Thermal method of remote sensing for prediction and monitoring Earthquake

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***Abstract*—Analyzing past earthquakes and their characteristics, perhaps a better understanding about the earthquake phenomena can be made. Pressure built-up due to tectonic activities and also associated subsurface degassing might create changes in thermal regime and if by any technique this change is detected, it can provide very important clues about future earthquake activities. Passive thermal satellite remote sensing which can sense the earth's surface emissivity at regular interval introduces a new way of analyzing this phenomenon. A method using MSG-SEVIRI (METEOSAT Second Generation-Spinning in Visible and InfraRed Imager) thermal infrared time series datasets is developed and applied in this research, AEPA (Active Earthquake Prediction Algorithm) method can depict some anomalous increases in surface temperature that occur before an earthquake. One past earthquakes in Oran (Algeria) from June, 06 2008 was analyzed for studying the thermal changes before and after the earthquakes. The study was successful in detecting pre-earthquake thermal anomalies prior to all these earthquakes. Significant thermal anomalies with a rise in temperature of about 4-6°K in the vicinity of the epicenters have been observed. The anomalies disappeared along with the events.**

Keywords—Earthquake; remote sensing; SEVIRI sensor; surface temperature anomaly; AEPA algorithm.

I. INTRODUCTION

Earthquakes, floods, fires, volcanic eruptions, mudslides are all natural disasters which are often unavoidable, but whose effects may be limited. Satellite imagery, combined with other sources of information, can be used to make maps showing areas vulnerable to specific hazards (erosion, fire, mudslides, floods, etc.), by integrating physical, meteorological, demographic and economic factors, etc.

Algeria is a nation plagued by earthquakes; there are typically five of moderately severe earthquakes every year. The most severe earthquake to occur in recent ten years was the Boumerdes earthquake of May 21, 2003 (M = 6.8). , in which 2266 lives were lost, 10261 people injured and 200 000 left homeless as a result of the earthquake. Reports indicate more than 1 243 buildings were completely or partially destroyed. Infrastructure was predictably damaged in Algiers, Boumerdès, Réghaïa and Thénia [1].

The whole of Algeria is monitored now routinely by the "Active Earthquake Prediction Algorithm" or AEPA method developed under this research project. A method in which infra-red data from MSG satellites identifies anomalous increases in surface temperature, that occurs, before an earthquake. The surface temperature may typically increase by 4 to 6 °K anywhere between several days and a month in advance of an earthquake. Data from the project, which was originally scheduled to last for ten and a half years, is acquired daily via a simple station installed and with some parts realized in Laboratory of Analysis and Application of Radiations (LAAR) situated in University of Sciences and Technology of Oran (North West of Algeria) [2]. The mean objective of our station is to predict some natural hazards (like forest fires, cyclones, Earthquake, inundation...etc) in the goal to facilitate disaster reduction.

The AEPA method is helping to reduce the loss of life and the financial impact of earthquakes in Algeria and other nations observed by satellite instruments. It offers an inexpensive and potentially more accurate alternative to other methods of earthquake detection (such as the GPS method which relies on measurements of the slight deformation of the earth's crust that occurs before an earthquake) because of the wide coverage and ready availability of data [3]. The method is applied in this work to an earthquake event happened in the north west of Algeria (Oran city) there are five years ago, with a shock magnitude of 5.5 M_s.

II. MATERIALS AND METHODS

A. Use of satellite data and additional resources

Using the thermal infra-red channels of SEVIRI instrument (with 3 Km of full spatial resolution) on MSG geostationary satellite series, one observation is made of the entire half full terrestrial disk (centered in Africa) every 15 minutes. The data from this instrument are calibrated to determine the brightness temperature and then undergoes geometric correction (plate Carrée correction) using information on the atmospheric temperature and pressure. The data is then geo-referenced and calibrated in order to produce a thermal infra-red map. Analysis of these maps is performed in order to identify surface temperature anomalies which may be indicative of future earthquake activity. From an anomaly's character, the time, location and magnitude of an earthquake may be predicted.

