Study of Equatorial Ionospheric Scintillation and TEC characteristics at Solar minimum using GPS-SCINDA data

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Abstract. This paper presents a study of ionospheric scintillation and the Total Electron Content (TEC) characteristics at low solar activity using GPS data from a West African location.
The data used are the scintillation index (S4) and the vertical TEC (vTEC) recorded at the GPS - SCINDA station of Abidjan (Latitude = 5.340 N, Longitude = 3.900 W). This work covers the period from January 2008 to January 2009.The results show that the scintillation is not intense with S4 values lower than 1 in most of the cases and during the course of the day. However from 2000 to 0200 local time, there are relatively high values of S4 confirming that scintillation is primarily a nighttime observed phenomenon. The scintillation shows a seasonal effect characterized by intense values in the equinoctial months compare to that of the solstice season. The vTEC in general exhibits a diurnal variation as a function of the solar zenith angle. Higher vTEC values are observed around 1500 local time and have the same seasonal variation with the S4 index.

Keywords: scintillation, ionospheric scintillation, multipath phenomenon, total electron content, satellites, GPS (Global Positioning System)

Introduction

One of the first known effects of space weather is the fluctuations in the amplitude and phase of radio signals that transit the ionosphere caused by the irregularity of electron density in the ionosphere [1]. The principal manifestation of a disturbed ionosphere on GPS signals is ionospheric scintillation, which if sufficiently intense to degrade the signal quality, reduce its information content, or caused failure of the signal reception.

The word "scintillations" typically refers to rapid amplitude and phase fluctuations in a received electromagnetic wave. The cause may be diffractive when electromagnetic waves are scattered in an irregular medium composed of many small changes in the refractive index. The fluctuations in the signal intensity are quantified by the scintillation intensity index S4 which is defines as follows:

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle}} \qquad (1)$$

where I is the signal intensity. S4 is the ration of the signal intensity standard deviation by the signal intensity mean.

Initial studies of ionospheric scintillations were primarily in the VHF and UHF radio bands and focused on the effect of the scintillations on communication signals [2].

Early investigators demonstrated that the most likely regions for observing scintillations were near the magnetic equator [3]. The scintillation amplitudes demonstrated solar cycle dependence with maximum amplitudes at the solar cycle maximum when solar UV fluxes and ionospheric density were also maximum [4]. The equatorial scintillations have also a diurnal and seasonal dependence [5, 6]. Scintillations are mainly confined to the equatorial region.

This present paper, focus on the characteristics of ionospheric scintillations and TEC at solar minimum in an equatorial region using GPS receiver. This work is done in the framework of the SCINDA project PI's by the Air Force Research Laboratory. This project aims to advise operational users in real time. Since we are currently at solar minimum (epoch 2008-2009), it is expected that both the frequency and severity of scintillation activity remain at a low level.

Data used and method of analysis

This work covers the period from January 2008 to January 2009, two years of low solar activity as illustrated by figure 1. The data used have been recorded by a NoVatel GPS receiver (model GSV 4004B) installed in the framework of the SCINDA project in Abidjan, Côte-d'Ivoire (Latitude = + 5.3440, Longitude = - 3.9004).

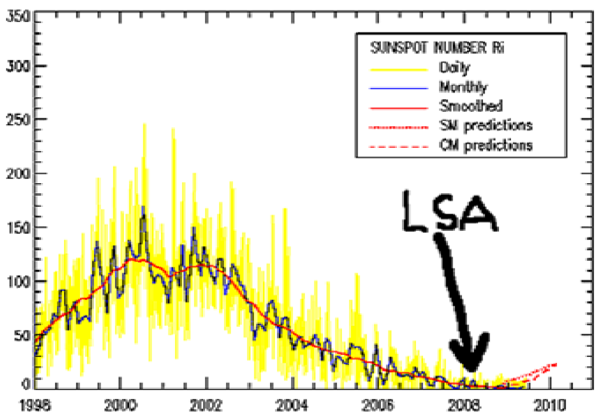

Fig 1: The sunspot Number from 1998 to 2010. (http://www.sidc.be)

