Characterization of lower ionosphere disturbance associated with classes of solar flare using VLF Monitoring System

A.Taat, M.H.Jusoh, S. A. Enche Abdul Rahim, M.Abdullah

***Abstract*— The response of the D-region low-latitude ionosphere has been studies for difference classes of Solar flares on October 2013 using VLF Signal from Northwest Cape, Australia (NWC, 19.8kHz) transmitter monitored at National University of Malaysia (UKM, 2.55^0N, 101.46^0E). Attention is restricted to diurnal variation and the solar x-ray effects on propagation of VLF Signal. The changes and the enhancement of amplitude signal (VLF) are related to the X-ray fluxes that measured by GOES satellite. The two main parameters of lower ionosphere which are reference height (*H'*) and sharpness factor (*β*) was estimated by using the Long Wave Propagation Capability (LWPC) Code. Statistical results show both parameters is strongly depend on the flare classes and local time of flare`s occurrence. This research are also presents the trend of the amplitude perturbations correlated with the intensity of the X-ray flux by difference classes of solar x-ray flares during second peak of solar cycle 24.**

***Index Terms*— VLF Signal; Solar flares; D-region; Ionosphere**

I. INTRODUCTION

D-REGION of the ionosphere has drawn serious attention as most of the ionization due to X-rays, entering the Earth`s atmosphere from these sources occur in the region between 60-90km. The Vey Low Frequency (VLF,3-30kHz) waves are reflected from this part of the ionosphere and the perturbations is well corresponding to Solar X-ray Flux. The measurement of VLF signals, generated by navigation transmitters has emerged as one of the reliable tools for remote sensing of the D-region electron density perturbations associated with solar flares [1]-[2]. The ionospheric respond to prompt changes in solar flares connected with burst in EUV, X-ray and particles [3] and geomagnetic storm conditions with time scale from several hours to 1-3days [4]-[5].The ionosphere also show seasonal variations [6] and diurnal variation; daytime and nighttime that affected the VLF wave [7].The diurnal variation on NWC (21.82^O S,114.20^O E) and JJI (32.04^ON,130.81^OE) transmitters signals received at UKM through EIWG path length are shown in Figure 1.

A. *Sudden ionospheric disturbance detector*

The condition of the ionosphere is highly significant to electromagnetic wave propagation and an idea tools for real-time monitoring observation for ionospheric study. The amplitude and phase of the VLF wave are sensitive to changes in electrical conductivity due to propagate through lower ionosphere (D-region in daytime and E-region during nighttime) [3][7]-[8] and effective in the space weather studies. The VLF wave also propagate in long distance with less attenuation within the EIWG and acts the lower ionosphere and earth surface as a good conductor for signal propagation. The signal is then received at various receiver over the world. Several researchers have been study the VLF perturbation with ionospheric disturbance due to solar x-ray flux and geomagnetic events [9]-[12].Others method to studies the ionospheric disturbance are include observational and experimental techniques tools such incoherent scatter radar, Global Navigation Satellite System (GNSS), Ionosonde, Magnetometers, etc. [3][13]-[15].

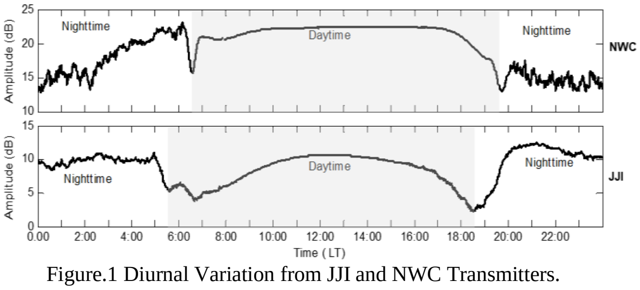

Figure.1 Diurnal Variation from JJI and NWC Transmitters.

B. *The ionospheric effects due to space weather variations*

Geomagnetic storms, is one of disturbance in the Earth`s magnetosphere caused by solar wind shock wave and cloud of

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Afifah binti Taat is with the Applied Electromagnetism Research Group of Faculty of Electrical Engineering in Universiti Teknologi MARA, 40450 Shah Alam, Malaysia (e-mail: afifahtaat.uitm@gmail.com).

Mohamad Huzaimy Jusoh was with International Center for Space Weather and Science Education (ICSWSE) of Kyushu University, Fukuoka, Japan. He is now the head of satellite department, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia (e-mail: huzaimy@salam.uitm.edu.my).

Siti Amalina Enche Ab Rahim is with the Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia (e-mail: amalinaabr@gmail.com).

Mardina Abdullah is with the Faculty of Electrical, Electronic & Systems Engineering, National University of Malaysia. She is now the head of Space Science Centre (ANGKASA) located at National University of Malaysia (e-mail: mardina@ukm.edu.my)

magnetic field which interacts with the Earth`s magnetic field. Besides the solar flares, magnetic storms are accompanied by ionospheric disturbance which can occur up to D and E regions. However, more attention on the geomagnetic storms impact on the ionosphere has been at high latitude [9].In 1974,[10] was found that the phase (VLF signal received at Uji,Japan from NWC transmitter) decreased in the nighttime in associations with the main phase of two large geomagnetic storms during 1968 to 1969. In additional, [16] also found distinct anomalies in the amplitude and phase based on signal received at Kamchatka (low-mid latitude path) from NWC transmitter. Based on the results, negative phase and amplitude variations of the VLF signal both during day and nighttime during the main storm phase days, but the nighttime variations were more pronounced. There have not been other studies on solar flares and geomagnetic storms associated subionospheric changes at low latitude paths. However, there have been several studies on VLF perturbations due to storm induced energetic electron precipitation at mid and high latitude [17]-[18].

