~~cannot be related to~~and TIR anomalies~~ because of the lack of data~~, and they are inevitably ~~counted~~classified into FNR, which is v in Molchan error analysis, making the correlation weaker. For ~~the~~ M ≥ 5.0, 5.5 and 6.0, the points are ~~obvious~~clear under the random guess, ~~with the increasing of~~and as M increases, the non-causal correlation is ~~becoming stronger~~strengthened.

Tronin indicated that the anomaly was sensitive to crustal earthquakes ~~with~~that were of a magnitude ~~more~~greater than 4.7 ~~and for~~over a distance of up to ~~1000km~~1,000 km (Tronin, Hayakawa et al., 2002). ~~But in~~In this study, however, when M~~=~~ = 4.7, the TPR is 9.6% and the FNR is 90.4%, and at the point in Fig. 10~~, when~~ at which M ≥ 4.5~~,~~ is very close to the random guess, ~~so~~ the statistical result does not support the ~~opinion~~theory that the TIR anomaly is sensitive to the earthquakes ~~with~~of M ≥ 4.7. When M ≥ 5.9, ~~the~~ earthquakes ~~seem~~appear to be sensitive to TIR anomalies~~ according to the~~, as may be seen from Table~~.~~ 3. ~~The reason for this~~This failure to conform to previous ~~conclusion~~conclusions may be attributable to the regional structure and geological movement, cloud cover, ~~the~~and effectiveness of the method for extracting TIR anomalies~~ and so on~~, among other factors. Further study is ~~needed~~required, however.

**Table~~.~~ ~~3~~ 4 A general summary ~~for~~of research ~~studying~~on the statistical correlation between TIR anomalies and earthquakes~~.~~**

| ~~Author's name~~Author | Data Source | Study area | Duration | PPV |
|---|---|---|---|---|
| Genzano | GMS-5/VISSR | Taiwan | 1995.09-2002.09 | 100%(M≥ 4 or 4.5)<br>94%(M≥ 5.0) |
| Tramutoli | | Italian southern Apennines | 2012.07-2013.06 | 67% |
| Eleftheriou Alexander | MSG/SEVIRI | Greece | 2004-2013 | 93% (M≥ 4.0) |
| Ying Zhang | MODIS | China, Sichuan Area | 2002.09-2018.03 | 5~~7.4~~1.7%(M≥ 4.0) |

We ~~have counted~~calculated the total number of TIR anomalies and ~~number~~numbers of FP ~~in~~for each month ~~of two~~in both studies~~. And it is,~~ and found that ~~the~~ in Eleftheriou's study TIR anomalies ~~are gathering~~clustered in November, September, January and February ~~in Eleftheriou's study~~, while in ~~this paper, TIR anomalies are gathering~~the present study they cluster in November, September and January. A line ~~which means~~indicating the percentage of area not blocked by clouds in the Sichuan ~~area~~region is also ~~presented~~illustrated in Fig. 11. In this paper, there is a significant positive proportional correlation between the number of TIR anomalies and the area not blocked by clouds. When the percentage is high, the number of TIR anomalies is also high, and when the percentage is low, the number of TIR anomalies is low. ~~So there might be many~~ Therefore, while several TIR anomalies related to earthquakes~~, but~~ may be present, they are blocked by ~~the clouds~~cloud cover and cannot be extracted. However, the question of what ~~is~~ the true cause~~, blocked by clouds, caused by~~ is, i.e., cloud clover, seasonal weather, or ~~else? It is remained~~some other factor, remains to be ~~solved~~answered satisfactorily. Moreover, ~~there is~~ another interesting phenomenon is that ~~many~~several TIR anomalies ~~corresponding~~that do not correspond to ~~no~~any earthquakes ~~are gathering~~cluster in November and September, ~~and~~ both of which are cold months ~~are~~that do not tend to be cloudy ~~and are in cold weather. So, why many FP~~



