

Research Article

Characteristic of Tweek Atmospherics Observed in Mid-latitude using AWESOME VLF Receiver

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Abstract: This study presents the analysis of tweek atmospherics received by AWESOME VLF receiver at station of Gakona (62.71°N, 143.99°W) during four months observation from January to April 2011. Tweek which originates from lightning discharge are used to monitor the nighttime D-region ionosphere using the fundamental cut-off frequency to measure the variations of the lower ionosphere's reflection height, the equivalent electron density at the reflection height and the propagation distance travel by tweeks. In this study, a total of 1316 tweeks are analyzed and from the analysis, it shows that equinox's season has the highest tweek occurrence compared to winter season in March and April. The maximum harmonic (m) of t weeks is found to be up to fourth ($m = 4$) and tweeks with mode number one ($m = 1$) are more dominantly occurred. Our observations indicate that the equivalent electron densities for tweeks varies from 22-27 eL/cm³ in the altitude ranged of 75 to 91 km and demonstrate that these ELF/VLF signals travel considerable distances up to 6700 km from the causative lightning discharges. The ionospheric parameters for three locations (high, middle and low latitude respectively) were compared and the results show that they are almost consistent for all the locations.

Keywords: D-region ionosphere, Earth-Ionosphere Waveguide (EIWG), ELF/VLF radio waves, lightning discharges, tweek, tweek atmospherics

INTRODUCTION

Tweek atmospherics are ELF/VLF electromagnetic waves that are originated from lightning discharges and propagated in Earth Ionosphere Waveguide (EIWG) over long distances. Lightning radiates electromagnetic pulse in a very wide bandwidth from few hertz (Burke and Jones, 1992) up to tens of megahertz (Weidman and Krider, 1986). However, the range of the frequency bands guided by the signal concentrated in the very low frequency (VLF: 3-30 kHz) and extremely low frequency (ELF: 3-3000 Hz) bands. This guided propagation occurs with low attenuation rates about a few decibels per 1000 km allowing VLF and ELF tweeks to be observed around the world far from their source lightning discharge. The reflection between two boundaries possesses many dispersive parts of tweek with different cut-off frequencies which make it a useful tool to study the characteristic of tweek atmospherics in D-region ionosphere.

The characteristics of tweeks are thus determined during various conditions in nighttime and different seasons. Tweeks observed under night time ionospheres because the D-region ionosphere is a significantly better reflector at night than at the day makes them

useful diagnostic tools to estimate D-region ionospheric parameters.

Previously, sferics had been used to study the wideband VLF attenuation and phase velocity (Jean *et al.*, 1960). Some work with sferics focused on measurements and theoretical understanding of the long-delayed sferic components which form the "tweek" (Yamashita, 1978; Ryabov, 1992). Other researches had used measured sferics to determine the distance and geographic bearing to the source discharge and to estimate the ionospheric reflection altitude along the propagation path (Kumar *et al.*, 1994; Hayakawa *et al.*, 1994). Ohya *et al.* (2006), Kumar *et al.* (2008), Saini and Gwal (2010) and Maurya *et al.* (2010) employed a similar technique that used in this study to estimate the ionospheric reflection height (h), equivalent electron densities (n_e) at reflection heights and propagation distance (d) that travel by tweek in EIWG.

The present study deals with the further observation on the tweek characteristic in mid latitude region since few measurements had been done for this region. In this study, we analyzed four months ELF/VLF broadband data recorded in Gakona station of Alaska during January to April 2011. The combination geographical location of the recording station on

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ground (65%) and sea surface (35%) which may be a good opportunity to observe tweeks with higher harmonics mode number with good dispersion. Tweek method is used in order to study the characteristic of D-region ionosphere which is propagated subionospherically from very far distance and contains very useful information about D-region ionospheric parameters in the EIWG.