II. DATA METHOD AND ANAYSIS

The Automatic weather Electromagnetic system for Observation Modeling and Education (AWESOME) VLF Receiver located at UKM (National University of Malaysia, 2.55^0N, 101.46^0E) is used to record the VLF signal by NWC transmitter (f:19.8kHz, 21.80^0S, 114.20^0E), Australia. The VLF signal propagate along the Earth-Ionosphere waveguide (EIWG) from NWC transmitter to UKM Station is shown in Figure.2. EIWG path length is about ~3040 km for NWC-UKM propagation path, which classified under medium path length under the path classification given by [8]. The month of October 2013 that occurred during solar cycle 24 are selected for analysis depending the availability of VLF data at UKM Station. The X-ray flux data recorded by the Geostationary Operational Environment Satellite (GOES) satellites is obtained from the USA National Oceanic and Atmospheric Administration. The flux intensities corresponding to different classes of the flares are given in Table 1. In this research the solar flux with 0.1 to 0.8 nm are used.

Table 1. X-ray flux intensities for different classes of flares

Class	Peak Flux Intensities (W/m^2)
A	$I < 10^{-7}$
B	$10^{-7} \leq I < 10^{-6}$
C	$10^{-6} \leq I < 10^{-5}$
M	$10^{-5} \leq I < 10^{-4}$
X	$10^{-4} \leq I$

In the present study we have estimated the change in amplitude ΔA as, $\Delta A = A_{perturbation} - A_{min}$, where $A_{perturbation}$ is the maximum VLF amplitude observed during the given solar flare event and A_{min} is the amplitude pre-flare. The perturbations in phase is not determine as it unstable during most of the flares.

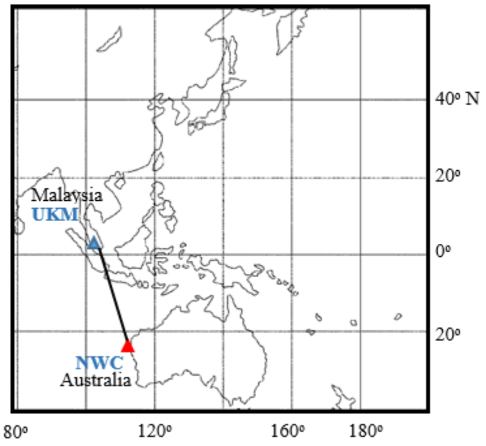


Figure 2. NWC-UKM propagation path along the Earth-Ionosphere waveguide (EIWG).

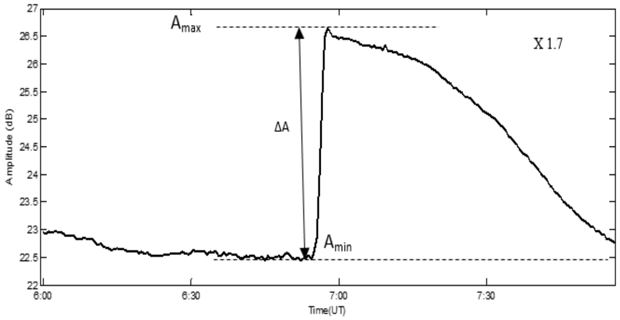


Figure 3. The estimate calculation of solar flare signature in VLF data; ΔA = $A_{perturbation}$ - A_{min}.

III. VLF WAVE OBSERVATION

A. *VLF variation during daytime and nighttime (diurnal variation)*

Diurnal behaviors have been monitored at UKM station that propagate through EIWG from NWC transmitter (21.80^0N, 114.20^0E). In this study, a month of amplitude data of 2010, 2013 and 2014 were selected. The characteristic variations of the amplitude perturbations that occurred before sunrise, between mid-day and after sunset have been calculated. For comparison, the calculation of amplitude monthly average of every May 2010, 2013 and 2014 of NWC VLF wave against local time (LT) over daylight has shown in Figure 4.

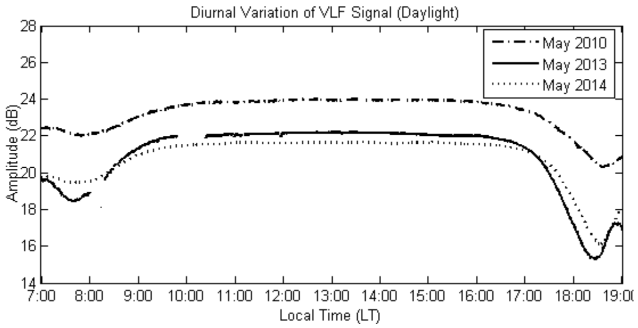


Figure 4. Variations of monthly average amplitude of VLF waves obtained from May 2010, May 2013 and May 2014.

Figure 4 shows monthly averaged amplitude values of NWC/19.8 kHz radio signal over daylight (daylight is treated because considered the solar flare events) [19] by order of succession three years. The shapes of the curves is similar to each other. Monthly average of May 2010 is greater compared to May 2013 and 2014, and assumed that changes in solar activity as illustrated in Figure 5.

