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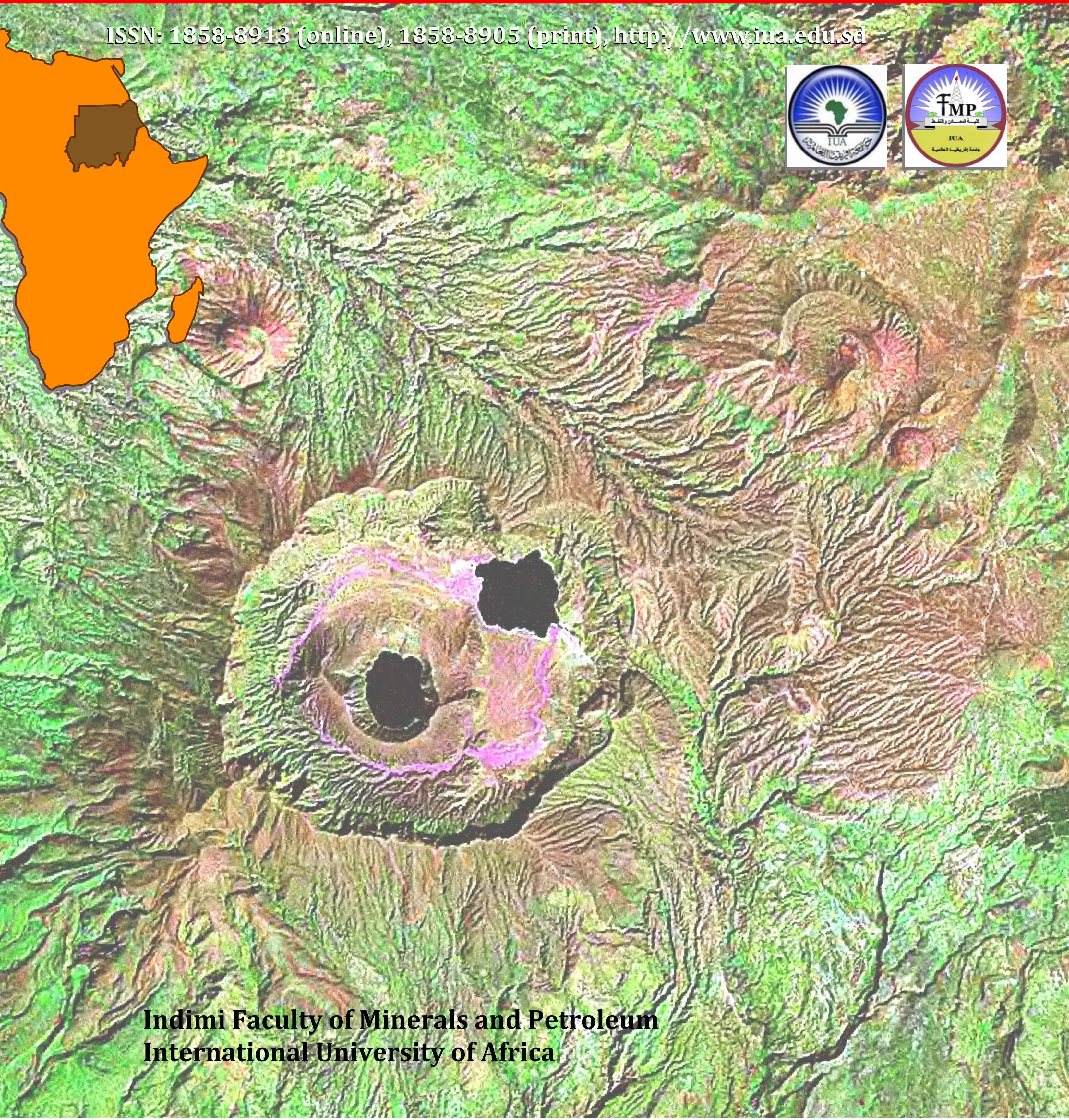

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Thermal Infrared Remote Sensing: A Possible Forerunner for Earthquake Prediction, Abu Deleig Area, Eastern Sudan

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Abstract

Satellite thermal imaging data indicate short-lived thermal anomalies prior to major earthquakes. These anomalies can be retrieved by means of multi-spectral images using IR remote sensing data from Earth Observation System satellites (EOS Terra and Aqua).The present study is an application of (Thermal anomaly Detection prior to earthquake events). The technique devised for predicting earthquakes using IR satellite images at Abu Deleig area east of Khartoum village .The aim is to assess the viability of using IR satellite images for the prediction of earthquakes and the use of satellite images in seismic studies. Eight IR images of the study area obtained from NASA, four images acquired before the earthquake and four images after the shock (2003), were found suitable for the present study. Digital image processing and interpretation of these images revealed a positive thermal anomaly in the image area. This anomaly emerged twelve days before the earthquake and faded away or dwindled in the following day. Two days before and two days after the shock, the thermal anomaly became well developed with a linear shape trending N-S. This is conformable with a major seasonal stream that has a linear course which is aligned in N-S direction at the area. Several days after the shock, the anomaly was diminished and concentrated in a small area. The linearity of the anomaly shape may enhance the link of this anomaly to linear structures such as faults or shear zones causing the earthquake. It is concluded that IR remote images have the capabilities of showing the thermal anomalies that appear 4-7 days before the earthquake. In conclusion, these techniques can be used in the prediction of earthquakes in the Sudan

