Journal of the Earth and Space Physics, Vol. 45, No. 4, Winter 2020, P. 181-188

DOI: 10.22059/jesphys.2019.259772.1007014

Effects of St Patrick's Day Intervals Geomagnetic Storms on the Accuracy of GNSS Positioning and Total Electron Content over Nigeria

Omojola, J.[1*] and Adewumi, T.[1]

1. Assistant Professor, Department of Physics, Faculty of Science, Federal University, Lafia, Nigeria

(Received: 10 June 2018, Accepted: 1 Jan 2019)

Abstract

Total electron content (TEC) and GNSS positioning error over two Nigeria GNSS stations (CLBR: Latitude; 4.9503°E, Longitude; 8.3514°N, FUTY: Latitude; 9.3497°E, Longitude; 12.4978°N) were studied during the geomagnetic storms of March 17, 2015 minimum Dst (Disturbed storm time) -223nT and that of March 17, 2013 minimum Dst of -132nT (the St. Patrick's Day intervals); TEC was estimated using GPS Gopi TEC analysis software over the two stations during the storms period and the selected international quiet day used as reference. Understanding TEC variation in the equatorial ionosphere during geomagnetic storm will enable adequate prediction of GNSS positioning accuracy and correction over the region. Variation and enhancement of TEC were observed during the storms. The positioning error and TEC were higher at CLBR than at FUTY during the March 17, 2015 storm that could be as a result of latitudinal variation. The result will be useful for satellite based navigational systems.

Keywords: Total Electron Content; Global Navigation Satellites System; Equatorial Ionosphere; Geomagnetic Storm; Positioning Accuracy.

1. Introduction

The equatorial ionosphere has remarkable processes such as equatorial electrojet, equatorial spread F and the ionization anomaly that make the dynamism of the ionosphere in that region an interesting subject to ionospheric physicists.

The response of the Ionosphere to the geomagnetic storm is important in the understanding of trans- ionospheric signal delay. The group delay of Global Navigation Satellite Systems (GNSS) is as a result of the variation in the local Total Electron Content (TEC). TEC has been a very important parameter for the studying and understanding GNSS positioning accuracy (Stankov et al., 2010). Much has been revealed about TEC behaviour both in the mid and high latitude ionosphere as reported by several authors (Stankov et al., 2010; Afraimovich et al., 2002; Buonsanto, 1999; Li et al., 2012).

Ionospheric impact on satellite navigation and communication is the major source of positioning error (Comberiate et al., 2012) since TEC is the number of electrons in a column of $1m^2$ cross section from the height of global positioning system (GPS) satellite at approximately 20,000 km to the receiver on the ground.

Several authors have attempted to study TEC behaviour in this region during both periods of high and low solar activity (Moreno et al., 2011; Bolaji et al., 2011; Adewale et al., 2013; D'ujanga et al., 2013; Olawepo et al., 2015, Chakraborty et al., 2015).

This study reports TEC during two geomagnetic storms that occur at the same period for different years and the positioning error associated with the storms over two GNSS stations situated in Nigeria (situated within the region of an equatorial ionospheric anomaly) in the equatorial region of African sector (see Figure 1) for the first time. The equatorial ionosphere is strongly influenced by the electromagnetic field occasioned by the horizontally aligned geomagnetic field over the equatorial region.

Thorough knowledge of storm time behaviour of TEC as it affects GNSS signal is our utmost desire.

