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Effect of the Geomagnetic Storm of April 5th to 7th, 2010, on the F2-Layer of the Ionosphere of Ilorin, Nigeria

Shola J ADEBIYI [1], Jacob O ADENIYI [2], Isaac A ADIMULA [3], Benjamin JOSHUA, Moh'd GWANI [4]

ABSTRACT [ENGLISH/ANGLAIS]

Enhancements in NmF2 at the F2-layer of Ilorin during the April 5th – 7th, 2010 storm were studied using data from University of Ilorin Magnetometer and Digisonde observatories. The analysis of the magnetic horizontal data H shows that the storm under consideration is a moderate storm, with minimum decrease of -98.2nT. The ion density increases dramatically up to magnitude of 87% on the first day, 41% on the second day and 23% on the third day above the peak hourly mean of the value of NmF2 on the five most magnetically quiet days of the month. Three mechanisms were considered to be responsible for the generation of storm-time ion density variations in this analysis: Electric fields produced by wind driven dynamo; prompt penetrating electric fields originating from magnetosphere – Ionosphere interactions that becomes stronger during magnetic storms/disturbances drive the dynamics and electrodynamics of ionosphere and Joule dissipation, lead to thermospheric heating.

Keywords: Magnetic storm, F2 layer, Ilorin, Ionosphere

RÉSUMÉ [FRANÇAIS/FRENCH]

Les améliorations apportées à NmF2 à la F2-couche de Ilorin lors de la 5e Avril - 7th, 2010 tempête ont été étudiés en utilisant les données de l'Université d'IlorinMagnétomètre et observatoires Digisonde. L'analyse du champ magnétique Hhorizontal des données montre que la tempête est à l'étude d'une tempête modérée,avec une diminution minimum de-98.2nT. La densité des ions augmente considérablement jusqu'à la magnitude de 87% le premier jour, 41% le deuxième jour et 23% sur le troisième jour dessus de la moyenne de pointe horaire de la valeur de NmF2sur les cinq jours les plus magnétiquement calmes du mois. Trois mécanismes ont été considérés comme responsables de la génération de la tempête-temps les variations de densité d'ions dans cette analyse: les champs électriques produits par dynamopoussée par le vent; rapides pénétrantes champs électriques provenant de la magnétosphère - ionosphère interactions qui devient plus fort pendant les orages magnétiques et perturbations conduire la dynamique et de l'électrodynamique de l'ionosphère et de la dissipation par effet Joule, conduire à un échauffementthermosphérique.

Mots-clés: Tempête magnétique, F2 couche, Ilorin, Ionosphère

Affiliations:

[1] Department of industrial Physics, Landmark University Omu-Aran, Kwara State, NIGERIA

[2] Department of Physics, University of Ilorin, Ilorin, Nigeria

[3] Department of Physics, Kebbi State University of Science and Technology, Aliero, NIGERIA

[4] Department of Physics, Kebbi State University of Science and Technology, Aliero, NIGERIA

Address for Correspondence/ Adresse pour la Correspondance: wisdomworld04@yahoo.com

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INTRODUCTION

For effective communications or surveillance operations for radio operators using the ionosphere as a medium of propagation, reliable information from solar and geomagnetic experts are useful to keep their business running.

Rapid variations in the magnetic field, known as magnetic storm, can affect high frequency ionospheric propagation and related military and commercial operations and can cause radio blackout. A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a disturbance in space weather associated with solar flares [1]. The perturbation of the electric field, due to solar-magnetosphere-ionosphere interactions, during geomagnetic storm and the action of thermospheric winds are considered as the main cause of variability in the ionospheric parameters. In the present investigation, we examined some ionospheric variability in F2-layer NmF2 and hmF2 of Ilorin ($8^0 32'$N, 4.5^0E), a low latitude equatorial station, during the geomagnetic storm of April 5^{th} – 7^{th}, 2010.