B. Satellite images from raw data to surface temperature

Data from the infrared channels of the MSG-SEVIRI imagers are scaled radiances packaged in 10-bit words. The conversion of the raw data from the instruments to scaled radiances is carried out in real time in the header part of each received image. Secondary, we converted the ten-bit SEVIRI count values (0-1023) of Thermal Infrared channels into scene radiances, brightness temperatures, and eight-bit word counts [4].

The first step is to convert raw counts to radiances with equation 1.

$$R = (C_r - I)/ S \qquad (1)$$

where R is radiance in $mW/(m^2\text{-sr-cm-1})$ and C_r is the raw count value (from SEVIRI). The coefficients S and I are the "scaling" slope and intercept, respectively, and appear in the header part of each acquired image. The units of S are $counts/(mW/[m^2\text{-sr-cm}^{-1}])$. Their values depend only on channel, not detector, and for a given channel we expect them to be constant for all time and to be the same for each satellite of the series.

To convert radiance to temperature, one first uses equation 2 (the inverse of the Planck function) to derive "effective" temperature:

$$T_{eff} = (c_2\nu)/\ln(1 + [c_1\nu^3]/R) \qquad (2)$$

where T_{eff} is effective temperature (in K), "ln" stands for natural logarithm, and R is radiance. The coefficients c_1 and c_2 are the two radiation constants, given by:

$$c_1 = 1.191066\ 10^{-5}\ mW/(m^2.sr.cm^{-4})$$

$$c_2 = 1.438833\ K/cm^{-1}$$

The quantity ν is the central wavenumber of the channel. For a given channel it may vary slightly among detectors, and it will vary from instrument to instrument. To convert effective temperature T_{eff} to actual surface temperature Ts (K), one uses the following formula:

$$Ts = \beta.T_{eff} + \alpha \qquad (3)$$

The constants ν, α, and β depend on channel, detector, and instrument. The use of T_{eff} accounts for the variation of the Planck function across the spectral passband of the channel. The differences between the values of T_s and T_{eff} increase with decreasing temperature. They are usually of the order of 0.1K. In the worst case, near 180K, they are approximately 0.3K.

The 1 byte count value X_a is derived from the surface temperature with the following equations (equation 4 and equation 5) [5].

$$\text{For } 163K \le Ts \le 242K, \quad X_a = 418 - T. \qquad (4)$$

$$\text{For } 242K \le Ts \le 330K, \quad X_a = 660 - 2T. \qquad (5)$$

X_a values are on an eight-bit scale and range in value from 0 to 255, with high counts representative of low surface temperatures. Beyond the difference in precision, there is a fundamental difference between a raw SEVIRI counts and X_a counts in their units. The first one is scaled radiances, whereas the last one is temperatures.

C. Active Earthquake Prediction Algorithm description

The main steps of the process of Active Earthquake Prediction Algorithm (AEPA) are as follows:

1. Identify isolated area of thermal infra-red increase. The surface temperature X_a may typically increase by 2 to 4 k or higher than the sounding area.
2. Track the direction of the development and movement of the surface temperature increase area.
3. Identify the surface temperature increase phenomenon as a precursor of earthquake by taking into consideration the effects of weather, topography, geomorphology, geotectonic and present tectonics stress field.
4. Provide a three element prediction (earthquake time, location and magnitude) by considering the distribution of active fractures and seismic belts.

Prediction estimates are based upon:

Time: after identification of a surface thermal infra-red anomaly of a certain size and condition, earthquakes tend to occur probably within 1-15 days.

Location: the directional 'front' of the surface temperature increase area is used to identify the epicenter of earthquake;

Magnitude:

- Surface temperature increase area larger than $12\ 10^5\ Km^2$ ~Ms 7,
- Surface temperature increase area larger than $4\ 10^5$ Km2 ~Ms 6,
- Surface temperature increase area larger than $2\ 10^5\ Km^2$ ~Ms 5,
- ie the larger the area the larger the main shock.

Surface temperature increases detected as precursors of earthquakes have been noted to possess the follow characteristics:

1) The abnormal temperature increase area is identifiable. Usually, it demonstrates itself as an isolated body in the thermal infrared image, and could be distinguished from other signals such as temperature anomalies caused by weather processes.

2) Our prediction practices prove that tracking of surface temperature anomalous increases as earthquake precursors is universally valid.

3) The temperature of the anomalous area is typically 2 to 6 °K higher than that of its surroundings.

