Investigating of VLF Signal Persecutors for Earthquake near Mentawai Island

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Abstract — **This paper investigate about Seismic-Ionosphere perturbation using Very Low Frequency (VLF) signal Observed in Malaysia. The propagation of VLF signals is between NWC transmitters and receiver at Selangor station. The length of the transmitter-receiver – Great Circle Path (TRGCP) is 3000km. The propagation path of VLF signal identify the possible ionospheric-perturbations related to the earthquake disaster occurred in Indonesia region within January 2009 – April 2011. Out of seven earthquakes detected within the period only one that show possible evidence is the earthquake at Mentawai Island on 25th October 2010. The magnitude is 7.7 and depth 20.6km. The data was analyzed using three methods (1) average nighttime and daytime amplitude variation (2) terminator time (TT and (3) nighttime fluctuation (NF) methods.**

I. INTRODUCTION

An earthquake is a very destructive natural disaster. The prediction of earthquake is important to decrease the number of earthquake events. The prediction can be classified depending on the time which is to be concerns. But in reality, the earthquake prediction it has been far (Hayakawa, 1996) [8].Earthquake is caused by a sudden release of energy by the Earth` crust which then creates seismic waves .Seismic activity of 20-30 days before an earthquake has been observed due to a shock with magnitude of 5.5 in the first Fresnel zone (Gufeld et al, 1994) [9].There is an evidence to show that ionospheric is extremely sensitive to seismic effect for a short period of earthquake prediction by significant finding from Kobe earthquake with magnitude ~ 7.3 and depth ~ 20km in 1995 (Hayakawa, 2007) [8]. The Very low frequency (VLF) range is between 30Hz to 300 kHz. It occurs in D region above the earth atmosphere. Variation of the ionospheric in D region affects the propagation of VLF transmission. Events like earthquake, solar flare, terrestrial gamma ray flashes, cosmic gamma ray, geomagnetic storms, and lightning energy make changes on the amplitude and phase of VLF transmission. The propagation distance from Tsushima Omega to Inubo observatory is a short path distance (~1000km). The first person check for seismic effect related to ionospheric perturbation was done by Russian (Gokhberg et al, 1989) and (Gufeld et al, 1992). They studied the propagation of VLF over a long distance to detect an earthquake in the Caucasia region from Reunion (Omega transmitter) to Omsk [9]. The Russian used the long path distance (5000 ~9000 km) because it shows that the fluctuation method used in long path is more effective compared to the short-propagation path distance. Three methods are used to analyze the effect on subionospheric VLF propagation from the earthquake event; (i) average nighttime and daytime amplitude variation (ii) terminator time and (iii) nighttime fluctuation. Terminator time method, concerns about sunrise and sunset shift before and after earthquake. This method is used in the short-path propagation (~1000km) between transmitter and receiver (Hayakawa, 2007). The terminator time method (morning and evening) time has been used by many researchers. This method is used to analyze the significant time shift in the morning and evening before an earthquake event (Hayakawa, 2007) [1]. The evening terminator time showed a significant result which is a few days before earthquake, the monthly average data exceeded the level of 2σ (Cliverd, 1999) [6]. About more than 10 earthquake with (M>6.0) has used this terminator time method (Molcanov et al, 1998) [10]. Five of these earthquakes showed significant results in the average evening terminator time ranges from 15 to 32 min and occurred in area of 70km (GCP) from Omega Japan to Inubo (Cliverd,199)[7]. On the other hand, average nighttime and daytime amplitude variation method is meant to check the VLF propagation in the Earth-ionosphere waveguide, as the attenuation depends upon the reflection height of the VLF signals, where higher height corresponds to lower attenuation. For the nighttime fluctuation method, the particular attention is given to data during local nighttime and mean time amplitude, and the level of fluctuation estimated. This method has also been used in the statically studies to determine the correlation between ionospheric perturbation and earthquakes (Maekawa et., 2006 ; Kasahara et al., 2008 ; Hayakawa et al., 2011)

II. METHODOLOGY

In this research study, the sets of data analyzed were recorded at Selangor station. The VLF/LF transmitter observed is NWC transmitter (19.8 kHz, Australia,-21.816°S, +114.167E). The Matlab software is used to simulate the result to collect the VLF phase and amplitude data. From the collected data; we observe and identify the earthquake events from January 2009 – April 2011 in the propagation of NWC transmitter. There was 7 earthquake events but the (M>5) are chosen to investigate any activities with seismo ionospheric effects within the VLF propagation. Figure 2 show the Fresnel zone for NWC transmitter and receiver station at Selangor, Malaysia. The distance between Sumatra earthquake and TRGCP is ~45km. According to Hayakawa and Molchanov (1998), any activities in lower ionosphere and within seismogenic perturbations in the atmosphere will be affect the VLF signal propagation [10].

