Original Research Article

Seasonal Variations of Ionospheric Scintillations and Total Electron Content over a Terrestrial Point within Magnetic Anomaly Region

Abstract

The dual frequency signals from the GPS satellites were recorded and analyzed to study the ionospheric variations in terms of Total Electron Content (TEC) as well as the Scintillation index (S4). Seasonal variations of Total Electron Content as well as the ionospheric scintillation activity within the Magnetic anomaly region were examined. TEC maximizes during Equinox months (March, April, September, October), and minimizes during the winter months (November, December, January, February), with intermediate values during summer months (May, June, July, August), showing a semiannual variation. The semiannual variation of TEC was asymmetry with a maximum in Spring Equinox. The average value for TEC in 2007, 2008 and 2009 were 48.34, 42.89 and 45.64 TECU respectively while the average of Scintillation index (S4) for each of the years was 0.103.

Key words: *Total Electron Content, Semiannual Variation, Equinox, Ionospheric*

Introduction

The ionosphere varies from place to place and from time to time. In other word the ionosphere exhibits both temporal and spatial variations hence it is important to study it at as many places as possible and for as long as possible. Equatorial Scintillations have not yet been well-understood (IHY-Africa Report, 2007). Ionospheric phenomena is referred to as total electron content and associated with scintillations that undergo spatial variations.

Significant research on ionospheric study has been done and several ionospheric models have been introduced for mid-latitude regions. Comparatively, few corresponding researches have been done on the low latitude (equatorial) ionosphere. The ionosphere in Nigeria is unique because of her location near the equator, where a lot of phenomena such as the equatorial anomaly and fountain effect make it interesting for studies. There are however, significant differences in the structure and effect on radio propagation of the ionosphere at these latitudes including the equatorial electrojet and the accompanying equatorial anomaly, greater absorption and the geomagnetic field orientation being nearly horizontal. The results obtained from this study will also be of interest to civilian users, particularly those attempting to achieve high levels of accuracy in equatorial regions.

Equatorial scintillations, on the other hand, are produced by irregularities in the F-layer of the equatorial ionosphere following the passage of the evening terminator and tend to disappear soon after midnight. In these regions, the most severe scintillations are associated with the crests of the equatorial anomaly which are centred approximately 15° either side of the magnetic equator (Aarons 1977). As equatorial scintillations are coupled with anomaly, they tend to become worse during the years of solar maximum when the anomaly is at its greatest.

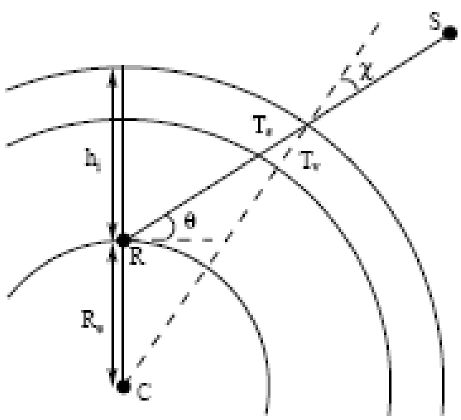

Figure 1: Geometry of a GPS satellite-receiver link

Slant TEC is a measure of the total electron content of the ionosphere along the ray path from the satellite to the receiver, represented in Figure 1 above as the quantity Ts. It can be calculated using pseudorange and carrier phase measurements. The receiver (known as a 'codeless' receiver because it does not require knowledge of the C/A or P pseudorandom noise codes), by cross correlating the L1 and L2 modulated carrier signals, obtains the time delay of the P-code and the carrier phase difference (Kyriaky Eftaxiadis et. al., 1999). These are used to calculate the pseudorange and differential carrier phase respectively, and hence the slant code TEC and slant phase TEC respectively.

As slant TEC is a quantity which is dependent on the ray path geometry through the ionosphere, it is desirable to calculate an equivalent vertical value of TEC which is independent of the elevation of the ray path. Vertical TEC enables TEC to be mapped across the surface of the earth. Figure 1 depicts the relationship between slant (T_s) and vertical (T_v) TEC. The two quantities are related by an obliquity factor, O(θ), as follows:

$$T_S = T_V O(\theta)$$

From simple trigonometry the obliquity factor can be shown to be

$$O(\theta) \quad {}^{1}\!\Big/ Cos\left[\arcsin\left(\frac{R_e Cos(\vartheta)}{R_e + h_i}\right)\right]$$

where R_e is the mean radius of the Earth and h_i is the effective ionospheric height.