MATERIALS AND METHODS

In this study, the ionospheric parameters (f_oF2, h_mF2) and the hourly values of the Earth's magnetic horizontal data (H) used for the storm analysis were obtained from the University of Ilorin Digisonde Portable Sounder (DPS) and Magnetometer respectively. We started this work by first collecting and analyzing the magnetic data to identify the storm periods in the month of April, 2010. The Ionospheric parameters that correspond to the storm period were collected and analyzed with two or three quiet days before and after those identified storm days.

Because of the unique feature of the equatorial ionosphere, the horizontal data is of the interest since the changes in the vertical component is insignificant at the equator. In this storm analysis, the per-second H data generated were extracted from the raw data using MATLAB program. The hourly H data were obtained from the per-second data by finding their respective averages.

The quantity DH (nT) were then computed by subtracting the hourly mean of the value of H on the five most magnetically quiet days of April, 2010 from the hourly value of H for any day of the month the month of April, 2010. i.e. $DH = H_i - \hat{H}_q$, where H_i is the hourly value of horizontal component for any days in April, while $\hat{H}_q$ is the hourly mean of the value of H on the five most magnetically quiet days of April, 2010. These quiet days were selected using the geomagnetic planetary indices supplied by the world data center for Geomagnetism, Kyoto, Japan.

All data generated by the Digisonde are store as Standard Archiving Output (SAO) file format and are made available for electronic transfer. Each SAO file contains the scaled data for one ionogram including the echo traces h'(f), echo amplitudes, frequency and range spread, etc. The various hourly values of foF2 and hmF2 were obtained from the standard archiving output (SAO) format of the University of Ilorin Digisonde_4. Using the scaled ionospheric characteristics chart as a guide, the various values of foF2 and hmF2 were obtained from the SAO Format, after which the NmF2 values were obtained from the values of foF2, using the relationship:

$$\mathbf{NmF2 = (foF2)^2 \div 80.5}$$

These values were used to plot the diurnal variation of NmF2 and hmF2.

RESULTS

Storm Description

In this work, the quantity DH is used for the storm description. For the selection of disturbed days, we made use of typically, data whose horizontal component of the magnetic field DH (nT) is ≤ -30nT. If the DH value is >-30nT, then the day was regarded quiet. Based on this value, a perusal of Fig.1 below indicates that the period between 96 - 168 hours of April, 2010 are magnetically disturbed periods. These periods fall between April 5th – 7th, 2010 with the storm starting weakly on the 5th. The figure indicates that, the period between 96hr (April 5th) to 168hr (April 7th) and 240hr (April 10th) to 288hr (April 12th) , 2010 were magnetically disturbed, while the remaining days in April, 2010 were quiet. Two storm occurred during the month under review, but shall limit this study to that of April 5th – 7th, 2010.

In Fig.2, the magnetic storm started just before noon on 5th with a slow decrease which continued to the following day and later recovered to normal condition two days after. The initial phase of the storm started around 1000LT on 5th April, 2010 and the main phase around 2400LT on the same day reaching its peak activity (DH = -98.2nT) around 1500LT the following day (i.e April 6th, 2010). The recovery phase started slowly, immediately after reaching its minimum decrease, restoring back to its normal condition at around 2100LT on 7th of April, 2010.

The Global averaged index observed (Dst-H) at World Data Center for Geomagnetism, Kyoto, (as shown in Fig.3 below) were similar to the changes of the DH observed here at the University of Ilorin magnetometer observatory. At WDC, Kyoto, the maximum decrease of H(i.e. Dst-H) was -73nT also peaking at same time.

Disturbed Days' Result

Figure 4 and 5 show the diurnal variations of hmF2 and NmF2 observed at University of Ilorin Digisonde Observatory during the period of April 3rd – 11th, 2010. During this period, it was observed that the diurnal variations of NmF2 on April 5th – 7th show an unusual increase when compare with the other quiet days.