There are three methods used to identify the activity of seismo-ionospheric effect. First, nighttime and daytime average amplitude variation method was used to analyze the VLF data. We compared the difference between the average of complete daylight and complete darkness. The TRGCP was a complete darkness when (12-18 UT) and complete daylight (01-06 UT). Second, we used terminator time method (TT), to find the significant shift of the terminator time before and after an earthquake. Before the earthquake happens, the signal of morning terminator time (tm) will shift to the right, and after the earthquake, it will shift back to the original signal (Kumar,et al, 2013) [5]. To use this method, we used only the amplitude data to get the signal.

.Meanwhile, in the night time fluctuation method, the equation of fluctuation $dA(t)=A(t) - \langle A(t)\rangle$, where A(t) is the amplitude of each day data for a certain time and <A(t)> is the average of amplitude for 11 days before and after the earthquake. Below is the flowchart of the studies.

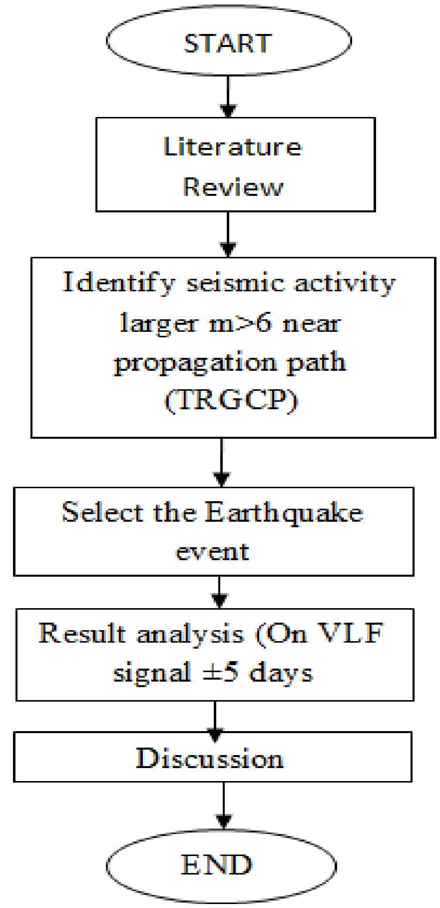

Figure 1: Flowchart of earthquake investigation using VLF

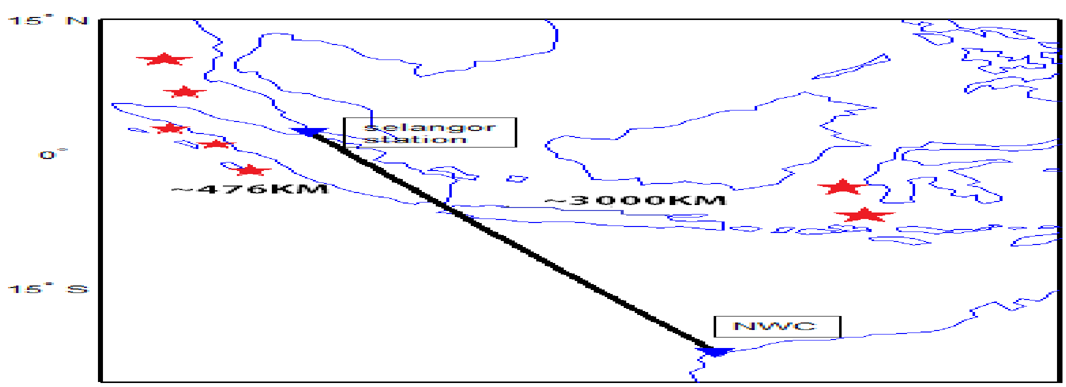

Figure 2: Propagation path between Selangor station and NWC-VLF transmitter (3000km). Mentawai region,Indonesia from TRGCP is 235km

III. RESULT

From January 2009 – April 2011, there are seven earthquake events in Indonesia region that give effect on VLF signal from NWC transmitter along the propagation-path received at UKM, Malaysia. Table 1 shows the details of the earthquake events including the location, date, earthquake magnitude and depth that were recorded in Richter scale. Out of seven earthquakes; we chose the earthquake which occurred on 25th October 2010 at 14:42:22 UTC. This earthquake has a latitude of 3.484`S and a longitude 100.114`E with a depth of 20.6 km. The magnitude of this earthquake was 7.7 and the energy released is 11.09 J.