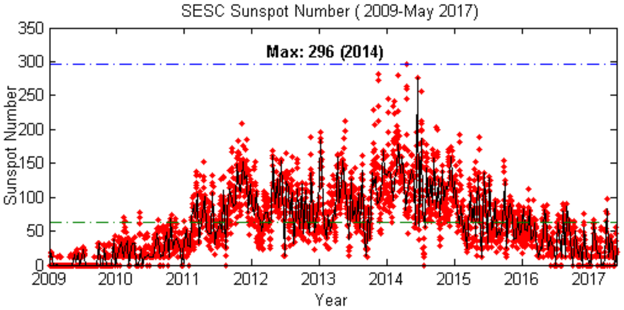


Figure 5. The illustration of solar activities from 2009 until May 2017.

B. *Solar Flare effect on VLF wave at low latitude station: UKM-Malaysia*

In this studies October 2013 have been selected due to high solar flare events nearly 227 solar flares (190 C-class, 33 M-class and 4 X-class). The data of VLF wave have been analyzed to examine the changes of the VLF amplitude, Wait`s parameters, electron density and local time dependence of flares effect. Figure 6 shows an example the amplitude perturbations in the NWC,VLF wave received at UKM-Malaysia corresponding to the X-ray flux (GOES data) for 25th October 2013.The amplitude enhancements are observed for two C-class, one M-class and one X-class flares that occurred on 25th October 2013. These enhancement due to extra ionization sharpens in D-region or upper boundary of EIWG and lowers it up to several kilometers depending the intensity of solar flare flux [8][20]. When very low frequency (VLF) wave propagate through the region of enhanced electron concentration, it is finds a sharper boundary which gives a mirror type of reflection [20], as a results the amplitude of the VLF waves is increased.

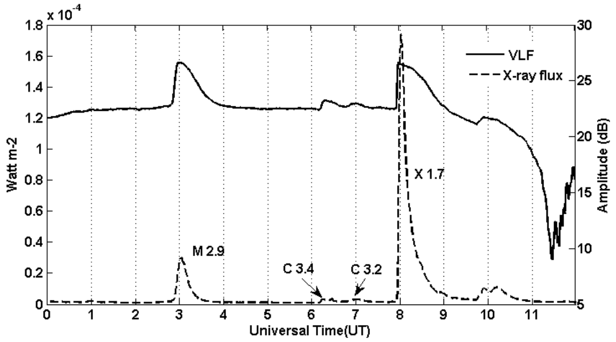
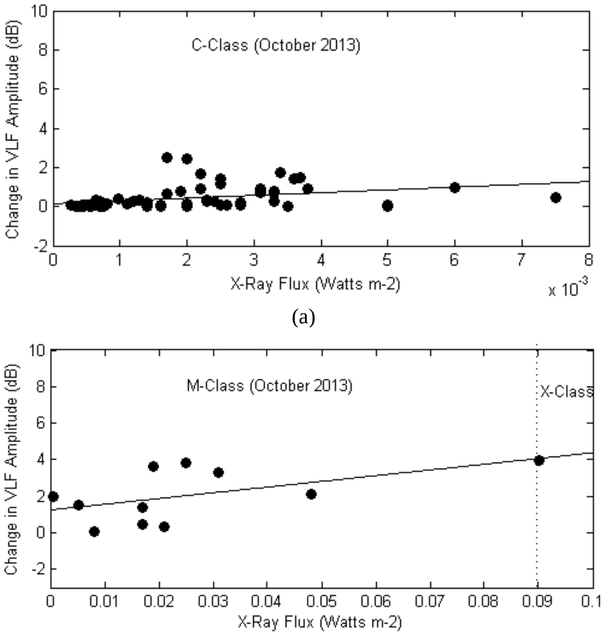


Figure 6. An example of variation of X-ray Flux detected by GOES and NWC VLF wave amplitude at UKM-Malaysia station on 25th October 2013.

Table 3 gives the details of all the solar flares events considered in this present study. The change in the VLF signal amplitude (Δ A) depends on the flares strength (solar x-ray flux) which can be effectively utilized to estimate the electron density change due to solar flares [21].Figure 7 (a and b) shows variation in the ΔA of NWC waves for October 2013.



(a)

(b)

Figure 7. Variation of change in the VLF amplitude with the X-Ray flux intensity for October 2013 (a) C-Class (b) M and X-class.

It can be seen the ΔA varies between 0.1 to 2.48 dB for C-class solar flares and between 1.3 to 4.0 dB for M-Class. The lowest flares which produced the perturbations in the signal amplitude is a C 1.2 class flare (0.1dB). There are only 1 X-class flare occurred during October 2013, therefore the data of top solar flares during solar cycle 24 have been analyzed. Table 2 shows the details of the solar flares range between M and X-class.

Table 2. Top flares during solar cycle 24 (M and X-class)

Date	**Year**	**Flares-Class**	**X-ray Intensity (Watt m-2)**	**ΔA**
Feb-25	2014	X 4.9	0.43	5.075
May-14	2013	X3.2	0.22	4.578
Feb-15	2011	X2.2	0.16	4.071
Oct-25	2013	X1.7	0.09	4.169
Apr-25	2014	X1.3	0.11	5.551
May-15	2013	X1.2	0.12	4.493
Nov-10	2013	X1.1	0.035	3.607
Nov-08	2013	X1.1	0.028	3.988
Oct-24	2013	M9.3	0.048	2.182
Jan-07	2014	M7.2	0.092	4.878
Apr-11	2013	M6.5	0.074	4.326

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Table 3. The available data on October 2013. The values of H' and β were calculated using LWPC v 2.1 and other parameters such as Δ Amp (dB) and Δ Time are also shown.

