# Tweek Atmospherics Reflection Height Measurements Due to Geomagnetic Storm Observed in the Low Latitude Region

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***Abstract*— Tweek atmospherics are ELF/VLF pulse signals with frequency dispersion characteristics that originate from lightning discharge and propagate in the Earth-ionosphere waveguide mode over long distances. 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 3 – 5 August 2010 geomagnetic storms.* The storm occurred in the local nighttime had a maximum reading of geomagnetic index, Dst of -65 nT recorded by the World Data Centre (WDC). Tweek measurements during this period show a small increase of 94 km in the ionospherics VLF mean reflection heights compared to the 86 km on the magnetically quite day height prior to the magnetic storm days. Tweeks atmospherics was estimated coming from distances as far as 5232 km from the lightning source on the magnetic storm days.**

***Keywords-Tweek Atmospherics, Very Low Frequency (VLF), Lightning Discharge, D-Region Ionosphere, Geomagnetic Storms***

## I. INTRODUCTION

The return strokes of lightning discharges are natural powerful transmitters of electromagnetic wave. The Extremely Low Frequency (ELF: 30 Hz–3 kHz) and the Very Low Frequency (VLF: 3–30 kHz) waves generated by lightning discharges propagate by multiple reflections through the waveguide formed by the earth and the lower ionosphere [1]. Earth and the ionosphere are good reflectors, the lightning radiated impulses, commonly known as radio atmospheric or sferics. When this radiated energy is received at VLF/ELF bands, the received signals do not exhibit any dispersion, except near the cut-off frequency of the waveguide and are known as tweeks [2].

The tweek has strong dispersion near the cut-off frequency of the waveguide around 1.8kHz. Generally, tweek is observed is only in nighttime, because the attenuation is less. Tweeks at a low-latitude station of Suva Fiji, in the South Pacific region, during September 2003–July 2004, the propagation features and the reflection heights of tweek atmospherics in the waveguide formed by the Earth's surface and the lower ionosphere. They estimated for 90% of tweeks, propagation distances are about 1000–5000 km. The previous studied was discovered that VLF amplitude measurements show little change from the normal day behaviour but the phase measurements show rapid fluctuations during the magnetic storm and an anomalous diurnal variation during the days following the recovery of the geomagnetic field [Kumar, 2008] [3]. The tweek method has the unique advantage of *enabling reflection-height (equivalent electron* densities) monitoring over a wide area of several thousand kilometers. The morphological features of tweek have been used to estimate the distance and geographic bearing of the source discharges, ionospheric reflection height and *D*-region electron density along the propagation path [Cummer, 1998] [4].

The amount of ionization in this region varies widely, as it depends on how much sunlight hits the region. D-region is the lowest part of ionosphere ranging from ~60–75 km in the daytime and ~75–95 km in the nighttime [Hargreaves, 1992] [5].

In this study, tweek atmospherics is observed to estimate the reflection height and electron densities in the D-region ionosphere from the causative lightning discharge at a low-latitude station in Selangor station, Malaysia (2.55°N, 101.46°E) during the 3$^{th}$ to 5$^{th}$ August 2010 geomagnetic storms.

## II. TWEEK ATMOSPHERICS RADIO

Tweeks are pulse signals that ELF/VLF electromagnetic waves originated from lightning discharges show the cut-off frequency characteristics due to long-distance propagation by the Earth-ionosphere wave-guide mode [6]. The properties of tweeks have been investigated and explained by a number of authors. Figure 1 shows, VLF/ELF *electromagnetic waves propagates over long distant* lightning and propagates in the Earth Ionosphere over long distances (>1000km).

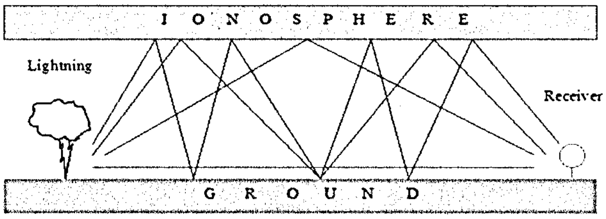


Figure 1. VLF/ELF electromagnetic waves propagates over long distant lightning and propagates in the Earth Ionosphere over long distances.