Methodology

The data obtained from NovAtel GSV 4004 GPS-SCINDA receiver were used for this study. The Scintillation Network and Decision Aid (SCINDA) being a network of ground-based receivers monitors scintillations at the ultra high frequency (UHF) and L-band frequencies caused by electron density irregularities in the equatorial ionosphere (Groves et al., 2007). It is a real-time, data driven, communication outage forecast and alert system. The purpose is to aid the specification and prediction of communications degradation due to ionospheric scintillation in the equatorial region of the Earth. UHF and L-band scintillation parameters are measured, modeled, and propagated in time to provide a regional specification of the scintillation environment in an effort to mitigate the impacts on the satellite communications (SATCOM) community.

The GPS-SCINDA receiver is capable of tracking signals from GPS satellites simultaneously at the L1 frequency (1575.42 MHz) and the L2 frequency (1227.6 MHz). The Slant Total Electron Content (STEC) is computed from the combined L1 and L2 pseudorange and carrier phase measurements for all the visible GPS satellites. The Signals were sampled at 50Hz and 1Hz and recorded every minute.

The STEC is obtained from the dual frequency code measurements using the relation:

$$STEC = \frac{1}{40.3}\left(\frac{1}{L1^2} - \frac{1}{L2^2}\right)^{-1}(P1 - P2) + TEC_{cal} \quad 1$$

where P1 is the pseudorange at L1; P2 is the pseudorange at L2, and TEC_{cal} is the bias error correction.

The equivalent vertical value of TEC (VTEC) which is independent of the elevation of the ray path was obtained by taking the projection from the slant to vertical using the thin shell model assuming a height of 350 km, following the technique given by Klobuchar (1996):

$$VTEC = STECos\left[\sin^{-1}\left(\frac{R_e \cos\theta}{R_e + h_{max}}\right)\right]$$

where R_e=6378 km, h_{max}=350 km, θ = elevation angle at the ground station.

Results

The mean vertical total electron content (VTEC) variations during different months and seasons recorded at Akure for the years 2007, 2008 and 2009, are shown in figures 2, to 7 and mean Scintillation Index (S4) variations during different months and seasons for the same period are shown in figures 8, to 13. It can be observed from Figure 1 that in the spring (September, October and November) and autumn (March, April and May), the Ionospheric VTEC values were generally higher than those of the other two seasons: Summer (December, January and February) and winter (June, July and August).

However, in the summer season, the VTEC values in December were as high as the spring and autumn and much higher than those of the other two months of the same season which is in good agreement with the work of Wu et. al., 2006.

In 2007, a few months (February, March and April) showed a bigger spread of VTEC which may be due to the occasional occurrences of solar flares pushing for higher TEC which could be probably attributed to high solar activity.