Date	Flares Class	Time (UT)	Time (LT)	H' (km)	β(km-1)	X-ray Flux (Watt m-2)	Δ Amp (dB)	Δ Time (min)
2013 10 13	C1.2	0:08	8:11	73.78	0.309	0.00027	0.103	3
	M1.7	0:43	8:45	64.59	0.38	0.031	3.317	2
2013 10 15	C2.4	1:46	9:49	73.16	0.301	0.0014	0.175	3
	C1.9	3:33	11:36	72.98	0.315	0.0024	0.281	3
	C1.5	4:21	12:24	72.86	0.303	0.0023	0.253	3
	C9.5	5:07	13:09	67.27	0.338	0.0017	2.485	2
	C2.8	8:10	16:12	73.78	0.309	0.0028	0.105	2
	M1.8	8:38	16:39	61.53	0.304	0.00056	2.012	1
2013 10 16	C2.5	3:48	11:50	71.58	0.316	0.0033	0.689	2
	C3.7	5:32	13:35	69.94	0.32	0.0036	1.386	3
2013 10 17	C4.7	3:28	11:30	70.96	0.302	0.0038	0.929	2
	C1.2	6:12	14:15	73.81	0.302	0.00055	0.039	3
2013 10 18	C2.7	1:01	9:04	73.36	0.301	0.00081	0.117	3
	C3.3	3:07	11:09	72.55	0.313	0.00097	0.384	2
	C5.3	5:08	13:10	68.83	0.426	0.0022	1.694	3
	C3.3	7:29	15:32	73.86	0.316	0.00075	0.161	3
2013 10 19	C2.9	9:34	17:37	73.66	0.303	0.002	0.092	3
2013 10 22	M1.0	0:22	08:24	69.68	0.316	0.0053	1.493	2
	C1.4	1:35	09:38	73.81	0.302	0.00063	0.044	3
	C1.7	2:03	10:06	73.98	0.306	0.00053	0.051	3
	C4.3	3:37	11:40	69.94	0.32	0.0025	1.393	3
	C4.0	4:21	12:23	71.44	0.397	0.0022	0.917	2
	C1.6	11:14	19:17	65.38	0.328	0.002	2.433	3
2013 10 23	C3.3	5:12	13:14	70.94	0.305	0.006	0.939	2
	C3.6	6:04	14:06	73.1	0.314	0.0012	0.258	2
2013 10 24	M9.3	0:30	08:31	62.05	0.309	0.048	2.091	1
	C3.1	3:43	11:46	71.74	0.329	0.0017	0.645	3
	C2.1	4:15	12:18	73.83	0.305	0.00048	0.074	3
	C3.4	5:07	13:09	71.3	0.318	0.0033	0.801	2
	C3.0	5:27	13:30	73.66	0.33	0.0013	0.326	3
	C9.3	5:59	16:02	69.26	0.332	0.0034	1.735	3
	M2.5	10:09	18:11	69.89	0.314	0.017	1.372	2
2013 10 25	M2.9	3:02	11:03	60.36	0.386	0.025	3.797	1
	C3.4	6:27	14:29	71.53	0.32	0.0031	0.708	2
	C3.2	7:01	15:03	72.74	0.304	0.0033	0.283	2
	X1.7	8:01	16:02	64.04	0.437	0.09	3.987	1
	M1.0	10:12	18:13	72.68	0.301	0.021	0.335	1
2013 10 26	C2.3	0:32	08:35	73.85	0.304	0.00065	0.057	3
	C1.9	0:54	8:56	73.79	0.304	0.00043	0.064	2
	C4.5	2:50	10:52	70.27	0.385	0.0025	1.130	2
	C2.3	3:07	11:09	73.06	0.306	0.00066	0.211	2
	C4.0	3:46	11:48	71.38	0.333	0.0019	0. 389	2
	M2.3	6:06	14:07	64.82	0.402	0..019	3.611	1
	C5.2	8:46	16:48	73.75	0.309	0.0025	0.101	2
	M1.5	9:37	17:38	72.16	0.309	0.017	0.480	1
2013 10 27	C3.5	9:36	17:39	73.85	0.302	0.005	0.035	3
2013 10 29	C1.7	0:16	0:19	73.94	0.305	0.00057	0.040	3
	C2.1	2:27	10:29	73.53	0.301	0.0016	0.074	2
	C3.3	3:10	11:12	73.94	0.334	0.0023	0.360	2
	C2.9	3:31	11:33	73.73	0.308	0.002	0.113	2
	C3.7	4:35	12:37	71.03	0.316	0.0031	0.918	2
	C2.3	7:48	15:50	73.72	0.302	0.0026	0.072	2
	C6.3	10:07	18:10	73.8	0.306	0.005	0.085	3

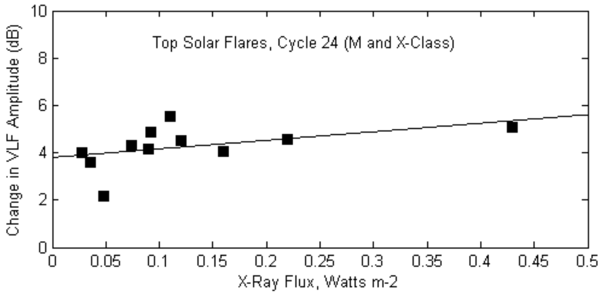

Figure 8. Variation of change in the VLF amplitude with the X-Ray flux intensity for M and X-Class (Solar Cycle 24)

The VLF wave amplitude (dB) is varies from 3.6 to 5.6 dB for M-class to X-class as shown in Figure 8.In general, as the intensity of the flares increase, the ΔA also increase but not linearly. For example, the ΔA for three X-classes flares, X4.9, X3.2 and X2.2 were estimated change to 5.1dB, 4.6dB and 4.1dB respectively. However some inconsistency in ΔA values is occurred. For example, the X1.3 flare on 25th April 2014 produced ΔA ~ 5.6dB which is more compared to X4.9 on 25th February 2014. The nonlinearity comes from the fact that

ΔA also depends upon pre-flare condition and local time [22]-[23].

