EARTHQUAKE PRECURSOR FROM SATELLITE IMAGERY: SIGNALS OR JUST NOISE?

Shattri MANSOR and Habibeh Valizadeh ALVAN, Malaysia

Key words: earthquake precursors; remote sensing; surface temperature; surface heat flux; sea surface height.

SUMMARY

Pre-earthquake physical and chemical interactions in the Earth's ground may cause anomalies in latent heat flux, air and surface temperature. Changes in latent heat flux and temperature, on and above the earth's surface can be detected with thermal infrared sensors such as NOAA-AVHRR, MODIS and Landsat TM. Geophysicists developed theories about the earthquake mechanisms and the underground geophysical and geochemical interactions involved in the process of ground shakes, and the related phenomena that might be detected as pre-earthquake signals. Earthquakes are triggered when the energy accumulated in rocks releases causing ruptures in place of faults. Elastic strain in rocks, formation of micro-cracks, gas releases and other chemical or physical activities in the earth's crust before and during earthquakes has been reported to cause rises in sea surface temperature (SST), surface latent heat flux (SLHF), and sea surface height (SSH). Spatio-temporal distributions of SLHF, SST and SSH before and after recent earthquakes in Indonesia have been studied. Anomalous patterns of higher SLHF formed few days before the earthquakes of 20 Feb 2008 (7.4M) and 25 Feb 2008 (7.2M) occurred in Simeulue and Kepulauan disappeared after the main events. These changes were also in accordance with the abnormal relative humidity over the region. Data analyses revealed at least 1–3°C rises in air temperature along the nearby fault zone, as well. The anomalous patterns started developing two weeks to a few days before the earthquakes and disappeared after the main shocks. Significant rises in SLHF and air temperature may lead us to understand the energy exchange mechanism during the earthquakes. These anomalies prior to impending earthquakes can be attributed to the thermodynamic, the tectonic blocks and micro-fracturing in the rocks especially along area's active fault. Continuous monitoring of these potential pre-cursors helps in differentiating earthquake related variations (signals) from seasonal changes and atmospheric effects (noise).

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1. INTRODUCTION

Earthquake is the trembling or shaking movement of the earth's surface. It occurs when energy stored within the earth, usually in the form of strain in rocks, suddenly releases. This energy is transmitted to the surface by seismic waves. Most earthquakes are minor tremors. Larger earthquakes usually begin with tremors, but rapidly take the form of one or more violent shocks, and end in vibrations of gradually diminishing force called aftershocks.

The emergence of high quality measurement devices from a decade ago had directed the courses of earth-related efforts towards providing better and more accurate knowledge of the mechanical and chemical ongoing in the earth during natural phenomena. Laboratory micro-scale experiments, powerful sensors, and advance imaging devices allow scientists to present detailed explanations of possible atomic and molecular interactions in materials. With the satellites research organizations that could send their sensors to high altitudes producing round-the-clock monitoring of the earth’s surface and atmosphere in wide scales, there is long list of image and non-image datasets proposing a wide array of views from any part of our globe. In this climate, theoreticians are able to base their theories about the origins and mechanisms of natural events upon encompassing, more accurate inspections of what is going on under, on, and above the earth’s surface.

During the past years, occurring numerous devastating earthquakes in different parts of the world that caused thousands of deaths and millions of dollars in property loss and impacts on strategic and scientific planning has stirred a lot of interest among researchers to work on the identification and detection of the earthquake precursory events to propose possible short-term prediction models that lead to mitigate damage from future earthquakes (Ryabinin et al. 2011). So far, they have identified some events that theoretically are expected to take place and practically are possible to detect before and during earthquakes. Studies on the surface and air temperature, surface latent heat flux, relative humidity, radon isotopes, ionosphere variations and some other precursors resulted in successful detection of extraordinary changes during several past oceanic and land earthquake instances and assumptions on the causes of these events observed during seismic activities (Wang and Shi, 1984; Gorny et al. 1988; Nosov, 1998; Freund and Ouzounov 2001, 2003; Tronin et al. 2002, 2004; Dey and Singh 2003; Cervone et al. 2004, 2006; Pulinets, 2004; Saraf and Choudhury, 2003-2005; Saraf et al. 2008; Choudhury et al. 2006; Parrot et al. 2006; Pulinets et al. 2006; Singh et al. 2006, 2007, 2010; Qin et al. 2009; Kumar et al. 2009; Marchese et al. 2010; Revathi et al. 2011; Alvan et al. 2012).

An abnormally increased infrared temperature before an earthquake can reflect seismo-tectonic activities (Tronin, 1996-2004; Nosov, 1998; Ouzounov and Freund, 2004; Saraf and Choudhury, 2005a, b; Choudhury et al. 2006; Ouzounov et al. 2006; Liu et al. 2007; Saraf et al. 2008; Ma et al. 2008, 2010; Marchese et al. 2010; Alvan et al. 2012). Thermal anomalies over the lands and oceans have been identified, associated with large linear structures and fault systems in the Earth's crust, on the basis of satellite infrared thermal images of the Earth's surface.

