F2-Layer Response to a storm time disturbance at equatorial/low- and mid-latitudes

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Accepted: March 03, 2014

Abstract The F2-layer response to a magnetic disturbance (Dst = -216nT) during the onset, main and recovery phases were investigated, using the percentage normalized deviation of the critical frequency (%D(foF2)). Observations were from the equatorial/low and mid-latitude stations. The onset phase recorded the highest enhancement at an equatorial station, Darwin (52%), and the least at a station along the equatorial ionization anomaly, Learmonth (23%). No significant response was observed for Puerto-Rico and Dyess. The main phase responded to a positive enhancement only at Learmonth, with a magnitude of 105%. Other stations (except Eglin AFB) recorded depletions ranging from 25-45%. We suggested non-simultaneous appearance of significant (D(foF2) ≥ 20%) response in the positive and negative phases of storms at 3h. segmented intervals of the first 12h. duration stretch during the recovery phase. This assertion is still left open. The simultaneous enhancement over Darwin and Learmonth during the first 9h. (1200-2100 24 August) of the recovery phase is attributed to the action of the eastward electric field; whereas the depletion observed in the mid-latitude stations and Puerto-Rico during the recovery phase finds its explanation in the rapid heating of the polar atmosphere during energy income from the magnetosphere. We conclude that the disturbance prompt penetration electric fields (PPEF), and the large IMF Bz southward orientation are the major disturbed time modifying factor of the equatorial and low latitude ionosphere in this study.

Keywords: magnetosphere; critical frequency; F2-layer; magnetic disturbance; equatorial; hemisphere.

1. Introduction

Risbeth and Mendillo (2001) had attributed the prominent causes of ionospheric F2-layer variability to four major causes. These are (i) Solar ionizing radiation (i.e. solar rotation variations, solar cycle variations, formation and decay of active regions); (ii) Electrodynamics (i.e. plasma convection at high latitudes, fountain effects at low latitudes, penetration of magnetospheric electric fields); (iii) Neutral atmosphere (i.e. planetary waves, surface phenomena like earthquakes and volcanoes, acoustic and gravity waves); and (iv) Geomagnetic activity (i.e. magnetic storms and sub-storms, IMF/solar wind sector structure, energetic particle precipitation and Joule heating). For the purpose of this study, we are more concerned with the fourth type of disturbed condition (i.e. geomagnetic disturbance, often referred to as geomagnetic storms). This kind of storm is a manifestation of extreme space weather results from the perturbation of the Earth's magnetic field as a result of unusual emission of streams of energetic particles (coronal mass ejections) by the Sun during solar activities (Olawepo and Adeniyi, 2012). During geomagnetic storms, the thermosphere is disturbed, leading to an alteration of the thermospheric neutral composition. The disturbance caused may have a reflective influence on human and societal life, ranging from communications, navigation and satellite anomalies to fluctuation in electrical power distribution grids; and may eventually pose socio-economic losses if the disturbances are not well managed.

However, the F2-layer effects of magnetic storms and disturbances have been investigated widely by numerous researchers and their results were well documented (e.g. Adebesin, 2012; Makhailov and Perrone, 2009; Liu et al., 2008; Huang et al., 2008; Adebesin, 2008a; Prolls, 2006; Gonzalez et al, 2001; Adeniyi, 1986). Prolls (1995) with over 400 references had presented a complete analysis of the morphology and evaluation of the F2-layer magnetic storms. Most of these documented effects are on high and mid-latitude ionosphere, with fewer at equatorial/low latitude regions (see the review by Danilov, 2013 and the work presented by Adekoya et al., 2012). The equatorial ionosphere on the other hand constitutes even more challenges to radio wave propagation and activities, because of its uniqueness, which is attributed to the nearly horizontal orientation of the magnetic field lines around the geomagnetic equator. Phenomena like the fountain effect, the Equatorial Ionization Anomaly (EIA), and Equatorial Spread-F (ESF) which emanates from the current system within the E-layer (the equatorial electrojet, EEJ) are major characteristics of the equatorial ionosphere (see the results of Adebesin et al., 2013a).

The present paper investigates the F2-layer response to the magnetic disturbance of 24 August, 2005 at equatorial and mid-latitude ionospheric stations, especially during the onset, main and the recovery phases of the storm. The relevance of this work to high frequency (HF) radio communication can be appreciated if it is understood from the perspective that any sudden decrease in critical frequency (foF2) will generate severe hitches at equatorial latitudes by the reason of the abrupt development in atmospheric radio noise with decreasing frequency in HF band. Magnetic storms had also been recorded to have severe effects on damage to power grids, pipelines, as well as ground and space-based measurement installations.