4) The larger the area of the surface temperature anomaly, the larger the magnitude of the future earthquake.

5) The dynamic evolution of the anomaly area and location may be monitored by satellite to predict the location of earthquake.

Based on our observations and experiments, we could suggest a preliminary model for the mechanism of the anomalous temperature increase as follows in figure 1.

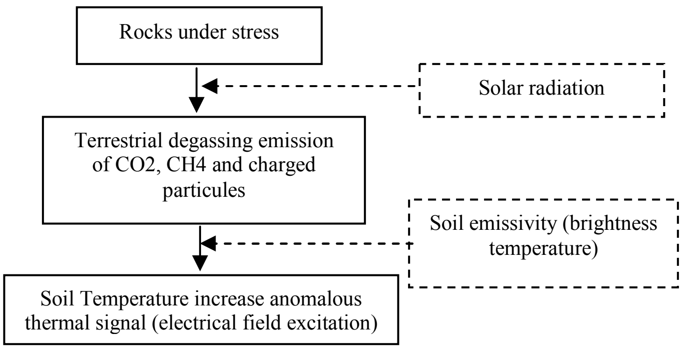


Fig. 1. A preliminary model for the mechanism of the anomalous temperature increase, based in Active Earthquake Prediction Algorithm (AEPA). The raw and processed data from this research are stored continuously and daily since October 27, 2007 from MSG-SEVIRI[6].

III. RESULTS AND DISCUSSIONS

Based on the thermal anomalous temperature increase, depicted by using AEPA method, we predicted that there would be an earthquake of magnitude 5 to 6 (Mw) in the north-western sea areas of Oran town (in North west of Algeria) on June 06, 2008. The predicted time window was from June 01 to June 10, 2008. As expected, there was an earthquake of magnitude 5.5 (Mw) on June 06, 2008 at 20:02 UTC. The epicenter is located at 35.883N, 0.658W. The predicted location was in the sea, which is 20 km away from the Bousfer beach. In early June, 2008, there appeared an anomalous surface temperature increase in the 3.9 µm thermal infrared band of SEVIRI-MSG2 imagery in the north west of Algeria. Figure 2 shows time series composite SEVIRI raw IR3.9 channels acquired from 04 to 07 June 2008 at 12:00 UTC (before and after the earthquake) with the corresponding histogram. The surface temperature composite map of the day of 04 June 2008 showed the appearance of a positive thermal anomaly towards an area south of the Bousfer-Oran earthquake epicenter. This anomaly intensified to a maximum buildup of thermal anomaly on the day of 05 June 2008, covering an approximate area around of 65 000 km2. The temperature rose to around 295-302ºK, about 5-6ºK higher than the surrounding area. After two main shocks occurred, of magnitudes 4.2 Mw (in 35.775N, 0.592W at 21:10 UTC) and 4.5 Mw (in 35.827N, 0.63W at 22:48 UTC) on 06 June 2008, the anomaly weakened. A less intense anomaly on the same night was probably a precursor to an earthquake of magnitude of 2.9 Mw, which occurred at 23:33 (UTC). The anomaly disappeared in the afternoon of 07 June (figure 3). Table 1 recapitulates details of June 06, 2008 Oran primary and Aftershocks earthquakes even studied for pre-earthquake thermal anomaly.

TABLE I. DETAILS OF JUNE 06, 2008 ORAN PRIMARY AND **AFTERSHOCKS** EARTHQUAKES STUDIED FOR PRE-EARTHQUAKE THERMAL ANOMALY.

Epicenter Location	**Time (UTC)**	**Magnitude (Mw)/Depth (Km)**	**Surface temperature (°K) On june,04 2008**	**Surface temperature (°K) On June, 05 2008**	**Surface temperature (°K) On June, 06 2008**	**Range of temperature increase (°K)**
35.883N, 0.658W	20:02	**5.5 / 4**	302	303	307	05
35.775N, 0.592W	21:10	**4.2/0**	302	304	307	05
35.875N, 0.602W	22:26	**3.3/0**	301	302-303	304	03
35.827N, 0.63W	22:48	**4.5/0**	301-302	301-302	306-307	05 to 06
35.903N, 0.547W	23:33	**2.9/0**	302	302	306	04

