Vietnam Journal of Earth Sciences, 38(4), 327-338, DOI: 10.15625/0866-7187/38/4/8794

(VAST)

Vietnam Academy of Science and Technology

Vietnam Journal of Earth Sciences

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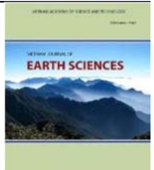

Study of the morphology of the low-latitude D region ionosphere using the method of tweeks observed at Buon Ma Thuot, Dak Lak

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Received 13 October 2015. Accepted 12 October 2016

ABSTRACT

Tweek is the electromagnetic waves at Extremely Low Frequency (3 - 3000 Hz) and Very Low Frequency (3-30 kHz) bands, which originates from lightning discharges and propagates about thousands of kilometers in the Earth-Ionosphere waveguide. Recording the tweeks with a maximum up to eighth harmonics using the receiver installed at Tay Nguyen University (12.65°N, 108.02°E), Buon Ma Thuot, Dak Lak, during January - June 2013, we have studied the morphology of the low-latitude D region ionosphere in the nighttime. The occurrence of tweeks with mode number $m = 2 - 3$ is more dominant. Tweeks with higher modes ($m \geq 4$) appear less than other tweeks due to the higher attenuation of wave energy for higher modes reflected at the ionospheric D region. The results show that electron density varies from 25.1-189.4 cm^{-3}, corresponding to the tweeks with m = 1-8 at the reflection height from 82.2-86.5 km. The reference height h' and electron density gradient β are higher during summer seasons as compared to those during winter and equinox seasons. The mean values of h' and β are 82.5 km and 0.53 km^{-1}, respectively. The electron density using the tweek method is lower by about 11-38 % than those obtained using the IRI-2012 model.

Keywords: The morphology of the D-region ionosphere, tweek, reflection height, reference height, electron density gradient.

1. Introduction

The D region with an altitude of 60-90 km is the lowest layer of Earth's ionosphere, where the collision between charged particles and neutral particles dominates. The D region ionosphere is an environment which absorbs radio waves. The absorption depends on the electron density and the electron - neutral collision frequency. The D region plays a role of the upper boundary of the Earth - ionosphere waveguide (EIWG). It can reflect the extremely low frequency (ELF; 3-

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3000 Hz) and very low frequency (VLF; 3 - 30 kHz) waves. The D region is too high for balloons and too low for satellite measurements. Especially, at night, the attachment and recombination rates of the electrons are so high that the free electron density is very low (< 10^3 cm^{-3}). This causes the ionosondes and radars not to operate. The ionospheric parameters can be measured by the rockets but this method is limited by the short observation period (Hargreaves, 1992). The physical processes of the D region ionosphere remain to be poorly understood and the ELF/VLF techniques become the effective tools to study this region.

Electromagnetic waves in the ELF/VLF ranges emitted by the lightning discharges travel thousands of kilometers by multiple reflection modes in the EIWG with the little attenuation of 2-3 dB/1000 km (Davies, 1965). They are strongly dispersed near the cutoff frequency of 1.8 kHz. These waves appear as "hooks" on the frequency - time spectrum and are heard as "tweet" through loudspeakers of the receivers, so that they are called "tweek" (Helliwell, 1965). Tweeks propagate by multiple modes such as the zero-order mode, the first-order mode, the second-order mode and so on. The mode means the number of field patterns in the plane of wave propagation in the EIWG (Davies, 1965). The tweek occurrence depends on the latitudes, seasons, activities of lightning and atmospheric phenomena. In particular, it also depends on the turbulence of the Earth's magnetic field (Yamashita, 1978).

In recent decades, many works have used the tweek method to study the morphology of the nighttime D region ionosphere. Ohya et al (2003) observed tweek with the first-order mode (m = 1) during October 2000 (the sunspot number, Rz = 119.6) at the mid-low latitude stations and found that the reflection height changed 80-85 km, which corresponded to the change in electron density of 20-28 cm^{-3}. Observing tweeks at Antarctica (70.45°S, 11.44°E) during January - March 2003 (Rz = 63.7) and January - March 2005 (Rz = 29.8), Gwal and Saini (2010) found that the reflection height changed 64-76.88 km and 67-79.03 km, respectively. These changes depended on the ionization levels due to the emissions from the Sun during daytime in the polar region. Analyzing tweeks observed at Suva (18.2°S), Fiji from September 2003 - July 2004, Kumar et al (2008) concluded that the tweek reflection height corresponding to m = 1-6 varied 83-92 km. At Universiti Kebangsaan Malaysia (UKM) (2.55°N, 101.46°E), Malaysia, Shariff et al (2011) recorded tweeks with m = 1 during August 2009 and October 2010 and reported that the reflection height varied 73-87 km and the electron density changed 24-28 cm^{-3}. The low latitude D region morphology has mainly been studied during the phase of weak solar activity. Therefore, it is necessary to investigate the D region during the high solar activity period for deep understanding of the physical processes of this region. The basic research on the physical processes of the D region ionosphere is the foundation for forecasting of the ionospheric conditions and the application in the navigation, communication and space technology.