2. Data and Methodology

The study is based on the ionospheric data from some equatorial and mid latitude ionosonde stations across the world obtained from Space Physics Interactive Data Resource network (available online at http://spidr.ngdc.noaa.gov). The stations are Darwin, Puerto Rico and Learmonth in the equatorial/low latitude region, as well as Eglin AFB and Dyess in the mid-latitude. Learmonth is along the EIA crests. Refer to Table 1. The hourly geomagnetic and solar wind parameters used are for the low latitude magnetic index Dst, the interplanetary magnetic field (IMF) Bz, the electric field, proton density, the solar wind flow speed, plasma temperature and plasma beta. These data were obtained from the National Space Science Centre's NSSDC OMNIWeb Service (available at http://nssdc.gsfc.nasa.gov/omniweb).

The study is concerned with deviation in foF2 during the disturbed period of 24 August, 2005, which falls under a period of moderate solar activity with radio solar flux index F10.7 = 101 sfu (1 sfu = 10^{-22} Wm^{-2} Hz^{-1}). The day is characterized with high magnetic index, Ap = 102 nT (see Figure 1). Generally, a disturbed day is one in which Ap is greater than 26 nT, otherwise it is a quiet day (Adeniyi, 1986). The solar and magnetic data spans 22-26 August, 2005. This implies a total of five days (i.e the storm day, as well as two days before and after the storm). Figure 1 revealed a quiet period scenario on the magnetic index Ap plot for 22-23 August and 25-26 August. Note that paucity of data at most stations during the days under investigation restricted the choice of ionosonde stations. The criterion used in selecting the stations is such that storm variations represented real changes in electron density and not simply redistribution of the existing plasma. The percentage normalized deviations of the critical frequency foF2 from the reference, which is used to denote the F2-region response to a geomagnetic activity is given by

$$D(foF2) = \frac{foF2 - (foF2)mean}{(foF2)mean} \; x \; 100\%$$

(Adebesin, 2012 and the reference therein). Adekoya et al (2012, and the references therein) had pointed out that positive and negative storms phases occur when the absolute maximum value of D(foF2) exceeds 0.20 or 20%. Furthermore, this limit is sufficiently large to prevent inclusion of random perturbation and disturbances of neutral atmospheric origin (gravity waves, etc.), thereby making the indicated positive and negative storms represent real change in electron density, as earlier highlighted by Adebesin (2012).

Table 1: Ionosonde stations with Geographic co-ordinates

Station	Geogr. Lat. (0N)	Geogr. Long. (0E)
Darwin	-12.5	131.0
Puerto Rico	18.5	-67.2
Learmonth	-20.5	114.3
Eglin AFB	30.4	-86.7
Dyess	32.4	-99.7

Hence, the analyzed ionospheric data consist of D(foF2) of respective hourly values of foF2 for the 23, 24 and 25 August, 2005, while the reference for each hour is the average value of foF2 for the hour calculated from the five quietest days in the month (refer to the work of Adebesin et al., 2013b). The use of D(foF2) according to Chukwuma (2007) and Soicher (1972) rather than foF2 provides a first-order correction for temporal, seasonal and solar cycle variation so that geomagnetic storm effects are better identified. Both an increase/depletion in electron density relative to a background level are observed during those storms and are often referred to as positive/negative phases of the storm respectively

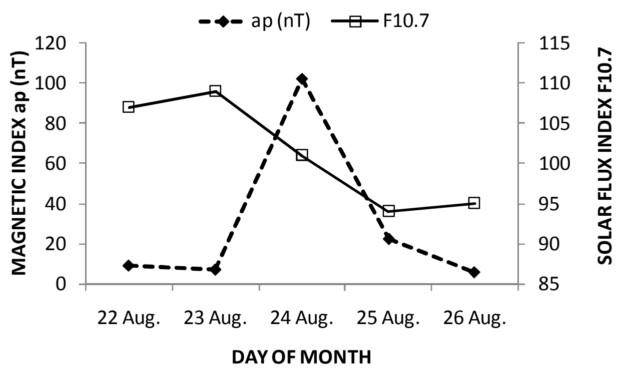

Figure 1: Daily average magnetic and solar flux index observations for 22-25 August, 2005.