Keywords: Remote sensing, IR image, earthquake, Abu Deleig, eastern Sudan

1. Introduction

Sudan is situated within the stable African Craton and as a consequence it is characterized by low seismic activity. Nevertheless, several earthquakes struck the country in the recent decades causing loss of life and damages to properties. Eastern Sudan is tectonically the most active part of the country, where there is frequent events of ground tremors that affected the Red Sea region. Likewise, central interpolate regions have experienced earthquakes capable of producing damage to properties. Irrespective of these facts, information, as with regards to seismicity as well as reliable and sufficient studies on earthquakes in Sudan are not, so far, adequate.

Since earthquakes represent the most dangerous natural hazards to human beings and their properties, their monitoring and early prediction signifies an important issue in order to mitigate their expected risks. Thus, the establishment of an efficient monitoring and prediction system is crucial.

2. IR satellite remote sensing

Recent developments of remote sensing methods for Earth satellite data analysis contribute to our understanding of earthquake related thermal anomalies (Ouzounov, 2015).

Latest field studies and satellite observations add confidence to reports of electromagnetic (EM) emissions before large earthquakes. There is likewise mounting evidence that, prior to seismic activity, electric fields are transmitted from the ground through the atmosphere into the ionosphere, that ‘‘thermal anomalies’’ may appear, that ions may be emitted from the ground, that the atmospheric conductivity is affected, that ground potentials may change locally or regionally. Increased lightning activity, due to growing seismic activity and the large currents thus induced may have an effect on the fracturing or micro fracturing of rocks, focusing the EQ energy release (Pulinets et al., 2000). Geostationary and polar- orbiting mission ongoing to study the seismic activity like GOES, ASTER, AVHRR, MODIS.

Infrared satellite images are useful techniques to test the viability of using satellite images in seismic monitoring studies. Further development of thermal satellite remote sensing which can sense the earth’s surface emissivity at regular interval of time introduces a new way of analyzing this phenomenon using data from Moderate Resolution Imaging Spectro-radiometer (MODIS) on board National Aeronautical Space Agency (NASA) Terra and Aqua Satellites.

In thermal remote sensing we measure the radiations 'emitted' from the surface of the target. This is as opposed to optical remote sensing where we measure the radiations 'reflected' by the target under consideration (Prakash, 2000). Useful reviews on thermal remote sensing are given by Kahle (1980), Gupta (1991) and Sabin's (1996).

Moderated Resolution Imaging Spectroradiometer (MODIS) is an Earth Observing System (EOS) instrument on board the Terra and Aqua platforms, launched in December 1999 and May 2002, respectively. The sensor scans ±55° from nadir in 36 spectral bands. During each scan, 10 along-track detectors per spectral band simultaneously sample the earth. From its polar orbit, MODIS provides daytime and night-time global coverage every 1 to 2 days.

MODIS has 16 bands in the emissive portion (3–15 μm) of the spectrum. The bands have a ground instantaneous field of view of about 1 km at nadir and a radiometric resolution of 12 bits. The detectors sample on board calibration before and after each scan of the Earth (Guenther et al., 2002). The absolute calibration accuracy is within 1% for the thermal infrared bands, except for band 36 (Saleous et al., (2002).

Prediction and monitoring earthquakes was conducted by, e.g., Mebrouk et al. (2017), who effectively utilized thermal anomaly detection prior to earthquake events. This fact was approved by many researchers over the past decades. Their results confirmed the importance of robust satellite technique as an effective and reliable approach.

It was realized that the thermal heat fluxes over areas of earthquake preparation is a result of air ionization by radon (and other gases) and consequent water vapor condensation on newly formed ions. Latent heat (LH) is released as a result of this process and leads to the formation of local thermal radiation anomalies (TRA) known as OLR (outgoing Long-wave radiation).We compared the LH energy, obtained by integrating surface latent heat flux (SLHF) over the area and time with released energies associated with these events (Ouzounov et al., 2007).

Extended studies of the TRA using the data from the most recent major earthquakes allowed establishing the main morphological features. It was also established that the TRA are the part of more complex chain of the short-term pre-earthquake generation, which is explained within the framework of a lithosphere-atmosphere coupling processes (Ouzounov et al., 2017).

Thermal satellite images of El Butana area of central Sudan provide good information about the changes in surface temperature that may be associated with an impending earthquake. Therefore, it has been assumed that, the utilization of the daily available Infrared (IR) satellite images can help in the prediction of earthquakes.

