Estimation of D-region ionosphere VLF reflection heights to geomagnetic storm

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***Abstract*—The low latitude nighttime D-region ionosphere variations were analyzed using tweek atmospherics received at Selangor station, Malaysia (2.55°N, 101.46°E) during the 10 – 13 October 2010 geomagnetic storms. The storm occurred in the local nighttime had a maximum reading of geomagnetic index, Dst of -79 nT recorded by the World Data Centre (WDC). Tweek measurements during this period show a small increase of 4 km in the ionospherics VLF mean reflection heights compared to the 81 km on the magnetically quiet day height prior to the magnetic storm days. The result of this project is produced using Matlab and GetData Graph Digitizer softwares.**

Keywords: Tweek atmospheric, cut-off frequency, ionospheric reflection height, geomagnetic storm

I. INTRODUCTION

Return lightning stroke radiates powerful electromagnetic wave from frequency of few hertz to Tera hertz [1]. Most of its energy resides between the frequencies of 6 to 7 kHz [2]. This includes radio spectrum that is within our interest which is the VLF range. The VLF ranges from 3 to 30 kHz. With VLF, it is possible for long distance propagation without excessive attenuation and due to its nature that can be reflected at low ionized region of ionosphere. The VLF signal itself travels near to speed of light.

Figure 1 shows VLF wave propgation in earth ionosphere waveguide (EIWG). Tweeks are VLF signals originated from lightning discharges that travel via multiple reflections in earth ionosphere waveguide. The signals can be detected by VLF receiver at very far distance. Tweek method has been a mean to investigate D-region ionosphere by measuring the reflection height (h), electron densities (n_e) and propagation distance (d). The fundamental of first mode cut-off frequency is ~1.8 kHz. This method is suitable for measuring reflection height over a wide area.

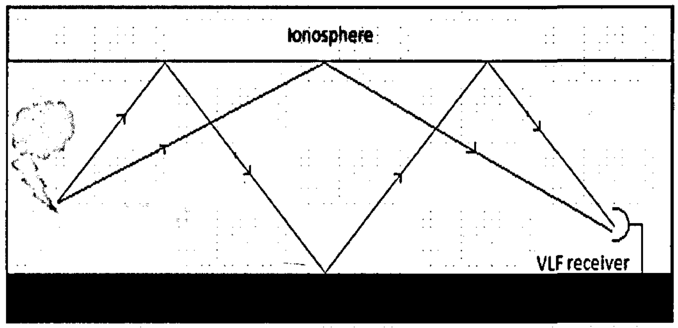

Figure 1: VLF wave propagation in EIWG.

Geomagnetic storm is a type of space weather that temporarily disturbs earth's ionosphere caused by the sun. The sun creates energetic particles that consist of electrons, coronal and solar wind ions. The earth ionosphere will be affected by the energetic particles produce by the sun. Energetic particles reach the earth ionosphere after 2 or 3 days after the launched of coronal mass ejection (CME) from sun [4]. The strength of geomagnetic storm is observed according to geomagnetic disturbance index (Dst). The data is obtained from magnetometer by WDC for Geomagnetism, Kyoto, Japan. Negative reading indicates geomagnetic storm is in progress. The lower the reading, the severe geomagnetic storm will be. The storm severely attenuates signals that pass through the space. The geomagnetic storm disrupts operations that rely on space based system and terrestrial systems [4].

[4] Ohya is the first to introduce the tweek method in measuring the reflection height of D-region ionosphere in response to geomagnetic storm. The observation was done in October 2000 in response to the massive geomagnetic storm detected in Japan. It is proven that there is a lowering/rising in ionospheric reflection height in response to the great geomagnetic storm. [5] Singh estimated D-region ionospheric VLF reflection height during solar eclipse on 22 July 2009 from the first cut-off frequency of tweeks. The reflection heights lowered by 2-3 km as compared to normal night time tweek reflection height.

