Study of the ionospheric scintillation and TEC characteristics at solar minimum in a West African equatorial region using Global Positioning System (GPS) data

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Abstract

Ionospheric scintillation is a rapid variation in the amplitude and phase of trans-ionospheric radio signal resulting from density irregularities in the ionosphere. It is referred to us by the index S4. The data used are the scintillation index (S4) and the vertical TEC (VTEC) recorded at the SCINDA (Scintillation Network Decision Aid) GPS station of Abidjan (Latitude = 5.34^{o} N, Longitude = 3.90^{o} W). This work covers the period from January 2008 to January 2009, two years of low solar activity with R12 equal to 2.8 and 4.2 respectively.

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 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 value 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 1100 and 1800 local time and have the same seasonal variation with the S4 index.

Keywords: Scintillation, ionospheric scintillation, multipath phenomenon, TEC, S4 index, satellites, GPS.

1. Introduction

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

The expression "scintillation" typically refers to rapid amplitude and phase fluctuations in a received electromagnetic wave. Scintillations are mainly confined in the equatorial region. Thus, the Air Force Research Laboratory's has developed SCINDA, a computer program that predicts communication satellite outages in the equatorial region and advises operational users in real-time when and where scintillation is likely to occur.

2. Data used and method of analysis

For studying the characteristics of ionospheric scintillation and TEC at solar minimum in equatorial region, we used data recorded by the SCINDA GPS receiver installed at Abidjan from January 2008 to January 2009, which configuration after decompression is illustrated in the table 1 with the useful definitions below:
YY: 2-digit year, MM: month, DD: day, UTSEC: seconds since midnight, EL: elevation (deg), S4: Scintillation intensity index, VTEC: vertical equivalent TEC (TECU), PRN: pseudorandom noise satellite identifier; -1 indicates missing values.

Table 1: An extract from a sample *.scn decompressed file showing ionospheric statistics for the satellites with PRN numbers 2, 4, 9, 10, 12, 15 the 01/01/2009 at 98 seconds after the beginning of the day.

#YYMM	DD	UTSEC	AZ	EL	PLAT	PLON	PCGLAT	PCMLT	S4	DPR	PTEC	STEC	STECE	VTEC	VTECE	PRN
09 01	01	00098	194.30	30.10	0.69	-5.17	-6.35	-0.76	0.05	12.49	0.00	-1.00	-1.00	-1.00	-1.00	02
09 01	01	00098	159.20	11.10	-4.41	-0.29	-11.29	-0.50	0.14	12.04	0.00	-1.00	-1.00	-1.00	-1.00	04
09 01	01	00098	268.50	24.50	5.16	-9.90	-3.30	-1.01	0.12	21.69	0.00	16.69	80.44	8.44	40.70	09
09 01	01	00098	359.00	79.90	5.88	-4.00	-3.15	-0.64	0.04	11.58	0.00	9.51	80.44	9.37	79.32	10
09 01	01	00098	208.80	16.00	-1.96	-7.99	-8.07	-0.98	0.23	26.19	0.00	-1.00	-1.00	-1.00	-1.00	12
09 01	01	00098	333.70	18.90	11.93	-7.31	0.12	-0.80	0.21	14.86	0.00	-1.00	-1.00	-1.00	-1.00	15

2.1 . Fundamental parameters

- Scintillation index S4: the scintillation is quantified by means of an index, defined as:

$$S4 = \sqrt{\frac{< I^2 > - < I >^2}{< I >^2}} \tag{1}$$

where I is the signal intensity [2, 3, 4, 5, 6, 7].

- Total Electron Content TEC: TEC is the number of electrons in a tube of 1 m^2 cross section extending from the receiver (R) to the satellite (S), defined as:

$$TEC = \int_S^R n_e(l)\,dl \tag{2}$$

where n_e (l) is the electron density along the signal path. We used calibrated TEC according to [6].

