ESKİŞEHİR TEKNİK ÜNİVERSİTESİ BİLİM VE TEKNOLOJİ DERGİSİ B- TEORİK BİLİMLER

Eskişehir Technical University Journal of Science and Technology B- Theoritical Sciences

2018, Volume:6 - pp. 67 - 72, DOI: 10.20290/aubtdb.489094

4th INTERNATIONAL CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY

THERMAL REMOTE SENSING TECHNIQUES FOR STUDYING EARTHQUAKE ANOMALIES IN 2013 BALOCHISTAN EARTHQUAKES

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ABSTRACT

The use of satellite technologies in remote sensing in recent years takes place in pre and post monitoring of earthquakes, especially in monitoring thermal anomalies before the earthquake. This paper discusses the thermal anomalies of the 2013 Balochistan Earthquakes that occurred in southwestern Pakistan on 24 September 2013 with a 7.7-moment magnitude. The earthquake caused six significant aftershocks. The strongest one occurred on 28 September 2013 with a moment magnitude of 6.8. In this paper, we use Landsat-8 satellite imagery to analyze the thermal behavior in the 2013 Balochistan earthquake and its biggest aftershock that occurred on 28 September 2013. The thermal behavior was analyzed using the Land Surface Temperature algorithm for Landsat 8 images. For this purpose, we used seven satellite images, two before the main earthquake, one two days after the main earthquake and two days before the strongest aftershock, and one image after the earthquakes. According to the results, unusual warming was noticed near the fault before the strongest aftershock. The results were compared with data from the Pakistan Meteorology Department and other studies related to the 2013 Balochistan Earthquakes.

Keywords: Earthquakes, Remote sensing, Land surface temperature (LST), Thermal anomalies

1. INTRODUCTION

A 7.7 moment magnitude and a maximum Mercalli intensity of VII (Very Strong) earthquake known as the 2013 Balochistan earthquake took place in southwestern Pakistan on 24 September. According to USGS the epicenter of the event is 69 km north of Awaran and 270 km north of Karachi with a population of 11.6 million. The epicenter was determined to be at 26.951°N and 65.501°E with depth of 15.0 km. The earthquake was felt in major cities across Pakistan and also was felt in Delhi, India, Muscat, Oman – 800 km from the epicenter, United Arab Emirates, Iraq, Afghanistan, and Qatar. According to Dunya News the earthquake took more than 825 lives, more than 30 villages with more than 20.000 homes were flattened across 15.400 square miles of the remote Balochistan region. The earthquake caused six significant aftershocks. The strongest one occurred on 28 September 2013 with a moment magnitude of 6.8 and depth of 14.8 km. On 24 September, the earthquake nucleated south of the Chaman strike-slip fault and propagated southwest along the Hoshab fault [1]. For studying the surface deformation from the 2013 Balochistan earthquake, in absent of permanents local geodetic network, and only few campaign GPS sites on the both sides of the rupture [2], number of researchers rely on remote sensing techniques to image the surface deformation field [3]. Lately, a number of studies have connected thermal anomalies with seismic activities. The idea starts back in the 1980s when researchers from different parts of the world reported observations on thermal anomalies before strong earthquakes. Thermal anomaly can be defined as an unusual increase in the Land Surface Temperature (LST) that occurs few days prior to an earthquake increasing the temperatures between 3 and 12°C or more and disappears few days after the event [4]. Evident correlation of thermal anomalies in LST, related to pre-seismic activities have been identified in several studies [5-9]. Remote sensing satellites such as NOAA-AVHRR, Aqua-MODIS, Terra-MODIS, Meteosat-5, Landsat-5, Landsat-7 and Landsat-8 can measure the radiation coming from the Earth in thermal bands and they can be used in studies on thermal anomalies [6, 10, 11].

