Centre for Atmospheric Research

2018 MONOGRAPH OF ATMOSPHERIC RESEARCH

Edited by A.B. Rabiu and O. E. Abiye

A Publication of
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National Space Research and Development Agency
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PREFACE

The Centre for Atmospheric Research was established in January 2013 with a compelling mission to improve our understanding of the behaviour of the entire spectrum of the Earth's atmosphere; promote capacity development in relevant atmospheric sciences as a way of facilitating international competitiveness in research being conducted by atmospheric scientists; and disseminate atmospheric data/products to users towards socio-economic development of the Nation. CAR's extant core research focus includes: space weather, tropospheric studies, atmospheric research software and instrumentation development, microgravity and human space technology, and atmospheric chemistry and environmental research.

Pursuant to the above, The *Monograph of Atmospheric Research* published by the Centre for Atmospheric Research (CAR), is a collection of peer-reviewed manuscripts in Atmospheric Sciences and closely related fields. This maiden edition comprises articles presented during two separate workshops; *1st National Workshop on Microgravity and Environmental Research* (26 - 29 November, 2017) and *1st National Workshop on Air Quality* (13 - 16 March, 2018). Such workshops are integral part of CAR's capacity building program and they were primarily aimed at advancing the course of atmospheric research in Nigeria towards sustainable development. The Microgravity workshop was geared towards introducing new research opportunities in space life science by simulating microgravity conditions here at the earth's surface as a means of investigation space biological environment. The Air Quality workshop was organized in collaboration with Ministry of Environment and Nigerian Meteorological Agency (NIMET). The workshop analysed current Air Quality scenario in Nigeria, explored new opportunities for collaborative research and offered novel means of improving the present quality of life of the populace without jeopardizing the chance of the future generation. Cumulatively 196 participants participated in these two workshops and about 52 articles were eventually submitted for publication consideration in this monograph. The twenty-one articles in this very monograph are the articles that eventually made it through the rigorous peer-review process. We remain grateful to the reviewers for doing thorough work on the articles.

Thus, we are very pleased to present the *2018 Monograph of Atmospheric Research* which contains twenty-one articles, including some review papers, to readers in all spheres of interest across Nigeria and beyond. It is our hope that this effort will continue and will serve as a reference to atmospheric researchers in Nigeria.

Prof. A. B. Rabiu and Dr. O. E. Abiye,
Editors

Centre for Atmospheric Research

Estimation of Total Electron Content gradient over Nigeria

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ABSTRACT

A study on the estimation of ionospheric TEC gradient over Nigeria was carried out using a year GPS data. Ionospheric TEC gradient is the change in TEC between two points over the distance between them. TEC value changes from one location to another. Spatial TEC gradient is an index to quantify the change in TEC over a region. The GPS data used in this study are for the year 2014 from seven (7) out of the fourteen (14) operational NIGNET stations in Nigeria located between geomagnetic latitudes – 4.33 and 0.72^{o} N. The data for the magnetically five most quietest and disturbed days for the representative months of March, June, September and December were considered in this study. GPS TEC gradients were derived using the GPS data, which was analysed for diurnal and seasonal variations. Calibrated TEC were observed and VTEC over the ionospheric pierce point (IPP) were obtained over the distance between them to obtain TEC gradient. The results obtained show diurnal variation in TEC gradient values with the minimum values of TEC gradient recorded between 05:00 and 07:00 UT (∼0.011 – 0.012 TECU/km), while the peak values were observed between 14:00 and 16:00 UT (∼0.54 – 0.55 TECU/km). The seasonal variation shows low values of TEC gradient in the solstice months of June and December (∼0.28 – 0.3 TECU/km), whereas slightly higher values were observed in the equinox months of March and September (∼0.54 – 0.55 TECU/km). TEC variation during geomagnetic disturbed period is found to be more than the quiet period. The results obtained show a regular pattern in the increase in TEC gradients from East to the West region of the plots. The results obtained provide external information about TEC gradient to get more accurate ionospheric delay over a region thereby bringing about improvement on the GNSS positioning accuracy. In general, the TEC gradient revealed higher values in daytime than in the nighttime. This is attributed to high intensity of solar radiation in the daytime which brings about higher ionization due to high level of photoionization.

Keywords: Global Navigation Satellite System (GNSS), Total electron content (TEC), Ionospheric pierce point (IPP), Nigerian Permanent GNSS network (NIGNET).

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INTRODUCTION

The Global Positioning System (GPS) is a satellite-based radionavigation system consisting of at least 24 satellites configured in six (6) orbital planes with a minimum of four (4) satellites in each plane. The satellite orbits are approximately 17700 km above the earth's surface and the satellites complete one orbit around the earth approximately every 12 hours. The Russian Space Forces operate the Global Navigation Satellite System (GLONASS), while China and Europe started development of COMPASS and GALILEO, respectively. In general, satellite-based radionavigation systems like GPS, GLONASS, COMPASS and GALILEO are referred to as Global Navigation Satellite Systems (GNSS) (*Misra et al., 2006*).