The amount of latent heat flux between the earth's surface (sea or land) and atmosphere have been repeatedly reported as a sign of underground heat generated by earthquake related processes (Freund and Ouzounov, 2001; Cervone et al. 2004, 2006; Dey and Singh, 2003, 2004; Singh et al. 2006,2007; Qin et al. 2009; Singh et al. 2010; Alvan et al. 2012). The speed of evaporation in large and small scales is a function of various factors from seasonal changes to the man-made structures; however, it is now believed that the earthquake preparation process may lead to higher SLHF concentration around epicenters and nearby active fault zones. Remote sensing techniques provide the opportunity of studying the consequences of seismic activities in large scales (Tronin, 2010; Alvan and Azad, 2011).

In this paper, two successive earthquakes in Indonesia, on 20th and 25th of February, 2008 with magnitudes of 7.4 and 7.2 were selected for the pre-earthquake anomalies study from tropical area. Spatial distributions of temperature during the occurrences of these major events are analyzed for three month period together with the variations of SLHF and SSH anomalies based on the theoretical explanations of earthquake preparation activities in the vicinity of oceanic earthquakes.

2.0 Earthquake prediction

The basic concept of the classical approach to earthquake prediction, which was suggested by Raid in 1910, is monitoring the places that have the previous records of this event (Ravathi et al. 2011). Knowledge of the earthquake experiences, tectonic setting, and geological characteristics of an area help determining the locations and recurrence intervals of earthquakes (Nelson, 2010). By studying the shake records of an area it will be possible to determine recurrence intervals of major earthquakes. In fact, long-term prediction methods suggest the occurrence of earthquakes soon or later but they do not give information about the location and time of an earthquake whose preparation stages have already begun. In contrast, monitoring surface and above surface phenomena during the earthquake preparation stage may provide clues to the location and time of an impending events.

Beside the anomalous events or processes that may precede an earthquake (precursory events) and might signal a coming earthquake, the energy built up in the earth's crust can cause swelling of rocks which result in ground uplift and tilting in active fault zones. This causes the formation of numerous small cracks and an unstable condition that may lead to small earthquakes before the main event (Nelson, 2010). These foreshocks are considered as seismic precursory signals and usually appear less than 30 days before the main shake (Ihmle and Jordan, 1994; Reasenberg, 1999, Gavrilov et al. 2008; Ryabinin et al. 2011). Thus, significant ground deformations and the occurrence of successive small shakes in the vicinity of active faults may warn the existence of seismic activities leading to a strong earthquake. However, short-term earthquake prediction through monitoring precursory events has always been difficult to obtain because earthquake related processes occur deep beneath the surface. Despite the array of precursors that are possible to monitor, successful short-term earthquake prediction has so far been difficult to obtain (Nelson, 2010). In order to produce enough information for monitoring seismic activities along active fault zones large number of ground observation stations are necessary. But, satellite-based monitoring methods yield wider coverage, rich information and higher spatial and spectral resolutions. Instead of relying on a single precursor for earthquake prediction, different in-site and remotely-sensed data should be integrated to produce better and more comprehensive earthquake studies. There are several national and international space programs for monitoring earthquake precursory events (Ryabinin, 2011).

3.0 Earthquake precursory signals

3.1 Active faults

Classical earthquake theories suggest that active faults are the generator of this event. Small shakes grow into main earthquakes while they are spreading along these faults. The first stage of a successful short-time prediction would be a successful detection of active faults. However, the identification of an earthquake producing fault is not easy. In Japan, it took fourteen years to survey 110 active faults but the next 6 major earthquakes (6.9-7.3) occurred along undetected ones. They suggested that the location and geometry of a source fault of a future earthquake can be inferred from fold structure. Other methods to get information about hidden faults are seismography and Radar imaging. Seismic data are used to detect faults with no ruptures on the earth's surface. Talebian et al. examined the 2005 Dahuiyeh earthquake sources (Talebian 2006). They used seismic body waves, radar interferometry and field investigation to examine the source processes of the destructive earthquake. Using Landsat TM, ETM and SAR ERS-1 data and conducting long termmonitoring of tectonic structures they identify linear features (active faults). Currently, researchers concentrate their Efforts on identifying local and hidden faults and monitoring the precursory events along them. Infrared images are used to show thermal anomalies around fault zone for past earthquakes. Higher concentration of atmospheric water vapor along nearby active faults was reported 11 days before Wenchuan earthquake (Liu et al. 2007).

Scientists used Landsat TM, ETM and SAR ERS-1 data to successfully detect linear features on the earth's surface (faults) through visual interpretation (Zoran 2010). They reported that remote sensing multi-spectral images have great potentials in large scale active faults investigation. They declared fabulous result of their efforts in detection of invisible faults. They attributed the successfulness of remote sensing to its wide recording spectrum from visible to microwave. Nevertheless, those faults buried by soil layers may not be detected with satellite-based.

Proper approach to identify the faults with no ruptures on the earth's surface or those which have been covered by soil is to perform geochemical surveys. In this method, sampling is carried away to record the amount of Radon gas in organized sampling networks or deep into the surface in certain points. By statistical analyses and re-sampling methods it will be possible to compare the resultant maps with fault maps and detect invisible faults deep enough to be a path to Radon reach the earth's surface.