Data acquisition: The data was collected using Stanford University developed AWESOME ELF/VLF receiver installed in station of Gakona. The analysis is based on four months broadband data in January-April 2011 which is divided into two different seasons of winter (January, February) and equinoxes (March, April). The broadband data is used in this study which is fully waveform data sampled at 100 kHz and the frequency range between 300 Hz to 40 kHz. The data are record every 5 min at every hour between 18:00-06:00 AKST (03:00-15:00 UT). The time used in this study is referring to Alaska Standard Time (AKST) which is 9 h behind Universal Time (UT). The hour of observation is representing by 1 min data to clearly show the occurrences of tweek in spectrogram.

Instrumentation: An AWESOME VLF receiver is place in Gakona station to collect signal from the lightning activities. It consists of three main component which is loop antenna, preamplifier and a line receiver. The loop antenna is sensitive to the component of magnetic field (small TM and TEM mode wave) in the direction orthogonal to the ground plane of the loop. It is also possible the NS and EW to pick up atmospheric signals from any location. The location of preamplifier is near to the antenna to reduce the resistive loss of the cable. The pre-amplifier impedance is kept matching to the antenna to provide maximum power transfer. The pre-amplifier amplifies the weak signal and the signal is then passed through to the line receiver placed inside the lab. The final processing for the signal is performs by the line receiver. The block diagram of the components is shown in Fig. 1.

METHODOLOGY

The methodology in this study consists of four steps as illustrate in Fig. 2. The first step involves the monitoring and collecting of ionosphere data recorded by Stanford University using AWESOME ELF/VLF receiver in station of Gakona. This part describes the VLF receiver equipment and also the type of recorded data which is useful for this study. The second step is translating the raw data to the frequency-time spectrogram using Fast Fourier Transform (FFT) codes in MATLAB. In this stage, we are identifying the occurrence pattern of tweeks seen from the spectrogram. The third step is analyzing the tweek characteristics of D-region ionosphere in term of the

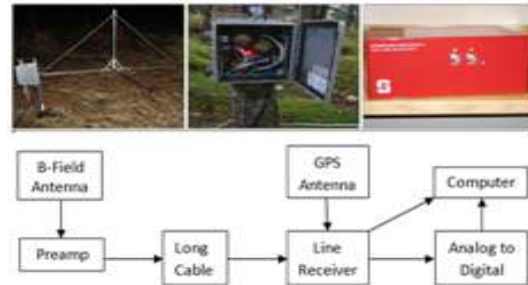


Fig. 1: The photographs of the three main components of the AWESOME VLF receiver and the block diagram of the system (Cohen *et al.*, 2010)

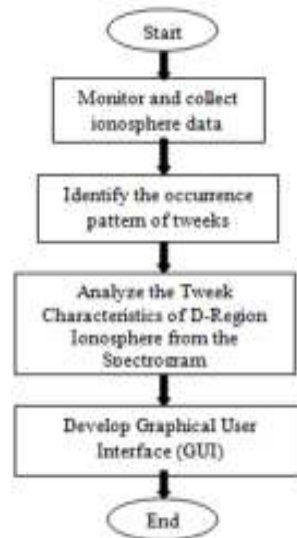


Fig. 2: Flow chart to determine the D-region ionosphere parameters

reflection height (h), electron density (n_e) and the propagation distance (d) in Earth-Ionosphere waveguide.

Estimation of the D-region parameters: In general, perfect reflecting boundaries can be occur in the EIWG which means electromagnetic wave can be divided into a sequence of independent field structures called mode. Basically, this wave will propagate into different group velocities. Each mode (m) is defined by its cut-off frequency f_{cm} by determining the height ' h ' of the waveguide or the VLF reflection height. In order to fulfill the boundary conditions, the reflection height can be estimate using (Budden, 1961; Yamashita, 1978):