The ionosphere is the ionized region of the atmosphere comprising free electrons and positive ions, generally in equal numbers, in a medium that is electrically neutral (*Hunsucker and Hargreaves, 1995; Baumjohann, 1999*). It plays a basic role in long-distance communication. Characterizing the ionosphere is of utmost interest due to the numerous complexities associated with the region (*Rabiu et al., 2007*).

Signals from these four systems propagate through the ionosphere before they reach the earth's surface. The positioning accuracy of GNSS is affected by several errors such as satellite and receiver clock errors, signal propagation delay errors due to ionosphere and troposphere, multipath error, receiver measurement noise and instrumental biases. Among all the error sources, ionospheric delay is the most predominant one and is of the order of 5-15 m during mid-afternoon (*El-Rabbany, 2002*). GPS signals are affected as they pass through the ionosphere resulting in range errors. The magnitude of error depends on the signal frequency and the density of free electrons along the signal path.

TEC is measured to estimate the impact of ionosphere to the signal transmitted by GPS satellites to the receiver on Earth. Among ionospheric parameters, the total electron content (TEC) is one of the particularly important physical quantities of the ionosphere. TEC has been extensively investigated and modelled for both scientific research of ionosphere and for applications (*Mukhtarov et al., 2013*).

Several studies have been done to characterise the ionosphere by studying on the variability of ionospheric total electron content (TEC) (*e.g., Rastogi et al. 1971; Jakowski, 1996; Jakowski et al., 1999; El-Rabbany, 2002; Bagiya et al. 2009; Chauhan et al., 2011; Fayose et al., 2012; Mukhtarov et al., 2013; Eyelade* *et al., 2017*).

This study estimates the ionospheric TEC gradients over Nigeria for a period of one year (i.e. year 2014) using data from seven (7) out the fourteen (14) operational Nigerian GNSS Reference Network CORS stations.

Data and method of analysis

The GNSS observation data in Receiver Independent Exchange (RINEX) format for the representative months of January, March, June, September and December 2014 were obtained from the Nigerian GNSS Reference Network (NIGNET) server (*http://www.nignet.net/data/*). Observation data, satellite navigation data and the Differential Code Bias (CDB) files were used for this study. Data for the five most quietest and disturbed days for the representative months of March, June, September and December, 2014 were considered in this study. The details of quiet and disturb days are obtained from the website of World Data Center, Kyoto, Japan. (*http://wdc.kugi.kyoto-u.ac.jp/*). Fig. 1 shows the spatial distribution of the NIGNET stations over Nigeria. The stations marked with cross '+' on the map are the stations used for this study. Table 1 shows details of the NIGNET stations used in the study.

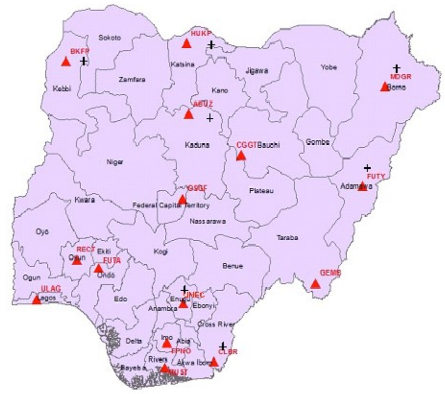

Fig. 1. Spatial distribution of the NIGNET receiver stations in Nigeria.

(Source: http://www.nignet.net/data/logs/)

Table 1. NIGNET GNSS CORS in Nigeria used in the study

STATIONS ID	GEOGRAPHIC		GEOMAGNETIC	
	LAT.	LONG	LAT.	LONG.
ZAIRA(ABUZ)	11.17⁰ N	7.79⁰ E	0.11⁰ N	79.88⁰ E
BIRNIN KEBBI (BKFP)	12.48⁰ N	4.34⁰ E	0.64⁰ N	76.72⁰ E
CALABAR (CLBR)	4.95⁰ N	8.36⁰ E	4.29⁰ N	80.10⁰ E
KATSINA(HUKP)	12.96⁰ N	7.66⁰ E	1.08⁰ N	79.84⁰ E
MAIDUGURI(MDGR)	11.88⁰ N	13.26⁰ E	0.57⁰ N	85.11⁰ E
ENUGU (UNEC)	6.50⁰ N	7.55⁰ E	3.18⁰ N	79.42⁰ E
YOLA(FUTY)	9.50⁰ N	12.63⁰ E	1.17⁰ N	84.44⁰ E

(Source: http://www.nignet.net/data/logs/)

Vertical total electron content (VTEC) values were obtained using software developed by Gopi Krishma Samela (*Gopi, 2012*). The input files to the software are the observation and navigation files while the output files are .std and .Cmn files. The ".Cmn" files are used for this study. The .Cmn files contain both the STECs and VTECs over the ionospheric pierce point (IPP). In *Gopi (2012)* VTEC values are obtained from STECs using equation (1).

$$VTEC = \frac{STEC}{S(E)} \quad (1)$$

where S(E) is the mapping function defined by equation (2)

$$(E) = \left\{1 - \left(\frac{R_E \cos(E)^2}{R_E + h_s}\right)\right\}^{-0.5} \quad (2)$$

where E is the elevation angles in degree; R_E and h_s are respectively the mean Earth radius and the ionosphere (effective) height above the Earth surface in km. The value of h_s used in this work is 350 km.