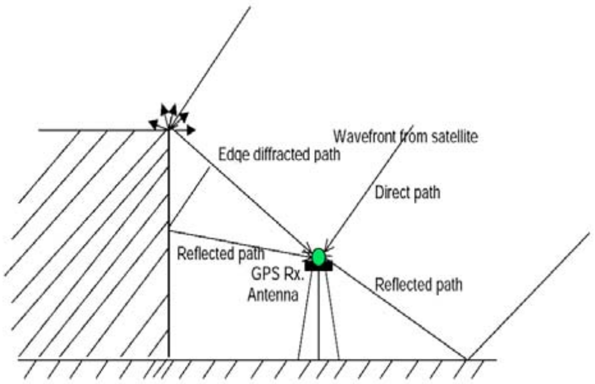

Fig. 2: Schematic explanation of a signal multipath.

The parameters are recorded every second and an average is made over each sixty (60) seconds and stored in a compressed file. The types of files generated by a GPS-SCINDA are differentiated according to their filename extensions. The parameters for this study are the S4 and the TEC among the so called ionospheric statistics stored in the compressed files with the extension *.scn. A GPS signal transmitted from a satellite may be reflected by some object or surface before being received by the antenna. Only the portion of the signal that travels along the direct path from the satellite is useful. All over contributions are called multipath that effects are merged to the proper scintillation. Figure 2 gives a schematic explanation of how the multipath occurs.

To increase the accuracy of the scintillation data, one must extract the effects of multipath. The multipath effects were cut off following the criteria of [7]. According to these authors, the multipath effects are significant when the elevation angle of the satellite signal is lower than 30^0.

The Total Electron Content (TEC), one of the most important parameter to study the characteristics of the ionosphere is defined as the integral of the electron number density along the signal path from a satellite to a receiver. Complications arise due to the hardware timing biases and cycle slips on the estimation of the TEC along a line of sight. The TEC value needs to be calibrated by subtracting satellite and receiver inter-frequency biases. The calibration technique used for this study is the one proposed by [8]. The S_4 and TEC recorded at every minute are averaged regardless the PRN of the satellite transmitting the signals to the receiver. Each season is defined by the whole of the measurements taken over one period of three (3) months. Thus, the equinox of Mars is consisted of February, March and April; solstice of June represents May, June and July; August, September and October indicate the equinox of September and finally the solstice of December gathers them November, December and January.

Results

In this section, we present the diurnal and seasonal and annual variations of the scintillation index S4 and the vertical Total Electron Content (vTEC) in terms of surface plots. The local time is along the X-axis, the day of the month along the Y-axis. The S4 and vTEC values are indicated by the colors bars. Due to data outage, we do not have any result for the month of August 2008.

The result for the scintillation index S_4

The diurnal variation

Figure 3(a-k) presents the diurnal variation of S_4 from January to December 2008.

The general trend shows by the surface plots indicate that the S4 value range from 0 to 0.14. Particularly, the smallest values are observed from 0200 to 2000 in almost the cases. The relatively high values are observed from 2000 to 0200 and ranged from 0.08 to 0.14. This general trend confirms the fact that the scintillation is significant during the night.