The ionospheric delay is related to the TEC along the propagation path (Klobuchar, 1997; Jakowski et al., 2012). Ionospheric delay is due to the refraction and dispersion of GNSS signal. As it travels through the ionosphere, the refractive group index of the ionosphere is greater than one (i.e. >1), which implies that the group velocity of the radio wave is less than the speed of light in a vacuum. If the refractive index of the ionosphere is less than one, the phase velocity of the radio

*Corresponding author: joseph.omojola@fulafiaphysics.org

wave is greater than the speed of light in vacuum. For this reason, there is an advance on the measured carrier phase and a delay on the measured pseudo-range (group delay) shown in Equations (1) and (2), where c is the speed of propagation, W_f and W are the critical frequency of the ionospheric plasma and the signal frequency respectively, with

$$V_g = c\sqrt{1-W_f^2}\,/W \tag{1}$$

is the group velocity delay (Navipedia, 2011) and

$$V_\phi = \frac{c}{\sqrt{1-W_f^2}\,/W} \tag{2}$$

is the phase velocity advance (Navipedia, 2011).

Geomagnetic storm usually commences with an increase in the Earth's magnetic field that is called initial phase, followed by a large decrease called the main phase, which could last a few days before the commencement of a recovery phase that is usually longer than the main phase (Adebiyi et al.,2012; Adekoya et al., 2012).

Understanding TEC behaviour during the geomagnetic storm will enhance better estimation of positioning accuracy and corrections.

2. Materials and Method

2-1. Description of March 17, 2015 Geomagnetic Storm

The storm occurred in the declining phase of solar cycle 24 and is the largest so far the driver of the storm were two interacting coronal mass ejection (CME) of March 15 (Zhang et al., 2015)

The storm of March 17 is a sudden commencement storm at 4.45 UT on March 17 and reached its minimum Dst of -223nT at 23 UT on the same day after which it began the recovery phase at about 11UT on March 18 to March 19.

2-2. Description of March 17, 2013 Geomagnetic Storm

The storm is a sudden commencement storm minimum Dst-index of which was -132nT on March 17 at 21.00UT. Though this storm is less in severity to that of 2015, they both share some uniqueness; both are sudden commencement and both occur at the same season on the same day popularly regarded as St. Patrick 's Day.

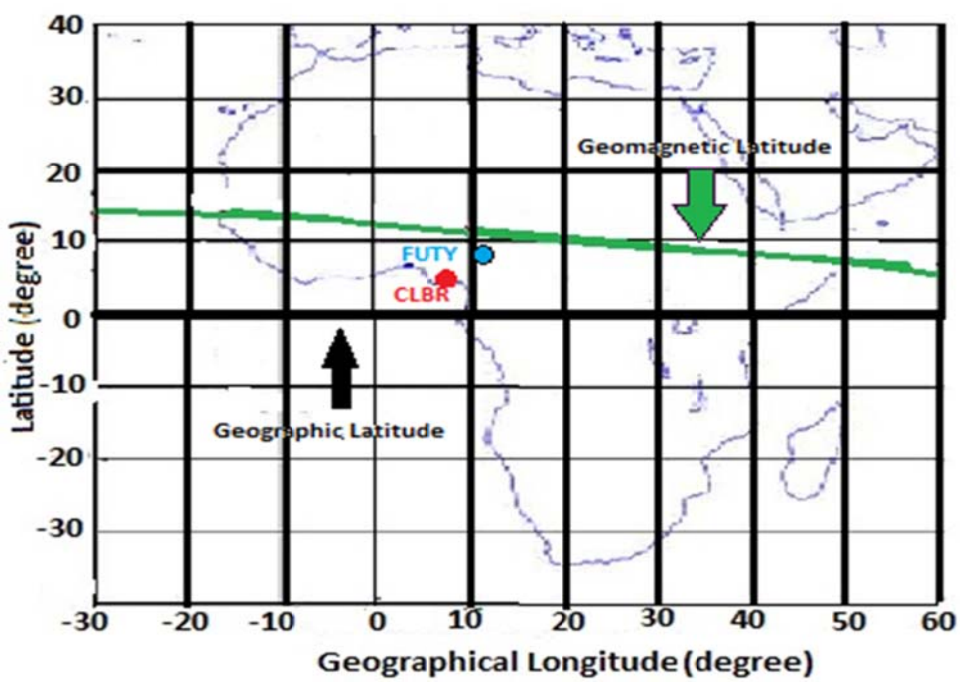

Figure 1. Map of Africa showing the stations and the geomagnetic latitude.