No	Date	Place	Magnitude	Depth (km)
1	5/3/2010	Southern Sumatra	6.8	26
2	6/4/2010	Northern Sumatra	7.8	31
3	9/5/2010	Northern Sumatra	7.2	45
4	16/6/2010	North Coast	7.0	18
5	25/10/2010	Kepulauan Mentawai	7.7	20.6
6	29/9/2010	South Coast	6.2	10
7	3/4/2011	South of Java	6.7	24

Table 1: Earthquake event in Indonesia region (January 2009 – April 2011)

1. Average of nighttime and daytime amplitude variation method

This method checks for average nighttime and daytime amplitude before and after earthquake for ±5 days. The nighttime and daytime was analyzed when the TRGCP is in complete darkness (01-06 UT) and complete daylight (12-18 UT) from 20th October to 30th October 2010.

$$average = \frac{data\ for\ 11\ days}{no\ of\ days}$$

The values when transmitter was off were removed (1300 UT-1400 UT). Five days before the earthquake, the average daytime was around 22dB.The average daytime amplitude on 25th October dropped to 14.39dB due to earthquake occurrence on that day. From 26th October to 30th October, the amplitude value increased from 22.79dB to normal. There is a difference between the average amplitude of daytime and nighttime because during the daytime, the values are around 22dB to 23dB, but during the nighttime, due to more ripples, the amplitude values keep changing. According to (Kumar et al., 2008) the amplitude values keep changing due to higher attenuation of VLF propagation in the Earth ionosphere because the attenuation depends on the reflection height of the VLF signal [2]. The inconsiderable change in the average on signal amplitude is higher in the daytime amplitude compared to nighttime; we assumed that, nighttime reflection is higher than daytime reflection on D-region [1].

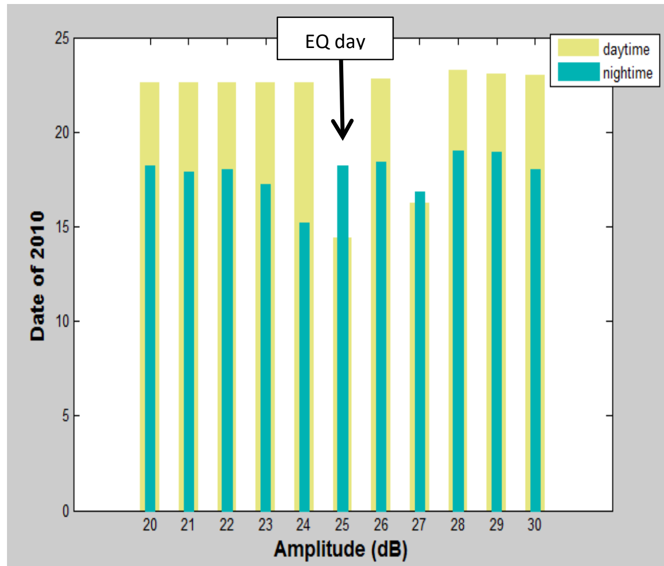

Figure 3: Average nighttime and daytime for ±5 days before and after earthquake

2. Terminator Time (TT) method

From the previous study, the propagation path between the E-W meridian and the distance over (>10,000 km) will be more effective to identify any seismo-ionospheric perturbations (Hayakawa and Maekawa, 2006) [1]. Figure 4 shows the VLF amplitude variation before and after earthquake for period from 22-28 October 2010 in 24 hour system using UT time. The amplitude variation shows the complete daylight of (01-06 UT) and marked as L1 and complete darkness of (12-18 UT) and marked as L2. These quotidian patterns are similar day by day. The amplitude during the daytime is slightly higher than the nighttime and the fluctuations during the daytime are more stable due to ionization process [5].

