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# Investigation of Ionosphere Scintillations Variability over Azure; a Terrestrial Point within the Equatorial Anomaly Region

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***Abstract:*** *The monitoring of Ionospheric Scintillation over a terrestrial point within equatorial anomaly region has been carried out by using the NovAtel GSV 4000B Global Positioning System Scintillation Network and Decision Aid (GPS-SCINDA) system at Akure (7.3°N, 5.2°E), Nigeria. This system is capable of tracking up to 14 Global Positioning System (GPS) satellites simultaneously. The dual frequency signals from the GPS satellites recorded and have been analyzed to study the ionospheric variations in terms of Scintillation index (S4) for the period from November 2006 to November 2009. Diurnal and mean monthly variations of the ionospheric scintillation activity as charaterised by scintillation index (S4) within the equatorial anomaly region were examined. The scintillations observed were generally weak with S4 index falling between 0.05 and 0.2*
***Key words:*** *Equatorial Anomaly, Ionospheric Scintillation, Total Electron Content*

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## I. Introduction

Ionospheric scintillation is caused by the existence of electron density irregularities in the ionosphere (Glenn MacGougan et al, 2001). Scintillations are rapid and temporal fluctuations in the amplitude and phase of transionospheric radio signals as they travel through electron density irregularities in the ionosphere. These amplitude and phase variations occur along side with high levels of solar and geomagnetic activities. Scintillations are therefore intimately linked to the underlying physical processes in the ionosphere that give rise to irregularities. Amplitude scintillations cause signal to fade below the average while phase scintillations cause loss of phase lock in GPS receivers. (Aaron and Basu, 1994). Hence, in the presence of scintillations, the performance of Earth-Space communication and navigation systems near the equator may be degraded (Sigh and Sigh, 2000). The degree of degradation depends on the depth and rate or duration of fading. The scintillation technique provides an integral measure of phase and amplitude fluctuations imposed on radio signals over a wide range of frequencies during their propagation through the ionosphere (Basu and Basu, 1981).

The ionosphere is a dispersive medium and hence its refractive index is a function of frequency. Therefore dual frequency GPS user can make use of this property to measure and correct to the first order range and range rate errors (Glenn MacGougan et al, 2001). The effects of the ionosphere on GPS include group delay of the modulated signal, carrier phase advances, and scintillations. Equatorial ionospheric scintillation occurs quite often between local sunset and midnight (Du et al., 2000). The scintillation in the daytime are mainly caused by the thin ionization layers in the E-region of the ionosphere (Woodman and Lahoz, 1976 and Dabas et al., 1992) which are often referred to as Sporadic E (Glenn MacGougan et al, 2001 and Kumar S. et al., 2007). Scintillation also has a seasonal dependence. It is less common at the American, African and Indian latitudes during the months of April to August while it has maximum frequency in the pacific region. These effects are reversed during the rest of the year (Klobuchar, 1996).

The scintillation index may be interpreted as the fractional fluctuation of the signal (e.g. S4=0.0 indicates no modulation whereas S4=1.0 indicates 100% modulation). The signal intensity is commonly detrended before using it to estimate the scintillation index.

Phase scintillation is characterized by the rapid random variation in the phase rate. The receiver carrier tracking bandwidth is usually not designed to accommodate this variation and results in loss of lock. Amplitude scintillations results in the fluctuations in the power of the received signal and can cause the received signal power to drop below the receiver tracking threshold.

Scintillations occur predominantly in the equatorial band that extends from about $20^0$S to $20^0$N of the magnetic equator, and in the auroral and polar cap regions. The processes that produce scintillations in these two regions are quite different, leading to significant differences in the characteristics of the resulting scintillations (Knight M. F., 2000).

Auroral and polar cap scintillations are mainly the result of geomagnetic storms that are associated with solar flares and coronal holes. Unlike equatorial scintillations, they show little diurnal variation in their rate of occurrence, and can last from a few hours to many days, beginning at any time during the day (Knight M. F., 200). Large and rapid variations in the plasma density are often associated with auroral (Klobuchar, 1991) and polar cap scintillations (Bishop et. al., 1994) and can lead to significant errors in differential GPS (DGPS) systems as well as rapid changes in the apparent range and range rate (Klobuchar, 1991; Klobuchar, 1996).