3. Research Data

The Dst values for the storm period and the reference were downloaded from world data centre for geomagnetism, Kyoto (wdc.kugi.kyoto-u.ac.jp), corroborated with Australian geosciences international quiet and most disturbed days (http://www.ga.gov.au/oracle/geomag/display_iqd.jsp). GNSS observation and navigation files were downloaded from Nigeria GNSS network (www.nignet.net) for the stations (see Figure 2 and Table 1) both during the storm period and the selected quiet day was chosen as a reference.

3-1. Data Analysis

Gopi GPS – TEC analysis software version 2.9.3 was used to estimate the vertical total electron content (VTEC) over the stations during the storm period, which was compared with the TEC of a typical selected quiet day. The quiet day TEC was plotted over the storm period TEC using the ASCII output file for further analysis with Matlab in order to depict the TEC behaviour during the storm period over the stations (1 TECU = 10^{16} electrons/m^2).

Real-Time Kinematic Library (RTKLIB) open source software for GNSS positioning estimation was utilized to compute the position of the stations during the storm. The deviation of the stations' position from the International Terrestrial Reference Frame (ITRF) and further analysis was done using Matlab software.

4. Results and Discussion

4-1. CLBR Station

4-1-1. March 17, 2015 Geomagnetic Storm

The five-panel plots of Figure 3 depicted the coordinate's error, the Dst, and the TEC over the station during the storm and the reference (quiet) day positioning error and TEC (thin line) superimposed on the storm period (thick line) positioning error and TEC. The maximum error (X=36.79 m, Y=8.24 m) for CLBR station occurs before the onset of the storm sudden commencement at about 23.40 UT on the 16th of March (Figure 2 and 3) that could be as a result of plasma redistribution and enhancement before the onset of the storm. The Z-coordinate do not show a significant signature of the storm as compared with the reference day. Generally, there is an improvement in the accuracy of the position of the station during the entire period of the storm. There is noon time enhancement of TEC with the maximum of 87.04 TECU occurring in the noon period during the main phase of the storm, which does not correlate with the maximum position error of the station.

4-1-2. March 17, 2013 Geomagnetic Storm

It can be inferred from the three panel plots of Figures 6, 7, and 8 that the storm of March 17, 2013 has minimum effect on positioning at CLBR. The maximum day time TEC enhancement (62.90 TECU) coincide with the main phase of the storm.

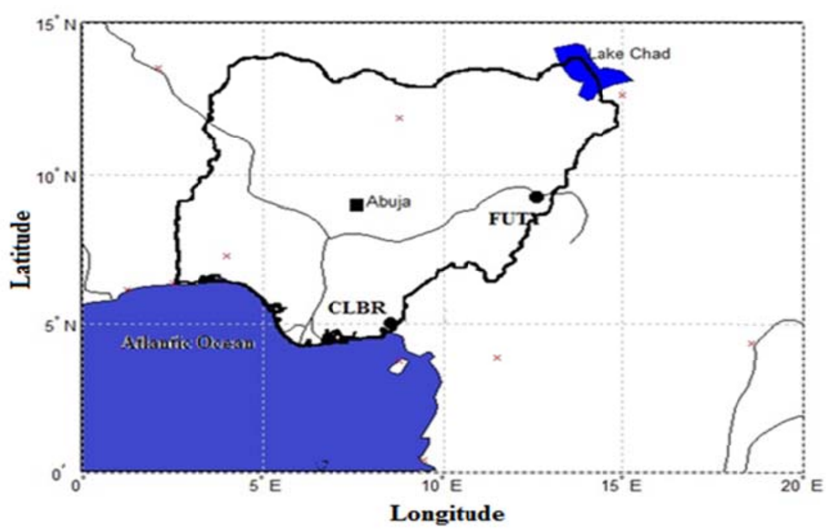

Figure 2. Map of Nigeria showing the stations coordinate.