Figure 9 shows the time delay (ΔT) varies from 1~3min with difference classes of solar flares. The approximately ~1min of ΔT is occurred for X-class and M-class of solar flare. The ΔT have been discussed from previous researchers [7][24] with difference term such as sluggishness and relaxation time. The changes or delay of time is caused by recombination-ionization process to recover balance due to the increasing of x-ray irradiance. In addition, the ionospheric is also fast respond when electron density become to high. Hence, the minimum time delay for M to X-Class. In 1972, [25] showed the time delay is decrease when solar induced ionization increase by using the x-ray data from Inter-Cosmos 1 Satellite. The results presented here for Malaysia (Low-Latitude) is show the significant variation in time delay due to time occurrence and difference classes of solar flare.

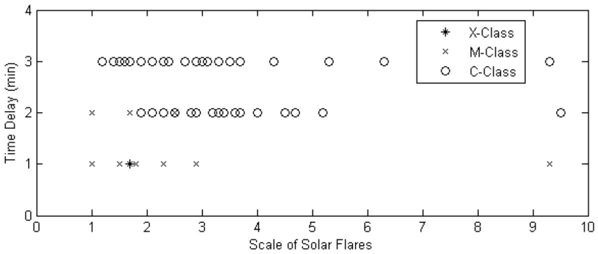

Figure 9. Time Delay versus Classes of Solar flare.

C. Variation in Wait`s D-region parameters due to solar flares

LWPC Code was developed by US Navy [26]. This code is used to calculate the changes in the Wait`s ionosphere parameters [19], ionospheric reflection edge height, denoted by H' (km) and exponential sharpness factor, denoted by β (km^{-1}) due to solar flares by using Eq.(1):

$$N_e(h, \beta, H') = 1.43 \times 10^7 e^{0.15H'} e^{[(\beta-0.15)(h-H')]} \quad (1)$$

This model has been used to simulate the VLF propagation through the Earth-ionospheric waveguide (EIWG) at regular conditions [27], as well as for the conditions corresponding to the flare peak irradiance [28].The change in the VLF signal propagates through the region of enhanced electron concentration and the sharper boundary which gives a mirror type of reflection [20]. The changes in the VLF signal amplitude (ΔA) depends on the flares strength which can be effectively utilized to estimate the electron density change to the solar flares [20]-[21]. Figure 10 shows the comparison of electron density profile at altitude 60-90km for normal day on 3rd October 2010 and for solar flares M-Class and X-Class on 11th August 2013 and 25th February 2014 respectively.

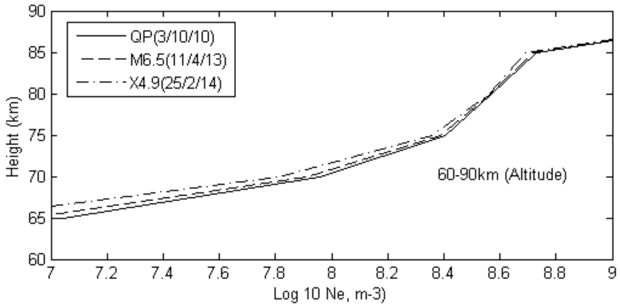

Figure 10. The electron density (Quiet) and the corresponding perturbed (Disturbed).

The electron density profile during perturbed day (flares) show the 10% increase in electron density as compared to the normal values. During the flare events the ionizations in the lower ionosphere, induced by electromagnetic radiation from the solar X-ray range (0.1-0.8nm), significantly exceeds the ionization of all the regular ionization factors (such as Lyman-α 121.6nm and cosmic rays) and causes photoionization of neutral constituents in the lower ionosphere, becoming a major source of ionization in this region. Electron density increase as a result of additional ionization of the lower ionosphere constituents and thus changes the lower ionosphere electron density heights profile, affecting the Earth ionosphere waveguide characteristics. Table 2 shows the H' and β values estimated using LWPC model for all solar flares considered in the present study. The variation of H' and β with local time for C, M and X classes of flares is shown in Figure 11a and b. In Figure 11a, it is seen the H' is minimum for M-class and X-class flare and maximum for C-class flares. The H' value is also seen that had maximum value in the morning and evening periods and minimum in noon period. The H' varies from 65.4 to 74km and 60.4 to 72.7km for C-class, M and X-Class respectively. Figure 11b shows the β follows an opposite trend as compared to H'. In this results, the maximum value of β is 0.45km^{-1} for X-Class and followed by C-Class with 0.43km^{-1}. There are also show 3 values of C-Class with high β value which are 0.43km^{-1}, 0.40km^{-1} and 0.39km^{-1} for C5.3, C4.0 and C4.5 respectively All these flares are ≥ 4.0 of C-Class and occurred in the noon period of local time. Several researchers [27][29] have been discussed the variation changes of β is due to energetic of electron precipitation and highly correlated with solar zenith angle. The maximum and minimum changes in H' and β are estimated to be 10km, 0.14km^{-1} for X1.7 flare and 0.2km,0.01km^{-1} for C1.2 respectively as referred to unperturbed (normal) condition by [21] .Good agreement defined for Wait`s parameters (H' and β) as compared with previous studies as per discussed.