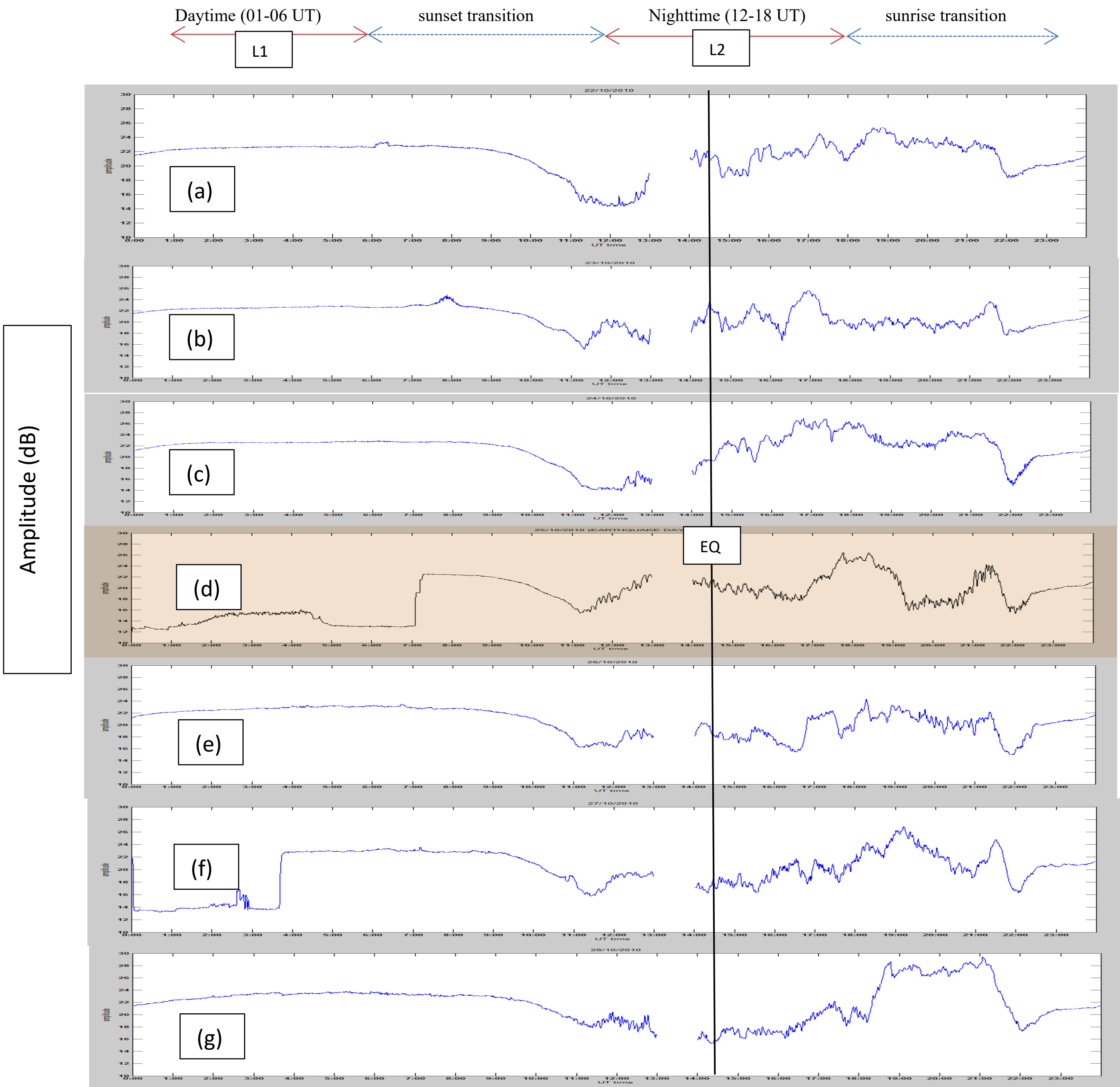

Figure 4: The VLF signal pattern for 22-28 October 2010, (a-c; VLF signal observation before the earthquake days, d; earthquake day, e-f; observation after the earthquake days)

During three days before the earthquake, there were no changes of amplitude during the daylight between (21db to 23 db). For 25th October, the sudden large drops in the signal amplitude on the day of earthquake from (~22db to ~12db). According to (Maekawa et al,. 2007) the subionospheric VLF signals is protracted for a few days before the earthquake and it will lower the ionosphere [1] .On 27 October 2010; once again the amplitude during the daylight decreased from

~22db, one day before to 15db on that day. Practically, the TT method is used to measure sunset and sunrise transition which is consistent day by day. According to (Cliverd et al., 1999) the sunset and sunrise changes gradually at lower ionospheric altitude (60-80km) [6]. In our case, there is a ripple on the amplitude sunset transition signal but as the propagation path between the transmitter and receiver are long, the signals did not show the evidence of sunset transition.