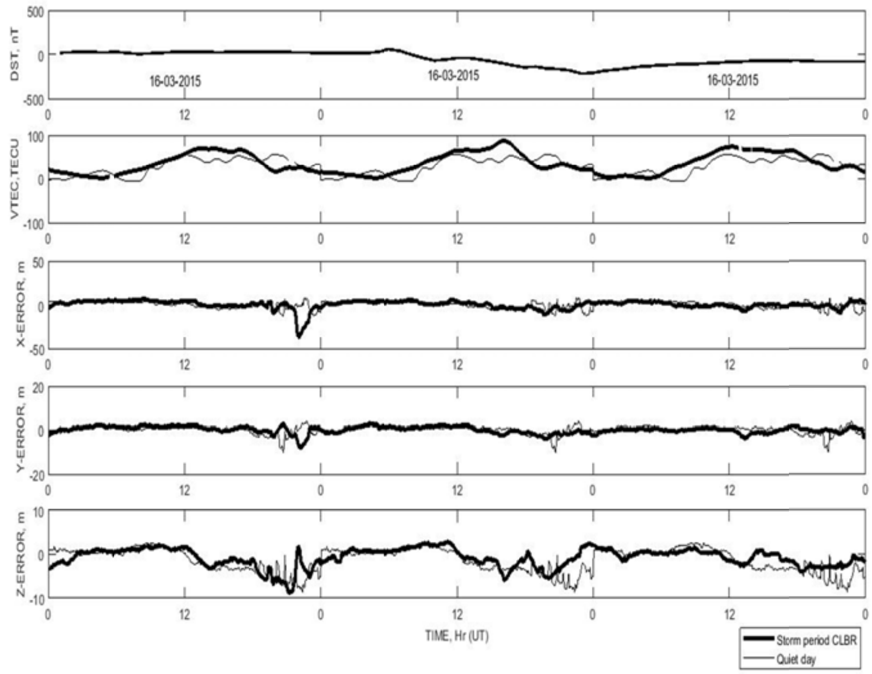

Figure 3. CLBR – Coordinates error with TEC during March 17, 2015 storm.

Table 1. Site Information for the two stations.

STATION ID	ITRF COORDINATES(m)	ELEVATION (m,ellipsoid)	RECEIVER TYPE	ANTENNA TYPE	SATELLITE SYSTEM
CLBR	X: 6287177.4886 Y: 922980.2137 Z: 546714.5521	61.5	TRIMBLE NETRS	TRM59800	GPS GLONASS
FUTY	X: 6145058.5066 Y: 1362078.8671 Z: 1029389.8941	248.4	TRIMBLE NETRS	TRM59800	GPS GLONASS