The conductivity of the boundaries of the waveguide and the total path traveled in it result in appreciable dispersion of the sferics at the lower frequency end, with a lower cut-off at around 1.8 kHz. Such long-delayed sferics is referred to as "tweeks" in the literature, due to the distinct chirping sound they make when heard on a loudspeaker or earphone. The properties of tweeks have been investigated and explained by a number of authors. Tweeks have been reported to be left-hand polarized (L) waves. The strong gyrotropy of the lower ionosphere provides total internal reflection for L-waves and transmission of right-hand polarized (R) waves into the outer ionosphere as whistler mode waves which can be recorded by satellites or at ground-based stations in the opposite hemisphere [7].

## III. GEOMAGNETIC STORMS

Geomagnetic storm is a temporary disturbance of the Earth's magnetosphere occur when the interplanetary magnetic field turns southward and remains southward for an prolonged period of time. It is because of a highly energized solar wind that is fast and embedded with a strong magnetic field. The magnetosphere is the region of space where the behaviour of the plasma is controlled primarily by the geomagnetic field, and is schematically illustrated in Figure 2. This distortion of the geomagnetic field is illustrated in Figure 2 where the black arrows indicate the direction of the magnetic field lines. The constant stream of solar wind particles flowing past the Earth can interact with the geomagnetic field lines and create strong convection patterns in the tail that push the incoming plasma in the sunward direction as indicated by the white arrows. [8]

During the main phase of a geomagnetic storm, charged particles in the near-Earth plasma sheet are energized and injected deeper into the inner magnetosphere, producing the storm-time ring current. This phase is characterized by the occurrence of multiple intense substorms, with the attendant auroral *and geomagnetic effects. (The nature of the relationship* between magnetic storms and substorms is a matter of some controversy.) When the interplanetary field turns northward again, the rate of plasma energization and inward transport slows and the various loss processes that remove plasma from the ring current can begin to restore it to its pre-storm state. The electric current in the magnetosphere create magnetic force which pushes out the boundary between the magnetosphere and the solar wind.

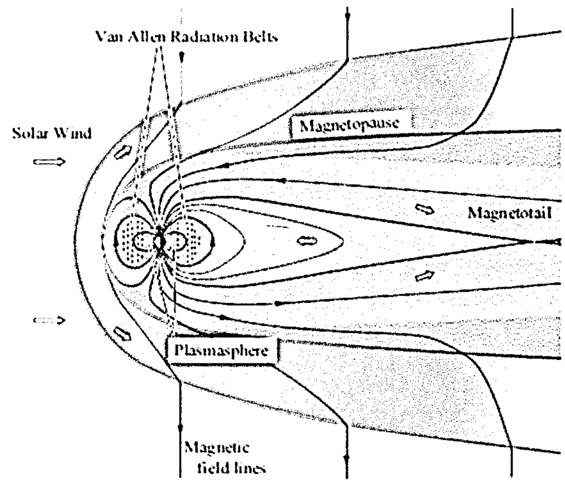


Figure 2. Schematic illustration of the magnetosphere showing the areas of greatest interest in this work, namely the (Van Allen) radiation belts, and plasmasphere [9].

A geomagnetic storm is changes in the Dst (disturbance – storm time) index. The size of a geomagnetic storm is classified as moderate ( -50 nT >minimum of Dst > -100 nT), intense (-100 nT > minimum Dst > -250 nT) or super-storm ( minimum of Dst < -250 nT).

## IV. METHODOLOGY

VLF data deployed from system called Atmospheric Weather Electromagnetic System for observation Modelling and Education (AWESOME) through its VLF receiver. Located at low latitude station, Selangor (03.5°N 101.31°E) Malaysia, VLF tweek data were recorded for 60 second at every hour only at the night are presented. The effects of geomagnetic storm of 3$^{rd}$ - 5$^{th}$ August 2010 on ionospheric irregularities are studied here using tweek VLF observation to examine the response in reflection height of the D-region ionosphere to the major magnetic storm in August 2010. This studies is to show reflection-height measurements of the D-region ionospheres of ELF/VLF broadband raw data *files from* 2$^{nd}$ *to* 6$^{th}$ *August 2010 for active mode* geomagnetic storm and 29th to 31th August 2010 for quite mode geomagnetic storm have been chosen to analyzed night-time *D*-region ionosphere characteristics.

The receiver consists of three major parts: a 1.7m$^2$ triangle shaped orthogonal crossed loop antenna aligned in the (N/S) and (E/W) directions, so that receiver picks up magnetic fields (horizontal) parallel to the ground from any direction. The antenna corresponds to right isosceles triangles covering a geometrical area of 25m$^2$ and base 10m. The impedance of the antenna is 1Ω and 0.5-1.0mH [10].