To obtain TEC gradient, stations that can see the same satellite with concurrent data at the same time were paired. The STECs and VTECs over the ionospheric pierce point (IPP) are obtained. The difference in VTECs are obtained and divided over the distance between the two stations at the ionospheric pierce point (IPP).

Movies of TEC gradient plotted against the geomagnetic coordinates of the stations over IPP at each epoch of 1.5 minutes interval for each day of the representative months considered in this study were created. Sample plots were then extracted and presented as results of this study.

Results will be presented for both the quiet and disturbed days for the representative months only when there is concurrent data for the paired stations.

RESULTS

Fig. 2. shows the plot of TEC gradient for March 08, 2014 for a magnetically quiet day. The plot is around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively.

Minimum TEC gradient is observed at nighttime around 00:00 UT (0.165 – 0.17 TECU/km). The TEC gradient value increases from sunrise around 06:00 UT (0.18 – 0.2 TECU/km) to an afternoon maximum around 15:00 UT (0.36 – 0.38 TECU/km) and then gradually decreases from around 18:00 UT (0.3 – 0.35 TECU/km). TEC gradient increases from East to the West region on the plots.

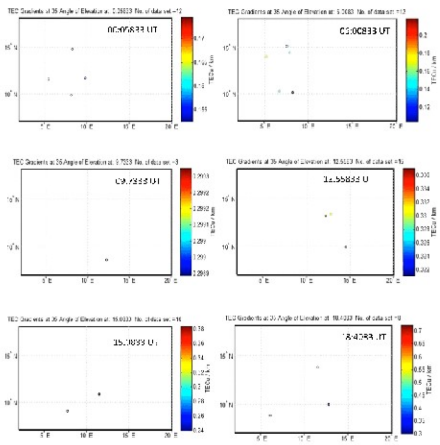

Fig. 2. Plot of TEC gradient for March 08, 2014 for magnetically quiet day at around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively.

Fig. 3. shows the plot of TEC gradient for March 25, 2014 for a magnetically disturbed day. The plot is around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 14:00 UT and 15:00 UT respectively. Minimum TEC gradient is observed at nighttime around 00:00 UT (0.1TECU/km). The TEC gradient value increases from sunrise around 06:00 UT (0.1 – 0.2TECU/km) to an afternoon maximum around 15:00 UT (0.54 – 0.55 TECU/km) and then decreases thereafter. TEC gradient increases from East to the West region on the plots.

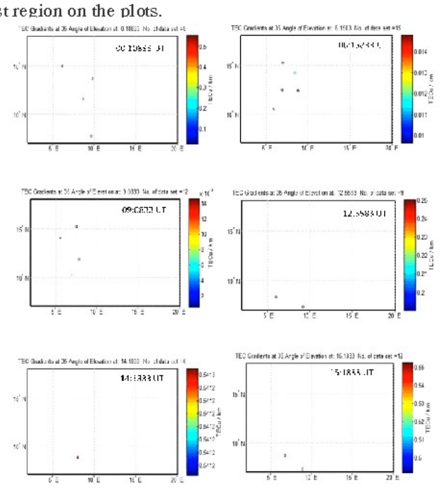

Fig. 3. Plot of TEC gradient for March 25, 2014 for magnetically disturbed day at around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 14:00 UT and 15:00 UT respectively.

Fig. 4. shows the plot of TEC gradient for June 27, 2014 for a magnetically quiet day. The plot is around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively. The TEC gradient value increases from sunrise around 06:00 UT (0.068 – 0.07 TECU/km) to an afternoon maximum around 15:00 UT (0.08 – 0.1 TECU/km) and then decreases from around 18:00 UT (0.02 – 0.04 TECU/km). TEC gradient is observed at nighttime around 00:00 UT (0.06 – 0.065 TECU/km). The minimum value in TEC gradient is observed around 18:00 UT. TEC gradient increases from East to the West region on the plots.

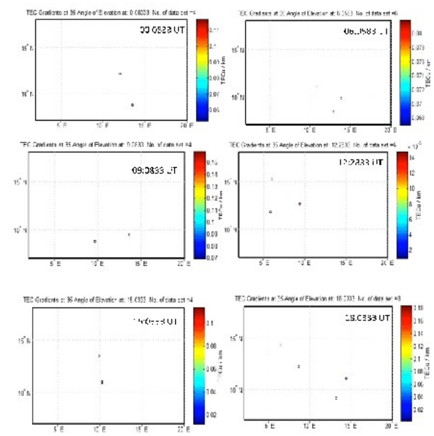

Fig. 4. Plot of TEC gradient for June 27, 2014 for magnetically quiet day at around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively.

