Case study: Investigation of seismo-thermal precursor of Goharan earthquake (2013) By Thermal data of MODIS SENSOR IN TERRA Satellite

ABSTRACT

The main objective of this research was to study seismo-thermal earthquake precursor of Goharan earthquake (2013) using TERRA satellite image and MODIS (Moderate-resolution Imaging Spectroradiometer) sensor. In order to reach this goal Land Surface Temperature (LST) data for seismo-thermal precursor were considered through colorization and time series analysis using wavelet transform. In addition, in considering of time series for reduction of noise effect on data, air temperature time series of the closest station is reduced from LST time series.

Results of colorization revealed that region with higher temperature can be used for recognition of fault plane and auxiliary plane. Subsequently, after plotting earthquake aftershocks, it is possible to estimate the location of the strike of earthquake fault and the found strike location is in agreement with higher temperature line. Also, time series analysis and application of wavelet transform analysis shows that before an earthquake, soil temperature reaches to the highest temperature four days before the event and afterward soil’s temperature subsides to the minimum on earthquake’s day.

[RC: The sentence above is confusing, needs revision]

[RC: The conclusion that there has been a precursory temperature change is based on extremely weak arguments. The work has failed to show that the observed change is NOT due to normal air circulation at ground level and has NOT examined air temperature changes during other periods.

More importantly, the work has FAILED to present data on temperature changes that occurred during other earthquakes in the same area. There has been 82 earthquakes with magnitude greater than 1.5 in Iran, in the last year.

The practice of SELECTIVE use of data is unscientific and should be discouraged.

Text in the abstract is Confusing, Needs revision]

Keywords: MODIS, earthquake prediction, seismo-thermal precursor, LST, Time-Series
1. INTRODUCTION

Since significant parts of the territory of Iran is located in the seismic belt of Alpine and has high seismicity, studies on the nature and characteristics of local seismic events are important. Most of the strong earthquakes have are accompanied by some diagnostic physical features such as sudden changes in local magnetic field of the earth, change animal behavior, change in level of underground water (Water table), increase in volcanic activity, or appearance of earthquake clouds. In addition, strong earthquakes produce mid-infrared anomaly. A lot number of precursor phenomena has been reported and some of these validated, scientifically [1-5].

Recently new precursors are introduced have been identified, that some of them are based on Remote Sensing (RS) studies on the thermal infrared region. Because RS technology, especially space-borne sensors, is available worldwide with at relatively lower cost, time, and manpower, when compared to with other methods. Nowadays, multiple satellites such as NOAA equipped with radiometer (AVHRR) and TERRA equipped with Spectroradiometer (MODIS) can detect mid-infrared precursor radiation [4, 6].

Since thermal data are available for almost all of the earthquakes and also thermal precursor for most of the earthquakes has acceptable answer therefore in this study seismo-thermal anomaly is used.

[RC: The above sentence is confusing. Needs revision]

Commonly thermal anomaly is detectable between 1 to 24 days prior the earthquake with temperature rises to 5 to 12°C and its effect remains after the main shock [3]. Some of scientists works have observed reported 2 to 10°C temperature rise [5, 7]. Relations between changes in temperature and earthquake validated have also been reported in with researches of works carried out in Russia, China, and Japanese scientists [6, 8].

[RC: Influx of subsurface gases giving rise to temperature rise of 5 to 12 C in air parcels near ground level is highly unlikely because of the low flow rates and heat capacity of gases. There are no independent confirmations of results mentioned in the references cited.]

At the same time land surface temperature (LST) depends on some parameter such as: a) geographic location, b) season of year, c) pure radiation of sun, d) soil texture and humidity level, e) land vegetation coverage, and f) atmospheric condition [9]. With the exception of the last case, all of these parameters are almost constant on the same day prior to earthquake.

[RC: Not necessarily true. Radiation intensity and soil humidity vary during daytime.]