$$h = \frac{mc}{2f_{cm}} \quad (1)$$

where,

c = The speed of light

f_{cm} = The cut off frequency that can be found from the spectrograms

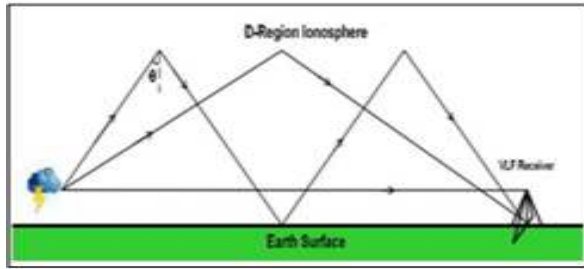


Fig. 3: The model of ELF/VLF signal travel in EIWG

In the simplest way, the exponential increase in the lower-ionospheric electron density (n_e) expressed in cm^{-3} , can be described by Wait and Spies (1964):

$$n_e = 1.241 \times 10^{-8} f_H f_{cm} \quad (2)$$

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

In EIWG, the ELF/VLF signal travels near the speed of light and the group velocity is given by Prasad (1981):

$$v_g = \frac{\delta \omega}{\delta k} = c \sqrt{1 - \left(\frac{f_{cm}}{f}\right)^2} \quad (3)$$

where, ω is the wave's angular velocity k is the wave number. The horizontal propagation distance, d travelled by the tweeks in the m^{th} mode is given as Prasad (1981):

$$d = \frac{\Delta t (v_{gf1} \times v_{gf2})}{|v_{gf1} - v_{gf2}|} \quad (4)$$

where, Δt is the time interval between f_1 and f_2 which are calculated from the spectrogram for each mode. Figure 3 shows the model of ELF/VLF signal travel in EIWG.

GUI development: In this study, all the finding output will be shown through GUI to make it easier for the users to view the characteristic of tweek during various conditions. From the simulation programme, the system starts with the main interface display with the title display "Tweek Atmospherics" as shown in Fig. 4. It is divided into five main buttons to show the D-region characteristic of tweek atmospherics at different conditions in mid latitude region. Hence, the first button which is start from the "Occurrence of tweeks in month", "Number of mode (m)", "D-region measurement", "Seasonal variation of tweeks" and last button is follow by "Comparison characteristic of tweeks between High-Mid-Low latitude region". All results of GUI are represents in Fig. 5.