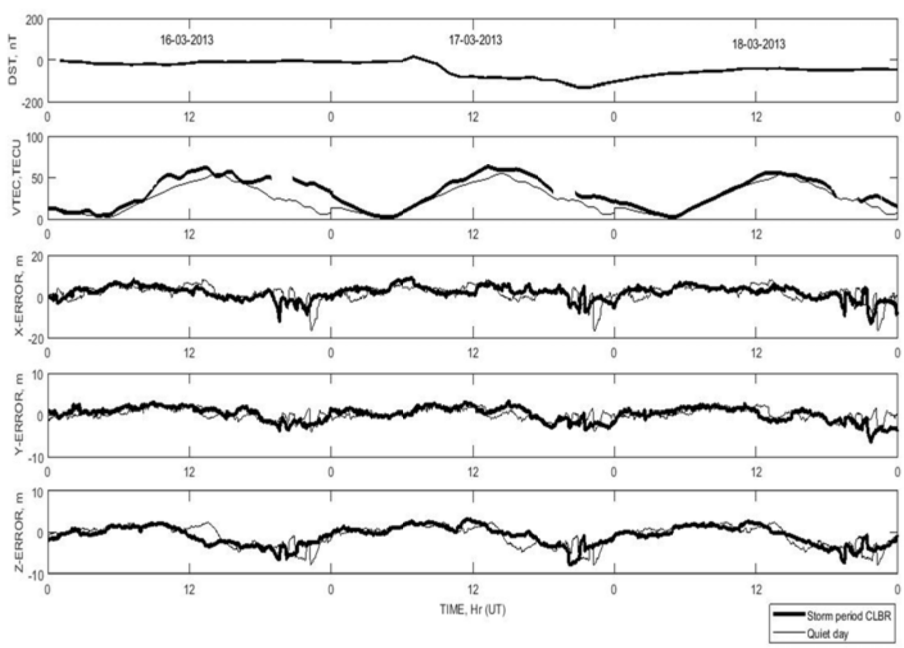

Figure 4. CLBR– Coordinates error with TEC during March 17, 2013 storm.

5. Futy Station

5-1. March 17, 2015 Geomagnetic Storm

The five-panel plots of Figure 5 depicted the coordinates error, the Dst, and the TEC over the station during the storm and the reference (quiet) day positioning error and TEC (thin line) superimposed on the storm period (thick line) positioning error and TEC. Maximum position error for this station occurs during the recovery phase of the storm X=12.68 m, Y =6.80 m. There is noon time TEC enhancement during the entire period of the storm the maximum (72.83TECU) of which coincide with the main phase of the storm. The maximum positioning error on the Z-coordinate (9.19 m) coincides with maximum TEC enhancement that occurs during the main phase of the storm.

5-2. March 17, 2013 Geomagnetic Storm

FUTY station has the maximum position error coincide with the main phase of the storm with the highest on the x-coordinate (10.67 m), while the Y and Z coordinates have position error of about 4.50 m and 4.12 m respectively. Figure 6 shows that the observed phenomenon in this station may be as a result of the station proximity to the geomagnetic equator with the attending electrodynamics effect in the equatorial ionospheric anomaly region.

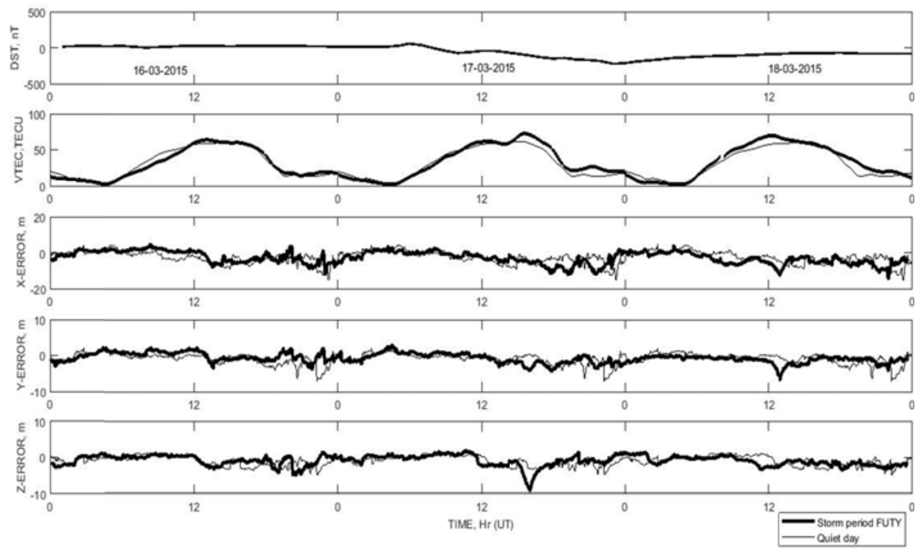

Figure 5. FUTY – Coordinates error with TEC during March 17, 2015 storm.