2. Heat Generation

Several processes have been considered as possible contributors to the transient short- lived ‘‘thermal anomalies’’:(a)rising fluids that would lead to the emanation of warm gases (Salmanetal.,1992; Gornyetal.,1988); (b) rising well water levels and CO_2 spreading laterally and causing a ‘local greenhouse’’ effect (Qiangetal.,1991;Troninet al., 2002; Tramutoli et al., 2005); (c) activating positive-hole pairs during rock deformation (Freund, 2002); (d) frictional heat around the active fault (Tagamietal, 2008); and (e) air ionization by radon and latent heat change due to change of air humidity (Pulinets and Ouzounov, 2011).

Arun et al. (2014) attributed the temperature increment prior to an impending earthquake to degassing from rocks under stress and/or to p-hole activation in stressed rock volume and their further recombination at the rock-air interface.

3. Earthquakes in Sudan

Though sporadic in time and space, recent seismic events sparked the interest of earth scientists on the seism tectonics of the country. Recent seismic events in different regions within the country warrant seismic hazard mitigation. Ambraseys (1966) reported that the earliest accounts indicating earthquakes in Sudan are those reports written by explorers: Driberg (1927). Much of such information came from the province of Equatoria, the northern extremity of one of the East African rift valleys. However, the first assertive earthquake which is reported to caused wide spread damage in Equatoria occurred in1850. It was reported to be associated with ground deformations, faulting, and to have left a deep impression on the local tribes.

The May 20, 1999, 7.4 magnitude earthquake and its aftershocks that hit Southern Sudan is the one of the largest seismic events ever recorded in cratonic Africa. In addition earthquakes struck Kordofan State first in August 1, 1993 with a magnitude of 5.5 and, second, in November 15, 1993 with a magnitude of 4.3.Central Khartoum is affected by all seismic sources in Sudan and its vicinity (Shaddad et al., 1995).

Anaccount on the field study of the Jebel Dumbeir Earthquake was given by Qureshi (1968). The event represents the strongest of a series of earthquakes that started in central Kordofan on October 9th, 1966 and continued for at least six months.

Seismic hazards of Sudan were assess by Abdalla et al. (1996), who utilized historical as well as instrumental earthquake catalogue of Sudan from 700 to 1994 to. They employed probabilistic approach of relationship between earthquake magnitude and earthquake frequency is established for each source taking regards that attenuation of intensities is presented as a function of magnitude and epicenteral distance.

Most of earthquakes have been located in the eastern and western part of Khartoum area like Abu Deleig earthquake in November 2003 (Ms =4.5). Abu Deleig earthquake is located about 149 km to the east of Khartoum. This event was followed by three aftershocks with short surface cracks observed (Ayad et al., 2004).

Based on the seismological data, a fault plane solution associated with a strike slip fault trending NE might be related with these earthquakes. All events occur at shallow depths from 5 to22 km, with magnitudes 1.8 to 3.6. In the eastern part of Khartoum area, the earthquake in November 2005 was associated with strike slip fault trending NW. This interpretation have been done using geological, geophysical (gravity and resistivity measurement) and remote sensing evidences (Mula et al., 2006).

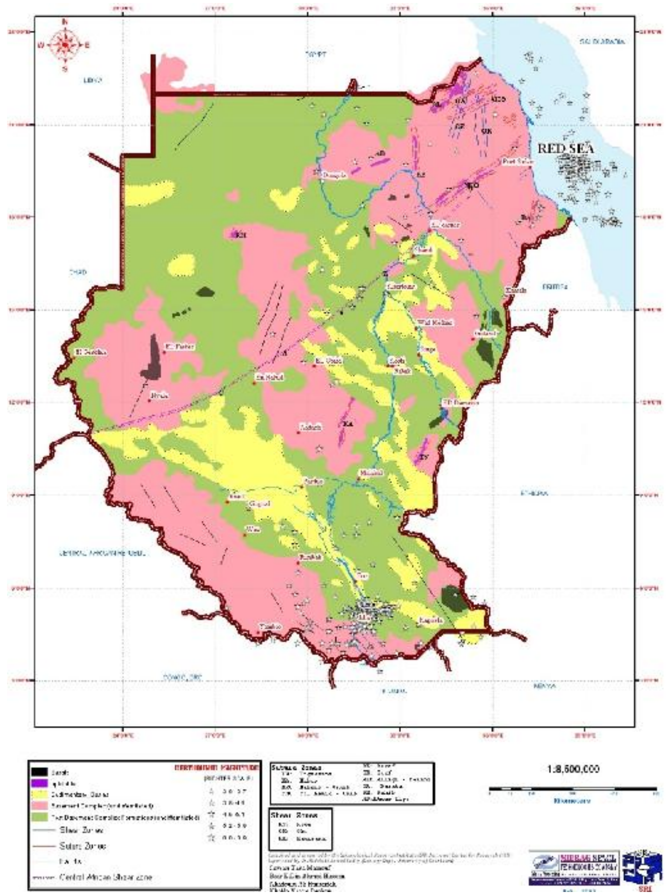

Figure 1. Seismo-tectonic map of the Sudan showing the locations of historical seismicity epicenters of Sudan and its vicinity (SRI, 2010).