3. Results and Discussions

3.1 Interplanetary and Geomagnetic observations

Figure 2 depicts the hourly plots of Interplanetary and geomagnetic observations that resulted into the geomagnetic disturbance of 24 August, 2005. However, the plot spans 22-26 August, revealing the quiet and disturbed variations. The interval between the first two vertical lines across the entire plots signifies the onset phase (OP) period of the storm, while the third vertical line depicts the peak disturbed level during the storms main phase (MP). The low latitude ring current index, Dst, was observed to maintain a quiet response from 0000UT 22 August up till around 0100UT 24 August. This is followed by a positive storm sudden commencement (SSC) of around 30nT. Kamide *et al.,* (1998) and Adebesin (2008b) had attributed the SSC or storm onset phase period as being the aftermath of a compression of the front side of the Earth's magnetosphere by enhanced solar wind pressure. From the figure, the enhanced plasma proton density (≈28 Ncm^{-3}) and the increased plasma speed (604 km/s) combine, and subsequently will result in a much larger solar wind ram pressure, which compresses the Earth's magnetosphere and increases the field magnitude near the equator. The Dst thereafter decreases downward, reaching its minimum peak value of -216nT around 1100UT. The decrease is attributed to a depression in the ring current encircling the Earth in the westward direction. Note that the sharp and abrupt decrease in Dst coincides with the high speed stream of solar wind, with a magnitude of 623km/s, and reaching a peak value of 721km/s at around 1300UT and high proton density value (29.8 N/cm^3); as well as the excitement of proton temperature to higher magnitude of 2666957K, also at 1300UT.

The Bz plot initially shows no significant magnetic field flow from 0000UT 22 August to around 0700UT 24 August. However, with immediate from this period, a shallow southward turning in Bz was imminent with a flow field of around -38.3nT at 1000UT, from where a northward rotation began reaching a positive peak value of 19.6nT also at 1300UT, before it recovered completely and maintained a magnetic field flow of little or no significant effect throughout the recovery phase. Consequently, the observed enhancement in plasma beta and proton temperature concurrently confirms that the shock produced was followed by ejecta which were not magnetic cloud type. A magnetic cloud is a region of slowly varying and strongly magnetic field (10-25nT or higher) with exceptionally low proton temperature and plasma beta typically ≈ 0.1 (Gonzalez *et al.,* 2002). Following this ejecta, one can observed a high speed stream, which overruns it. Dal-Lago *et al.,* (2004) had earlier suggested that the interaction of the high speed stream and ejecta result in an increase in speed, density and temperature. All this assertions are confirmed in our plots.

For the electric field component which comprises of the solar wind velocity V and the southward interplanetary magnetic field (IMF), an enhanced northward field flow, which occurs about the same time the Bz recorded its maximum positive value was imminent. Gonzalez and Tsurutani (1987) had shown empirically that intense storms with peak Dst ≤ -100nT are primarily caused by large Bz ≥ 10nT fields with duration greater than 3 hours. It is also important to note that in several occasions; more than one interplanetary structure can be associated with the origin of intense storms, which are complex in nature. These complex structures have been discussed extensively in the work of Gonzalez et al., (2001).

3.2 F2-layer Response

The general ionospheric response to the disturbance of 24 August, 2005 in each of the selected stations is highlighted in Figure 3. The percentage normalized deviation of the critical frequency spans 23-25 August. Data were not available for Puerto-Rico between 0000-1300UT 23 August. Severe long lasting decreases (negative storm phase) or increases (positive phase storm) of ionization, characterised by percentage D(foF2) value of more than 20% at low and mid-latitudes which constitute the typical ionospheric response to the intense geomagnetic storm are observed.

