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# Investigation of the morphology and Wait's parameter variations of the low-latitude D region ionosphere using the multiple harmonics of tweeks

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**Abstract**

Recording the tweeks with a maximum up to eight harmonics using the receiver installed at Tay Nguyen University (12.65° N, 108.02° E) during 2013–2014, we investigated the morphology of the nighttime D-region ionosphere. Tweeks were recorded on 5 quiet nights per month. The results show that the mean reflection height in 2014 ($R_z = 79.3$) is lower by 3.3 km than that in 2013 ($R_z = 64.9$). The reflection height at low latitudes is higher than that at high latitudes. The mean reference height $h'$ in 2013 is higher about 0.9 km than that in 2014 and the mean sharpness factor $\beta$ in 2013 is higher by 0.07 km$^{-1}$ than that in 2014. The short-term variation of reflection heights for tweeks with harmonics $m = 1$–3 and sunspot number have the negative correlation coefficients. However, the correlations between them are not clear. On some nights, from 19:00–21:00 LT, the reflection height temporal variability shows a moderate to strong negative correlation with the tweek occurrence. This suggests that the reflection height variation may be caused by QE fields generated by lightning discharges. The variations of tweek reflection heights observed during 2013–2014, at low latitudes could be significantly caused by the ionization effect by Lyman-$\alpha$ and Lyman-$\beta$ coming from geocorona, variation of neutral density, particle precipitations, and by direct energy coupling between lightning and lower ionosphere.


*Keywords:* The D-region ionosphere; Extremely Low Frequency and Very Low Frequency; Tweek; Ionospheric reflection height; Electron density

## 1. Introduction

It is well known that lightning discharges can emit electromagnetic waves in the range of Extremely Low Frequency (ELF; 3–3000 Hz) and Very Low Frequency (VLF; 3–30 kHz), which propagates by multiple reflections in the waveguide bounded by the surface of the Earth and lower ionosphere. The sferics generated by lightning discharges travel large distances due to low attenuation rate (2–3 dB/1000 km) offered by Earth – ionosphere waveguide (EIWG) (Barr et al., 2000). The D-region ionosphere is in the altitude range of 60–90 km. It is relatively difficult to observe this region by using the common methods such as using balloons, ionosondes, radars, rockets,etc, because in the nighttime electron density is very low ($<10^3$ cm$^{-3}$) (Budden et al., 1961). The ELF/VLF technique is powerful for exploring the physical processes of the lower ionosphere. There is a type of sferics which produces the chirping sounds at loudspeaker of the receivers. This type of atmospherics is known as "tweeks" (Helliwell, 1965; Yamashita, 1978). Scientists have evaluated the cut-off frequency captured from the tweek spectrogram to estimate the ionospheric reflection height $h$, nighttime electron density of the D-region ionosphere $n_e$,

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and tweek propagaion distance $d$ (Ohya et al., 2003; Kumar et al., 2008; Kumar et al., 2009; Saini and Gwal, 2010; Maurya et al., 2010, 2012a,b; Tan et al., 2015, e.g). In recent decades, the tweek method has used to study the morphology of the nighttime D-region ionosphere. Observing tweeks in Antarctica (70.45° S, 11.44° E) from January–March in 2003 (sunspot number, $Rz = 63.7$) and 2005 ($Rz = 29.8$), Saini and Gwal (2010) found that the $h$ increases from January to March and its variations depend on the polar daytime solar ionization. These authors found that the $h$ in 2003 and 2005 changes from 64 to 76.88 km and 67 to 79.03 km, respectively. Ohya et al. (2003) observed tweek with $m = 1$ in October 2000 ($Rz = 119.6$) at the low and middle latitudes and found that the $h$ changes from 80–85 km and $n_e$ varies from 20–28 cm$^{-3}$. Observing tweeks in Suva (18.2° S), Fiji from September, 2003 to July, 2004, Kumar et al. (2008) found that the $h$ changes from 83–92 km for harmonics $m = 1$–6. These authors used first-three modes of tweeks recorded at Suva during 2006 ($Rz = 15.2$) to estimate the reference height $h'$ and sharpness factor $\beta$ to be 83.1 km, and 0.64 km$^{-1}$, respectively (Kumar et al., 2009). In Universiti Kebangsaan Malaysia (2.55° N; 101.46° E), Malaysia, Shariff et al. (2011) recorded tweek with $m = 1$ in August, 2009 and October, 2010 to estimate the $n_e$ in the range of 24–28 cm$^{-3}$ at the $h$ of 73–87 km. At Allahabad (16.05° N), India, Maurya et al. (2012a) observed tweek in January, March and June of 2010 ($Rz = 16.5$) to study the seasonal variations of the Wait's parameters and electron density profiles. Surveying the seasonal variation of $h$ over three solar cycles (21st, 22nd and 23rd cycles), Ohya et al. (2011) reported that the $h$ was relatively low in March–April and high in July–October. These authors suggested that the tweek reflection height variations could be caused by geocorona, Galactic Cosmic Rays (GCRs), particle precipitation and by variations of neutral density. Nevertheless, in the majority of previous works, the low-latitude D region ionosphere has been studied in the periods of weak solar activities. Therefore, it is necessary to investigate the morphology of the D-region in the period of stronger solar activities to deeply understand the physical processes of this region. The research on physical processes of the ionospheric D-region is as the basis for the prediction of ionospheric conditions in the applications of the navigation, communication and space technology.