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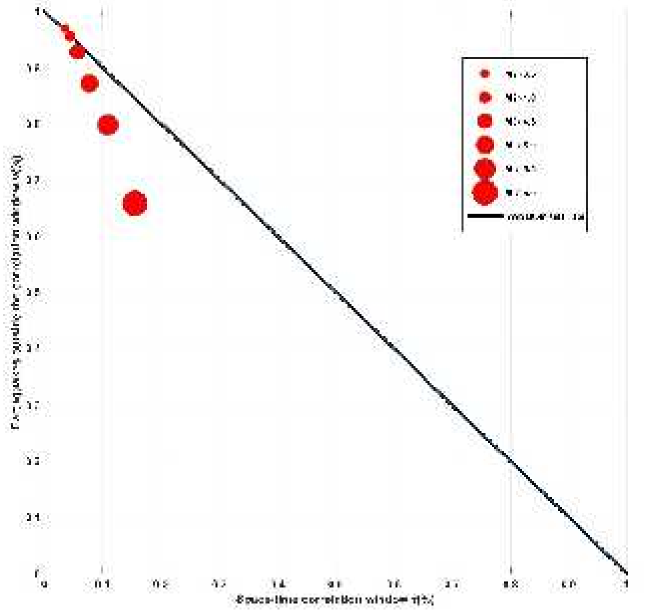
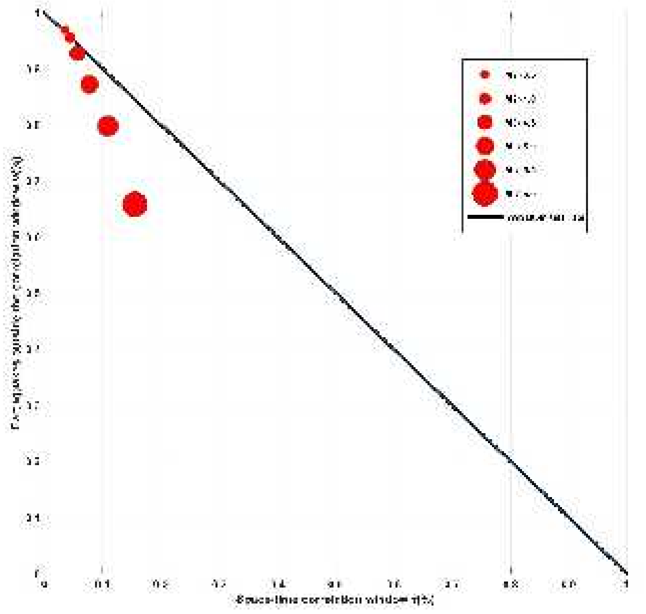
~~are gathering in~~. Therefore, the clustering of numerous FPs during these ~~two~~2 months ~~is~~ also ~~remained~~remains to be ~~studied~~fully investigated.





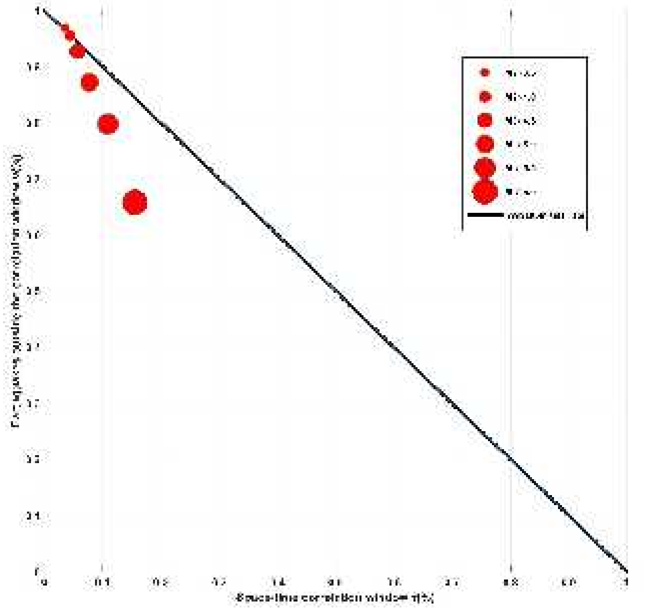


Fig. 10 Molchan error diagram analysis computed for different ~~class~~classes of magnitude and TIR anomalies ~~on~~during the study period (from 2002.09~~-~~ to 2018.03~~), and~~); the red circles refer to earthquakes that occurred before and after the ~~appearances~~appearance of TIR anomalies.