4. The study area

Abu Deleig area is located in central Sudan approximately 150 km east of Khartoum, the capital (Fig. 2). Arid to semi-arid climate with long hot summer season and scarce sporadic rainfalls prevails the central Butana area. As a consequence, diverse types of grass cover the plain during the rainy season and the few succeeding months with decreasing intensity from south to north.

Central Sudan is generally characterized by gently undulating plains of low relief with an average altitude ranging from 350 to 500 m (Fig. 3). This plain is mostly covered with clays and its monotony is often protruded by isolated hills or clusters of hills in the form of inselbergs. Butana region host a number of isolated outcrops of pre-Cambrian basement complex rocks which scatter over the central plains of Sudan.

Figure 2. Location map of the study area

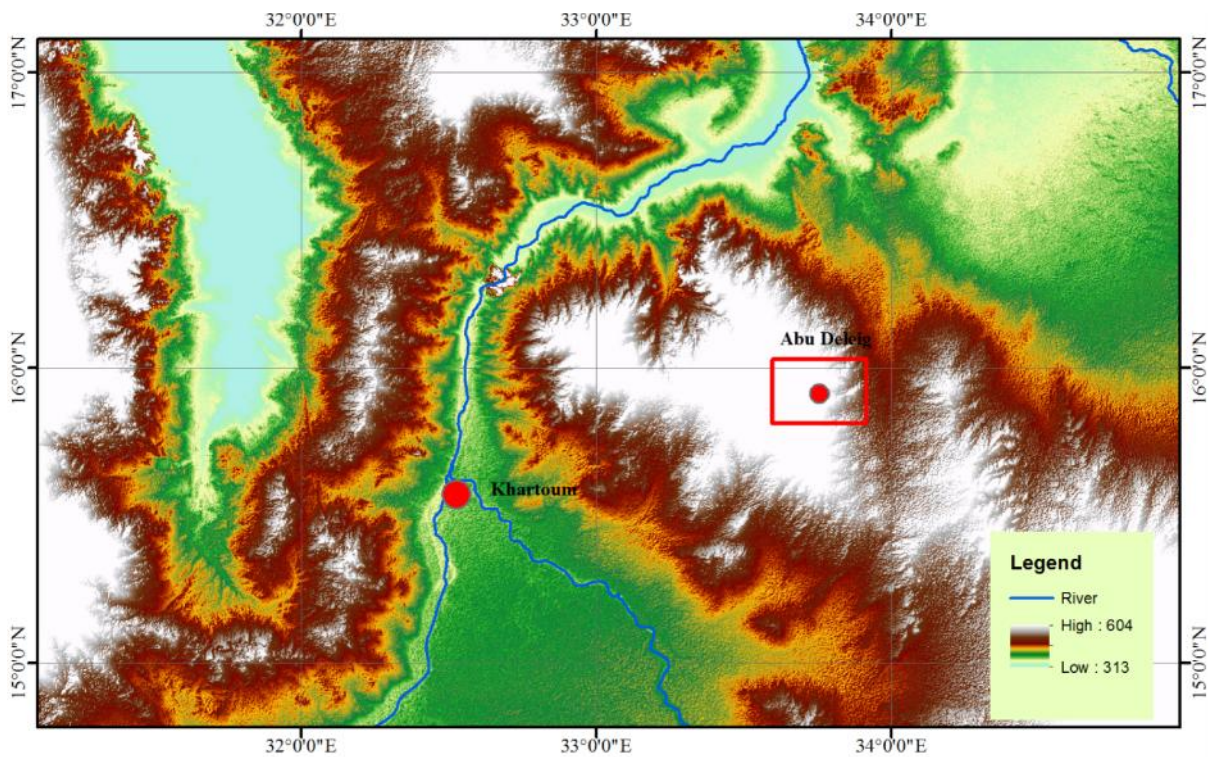

Figure 3. Topographic map showing the location of the 2003 earthquake epicentre northeast of Khartoum

5. Methodology

5.1 Data types

MODIS Terra 11 images in digital format obtained from NASA WIST and USGS Earth Explorer web sites. This data includes: Land Surface Temperature and Emissivity (LST/E) Daily L3 Global 1 km Grid product (MOD11A1) is tile-based and gridded in the Sinusoidal projection, and produced daily at 1 km spatial resolution.

5.2 Methods

The method of earthquake prediction is implemented using thermal IR survey such that 8 IR images downloaded, 4 images acquired before the earthquake and 4 images after the shock. These images are used to determine the require procedure in Abu Deleig area.

The Images obtained from NASA to study Abu Deleig earthquake of Nov 5, 2003, with magnitude M= 5.2.The images were processed for geometrical correction. It was planned at the beginning of this study to use 17 different IR images to study Abu Deleig earthquake. However, only 8 images were found suitable for this study. Each image must be acquired on a separate day and as much as possible at the same time to avoid variation of temperature during the day and to make the comparison reasonable. Huge number of images was downloaded to cover the period spanning 8 days before the earthquake, the shock day and 8 day after the earthquake. The temperature variations that are measured by MODIS land surface temperature (LST) images which may be due to the movement along faults causing the earthquake. The interpretation of the LST images is based on relative differences rather than the absolute change in the temperature values.