In this paper, we analyzed tweeks with the first - to eighth -order modes observed at Tay Nguyen University (TNU) (12.65°N, 108.02°E), Buon Ma Thuot city, Dak Lak province from January to June 2013 (under the high solar activity period of the 24th cycle). We used the tweek cut-off frequency to calculate the reflection height and electron density of the nighttime D region ionosphere at low latitudes. We evaluated the seasonal variations in Wait parameters (h', β) and compared the nighttime electron density profile obtained using the tweek method with those calculated using the International Reference Ionosphere 2012 (IRI-2012).

2. Background theory

According to the waveguide theory, electromagnetic waves propagate in the ideal EIWG by the transverse electric (TE), transverse magnetic (TM) and transverse electromagnetic (TEM) modes. The TE modes have no electric field component along the direction of wave propagation (*x* direction) but have a vertical magnetic field component in the z direction and a horizontal magnetic field component in the *x* direction. The TM modes have no magnetic field component in the *x* direction but have a vertical electric field component and a horizontal electric field component in the *x* direction. Regarding the TEM modes, both electric and magnetic field components are particular to the direction of wave propagation. For the real EIWG, both ground and upper boundary are not the perfect conductors. Therefore, the ELF/VLF waves propagate in the EIWG with the quasi-transverse electric (QTE) and quasi-transverse magnetic (QTM) modes. The QTM modes are similar to the TM modes but they have a small magnetic field component in the *x* direction. The QTE modes also have a small electric field component in the *x* direction. The propagation modes with no cutoff frequencies and with frequencies less than 1.8 kHz are called the quasi-transverse electromagnetic (QTEM) modes (Budden, 1962). For the frequencies less than 15 kHz, the lower-order QTM and QTE modes are nearly similar to the TM and TE modes, respectively (Wood, 2004). In present work, we have considered the tweeks with the cutoff frequencies below 15 kHz.

Figure 1 shows the TM modes of the wave propagation in the EIWG. Figure 1a and 1b show the electric field patterns of the first-order mode (TM_{01}) and second-order mode (TM_{02}), assuming that the Earth is a perfect electrical conductor (reflection coefficient $R = +1$) and when the ionosphere is a perfect magnetic conductor ($R = -1$). The mode patterns can be obtained from Maxwell's equations with the conditions of the ideal EIWG and when the vertical electric field under the upper boundary of the EIWG reaches to zero (Davies, 1965). In Figure 1a, the plane of the ionospheric boundary contains the images of the ELF/VLF wave sources and the curves present the polarized wave. The curves on the left side of the electric field lines represent the variations in the vertical electric field (E_V) and horizontal electric field (E_H) strengths.

The theory of the electromagnetic wave propagation in the plasma with a magnetic field and collisions between charged particles is based on magneto-ionic theory applied to the ionosphere. The refractive index of the medium of the wave propagation in the ionospheric plasma is described by Appleton-Hartree formula (Budden, 1961).

$$n^2 = 1 - \frac{X}{1 - iZ - \dfrac{Y_T^2}{2(1 - X - iZ)} \pm \left(\dfrac{Y_T^4}{4(1 - X - iZ)^2} + Y_L^2 \right)^{1/2}} \quad (1)$$

The quantities X, Y_T, Y_L and Z are determined as:

$$\begin{aligned} X &= \left(\frac{\omega_p}{\omega} \right)^2 \\ Y_T &= \frac{\omega_H}{\omega} \sin\theta \\ Y_L &= \frac{\omega_H}{\omega} \cos\theta \\ Z &= \frac{\nu}{\omega} \end{aligned} \quad (2)$$

where, ω_p is the plasma angular frequency, ω_H is the angular gyro-frequency of electron, ω is the angular frequency of the wave, the electron-neutral collision frequency and θ is the angle between the magnetic field strength vector and the direction of wave propagation.