Therefore, an abrupt local change in air temperature is a good indicator of an upcoming earthquake.
The above statement is controversial. Air temperature changes occur in response to atmospheric circulation and vary during daytime.\[RC: The above statement is controversial. Air temperature changes occur in response to atmospheric circulation and vary during daytime.\]

Note that other factors including volcanic activities could cause thermal anomaly. If the anomaly is caused by an earthquake then the reason for that anomaly would be a change in soil properties of further increment of stress in earth lower layers. Studies showed that several days prior to an earthquake some gas such as methane, carbon dioxide, and hydrogen emit from porous of soil, therefore greenhouse gas and magnetic field are intensified during that time \[10\].

\[RC: Gas flow cannot change magnetic field !!\]

Some other theories have been proposed to explain the thermal anomaly before an earthquake including piezoelectric and strain dilation. However these theories are not fully validated for seismo-thermal anomaly and precise mechanism of anomaly is questionable \[6, 11, 12\].

Some of remote sensing (RS) satellite (i.e. TERRA) are able to measure the land surface radiation in thermal band. These satellites due to proper spatial and temporal resolution in thermal band are useful for earthquake prediction.

\[RC: Satellite sensors do not have ability to distinguish thermal anomalies generated at ground level by atmospheric circulation from those by deep-seated earthquake processes.\]

In this paper Goharan earthquake with Magnitude of 5.6Mw is studied with seismo-thermal approach by using processing of thermal bands of MODIS sensor of TERRA satellite.

1.1 Earthquake information
According to Institute of Geophysics at the University of Tehran (IGUT), on February 2\textsuperscript{nd}, 2014 an earthquake with magnitude of 5.6 in Mw scale struck Goharan. Epicenter’s location was 26.71 N, 57.79 E and depth of it was 5 km.

\[RC: Reference is needed here, as the coordinates of epicenter is quoted as having different values in other publications.\]

According to Global CMT (www.globalcmt.org) at Harvard University, fault type is strike slip.

\[RC: Why drag in only Harvard University?\]
\[Has no work been done by Iranian geologists and seismologists?\]
Also according to National Geoscience Database of IRAN (NGDIR), Minab fault caused this earthquake. However, by consideration of earthquake focal mechanism, Goharan-Bashagard fault was a candidate for caused fault. Considering of foreshocks and aftershocks approves, the caused fault has W-E strike.

**[RC: Movement along faults lead to earthquakes. Text lacks scientific rigor]**

2. DATA AND METHODOLOGY

This section is comprised of three parts. The LST and air temperature data are discussed in the first and the second parts are dedicated to presenting respectively. The third part reviews wavelet theory as filtering.

2.1 LST Data

In this study the LST data is obtained from two different sources, local sensing (measured at the studied location) and remote sensed data (obtained from satellite). The first set of data are local data which are obtained from buried thermometers in soil at several depths (5, 10, 20, 30, 50 and 100 cm). The temperature data of those sensors are recorded at 3:00, 9:00 and 15:00 (Local Time). Location of each sensor along with time and depth of sensors are logged in the data. The most favorable depth for placing the sensor for seismo-thermal precursor detection purpose is 100 cm, because it receives the lowest impact from surface parameters. Second set of LST data belongs to data which is obtained from meteorology satellites. It is possible to extract information on temperatures from the satellite data, which record Land Surface Radiation (LSR) in thermal infrared region. In addition, geostationary stations record LST every 30 minutes. Also three satellites NOAA, TERRA and AQUA record LST twice a day.

The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra satellite, was launched on December 18, 1999 for global monitoring of the atmosphere, terrestrial ecosystems, and oceans. MODIS, flying on these two satellites (RC: repetition of information) with its 2330 km swath width provides almost complete dual global daily coverage in 36 spectral bands between 0.415 and 14.235 μm with spatial resolutions of 250 m (bands 1 and 2), 500 m (bands 3, 4, 5, 6 and 7) and 1000m (bands 8–36) [13]. In this study, LST variations near epicenter of the studied earthquake have been analyzed using the daytime LST images provided by NASA (http://modis.gsfc.nasa.gov/data). These data are generated on a daily basis at a temperature resolution of 0.02 K. Each pixel of a LST image covers an area of 1×1 km on the ground. For each image, the average of LST values of a 3×3 pixel area centered on the earthquake epicenter is used.