6. Results and Discussions

In the current work, MODIS land surface temperature (LST) was used to track the temperature variations which may be due to fictional heating produced by the movement along major faults causing the earthquake. Pre- and post- LST images revealed a positive thermal anomaly developed 12 days before the earthquake in the eastern part of Abu Deleig area.

6.1 Digital processing of Abu Deleig LST image set

The LST images were sub-set to reduce the size of the image file to include only the area of interest. Then the image was converted from 16-bit to 8-bit image format. Image enhancement techniques were used to improve the quality of the images, which was necessary for visual investigation. One of these techniques involves contrast of the image or change to colour representation. The further enhancement of images will allow us to record very fine difference in surface temperature.

MODIS image classification is used in remote sensing to categorize all pixels in an image to produce thematic maps of the existing temperature. Cluster analysis was carried out using unsupervised classification. The pixels were classified into ten emissivity classes and gave satisfactory result. In images classification the high temperature appears as light tones, whereas, the low temperature is display as dark tones.

A cluster analysis was carried out using unsupervised classifications, as well as the supervised classifications, gave satisfactory results both classifications gave positive results. In these classifications the image data has been divided into 10 classes. In the pre-earthquake images (Plates 1, 2, 3, 4), the red colour represented the abnormal behavior of the LST that means high temperature.

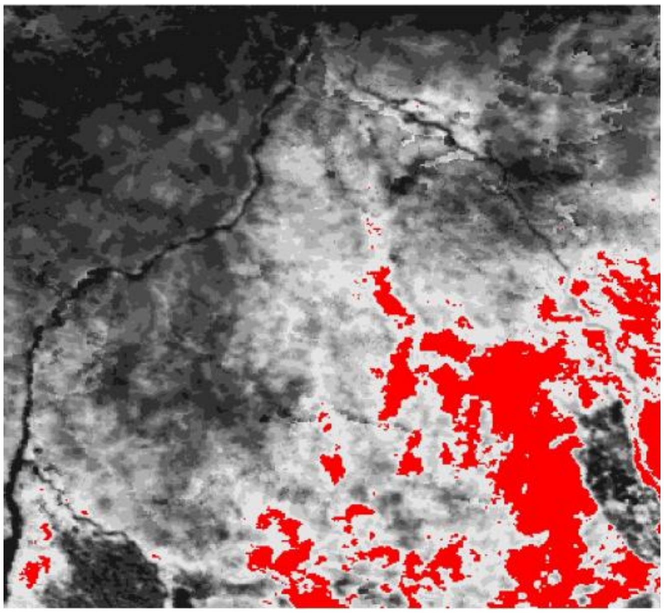

Plate 1. Classified LST image acquired in 2003 day 297, 12 days before the shock.

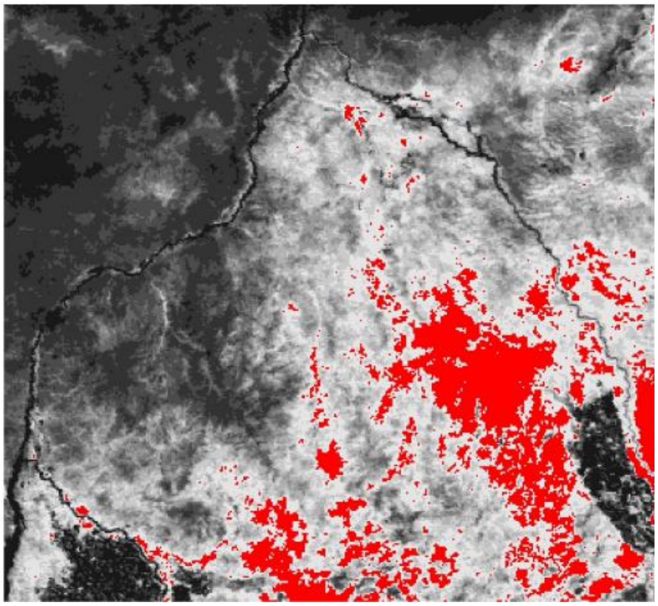

Plate 2. Classified LST image acquired in 2003 day 303, 6 days before the shock.

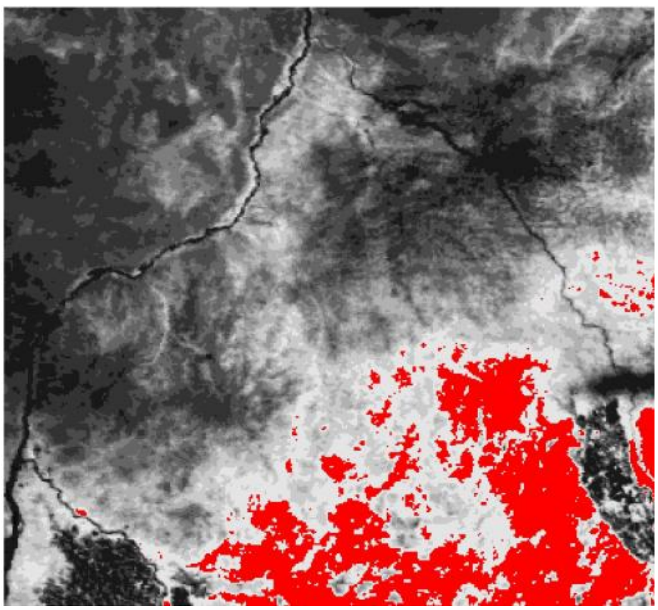

Plate 3. Classified LST image acquired in 2003 day 305, 4 days before the shock.

