TEC And Scintillation Studies In Malaysia Of The Post-Tsunami Event On 26 December 2004

Ho Yih Hwa[1] & Ahmad Faizal Mohd Zain[2]

*[1] **Telecommunication Engineering, Faculty of Electronics & Computer Engineering, National Technical University College of Malaysia, Ayer Keroh, Melaka, Malaysia***
*[2] **Wireless and Radio Science Centre, Tun Hussein Onn University College of Technology, Batu Pahat, Johor, Malaysia***

ABSTRACT

The Earth ionosphere variations are considered after tsunami associated with the long-period Rayleigh waves occurred December 26, 2004 in Indonesia (Ms = 9.0). In this paper we focus on the relative variations in ionospheric parameters (TEC and S4 parameter) with respect to a quiet period. Differential ionospheric parameters are made by computing the percent change of seismic-time parameters relative to ionospheric parameters computed for quiet conditions.

INTRODUCTION

It was recently establish and acknowledge by scientific community that a violent earthquake will set the sky shaking as well as the land. There exist electromagnetic coupling between the processes within the earth crust and troposphere and anomalous variations within the ionosphere. This can be explained by the propagation of pressure waves in the atmosphere, generated by the ground displacement near the source or due to Rayleigh waves. The wave amplitude increase exponentially as it propagates towards the ionosphere, and can reach several tens of meters for Ms > 6. At ionospheric heights, these low frequency acoustic waves interact with the ionospheric plasma and induce variations in the electron density. Attenuation of seismic pressure waves in the upper atmosphere and ionosphere will also lead to an increase of thermal energy and make ionospheric perturbations due to energy dissipation. Calais & Minster [1] have observed post-seismic disturbance on Total Electron Content (TEC) measurements by using dual-frequency GPS receivers.

The paper presents the studies of Total Electron Content (TEC) and scintillation in Malaysia after the post-tsunami event on 26 December 2004, using the Malaysian network of Global Positioning System (GPS) receivers. A magnitude = 9.0 earthquake occurred at 00:58:53 UTC on 26 December off the west coast of northern Sumatra (3.307° N 95.947° E). This is the fourth largest earthquake in the world since 1900 and is the largest since the 1964 Prince William Sound, Alaska earthquake. In total, more than 283,100 people were killed, 14,100 are still listed as missing, and 1,126,900 were displaced by the earthquake and subsequent tsunami in 10 countries in South Asia and East Africa. The tsunami caused more casualties than any other in recorded history and was recorded nearly world-wide on tide gauges in the Indian, Pacific and Atlantic Oceans [2].

IONOSPHERIC PERTURBATIONS

There are two types of post-seismic effects in the ionosphere after the earthquake. That is a direct perturbation in electron content due to the wave induced by the seismic during the event and the heating related perturbation due to energy dissipation after the event.

The direct perturbation induced having the same characteristics as the seismic pressure wave, whereas horizontal and apparent velocity similar to the Rayleigh wave and vertical parameters are those of an upward propagation acoustic wave.

However the heating related perturbation in ionosphere is due to the attenuation of seismic pressure waves in the upper atmosphere and ionosphere and lead to an increase of thermal energy, mostly above the epicenter.

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TOTAL ELECTRON CONTENT FROM GPS

The nationwide GPS network operated and maintained by Jabatan Ukur dan Pemetaan Malaysia (JUPEM) contains15 ground-based station [3]. Each receiver at these stations is capable of receiving the dual frequency GPS signals from 8 to 12 satellites (24 in total) in different directions simultaneously. The network has the capabilities of near real-time data acquisition, uniform calibration and centralized processing. The GPS receivers collect dual -frequency data at 30 second intervals, making it possible to monitor high frequency variations of the ionosphere. The observations of oblique total electron content can be obtained from the delays of GPS radio signal on channels L1 (1575.42 MHz) and L2 (1227.6 MHz) under the assumption of an infinitesimal thin-shell ionospheric model at a fixed height *h* (=450 km). However, that is only 4 stations used for the studies. Fig. 1 shows GPS tracking stations processed. The blue pentagon indicates exact locations of earthquake. And the probed ionospheric regions indicated by red circles when thinshell ionospheric model at height *h* = 450 km and 20^o elevation angle were used. Using the techniques developed at the Astronomical Institute, University of Berne [4], interpolated regional ionospheric maps of vertical TEC are obtained. The entire mapping is conducted in an earth-fixed geocentric latitude system. It should be noted that the mapping involves the oblique to vertical TEC conversion, which in general may cause some degradation of the map accuracy with distance away from GPS receivers.