The meanings of the sign "±" in the denominator of the formula (1) are as follows: the upper sign "+" corresponds to the ordinary waves and the lower "-" corresponds to the extraordinary waves in the ionospheric plasma.

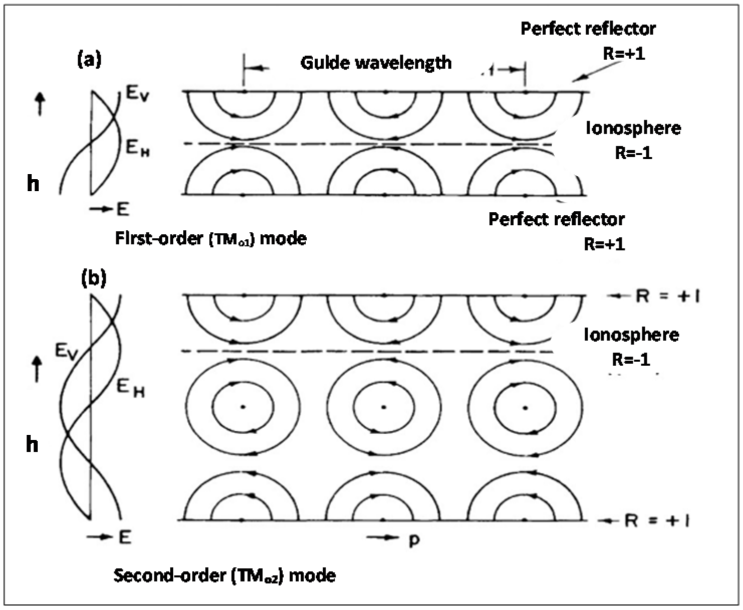

Figure 1. The electric field patterns corresponding to the first- and second- order modes in the EIWG (Davies, 1965)

The X values where n^2 in (1) becomes zero are given by X = 1 (corresponding to the ordinary mode waves) and $X = 1 \pm Y$ (corresponding to extraordinary mode waves). The extraordinary mode waves correspond to $X = 1 + Y$ when $Y > 1$ $(\omega_H > \omega)$ and $X = 1 - Y$ when $Y < 1$ $(\omega_H < \omega)$. For the case of tweeks in the ELF/VLF ranges $(\omega < \omega_H)$, $X = Y + 1$ is chosen. Therefore, the electron density (cm^{-3}) is estimated from the condition $X = 1 + Y$ (Ohya et al., 2003).

$$N_e = 1,241 \times 10^{-8} f_{cm} f_H \tag{3}$$

Where, f_{cm} is the cut-off frequency of the m^{th}-order modes, f_H is the gyro-frequency of electron. Because tweeks mainly occur in the low-latitude and equatorial regions, f_H is calculated by using the IGRF (International Geomagnetic Reference Field) model and f_H = 1,1 ± 0,2 MHz (Ohya et al., 2003).

Following theory waveguide with the case of the ideal boundary of waveguide, electromagnetic waves with a wavelength λ ($\lambda = c/f_c = mc/f_{cm}$) propagate between two reflective boundaries and if they meet the condition $\lambda/2 = h$ (h is the reflection height). Since then, the height of EIWG is determined through the cutoff frequency f_{cm} for each mode (Wood, 2004):

$$h = \frac{mc}{2 f_{cm}} \tag{4}$$

The waves reflect at two boundaries of the EIWG with the incident angle θ (excepting the TEM mode), so the speed of energy propagation of each mode is smaller than the speed of light. For the given mode (e.g. TM mode), the group velocity is as a function of the frequencies:

$$v_{gm} = c\cos\theta = c\sqrt{1 - \left(\frac{f_{cm}}{f}\right)^2} \tag{5}$$

If the wave propagation distance is greater than 2000 km and the curvature of the Earth is taken into consideration, the group velocity is determined (Ohya et al., 2008) as,

$$v_{gm} = c\sqrt{1 - (f_{cm}/f)^2} / (1 - c/2Rf_{cm}) \tag{6}$$

where, R is the radius of the Earth.

From (6), when the f reaches near the f_{cm}, the v_{gm} approaches zero, and if the f is greater than the f_{cm}, the v_{gm} approaches to the speed of light. When the f is less than the f_{cm} the waves are attenuated faster along the propagation path. The TEM modes of the waves propagate with the speed of light, so that the modes with all the frequencies arrive at the receiver at the same time. The TM_1 modes arrive later than TEM modes. The TM_1 modes with the frequency as far as the cut-off frequency traveling with near the speed of light arrive at nearly the same time as the TEM modes. The similar property appears for the higher modes (Wood, 2004).