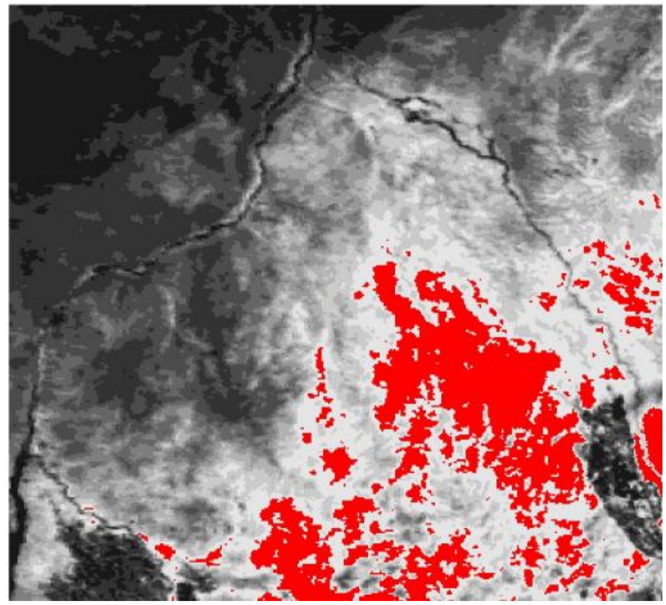

Plate 4. Classified LST image acquired in 2003 day 307, 2 days before the shock.

In the post-earthquake images (Plates 5, 6, 7, and 8), the anomaly temperature was normal without development of linearity. This anomaly occurred one day after the shock. 3 days after the earthquake the temperature was rising and concentrated in the eastern region with N-S direction. 6 and 12 days after the earthquake a weak anomaly again appeared around the area.

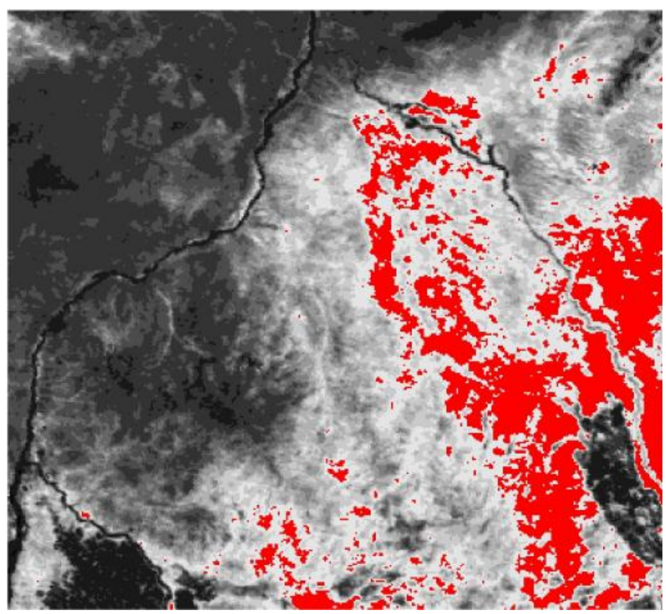

Plate 5. Classified LST image acquired in 2003 day 310, 1 days after the shock.

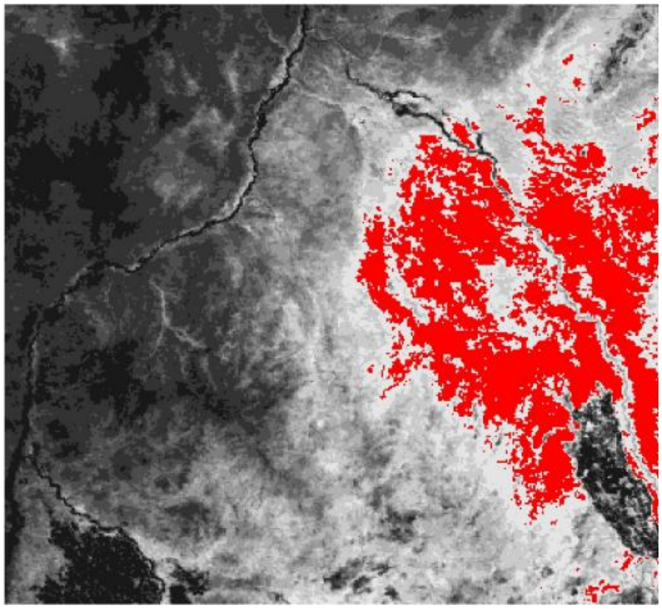

Plate 6. Classified LST image acquired in 2003 day 312, 3 days after the shock.