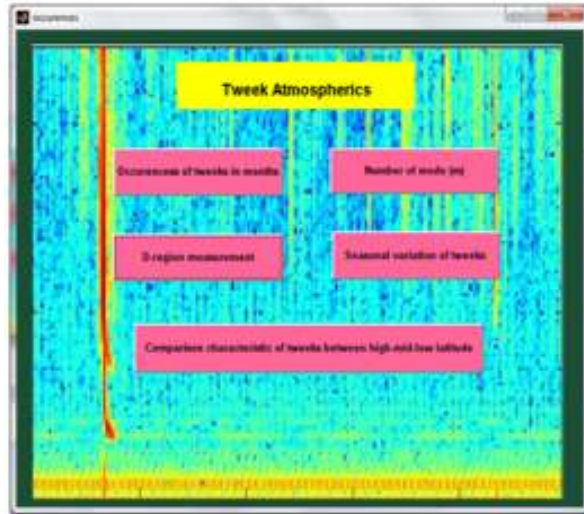


Fig. 4: The main page of GUI

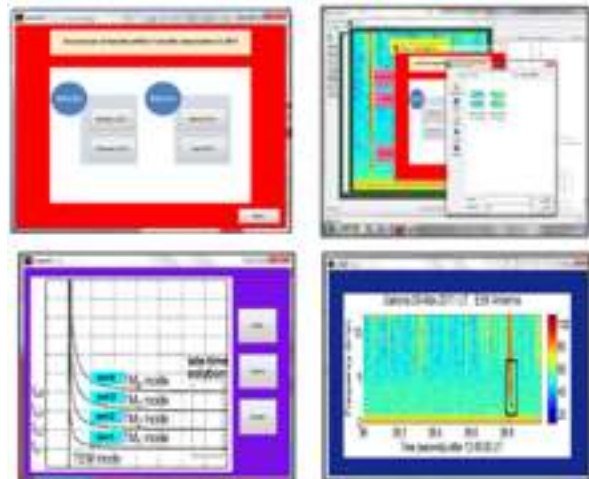


Fig. 5: Results of GUI

RESULTS AND DISCUSSION

D-region measurement: The VLF broadband data analyzed in this project are recorded using Stanford University developed AWESOME VLF receiver installed in station of Gakona. The observation of tweeks was made during nighttime of March and April 2011 between 18:00-06:00 AKST (03:00-15:00 UT). From the analysis, it showed a total of 1312 tweeks were selected on the basis of clarity of tweeks seen in the spectrograms.

Figure 6a to d represents the spectrograms showing typical multimode tweeks observed on (a) 8 March 2011 at 03:30:00 AKST, (b) 9 March 2011 at 03:45:00 AKST, (c) 9 March 2011 at 05:25:00 AKST and (d) 9 March 2011 at 05:05:00 AKST at Gakona. Tweeks with mode number $m = 1, 2, 3$ and 4 are visually identified from spectrograms within the 2 months observation.

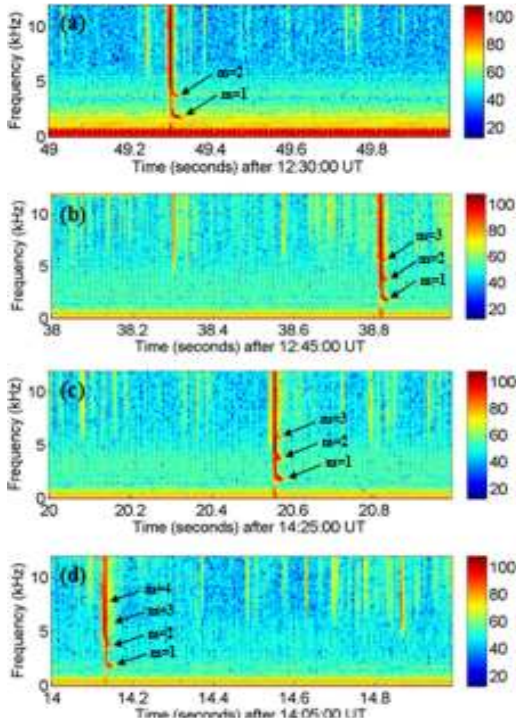


Fig. 6: (a-d) Spectrogram of 1 sec duration showing multimode tweek atmospherics observed in March 2011

The results show that the maximum harmonic of tweek recorded is fourth ($m = 4$) and it occurs sporadically during dawn period reported from Gakona mid latitude station as shown in Fig. 6d. Most of their propagation for this path is on the ground and only 35% on the sea surface which may be one of the factors to observe good quality tweeks with higher harmonics mode number in this region.

The duration of the tweek dispersion is between 9-29 msec. The time scale is set to 1 sec to clearly show the tweek signal. The dispersion tail for higher mode tweeks ($m = 3$) is always shorter than the previous mode ($m = 2$) and ($m = 1$) as seen in Fig. 6b and c. By using the waveguide theory in Eq. (1), (2) and (4), the tweek reflection height (h), electron density at

reflection height (n_e) and the distance travelled (d) by the tweeks to station of Gakona in the earth-ionosphere waveguide for each mode are calculated from the causative lightning source.