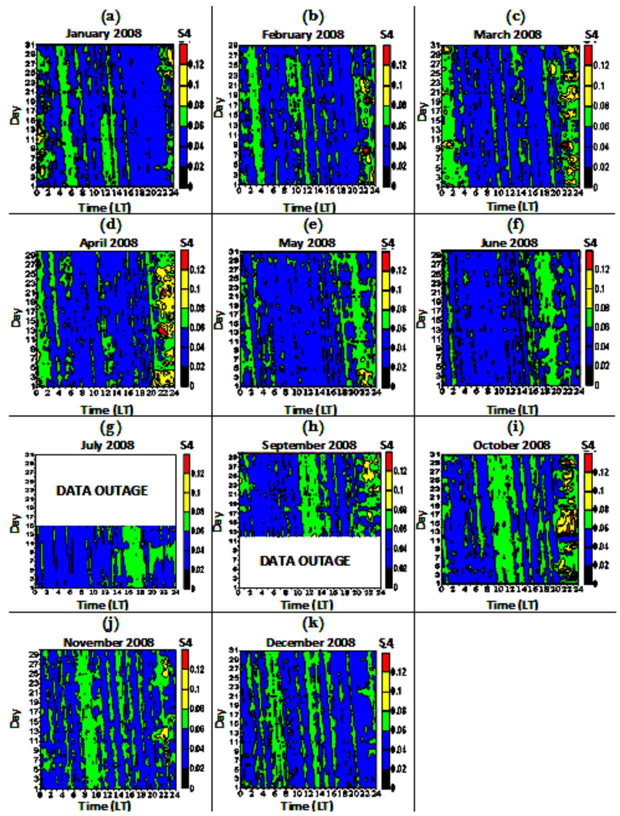

Fig 3: Diurnal variation of S4 from January to December 2008.

The seasonal and annual variation

Figure 4 (a-d) shows respectively the seasonal variation of the scintillation index S4 in March and September equinoxes and in June and December Solstices.

In March equinox, we note that the scintillation index is constantly lower than 0.08 between 0200 and 2100. However, from 2100 to 0200 the S4 index exceeds 0.08 and reaches 0.14. In September equinox, we observe the same mode of variation with a light difference. Indeed, during the time intervals going from 0000 to 2100 and from 2300 to 2400, the values of S4 are higher than 0.04 but lower than 0.08. Apart from these schedules i.e. between 2100 and 2300, the index S4 is high with values confined between 0.08 and 0.1.

In June and December solstice, the index S4 presents a variation that does not shown significant difference from 0000 to 2400 in general. The average of the index of scintillation is confined between 0 and 0.08. All things considered, we can say that the variation of the scintillation is appreciable at night. It is more significant in equinoxes than in solstices with a higher rate of occurrence in March equinox.

This result is confirmed by the annual variation that clearly exhibits the seasonal asymmetry (see figure 5).

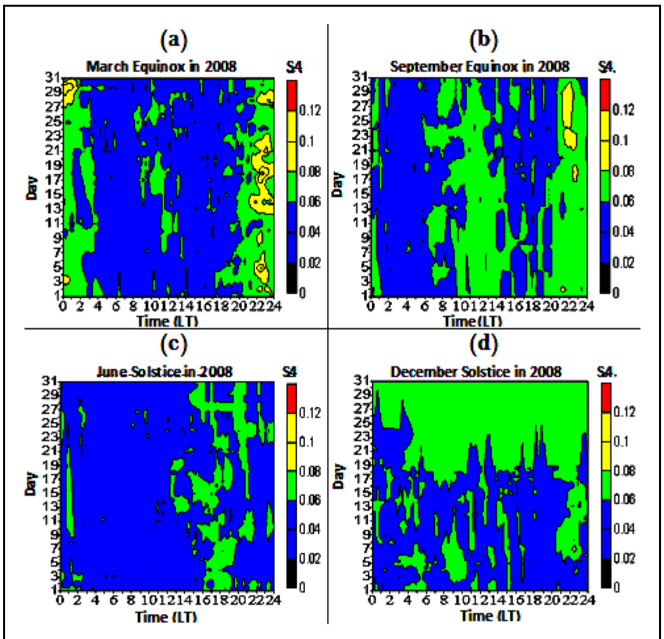

Fig 4: Seasonal variation of S4 in 2008.