IV. CONCLUSION

The proposed AEPA method for earthquake prediction has been shown to provide timely information on earthquakes more accurately and economically than other proposed methods. From 2007 to the present time, an important earthquake was occurred in June 2008 in Oran city (North West of Algeria), with a magnitude around 5.5 Ms, the disaster resulted in the without any loss of lives, over 30 severe injuries and an estimated direct financial loss. As successfully demonstrated in the present study, the earthquakes in Oran (Algeria), was associated with the presence of pre-earthquake thermal anomalies. The anomalies appeared a few days to a few hours before the earthquakes. The increase in temperature ranges between 4 to 6°K. These anomalies are seen to disappear after the earthquakes. The AEPA method offers an inexpensive and potentially more accurate alternative to other methods of earthquake detection (such as the GPS method which relies on measurements of the slight deformation of the earth's crust that occurs before an earthquake [7][8]). Because of the wide coverage and ready availability of data from SEVIRI, many other areas of the world could potentially benefit from the technique within a short timescale and for very little investment. One potential drawback of the technique is the masking of the ground caused by the presence of clouds in some infra-red imagery - experience has shown that this may be overcome by using the short wave infra-red radiometers carried on meteorological satellites. Proposals are also currently being put forward to use the same satellite thermal infrared data to study precursors of volcanic eruptions.