3.2 Heat and thermal anomalies

The accumulated stress in the ground causes the generation of two phenomena; Heat and seismic waves. Heat is a direct result of the compression in underground rocks. Rocks are packed together to absorb some of the stress. In this level the underground water comes up causing higher resistance capability of the crustal and upper crustal part of the ground (Plastino et al. 2012). But, when the tolerance limit has passed the rocks break and micro-cracks form. This allows the water to come back filling the newly formed holes causing the loss of resistance of the whole system. It is when the ground is waiting for another pressure to rupture or move along the already existing faults. During this process the friction between rocks and the release of gases caught inside rocks causes increase in temperature. The heat, water vapor and gas reach the Earth's surface and as a result the litho-atmospheric coupling starts. First, convective heat flux (hot water and gas) changes the temperature of the Earth's surface. Second, changes of the water level with usual temperature lead to alterations in soil moisture, and consequently the physical properties of the soil (Israel and Bjornsson, 1966; King, 1980, 1996; Imme et al. 2006a; Giammano et al. 2007; Giammanco and Bonfanti, 2009). The difference in physical properties determines the different temperatures on the surface. Third is the greenhouse effect, when the optically active gases are escaped to the surface (Tronin et al. 2004).

The anomalies in heat and related phenomena occur in a vast area. Remote sensing techniques provide the opportunity of studying the consequences of seismic activities in large scales. However, other non-seismic factors like surface formation type and characteristics, seasonal changes, solar radiation, etc. may be affecting the temperature regime of an earthquake prone region. The heat generated by the chemical and physical processes inside the earth's ground may not be high enough to be distinguished from background noise. Nevertheless, the resultant phenomena like air humidity are found to be increased by the earthquake related energy release.

The idea that the thermal anomalies may be connected with seismic activity was put to application in Russia, China and Japan. In 1980, Russian researchers detected thermal anomalies prior to an earthquake in central Asia using satellite images. After that, thermal anomaly in surface temperature has been observed around 1–14 days before many strong earthquakes instances with abrupt change in the temperature value of the order of 3–7° C or more and disappeared a few days after the main events (Gorny, 1988; Qiang et al. 1999; Tronin, 2000; Tronin et al. 2002; Ouzounov and freund, 2004; Saraf and Choudhury, 2005; Choudhury et al. 2006; Genzano et al. 2007; Ma et al. 2008, 2010). Some remote sensing satellites can measure the radiations coming from the earth in thermal bands and provide useful information prior to earthquakes. Due to their suitable temporal and spatial resolutions, the thermal infrared bands of Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) data can be used (Ravathi 2011).

Amount of water vapor in atmosphere in a region is highly related to the speed of evaporation. Under stable conditions of water supply this factor is mainly proportional to the temperature. So changes in SLHF are controlled by variation in surface temperature, which is believed to be a precursory parameter during an earthquake. However topography, feature type, solar radiation, weather, seasonal changes and many non-shock factors can affect the temperature in a large area and some causes, such as human or construction activities may also influence on the temperature of a small area (Tronin 2000; Liu et al. 2007). Relationships between inland and oceanic seismic activities and anomalous changes in SLHF in different parts of the world have been registered by many researchers. Time series of SLHF have shown meaningful rises from a month to few days before the earthquake events (Cervone et al. 2004, 2006; Dey et al. 2004; Singh et al 2006; Alvan et al. 2012, 2013). SLHF data with resolution of 1.9° by 1.9° are available from the National Center for Environmental Prediction (NCEP-NCAR), reanalysis data of the IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu) which are generated by taking into considering the measured values at various worldwide stations and also those retrieved from satellite data.

Among all gases emitted from rocks during the earthquake preparation stages, radon is the only gas which has radioactive isotopes under normal conditions. Its most stable isotope, ^{222}Rn, has a half-life of 3.8 days. Once the isotope Radon222 seeps out of rocks and its decaying begins. This causes emitting the α-particles from active tectonic faults. Emission of this positive ions results in ionization of the near-ground layer (Igarashi et al. 1995; Toutain and Baubron 1999; Omori et al. 2007; lnan 2008; Ondoh 2009; Choubey et al. 2009; Kuo et al. 2010; Sac et al. 2011). The air ionization and emanation of some other gases like CO_2 leads to the changes in air temperature and humidity (Pulintets and Ouzounov 2011). But in fact, the origins and mechanisms leading to an expected higher air temperature in the seismic area is still a matter of debate among scientific theoreticians. In 2009 Freund et al. attributed this phenomenon to the local earthquake related electronic fields. They suggested that the ever increasing level of stress on rocks during the preparation stage of an earthquake causes the activation of highly mobile electronic charges in rocks and consequently air ionization. Then, a large number of atomic (ionic or covalent) bonds break increasing the crystal structure of the rocks. Finally, a chain of reactions result in an unbalanced charge distribution in underground material and the onset of strong local electric fields (Zoran 2010).