The tweek propagation distance is obtained (Prasad, 1981) by,

$$d = \frac{|t_2 - t_1|(v_{gf1} \times v_{gf2})}{|v_{gf1} - v_{gf2}|} \tag{7}$$

Where, t_2 - t_1 is the difference in arrival times of the two frequencies, f_2 and f_1, close to the tweeks of any modes, corresponding to group velocities v_{gf2} and v_{gf1}.

The change in electron density with the altitude is decided by two Wait's parameters, the reference height h' and the electron density gradient β. The electron density profile is determined by the Wait and Spies model (Wait and Spies, 1964):

$$N_e(h) = 1{,}43 \times 10^7 \exp(-0{,}15\,h') \times \exp\left[(\beta - 0{,}15)(h - h')\right] \tag{8}$$

Applying the formula (3), (4), (7) and (8), we can determine the electron density, reflection height, tweek propagation distance from the sources to the receivers and the electron density profile of the nighttime D region ionosphere.

3. The instrument and research method

3.1. The research instrument

The UltraMSK receiver which was used to collect tweeks includes a VLF antenna, a preamplifier, a SU (Service Unit), a sound card (M-Audio Delta 44) with 96 kHz sampling frequency, a GPS receiver, a computer connected with the internet, and recording software. The ELF/VLF antenna (including two orthogonal copper loops) receives the magnetic field components of electromagnetic waves. The preamplifier is placed near the antenna to filter and amplifier the small signals for the digitization of analog signals using the analog to digital converter (ADC). The GPS 1PPS (pulse per second) makes the center frequency for the purpose of the sampling of the sound card's ADC. The ELF/VLF signals from East - West channel of preamplifier are sent to the soundcard. SpectrumLab software records the broadband ELF/VLF signals with audio files having the extension ".wav". This receiver system was described in the details on the website www.ultramsk.com/ and in the previous work (Tan et al., 2014).

3.2. The methods of recording and analysing data

Tweeks were continuously recorded from January to June 2013. The receiver recorded the data with the duration of 2 minutes at every 15 intervals. The data was selected for five geomagnetically quiet nights (*Dst* index is satisfied with - 20 nT ≤ *Dst* ≤ 20 nT) of each month. When analyzing the data, the universal time (UT) was converted to the local time (LT) (LT = UT + 7 hours). Through observation, tweeks did not often appear during the sunset period (17:00-19:00 LT) and sunrise period (5:00-7:00 LT). Therefore, we selected only tweeks captured during the period from 19:00-5:00 LT. In order to analyze the tweek data, we used Sonic Visualiser software developed by Cannam et al (2010). The tweeks propagating in the EIWG with the distance less than 5000 km were selected to avoid the errors in the reflection height and electron density due to the tweeks propagating with the east-west direction from the day parts of the Earth (Maurya et al., 2012).

Figure 2a, b shows an example of the frequency - time spectrum with a frequency range of 0-16 kHz at 1:30 LT and 2:30 LT on 15 May, 2013. On the spectrum, many vertical lines presenting the electromagnetic pulses generated by the lightning discharges around the world are called "sferics" and propagate in the EIWG to the receiver. On spectrogram of Figure 2a, the second to third harmonic tweeks can be seen. In Figure 2b, a tweek appears with the eighth harmonic. The QTEM components indicated by arrows are under the first order-mode of tweeks.

All tweeks which clearly displayed on the spectrum of Sonic Visualiser software with the intensity levels ≥ - 35 dB are chosen. The frequency and time resolutions are 35 Hz and 1 ms, respectively. The reflection height is calculated within the error of ± 1.5 km for the first-order modes. These errors decrease with the increasing of the mode number. The D region electron density is calculated within the error of ± 0.5 cm^{-3}.

In order to determine the electron density profile, tweeks occurring from 21:00-3:00 LT are selected to avoid the effects of the day-night transitions (Kumar et al., 2009). We use the method of fitting function $y = ae^{bx}$ for the plotting of the electron density profile and combine with the equation (5) to calculate the h' and β for five geomagnetically quiet days of each month. The electron density profile obtained by using the tweek method is compared with that obtained using the IRI-2012.