Fig. 5. shows the plot of TEC gradient for June 18, 2014 for a magnetically disturbed day. The plot is around 00:00 UT, 05:00 UT, 12:00 UT, 14:00 UT, 15:00 UT and 18:00 UT respectively. The TEC gradient value increases from sunrise around 05:00 UT (0.036 – 0.037 TECU/km) to an afternoon maximum around 14:00 UT (0.045 – 0.05 TECU/km) and then decreases from around 18:00 UT (0.032 – 0.034 TECU/km). TEC gradient is observed at nighttime around 00:00 UT (0.1 – 0.15 TECU/km). Minimum value in TEC gradient is observed around 18:00 UT. TEC gradient increases from East to the West region on the plots.

Fig. 6. shows the plot of TEC gradient for September 27, 2014 for a magnetically disturbed day. The plot is around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively. The TEC gradient value increases from sunrise around 06:00 UT (0.0799 TECU/km) to an afternoon maximum around 15:00 UT (0.45 – 0.55 TECU/km) and then decreases from around 18:00 UT (0.15 – 0.2 TECU/km). TEC gradient is observed at nighttime around 00:00 UT (0.3068 – 0.307 TECU/km). Minimum value in TEC gradient is observed around 06:00 UT (0.0799 TECU/km). TEC gradient increases from East to the West region on the plots.

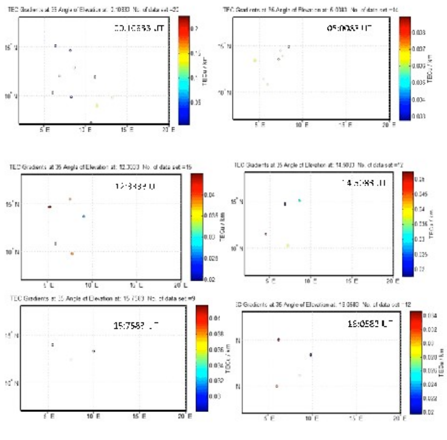

Fig. 5. Plot of TEC gradient for June 18, 2014 for magnetically disturbed day at around 00:00 UT, 05:00 UT, 12:00 UT, 14:00 UT, 15:00 UT and 18:00 UT respectively

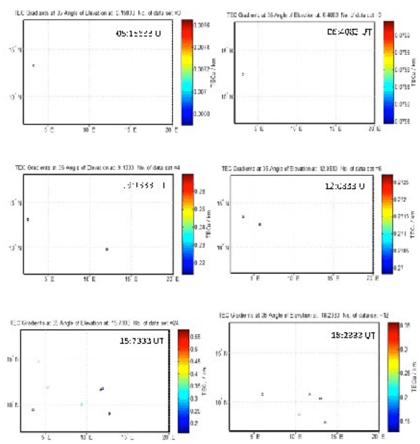

Fig. 6. Plot of TEC gradient for September 27, 2014 for magnetically disturbed day at around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively.

Figiures 7 shows the plot of TEC gradient for December 17, 2014 for a magnetically quiet day. The plot is around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively. The TEC gradient value increases from sunrise at around 06:00 UT (0.032 – 0.033 TECU/km) to an afternoon maximum between 12:00 and 16:00 UT (0.2 – 0.25TECU/km) and then decreases from around 18:00 UT (0.017 – 0.018 TECU/km). TEC gradient is observed at nighttime around 00:00 UT (0.05 – 0.1 TECU/km). The minimum value in TEC gradient is observed around 18:00 UT. TEC gradient increases from East to the West region on the plots.

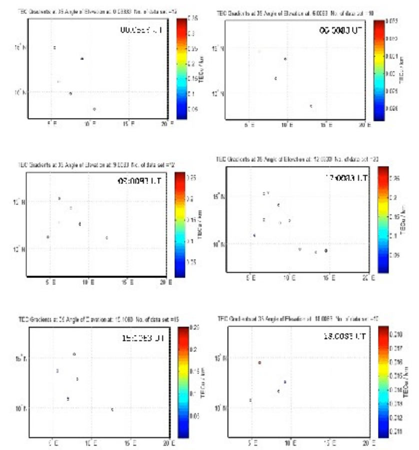

Fig. 7. Plot of TEC gradient for December 17, 2014 for magnetically disturbed day at around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively.

Figures 8 shows the plot of TEC gradient for December 29, 2014 for a magnetically disturbed day. The plot is around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively. The TEC gradient value increases from sunrise at around 06:00 UT (0.011 – 0.012 TECU/km) to an afternoon maximum between 12:00 and 16:00 UT (0.15 – 0.2 TECU/km) and then decreases from around 18:00 UT (0.005 – 0.006 TECU/km). TEC gradient is observed at nighttime around 00:00 UT (0.016 – 0.018 TECU/km). The minimum value in TEC gradient is observed around 18:00 UT. TEC gradient increases from East to the West region on the plots.