In this paper, we recorded tweek with the first to eighth modes of tweeks at Tay Nguyen University (TNU) (12.65° N, 108.02° E) during 2013–2014 (under the solar maximum of the 24th cycle). The next section describes the experiment setup. The third section indicates how to record and analyze the data. The fourth section reports the findings of the study. A subsequent section on the discussion considers the comparison with other results and the International Reference Ionosphere 2012 (IRI-2012) model. The final section provides the conclusions.

## 2. Experimental setup

The ELF/VLF receiver used in our work consists of a magnetic antenna, a pre-amplifier, a service unit (SU), a GPS receiver and Data acquisition. The magnetic antenna includes the orthogonal loops. Its shape is a right isosceles triangle with the base of 2.6 m. Each loop has 8 turns of 18 American Wire Gauge (AWG) copper wire. These loops are installed with the North–South and East–West directions. The signals from the antenna are amplified and transmitted by the coaxial cables to the analog to digital converter (ADC) in the distance of 150 m. The sound card, M-audio delta 44, is used as an ADC. The precise sampling frequency of the sound card is calibrated using 1 PPS of the GPS receiver. The loop of antenna facing the East–West is chosen to record the tweeks because it is more sensitive to tweek atmospherics. SpectrumLab v2.77b22 is used to record the audio files with extension "wav". The audio files are recorded with a duration of 2 min at every 15 min interval. The details of experimental setup were mentioned in our previous work (Tan et al., 2015).

## 3. Formulas utilized and tweek analysis

The reflection height of the EIWG is calculated by equation (Budden et al., 1961):

$$h = \frac{cm}{2f_{cm}} \tag{1}$$

where, $c$ is the velocity of light in free space, $m$ is the order mode number, $f_{cm}$ is cut-off frequency. The electron density is given (Shvets and Hayakawa, 1998; Ohya et al., 2003) as.

$$n_e = 1.241 \times 10^{-8} f_c \, f_H \tag{2}$$

where, $f_H$ is the electron gyro-frequency. Tweeks mainly occurred in the low-latitude and equatorial regions, so we choose $f_H = 1.1 \pm 0.2$ MHz (Ohya et al., 2003). The group velocity $v_{gm}$ of $m$th mode in the homogeneous spherical EIWG is obtained by Yano et al. (1989)

$$v_{gm} = c\left(1 - f_{cm}^2/f^2\right)^{1/2}/(1 - c/2Rf_{cm}) \tag{3}$$

where, $R$ is the radius of the Earth. The propagation distance of tweeks is calculated using

$$d = \frac{|t_2 - t_1|(v_{g1} \times v_{g2})}{|v_{g1} - v_{g2}|} \tag{4}$$

where $t_2 - t_1$ is the difference in arrival times of the two frequencies, $f_2$ and $f_1$ closed to the tweeks of any mode, and $v_{gf1}$ and $v_{gf2}$ are the group velocities of the radio waves centered at frequencies $f_1$ and $f_2$.

Tweeks were continuously recorded from 19:00–5:00 LT (12:00–22:00 UT) during 2013 and 2014. Tweeks in five international quiet days during one month each were analyzed. Sonic Visualiser software (Cannam et al., 2010) is used to show the dynamic spectrum of tweeks. Fig. 1 shows the dynamic spectrum and waveform of one tweek at 18:30