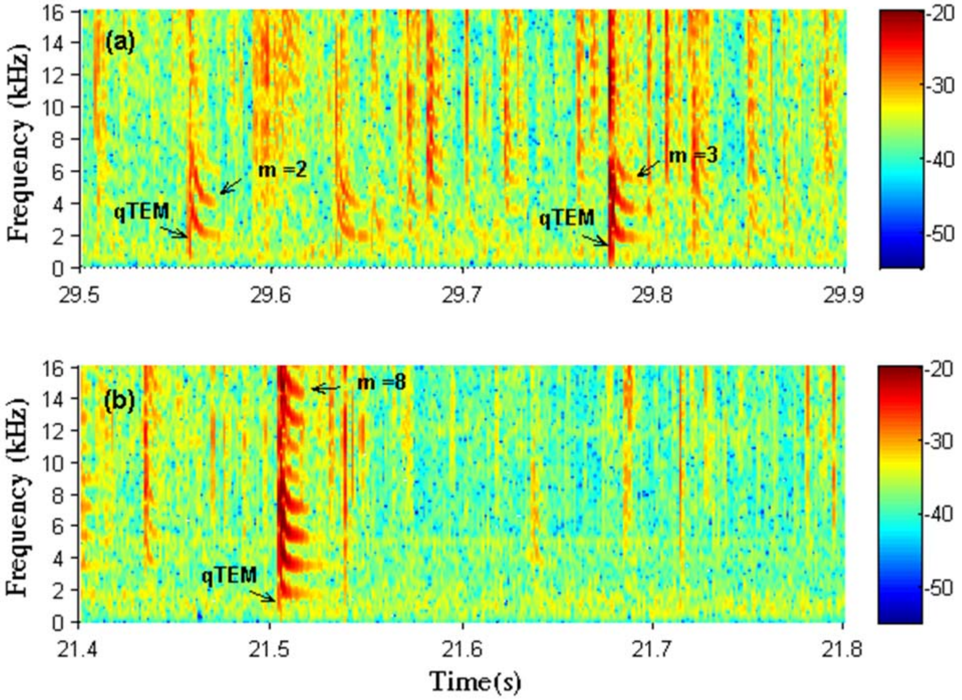

Figure 2. An example of the frequency - time spectrum with a frequency range of 0-16 kHz at 1:30 LT and 2:30 LT on 15 May 2013

3. Researh results

3.1. The characteristics of the tweek propagation

In Table 1, the tweeks observed before midnight (19:00-00:00 LT) and after midnight (00:00-05:00 LT) are 11731 and 11342, respectively. Tweeks with the mode number $m \geq 4$ appeared before midnight is much more than those appeared after midnight. The second to fourth harmonic tweeks often occurred and the eighth harmonic tweeks appeared rarely (representing 1.08 % for before midnight and 0.5 % for after midnight).

Tabble 1. Statistic of tweek occurrence observed during the quiet nights from January to June 2013

Time (LT)		Harmonic tweeks								Total
		1st	2nd	3rd	4^{th}	5^{th}	6th	7th	8th	
19:00-00:00	Tweek number	330	3549	3374	2161	1220	636	334	127	11731
	% count	2.81	30.25	28.76	18.42	10.40	5.42	2.85	1.08	
00:00-05:00	Tweek number	290	3841	3380	1775	1158	582	259	57	11342
	% count	2.56	33.87	29.80	15.65	10.21	5.13	2.28	0.50	

Table 2 shows the mode number (*m*), fundamental cutoff frequency (f_{cm}/m), tweek duration (*dT*), reflection height (*h*), propagation distance (*d*) and electron density (*Ne*) corresponding to the second and third harmonic tweeks (Figure 2a) and the eighth harmonic tweeks (Figure 2b). It can be seen in Table 2 that the fundamental cutoff frequency varies 1747 to 2135 Hz. The reflection height changes from 70.3 to 85.9 km and tends to increase when the mode number increases. In addition, the electron density varies 25.6-198.5 cm^{-3}. The propagation distance of tweeks is in the range of 610-3438 km.