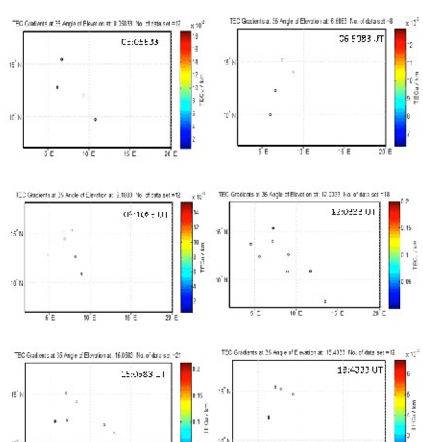

Fig. 8. Plot of TEC gradient for December 17, 2014 for magnetically disturbed day at around 00:00 UT, 06:00 UT, 09:00 UT, 12:00 UT, 15:00 UT and 18:00 UT respectively.

DISCUSSION

The diurnal variations in TEC gradients observed over Nigeria showed an increase in TEC gradient from about sunrise to an afternoon maximum and then falls to attain a minimum just before sunset. The results obtained showed increase in TEC gradient from sunrise to an afternoon maximum and decrease before the sunset with the minimum values of TEC gradient recorded between 05:00 and 07:00 UT (0.011 – 0.012 TECU/km), while the peak values were observed between 12:00 and 16:00 UT (0.54 – 0.55 TECU/km).

The seasonal variations shows low values in TEC gradient in the solstice months of June and December (0.28 – 0.3 TECU/km), whereas slightly higher values were observed in the equinox months of March and September (0.54 – 0.55 TECU/km). The results obtained show a regular pattern in the increase in TEC gradients from East to the West region of the plots. In general, the TEC gradient revealed higher values in daytime than in the nighttime. This is attributed to high intensity of solar radiation in the daytime which brings about higher ionization due to high level of photoionization.

The day-to-day variations of TEC may be attributed to the changes in solar activity which is associated with changes in the intensity of the incoming radiations *(Kane, 1980; Mendillo et al., 1980; Modi & Lyer, 1989)*. The diurnal variation in TEC gradient shows that the time at which TEC gradient attains maximum vary from day to day. Large variations of TEC gradients are observed in daytime while nighttime variations are found to be almost constant. However, this result shows a similar trend that is in accordance with the diurnal variation in TEC at some other locations in the earlier works of *Rastogi et al. (1971), Warnant (2000), Rama Rao et al. (2006a, b), Bagiya et al. (2009), Chauhan et al. (2011), Bolaji et al. (2012), Rabiu et al. (2017)* and others, which showed that the diurnal variation in TEC shows a minimum value during the early morning, followed by an afternoon maximum and gradual fall after sunset.

Data during the magnetically quiet and disturb periods for the representative months of March, June, September and December have been considered for this study. TEC gradient variation during geomagnetic disturbed period is found to be more than the quiet period. The observation of diurnal variations in TEC show that the time at which TEC reaches diurnal peak vary from day to day and month to month *(Chauhan et al., 2011)*. In general, it is shown from the plots that peak values in TEC gradient is found during the hours of 12:00 to 16:00UT. Large variations in TEC gradient are observed in daytime, while variations at nightime are found to decrease in value.

CONCLUSION

The study on the variation of ionospheric TEC gradients over Nigeria has been carried out using data from NIGNET stations for the representative months of March, June, September and December, respectively for the year 2014. The results obtained show that the TEC gradient varies with time of the day. The TEC gradient values start to increase from sunrise between 05 UT and 07:00 UT, reach a maximum around 12:00 UT and 16:00 UT and then decrease thereafter. The results obtained revealed that the maximum value occurs between 12:00 and 16:00 UT. Similarly, the daytime minimum in the TEC gradient value occurs between 05:00 and 07:00 UT. The seasonal variations shows low values of TEC gradient in the solstice months of June and December (0.28 – 0.3 TECU/km), whereas slightly higher values were observed in the equinox months of March and September (0.54 – 0.55 TECU/km).

The accuracy of GNSS positioning can be improved via an augmentation system. GNSS augmentation system is a method of improving the navigation system's attributes, such as accuracy, reliability, through the integration of external information into the calculation process. Thus, a study on the ionospheric TEC gradient over Nigeria will help to provide external information about TEC gradient to get more accurate ionospheric delay over a region thereby bringing about improvement on the GNSS positioning accuracy and to mitigate the aforementioned effects that this parameter has on our surveying, communication and navigation industries.

REFERENCES

Alizadeh, M., Schuh, H. and Schmidt, M. (2010). Multi-dimensional modelling of electron density using spherical harmonics and chapman function. Geophysical Research Abstracts, vol 12, EGU2010-4103-1.