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Received: 09.05.2018 Accepted: 29.06.2018

In this paper, we use four Landsat 8 satellite images to analyze the thermal behavior in the 2013 Balochistan earthquake and its` bigger aftershock that occurred on 28 September 2013. For this purpose, the thermal behavior was analyzed using LST algorithm. Afterward, the results from the LST analysis were compared with data from the Pakistan Meteorological Department for 2013 and with data from study that elaborates the ground surface deformation measured from sub-pixel correlation of Landsat-8 images [1].

The Landsat program start back in the 1970s when in July 23, 1972 Landsat-1 has been launched. In 1984, world longest-operating Earth observation satellite, Landsat-5 has been launched and it has been active for 28 years and 10 months. With the launch of Landsat-8 in 2013, the Landsat Mission, Imaging the Earth Since 1972 continues today on daily basis. Landsat – 8 contains eleven bands with spatial resolution 15-100 meters. The algorithm used is this paper for retrieving LST, uses near infrared and red band with 30 meters resolution, and thermal band with central wavelength 11.25 μm and 100 meters resolution [12].

2. DATA AND METHOD

2.1. Data

Seven satellite images from Landsat-8 were downloaded for free from the USGS web page. The first image was collected on August 25, 2013, approximately one month before the main shock. The second pair of images was collected on September 10, 2013, 14 days before the main shock, and 18 days before the biggest aftershock. The third pair of satellite image images was collected on September 26, 2013, two days after the main shock and two days before the biggest aftershock, and the fourth pair of images was collected on October 12, 2013, 18 and 16 days after the main shock and the biggest aftershock respectively. All of the images were free of cloud and of high quality (Table 1). As an additional data, fault map, surface displacement map, USGS shake map, and data from the Pakistan Meteorological Department for 2013 were used [1].

Table 1. Details about the images used in this study

Sensor	Date	Path	Row	Cloud Cover	Image Quality
Landsat 8	25 August 2013	154	41	0.07	9
Landsat 8	10 September 2013	154	41	0.01	9
Landsat 8	10 September 2013	154	42	1.43	9
Landsat 8	26 September 2013	154	41	0.03	9
Landsat 8	26 September 2013	154	42	0.74	9
Landsat 8	12 October 2013	154	41	0.21	9
Landsat 8	12 October 2013	154	42	3.08	9

2.2. Method

In order to retrieve the LST for the downloaded images, a tool developed in ERDAS IMAGINE was used [12]. The tool is used for calculating the LST of a given LANDSAT 8 image with the input of the red, near infrared (NIR), and thermal bands (Figure 1).

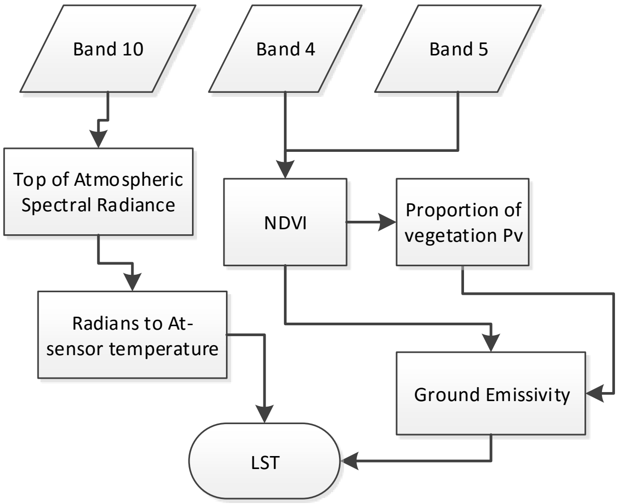

Figure 1. Flowchart of the LST algorithm

After the calculation, all of the LST maps were analyzed and compared with the other available data. The method of this study relies on a comparison between the LST maps retrieved before and after the earthquakes. For the comparison, statistical analyses using random points were made in ArcGIS software. Also, data from other studies were taken into consideration in this study. Data from the faults near the affected areas, vector displacement, and surface slip data taken from studies related to the Balochistan earthquake were georeferenced and then compared to the LST maps (Figure 2). The results were also compared with data from the Pakistan Meteorological Department.