3. Nighttime fluctuation (NF) method

The significance of this method is vital to study and examine any changes in the nighttime signal fluctuations around the day and after earthquake (Maekawa et al., 2006; Hayakawa et l., 2011; Kasahara et al., 2008). We analyze only the nighttime part (12-18 UT) from 22-28 October 2010. The value of nighttime dA(t) value were plot in figure 5.

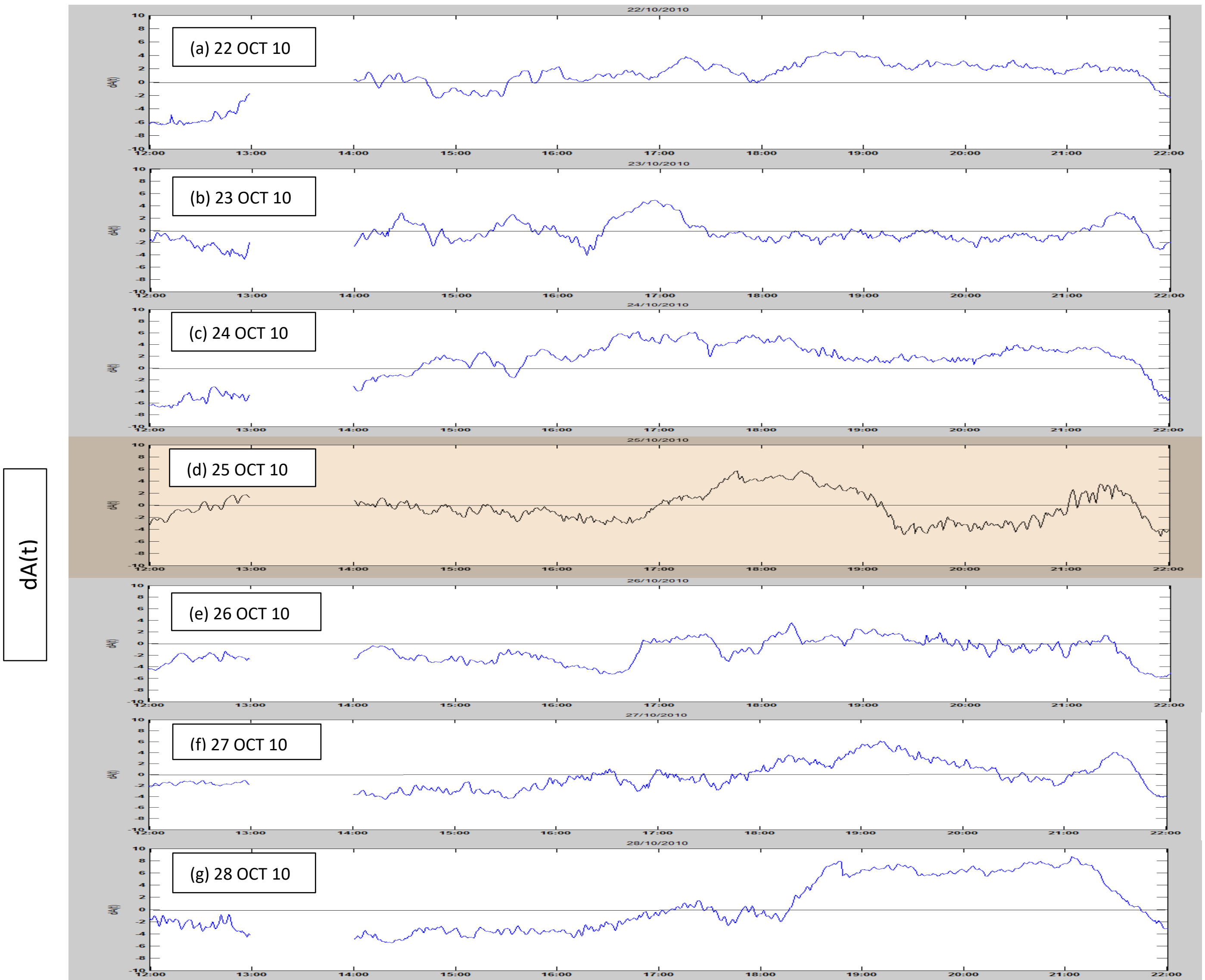

Figure 5: The fluctuation in the nighttime signal strength (in dB plotted on the y-axis) during the period 22-28 October 2010.