Auroral scintillations also show a seasonal dependence which is the reverse of that observed at low latitudes, being greatest from the autumn equinox through winter to the spring equinox, and a minimum during the summer months (Aarons et al., 1994). Indeed, the geomagnetic disturbances that excite auroral and polar cap scintillations tend to suppress the onset of equatorial scintillations during solar maximum periods (Aarons et al., 1994; Davies, 1990 and Klobuchar 1996). Because geomagnetic storm activity is linked to solar activity through solar flares and coronal holes, auroral and polar cap scintillations also show a strong dependence on the 11 year solar cycle, being most intense during solar maximum periods, but almost non-existent during minima.

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 the regions of the F-layer, the most severe scintillations occur over the crests of the equatorial anomaly which are found approximately 15° either side of the magnetic equator (Aarons 1977). Since equatorial scintillations are coupled with anomaly, they tend to become worse during the years of solar maximum when the anomaly is at its greatest.

Equatorial scintillations also show a strong seasonal dependence, being greatest during the months of April to August in the Pacific longitudinal sector, but a minimum during these months in the American, African and Indian sectors. This situation is reversed during the months of September to March (Knepp et al., 1991). During the seasons of high scintillation activity, the equinoctial months of March and September have the highest levels of activity, although this does not appear to be true at all longitudes (Basu and Basu 1981).

Equatorial scintillations are mainly produced by irregularities created by instabilities in the F-layer of the ionosphere during the evening hours. After sunset, the lower region of the F-layer recombine more rapidly than the upper region, leading to an unstable situation akin to a heavy fluid being supported by a lighter fluid. This situation eventually leads to the formation of bubbles of low density plasma which are forced upwards through the denser upper regions. As the bubbles grow, steep density gradients on the walls cause smaller irregularities to form (Ossakow et al 1978). At GPS frequencies, these smaller irregularities, which can be of the order of the Fresnel zone radius or less (< 300 m), are responsible for scintillations.

The low density bubbles eventually form into irregularity patches, or plumes, which can reach heights of up to 1500 km at the magnetic equator. Once formed, the plumes extend along the magnetic field lines in a North-South direction for over 2000 km, leading to an accumulation of irregularities in the Northern and Southern anomaly regions (±15° to ±20° dip latitudes). Because of the higher background densities in these regions, the irregularities tend to produce much stronger scintillation effects than at the magnetic equator.

Scintillations are often experienced in patches that can last for an hour or so with periods of little or no activity in between. Eventually, in the absence of solar radiation, the irregularities begin to fade along with the associated scintillation activity. This usually occurs around local midnight, although at times scintillations can persist until early morning.

Scintillations can also occur during daytime hours and at mid-latitudes when Sporadic-E is present in the E-layer. However, scintillations produced by Sporadic-E are much less common and less predictable than those produced by the F-layer processes described above.

In addition, the latitude band that is affected by equatorial scintillations covers approximately 50% of the Earth's surface, compared to 7% for the auroral and polar cap regions. However, it should be mentioned that during intense magnetic storms, auroral disturbances can extend well into the mid-latitudes, disrupting GPS through both scintillation activity and large density gradients.

## II. Methodology

The data used for this study span from January 2007 to December 2009 and were collected at the Space Physics Research laboratory of the Department of Physics, Federal University of Technology, Akure (7.3°N, 5.2°E) Nigeria using NovAtel GSV 4004 GPS-SCINDA receiver. The GPS-SCINDA receiver tracks up to 14 GPS satellite signals simultaneously at the L1 frequency (1575.42 MHz) and the L2 frequency (1227.6 MHz). The GPS-SCINDA data acquisition system runs on a PC or laptop running LINUX and displays GPS tracking and ionospheric parameters with real-time updates. It measures phase and amplitude (at 50-Hz rate) and code/carrier divergence (at 1-Hz) for each satellite tracked. The fluctuations in the signal amplitude are quantified by the scintillation intensity index, S4, which is defined as follows (Briggs and Parking, 1963):

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$

where I represent the signal intensity (amplitude squared). The Signals were sampled at 50Hz and 1Hz and recorded every minute (60seconds interval).

## III. Results and Discussion

The data were calibrated to first order with respect to system delay bias, ambiguity resolution and multipath. Figures 1, 2, and 3 show the mass plots of diurnal variations of Scintillations Intensity Index (S4) for 2007, 2008 and 2009, respectively, and the monthly mean diurnal variations of scintillations intensity index (S4) for 2007, 2008 and 2009 are shown in figures 4, 5 and 6 respectively.