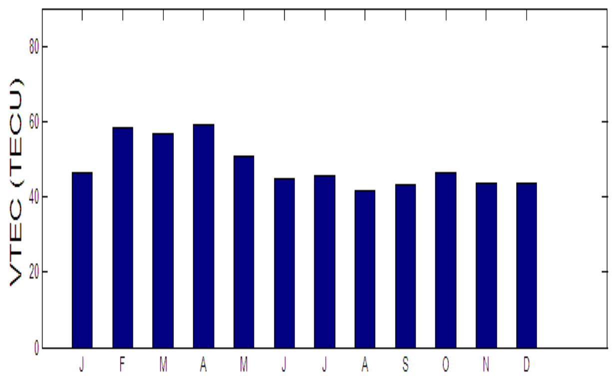

Figure 2: 2007 Monthly variations of VTEC

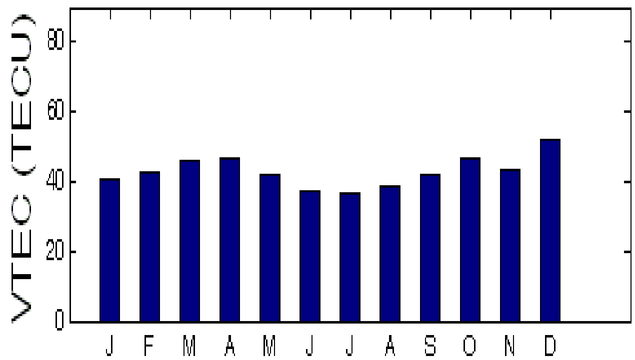

Figure 3: 2008 Monthly variations of VTEC

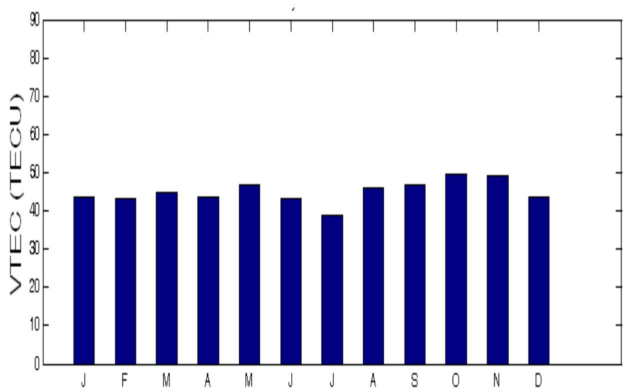

Figure 4: 2009 Monthly variation of VTEC

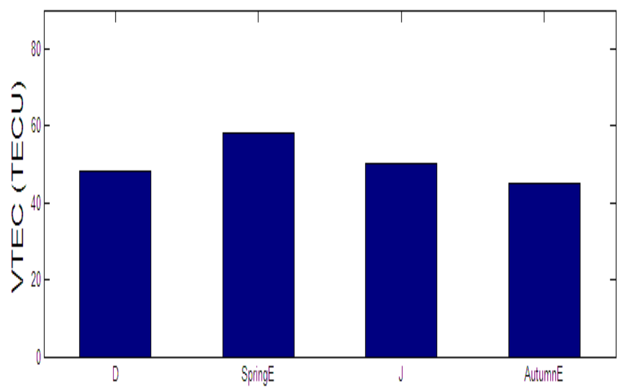

Figure 5: 2007 Seasonal variations of VTEC

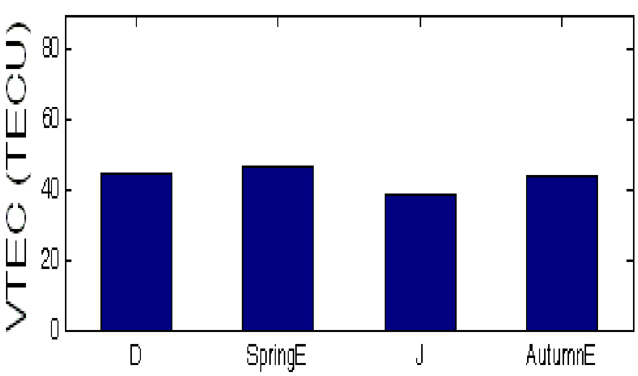

Figure 6: 2008 Seasonal variations of VTEC

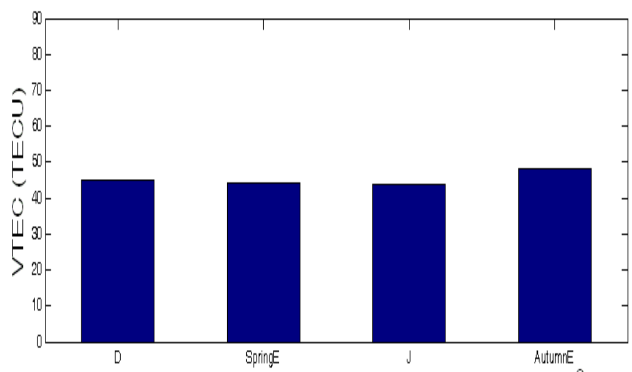

Figure 7: 2009 Seasonal variation of VTEC

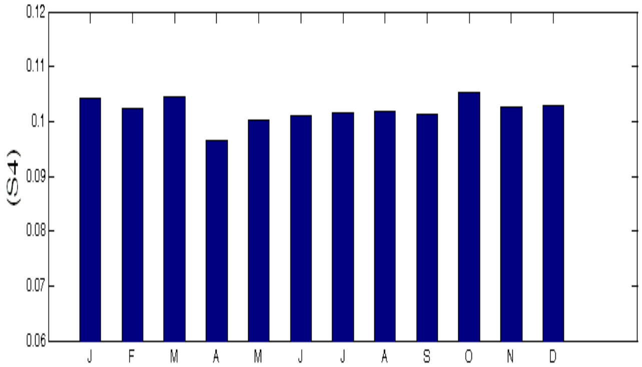

Figure 8: 2007 Monthly variations of S4

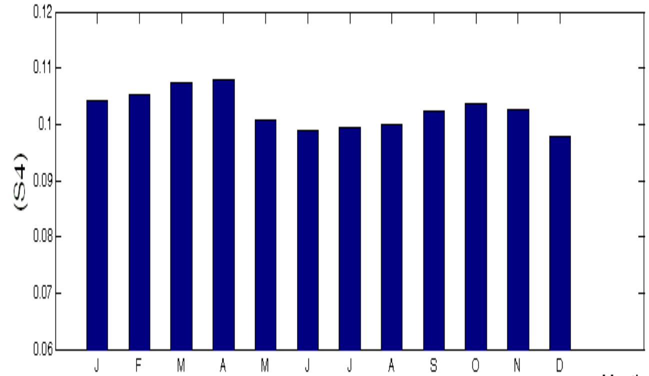

Figure 9: 2008 Monthly variation of S4

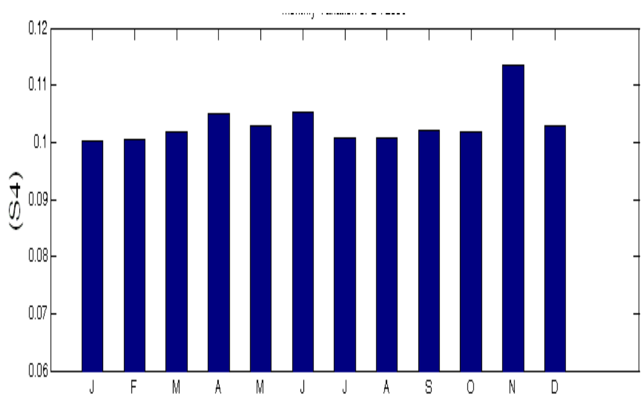

Figure 10: 2009 Monthly variation of S4

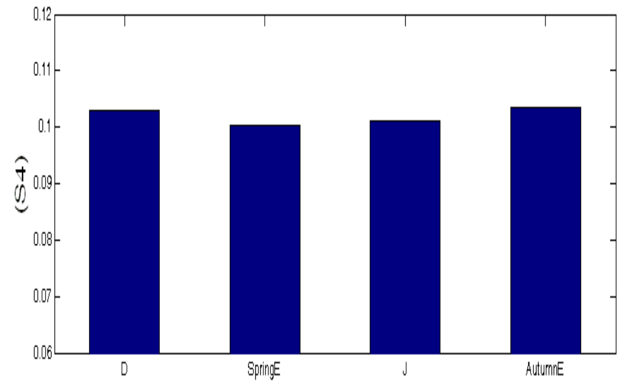

Figure 11: 2007 Seasonal variation of S4

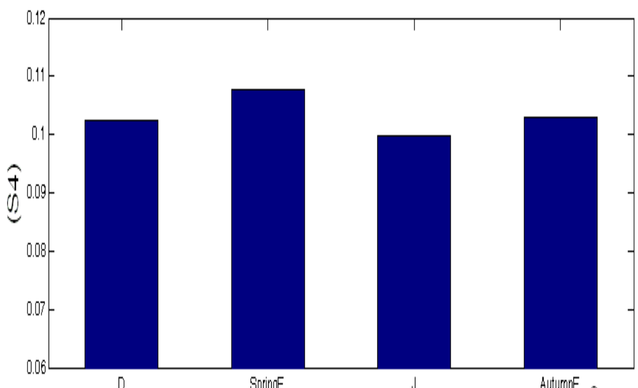

Figure 12: 2008 Seasonal variation of S4

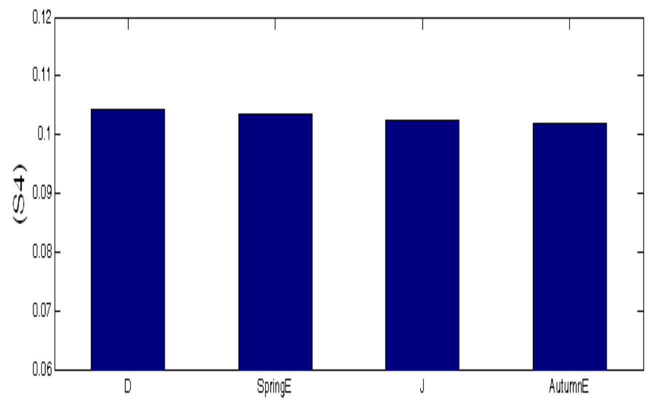

Figure 13: 2009 Seasonal variation of S4

In the period of high solar activity, even though the average absolute monthly VTEC increases, the spread is relatively low showing that VTEC values within the same month are consistently high (Wu et. al., 2006). This could be attributed to winter anomaly a daytime phenomenon. TEC maximizes during Equinox months (March, April, September, October), and minimizes during the winter months (November, December, January, February), with intermediate values during summer months (May, June, July, August), showing a semi-annual variation. The maximum value occurred in 2007 Equinox having a value of 60TECU, followed by 50TECU in 2008 and 48TECU in 2009. Similarly the minimum value occurred in D season with the value of vertical total electron content (VTEC) as 48 TECU, 42 TECU, and 43 TECU in 2007, 2008 and 2009 respectively. It could be seen that in the spring and autumn the daytime ionospheric TEC values were greater than those of the other two seasons (summer and winter). In the summer season, the TEC values in December were as great as in spring and autumn. The results from the