To better appreciate these results, the responses of the diurnal NmF2 and hmF2 to the storm were observed by comparing the diurnal plots of NmF2 and hmF2 on storm days with the average of NmF2 and hmF2 variations for the five most magnetically quiet days of the month of April, 2010 as shown in Fig. 6 and Fig 7.

From Fig. 6, there is a significant growth of ion density observed in the dayside and night-side ionosphere except the night of April 6th that experienced little or no difference. Most prominent increases of ion density are observed in the crest regions. It is interesting to note that a dayside feature observed during the storm is characterized by extreme high variations of ion density with magnitude of 87% on the first day, 41% on the second day and 23% on the third day above the average of five most magnetically quiet days of the month. The pre-noon peaks on storm days also experienced higher growth in their ion density than their respective post-noon peaks, which was vice versa on quiet days. The trough that usually appears on the day-time NmF2 appears narrower in width on the storm days than on quiet days. The sharp drop in NmF2 usually experience immediately after the post-noon peak were present on the first and second days of the storm but was absent on the third day. The night-side of the storm days also experienced an enhancement in their NmF2. Slight increases in NmF2 were observed on the second day while the first and third days experienced remarkable increased.

Figure 1: This figure shows geomagnetic activity observed at University of Ilorin Magnetometer Observatory for April, 2010

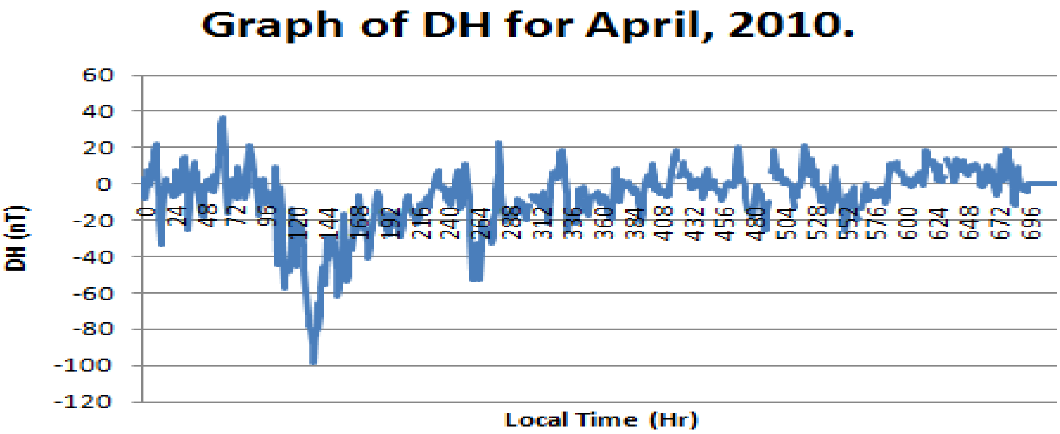
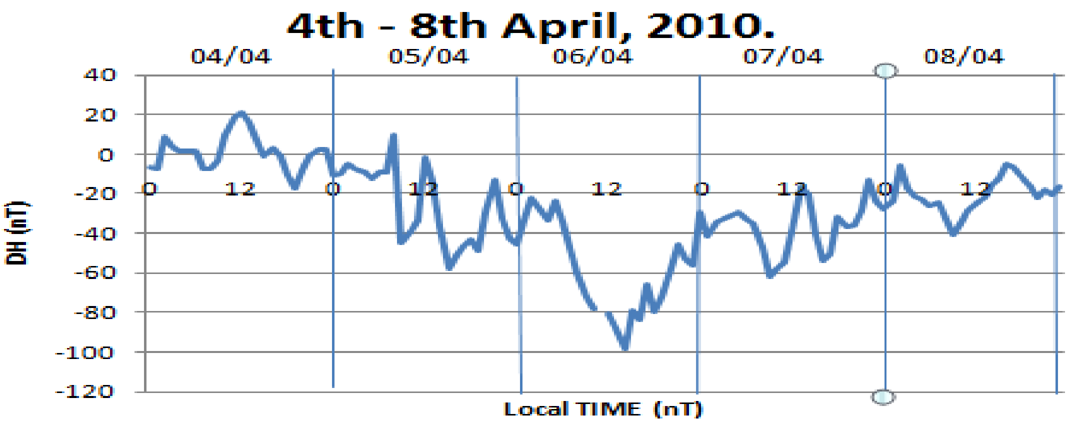