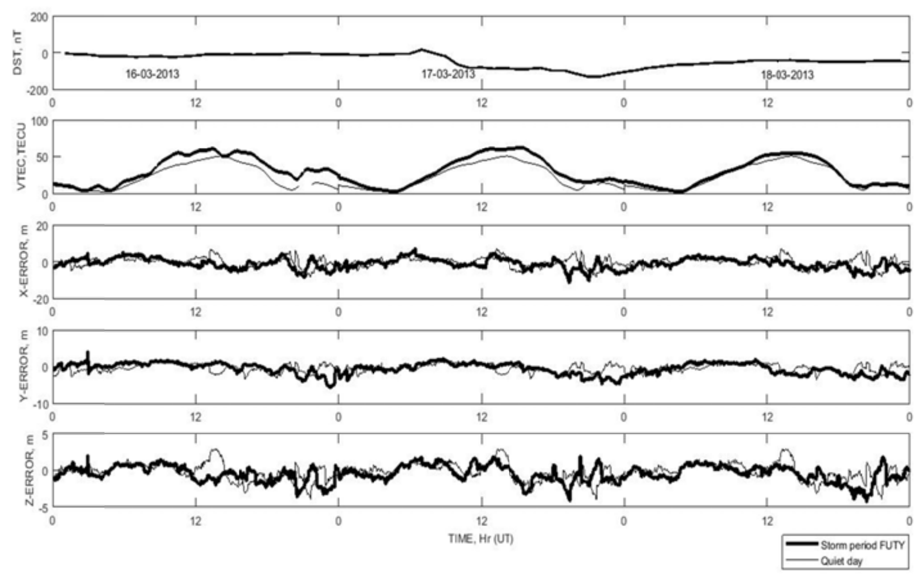

Figure 6. FUTY– Coordinates error with TEC during March 17, 2013 storm.

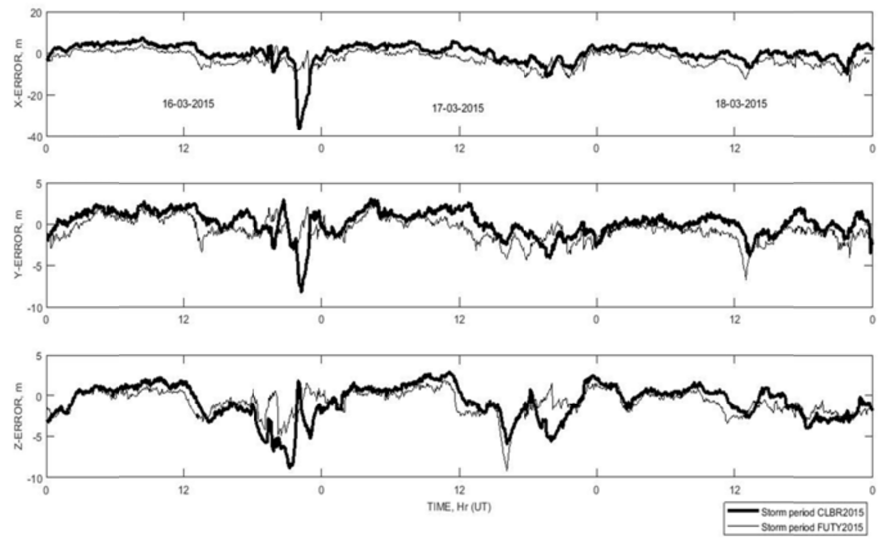

Figure 7. Latitudinal differences between the two stations March 17, 2015 storm.