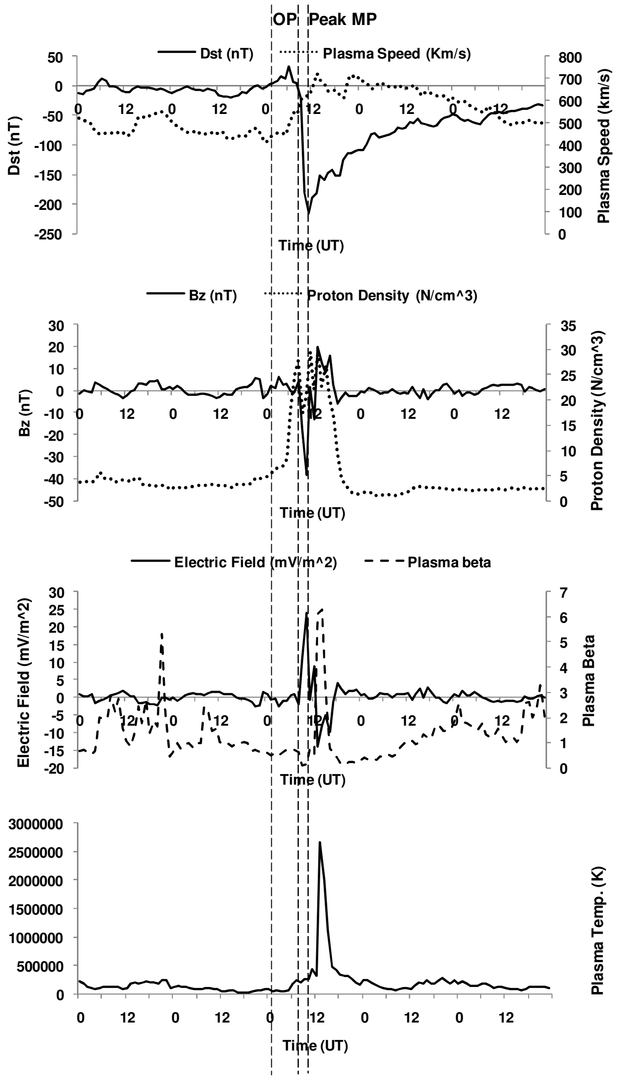

Figure 2: Hourly plots of Interplanetary and Geomagnetic observations that resulted into the magnetic disturbance of 24 August, 2005. The plot spans 22-26 August, revealing the quiet and disturbed variations. The interval between the first two vertical lines across the entire plots signifies the onset phase (OP) period of the storm, while the third vertical line depicts the peak disturbed level during the storms main phase (MP).

The % D(foF2) generally responded with a positive ionospheric storm at the early period of 23 August except for Dyess, whose response is not significant (≤ 20%) between 0000UT 23 August and 1300UT 24 August. The response over the equatorial station of Darwin is somewhat wave like, and extended to the storm onset period with enhancement in electron density, originating from the mass input of energetic particle that change the daytime eastward electric field. This positive storm phase soon turn into negative storm phase with magnitude of about 42% at 1100UT 24

August (the storm day). The interval between the first two vertical lines (OP) across the entire plot signifies the SSC interval, while the third line coincides with the exact time the minimum peak Dst magnitude was observed in Figure 2. Consequently, the percentage critical frequency variability over Darwin increases, reaching its peak positive magnitude of 72% around 1500UT, then another enhancement (44%) at 2000UT on the same day before a sharp decrease with negative storm magnitude of 34% at 2200UT. This negative phase appearance persists for about 6 hours before it oscillates back through the recovery phase.

The positive ionospheric storm response over Puerto Rico started around 1400UT 23 August, reaching a peak of ≈ 30% two hours later. An abruptly depletion was significant over this station from around 1800UT 23 August through the storm onset and main phase periods up till 0100UT 25 August. This significant depletion was later followed by an enhancement with reasonable peak positive value of around 27% at 0300UT, and thereafter, oscillate along both phases throughout the recovery phase. The ionosphere at the mid-latitude stations of Dyess and Eglin AFB shows similar foF2 response compared to Puerto Rico at the main phase, but the storm onset period over Dyess is in its quiet condition when Eglin AFB is fiercely increased with peak magnitude of 59% at a colliding period of negative storm phase. The storm onset period over Learmonth was observed to increase with noticeable positive phase storm through the main phase, recording the highest percentage deviation of 111%, coinciding with the period of peak Dst value. The positive phase storm condition at this station extends till the recovery phase interval (though with a trough in-between) with a positive value of about 106% at 2100UT 24 August, and then a depletion through the remaining periods of the recovery phase.

3.3 Analysis of foF2 response during Storm onset, main and recovery phases

Table 2 presents the analysis of the percentage normalized deviation of the critical frequency for the respective ionosonde stations. Incorporated in the Table are the respective enhancement/depletion peak percentage values during the storm's onset phase interval (OP, as indicated in Figure 2 by the first two vertical lines down the plot), the exact %D(foF2) magnitude during the main phase peak activity (i.e., the point at which Dst recorded its peak minimum value), as well as a continuous 12h. stretch of the recovery phase (at 3h. interval). The values indicated in Table 2 were all extracted from the percentage D(foF2) observations in Figure 3. As a consequence, the Table is an added information to the observation in Figure 3, showing quantitatively the values obtained in Figure 3. Hence, in itself, Table 2 is neither a new nor another set of data, but rather a clearer representation of the observation in Figure 3 with respect to the storm onset, main phase and the 12h. stretch recovery phase. During the storm onset phase, an enhancement over the F2-layer was recorded over Darwin (52%), Eglin AFB (38%) and the least in Learmonth (23%). No significant response was observed for Puerto-Rico and Dyess, just as it was for the entire stations for negative storm (depletion) for the same phase. The main phase of the storm recorded an enhancement only over Learmonth, a station on the crest of the EIA with a magnitude of 105%.