Figure 2: This figure shows geomagnetic Activity observed between 4th – 8th April, 2010



It was also observed that the initial phase of the storm has a quick and greater influence on the F2-layer than the main phase and the early part of the recovery phase. This is evidence in the magnitude and the sudden increase in NmF2 recorded just immediately after the storm commenced, with the crest-to-trough ratios of 1.58 and 1.52 for the initial and main phases respectively.

The morphology of hmF2 on storm days differs a little bit from the one observed on quiet days. There is significant reduction in hmF2 on storm days. This is noticeable on the first day and the night-side of the third day of the storm. The comparison between the storm day's hmF2 and the averaged hmF2 of five most quiet days of the month [See fig. 7] shows that the pre-noon minimum observed on April 5th is less than the month's hmF2 quiet averaged. The evening rise of the F2-layer, a very pronounced feature of the equatorial ionosphere [2], were seen on the first (a bit less) and second days but was completely absent on the third day of the storm.

The low-latitude ionosphere undergoes changes as a result of storm-time variations in plasma motion perpendicular to the geomagnetic field, B, direction due to an electric field, E, which is generated in the E-region. This electric field affects F-region plasma, causing both ions and electrons to drift in the same direction.

Figure 3: This figure shows comparison of geomagnetic activities observed at University of Ilorin Magnetometer Observatory and the Global Averaged Dst-H observed at World Data Center, Kyoto, Japan

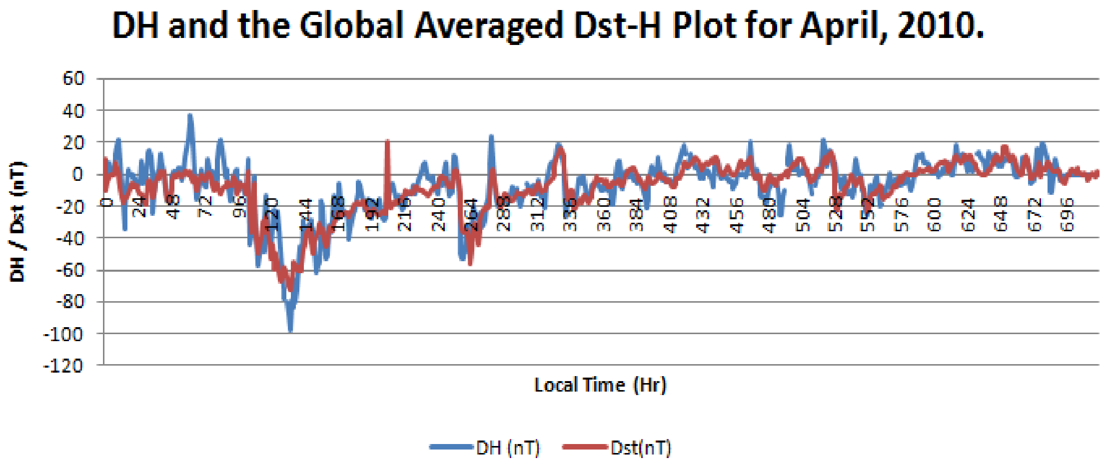


Figure 4: This figure shows diurnal Variations of NmF2 observed from 3rd – 11th of April, 2010