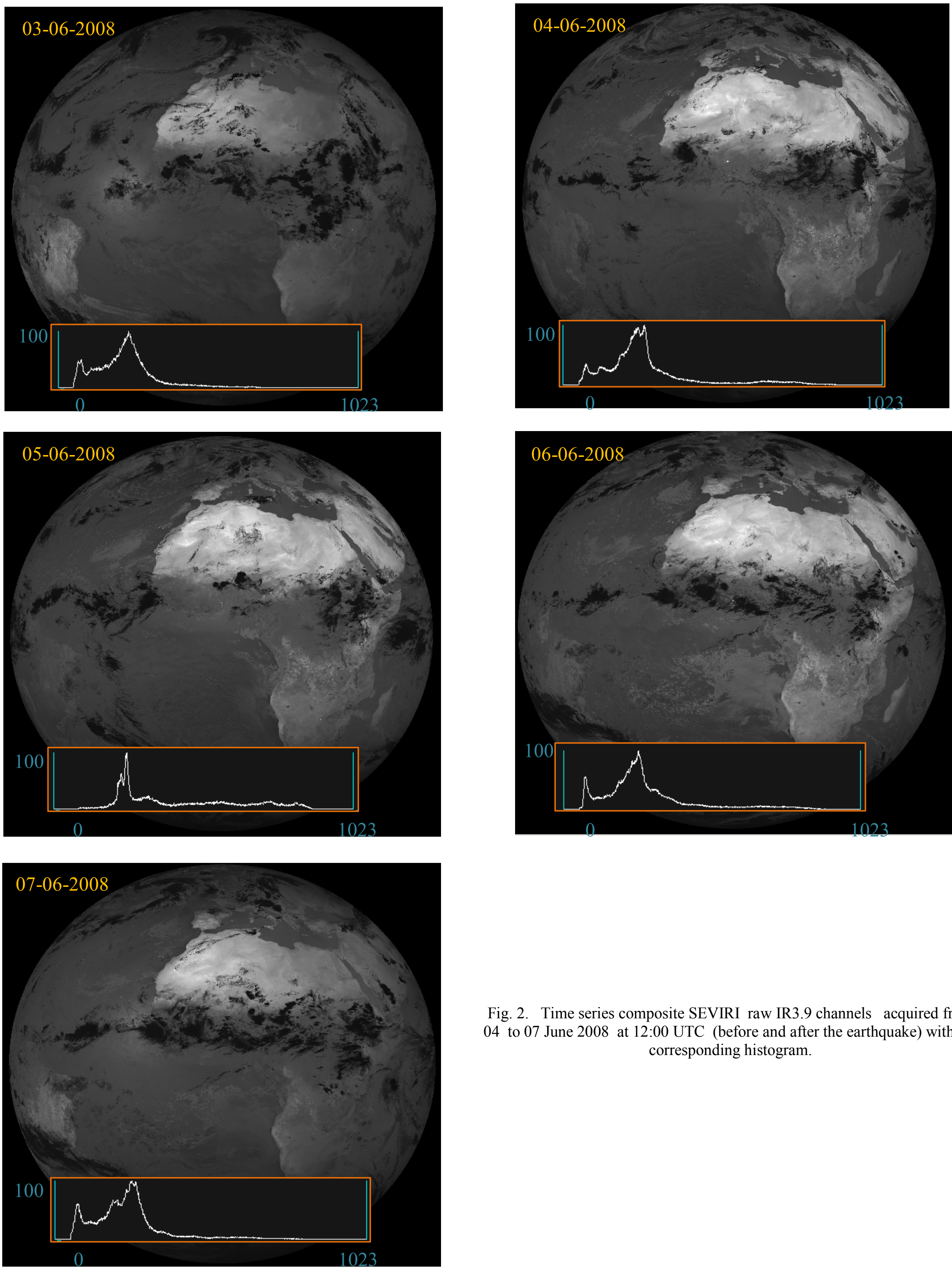
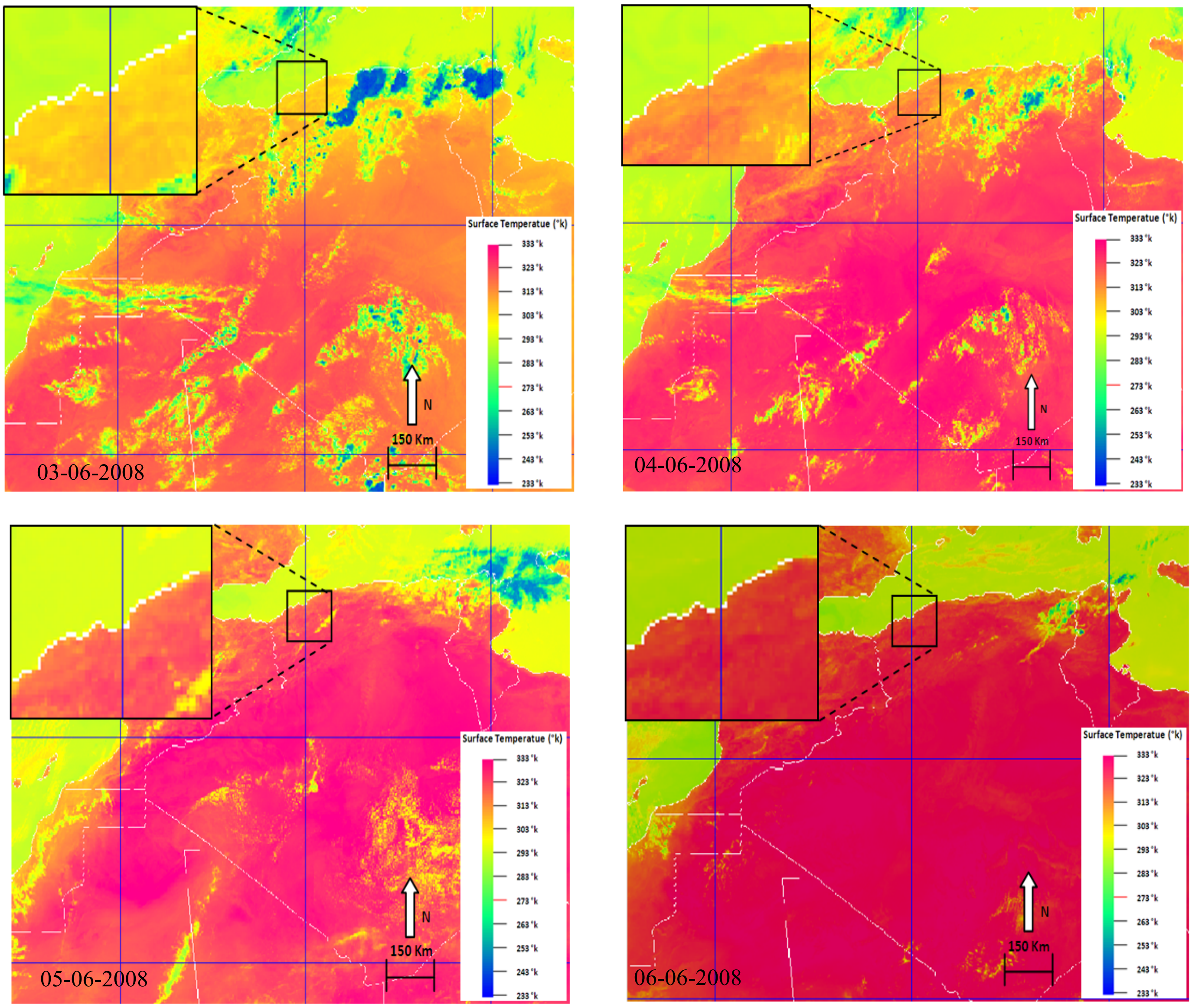