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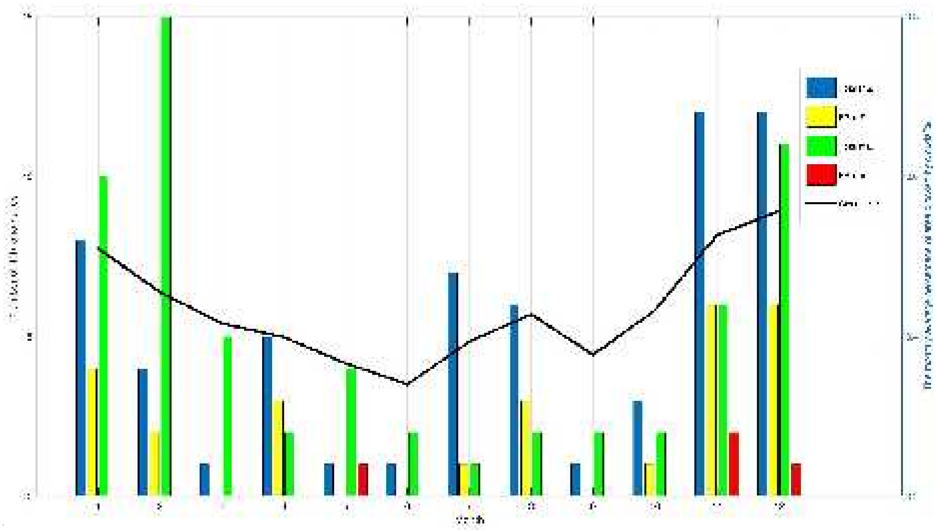