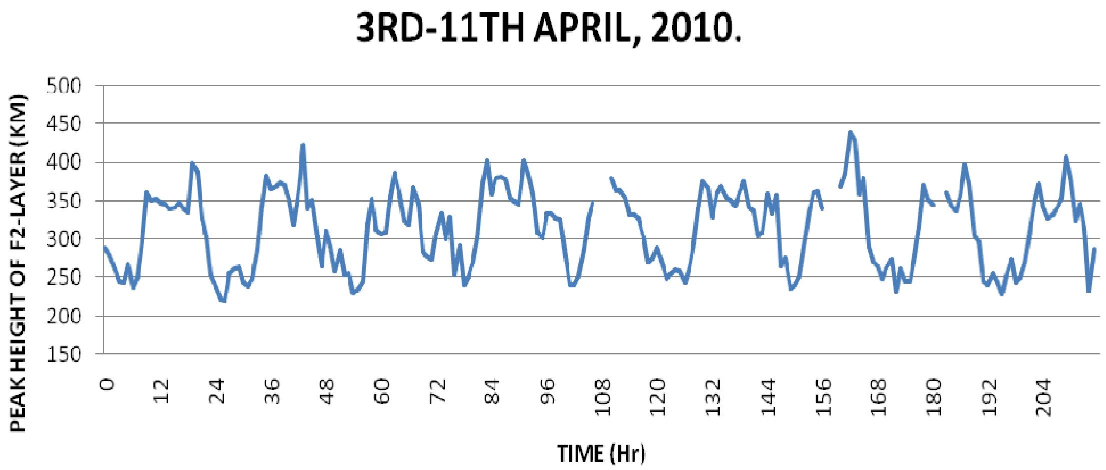


Figure 5: This figure shows diurnal Variations of hmF2

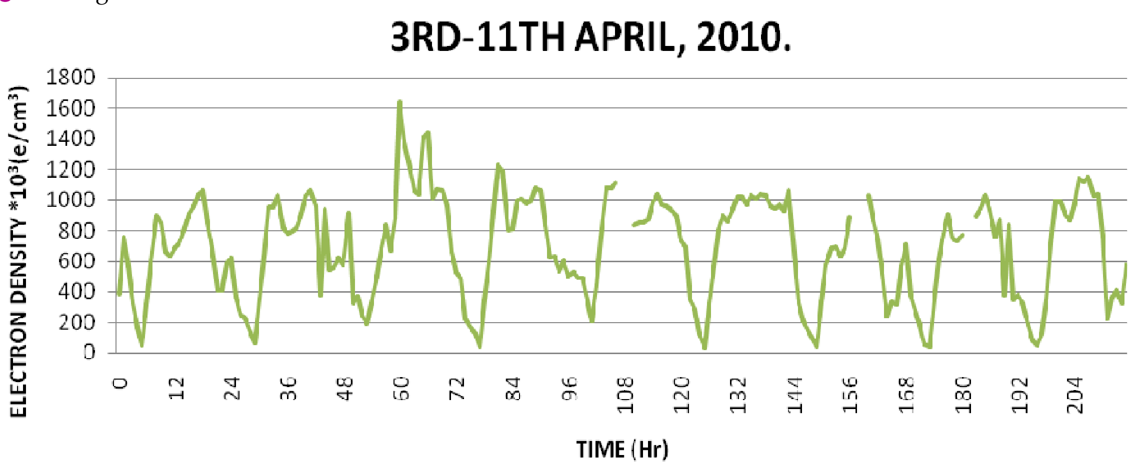


Figure 6: This figure shows diurnal Variations of NmF2 and the Averaged NmF2 of five most quiet days of the month from 3rd – 10th