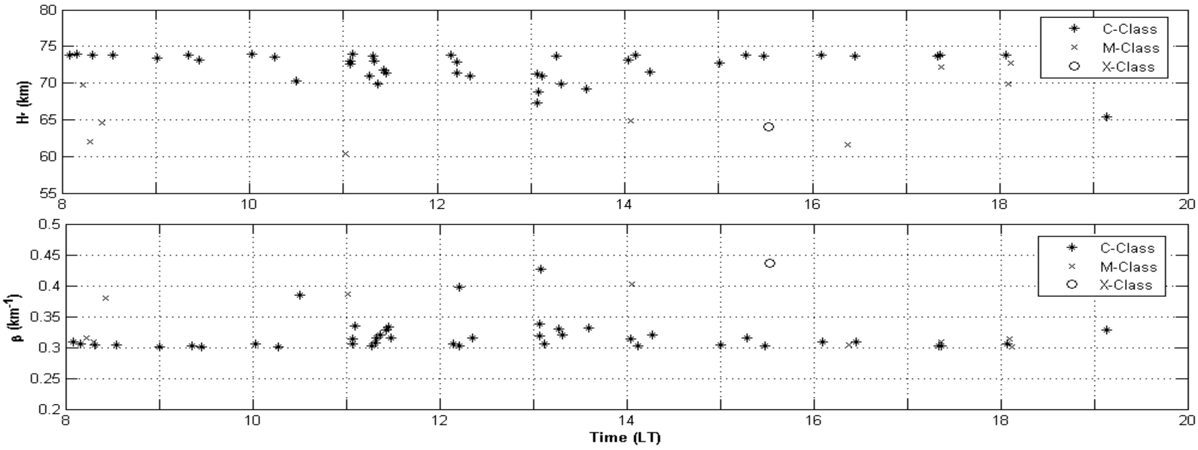

Figure 11. a) Variation of reflection (*H'*) with respect to C, M , and X classes of flares. b) Variation of sharpness factor *(β)* for C, and X classes of flares.

IV. CONCLUSION

In this research studies we have analyzed the effect of C, M and X-class of solar flares on NWC transmitter on period of second peak Solar cycle 24 which is October 2013. The one month data was filtered according to available data at UKM receiver station. The details of parameters and flares was shown in Table 3. The results shows that ΔA varies from 0.1-5.6dB for C to X-Class. The ΔT varies from 1~3minutes and is approximately minimum for M and X-Class due to fast respond of ionosphere when electron density become high. The maximum increase of signal amplitude is 4dB for X1.7 that occurred during daytime,16:02LT. The intensity of X-ray flux are also change the D-region parameters when the variation of reflection height (*H')* and sharpness factor (*β)* are show opposite trend respectively for each classes of solar flare. This research will provide further opportunity to investigate the correlation of D-region parameters and geomagnetic response with larger data set in Malaysia.

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REFERENCES

[1] A. Kumar and S. Kumar. (2014, July). Space weather effects on the low latitude D-region ionosphere during solar minimum. *Earth, Planets Space.*[Online].*66(1),* pp.66-76. Available: https://doi.org/10.1186/1880-5981-66-76.

[2] K. N. K. Ajeet K. Maurya1, D. V. Phanikumar, Rajesh Singh1, Sushil Kumar, B. Veenadhari, Y.-S. Kwak, Abhikesh Kumar, Abhay K. Singh. (2014, Oct.). Low-mid latitudeDregion ionospheric perturbations associated with 22 July 2009 total solar eclipse:Wave-like signatures inferred from VLF observations. *J. Geophys. Res. Space Physics.* [Online].*119,* pp. 8512–8523. Available:http://onlinelibrary.wiley.com/doi/10.1002/2013JA019521.

[3] L. Alfonsi, A. J. Kavanagh, E. Amata, P. Cilliers, E. Correia, M. Freeman, K. Kauristie, R. Liu, J. P. Luntama, C. N. Mitchell, and G. A. Zherebtsov.(2008,July). Probing the high latitude ionosphere from ground-based observations: The state of current knowledge and capabilities during IPY (2007-2009). *J. Atmos. Solar-Terrestrial Phys.* [Online].*70(18).* pp. 2293–2308. Available: https://www.sciencedirect.com/science/article/pii/S1364682608001715?via%3Dihub.

[4] M. J. Buonsanto. (1999,Apr.).Ionospheric storms – A review. *Space Sci.* [Online] *88(3-4).* pp. 563–601. Available: https://link.springer.com/article/10.1023/A:1005107532631.

[5] I. Kutiev, I. Tsagouri, L. Perrone, D. Pancheva, P. Mukhtarov, A. Mikhailov, J. Lastovicka, N. Jakowski, D. Buresova, E. Blanch, B. Andonov, D. Altadill, S. Magdaleno, M. Parisi, and J. Miquel Torta. (2013,Feb.).Solar activity impact on the Earth's upper atmosphere. *J. Space Weather Space Clim*. [Online].*3*. Available: https://doi.org/10.1051/swsc/2013028.