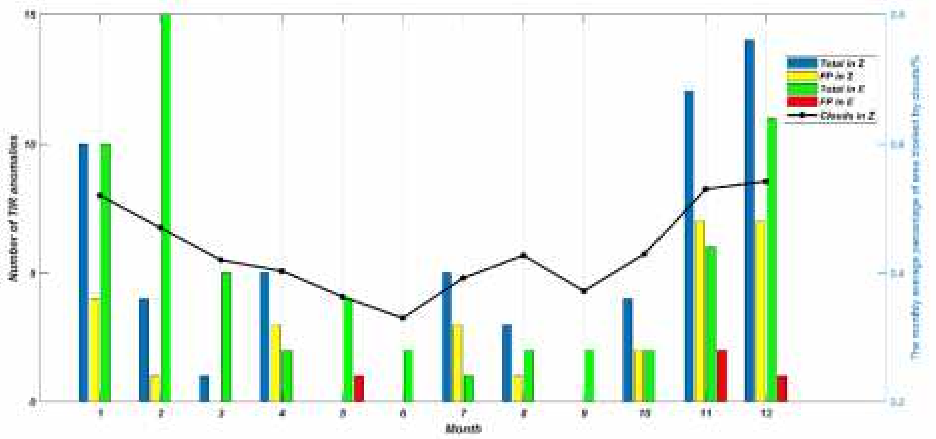


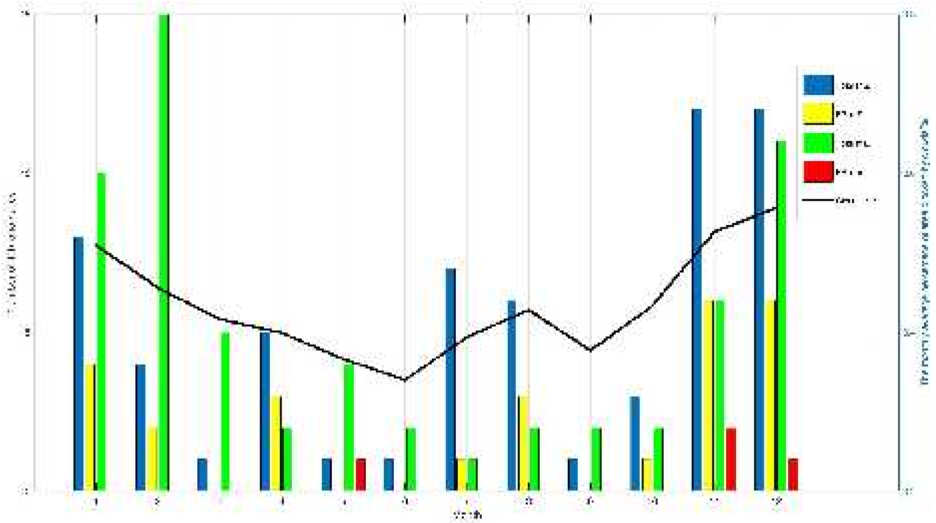

Fig. 11 The monthly average percentage of the area not blocked by clouds in ~~study region in~~ Zhang's study~~, or in other words, in~~ region, i.e., that of this study. ~~And the~~The bar chart ~~is~~presents the numbers of ~~different kind~~various types of TIR ~~anomalies~~anomaly. ‘Total in Z’ is the total number of TIR anomalies in this study~~,~~; ‘FP in Z’ is the number of TIR anomalies ~~corresponding~~that do not correspond to ~~no~~any earthquakes in this study~~.~~; ‘Total in E’ is the total number of TIR anomalies in Eleftheriou’s study~~,~~; ‘FP in E’ is the number of TIR anomalies ~~corresponding~~that do not correspond to ~~no~~any earthquakes in Eleftheriou’s study.

## 6. Conclusions

(1) ~~18 years statistical~~Statistical analysis ~~for~~of 18 years’ worth of data on the correlation between earthquakes and TIR anomalies ~~shows~~indicate that ~~57~~51.~~7~~4% of TIR anomalies correspond to

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~~the~~ earthquakes ~~with~~of $M \geq 4.0$ in the Sichuan ~~area~~region, and the ~~bigger~~higher the M ~~is~~, the more likely it is that the earthquakes will correspond to TIR anomalies. The low PPV and TPR may be ~~due~~attributable to the large ~~areas in~~portions of the study region that are covered by clouds ~~all~~ throughout the year ~~round~~.

(2) The low PPV and TPR suggest that the ~~earthquakes~~earthquake prediction ~~ability in~~ potential of RST using MODIS LST data with regard to the Sichuan ~~area with use of RST~~ region is limited. For ~~the strong~~stronger earthquakes, with $M \geq 6.0$, ~~though~~although the false alarm rate is high, the missing rate is relatively low. RST was applied to the study area and ~~has certain prediction ability for~~was found to have significant predictive potential with regard to strong earthquakes.

(3) There is no obvious correlation between ~~the~~ earthquakes ~~with~~of $M < 5.0$ and the TIR anomalies extracted ~~by~~using RST and MODIS LST data in the Sichuan ~~area~~region. However, the underlying causes of this situation ~~need to be~~merit further ~~studied~~investigation.

(4) The RST ~~put up~~proposed in this ~~paper or~~study and in Eleftheriou's study is still ~~seriously~~considerably affected by ~~the clouds~~cloud cover and ~~the seasons~~seasonal influences. It is necessary to improve and optimize algorithms and statistical methods ~~to exclude~~that facilitate the ~~influence~~exclusion of ~~clouds~~cloud and ~~seasons~~seasonal influences.

~~(4)~~

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