Azpilicueta, F., and Brunini, C. (2011): A new concept regarding the cause of ionosphere semiannual and annual anomalies. Journal of Geophysical Research. 116:A01307. doi:10.1029/2010JA015977

Bagiya, M. S., Joshi, H. P., Iyer, K. N., Aggarwal, M., Ravindran, S., and Pathan, B. M. (2009): TEC variations during low solar activity period (2005–2007) near the Equatorial Ionospheric Anomaly Crest region in India, Annals of Geophysics, 27, 1047–1057. doi:10.5194/angeo-27-1047-2009.

Bevis, M., Businger, S., Chiswell, S., Herring, T. A., Anthes, R. A., Rocken, C., and Ware, R. (1994). GPS meteorology: mapping zenith wet delays onto precipitable water. Journal of Applied Meteorology, Vol. 33, pp. 379-386.

Bishop, G. J., Coco, D. S., and Coker, C. (1991) Variations in Ionospheric Range Error with GPS Look Direction. Proceedings of ION GPS-91, the 4th InternationalTechnical Meeting of the Satellite Division of The Institute of Navigation, Albuquerque, NM, 11-13 September, The Institute of Navigation, Alexandria(VA), pp.1045-1054.

Chauhan, V., and Singh, O. P. (2010). A morphological study of GPS-TEC data at Agra and their comparison with the IRI model. Advances in Space Research. 46, 280– 290.

Chauhan, V., Singh, O. P., and Singh, B. (2011). Diurnal and seasonal variation of GPS-TEC during a low solar activity period as observed at a low latitude station Agra. Indian Journal of Radio & Space Physics, 40(1), 26-36.

Dabas, S. R. (2000). Ionosphere and its Influence on Radio Communication. Journal of Science Education, 5, 28 – 43.

Davies, K. (1990). Ionospheric radio. IEE Electromagnetic waves series, 31, Peter Peregrinus Ltd, Exeter.

Davies, K., and Liu, X. M. (1991). Ionospheric slab thickness in middle and low latitudes. Radio Science, vol.26, pp. 997-1001.

E. D. Kaplan and C. J. Hegarty, "Understanding GPS Principles and Applications," 2nd edition, Artech House Inc., Norwood, MA, 2006, pp.387388.

Eleman, F.: The geomagnetic field, in: Cosmical Geophysics, Chap. 3, edited by: Egeland, A., Holter, O., and Omholt, A., Scandinavian University Books, Oslo, 45–62, 1973.

El-Rabbany, A. (2002). The Global Positioning System. Massachusetts, USA: Artech House Inc. Retrieved from www2.pv.infn.it/~genova/gps/Rabbani.pdf.

Fayose, R. S., Babatunde, R., Oladosu, O. and Groves, K. (2012). Variation of Total Electron Content [TEC] and Their Effect on GNSS over Akure, Nigeria, Applied Physics Research, 4(2). doi:10.5539/apr.v4n2p105. ftp://cddis.gsfc.nasa.gov/pub/gps/data/daily

Feng, Y (2003), Combined Galileo and GPS: A Technical Perspective. Journal of Global Positioning Systems, 2 (1): 67-72.

Galav, P., Sharma, S., Pandey, R. (2010). Total electron content in peninsular India during the eclipse of 15 January 2010, Current Science, 99 (6), 732.

Galileo (2003). Mission Requirement Document (MRD). European Commission, Issue 5–Rev. 1.1, 27. March 2003. Available at http://www.Galileoju.com.

Galileo (2005). Mission High Level Definition (HLD) (2002). European Commission Communication Document, W. Doc. 2002/05, Version 3, 23. Retrieved from http://www.Galileoju.com.

Gopi, S. (2012). RINEX GPS-TEC program Version 2.2.0, Boston College.

Habarulema JB. A (2010). Contribution to TEC modelling over Southern Africa using GPS data [PhD Thesis]. Rhodes University.

Habarulema, J. B., McKinnell, L. A., and Opperman, B. D. (2010). TEC measurements and modeling over Southern Africa during magnetic storms; a comparative analysis. Journal of Atmospheric and Solar Terrestrial Physics, 72, pp. 509–520.

Hanslmeier, "The Sun and Space Weather," Kluwer Academic Publishers, Heinrichs, G., Germany, G., Winkel, J., Drewes, C., Maurer, L., Springer, A., Wicpalek, C., (2005). A Hybrid Galileo/UMTS Receiver Architecture for Mass Market Applications. GNSS 2005. Retrieved from http://www.gawainreceivers.com/publications/IfEN_Paper_GAWAIN_GNSS 2005.pdf.

Hernandez-Pajares M, Juan J, Sanz J. (1997). Neural network modeling of the ionospheric electron content at global scale using GPS. Radio Sci.; 32:1081e90.

