Case study


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, air effects reduction air temperature time series of the closest station subtracted 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 occur, 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.

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

1. INTRODUCTION

Since significant parts of the Iran's territory is located in the seismic belt of Alpine and has high seismicity, studies on the nature and characteristics of local seismic event are important. Most of the strong earthquakes are accompanied by sudden change in local magnetic field of the earth, change in animal behavior, change in level of underground water table, volcanic activity, or appearance of earthquake clouds [1-4]. In addition, strong earthquakes produce mid-infrared anomaly [5-7]. Recently new precursors have been identified, some of them based on Remote Sensing (RS) studies of the thermal infrared region. RS technology, especially space-borne sensors, is available worldwide at relatively low cost, time, and manpower, when compared with other methods. Nowadays, multiple satellites such as NOAA equipped with radiometer (AVHRR) and TERRA equipped with Spectroradiometer (MODIS) can detect mid-infrared radiation [6, 8].

Thermal precursor for most of the earthquakes has acceptable answer because thermal data are available for more earthquakes, therefore in this study seismo-thermal anomaly is used. 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 [5]. Some of work have reported 2 to 10˚C temperature rise [9, 10]. Relations between change in temperature and earthquake have also been reported in works carried out in Russia, China and Japan [8, 11].

At the same time land surface temperature (LST) depends on some parameter such as; a) geographic location, b) season of year, c) radiation of sun, d) soil texture and humidity level, e) vegetation cover, and f) atmospheric condition [12]. With the exception of the last case, all of these parameters are almost constant on the same day prior to earthquake. Therefore, an abrupt local change in air temperature is a good indicator of an upcoming earthquake. 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 [13]. 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 [8, 14, 15].

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. 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 2nd, 2014 an earthquake with magnitude of 5.6 in Mw scale struck Goharan. The Epicenter’s location was 26.71 N, 57.79 E and depth of it was 5 km. According to Global CMT (www.globalcmt.org) solution at Harvard University, the fault type is strike slip. 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.

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 respectively. The third part reviews wavelet theory as filtering.

2.1 LST Data
In this study the LST data was 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 was obtained from meteorology satellites. It is possible to extract information on temperatures from the satellites 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 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) [16]. 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 were 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 km² 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 were obtained 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 subtracted from 2014’s AT time series of Darshahr station. It has been argued that LST nighttime of MODIS sensor is proportional to minimum temperature in day [11].
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 performing 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 [17]. Here, Haar wavelet or daubechies-1 wavelet is used. 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) [18].

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.
Investigation of a series of satellite images of Goharan earthquake through color mapping reveals a rising in temperature around of the epicenter (figure 2). Figure 2 clearly shows high temperature above of epicenter, several days before earthquake. However, there is no information a day prior the earthquake due to the cloud coverage at the study area. Obviously chaotic LST before main shock returned to normal condition 5 days after earthquake and temperature decreased from coast to land gradually.
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. **High temperature line which paced above of Strike of caused fault conforms that.** Also high temperature line is inside of effective region that introduced by Dobrovolsky (1979) [19]. 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 [20], so regards to pixels close to each other, this approach decreases error better than considering only epicenter pixel.

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**Figure 3.** Temperature image with active faults (Blue solid lines). Foreshocks, aftershock and main shock (purple circles) illustrated in this figure. Black line indicates inferred fault.

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

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.
Figure 5. LST time series of Goharan earthquake

By subtraction AT time series from LST, effects of air condition are reduced significantly. Since other effective parameters of LST for the same earthquake are constant, their effects are negligible. Because of keeping real range of LST time series, average value of AT time series is reduced from AT time series and the residual of this process reduced from LST time series (Figure 6).

Figure 6. Pure LST time series. In this curve, AT time series 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.
According to LST time series, temperature is at normal during 8 days prior to earthquake and it reaches maximum 4 days before earthquake. Then it sharply decreases to minimum on earthquake day. After this drop in temperature, time series curve returns to background level. Wavelet filtering removed effect of noise from modified time series curve and produced a smooth curve for better interpretation.

4. DISCUSSION AND CONCLUSION

Detail location prediction, seismo-thermal prediction and time prediction was carried for earthquake predicted using colorization images -that high temperature region can be specified from others clearly- and time series analysis.

Figure 2 shows an existence of high temperature region in the west of Makran seismotectonic zone. This zone increased in temperature in days prior to main quake and decreased in days after that.

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 hence this high temperature zone disappears in days after earthquake, probably that relates to earthquake. By this method we can reveal caused faults with having earthquake. In other zone of the map, faults have a good agreement with high temperature lines. Also for considered earthquake, aftershocks conform strike of caused faults.

In the other parts of article, LST time series of Goharan earthquake survived by usage of wavelet filter. Also air temperature circulation is applied on LST time series. This applying done because we want to remove air effect. By removing of air effect we somewhat make sure that anomaly behavior in NOT due to change in climate condition.

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 degrees decreasing in temperature, in four days is a good sign for record this anomy. But we believe maybe there was other reason except of earthquake.
REFERENCES