ELF/VLF broadband raw data files for eight days sample was collected and classified from 10:00:00 UT to 22:00:00 UT; (18:00 LT to 6:00 UT). Then, these raw data will be simulated in MATLAB which will takes a single pair of ELF/VLF broadband data and produces 60 figures. After the simulation process, few selected spectrograms will be digitized using graph digitizer to record the fundamental cut-off frequency. The spectrograms will be analysed. The reflection height *(h)*, equivalent electron density *($n_e$)* and propagation distance *(d)* will be calculated from the fundamental cut-off frequency value. Then, graph of *h*, $n_e$ and *d* will be plotted from the result.

## V. THEORITICAL CONSIDERATION

The electromagnetic propagation model proposed by ELF/VLF electromagnetic pulses (EMPs) radiated by lightning discharges are trapped between the Earth and lower ionosphere due to the earth's surface and the lower ionosphere's high conductivity for these frequency bands. ELF/VLF waves propagate in different modes with diverse group velocities [11].

The electromagnetic field in the waveguide can be decomposed into a sequence of independent field structures (modes) which propagate with different group velocities. Each of the modes (*Ne*) is defined by its cut-off frequency ($f_{cn}$) which is determined by the height *h* of the waveguide or the VLF reflection height [11].

$$h = \frac{nc}{2f_{cn}} \tag{1}$$

where *c* is the velocity of light in free space.

If $f > f_{cn}$ and close to $f_{cn}$, the mode propagates with a group velocity $V_{gn}$ given is:

$$V_{gn} = c\,(\frac{1-f_{cn}^2}{f^2})^{1/2} \tag{2}$$

The $V_{gn}$ approaches zero as $f$ approaches $f_{cn}$. No propagation occurs if $f > f_{cn}$, as the wave is strongly attenuated [10].

Using the Eq. (2), total distance *d*, propagated by the tweek of the nth mode with a perfect conducting, the EIWG can be obtained as:

$$d = \frac{\partial t\,(V_{gf1}\, x\, V_{gf2})}{V_{gf1}\, x\, V_{gf2}} \tag{3}$$

Where, $\partial t = t_2 - t_1$ is the difference in arrival times of the two frequencies, $f_2$ and $f_1$, close to $f_{cn}$ of the tweeks of any mode; $V_{gf1}$ and $V_{gf2}$ are the corresponding group velocities of the waves centered at frequencies $f_1$ and $f_2$. From the previous study, the variation of D-region electron density with solar activity using radio wave propagation in a broad range (10–2500 kHz) of frequencies. The normal reflection height of the electromagnetic waves in the ionosphere varies with frequency, with lower frequencies usually reflected at lower heights due to lower electron densities. Electron density is estimated using Eq. (4) as proposed by IGRF.

$$Ne = 1.241 \times 10^{-8} f_c f_H \tag{4}$$

where $f_H = 1.1 \pm 0.2$ *MHz* for low-latitude and equatorial regions based on the model proposed by the International Geomagnetic Reference Field (IGRF).

## VI. RESULTS AND DISCUSSIONS

This research uses eight days sample of tweeks observation located at low latitude station, Selangor (03.5°N 101.31°E) Malaysia, for every hour during nighttime from 2nd to 6th August 2010 during active geomagnetic storm and 29th to 31st August 2010 for normal quiet day. The ELF-VLF signal are analyzed using a MATLAB to produces dynamic time-frequency spectrograms of one-second duration for every hour starting from 10:00:00 UT to 22:00:00 UT; (06:00 p.m. to 06:00 a.m.) which (LT = UT + 8) during the eight days period to estimate the ionospherics parameters need and the geographic locations of the source discharge.

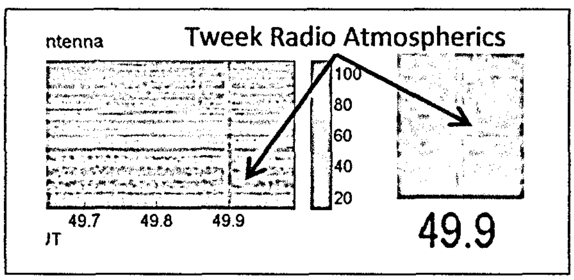


Figure 3. Tweek Radio Atmospherics

As a result, a total of 2426 tweeks occurred randomly. About 1406 tweek found 2nd to 6th August 2010 (active geomagnetic storm) and 1020 tweek from 29th to 31st August 2010 (quiet day) extracted from the spectrogram. The spectrogram was being digitized using the graph digitizer to record the fundamental cut-off frequency ($f_{cn}$). Then, by using Eqn. (1), Eqn. (3) and Eqn. (4), D-region ionospheric reflection height ($h$), equivalent electron density ($Ne$) and propagation distance ($d$) parameters were calculated based on their respective fundamental cut-off frequency ($f_{cn}$). Figure 4 shows that spectrogram of 1second duration showing tweek occurrences observed at night on August 2010.