4. DATA AND METHODOLOGY

In this research, two successive earthquakes in Indonesia, on 20th and 25th of February, 2008 with magnitudes of 7.4 and 7.2 were selected for the pre-earthquake anomalies study from tropical area. Spatial distributions of temperature during the occurrences of these major events are analyzed for three month period together with the variations of SLHF and SSH anomalies based on the theoretical explanations of earthquake preparation activities in the vicinity of oceanic earthquakes.We have used optical and microwave data from several satellites orbiting the earth that provide information about land and ocean surface, and meteorological and atmospheric parameters such as surface temperature and relative humidity. For monitoring the changes in sea surface temperature, Advanced Microwave Scanning Radiometer (AMSR-E) /Aqua datasets provided by the National Space Development Agency of Japan (NASDA), which is capable of seeing through clouds and providing uninterrupted view of global, have been used. SLHF data are provided by National Centers for Environmental Prediction (NCEP) Reanalysis Project of the IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu). The datasets are in resolution of global grid 1.9° by 1.9° and generated by taking into consideration the measured values at various worldwide stations and also those retrieved from satellite data. The daily values of the SLHF for three-month period prior to and after the earthquakes have been studied in a rather wide area with the pixel covering the epicenter. Sea surface height maps have been used in this work are available in Ocean Watch website (http://las.pfeg.noaa.gov/oceanWatch) which are produced by altimeters. Altimeters are radar systems that point straight down from the sensor to the surface of the earth and map the height of an ocean's surface as well as measuring land surface elevations. Variations of SST and SLHF near the epicenters are plotted from several weeks before the events together with the sea surface height anomalies. Some details about the epicenters of these earthquakes are shown in Table 1. Figures 1 also show the epicenter locations.

Table 1. Details of the earthquakes (Source: http://earthquake.usgs.gov)

No.	Place	Date	Longitude	Latitude	Magnitude	Focal Depth (km)
1	Simeulue, Indonesia	Feb 20, 2008	95.978 E	2.778 N	7.4	35
2	Kepulauan, Indonesia	Feb 25, 2008	100.018 E	2.351 S	7.2	35

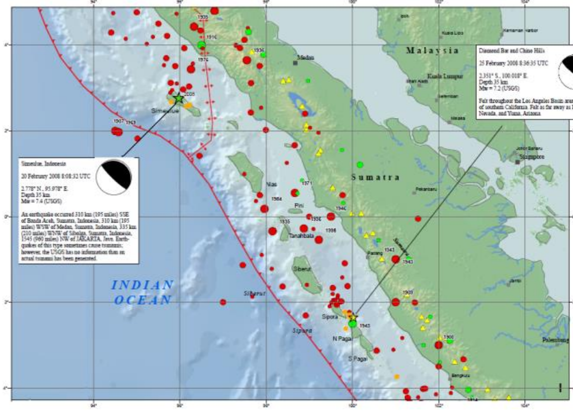

Figure 1. Locations of the two major oceanic earthquakes occurred in Indonesia on Feb 2010 (Source: http://earthquake.usgs.gov)

5. RESULTS AND DISCUSSION

Prior to tectonic earthquakes, the release of the accumulated energy in the earth's crust generates heat and seismic waves. Seismic waves transfer through tectonic plates to reach the epicenter and vibrate the ground. It happens few minutes before the earthquake so does not give enough time for a prediction. Nonetheless, there are seismology-based methods to monitor the earth's activities before earthquakes which cause silent shakes. On the other hand there is the heat which triggers physical and chemical interactions in the earth's crust. In case of oceanic and coastal earthquake it is proposed that energy exchange between earth and ocean causes the warm-up of water in lowest stratums of the sea. This will cause upwelling event. But, in contrast to normal upwelling, this results in higher sea surface temperature on the sea surface. The increased amount of evaporation will also enhance the recorded SLHF values.

In case of the both earthquakes occurred in Indonesia on February, 2008 AMSR SST maps (Figure 2a) show the build-up of positive thermal anomalies near the epicentral regions. Around the epicenter of 25 Feb earthquake, temperature is found to be temperature exceeded 30 °C on three occasions, on February 4, 11-12 and 17-19. Moreover in daily values of sea surface temperature at the epicenter (Figure 2b), a significant increasing trend is found from first January to the end of February followed by a sharp drop in March. Whilst the daily 8-year averaged values of SST (2000-2007), shown at the same figure (Figure 2b), have a steady pattern during Jan-Feb and then increase on March.

At the epicentral region of 25 Feb earthquake, temperature maps show some rises from fortnight to ten days prior to the main event (Figures are not shown here) and increase after the main event can be related to the aftershocks. In SLHF maps covering the both study earthquakes epicenters (Figure 2c), a significant anomaly is observed around the epicenter of 25 Feb earthquake on February 1-2, 20-21 and finally at the day of the main event (Feb 25). The statistical graphs of the heat flux daily values at the epicenter of the both earthquakes are also prove these anomalies. SLHF time series of Kepulauan earthquake is also shown in Figure 2d that proves the observed anomalies in maps.

Geoid height changes link with mean sea surface height changes, and one of the most useful ways to calculate them is to use satellite altimeter. In this study, we used sea surface height anomaly (SSHA) data of satellite altimeter Jason-2 (measuring precision of 2˜3cm) and searched for geoid height changes due to the earthquakes occurred in west Sumatra coasts on 20th and 25th February, 2008 (Figure 2e). From the eight-year averaged data of SSHA (2000-2007) it is expected that the sea surface height reaches its lowest amount at this time of the year (less than zero) but on February, 2008 (prior to the earthquake events) it was even more than 10cm at the epicentral area (Figures 2f).