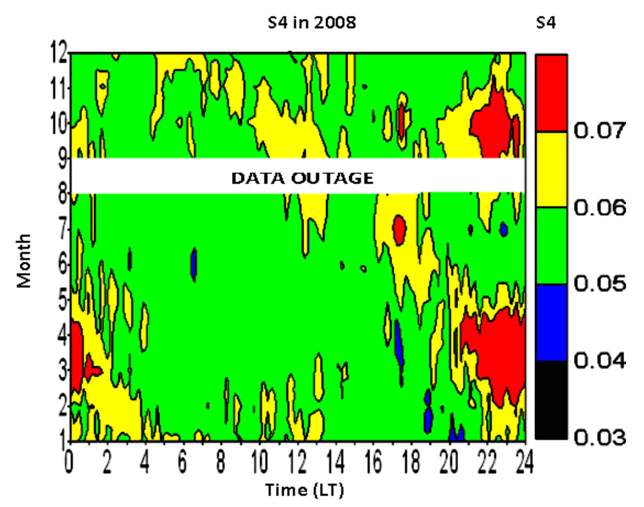

Fig 5: Annual variation of S4 in 2008.

The result for vTEC

The diurnal variation

The result for the vTEC is presented in figure 6(a-k).

The maximum value of vTEC observed from January to December 2008 is about 35 TECU. The diurnal variation shows that vTEC variation depends on the solar zenithal angle. vTEC values are lower than 20 TECU from midnight to 1100 and from 1700 to midnight. The highest values are observed during the course of the day and particularly around 1500 LT where we have values greater than 20 TECU. The highest values are observed in the months of March and April.

The seasonal and annual variation

The vTEC dependence upon the season can be easily seen from figure 7(a-d) which displayed respectively the vTEC in March and September equinox and in June and December solstice. It is observed that the vTEC values are below 20 TECU during the time interval going from 0000 to 1100 and from 1900 to 2400 LT. Its highest values are observed around 1500 LT with vTEC value reaching 40% of the average vTEC.

In September equinox, we observe the same type of variation with a light difference. The rate of highest value is lower than that of the March equinox. The case for June and December solstice presents a variation which almost does not show any particular aspect in general. The average vTEC is confined between 0 and 20 TECU with cells of 25 TECU around 1500 LT. This seasonal behavior is confirmed by the annual variation that shows two remarkable cells. The largest one during the equinoctial months and a smaller one in the solstice months (figure 8).

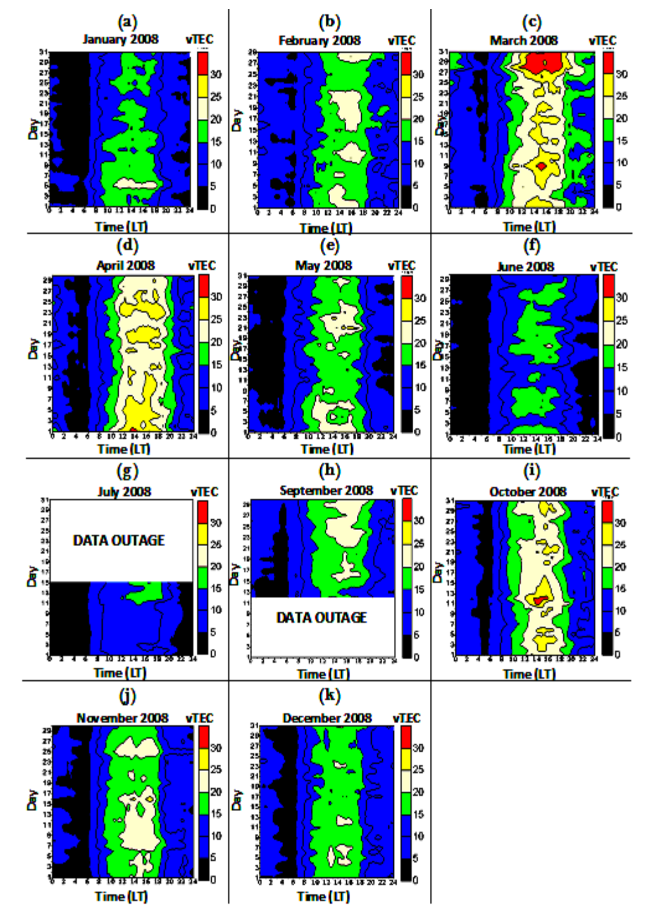

Fig 6: Diurnal variation of vTEC from January to December 2008.