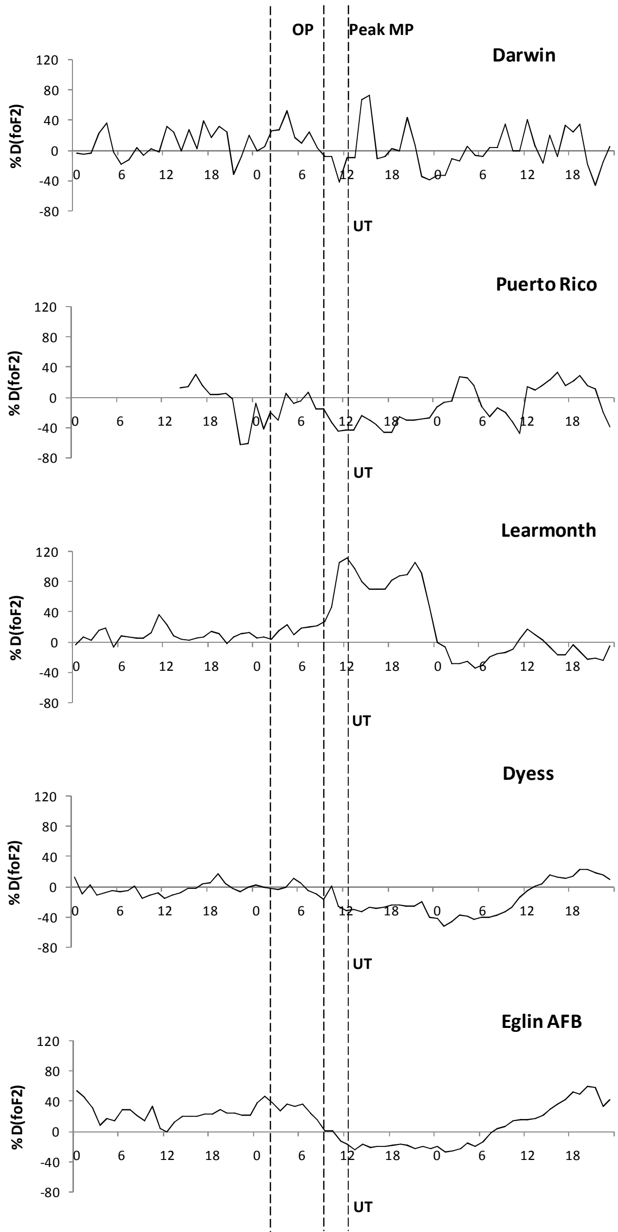

Figure 3: Hourly F2-Layer normalised variation to the disturbed condition of 24 August, 2005. The plot spans 23-25 August. The three vertical lines across the entire plots are as represented in Figure 2.

Other stations (except Eglin AFB) recorded depletions ranging from 25% over Dyess to 45% at Puerto-Rico. The recovery phase however is segmented into 3h. interval as shown. One feature that is so intriguing about this phase (as shown on the Table) is that there is no time interval when the enhancement value is significant that a corresponding significant value would be observed for the depletion, and vice-versa. It can therefore be suggested that there can be no simultaneous significant (≥ 20%) response in the positive and negative phases of storms at 3h. intervals during the recovery phase up till the fourth segment (i.e., 12 hours stretch). This is still left open anyway, as larger database are needed for the confirmation.

This recovery phase characteristics is further buttressed in Figure 4. Figure 4 is a bar chart representation of the F2-layer response to the recovery phase of the magnetic disturbance of 24 August, 2005, for four sets of segmented time intervals immediately after the storm's main phase. This are the 1200-1400, 1500-1700, 1800-2000 and 2100-2300UT time intervals represented by the 3h., 6h., 9h., and 12h. segmented intervals respectively. The plot is for the entire five stations under investigation, for both their peak enhancement/depletion values within each time interval. It must be mentioned again that the bar chart illustration in Figure 4 is extracted from Figure 3 in other to show a clearer picture of the recovery phase response at successive 3h. intervals. Fares Saba et al. (1997) had used similar bar chart illustration approach to investigate the relationship between three geomagnetic indices during years of high and low solar activities. The bar chart plot in the present study is for each station during the enhancement period, and then followed by the depletion observation over the same station, before moving on to the next station. For instance, there are enhancement observations for Darwin for 3h., 6h., and 9h. alone, whereas there is no observation for its enhancement into the 12h. recovery phase time. The reverse is the case during its depletion state in which only the 12h. time interval had value. Moreover, there is no observation for Puerto Rico, Eglin AFB, and Dyess for the entire four-segmented hours during the enhancement period; as well as Learmonth during the depletion episode. Further, the vertical line observed on the figure demarcates the different enhancement/depletion plots from one station to another.

Table 2: Percentage normalized deviation of the critical frequency for respective ionosonde stations during storm onset phase, main phase and recovery phase (ranging from the interval of 3-12h.)