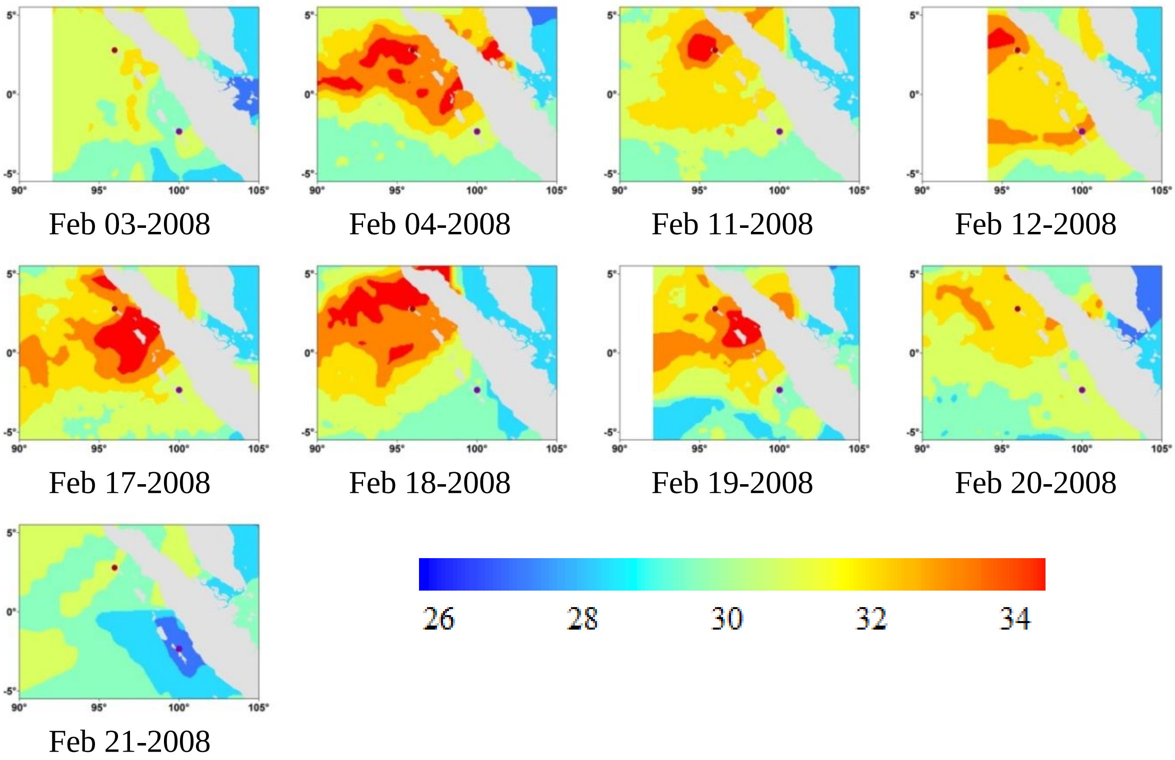

Figure 2a. Images of SST retrieved from AMSR-E in the Indian Ocean during the Indonesia earthquake of February, 2008 showing significant rises in some occasions related to the main events and the aftershocks.

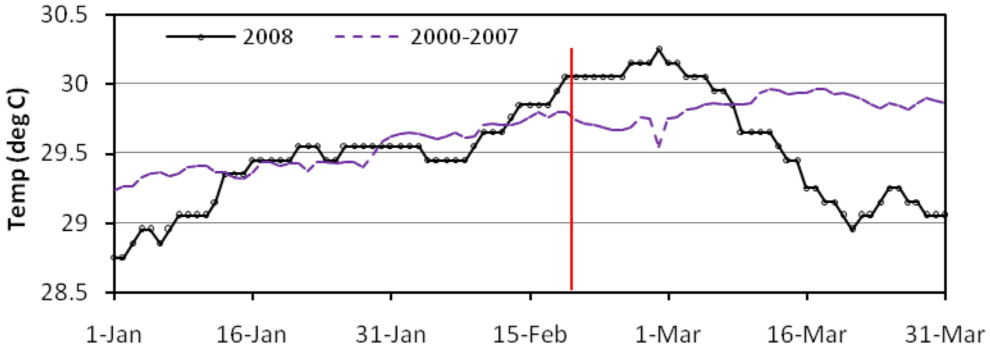

Figure 2b. Daily averaged sea surface temperature of the pixel covering the epicenter of Simeulue 20 Feb 2008 earthquake showing an uprising trend before the earthquake, during the preparation stage, and a sudden fall few days after the main event; the purple dashed line is the 8-year-average values.