Discussion and conclusion

This study is an observational overview of the characteristics of the equatorial scintillation and the TEC based on the data collected with a GPS receiver. The result exhibit an occurrence frequency of scintillation observed mainly at nighttime hours (2000-0000 extended to 0200 LT in some cases). This result is consistently in agreement with those obtained by former similar works reported by [6, 9, 10]. The result show a seasonal behavior confirm by the annual variation of S4 (see figure 5).

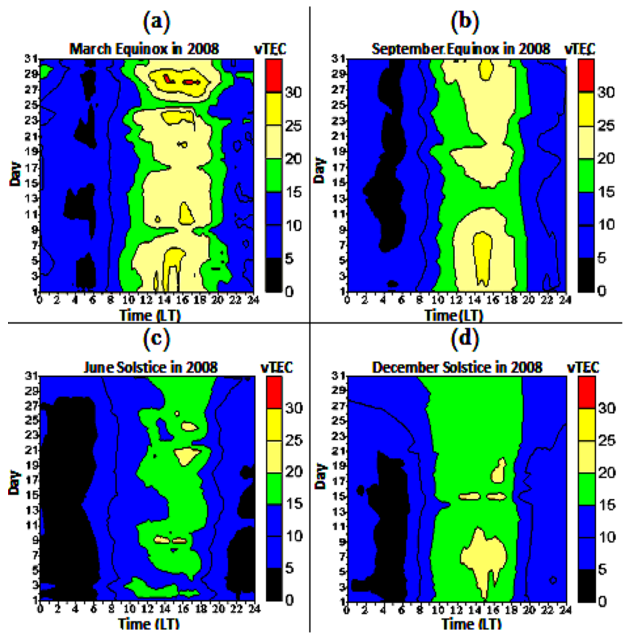

Fig 7: Seasonal variation of vTEC in 2008.

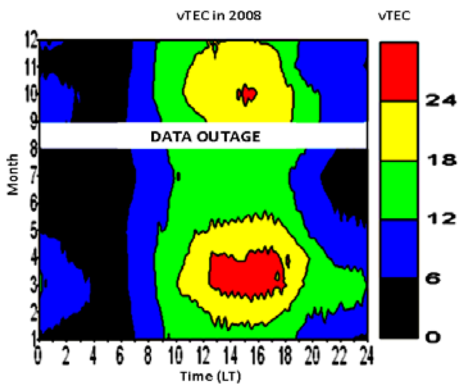

Fig 8: Annual variation of vTEC in 2008.

The diurnal and seasonal variation of the scintillation observed with the GPS data recorded in Abidjan, an equatorial station may be related to the plasma irregularity within the bubbles as reported by [11]. Some theoretical explanations of the occurrence rate of scintillation have been pointed out by [12, 13] and are consistent with our observations. In general, plasma bubbles are generated at sunset and survive until sunrise. In contrast, we have shown that scintillation is observed between sunset and two hours after midnight. This result indicates that the 400-meter scale irregularities, which cause GPS scintillations, disappear by the midnight. [14] have shown that during the generation phase of equatorial irregularities in the evening hours, the kilometer and meter-scale irregularities coexist, whereas in the later phase, the meter-scale irregularities decay but the large-scale irregularities persist. These results suggest that large-scale structures, such as plasma bubbles which have more than several ten-kilometer scale-sizes, are maintained long after small scale irregularities disappear. The seasonal asymmetry observed in terms of occurrence rate confirms the results obtained by [7, 15] in the Asian sector. On the other hand, at the longitude of Hawaii, the occurrence rate is higher in September equinox than March equinox (e.g. [16]), indicating the longitudinal dependence of the equinoctial asymmetry. The mechanism of the equinoctial asymmetry is argued by [17], but its longitudinal dependence is not fully studied. The equinoctial asymmetry of the plasma bubble occurrence and TEC over Africa, reported in the present paper, could provide important information to these studies.