This paper intends to evaluate the night time ionospheric reflection height (h) during the geomagnetic storm by utilizing the tweek method from return lightning stroke received at low latitude station in Selangor. The first mode cut-off frequency of tweeks is used for this study. The observation starts from 10 to 13 October 2010.

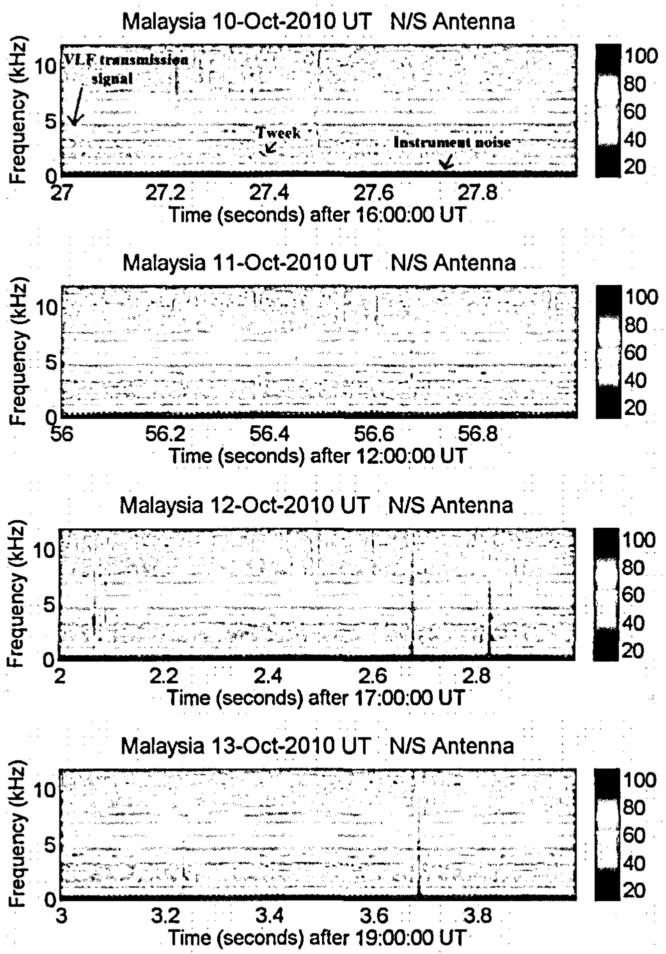

Figure 2: Examples of tweek atmospheric (m=1).

As for Figure 2, the spectrograms show tweeks with first mode cut-off frequency (m=1). The spectrograms vertical axis represents frequency from 0 Hz to 10 kHz. The horizontal axis shows positive time toward right. The colour bar represents energy rate with red denoting the peak energy.

II. INSTRUMENTATION

The broadband raw data were retrieved at Institute of Space Science in UKM (ANGKASA; 2.55°N, 101.46°E) in 2009 by AWESOME VLF receiver. The receiver consists three important parts. The items are: a 1.7 m^2 triangle shaped orthogonal crossed loop antenna arranged in N/S and E/W directions, a preamplifier is placed near to the antenna to minimize resistive loss then passes the signals to line receiver that is connected to PC that extends from 0.8 to 47 kHz. The data sampled to 100 kHz signal and converted to digital format using 16 bit ADC card installed in the PC. MAT-file format is generated via data acquisition software produced by the Stanford University [6].