From the measurement, the time, mode number, cut-off frequencies for each mode, reflection height and equivalent electron density and propagation distance of tweeks are tabulated in Table 1. It is shown that the cut-off frequency for each mode is not the same for the tweek (a), (b), (c) and (d). It can be seen from the Table 1 that the cut-off frequency is gradually increase as mode number increases from one to fourth ($m = 1-4$). For the first harmonic tweek, the cut-off frequency (f_c) and two other close frequencies (f_1 and f_2) near the cut-off frequency in spectrograms are estimated in order to measure the ionospheric reflection height, equivalent electron density and propagation distance for the tweeks shown in Fig. 6a to d. The results show the equivalent electron density estimated at the reflection height varies from 76.53-90.36 km changes from 22.52-26.76 el/cm^3 and tweek was measured to propagate in large geographically area from 736 to 5689 km from Gakona's receiving station in nighttime.

Tweeks are mostly observed during dawn period between 03:00-05:00 AKST as presented in Table 1. Tweek with fundamental mode ($m = 1$) is having higher reflection height and travels with larger distance compared to higher modes ($m = 4$) which reflected at lower reflection height with short distance. The reflection height decrease as mode number increase found in this study and it similar reported by Khairul *et al.* (2011). For the equivalent electron density, the results show that it increase as mode number of tweeks increases. Consequently, the higher mode will give higher electron density in lower reflection height compare to lower mode number as shown in Table 1. Therefore, a higher harmonic of tweeks are not observed frequently due to larger attenuation rate propagate in EIWG. The far distance travelled by tweeks shows the usefulness as a diagnostic tool for the D-region ionospheric study in large geographical region.

Table 1: The time, mode numbers, cutoff frequencies, ionospheric reflection height 'h' and equivalent electron density 'ne', calculated for tweeks shown in Fig. 6a to d

Tweek	Time (AKST)	Mode number (m)	Cut-off frequency, f_c (kHz)	Reflection height h (km)	Equiv. electron density n_e (el/cm^3)	Propagation distance (km)
(a)	03:30	1	1.66	90.36	22.66	3921
		2	3.62	82.87	24.71	1886
(b)	03:45	1	1.65	90.91	22.52	4983
		2	3.60	83.33	24.57	2430
		3	5.55	81.08	25.25	736
(c)	05:25	1	1.65	90.91	22.52	5689
		2	3.67	81.74	25.05	2819
		3	5.63	79.93	25.62	801
(d)	05:05	1	1.74	86.21	23.75	4093
		2	3.60	83.33	24.57	2795
		3	5.64	79.79	25.66	1100
		4	7.84	76.53	26.76	843

Table 2: Occurrence pattern of tweeks observed on March and April 2011

Period of night	Total number of tweek	Occurrence percentage (%)	Number of tweek with different modes observed during local night			
			1 st	2 nd	3 rd	4 th
Dusk (18:00-21:00 AKST)	109	8.30	109	-	-	-
Early night (21:00-00:00 AKST)	338	25.76	336	2	-	-
Late night (00:00-03:00 AKST)	511	38.95	493	18	-	-
Dawn (03:00-06:00 AKST)	354	26.98	342	8	3	1
Total	1312	100	1280	28	3	1

For a closer look, observation of tweeks during local night is separated into four periods which is during dusk (18:00-21:00 AKST), early night (21:00-00:00 AKST), late night (00:00-03:00 AKST) and dawn (03:00-6:00 AKST) periods. By analyzing tweeks, for different period at local night, we computed total number of tweeks, occurrence percentage and number of tweeks with different modes in each interval as shown in Table 2. This result shows that the maximum tweeks occurs during late night with total number of tweeks 511 tweeks follow by dawn 354 tweeks, early night 338 tweeks and the minimum tweek occurs during a dusk period 109 tweeks.

As is clear from Table 2, first harmonic tweek ($m = 1$) appears to be the most occurred (1280 out of 1312 samples) compared to other modes basically due to the lower attenuation for ELF/VLF propagation in EIWG during the nighttime (Kishore *et al.*, 2005). As expected, the occurrence of the higher harmonic tweeks (in this case, $m = 3$ and $m = 4$) is only made up of less than 1% of the total tweeks found in the observation due to higher attenuation in EIWG as stated earlier. Figure 7 illustrates the percentage of tweeks occurrence pattern during different periods in local night. The late night period contribute higher percentage ~38.95% compared to other period. This is supported by previous observation by Maurya *et al.* (2011) which stated that tweek occurrence is more frequent in late night period ~34%.