Fig. 2. Time series composite SEVIRI raw IR3.9 channels acquired from 04 to 07 June 2008 at 12:00 UTC (before and after the earthquake) with the corresponding histogram.



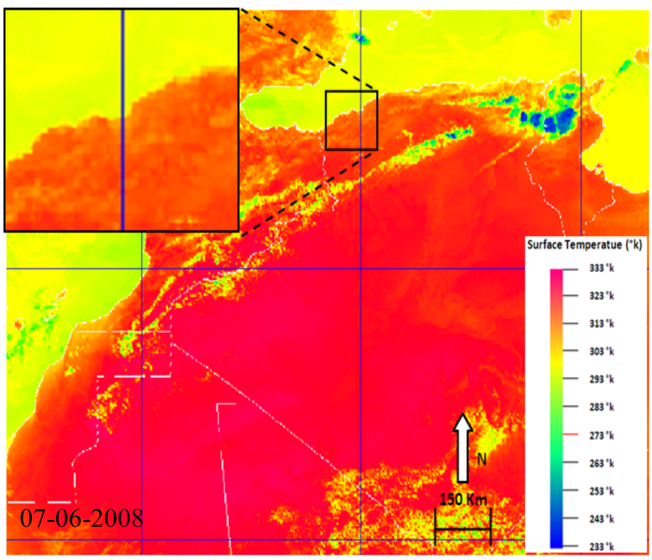


Fig. 3. Time series composite Surface Temperature maps of Algeria before and after the earthquake. The temperature was seen to be maximum on June , 06 2008 at 12:00 UTC.

REFERENCES

[1] A.B. Curtis L. Edwards, ed. (2004). Zemmouri, Algeria, Mw6.8 Earthquake of May 21, 2003. Reston, VA: ASCE, TCLEE. ISBN 9780784407462.

[2] SOURCE: STA/NASDA, 1995. The information was originally supplied by the National Remote Sensing Center of China.

[3] Choudhury, S., Development of remote sensing based geothermic techniques in earthquake studies, Ph.D. Thesis, Department of Earth Sciences, Indian Institute ofTechnology Roorkee, Roorkee (Unpublished). 2005.

[4] Hassini, Abdelatif, Belbachir, Ahmed Hafid, Hardware and software consideration to use near real time MSG-SEVIRI and NOAA-AVHRR images, 11th International Symposium on Programming and Systems (ISPS), Page(s): 12 - 16 Print ISBN: 978-1-4799-1152-3, Algiers, Algeria Digital Object Identifier : 10.1109/ISPS.2013.6581487 , 22-24 April 2013.

[5] Bristor, C.L. (ed.), "Central processing and analysis of geostationary satellite data," NOAA Tech. Memo. NESS 64, U.S. Dep't. Commerce, National Oceanic and Atmospheric Administration, Washington, DC, 155 pp. (1975).

[6] Hassini A., F. Benabdelouahed, N. Benabadji and A. H. Belbachir, Active Fire Monitoring with Level 1.5 MSG Satellite Images, American Journal of Applied Sciences, 6:1, pp 157-166, 2009.

[7] Andrew A. Tronin, Satellite Remote Sensing in Seismology. A Review, Remote Sens. 2010, 2, 124-150; doi:10.3390/rs2010124.

[8] Freund, F., Takeuchi, A., Lau, B.W.S., Al-Manaseer, A., Fu, C.C., Byrant, N.A., and Ouzounov, D., (2007), Stimulated infrared emission from rocks: assesig a stress indicator,eEarth, Vol. 2, pp. 1-10.