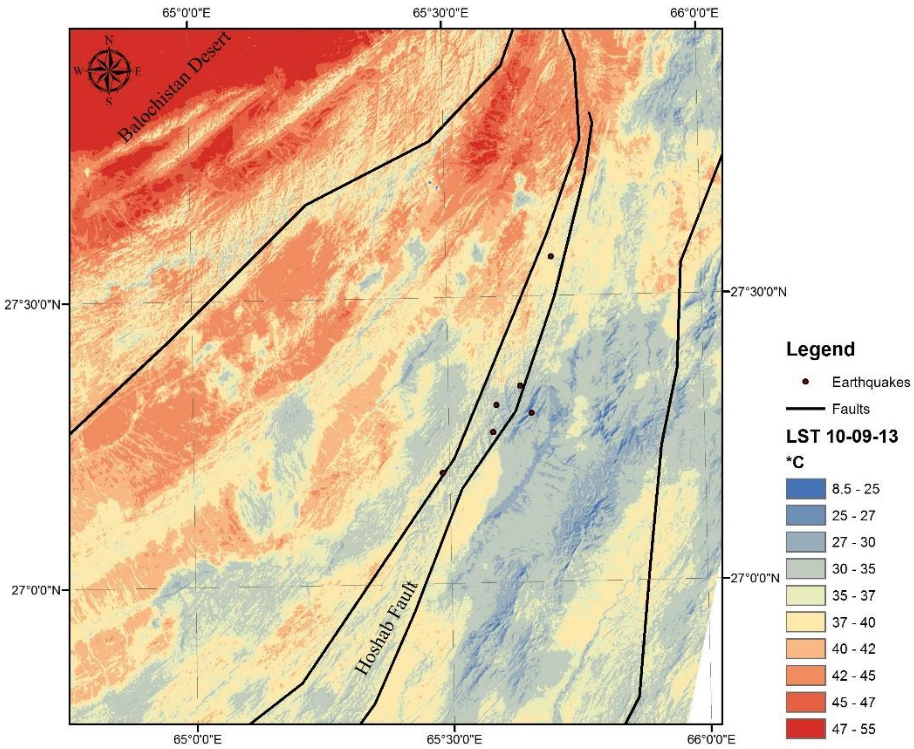

Figure 2. LST map of the study area from 10 September 2013 together with the Epicenters' and the Faults involved in the 2013 Balochistan Earthquakes.

3. RESULTS AND DISCUSSION

Figure 3 shows the LST maps from the four satellite images downloaded from 25th August, 10th September, 26th September and 12th October 2013 (Figure 3).