2.2. Multipath phenomenon

Multipath is the phenomenon by which the GPS signal is reflected by some object or surface before being detected by the antenna. During the emission of the signals by the satellites, only the portion of the signal that travels along the direct path from the satellite is useful. All over contributions are called multipath. Multipaths were cut off following the criteria of [5]. Multipath phenomenon is no significant if the EL > 30°.

3. Results

In this section, we present the diurnal and seasonal variations of the means of S4 index and VTEC. On the following figures, we have in X-coordinate the local time (LT) in hour. In ordinate, each day of the month or each month of the year is represented. The values of the S4 index and VTEC are indicated by a bar of colors.

3.1. Diurnal variation of the scintillation index S4 and the VTEC

In this step figure 1 indicates that the S4 index is included between 0 and 0.14, very weak than 1. In a particular way, we note that its variation is very weak from 0200 to 2000 where the index S4 varies between 0 and 0.08. However, the values of the index S4 are relatively raised during the time interval going from 2000 to 0000 and extend to 0200 in some cases. These values are confined between 0.08 and 0.14.

From figure 2, we can see that the VTEC diurnal variation is confined between 0 and 35 TECU. In detail, we observe that the VTEC is lower than 20 TECU during the time intervals going from 0000 to 1100 and from 1800 to 0000. However, the values of the VTEC are relatively high during the time section from 1100 to 1800 and reach 35 TECU.

These results show that the diurnal variation of S4 is significant during the night with a maximum equal to 0.14 while the variation of the VTEC is more marked in the middle of the day, precisely between 1100 and 1800 with a maximum equal to 35 TECU.

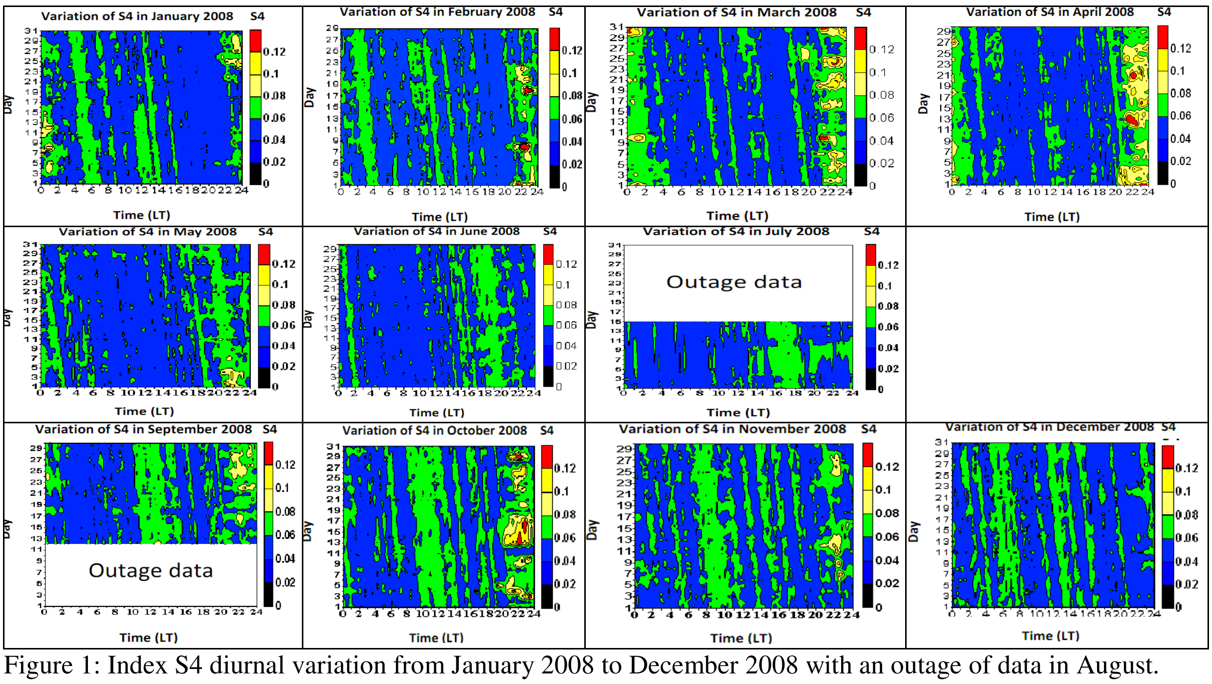

Figure 1: Index S4 diurnal variation from January 2008 to December 2008 with an outage of data in August.