winter season show that TEC values were very smaller than those of other three seasons. The semi-annual variation of TEC was asymmetry with a maximum in Spring Equinox. An increase in the electrodynamic drift will lift more plasma from the equatorial region and diffuse it down along the field lines to higher latitudes and this can result in the increase of the vertical total electron content (VTEC). This semiannual variation may be due to the annual and semiannual changes that are observed in the Earth's heating and ionization during the yearly path around the Sun (Rabiu, 2004). Equatorial scintillations also show a strong seasonal dependence, being greatest during the months of April to August in the Pacific longitudinal sector, but a minimal during these months in the American, African and Indian sectors.

CONCLUSIONS

TEC maximizes during Equinox months (March, April, September, October), and minimizes during the winter months (November, December, January, February), with intermediate values during summer months (May, June, July, August), showing a semiannual variation. The semiannual variation of TEC is asymmetry with a maximum in Spring Equinox which is due to the changes that are observed in the Earth's heating and ionization during the yearly path around the Sun (Rabiu, 2004). The occurrence time of the maximum/minimum ionosphere TEC values varies with season. A high positive correlation (r = 0.61) was obtained between daytime peak VTEC and Solar F10.7 flux for the period of study.

Reference

Aarons, J. A., “Equatorial Scintillations (1977): A Review”, IEEE Transactions on Antennas and Propagation, vol. AP-25, No. 5, pp. 729-736.

Brahmanandam P. S., Uma G. and Pant T. K. (2017): Ionosphere VHF scintillations over Vaddeswaram (Geographic Latitude 16.31Â°N, Geographic Longitude 80.30Â°E, Dip 18Â°N), a latitude Indian station -A case study, Advances in Space Research, Vol. 60, Issue 8, , pp. 1688-1697.

Brahmanandam P. S., Uma G., Chu Y. H. and Liu J. Y. (2012): Global S4 index variations observed using FORMOSAT‐3/COSMIC GPS RO technique during a solar minimum year; Journal of Geophysical Research: Space Physics, 117 (A9) & ISSN: ISSN: 0148-0227.