As mentioned earlier, 65% of tweeks propagate on the ground which due to the fact that Earth is considered as perfect conductor. However, the ionosphere could be treated as an anisotropic medium where the electron density increases as the altitude decreases as shown in Fig. 8. In this study, the normal reflection height of the electromagnetic waves in the ionosphere is affected by the frequency whereby higher frequencies usually reflected at lower heights and vice versa. This is contradicting with previous observation by Cummer and Inan (2000). D-region is a good reflector during nighttime compared to daytime especially for ELF and VLF waves which in turn, proves it's worth as a useful diagnostic tools to estimate the nighttime electron densities (n_e) at the ionospheric reflection heights (h).

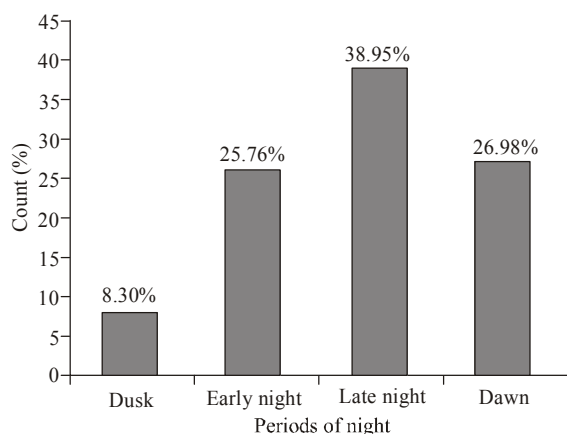


Fig. 7: The percentage during different periods in local night

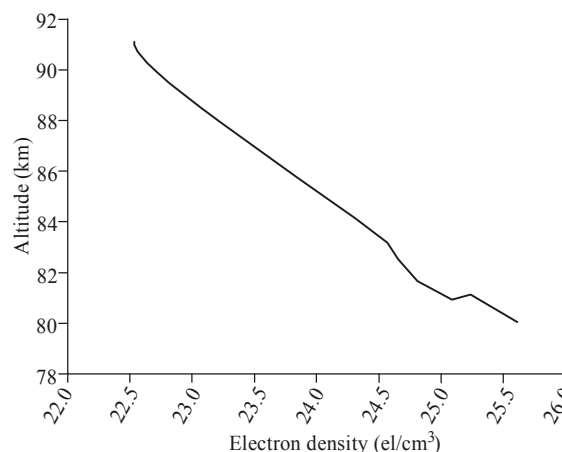


Fig. 8: Variations of nighttime D-region equivalent electron density (n_e)

Seasonal variation of tweek occurrence pattern: Figure 9 shows the seasonal variation percentage of tweeks occurrence pattern in Alaska during January-April 2011. The season is divided into two different seasons for winter (January and February) and equinoxes (March and April). The result shows that almost 1312 tweeks are found during equinox's season which is highest compare to winter season about 4 tweeks were observed. The maximum tweek occurred in equinoxes seasons about 99.54% and very small

Table 3: Comparison in the D-region ionospheric parameters between high, mid and low latitude region

Parameter	High-latitude	Mid-latitude	Low-latitude
Station	Matitri, Antarctica	Gakona, Alaska	UKM, Malaysia
Author	Saini and Gwal (2010)	This study	Khairul <i>et al.</i> (2011)
Location	70.45°S 11.44°E	62.71°N, 143.99°W	2.55°N, 101.46°E
Date collection	January-March 2003 and 2005	March and April 2011	August 2009 and October 2010
Number of occurrence of tweeks	-	1312	1383
Maximum mode number (m) observed	-	4	6
Distance (km)	3897-5958	702-6700	800-7200
Reflection height (km)	64-79	75-91	73-87
Electron density (eL/cm ³)	-	22-27	24-28