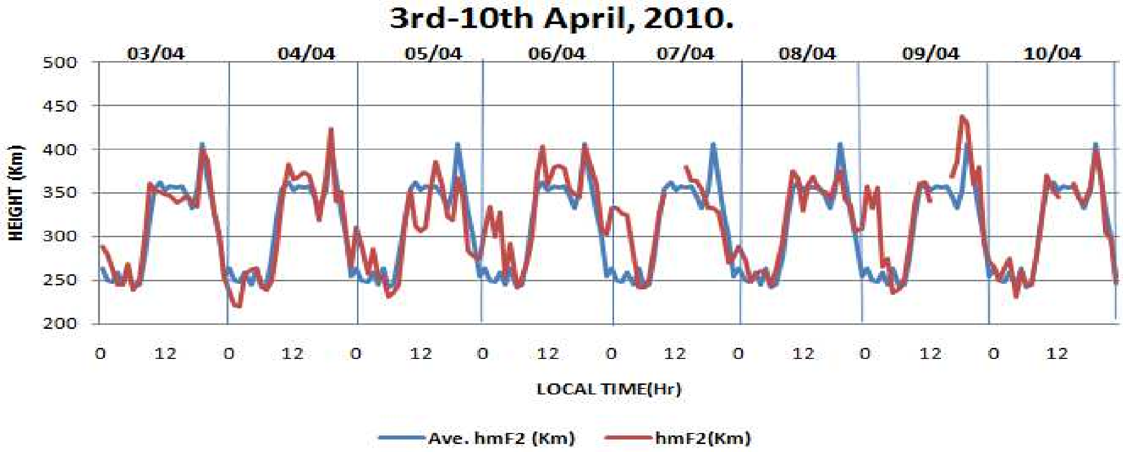
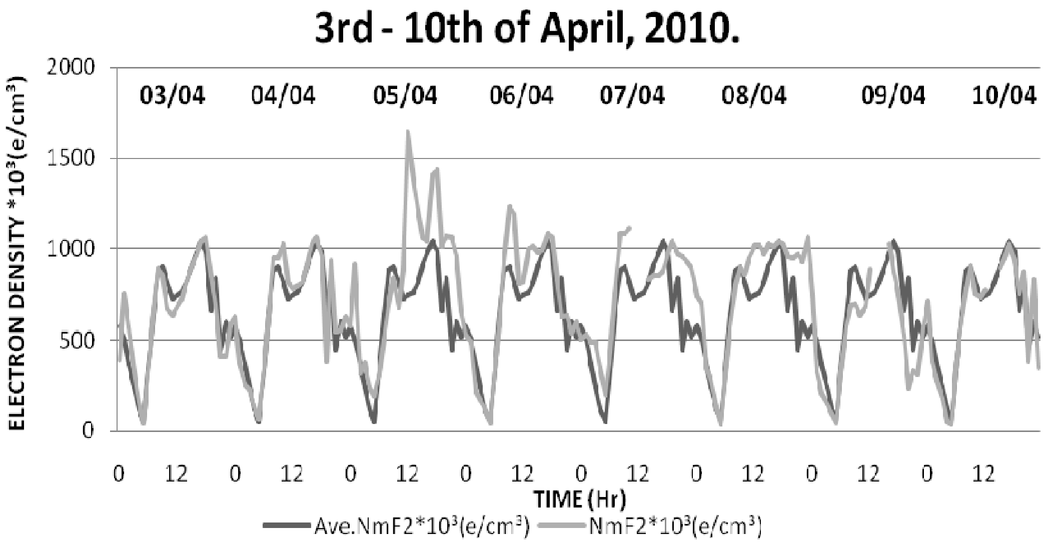


Figure 7: This figure shows diurnal Variations of hmF2 and the month Averaged hmF2 from 3rd – 10th of April, 2010



DISCUSSION

Many authors [3-7 etc] have indicated the effect of wind and the E × B force on the equatorial region. The global distribution of ionospheric currents and electric fields can be altered by the perturbations in the solar wind magnetosphere dynamo and the ionospheric wind dynamo [4]. The east-west electric field, in conjunction with the Earth's north-south magnetic field lines (which are about horizontal around the equator) produces the E × B force that causes vertical plasma drift. The electric field E in the equatorial region is eastward during the day and westward at night [8]. During the day-time, the E × B force is upwards when E is eastward and downward when E is westward [6]. The electrons tend to move along magnetic field lines, giving rise to the so called 'equatorial fountain effect'. This explains the equatorial anomaly on a global basis and also the trough in the day-time NmF2 observed locally at Ilorin.