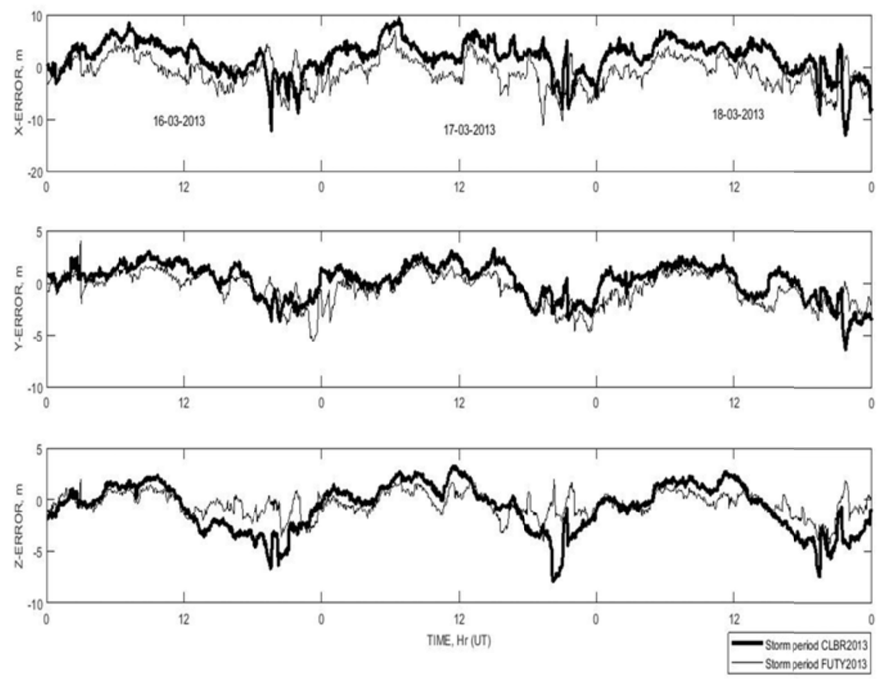

Figure 8. Latitudinal differences between the two stations March 17, 2013 storm**.**

6. Conclusion

The two storms behave differently at a different latitude, which agrees with previous authors (Amit et al., 2010; Stankov et al., 2010; Li et al., 2012).

While the effect of the storms is consistent with the maximum TEC during the main phase of the two storms, the position error is highest during the March 17, 2015 storm at CLBR of lower latitude than at FUTY, which falls directly in the region of equatorial electrojet.

There is an enhancement of TEC during the entire period of the storms, and the enhancement becomes maximum during the main phase of the storms. The position error of CLBR is higher during the onset of the initial phase of the storm on March 17, 2015, which occurs on the 16^{th} of March and improves throughout the main phase and the recovery phase of the storm. This error may not be associated with the enhancement in

TEC due to other parameters involved in the equatorial ionosphere electrodynamics and perturbations. FUTY station has lesser position error during the storm and lesser TEC enhancement, which may be a signature of latitudinal variation in total electron content.

Acknowledgement
The authors wish to express gratitude to (i) World data centre for geomagnetism, Kyoto, Japan (ii) Nigeria GNSS network (NIGNET); for the data used in this study, and (iii) Dr. Gopi Krishna Seemala, Indian Institute of Geomagnetism (IIG), Navi Mumbai, India for the GPS - TEC analysis software. They also wish to thank the reviewers for their suggestions in improving the content of the paper.

References

Adebiyi, S. J., Adeniyi, J. O., Adimula, I. A., Joshua, B. and Gwani, M., 2012, Effect of the Geomagnetic Storm of April 5^{th}– 7^{th}, 2010, on the Layer of the Ionosphere of Ilorin, Nigeria. World Journal of Engineering and Pure and Applied Sciences, 2(2), 56-62.

Adekoya, B. J., Chukwuma, V. U., Bakare, N.O. and David, T. W., 2012, Effects of Geomagnetic Storm on middle Latitude Ionosphere F2 during Storm of April 2^{nd} – 6^{th}, 2004. Indian Journal of Radio and Space Physics, 41, 606-616.

Adewale, A. O., Oyeyemi, E. O., Adeloye, A. B. and Adedokun, M. B., 2013, Ionospheric Effects at Hobart and comparison with IRI model Predictions. Journal of Scientific Research and Development, 14, 98 – 105.

Afraimovich, E. L., Demyanov, V. V. and Kondakova, T. N., 2002, Degradation of GPS performance in geomagnetically disturbed conditions. E-print archive: http://xxx.lanl.gov/abs/physics/0211015.