The scintillation intensity index was computed as the standard deviation of the received signal power to average signal power over every 60. Based on global ionosphere Scintillation Model (GISM) scintillation activity indicated by S4, has four categories which are $S4 \leq 0.25$ is weak, $0.25 < S4 \leq 0.5$ is moderate, $0.45 < S4 \leq 1$ is disturbed and $S4 > 1$ is severe (Abdullah et. al., 2009). From figures 4 to 6, the scintillations observed were generally weak with S4 index falling between 0.05 and 0.2. From Figure 4, minimum value of S4 (0.02) occurs in the month of occur in February 2007 and the maximum value of 0.2 in the month of August 2007. Similarly, from Figure 5, the minimum value of S4 (0.02) occurred in the month of June 2008 and the maximum value of 0.2 in the month of May 2008. It was also observed that the moderate scintillations (S4=0.35) occurred in May 2009, which corresponds to the characteristics of scintillations at L band frequencies (Kumar et. al., 2007 and Rama Rao et. al., 2005). In 2009, as shown in Figure 7, the value of S4 (≈ 0.115) was higher in the month of November as compared to other months of the same year and that of other years (2007 and 2008) this could be due to the enhanced scintillation activity in the equatorial ionization anomaly belt (Kumar et. al., 2000 and Singh et. al., 2002). Scintillation tends to be more severed at low latitudes within ± 20° of the geomagnetic equator due to ionospheric anomalies in that region (Skone et. al.; 2001; Basu and Basu, 1981). It is strongest from local sunset until just after midnight and during the period of high solar activity. Scintillations observed during the day were generally weak and of short duration. The strength of scintillation decreases with increase in the frequency (Kumar et. al., 2007 and Basu et. al., 2002).