STATION	LATITUDE	ONSET PHASE PEAK (%)		MAIN PHASE PEAK (%)		3hrs. (1200-1400UT)		6hrs. (1500-1700UT)		9hrs. (1800-2000UT)		12hrs. (2100-2300UT)	
		Enhanced	Depletion	Enhanced	Depletion	Enhanced	Depletion	Enhanced	Depletion	Enhanced	Depletion	Enhanced	Depletion
Darwin	Equatorial	52	**	Nil	42	68	**	72	**	44	**	**	39
Puerto Rico	Equatorial	**	**	Nil	45	**	43	**	46	**	47	**	30
Learmonth	Crest of EIA	23	**	105	Nil	111	**	71	**	89	**	106	**
Dyess	Mid-latitude	**	**	Nil	25	**	33	**	28	**	26	**	40
Eglin AFB	Mid-latitude	38	**	Nil	**	**	24	**	21	**	20	**	23

** Insignificant (i.e % D(foF2) ▯ 20%)

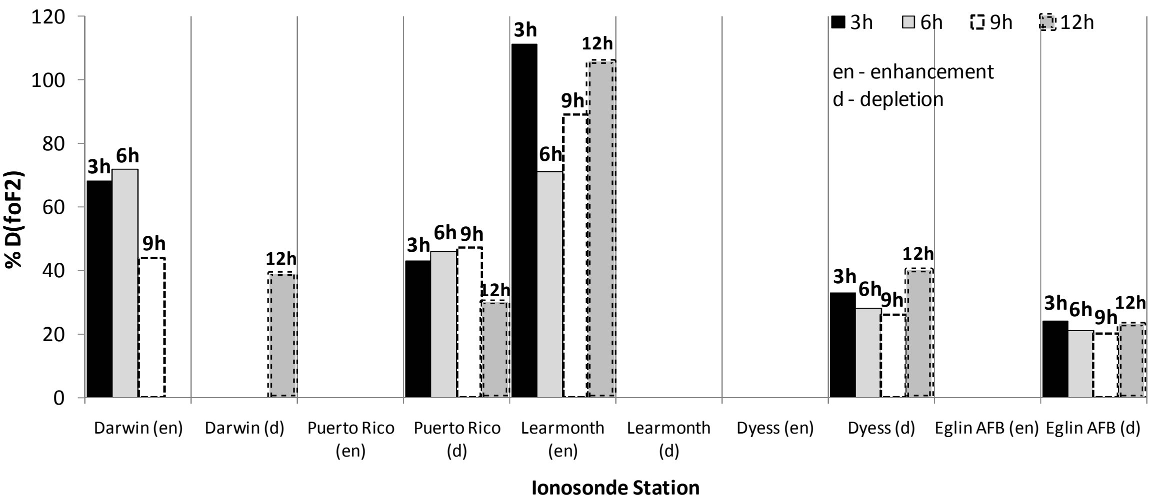

Figure 4: Bar chart showing the F2-layer response to the recovery phase of the magnetic disturbance of 24 August, 2005, for four sets of time intervals (1200-1400, 1500-1700, 1800-2000 and 2100-2300UT). The plot is for both peak enhancement/depletion values within each time interval.

From the figure, the average enhancement pattern is highest at the first 3h. segmented interval as observed over Darwin (≈ 68%) and Learmonth (≈ 111%) yielding an average enhancement of about 90%, and drops progressively towards the other segments of the interval over Darwin, drops at 6h. segmented interval over Learmonth, then picks again through the 9h. and 12h. at Learmonth. However, the situation is different for the depletion process, in that an average of approximately 32% was observed for all the time intervals (i.e 3, 6, 9 and 12h.) into the recovery phase. It can therefore be stated that the aftermath of the storm event of 24 August, 2005 resulted in a negative phase response over the F2-layer.

The effects of ionization depletion at the F2-layer observed at all stations (except Learmonth) during the recovery phase, in the first twelve hours (1200UT 24 August-0000UT 25 August), and between 0000-1200UT 25 August for all stations could be attributed to the rapid heating of the polar atmosphere during energy income from the magnetosphere. The long-duration positive phase storm (enhancement) that characterized Learmonth can be attributed to the respective solar wind flow speed and the Electric field as indicated in their plots before the storm onset (Figure 1), which show that there was no large equator-ward wind during the daytime, so the electron density increases cannot be attributed to equatorward disturbance winds (as opposed to the general theory that a widely accepted mechanism for daytime positive storm phases at mid-latitudes is equatorward wind disturbances that can uplift the F region plasma (Jakowski et al., 1999; Lu et al., 2001).

This is because if the energy transfer were to be carried by equatorward neutral winds, it will take several hours for disturbance winds originating in the auroral zone to reach mid-latitude or stations on the crest of the EIA to cause the decrease of the mean molecular mass. Far from this, the observed positive phase started to occur just after the storm onset, and any variations of molecular mass caused by storm-associated winds at mid-latitudes could not have been generated within such a short time. Subsequently, the only process that can quickly propagate from high to low latitudes without obvious delay according to Huang et al. (2005) is the penetration of electric fields. An eastward electric field will move the mid-latitude ionospheric F region plasma to higher altitudes with lower recombination, resulting in increases of the electron density (Adebesin et al., 2013c; 2013d). . It is therefore suggested that this action may be responsible for the observed long-duration positive phase over Learmonth and during some intermittent periods in Darwin. Adebesin et al. (2013b and the reference therein) had shown that a decrease in the daytime electric field occurs during geomagnetic disturbances. Subsequently, a reduction in the eastward electric field at daytime will result in decrease in the upward drift of the equatorial F2 layer. This is what is responsible for the observed increases in electron density during the day when geomagnetic storms occur.