[6] S.-R. Zhang, S. Fukao, W. L. Oliver, and Y. Otsuka. (1999,Dec.).The height of the maximum ionospheric electron density over the MU radar. J. *Atmos. Solar-Terrestrial Phys.* [Online].*61(18)*.pp.1367–1383.Available: https://doi.org/10.1016/S1364-6826(99)00088-7.

[7] A.P.Mitra. "Flare radiations responsible for ionospheric effects,"in *Ionospheric Effects of Solar Flares,*1st ed.Holland:D.Reidel Publishing Company,1974,pp.60-83.

[8] N. R. Thomson and M. A. Clilverd.(2003,Nov.).Solar flare and ionospheric D-region enhancements fro VLF amplitude observations.*J. Atmos. Solar-Terrestrial Phys.*[Online].*63*.pp. 1729–1737. Available: https://doi.org/10.1016/j.jastp.2003.09.009.

[9] T. Kikuchi and D. S. Evans.(1983,Nov.).Quantitative study of substorm-associated VLF phase anomalies and precipitating energetic electrons on November 13, 1979. *J. Geophys. Res.* [Online].*88(A2).* p. 871. Available: http://onlinelibrary.wiley.com/doi/10.1029/JA088iA02p00871

[10] T. Araki. (1974,Nov.).Anomalous phase changes of transequatorial VLF radio waves during geomagnetic storms. *J. Geophys. Res.*[Online].*79(31).* pp. 4811–4816. Available: http://onlinelibrary.wiley.com/doi/10.1029/JA079i031p04811/full.

[11] S. K. Chakrabarti, S. Pal, S. Sasmal, S. K. Mondal, S. Ray, T. Basak, S. K. Maji, B. Khadka, D. Bhowmick, and A. K. Chowdhury.(2012,Sep.).VLF campaign during the total eclipse of July 22nd, 2009: Observational results and interpretations.*J. Atmos. Solar-Terrestrial Phys.*[Online].*86*.pp. 65–70. Available: https://doi.org/10.1016/j.jastp.2012.06.006.

[12] J. P. Raulin, G. Trottet, M. Kretzschmar, E. L. Macotela, A. Pacini, F. C. P. Bertoni, and I. E. Dammasch.(2013,Jan.).Response of the low ionosphere to X-ray and Lyman-α solar flare emissions.*J. Geophys. Res. Sp. Phys.*[Online].*118(1)*. pp. 570–575. Available:http://onlinelibrary.wiley.com/doi/10.1029/2012JA017916/full.

[13] J. Goldstein, J. L. Burch, B. R. Sandel, S. B. Mende, P. Cson Brandt, and M. R. Hairston. (2005,Mar.).Coupled response of the inner magnetosphere and ionosphere on 17 April 2002.*J. Geophys. Res. Sp. Phys.*[Online].*110(A3)*. pp. 1–22. Available: http://onlinelibrary.wiley.com/doi/10.1029/2004JA010712/full.

[14] J. M. Ruohoniemi and R. A. Greenwald.(2005,Sep.).Dependencies of high-latitude plasma convection: Consideration of interplanetary magnetic field, seasonal, and universal time factors in statistical patterns .*J. Geophys. Res. Sp. Phys.*[Online].*110 (A9)*. pp.124.Available:http://www.uio.no/studier/emner/matnat/fys/FYS3610/h11/undervisningsmateriale/kompendium/Ruohoniemi%26Greenwald.pdf.

[15] S. N. A. Ahmad, M. H. Jusoh, F. A. M. Kasran, M. Abdullah, B. Veenadhari, T. Uozumi, and S. Abe.,"Variations of ULF and VLF During Moderate Geomagnetic Storm At Equatorial Region,"in *Space Science and Communication (IconSpace)*,2015,pp.10–12. Available: http://ieeexplore.ieee.org/document/7283762/

[16] N. Kleimenova, O. Kozyreva, A. A. Rozhnoy, and M. S. Solovieva.(2004,Sep.)*V*ariations in the VLF signal parameters on theAustralia-Kamchatka radio path during magnetic storms. *Geomag. Aeron.* [Online].*44*.pp.385-393.

[17] M. A. Clilverd, C. J. Rodger, R. J. Gamble, T. Ulich, T. Raita, A. Sepäplä, J. C. Green, N. R. Thomson, J. A. Sauvaud, and M. Parrot.(2010,Dec.).Ground-based estimates of outer radiation belt energetic electron precipitation fluxes into the atmosphere.*J. Geophys. Res. Sp. Phys.*[Online].*115(12)*. pp. 1–11. Available: http://onlinelibrary.wiley.com/doi/10.1029/2010JA015638/

[18] W. B. Peter, M. W. Chevalier, and U. S. Inan.(2006,Mar.).Perturbations of midlatitude subionospheric VLF signals associated with lower ionospheric disturbances during major geomagnetic storms.*J. Geophys. Res. Sp. Phys.*[Online]. 111(3).pp.1–14.Available:http://onlinelibrary.wiley.com/doi/10.1029/2005JA011346/.

[19] J. R. Wait and K. Spies.(1964,Dec.).*Characteristics of the Earth - Ionosphere waveguide for VLF radio waves*.[Online]. Available: http://nvlpubs.nist.gov/nistpubs/Legacy/TN/nbstechnicalnote300.pdf.

[20] D. Grubor, D. Sulic, and V. Zigman.(2005,Oct.).Influence of solar X-ray flares on the earth-ionosphere waveguide.*Serbian Astron. J.*[Online].*171(171)*.pp.29–35.Available: http://www.ssag.matf.bg.ac.rs/ katedre/astronomija/saj/171/pdf/029-035.pdf.