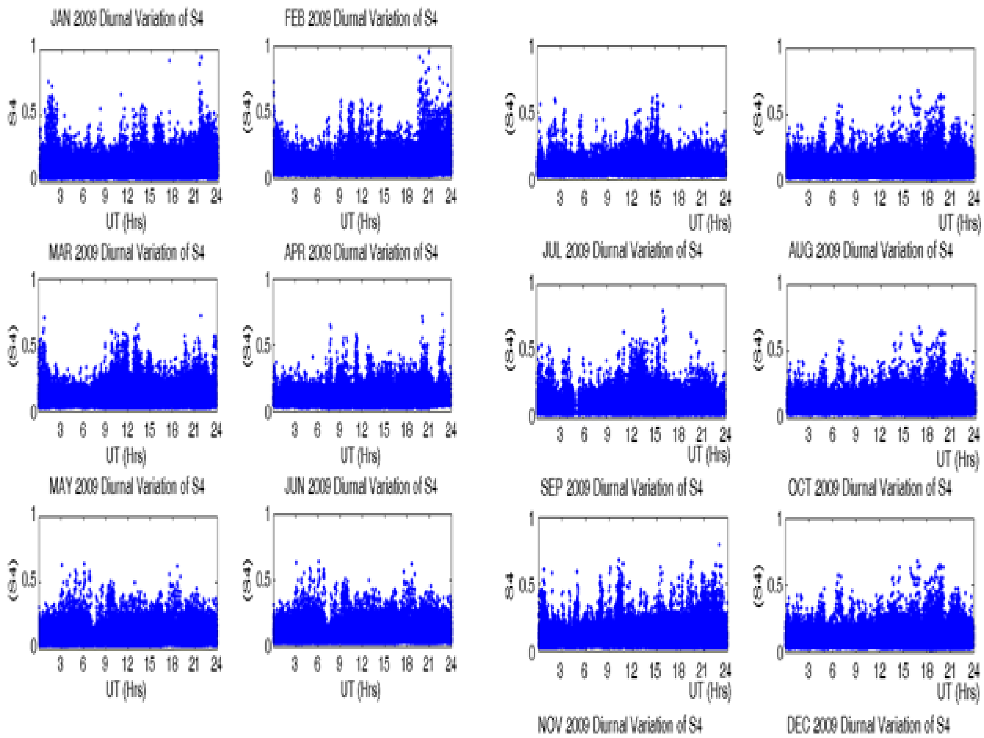


Figure 3: Diurnal variation of Scintillation Intensity Index (S4) for 2009

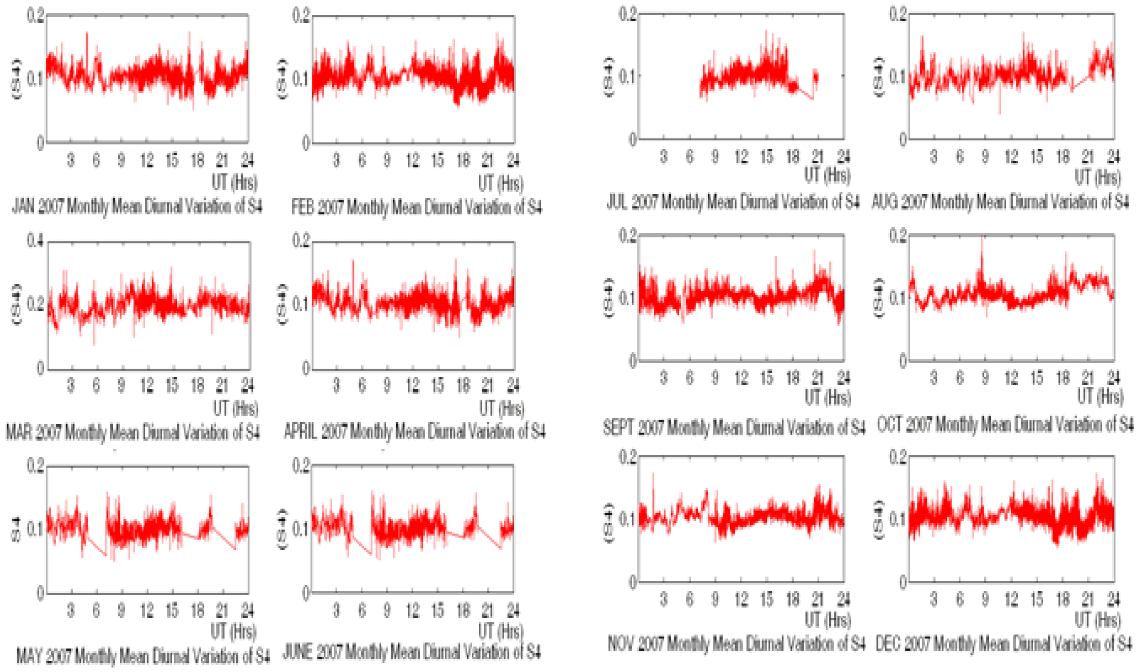


Figure 4: Monthly mean diurnal variations of S4 for 2007

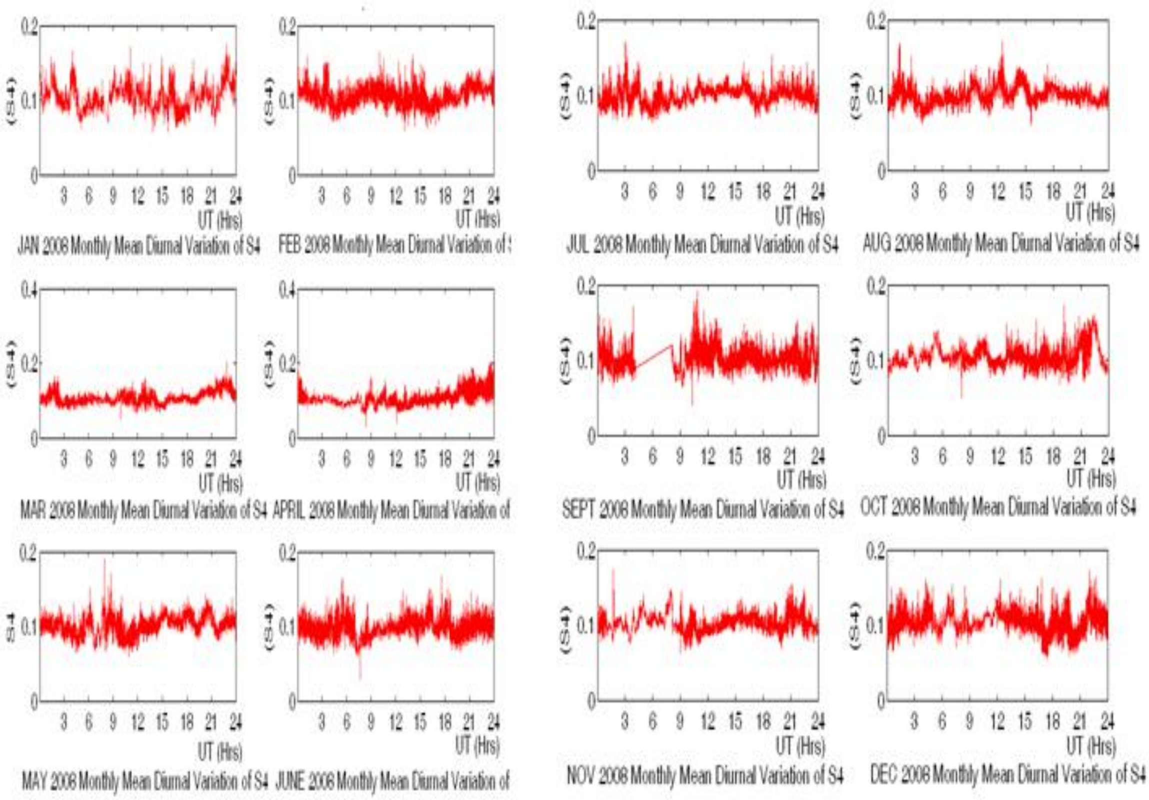


Figure 5: Monthly means Diurnal Variation of S4 for 2008

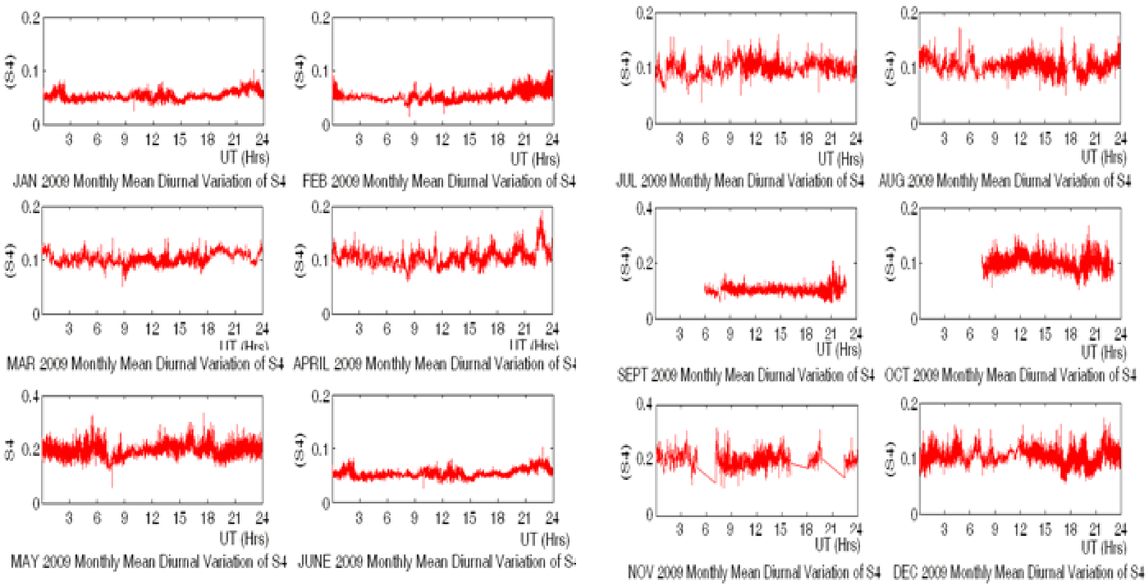


Figure 6: Monthly means Diurnal Variation of S4 for 2009

## IV. Conclusion

SCINDA provides real-time monitoring of scintillation activity and ionospheric structure for a wide range of modeling and research activities. The result shows pre-dawn minimum for a short period of time, followed by a steep early morning increase and then reaches maximum value between 14:00 UT and 16:00 UT. ). It is strongest from local sunset until just after midnight and during the period of high solar activity. Scintillations observed during the day were generally weak and of short duration. It was also observed that the moderate scintillations occurred in May 2009, which corresponds to the characteristics of scintillations at L band frequencies.

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