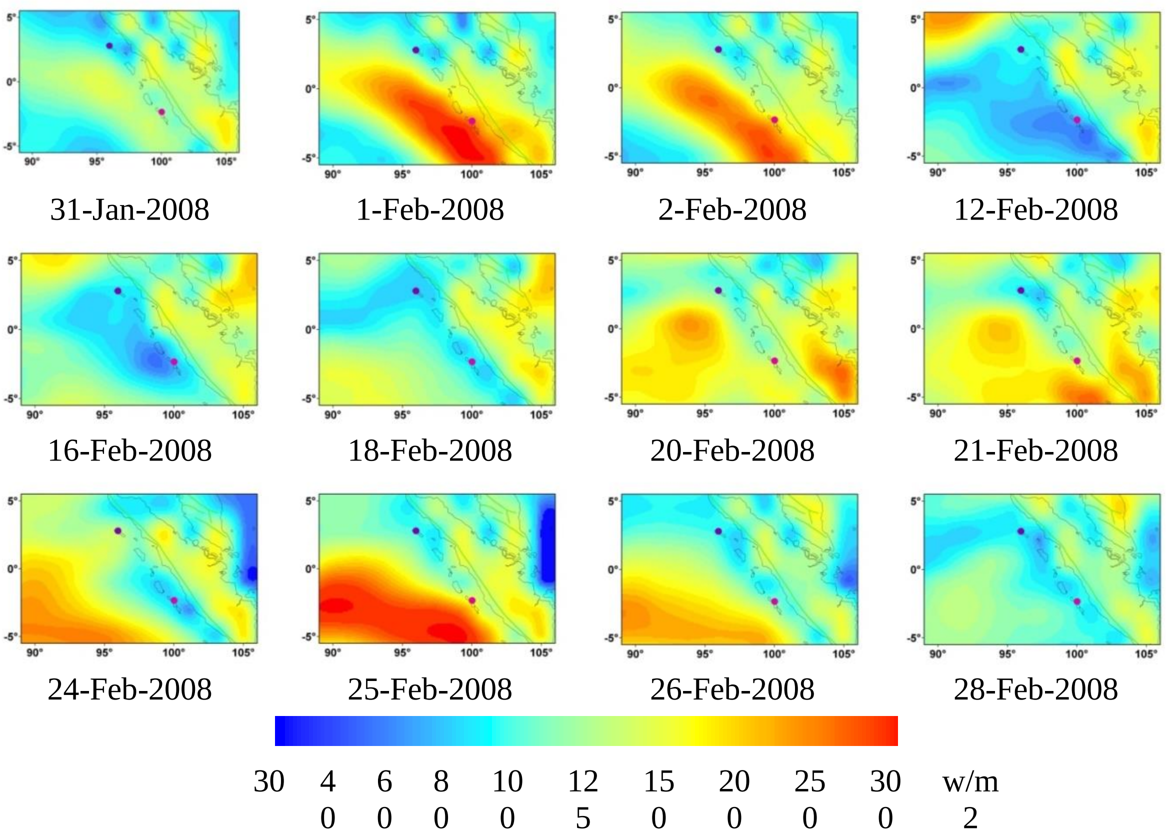

Figure 2c. Spatial distribution of SLHF anomaly in Indonesia before February 2008

earthquakes; Anomalies related to the seismic activity at the area of the epicenter are observable in some occasions such 1-2 and 20-25 Feb SLHF maps.

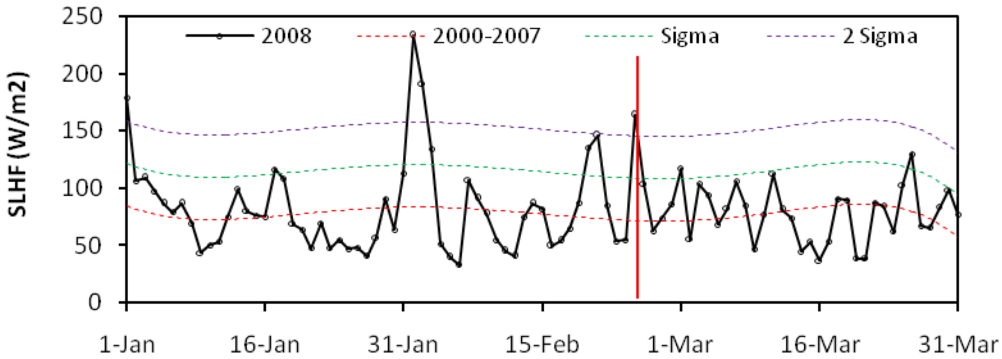

Figure 2d. Sharp rises in SLHF values of the pixels covering the epicenter of 25th Feb, 2008 earthquake is observable from the end of January to few days before the main event. Red bar is the day of the main event.

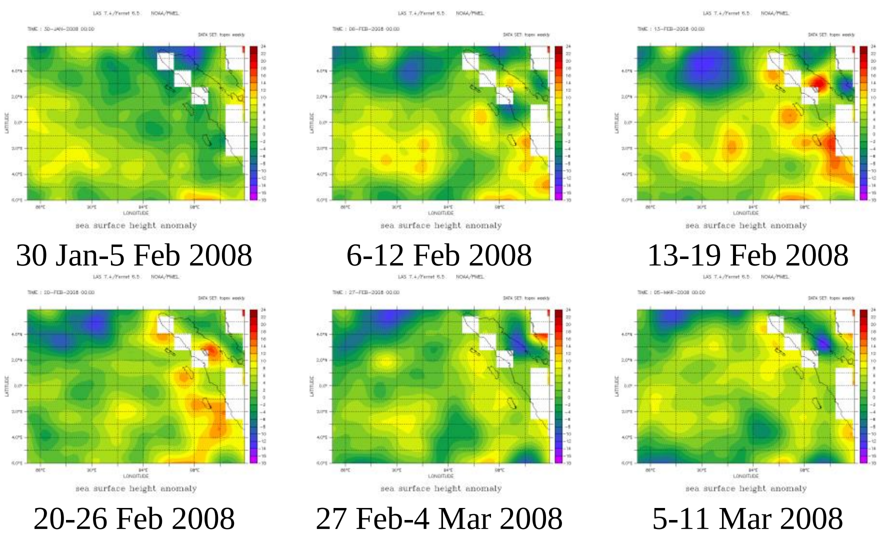

Figure 2e. Images of SSH retrieved from AMSR-E in the Indian Ocean during the Simeulue and Kepulauan earthquakes of February, 2008 showing significant rises near epicenters one week before and during the earthquake events.