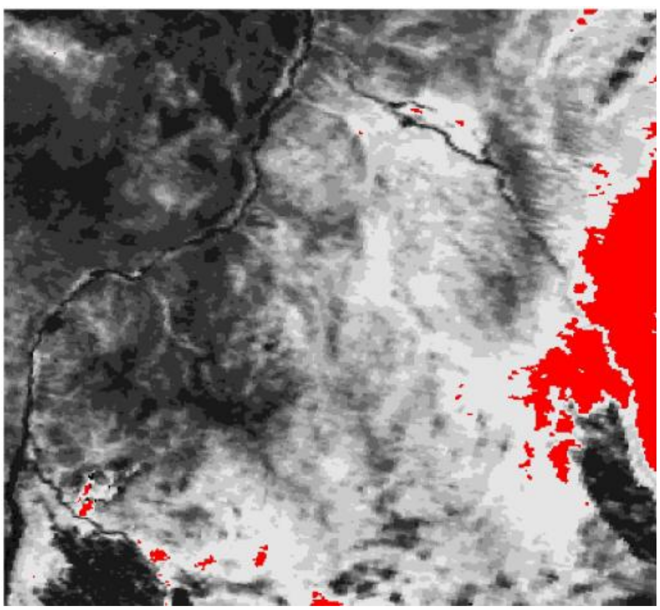

Plate 7. Classified LST image acquired in 2003 day 315, 6 days after the shock.

6.2 Interpretation and discussions

Plate (1) shows the appearance of a positive thermal anomaly in the image area. This anomaly was developed 12 days before the earthquake. The LST begin to increase in the eastern part of the study area. The anomaly has approximately N-S trend, but the linearity of its shape is not clearly developed. In plate (2) insignificant thermal anomaly was observed with no linearity. The anomaly in this image was weakened and concentrated in a small area west of the River Atbara, in the eastern part of the image area. The high LST values were classified as one group and are not distributed all over the area. This may help in linking the anomaly to one geological structure.

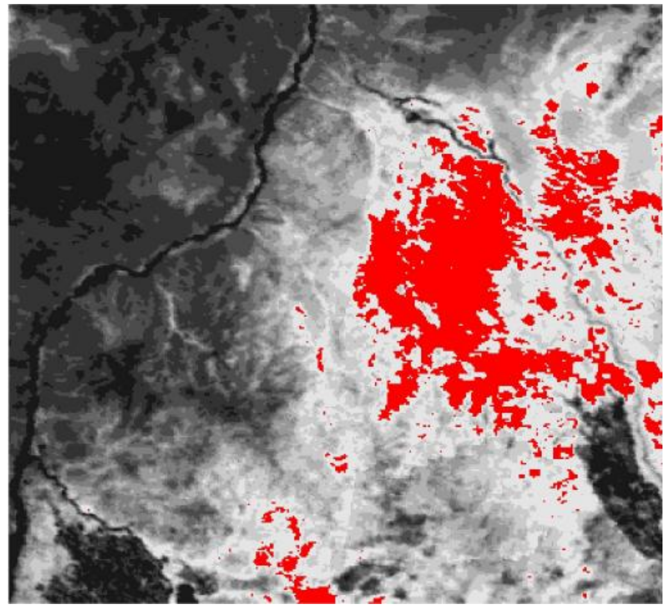

Plate 8. Classified LST image acquired in 2003 day 321, 12 days after the shock.

In Plate (3) an overall increase in the temperature was noticed in the southern and southeastern parts of the plate, with NW-SE general trend. This can be observed from the light tones covering the majority of the image compared to the previous images. In the northern part of the plate it can be observed that the temperature was low compared with the southern part of the image Likewise, Plate (4) once more shows overall increase in the temperature, with higher values at the center of the image and growth to the north with linear trend.

Plate (5) shows the LST covering the eastern part of the image with developing trend to the north. The temperature appeared in the right side of Atbara River. The image shows relatively light tone to the East and dark tone to moderately dark to the West. Likewise, Plate (6) the LST covers the entire eastern part with huge area, and became lighter than in the other parts, also with NW-SE direction.

In Plate (7), the anomaly was decreased and located on the eastern part of the plate with no clear direction. Comparing this plate with Plate (8), the temperature for the latter was developed and increased to high value. This can be observed in the central part of the Plate (7) with undeveloped orientation.

The thermal anomaly appeared twelve days before the earthquake and faded away in the following day. 2 days before and 2 days after the shock, the thermal anomaly became well developed with a linear shape trending N-S in some images, and NW-SE in others. Several days after the shock, the anomaly was weakened and concentrated in a small areas. The anomaly has approximately N-S trend. But the linearity of its shape is not clearly developed. Significant thermal anomaly was observed 6 days before earthquake. This temperature rising higher than the usual temperature of the region. On the following days, the LST start decreasing, and became weak on 4 and 2 days before the shock.