Table 2. Example of the estimated fundamental cut-off frequency, tweek duration, reflection height, tweek propagation distance and electron density

Spectrum	m	f_{cm}/m (Hz)	dT (s)	h (km)	d (km)	N_e (e/cm^3)
a	1	2135	0.015	70.3	3438	29.15
	2	1922	0.009	78.1	2059	52.47
	1	1876	0.013	79.9	2540	25.61
	2	1792	0.010	83.7	1922	48.93
	3	1747	0.009	85.9	1673	71.55
b	1	1931	0.008	77.7	1413	26.35
	2	1882	0.007	79.7	1249	51.38
	3	1847	0.010	81.2	1418	75.65
	4	1844	0.011	81.4	1597	100.68
	5	1853	0.008	81.0	965	126.46
	6	1822	0.006	82,3	755	149.21
	7	1792	0.008	83.7	1009	171.21
	8	1818	0.006	82.5	610	198.51

Figure 3a represents the propagation distance of the harmonic tweeks. Tweeks with the propagation distance of 2000-3000 km appeared often. The occurrence rate of tweeks with the propagation distance of 1000-5000 km is about 94 %. The tweeks with the propagation distance of 2000 km appeared with the highest percentage (39 %) and others having the propagation distance of 11000-12000 km appeared with the lowest percentage (0.003 %).

From Figure 3b, the mean reflection height increases when the mode number of tweeks increases from 1 to 8. Figure 3b shows that the mean reflection height increases linearly with the mode number and the approximately linear line has a slope of 0.66 and a high determination coefficient (R^2) of 0.982. In the graph, the error bars shows the standard deviation (SD). The mean electron density corresponding to m=1-8 varies 25.1-189.4 cm^3 at the mean reflection height of 82.2 to 86.5 km.

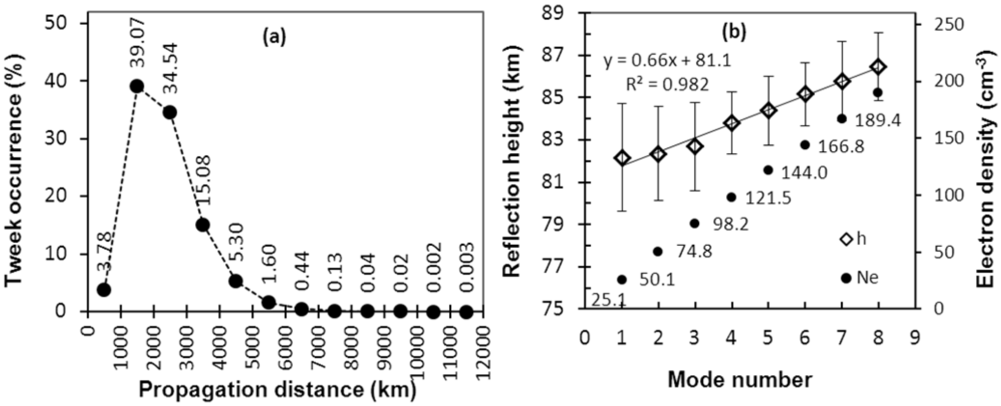

Figure 3. The week occurrence rates as a function of the propagation distance (a) and the variations in the reflection height and electron density with the mode number (b)

3.2. The temporal variations in the reflection height and Wait's parameters

The tweek reflection height with m = 1 decreases from 7:00 to 21:30 LT and gradually increases from 21:30 to 5:00 LT (Figure 4a). The trend line (with the linear form) shows that the tweek reflection height gradually increases from evening to morning. The tweek reflection height changes 81.0 - 83.4 km with the *SD* = 2.9 km to ± 1.1 km.

The *h'* and β values are higher during summer season (May and June) as compared to those during winter (January and February) and equinox (March and April) seasons (see Figure 4). The *h'* and β values change 81.5-83.9 km with the *SD* = ± 1.1 km to ± 0.4 km and 0.4-0.61 km^{-1} with the *SD* = ± 0.4 km^{-1} to ± 0.06 km^{-1}, respectively. The variation trend of the *h'* is nearly opposite to that of the β.

3.3. The variation in the nighttime D region electron density

Figure 5 a-c represent the temporal variations in the mean electron density corresponding to m = 1 - 3 during three seasons. In all three cases, before midnight, the electron density is lower during summer and equinox seasons as compared to that during winter season, but after midnight, the differences in electron density between the seasons are not significant.