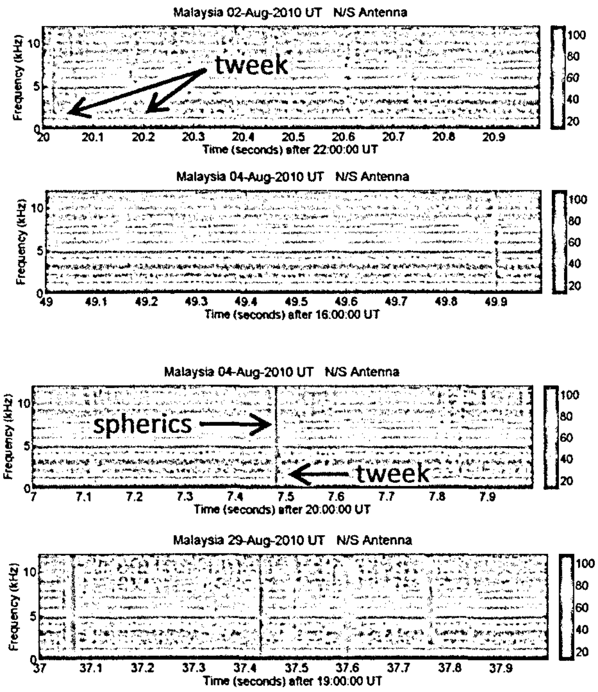


Figure 4. Four examples of spectrogram of 1-s duration showing multimode tweek sferics observed at night by the time observed in August 2010. (LT= UT+ 8).

TABLE 1 shows tweek atmospherics reflection height during the active mode of geomagnetic storm on 4th August 2010 about 88-96 Km compared to the quiet mode geomagnetic storm on 29th August 2010 of 79-86 Km. Furthermore, estimated ionospheric electron density variation is at 22.18-24.53 $el/cm^3$. The ELF/VLF signals travel considerable distances, up to 5232 to the receiver.

TABLE I. CUT-OFF FREQUENCY ($f_{cn}$), REFLECTION HEIGHT ($h$), EQUIVALENT ELECTRON DENSITY ($n_e$) AND PROPAGATION DISTANCE ($d$) FOR AUGUST 2010

| UT Date | LT | Reflection Height, h (km) | Propagation Distance, d (km) | Equivalent Electron Density, Ne (el/cm3) |
|---|---|---|---|---|
| 2.8.10 | 6:00 | 85.65 | 2031.91 | 23.89 |
| 4.8.10 | 4:00 | 88.83 | 5231.69 | 23.04 |
| 4.8.10 | 0:00 | 92.24 | 1859.06 | 22.18 |
| 29.8.10 | 3:00 | 88.83 | 2224.23 | 23.04 |
| 29.8.10 | 3:00 | 92.24 | 1859.03 | 22.18 |

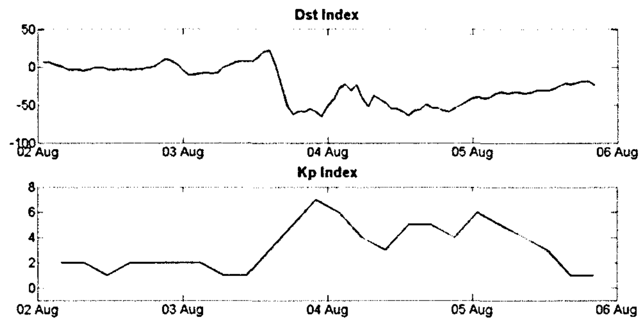


Figure 5. Variation of Dst index and Kp index during the period 2nd to 6th August 2010.

The variation of Kp and Dst index for 2nd to 6th August 2010 are shown in Figure 5. As shown, at 19:00 LT on 3rd August 2010, Dst index turned southward at and reached the maximum value of -65 nT. Except for several northward excursions, it remained negative for several hours until 03:00 UT on 4th August 2010. On the same exercusion, Kp index reach the highest Kp index of 6. The Dst index and Kp index both respectively shows two maximum negative excursions -62 and -65 nT and maximum disturbance level of 6 at about 19:00 LT and 12:00 LT.