2.1.1 Air Temperature data

Air Temperature (AT) data are collected from Wunderground web site (http://www.wunderground.com/) from January 16 to February 12 in 4 years 2011-14. These data have been collected by the meteorological stations close to the studied earthquake’s epicenter. Figure 1 shows the average of 3 years AT time series
reduced (subtracted?) from 2014’s AT time series of Darshahr station. It can be noticed has been argued that LST nighttime of MODIS sensor is proportional to minimum temperature in day [8].

Figure 1. Average of 3 years AT reduced (subtracted?) from 2014’s AT time series at closest station to epicenter.

2.2 Anomaly detection by wavelet transform

The wavelet transformation technique (Equation 1) has been applied on the LST time series of earthquakes to obtain the time variability of the main periodicities. Similarity to Short Time Fourier Transform (STFT) for preforming wavelet transform on data, signal (in this article, LST time series) product to wavelet function that in reality it has the same role of window function.

\[
\psi(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t) \psi^* \left( \frac{t-b}{a} \right) dt
\]  

(1)

Where, ‘a’ is the scaling factor, ‘b’ is the location parameter, \(\psi^*\) is the complex conjugate of continuous wavelet function and \(f(x)\) is the time series under analysis [14].

Here, Haar wavelet or daubechies-1 wavelet is used. High Significant correspondence between signal (time series) and daubechies family wavelets is the main reason for selecting this method. According to what is stated in previous studies, thermal anomaly has a peak and then a valley, daubechies wavelets have also the same shape. More correlations between signal and wavelet results a higher signal to noise ratio (SNR) [15].

3. PROCESSING AND INTERPRETATION

A visual analysis of thermal images followed by a detailed analysis was carried out to determine the approximate location of appearance of a thermal anomaly, intensity of thermal rise, and its spatial extent. Since MODIS cannot penetrate through clouds, cloudy areas will give the temperature of the cloud top and not the actual LST of the area. Therefore pixels with cloudy cover were excluded from the image. For preparation of time series LST maps the datasets were treated identically and a user-specified temperature range consistent for all scenes of a particular earthquake was defined to distinctly delineate the thermal
anomalous area. By applying the above mentioned modifications and making LST time series map with these maps, the effect of seismo-thermal precursor are emerged as shown in Figure 2.

[RC: It is not possible to identify any "seismo-thermal precursor" in figure 2.

The longitude value of epicenter seems to be incorrect.]

Investigation of a series of satellite images of Goharan earthquake through color mapping reveals a rising in temperature around of the epicenter (figure 2). This figure clearly shows high temperature above of epicenter, several days before earthquake.

[RC: The statement above is incorrect. There is no high temperature anomaly near the epicenter. Panel 6 points to low temperatures !!]

However, there is no information a day prior the earthquake due to the cloud coverage at the study area.

[RC: This statement contradict the one on the previous page: "Therefore pixels with cloudy cover were excluded from the image"]
Obviously 5 days after earthquake chaotic LST before main shock returned to normal condition and temperature decreased from coast to land gradually.

[RC: The above statement is confusing.]

Active faults, foreshocks and aftershocks were overlaid on the temperature image on Figure 3. According to this figure, a correlation between faults and region of high temperature and quakes can be inferred.

[RC: No correlation can be identified in figure 3. The statement appears to be personal opinion of the author.]

Strike of caused fault corresponds to high temperature line which placed above that line. Also high temperature line is inside of effective region that introduced by Dobrovolsky (1979) [16].

[RC: These are confusing statements.]