Hofmann-Wellenhof B, Lichteneeger H, Collins J. Global positioning system: theory and practice. Wien, New York: Springer-Verlag; 2001.

Hugentobler, U., Schaer, S., and Fridez, P. (2001). Bernese GPS software, Version 4.2. Switzerland: Astronomical Institute, University of Bern.

Jakowski, N. (1996). TEC Monitoring by using satellite positioning system, in Modern Ionospheric Science. Journal of Atmospheric and Solar Terrestrial Physics, 60, 371-390, 1996.

Jakowski, N., Heise, S., Wehrenpfenning, S., and Schluter, S. (2001). TEC monitoring by GPS – a possible contribution to space weather monitoring. Physics and Chemistry of the Earth, (C) 26, 609–613, 2001.

Jakowski, N., Heise, S., Wehrenpfenning, S., Schluter, S., and Reimer, R. (2002). GPS/GLONASS-based TEC measurements as a contributor for space weather forecast. Journal of Atmospheric and Solar Terrestrial Physics, 64, 729–735, 2002.

Jakowski, N., Mayer, C., Hoque, M. M., and Wilken, V. (2011). Total electron content models and their use in ionosphere monitoring. Radio Science, 46, pp. 1–11.

Jatau, B., Fernandes, R. M. S., Adebomehin, A., and Gonçalves, N. (2010). NIGNET – The New Permanent GNSS Network of Nigeria. FIG Congress 2010 Facing the Challenges – Building the Capacity, Sydney, Australia, 11-16 April 2010.

Klobuchar JA. Ionospheric effects on GPS. In: Parkinson BW, Spilker JJ, editors. Global positioning system: theory and applications, vol. 2. Progress in Astronautics and Aeronautics; 1996. p. 164.

Klobuchar, J.A. (1996). Ionospheric effects in Global Positioning System: theory and applications, I, ed. Parkinson, B. W., and Spilker, J. J., American Institute of Aeronautics and Astronautics, Washington, D.C., USA.

Lachapelle, G., Cannon, K., and Alves, P. (2002). How Will Galileo Improve Positioning Performance? GPS World, 13 (9): 38 – 48.

Leandro RF, Santos MC. (2007). A neural network approach for regional vertical total electron content modeling. Studia Geophysica et Geodaetica; 51:279e92. http://www.ann-geophys.net.

Liu, J. Y., Chuo, Y. J., Shan, S. J., Tsai, Y. B., Chen, Y. I., Pulinets, S. A. and Yu,S.B. (2004). Preearthquake Ionospheric Anomalies Registered by Continuous GPS TEC Measurements. Annals of Geophysics, pp. 1588-1589.

Liu, J. Y., Tsai, H. F., and Tsai, L. C. (1999). Ionospheric total electron content observed during the 24 October 1995 solar eclipse, Advances in Space Research, 24(11), 1495-1498.

Liu, L. B. and Chen, Y. D. (2009). Statistical analysis of solar activity variations of total electron content derived at Jet Propulsion Laboratory from GPS observations, Journal of Geophysical Research, 114, A10311. doi:10.1029/2009JA014533.

Liu, L. B., Zhao, B. Q., Wan, W. X., Ning, B. Q., Zhang M. L., and He, M. S. (2009). Seasonal variations of the ionospheric electron densities retrieved from Constellation Observing System for Meteorology, Ionosphere, and Climate mission radio occultation measurements, Journal of Geophysical Research, 114, A02302. doi:10.1029/2008JA013819.

Liu, L., Wan, W., Yue, X., Zhao, B., Ning, B., and Zhang, M. L. (2007). The dependence of plasma density in the topside ionosphere on solar activity level, Annals of Geophysics, 25(6), 1337–1343.

Liu, Z. Z., and Gao, Y. (2001). Ionospheric tomography using GPS measurements. Proceedings of the International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, June 5-8, Banff, Alberta, Canada, 111-120. Loewe, C. A. and Prölss,

Mannucci, A. J., Tsurutani, B. T., Iijima, B. A., Komjathy, A., Saito, A., Gonzalez, W. D., ... Skoug, R. (2005). Dayside global ionospheric response to the major interplanetary events of October 29–30, 2003 ''Halloween storms,'', GeophysicalResearch Letters, 32, L12S02. doi:10.1029/2004GL021467. Netherlands, 2002, pp. 169-171.

Mukhtarov, P., Pancheva, D., Andonov, B., and Pashova, L. (2013). Global TEC maps based on GNSS data: 1. Empirical background TEC model. Journal of Geophysical Research: Space Physics, 118, doi:10.1002/jgra.50413.

Mulassano, P., Dovis, F., and Cllomb, F. (2004). European projects for innovative GNSS-related applications. GPS Solutions, 7, 268-270.

Ojigi, L. M. (2014). GEOM 810 Satellite Altimetry and Applications, Course Notes. Department of Geomatics, Ahmadu Bello University, Zaria, Nigeria.