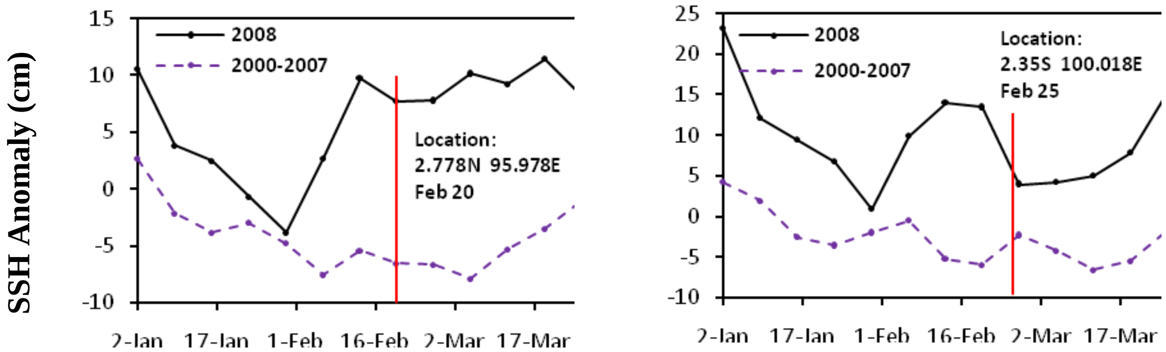

Figure 2f. Daily sea surface height data in the Indian Ocean at the point of our earthquake case studies' epicenters showing significant increase from two weeks before the main events comparing with the 8-year-average values (2000-2007); High values of SSH after the events may also be related to the effect of aftershocks.

6. CONCLUSION

The study was done in terms of the amount and spatial distribution of abnormalities around the epicenters and surrounding regions. The effects of earthquake preparation activities on sea surface temperature, surface height, and SLHF were successfully detected in these studies. However, the significance and appearance time of these signs are not similar. Although the heat generated before an earthquake is an underlying factor for some others, the detection of it is not very easy from SST data. Water is a better media to transport the earthquake related heat to the surface, but the temperature at the sea surface, itself, will not be changed by more than 1 or 2°C with the energy exchange on the ocean floor through the strong earthquakes. Significant increase in SLHF values from about three weeks prior to these events were accompanied by higher SST and SSH.

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REFERENCES

[1] Alvan, H.V., Azad, F.H., 2011, Satellite remote sensing in earthquake prediction, A review, *IEEE Xplore*, doi: 10.1109/NatPC.2011.6136371.

[2] Alvan, H.V., Azad, F.H., Omar, H.B., 2012, Chlorophyll concentration and surface temperature changes associated with earthquakes, *Nat. Hazards* 64 (1), 691-706.

[3] Cervone, G., Kafatos, M., Napoletani, D., Singh, R.P., 2004, Wavelet maxima curves of surface latent heat flux associated with two recent Greek earthquakes, *Nat Hazards Earth Syst. Sci.* 4, 359-374.

[4] Cervone, G., Maekawa, S., Singh, R.P., Hayakawa, M., Kafatos, M., Shvets, A., 2006, Surface latent heat flux and nighttime LF anomalies prior to the Mw=8.3 Tokachi-Oki

earthquake, *Nat Hazards Earth Syst. Sci.*6, 109–114.

[5] Choudhury, S., Dasgupta, S., Saraf, A.K., Panda, S., 2006, Remote sensing observations of pre-earthquake thermal anomalies in Iran, *Int. J. of Remote Sensing* 27(20), 4381-4396.

[6] Dey, S., Singh, R.P., 2003, Surface latent heat flux as an earthquake precursor, *Nat Hazards Earth Syst. Sci.*3, 749-755.

[7] Dey, S., Sarkar, S., Singh, R.P., 2004, Anomalous changes in column water vapor after Gujarat earthquake, *Adv. Space Res.* 33, 274-278.

[8] Freund, F., Ouzonouv, D., 2001, Earth-Atmospheric Coupling Prior to Strong Earthquakes Analyzed by IR Remote Sensing Data, *AGU, Fall Meet.* 82 (47).

[9] Gorny, V.I., Salman, A.G., Tronin, A.A., Shilin, B.B., 1988, Outgoing IR radiation of the Earth as an indicator of seismic activity, *Proceeding of the Academy of Sciences of the USSR* 301(1), 67-69.

[10] Liu, S.J., Wu, L.X., Li, J.P. and et al., 2007, Features and mechanisms of the satellite thermal infrared anomaly before Hengchun earthquake in Taiwan region, *Science & Technology Review* 25 (6).