The quiet time equatorial and low latitude ionosphere according to Sharma et al. (2012) is observed to be mostly influenced by the zonal (east–west) electric field, which results in the EIA formation during quiet geomagnetic conditions. Consequently, we put forward that the disturbance electric fields are the major disturbed time modifying factor of the equatorial and low latitude ionosphere. The storm time disturbance has been projected to be of two forms. First is the disturbance dynamo electric fields, DDEF (e.g. Blanc and Richmond, 1980), arising from the changes in large-scale thermospheric wind circulation, resulting from the action of storm time disturbance joule heating at high latitudes. Second is the type experienced in the present study, which is the prompt penetration electric fields, PPEF (e.g. Spiro et al., 1988). The latter is associated with the solar wind-magnetosphere coupling, and may last for about an hour. According to Sharma et al. (2012, and the references therein), large IMF Bz southward turning from its northward orientation can generate the under shielding form that may eventually generate the PPEF, which are westward during the night, and eastward at daytime. Hence the simultaneous depletion observed at the mid-latitude stations and Puerto Rico from 0600UT 24 August to around 1200UT 25 August (Figure 3) may not be unconnected with the PPEF action, as the prompt penetration fields has the characteristics of simultaneity appearance over a range of latitudes from mid-low-equatorial latitudes (Fejer et al., 2007). In general, the negative phase exhibit a well pronounced dependence on the intensity of the magnetic disturbance as expressed by various geomagnetic indices (Danilov, 2013). The most pronounced dependence is seen on the AE index. A good example of the dependence of the negative phase maximum intensity on AE index is found in Danilov and Belik (1991).

4. Summary and Conclusion

We have used the percentage normalized deviation of the critical frequency to investigate the effect of the intense storm of 24 August, 2005, on the ionospheric F2-layer, during storm onset, main and recovery phases. Two equatorial stations, one station on the crest of the EIA, and two mid-latitude stations were used for the observation.

During the onset phase of the storm, the enhancement over the F2-layer was highest at the equatorial station of Darwin (52%) and the least in Learmonth (23%). No significant response was observed for Puerto-Rico and Dyess. Similarly, no significant depletion rate was observed over the entire stations for the same phase. The main phase responded to a positive enhancement only at Learmonth, with a magnitude of 105%. Other stations (except Eglin AFB) recorded depletions ranging from 25-45%. We suggested non-simultaneous significant (≥ 20%) response in the positive and negative phases of storms at 3h. intervals during the recovery phase up till the fourth segment (i.e., 12 hours stretch). This assertion requires larger database for a better confirmation. Here, the average enhancement pattern is highest during the first 3h. segmented interval (≈ 90%) and drops progressively towards the other segments of the interval. However, the situation is different for the depletion process, in that an average of approximately 32% was observed for all the time intervals (i.e. 3, 6, 9 and 12h.) into the recovery phase.

The simultaneous enhancement observed over Darwin and Learmonth during the first 9h. (1200-2100UT 24 August) of the recovery phase could be attributed to the action of the eastward electric field. This is because the E x B vertical drift, which is the main contributing factor for the formation and development of EIA at the dayside of the globe, gets drastically modified by prompt penetration electric fields (e.g. Adebesin et al., 2013c; 2013d).. During the daytime these eastward directed fields enhance the vertical drift that results in the uplifting of the plasma to higher altitudes where it survives for longer time due to slower recombination rates. However, the depletion observed in the mid-latitude stations and Puerto-Rico during the recovery phase finds its explanation in the rapid heating of the polar atmosphere during energy income from the magnetosphere.

References

Adebesin B.O., Adeniyi, J.O., Adimula, I.A., Reinisch, B.W., and K. Yumoto: 2013a, Adv. Space Res. 52(5), 791-800. http://dx.doi.org/10.1016/j.asr.2013.05.025. ISSN: 0273-1177.

Adebesin, B. O., Ikubanni S. O., Adebiyi J. S., and Joshua, B.W.: 2013b, Adv. Space Res. 52(4), 604-613, http://dx.doi.org/10.1016/j.asr2013.05.002.

Adebesin B.O., Adeniyi J.O., Adimula, I.A., and Reinisch, B.W.: 2013c, Adv. Space Res. 52(12), 2226-2237. http://dx.doi.org/10.1016/j.asr.2013.09.033.