Effective radius of Goharan earthquake was calculated by equation 2. According to the result Goharan effective radius is 255.85 km that covered high temperature line.

\[
R = 10^{0.43M}
\]

At second part, the data were investigated by time series analysis. In order to reduce the effect of noise and inaccuracy caused by presents of clouds the LST data of epicenter pixel and 8 closest pixels was used (Figure 4). Therefore, average of 9 pixels was considered as temperature of the day for each location. Previous studies show that temperature around a rupture zone decreases logarithmically with distance [17], so regards to pixels close to each other, this approach decreases error better than considering only epicenter pixel.
Figure 3. Temperature image with active faults (Blue solid lines). Foreshocks, aftershock and main shock (purple circles) illustrated in this figure. Also, Black line suggested caused indicates inferred fault.

![Temperature Image](image)

Figure 4. Square array for extracting LST data. Pixel number 1 matches to epicenter.

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  2 3 4
  5 1 6
  7 8 9
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Goharan temperature time series is extracted from 16 days prior to earthquake to 10 days after it (Figure 5). Earthquake day is considered as indicating zero in the time axis.

According to time series curve, temperature rises from 3 days prior to earthquake and then decreases 1 day after earthquake. After this fall, temperature returns to normal condition that previously was.

![Temperature Time Series](image)

Figure 5. LST time series of Goharan earthquake
By deduction (subtraction?) AT time series from LST, effects of air condition are deduced (reduced?) significantly. Since other effective parameters on of LST for the same earthquake are constant, so their effects are negligible. Because of (In order to?) keeping real range of LST time series, average value of AT time series is reduced (has been subtracted?) from AT time series and so the residual of this process reduced (subtracted?) from LST time series (Figure 6).

[RC: It is important to provide numerical values or graphical details of these data processing steps. It is necessary to demonstrate that similar variations have not occurred during compatible periods in years prior to 2014, and/or after 2014.]

Figure 6. Pure LST time series. In this curve, AT time series reduced (subtracted?) from LST time series.

In time series filtration step, stationary wavelet transform is used for keeping length of signal. Here Haar function is selected as wavelet. Wavelet at 3 levels was performed on time series, then thresholding process was applied on filtered time series. After performing wavelet transform original and filtered signals are plotted in Figure 7.

Figure 7. Performing wavelet transform on time series. Curve in red is filtered curve and dotted curve in blue is original curve before performing filtration.
According to LST time series, temperature is at normal until during 8 days prior to earthquake and it reaches to maximum amount at 4 days before earthquake. Then it sharply decreases to minimum amount on earthquake day. After this valley of drop in temperature, time series curve arrives returns to background amount level. So Wavelet filtering removed the effect of noise from modified time series and curve to and produced a smooth curve for better interpretation.

[RC: It is necessary to demonstrate that similar variations in temperatures have not occurred during compatible periods, in years prior to 2014, and/or after 2014.]

4. DISCUSSION AND CONCLUSION

In this article, besides of location prediction, time prediction is did. In topic of location prediction by study on colorization images (figure 2), high temperature region can be specified from others clearly.

In figure 3, this correlation with investigation of the faults zone, high temperature zone and also strike of probabilistic caused fault, specified that high temperature zone has a good correspondence with probabilistic caused faults. And thence this high temperature zone disappears in days after earthquake, probably that relates to earthquake.

By this method can relevant they caused faults with having earthquake. In the other parts of article, time series of Goharan earthquake survived by usage of wavelet filter. Wavelet, eliminate high frequencies that they are as a noise. Moreover shows time series of ground surface temperature before earthquake has the maximum entity. In addition, in earthquake day and some days after earthquake, has the minimum entity. 17 reduction temperature degree, in four days is a good sign for record this anomy. Maybe there is not have any other reason except of earthquake.

[RC: The conclusion that there has been a precursory temperature change is based on extremely weak arguments. The work has failed to show that the observed change is NOT due to normal air circulation at ground level and has NOT examined air temperature changes during other periods.]

More importantly, the work has FAILED to present data on temperature changes that occurred during other earthquakes in the same area. There has been more than 80 earthquakes with magnitude greater than 1.5 in Iran, last year

The practice of SELECTIVE use of data is unscientific and should be discouraged.

[RC: The text in the above paragraphs need to be revised for language style and grammatical errors. It is difficult to make any sense out of it.]
REFERENCES


[RC: Translation to English needed.]