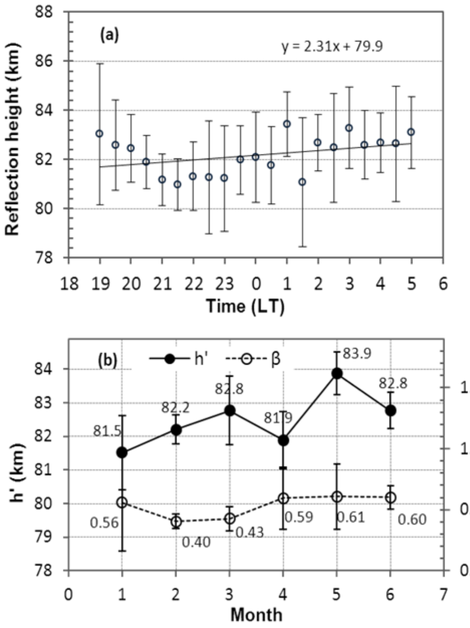

Figure 4. The variations in reflection height (a) and the *h'* and β (b)

The electron density increases from 23 - 6980 cm^{-3} with the exponential rule, which corresponds to the altitude range of 80 - 95 km (Figure 6). The electron density calculated using the tweek method is lower by 11- 38 % than that obtained using the IRI-2012 model in the altitude range of 84-87 km with a good match at 87 km.

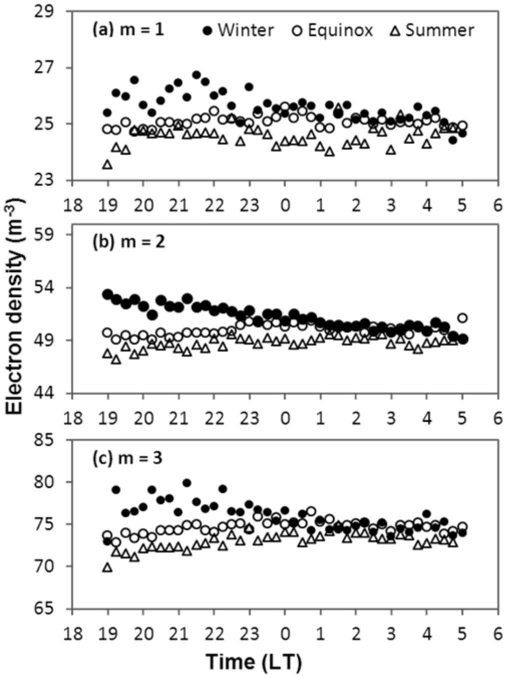

Figure 5. The variations in the electron density during winter, equinox and summer seasons

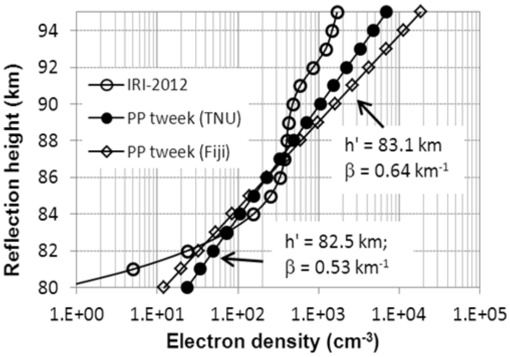

Figure 6. Comparison of the electron density profiles obtained using tweek method at TNU and Fiji with those obtained using IRI-2012 model

4. Discussions

Tweeks with the higher harmonics do not appear often (see Table 1) because the attenuation of the energy increases for the higher mode (Kumar et al., 2008). The increase in the reflection height versus the mode number (Figure 3b) can be explained that the mode can reflect at the altitude where the plasma frequency equals the cutoff frequency for that particular mode, so that the higher harmonics can reflect at the higher altitude corresponding to the higher electron density (Shvets and Hayakawa, 1998). The ELF/VLF waves propagating over the sea get less attenuation than that propagating on the land (Ohya et al., 1981), therefore most of tweeks from the East sea arrived to the Tay Nguyen University.

Observing tweeks at Antarctica (70.45°S) during January to March 2003 (*Rz* = 63.7), Gwal and Saini (2010) found that the mean reflection height was about 70.4 km. The mean reflection height observed at TNU (12.65°N) during January to June 2013 (*Rz* = 64.9) was 82.2 km. In the study of Kumar et al (2009), the mean reflection height for $m = 1$ recorded at Suva (18.2°S), Fiji during September 2003 - July 2004 was 83.4 km. Thus, in the conditions of the insignificant difference in *Rz* between the observation periods, the mean reflection height observed at lower latitudes is higher by 12-13 km than that observed at higher latitudes.