Amit, J., Sunita, T., Sudhir, J. and Gwal, A. K., 2010, TEC response during severe geomagnetic storms near the crest of equatorial ionization anomaly. Indian Journal of Radio and Space Physics, 39, 11-24.

Bolaji, O. S., Adeniyi J. O., Radicella S. M. and Doherty P. H., 2011, Variation of TEC over an Equatorial West African Station during low solar activity Radio Sci., 47, RS 1001, doi: 10.1029/2011RS004812.

Buonsanto, M. J., 1999, Ionospheric Storms. Space Science Reviews, 88, 563 - 601 Earth-prints. Internet repository of scientific papers. Available at: http://www.earth-prints.org.

Comberiate, J., Kelly, M., Dyrud, L. and Weaver G., 2012, Space Weather Effects on GPS Systems. Conference Proceeding at Applied Physics Laboratory, USA.

D'ujanga, F. M., Baki, P., Olwendo, J. O. and Twinamasiko, B. F., 2013, Total electron content of the ionosphere at two Stations in East Africa during the 24 – 25 October 2011 geomagnetic storm, Advances in Space Research, 51(5), 712 – 721.

European Space Agency (ESA), Navipedia. Available at: https://gssc. esa. int/ navipedia/index.php/Ionospheric_Delay.

Jakowski, N., Beniguel, Y., De Franceschi, G., Pajares, M., Jacobson, K., Stanislawska, I., Tomasik, L. and Waenant, R., Wautelet, G., 2012, Monitoring, tracking and forecasting Ionosphere perturbations Using GNSS techniques. Journal of Space Weather Space Climate, 2, doi: 10.1051/swsc 2012022 EDP sciences.

Klobuchar, J. A., 1997, Real-Time Ionospheric Science: The New Reality. Radio Science, 32(5), 1943 – 1952.

Kutiev, I., Tsagouri, I., Perrone, L., Pancheva, D., Mukharov, P., Mikhailov, A., Lastovicka, J., Jakowski, N., Buresova, D., Blanch, E., Andonov, B., Altadill, D., Magdaleno, S., Parisi, M., Tortaj, J.M., 2013, Solar activity on the Earth's upper atmosphere. Journal of Space weather Space Climate, 3(A06), Doi: 10.1051/swsc/2013028.

Li, J., Ma, G., Maruyama, T. and Li, Z., 2012, Mid-Latitude Ionospheric Irregularities persisting into late morning during the magnetic storm on 19 March 2001. Journal of Geophysical Research, doi: 10.1029/2012JA017626.

Moreno, B., Radicella, S., de Lacy, M. C., Herraiz, M. and Rodriguez-Caderot, G., 2011, On the effects of the Ionospheric disturbances on Precise Point Positioning at Equatorial latitudes. GPS Solutions, 15(4), 381 – 390.

Monti, Ch., Sanjay, K., Barin Kumar, De. and Anirban, G., 2015, Effects of geomagnetic storm on low latitude ionospheric total electron content: A case study from Indian sector. Journal of Earth System Science, DOI: 10.1007/s12040-015-0588-3.

Olawepo, A. O., Oladipo, O. A., Adeniyi, O.A. and Doherty, P. H., 2015, TEC Response at two equatorial Stations in the African Sector to Geomagnetic Storms. Journal of Advances in Space` Research, 56(1), 19 –27, doi: 10.1016/j.asr.2015.

Stankov, S. M., Stegen, K. and Warnant, R., 2010, Seasonal variation of Storm time TEC at European middle latitudes. Advances in Space Research, 46, 1318-1325.

Zhang, S., Zhang, Y. and Huang, C., 2015, Profiles of Ionospheric storm enhanced density during the 17 March, 2015 great storm. Journal of Geophysical Research, 121, 727 – 744, DOI: 10.1002/2015JAO21832.