The linearity of the shape of the anomaly may enhance the link of this anomaly to linear structures such as faults or shear zones causing the earthquake. This lineament coincides with the linear course of a major seasonal stream east of Abu Deleig village (i.e. Wadi Al Hawad), which may represent the southern extension of the Keraf Shear Zone, according to Elsheikh et al. (2014).

There is an actively evolving sedimentary basin around the epicenter (i.e. Atbara Basin to the north and Khartoum Basin to the west and southwest) and accordingly earthquake might occur as a result of the sedimentary basin subsidence. However, the influence of the tectonically active East Africa Rift may be strong in this area.

7. Conclusion

The scope of this paper was to compare estimates of land surface temperature derived from using the MODIS sensor. The visual interpretation of the thermal images (LST) allowed the recognition of thermal anomalies located around the epicenters of the 2003 Abu Deleig earthquake. The increase in temperature, the systematic distribution of pixels with high LST and the linearity of the shape enhanced the link of the anomaly to linear structures such as faults or shear zones causing the earthquake.

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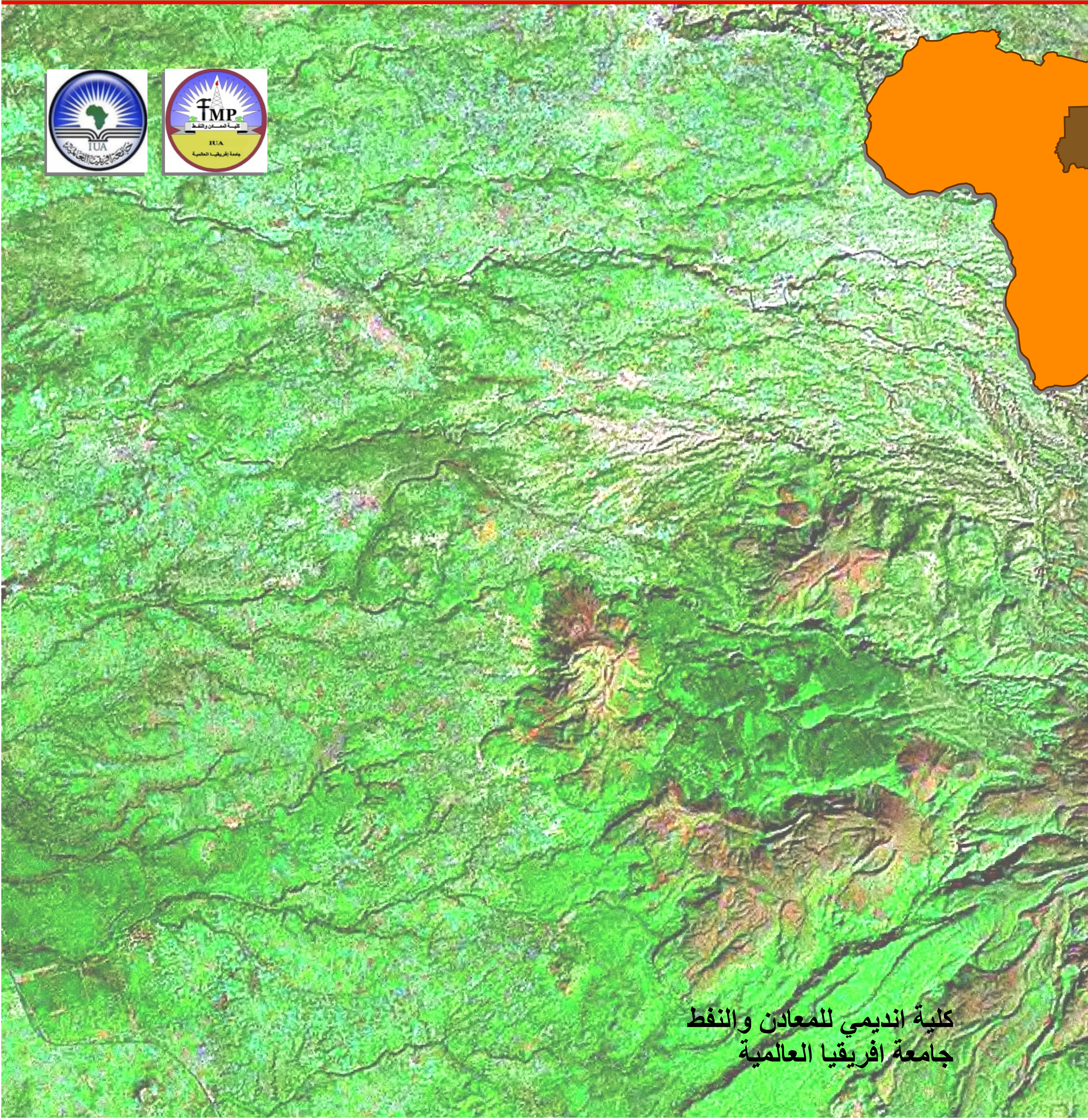

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