[11] Ma, W., Zhao, H., Li, H., 2008, Temperature changing process of the Hokkaido (Japan) earthquake on 25 September 2003, *Nat. Hazards Earth Syst. Sci.* 8, 985-989.

[12] Ma, Y., Zhao, Y., Liu, S., Wu, L., 2010, Possible Abnormal Phenomenon of the Atmospheric Water Vapor before Hengchun Earthquake. *Proc. of Electromagnetic Research Symposium China 2010*, 109-113.

[13] Marchese, F., Ciampa, M., Filizzola, C., Lacava, T., Mazzeo, G., Pergola, N., Tramutoli, V., 2010, On the Exportability of Robust Satellite Techniques (RST) for Active Volcano Monitoring, *Remote Sens.* 2, 1575-1588.

[14] Nosov, M.A., 1998, Ocean surface temperature anomalies from underwater earthquakes, *Volcanology and Seismology Journal* 19(3), 371–376.

[15] Ouzounov, D., Freund, F., 2004, Mid-infrared emission prior to strong earthquakes analyzed by remote sensing data, *Adv. Space Res.* 33 (3), 268-273.

[16] Ouzounov, D., Bryant, N., Logan, T., Pulinets, S., Taylor, P., 2006, Satellite thermal IR phenomena associated with some of the major earthquakes in 1999–2003, *Phys. Chem. Earth* 31, 154-163.

[17] Qin, K., Guangment, G., Wu, L., 2009, Surface latent heat flux anomalies preceding inland earthquakes in China, *Earthq Sci.* 22, 555-562.

[18] Saraf, A.K., Choudhury, S., 2005a, NOAA-AVHRR detects thermal anomaly associated with 26 January, 2001 Bhuj Earthquake, Gujarat, India, *Int. J. of Remote Sensing* 26 (6), 1065–1073.

[19] Saraf, A.K., Choudhury, S., 2005b, SSM / I Applications in studies of thermal anomalies associated with earthquakes, *Int. J. Geoinformatics* 2 (3), 197-207.

[20] Saraf, A.K., Rawat, V., Banerjee, P., Choudhury, S., Panda, S.K., Dasgupta, S., Das, J.D., 2008, Satellite detection of earthquake thermal precursors in Iran, *Nat. Hazard* 47, 119-135.

[21] Singh, R.P., Dey, S., Bhoi, S., Sun, D., Cervone, G., Kafatos, M., 2006, Anomalous increase of chlorophyll concentrations associated with earthquakes, *Adv. Space Res.* 37, 671-680.

[22] Singh, R.P., Cervone, G., Kafatos, M., Prasad, A.K., Sahoo, A.K., Sun, D., Tang, D.L. and Yang, R. (2007) Multi sensor studies of the Sumatra earthquakes and tsunami of 26

December, 2006. *Int. J. of Remote Sensing* 28: 13-14, 2885-2896.
[23] Singh, R.P., Cervone, G., Singh, V.P., Kafatos, M., 2010, Complementary nature of surface and atmospheric parameters associated with Haiti earthquake of 12 January 2010, *Nat. Hazards Earth Syst. Sci.* 10, 1299–130.
[24] Tronin, A.A., 1996, Satellite thermal survey-A new tool for the study of seism active regions. *Int. J. of Remote Sensing* 17, 1439-1455.
[25] Tronin, A.A., 2000, Thermal IR satellite sensor data application for earthquake research in China. *Int. J. of Remote Sensing* 21 (16), 3169–3177.
[26] Tronin, A.A., Biagi, P.F., Molchanov, O.A., Khatkevich, Y.M., Gordeeev, E.I., 2004, Temperature variations related to earthquakes from simultaneous observation at the ground stations and by satellites in Kamchatka area, *Phys. Chem. Earth* 29, 501-506.
[27] Tronin, A.A., 2010, Satellite remote sensing in seismology, A review, *Remote* Sens. 2, 124-150.

BIOGRAPHICAL NOTES

Prof. Shattri Mansor, is currently the Head of Geospatial Information Science Research Centre at Universiti Putra Malaysia. His major research effort includes feature extraction from satellite imagery, spatial decision support system, fish forecasting, oil spill detection and monitoring system, UAV-based remote imaging, disaster management and early warning system. He has published over 300 articles in and conference proceedings. In tandem with his expertise, Dr. Shattri has also supervised and co-supervised a total of *22 MS students, 24 PhD students and 6 post doctorates*. Dr. Shattri holds membership to various organizations and institutions. He has served as a *councilor* for the Institution of Surveyors Malaysia (ISM), an *Editor* of the Journal of the Malaysian Surveyor and an executive committee for Malaysian Remote Sensing Society and an *executive committee* for the Royal Institution of Surveyors Malaysia (ISM Geomatics and Land Surveying Division). He is currently the Editorial Board member of Disaster Advances Journal and International Journal of Geoinformatics

CONTACTS

Prof. Dr. Shattri Mansor
Geospatial Information Science Research Centre
Faculty of Engineering
Universiti Putra Malaysia
43400 UPM Serdang
Selangor
MALAYSIA
Tel. +603-89467543
Fax + 603-8656
Email: shattri@upm.edu.my
Web site: www.eng.upm.edu.my