According to (Rozhnoi et al., 2004 and Hayakwa et al., 2011), the quantity of nighttime value dA(t)<0 is absolutely due to seismogenic effect because the mean nighttime amplitude value decreased in between the days of earthquake. Figure 5 shows the dA(t) values started to decrease from 22-25, however the dA(t)value rose again on 26th October. The increment of dA(t) values were marked on figure 5.The dA(t) values were calculated at a time t during the current day using the following equation :

$$dA(t) = A(t) - \langle A(t) \rangle$$

Where A (t) is the amplitude at any time of t for each day and for <A (t)> value is corresponds to the average of the similar time for ±5 days before and after earthquake (Hayakawa, 2007). According to (Hayakawa et al., (2010b) for a better statically analysis of VLF data where the variabilities of different propagation path are to avoid, the normalize values called trend (Trend*) is calculated using the formula :

$$Trend* = (trend - \langle trend \rangle)/\sigma T$$

Where the (trend) value comes from dA (t) value that was calculated at any time of t for each day, <trend> is the average trend for ±5 around earthquake and σT is the standard deviation of the trend for these selected days. The trend value has been plot in figure 5. According to (Kumar et al., 2013) the trend method does not yield a very promising result in identifying any seismo-ionospheric effects [5]. However, in this paper, the result obtained shows that there is a trends patterns in the signals. On the day of the earthquake, the trend showed negative reading, while the other days show positive value.

IV. CONCLUSSION

VLF amplitude data for the 19.8 kHz NWC transmission received at Selangor, station during January 2010 – April 2011 was analyzed to study any possible seismo-ionospheric effects due to earthquakes occurring along the great circle path, mainly around the Indonesia region. The VLF propagation path ~3000km that has been observed, on 25th October 2010 with the earthquake (magnitude=7.7) at a depth of 20.6km. After analyze the result it show that, there is no convincing result to show that the anomalies are from the VLF signal propagation.

V. ACKNOWLEDGMENT

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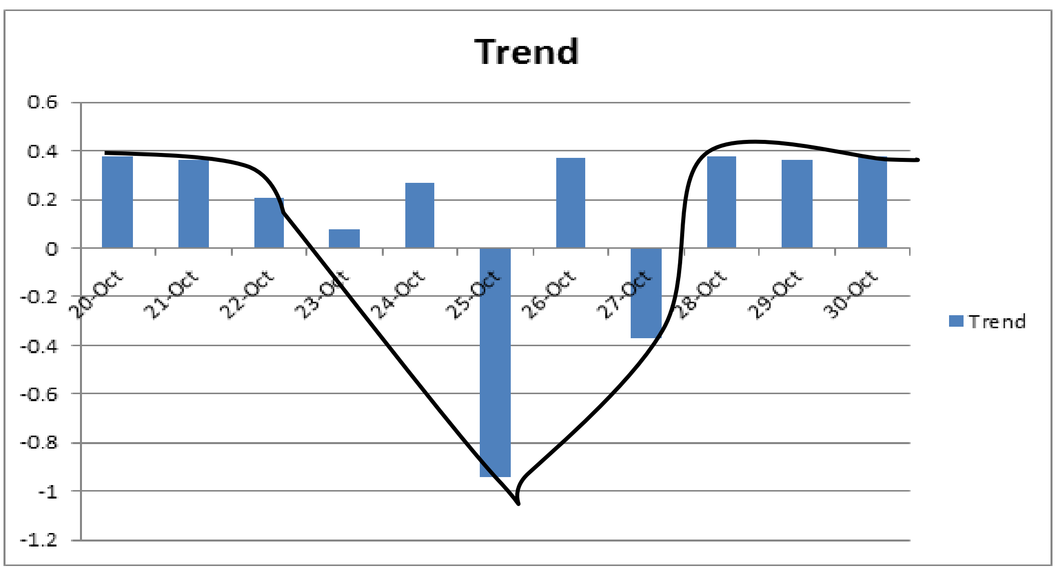

Figure 5: Trend value for nighttime fluctuation

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