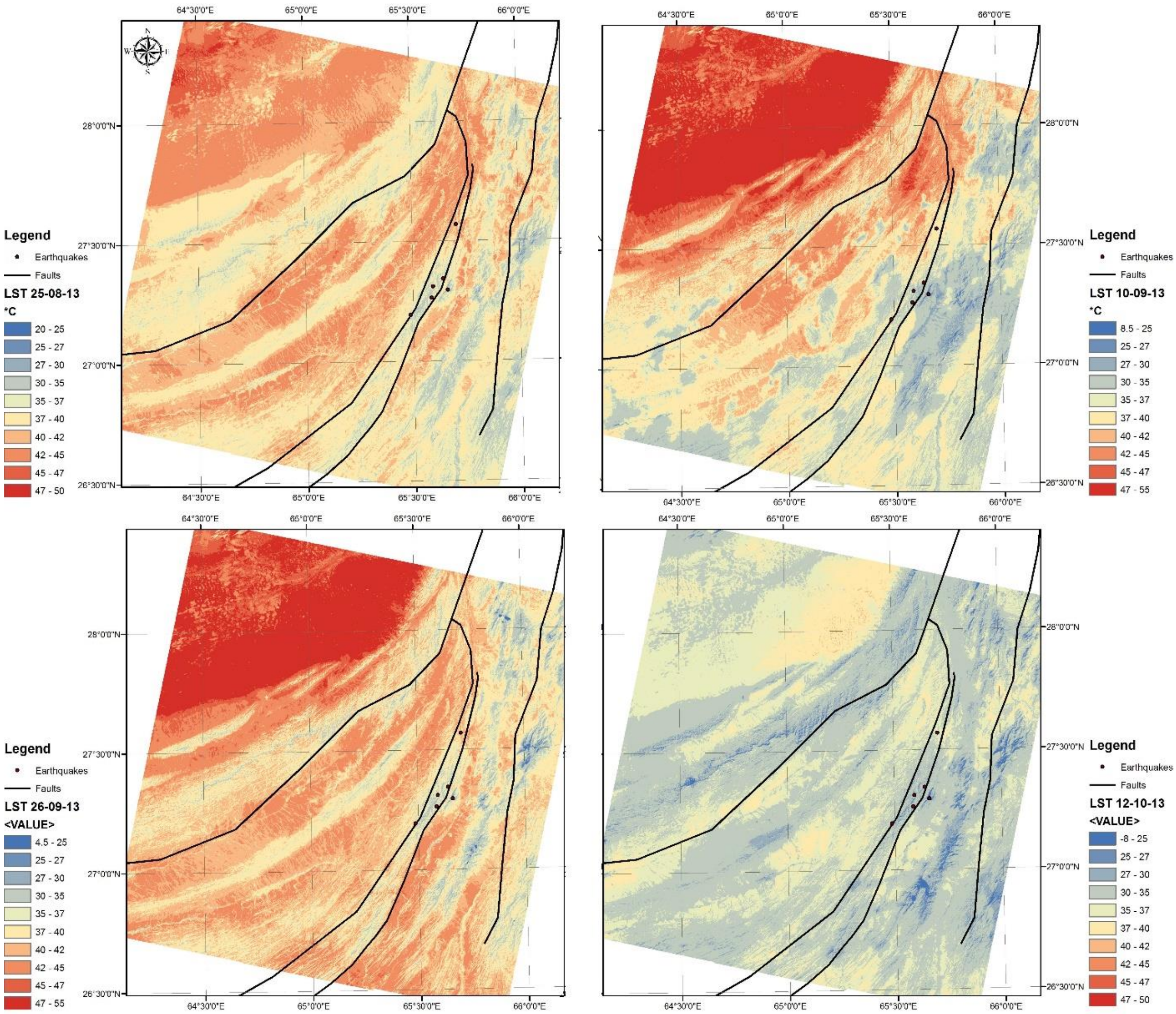

Figure 3. LST results maps

The results from the LST maps were first compared with the data for the climate of Pakistan from 2013 from the Pakistan Meteorological Department [13]. In the given report, the average monthly temperatures of Pakistan for the year 2013 are compared with average monthly normal temperatures from 1981 to 2010. As a result, from the report, it is stated that the monthly mean temperatures of 2013 were above the average in October and November, while in August were slightly below the average. The temperatures from the other months were normal or equal to normal. It should also be noted that the average temperatures were slightly dropping from August (around 29 °C), September (around 27 °C) and October (around 25 °C).

From the LST maps, it can be noticed that the temperatures from August 25th, approximately one month before the first earthquake, were varying from 20 to 50°C. Then, the temperatures from September 10th, or 13 days before the first earthquake, were varying from 8.5 to 55°C, so while the minimum temperature was lower, the maximum temperature was 5°C higher that the temperature from 25th August. At the first two LST maps, it can be noticed warming starting from the Balochistan desert up in the left corner, and that warming is spreading all the way to the Hoshab Fault. The warming can be seen even clearly on the LST map from September 26th where the warming is spreading all over the study area covering the Hoshab fault. The LST map from October 12th, or approximately 17 days after the earthquakes, shows no sights of unusual warming. For the statistical analysis, approximately 880 random points were used. The results showed that the highest warming between 10th and 26th September 2013 was 14 °C (Figure 4). The comparison from the LST maps and the surface slip, showed that the unusual noticed warming has not only appeared on the slipped surfaces, but also many kilometers left and right from the Hoshab fault.