Adebesin B.O., Adeniyi J.O., Adimula, I.A., and Reinisch, B.W.: 2013d, J. Atmos. Solar Ter. Phys. 97, 58-64, http://dx.doi.org/10.1016/j.jastp.2013.02. 010. ISSN: 1364-6826.

Adebesin, B.O. :2012, Indian J. Radio and Space Phys., 41(3), 323-331.

Adebesin, B.O :2008a, African Rev. Phys., 2:0017, 143-158, ISSN: 2223-6589.

Adebesin, B.O.: 2008b Acta Geod.Geophys. Hungarica. 43(4), 383-408, DOI: 10.1556/AGeod.43. 2008.4.2.

Adekoya B.J, V. U. Chukwuma, N. O. Bakare & T. W. David.: 2012 Astrophys. Space Sci., 340 (2), 217-235, doi: 10.1007/s10509-012-1082-x.

Adeniyi, J.O. :1986, J. Atmos. Solar Ter. Phys, 48 (8), 695-702.

Blanc, M., Richmond, A.D.: 1980, J. Geophys. Res. 85, 1669.

Chukwuma V.U.: 2007, Acta Geophysica, 55(4), 469-489, doi: 10.2478/s11600-007-0030-6.

Dal-Lago, A; Vieira, L. E. A; Echer, E; Gonzalez, W. D; Cl'ua de Gonzalez A.L; Guarnieri, F.L; Balmoceda, L; Santos, J, Da Silva, M.R; De Lucas A; Schuch, N.J.: 2004, Brazilian J. Phys., 34(4b), 1542-1546.

Danilov, A,D. (2013): Adv. Space Res. 52, 343-366.

Danilov, A.D., and Belik, L. D. (1991): Geomag. Aeron. 31 (2), 157–167.

Fares Saba, M. M, W. D. Gonzalez, and A. L. CluÂ a de Gonzalez (1997): Ann. Geophysicae 15, 1265±1270.

Fejer, B.G., Jensen, J.W., Kikuchi, T., Abdu, M.A., Chau, J.L., (2007). J. Geophys. Res. 112, A10304. doi:10.1029/2007/JA012376.

Gonzalez, W.D., B.T. Tsurutani, R.P. Lepping and R. Schwenn, (2002): J. Amos. Sol. Terr. Phys. 64, 173 - 181.

Gonzalez, W.D., Clua de Gonzalez, A.L., Sobrai, J.H.A., Dal Lago, A., Vieira, L.E. (2001): J. Atmos. Sol.-Terr. Phys. 63, 403–412.

Gonzalez, W.D, and B.T. Tsurutani, (1987): Plan. Space Sci. 35,1101 – 1109.

Huang, C.M., Chen, M.Q., Su, S.Y.: 2008 J. Geophys. Res. 113, A11301. doi: 10.1029/2008JA013405

Jakowski, N., S. Schluter, and E. Sardon (1999), J. Atmos. Sol. Terr. Phys., 61, 299.

Kamide, Y., W. Baumjohann, I.A. Daglis, W.D. Gonzalez, M. Grande, J.A. Joselyn, R.L. Mc Pheron, J.L. Philps, E.G.D. Reeves, G. Rostoker, A.S. Sharma, H.J. Singer. B.T. Tsurutani and Vasyliunas,: 1998, Geophys. Res. 103, 17,705 -17,728.

Liu, J., Zhao, B., Liu, L.: (2008, Ann. Geophys. 28, 795–805.

Lu, G., A. D. Richmond, R. G. Roble, and B. A. Emery,: 2001, J. Geophys. Res., 106, 24,493

Makhailov, A.V., Perrone, L. :2009, Ann. Geophys. 27, 1321–1330.

Olawepo A.O and Adeniyi J.O. : 2012 African Rev. Phys., 7: 0031, 277-281.

Prölss, G.W. :2006 Proc. RTO-MPIST- 056, Paper 10, pp. 10-1–10-20. RTO, Neuilly-sur-Seine.

Prolls, G.W.: 1995, Ionospheric F-region storms, in: Handbook of Atmospheric Electrodynamics, vol. 2, Volland ed., CRC Press/Boca Raton, p. 195–248.

Rishbeth, H. and M. Mendillo: 2001, J. Atm. Sol. Terr. Phys. 63, 1661-1680.

Sharma, S., P. Galav, N. Dashora, R.S. Dabas, R. Pandey: 2012 J. Atmos. Sol. Terr. Phys., 75–76, 133–140.

Soicher, H.: 1972, Nature 239, 93-95.

Spiro, R.W., Wolf, R.A., Fejer, B.G.: 1988. Ann. Geophys. 6, 39.