Changes in equatorial ionospheric electric fields have been observed during the storm periods [8, 9]. Also [10] reported a reversal of the day-time equatorial current during the storm. During geomagnetic storm, the westward electric field is imposed on the dayside of the electrojet [4], which may overbalance the normal usual eastward electric field. This analysis indicates a quick and persistent electric field imposed on the F2-layer during the initial phase than the main phase of the storm. Such changes should normally play a major role in storm effects on the F2-layer electron density, since the E × B force has a great influence on the quiet day variation of the F2-layer, as explain earlier. A decrease in H during the storms indicates a reduction in the eastward electric field during the day. This implies a decrease in the E X B force, which would result in a decrease in the drift of ionization away from the equatorial F2-layer during the day [3].

A midday decrease in H during the storm corresponds to midday increase in NmF2 observed, suggesting the generation of a westward equatorial electrojet current and reduction of eastward electric field during the main phase of the storm [11]. This would result in decrease in the drift of ionization away from the equatorial F2-layer during the day. This, in addition to direct ionization effect, accounts for the observed pre-noon peaks higher than the post-noon peaks of all the storm days.

Storm-time prompt penetration of the interplanetary electric field to the mid- and low-latitude ionosphere has been revealed experimentally [12]. According to him, there is practically no time delay for the penetration. This accounts for the quick ion density enhancements observed during the initial phase of the storm.

The sharp drop of NmF2 experienced immediately after sunset and the complete absent of F2-layer evening rise observed on the third day of storm can be explained in terms of changes in thermospheric wind action. Variations in hmF2 are predominantly determined by variations in the thermospheric wind at the ionosonde stations [13]. The evening rise is due to an enhanced eastward electric field generated by F-region dynamo (and not the E-region dynamo) and driven by thermospheric wind [14]. It is particularly effective after sunset when thermospheric winds are strong and the F-region electron density still quite high. The depletion rate of post-sunset periods, due to ion drift away from the F2-layer, is faster during the first and second day but a bit slower on the third day. The absent or the weak effect of thermospheric wind action accounts for the gradual drop of NmF2 behavior observed on the third day of the storm.

A decrease in H during the storm also indicates an enhancement of the westward electric field at night [3]. This would result in an increase in the drift of electrons toward the F2-layer at night. This explains the enhancements in NmF2 observed on the nights of storm days which indicates that more electrons are fed from the top of ionosphere (likely from the protonosphere [15]) into the F2-layer. This means that more electrons are fed into the F2-layer on the first and third day, whereas no or little are fed on the second day.

Geomagnetic storm processes, such as particle precipitation and Joule dissipation, lead to thermospheric heating and, as a result, disturbed thermospheric winds, and composition changes which reach low latitude regions with a delay of a few hours from the geomagnetic storm onset [13]. Also the storm time auroral heating that produces disturbance thermospheric winds and dynamo electric fields (after storm commencement) modify the dynamics and the plasma distribution of the system. This is due to large energy input into the ionosphere during the storm, which causes an increase in electron temperature [3]. An increase in electron temperature would lead to an increase in recombination, which will lead to an increase in loss rate. This may therefore account for the decrease in NmF2 (compared to the initial phase of the storm) and the slight increase in hmF2 observed during the main phase of the storm.

CONCLUSION

In conclusion, the effect of a moderate storm (DH = -98.2nT) of 5th – 7th April, 2010 on the F2-layer of Ilorin were analyzed.

Thus, by utilizing data from the University of Ilorin Digisonde and Magnetometer Observatories, our study of the effect of magnetic storm of April, 5th -7th , 2010 on the F2-layer of Ilorin, a low latitude equatorial station, reinforces the conclusions of previous studies in which the magnitude of NmF2 are enhanced (known as the positive storm effect) during geomagnetic storm at both day-time and night-side for a low latitude stations

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CONFLICT OF INTEREST

No conflicts of interests were declared by authors.