[21] V. Žigman, D. Grubor, and D. Šulić.(2007,May).D-region electron density evaluated from VLF amplitude time delay during X-ray solar flares.*J. Atmos. Solar-Terrestrial Phys.*[Online].69(7). pp. 775–792. Available: http://www.sciencedirect.com/science/article/pii/S1364682607000259.

[22] L. M. Tan, N. N. Thu, T. Q. Ha, and M. Marbouti.(2014,Jun.). Study of solar flare induced D-region ionosphere changes using VLF amplitude observations at a low latitude site.*Indian J. Radio Sp.Phys.*[Online].43(3).pp.197–204.Available:http://nopr.niscair.res.in/bitstream/123456789/29052/1/IJRSP%2043%283%29%20197-204.pdf.

[23] R. Selvakumaran, A. K. Maurya, S. A. Gokani, B. Veenadhari, S. Kumar, K. Venkatesham, D. V. Phanikumar, A. K. Singh, D. Siingh, and R. Singh.(2015,Feb.).Solar flares induced D-region ionospheric and geomagnetic perturbations.*J. Atmos. Solar-Terrestrial Phys.*[Online].*123(1)*. pp. 102–112. Available: http://www.sciencedirect.com/science/article/pii/S1364682614002910.

[24] E. V.Appleton, "A note on the 'sluggishness' of the ionosphere," no. May, p. 1953, 1953.

[25] B.Valnicek.(1972, Jan.).X-ray Emission and D-Region 'Sluggishness'.*Czechoslov. Acad. Sci.*[Online].*23*.pp. 318–322. Available: http://adsabs.harvard.edu/full/1972BAICz..23..318V.

[26] A. Kolarski and D. Grubor.(2014,Jun.).Sensing the Earth's low ionosphere during solar flares using VLF signals and goes solar X-ray data.*Adv. Sp. Res.*[Online].*53(11)*. pp. 1595–1602. Available: http://www.sciencedirect.com/science/article/pii/S0273117714001434.

[27] W. M. McRae and N. R. Thomson.(2000,May).VLF phase and amplitude: daytime ionospheric parameters.*J. Atmos. Solar-Terrestrial Phys.*[Online].*62(7)*.pp. 609–618. Available: http://www.sciencedirect.com/science/article/pii/S1364682600000274.

[28] N. R. Thomson, C. J. Rodger, and M. A. Clilverd.(2005,Jun.).Large solar flares and their ionospheric D region enhancements. *J. Geophys. Res. Sp. Phys.*[Online].*110 (A6)*.pp.1–10.Available:http://onlinelibrary.wiley.com/doi/10.1029/2005JA011008/.

[29] Z. Cheng, S. A. Cummer, D. N. Baker, and S. G. Kanekal.(2006,May).Nighttime D region electron density profiles and variabilities inferred from broadband measurements using VLF radio emissions from lightning. *J. Geophys. Res. Sp. Phys.*[Online].*111(5)*.pp.1–9.Available:http://onlinelibrary.wiley.com /doi/10.1029/2005JA011308/full.

A.Taat is currently pursuing her study for Ph.D in Radio frequency and Electromagnetism (RF) in Universiti Teknologi MARA (UiTM), Shah Alam. She received her bachelor and Master of Electrical Engineering (Telecommunication) at Universiti Teknologi Malaysia (UTM), Skudai in 2010 and 2013 respectively. She has produced 6 publications and 2 patents from 2010 until now. She has done a research attachment in International Center in Space Weather and Science Education (ICSWSE), Kyushu University, Japan and has a research collaboration with National Space Agency (ANGKASA), Malaysia. Her research interests include the very low frequency (VLF) in the equatorial region, space weather perturbations, solar flares, Earth`s electromagnetism and Satellite Communication.

M.H.Jusoh is a senior lecturer at Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia. He received his bachelor of engineering degree in Electronic Communication from Universiti Teknologi MARA and his master of engineering in Communication and Computer from Universiti Kebangsaan Malaysia (UKM). His Ph.D. degree in satellite and space communication was at Kyushu University, Japan in 2013. His research interests are focusing on space and Earth's electromagnetism and have done several magnetometer installations that belongs to Magnetic Data Acquisition System (MAGDAS) arrays, conducted by International Center in Space Weather and Science Education (ICSWSE), Kyushu University, Japan. Now, he is the person in charge of this MAGDAS network in Malaysia. Besides that, he is currently the project leader for Malaysia Team BIRDS-2 Nano Satellite project, which is the first Nano satellite for Malaysian university with the collaboration of Kyushu Institute of Technology (KyuTech), Japan.

S. A. Enche Abdul Rahim is a senior lecturer at Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia. She received her Ph.D. degree in Electrical Engineering at Kyushu University, Japan in 2016. Her research interests included the electrical engineering, electronics microelectronics and communications engineering.

M.Abdullah is head of Space Science Centre (ANGKASA) at Universiti Kebangsaan Malaysia. She received his bachelor of engineering degree in Electronic & Information Engineering at University of The Ryukyus, Japan and her master of engineering in Electrical, Electronic and System from Universiti Kebangsaan Malaysia (UKM). She received her Ph.D. degree in Electronic & Electrical Engineering at University of Leeds, United Kingdom in 2004. Her research interests included the Global Positioning System, engineering and material science and physic astronomy.