Seasonal variation of tweek occurrence pattern

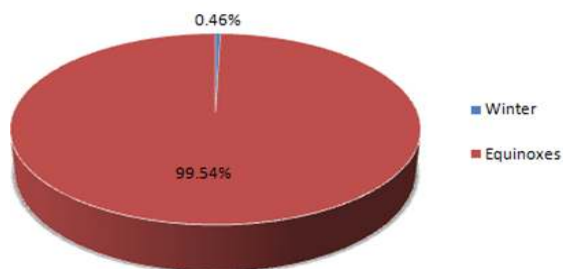


Fig. 9: The seasonal variation percentage of tweek occurrence pattern

occurrence percentage in winter about 0.46% as shown in Fig. 9. This is because of large number of lightning activities happen in March and April 2011 based on data collection compare in January and February 2011.

Comparison tweek characteristics between high-medium-low latitude: This study also summarizes the findings of the D-region ionospheric parameters by comparing the characteristic of tweeks occurred in high latitude station of Maitri, mid latitude of Gakona station and low latitude station in UKM, Malaysia. The comparison of the D-region parameters is tabulated as shown in Table 3 and according to the authors of the study. As a note, some parameters shown in Table 3 are not provided by Saini and Gwal (2010), hence no comparison could be carried out for certain parameters, specifically for the number of occurrences of tweeks, maximum mode number observed and electron density.

From the Table 3, there is not much different for the number of tweek found in current work compared to low latitude Malaysia. Nevertheless, the higher harmonic mode number found in low latitude up to six mode due to the location is near to the equatorial line which give a large number of lightning happen compare to mid and high latitude region as reported by Christian *et al.* (2003). The range of propagation distance is also found to be varying between the papers. Saini and Gwal (2010) measured the tweeks are propagated from 3897 to 5958 km and Khairul *et al.* (2011) recorded tweeks coming from 800 to 7200 km during the sunrise and sunset. The current work observed tweek to be travel from 702 to 6700 km from the receiving lightning source. The propagation distance of the tweek

atmospheric is different based on the geographical location (i.e., latitude and longitude) whereby it is affected by the conductivity of the earth surface where it is being reflected. The minimum and maximum reflection height across all authors is varies from 64-91 km and the estimated equivalent electron density at the reflection height varies from 22 to 28 eL/cm³.

CONCLUSION

Tweek atmospherics were observed during various conditions at mid latitude station of Gakona, Alaska during January-April 2011. Tweeks had been utilized to estimate the nighttime D-region ionospheric parameter which contains useful information about the height of the D-region ionosphere along its propagation, the electron density at the reflection height and the distance propagated by the tweeks in the earth-ionosphere waveguide. Based on the results, some important key findings could be outlined as follow:

- Tweeks occurred mainly between 18:00-06:00 AKST especially in late night period with higher occurrence percentage 38.95%.
- A total of 1316 tweeks recorded during the observation.
- Analysis of tweek atmospherics indicated that tweek with mode one ($m = 1$) are dominantly occurs compared to higher mode number to have fewer occurrence at one time because of higher attenuation.
- The combination in the path of ground (65%) and sea surface (35%) may provide an excellent opportunity to recorded good quality of tweeks up to fourth ($m = 4$) in good dispersion.
- An equivalent electron density for tweeks varies from 22-27 eL/cm³ in the altitude ranged of 75 to 91 km and able to travel long distances up to 6700 km due to low attenuation for ELF/VLF electromagnetic waves.
- Tweeks have highest occurrence percentage about 99.54% during equinoxes and lowest 0.46% during winter season.
- The ionospheric parameters at high, mid and low latitude show that the reflection height and electron density is almost consistent for all the latitude tweek measurements.

- GUI are successfully developed make it easier for the users to view the characteristic of tweek atmospherics in mid latitude region.

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