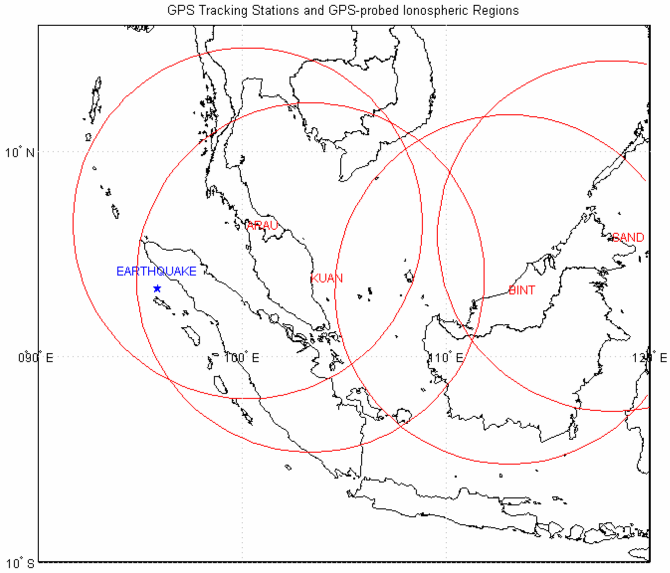

Fig. 1. GPS Tracking Stations and GPS-Probed Ionospheric Regions

REGIONAL IONOSPHERIC ELECTRON CONTENT DISTURBANCES

In this study we focus on the relative variations in TEC at Malaysia and equatorial region (Latitude 10^0 S to 16^0 N, Longitude 90^o E to 120^o E) with respect to a quiet period.

Fig. 2 shows TEC variations over Malaysia and equatorial region during the seismic event on 26 December 2004. The global trend seems to be identical. The deviation could be explained by the different solar activities along the day, which associated record the maximum TEC value during the day time and minimum TEC value during the night time.

In order to quantify the ionospheric perturbation that we can expect from the Northern Sumatra earthquake, we have to remove the diurnal variation and the instrumental biases previously determined from TEC measurements and to analyze the differences. The percent changes relative to the quiet time profiles are calculated. In this study, we have used 3 days (23 – 25 December 2004) of TEC average as the quiet time reference. From the Fig. 3 we can clearly see the ionospheric perturbation along the day. Over this region the positive phase started immediately after the seismic event. This could be explained by the direct perturbation of ionospheric electron content due to seismic wave. The second TEC enhancements appearing later (~ 8 hours after seismic event) and reach their maximum during 1500 UT, whose change ratio exceeds 25%. This could be explained by the heating of ionosphere by the energy dissipation. After 1500 UT, the entire ionosphere gradually recovered to normal.

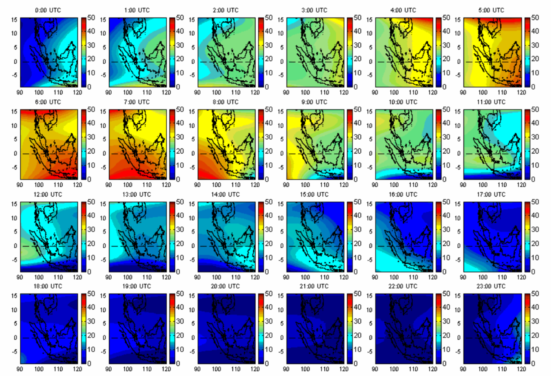

Fig. 2. TEC Map over Malaysia on 26 December 2004

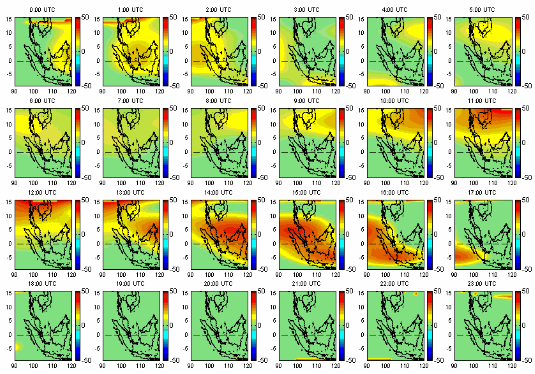

Fig. 3 Percent Changes of Ionospheric TEC Relative to Quiet Time over Malaysia

AMPLITUDE SCINTILLATION

Amplitude scintillation monitoring is traditionally accomplished by monitoring index S4. The S4 index is derived from signal intensity of signals received from satellites. Signal intensity is actually received signal power, which measured in a way that its value doesn't fluctuate with noise power. Since the S4 index is normalized, the receiver's absolute gain is not important, as long as it is relatively constant during the period. It is also important that the intensity measurements be linear with respect to the signal power over its entire range including deep scintillation fades.