A considerable number of tweeks with multiple modal cutoffs were observed during this event. About 96 tweeks were selected and the parameters were plotted for the fundamental mode. The graph is plotted based on the average value (mean) of tweek atmospherics selected. Figure 6 (a) and (b) shows the *D*-region reflection height when there is active geomagnetic storm for 2nd to 6th August 2010 and 29th to 31st August 2010 for quiet day mode. Tweeks atmospherics were reflected at 72.24 km before nightfall and 85.6 km at night due to the lack of extra ionization from sun. The ionospheric reflection height is decreased from 85.2 km to 77.8 km during sunrise. During the maximum excursions around 19:00 LT on 3rd August 2010, the ionospheric D-region reflection height increased between 86-96 km compared to quiet day on 29th to 31st August is about 79-82 km. The highest tweek reflection height occurred is 96.64 km. However the tweek reflection height was quite stable during the quiet mode geomagnetic storm on 29th to 31st August 2010. These increases in reflection height occur in response to the characteristic *D*st variations, and may indicate temporal decrease of energetic electron fluxes in the inner radiation belt [6].

Besides that, the tweeks travelled distances of between 800 and 5400 km. A total of 457 tweeks were observed from the recordings in 4th August 2010 at night. Figure 6 (c) shows the occurrence pattern of tweeks through the night. The pattern of tweek occurred towards night is depends on the lightning events. Tweek atmospherics occurred throughout the night, but there are more in the post-midnight period. Therefore, highest number of tweek atmospheric found is 74 tweek on

05:00 LT. On the other hand, at the pre midnight, about 4-36 number of tweek occurs.

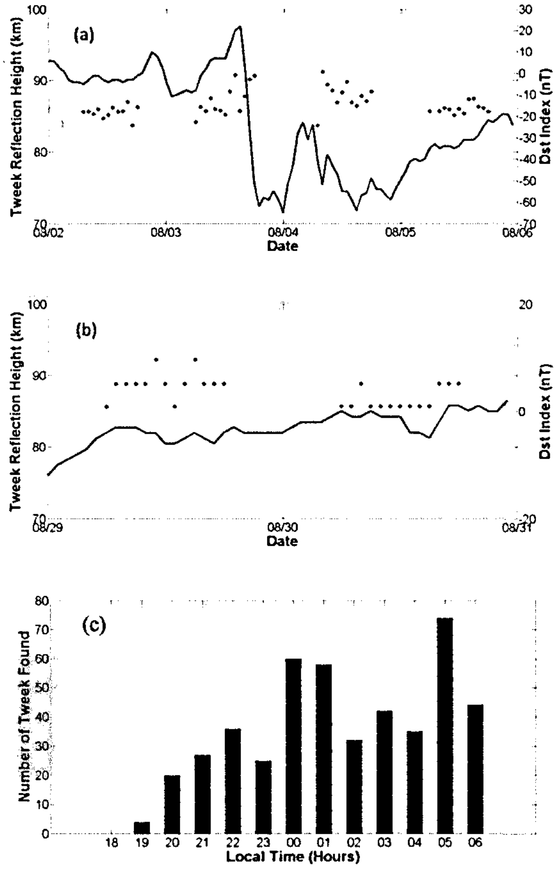


Figure 6. Tweek reflection height for 2-6 August 2010 (active mode), tweek reflection height for 29-31 August 2010 (quite mode) and number of tweek found in 12 hours for 4 August 2010.

## VII. CONCLUSIONS

The low latitude nighttime D-region ionosphere variations were analyzed using tweek atmospherics received at Selangor station, Malaysia during the 3 – 5 August 2010 geomagnetic storms. The storm occurred in the local nighttime had a maximum reading of geomagnetic index, Dst of -65nT. The result shows, there is slightly different on reflection height on the effect when the geomagnetic storms occurred. The tweek measurements during this period show a small increase of 94 km in the ionospherics VLF mean reflection heights compared to the 86 km on the magnetically quite day height prior to the magnetic storm days. Tweeks atmospherics was estimated coming from distances as far as 5232 km from the lightning source on the magnetic storm days. Hence, estimated ionospheric electron density variation is at 22.18-24.53 el/cm3 during the local night.

## ACKNOWLEDGMENT

The author is grateful to Stanford University VLF research group, and Prof. Umran Inan and Dr. Morris Cohen in particular for providing the online VLF Data on http://vlf.stanford.edu/vlfdata/. Special thanks to the World Data Centre (WDC), Kyoto for providing the recorded data of Dst geomagnetic index.

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