Grooves Keith and Charles. Carrano (2009): Scintillation Impacts on GPS Workshop for Sustainable Development in Navigation Studies and Technology in Africa, lecture delivered at Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, March 23 – April 9.

Grooves Keith (2009): SCINDA Status & Plans, lecture delivered at Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, April 07.

Klobuchar, J A. (1996): “Ionospheric Effects on GPS”, in “Global Positioning System: Theory and Applications, Vol 2”, edited by Parkinson, B W and Spilker, J J, Progress in Astronautics and Aeronautics, Progress in Astronautics and Aeronautics, vol. 163, Chapter 12, pp. 485-515.

Klobuchar, J. A. (1996): “Ionospheric Effects on GPS”, in “Global Positioning System: Theory and Applications, vol. 2”, edited by Parkinson, B W and Spilker, J J., Progress in Astronautics and Aeronautics, vol. 164, page 485.

Kyriaky Eftaxiadis, Dr Manuel A. Cervera, Dr Richard M. Thomas (1999): “A Global Positioning System Receiver for Monitoring Ionospheric Total Electron Content” DSTO Technical Report No. DSTO-TR-0742.

Rabiu A.B. (2004): Semiannual Variation of Geomagnetic activity Ak Index and its Response; Zuma Journal of Pure and Applied Sciences, vol. 6, pp. 40-47.

Rideout, W. and A. Coster (2006): Automated GPS processing for global total electron content data, GPS Solutions, vol. 10, no. 3.

Srinivasu V. K. D., Brahmanandam P. S., Uma Gouthu, Prasad D. S. V. V. D.; & others (June 2017): Long-term morphological and power spectral studies of VHF amplitude scintillations recorded over Waltair (17.7°N, 83.3°E), India.’ Terrestrial, Atmospheric & Oceanic Sciences. Vol. 28 Issue 3, p385-394.

Van Dierendonck, A. J. (2005): GSV4004B GPS Ionospheric Scintillation & TEC Monitor (GISTM) User's Manual.

Wu Siquin, Zhang Kefei, Yuan Yunbin and Wu Falin (2006): Spatio-temporal Characteristics of the Ionospheric TEC variation for GPSnet-based Real-time positioning in Victoria; Journal of Global Positioning Systems, vol. 5 pp. 52-57.