A. Theoretical background

For this project, electromagnetic propagation model proposed by J.R.Wait and K.G.Budden is used. VLF electromagnetic pulses (EMPs) emitted from lightning are confined in EIWG due to the conductivity of earth's surface and D-region ionosphere. The VLF waves propagate with different group velocities and modes (m). The electromagnetic propagation model equation is as below [7]

$$R_g(\theta).R_i(\theta)e^{(-i2hk\cos\theta)} = e^{(-i2\pi m)} \quad (1)$$

$R_g(\theta)$ and $R_i(\theta)$ are reflection coefficients for earth surface and ionosphere. θ is the incident angle and h is the ionospheric reflection height. Equation 2 below is used to calculate the respective reflection height [8]

$$h = \frac{mc}{2fc} \quad (2)$$

where c is speed of light and f_c is cut-off frequency. As regard to Equation 3 below the Appleton-Hartree formula, it is the complex refractive index of wave propagation in magnetoactive plasma [9]

$$n_r^2 = 1 - \frac{X(1-X-jZ)}{(1-jZ)(1-X-jZ) - \frac{Y^2\sin^2\theta}{2} \pm \sqrt{Y^2\cos^2\theta(1-X-jZ)^2 + \frac{Y^4\sin^4\theta}{4}}} \quad (3)$$

where X, Y and Z denote

$$X = \left(\frac{\omega_P}{\omega_H}\right)^2$$

$$Y = \left(\frac{\omega_H}{\omega}\right)$$

$$Z = \left(\frac{\nu}{\omega}\right)$$

where n_r is the refractive index, ν is the angular collision frequency of electrons with neutrals and ω is the angular frequency of the wave.

The electron density equation below is proposed by [9]

$$n_e = 1.241\times10^{-8} f_H f_c$$

where f_H = 1.1±0.2 MHz according to International Geomagnetic Reference Field (IGRF) model.

The group velocity is given below by [10]

$$V_g = \frac{\delta\omega}{\delta k} = c\sqrt{1-\left(\frac{f_c}{f}\right)^2} \quad (5)$$

where k is the number of waves. The propagation distance of the related tweek is estimated by using Equation 6 [10]

$$d = \frac{\Delta t(V_{gf1} \times V_{gf2})}{|V_{gf1} \times V_{gf2}|} \quad (6)$$

where Δt is time interval between f_1 and f_2. Both frequencies are coming from the spectrograms generated by Matlab.

III. RESULT AND DISCUSSION

The tweeks were observed from 10 to 13 October 2010 during night time starting from 11:00 UT to 22:00 UT. Local time (LT) is 8 hours ahead of Universal time (UT): LT = UT + 8. The magnetically quiet days are 10, 12 and 13 October 2010 while, 11 October 2010 is magnetically active day in response to the geomagnetic storm. The maximum geomagnetic index, Dst reading of -79 nT was recorded on 11 October 2010 nighttime. In total, 448 tweeks with first mode cut-off frequency were found during the four days of observation. The tweeks occur only at night time because of less attenuation at night.

Table 1 shows the measurements of the cut-off frequency and reflection heights of the tweeks shown in Figure 2. The reflection height is calculated using Eq. (2).

TABLE 1. CUT-OFF FREQUENCY, REFLECTION HEIGHT MEASURED FROM FIGURE 2.

Spectrogram	**Mode, m**	**Cut-off frequency, *fc* (kHz)**	**Reflection height, *h* (km)**
a	1	1.78	84.03
b	1	1.78	84.03
c	1	1.68	89.45
d	1	1.78	84.03

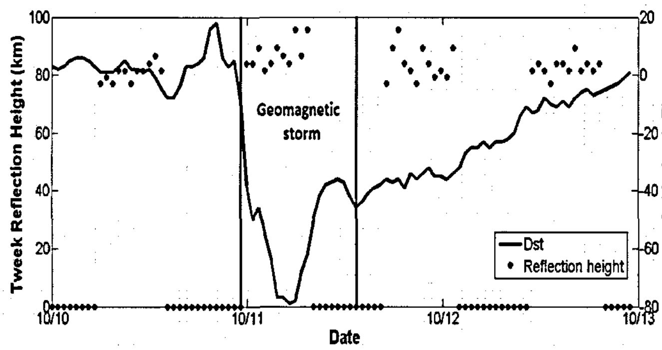

Figure 3: D-region ionosphere reflection heights

Figure 3 shows plot of reflection heights from 10 to 13 October 2010. The dot represents reflection heights and the line denotes Dst index. The variation of Dst index is also presented with maximum reading of ~-79 nT on 11 October. The mean reflection height for magnetically quiet days is 81.84 km and increases by 4 km during magnetically active day. The disappearance of ionization from the sun decreases the night time electron density. As electron density increases, the ionospheric reflection height decreases.