Opperman, B. D. L. (2007). Reconstructing Ionospheric TEC over South Africa using signals from a regional GPS network. (Doctoral thesis, Rhodes University).

Pedatella, N. M., Lei, J., Larson, K. M., and Forbes, J. M. (2009). Observations of the ionospheric response to the 15 December 2006 geomagnetic storm: Longduration positive storm effect. Journal of Geophysical Research, 114, pp.12313-12323.

Perevalova, N. P., Afraimovich, E. L., Voeykov, V., and Zhivetiev, I. V. (2008). Parameters of large-scale TEC disturbances during the strong magnetic storm on 29 October 2003. Journal of Geophysical Research, vol.113, pp.13-26.

Perevalova, N. P., Polyakova, A. S., and Zalizovski, A. V. (2010). Diurnal variations of the total electron content under quiet heligeomagnetic conditions, Journal of Atmospheric and Solar-Terrestrial Physics, 72, 997–1007.

Priya, S., and Parameswari, A. (2013). Predictive Models for Vertical Total Electron Content in Ionosphere. International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, 2, Issue-5.

Rama Rao, P. V. S., Gopi, K. S., Niranjan, K., and Prasad, D. S. V. T. (2006). Temporal and spatial variations in TEC using simultaneous measurements from the Indian GPS network of receivers during the low solar activity period of 2004–2005, Annals of Geophysics, 24, 3279–3292, doi:10.5194/angeo-24-3279-2006.

Rao PVS, Gopi KS, Niranjan K, Prasad SVVD. (2006). Temporal and spatial variations in TEC using simultaneous measurements from the Indian network of receivers during the low solar activity period of 200&2005. Ann Geophys; 24:3279e92.

Ray, J. (2000). Mitigation of GPS code and carrier phase multipath effects using a multiantenna system. (Doctoral Thesis, Department of Geomatics Engineering, University of Calgary, Calgary, Canada). Retrieved from www.ucalgary.ca/engo webdocs/MEC/00.20136.JayantaRay.pdf.

Ray, J., Cannon, M. E., and Fenton, P. (1998). Mitigation of static carrier phase multipath effects using multiple closely-spaced antennas. Proceedings of ION GPS-98, Nashville, Tennessee, Institute of Navigation, pp. 1025-1034.

Schunk, R. W., and Nagy, A. F. (2000). Ionospheres. New York: Cambridge University press.

Shrestha, S. M. (2003). Investigations into the Estimation of Tropospheric Delay and Wet Refractivity Using GPS Measurements. (Master's thesis, University of Calgary,Alberta).Retrieved from:http://www.geomatics.ucalgary.ca/links/Gradheses.html, last accessed October 29, 2014.

van Dierendonck, A. J., Fonton, P., and Ford, T. (1992). Theory and performance of narrow correlator spacing in a GPS receiver. Navigation, 30, No. 3 Fall, pp. 265-283.

Ya'acob, N., Abdullah, M. E, and Ismail, M. (2010). GPS Total Electron Content (TEC) Prediction at Ionosphere Layer over the Equatorial Region, Trends in Telecommunications Technologies, Christos J Bouras (Ed.), ISBN: 978-953-307-072-8, InTech, DOI:10.5772/8474. Retrieved from:http://www.intechopen.com/books/trends-in-telecommunicationstechnologies/gpstotal-electro-content-tec-prediction-at-ionosphere-layer-overthe-equatorial-region.

Ya'acob, N., Abdullah, M., Ismail, M., and Zaharim, A. (2009). Model Validation for GPS Total Electron Content (TEC) using 10th Polynomial Function Technique at an Equatorial Region. WSEAS Transactions on Computers, 8, pp.15331542.

Yizengaw, E., and Essex, E. A. (2002). Storm Time Seasonal Variation of TEC on the Southern Hemisphere Mid-Latitude Regions Using Signals from Gps Satellite. OIST-4 proceedings, pp.221-224.

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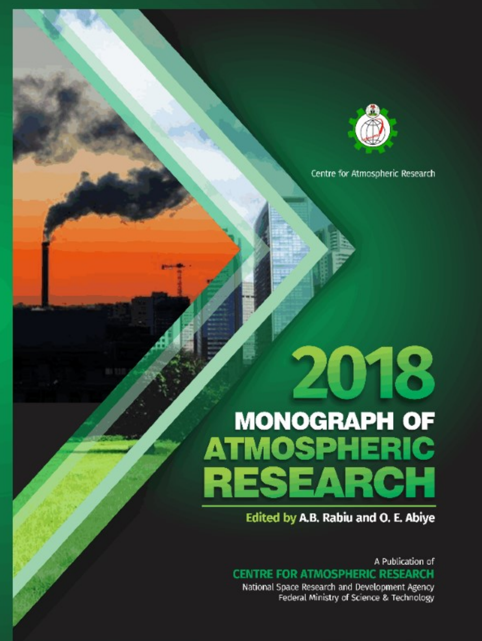

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