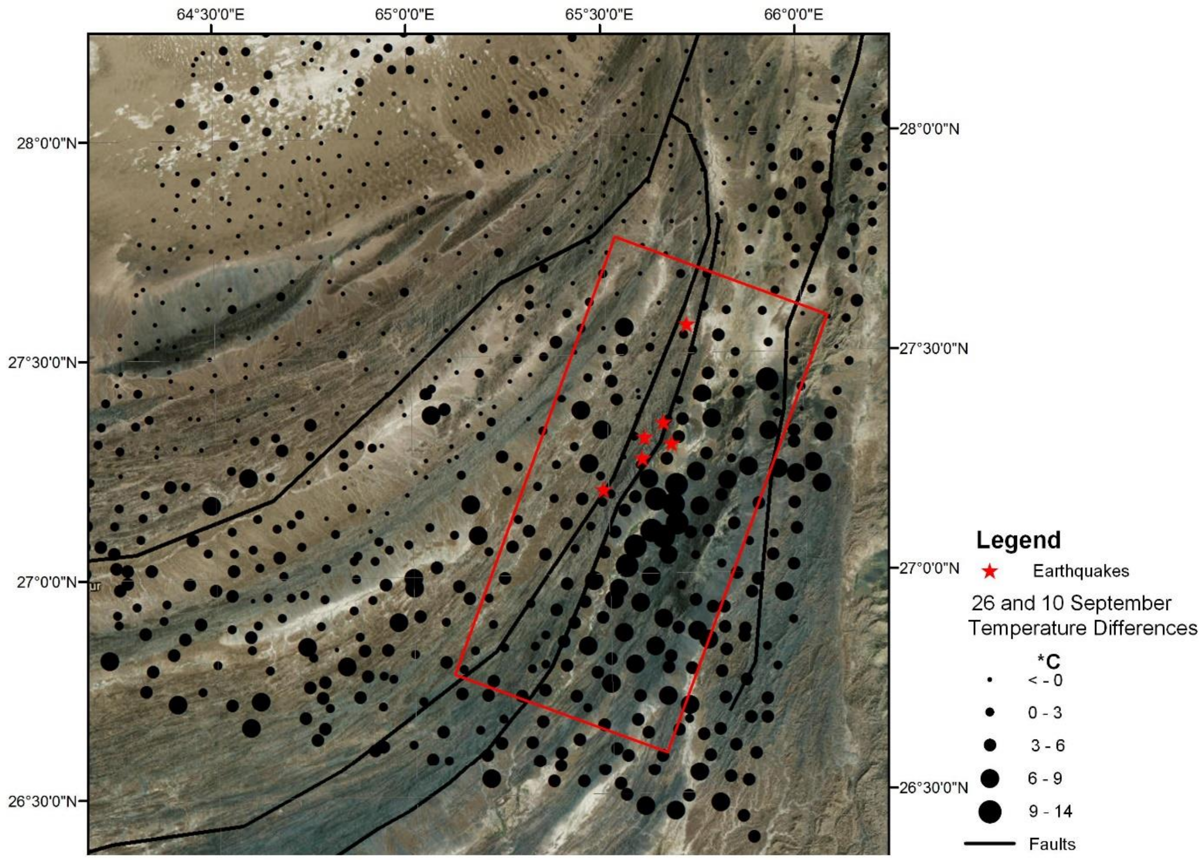

Figure 4. Temperature differences between 26 and 10 September shown on a Google Earth map

Although it is hard to connect any thermal anomalies with an earthquake, studies have shown that most of the times thermal anomalies appear 7-14 days before the event and disappear few days after the event [14]. It this paper, the comparison of the meteorological data, the LST maps, and the statistical analysis showed unusual warming in the study area that did not disappear two days after the biggest event, which may have indicated the aftershock followed two days later. For future studies, thermal anomalies should be monitored trought satellites with higer timley resolution, as well as with in-suti measurment done frequently.

ACKNOWLEDGEMENTS

We thank the 4th International Conference of Earthquake Engineering and Seismology Organization Committee 2017, for rewarding this paper for outstanding poster presentation (Second Prize).

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