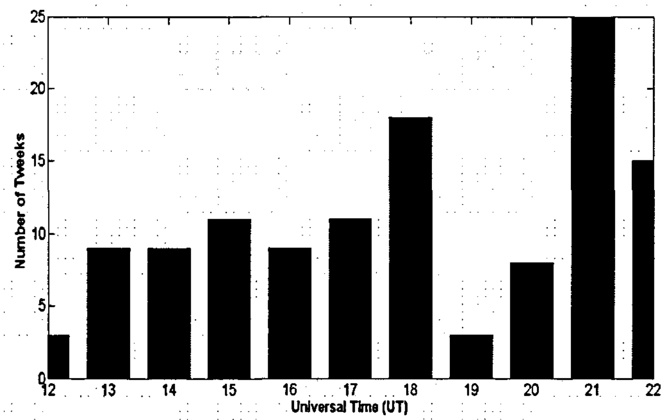

Figure 4: Number of tweeks per day

Figure 4 shows the distribution of tweeks on 11 October, during the magnetically active day. In total, 121 tweeks were recorded during night time. It can be said that the highest number of tweeks recorded is at 21:00 UT and the lowest is at 12:00 UT and 19:00 UT. It clearly shows that the tweeks have no pattern as they originated from different lightning. There are no tweeks recorded after 22:00 UT.

[11] Mechtly obtained an increase of electron concentration in the lower part of D-region (height of 60 km) with solar activity. [4] Ohya obtained an increase of reflection height with Dst index reading of ~80 nT. The increase of reflection height estimated by Ohya is similar to our project. It can be seen in Figure 5, from 4 to 6 October.

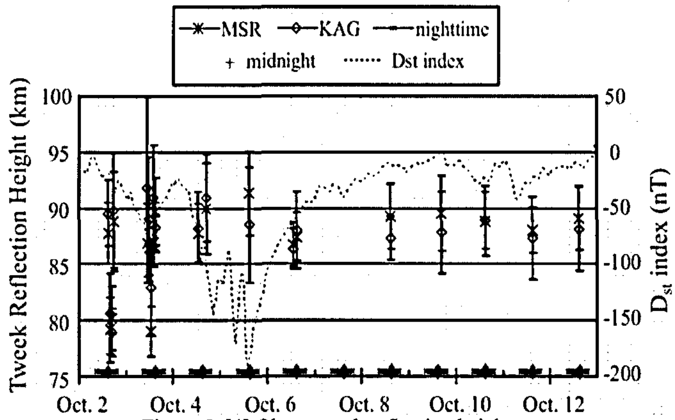

Figure 5: [4] Ohya tweek reflection height.

IV. CONCLUSION

This paper presents an estimation of D-region ionosphere reflection heights to the geomagnetic storm detected in Japan. Tweek method with first mode cut-off frequency ~1.8 kHz has been used for this project. The tweeks were recorded at Selangor station. From the observation, it can be said that all 448 tweeks occurred only at night time. It is measured the reflection height varies from 77 to 95 km during the 4 days observation. On magnetically quiet days, the estimated mean reflection height is 81 km while on magnetically active day, the reflection height increases by 4 km compared to normal night time tweek reflection height.

Malaysia is subjected to the greatest mean annual flash density compared to other Asia countries. It is useful to utilize this natural source of VLF to conduct researches related to space weather and ionospheric disturbances. With further research, signal propagation delay and effects of geomagnetic storm can be encountered. With the use of VLF, many earth's natural events can be investigated.

ACKNOWLEDGMENT

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