The hourly changes in the reflection height (Figure 4a) could be due to the D region heated by the quasi-electrostatic field and the electromagnetic radiated by the lightning discharges (Inan et al., 2010). The increase in the nighttime reflection height corresponds to the decrease in the electron density due to the attachment and recombination processes. The decrease in the nighttime electron density can be also due to change in the neutral temperature. The neutral temperature change causes the change in the effective recombination coefficient, and thus the electronic density changes around 10^1 cm^{-3}. In terms of the high solar activity period, the enhanced hydrogen Lyman-α and Lyman-β emissions from the geocorona play an important role for the D-region ionization. The intensity of galactic cosmic rays (an important ionization source of the nighttime D region ionosphere) decreases in the high solar activity conditions (Ohya et al., 2011). Moreover, the intensity of galactic cosmic rays depends on the latitude and is very weak at the equator (Heaps, 1978). Therefore, at the observational region and period of our work, the contribution of galactic cosmic rays to the D region ionization may not be significant, while the hydrogen Lyman-α and Lyman-β emissions, neutral temperature, lightning activity play the important roles for the low latitude D region ionization during nighttime.

From the evening to the pre-midnight, the electron density is higher during winter season as compared to that during summer and equinox seasons (Figure 5). Such a phenomenon can be caused by the lower electron density during daytime in the winter giving rise to slower the electron loss due to recombination and attachment processes.

During 2006 (Rz = 15.2), Kumar et al (2009) observed tweeks at Suva (18.2°S) and used the first three modes of tweeks to estimate the h' and β to be 83.1 km and 0.64 km^{-1}, respectively. At Allahabad (16.05°N), India, Maurya et al (2012) observed tweek during January, March and June 2010 (Rz = 16.5) and calculated the mean value h' and β during summer equinox and winter seasons to be 83.54 km and 0.61 km^{-1}, 85.7 km and 0.54 km^{-1}, and 85.9 km and 0.51 km^{-1}, respectively. In present work, the h' values are lower than those estimated by Kumar et al (2009) and Maurya et al (2012). The values of electron density in the profile at the altitude range of 82-86 km in our work (see Figure 6) are higher than those observed at Suva, Fiji (Kumar et al., 2008). Shvets and Hayakawa (1998) indicated that when solar activity is stronger, the electron density increases, corresponding to the decrease in the reflection height. Other studies also demonstrated the solar activity can affect the D region electron density (Bremer and Singer, 1977; Danilov, 1998). Minh et al. (2016) investigated the variation in TEC (total electron density) in the Southeast Asian region during the 2006 - 2013 period and found that the level of correlation between the amplitude of the TEC at two crests and the sunspot number is very high (~ 0.9). These works support our finding that the electron density values in the profile observed at TNU also is higher than that observed at Suva, Fiji because our observation period belongs to the higher solar activity period.

5. Conclusions

Observing 23073 tweeks with the first to eighth harmonics using the UltraMSK receiver installed at Tay Nguyen University (12.65°N, 108.02°E) during January - June 2013, we have studied the morphology of the nighttime D region ionosphere. We can conclude as follows,

- The second to third harmonic tweeks occurred often. The tweeks with the high harmonics ($m \geq 4$) occurred with the lower percentage compared to that of other tweeks due to the increasing of the wave energy attenuation in the D region ionosphere.
- The reflection height for the first-order modes of tweeks changes from 81.0 to 83.4 km and increases towards the dawn. The electron density corresponding to m = 1 - 8 varies 25.1 - 189.4 cm^{-3} at the reflection height of 82.2 - 86.5 km. The tweek reflection height at low latitudes is higher than that at high latitudes. The Wait parameters, h' and β, during summer season are higher than those during winter and equinox seasons.
- Before midnight, the electron density (for the first- to third-order modes of tweeks) during summer and equinox seasons is much lower than that during winter season. The electron density values of the electron density

profile calculated using the tweek method are lower by 11-38 % than those obtained using the IRI-2012 model in the altitude range of 84-87 km with a good match at 87 km.

The results observed during the high solar activity period of the 24th cycle have contributed to demonstrate the impact of solar activity on the morphology of the nighttime D region ionosphere. Vietnam is located in the region of a thunderstorm center in Asia, which is very convenient for the using of tweek method to study the nighttime D-region ionosphere. In the near future, we continuously record tweeks with the longer period and compare our data with that obtained from other stations to study the dynamic variations of the Southeast Asian D region ionosphere.

Acknowledgements

The authors are very grateful to Dr. Jame Brundbell for helping us to set up the UltraMSK receiver. We would like to thank Department of Physics Faculty of Natural Science and Technology, Tay Nguyen University for supporting us the facilities to install the recording receiver.

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