References

[1] Hey, J. S., S. J. Parsons, and J. W. Phillips: Fluctuations in cosmic radiation at radio-frequencies, Nature, 158, 234, 1964.

[2] Withney, H. E., and S. Basu: The effect of ionospheric scintillation VHF/UHF satellite communication, Radio sci., 12, 123-133, 1977.

[3] Basu, S., E. Mackenzie, and Su. Basu: Ionospheric constraints on VHF/UHF communication links during solar maximum and minimum periods, Radio sci., 23, 363-378, 1988.

[4] Briggs, B. H.: Observations on star scintillations and spread-F echoes over a solar cycle, J. Atmos. Terr. Phys., 26, 1-23, 1964.

[5] Wiens, R. H., M. Afeworki, and P. M. Kintner: The annual/diurnal variation of GPS scintillation occurrence over ERITREA, European Geophysical Society, Vol. 5 (08145), 2003.

[6] Boutiouta, S., A. H. Belbachir, and H. Dekkiche: Contrôle de l'activité ionosphérique à partir des données GPS, Comtemporary Publishing International, Vol. 5 (n°4), p. 325-338, 2006.

[7] Otsuka, Y., K. Shiokawa and T. Ogawa: Equatorial ionospheric scintillations and zonal irregularity drifts observed with closely-spaced GPS receivers in Indonesia, Journal of the Meteorological Society of Japan, Vol. 84A, pp. 343-351, 2006.

[8] Carrano, C., and K. Groves: The GPS segment of the AFRL-SCINDA Global Network and the Challenges of Real-Time TEC estimation in the equatorial ionosphere, Processing of the Institute of Navigation NTM, Monterey, CA, 2006.

[9] Knight, M., and A. Finn: The Impact of Ionospheric Scintillations on GPS Performance, Proc. of ION GPS, p. 555, 1996.

[10] Visessiri, K., V. Torchakul, N. Leelaruji, and N. hermannkorn: Analyse VHF satellite signal effect by amplitude scintillation, 2003.

[11] Burke, W. J., C. Y. Huang, L. C. Gentile, and L. Bauer, Seasonal longitudinal variability of equatorial plasma bubbles, Ann. Geophys., 22, 3089–3098, 2004,

[12] Tsunoda, R. T.: Control of the seasonal and longitudinal occurrence of equatorial scintillations by the longitudinal gradient in integrated E region Pedersen conductivity, J.Geophys. Res., 90, 447-456, 1985, 1985.

[13] Maruyama, T. and N. Matuura: Longitudinal variability of annual changes in activity of equatorial spread F and plasma bubbles, J. Geophys. Res., 89, 10,903-10,912, 1984.

[14] Basu, S., Su. Basu, J. Aarons, J. P. McClure, and M. D. Cousins. On the coexistence of kilometer - and meter-scale irregularities in the nighttime equatorial F region, J.Geophys. Res., 83, 4219-4226, 1978.

[15] Maruyama, T. and M. Kawamura: Equatorial ionospheric disturbance observed through a transequatorial HF propagation experiment, Ann. Geophys., 24, 1401–1409, 2006

[16] Makela, J. J., B. M. Ledvina, M. C. Kelley, and P. M. Kintner, Analysis of the seasonal variations of equatorial plasma bubble occurrence observed from Haleakala, Hawaii, Ann. Geophys., 22, 3109–3121, 2004

[17] Maruyama, T., S. Saito, M. Kawamura, K. Nozaki, J. Krall, and J. D. Huba: Equinoctial asymmetry of a low-latitude ionosphere-thermosphere system and equatorial irregularities: evidence for meridional wind control, Ann. Geophys., 27, 2027–2034, 2009