S4 measured at L band needs to have the effects due to ambient noise removed. It is because of the ambient noise at the L1 frequency translates to a relatively high S4 at lower frequency VHF and UHF frequencies band. It is desired that the resulting S4 value be less that 0.05 for all received signal levels above -139 dBm.

The total amplitude scintillation index $S4_T$, including the effects of ambient noise, is defined as follows: [5]

$$S4_T = \sqrt{\frac{\langle SI^2 \rangle - \langle SI \rangle^2}{\langle SI \rangle^2}} \quad (1)$$

$S4_T$	-	Total amplitude scintillation index
SI	-	Satellites signal intensity

Where $S4_T$ represents the expected (or average) value over the interval of interest (60 seconds).

The ambient noise of Equation (1) can be removed by estimating the average signal-to-noise density over the entire evaluation interval (60 seconds), and using that estimate to determine the expected S4 due to ambient noise. This is legitimate since the amplitude scintillation fades do not significantly alter the average signal-to-noise density over a 60 seconds time interval.

If the signal-to-noise density (S/N) is known, the predicted S4 due to ambient noise is

$$S4_N = \sqrt{\frac{100}{S/N}\left(1 + \frac{500}{19S/N}\right)} \quad (2)$$

Thus, by replacing the S/N with the 60 second estimate $\hat{S}/\hat{N}$, an estimate of signal-to-noise density, we obtain an estimate of the S4 due to noise $S4_{\hat{N}}$.

$$S4_{\hat{N}} = \sqrt{\frac{100}{\hat{S}/\hat{N}}\left(1 + \frac{500}{19\hat{S}/\hat{N}}\right)} \quad (3)$$

Subtracting the Equation (3) from Equation (1) yields the corrected value of S4 as following:

$$S4 = \sqrt{\frac{\langle SI^2 \rangle - \langle SI \rangle^2}{\langle SI \rangle^2} - \frac{100}{\hat{S}/\hat{N}}\left(1 + \frac{500}{19\hat{S}/\hat{N}}\right)} \quad (4)$$

Generally $S4 \geq 0.7$ is considered strong scintillation. Due to the saturation effects, S4 is rarely larger than 1.0, except under conditions of very strong scintillation. When there is no scintillation the value under the radical may go slightly negative. If it does, we are truly removing the effects of ambient noise. This problem can be eliminated by simply setting S4 to zero in those cases.

Amplitude Scintillation Parameter S4 Measurement

Raw data was collected from all visible satellites on 26 December 2004. Corrected value of S4 was computed each 60 seconds of 24 hours period. The result was shown in Fig. 4. Note that the corrected S4 values constantly low during the day showing that is no significant event due to the seismic wave.

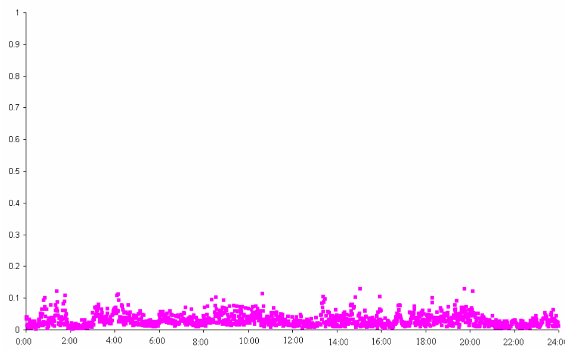

Fig. 4. 24 Hours of Corrected S4 Values for All Visible Satellite on 26 December 2004

SUMMARY

Through 4 nationwide GPS network measurement; we have seen some significant morphological features for Malaysian regional ionospheric TEC variations after the tsunami event. The first positive phase or TEC enhancement was detected immediately after the perturbation and follow by the second positive phase later (8 hours delay). Finally, the entire ionosphere gradually recovered to normal. That is no significant scintillation event due to the earthquake. However, these preliminary results need to be compared further with other measurements from ionosonde and satellites to understand the perturbation evolution process and the physical mechanisms in detail.

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