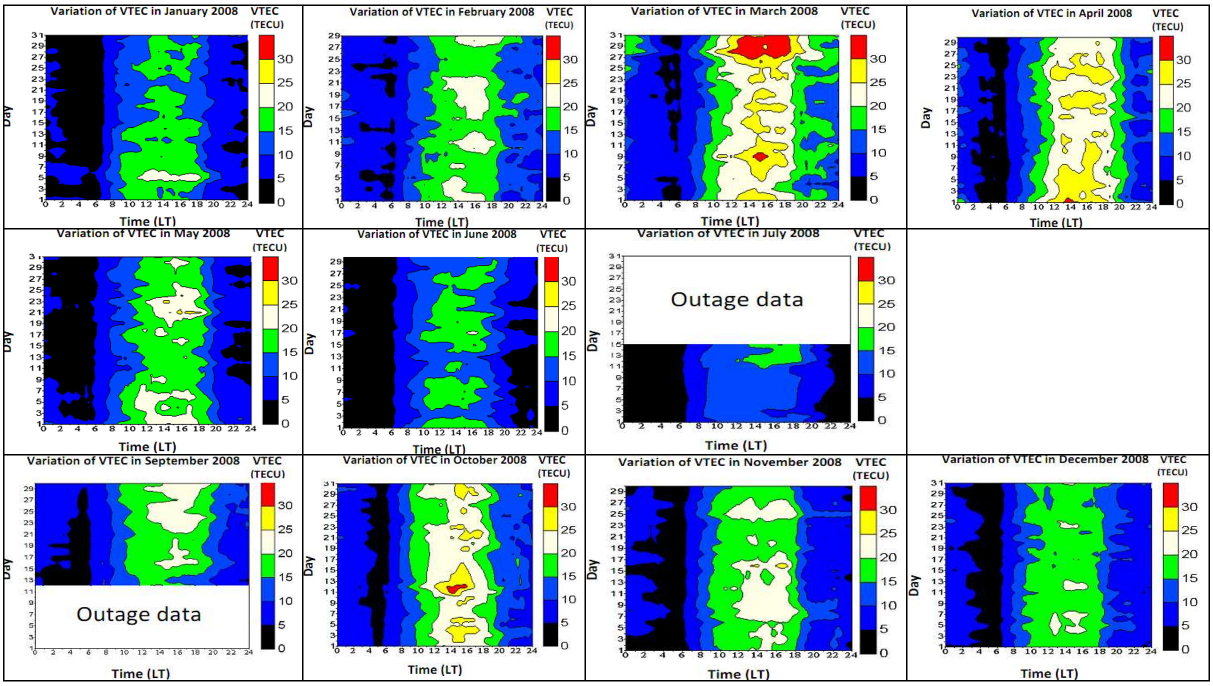

Figure 2: VTEC diurnal variation from January 2008 to December 2008 with an outage of data in August.

3.2. Seasonal variation of the scintillation index S4 and the VTEC

Figure 3 shows respectively the scintillation index S4 at equinoxes (March and September) and Solstices (June and December).

In equinox of Mars, we note that S4 is constantly lower than 0.08 between 0200 and 2100. However, from 2000 to 0200 the index S4 exceeds 0.08 and reaches 0.14.

In equinox of September, 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. Between 2100 and 2300, the index S4 is high with values confined between 0.08 and 0.1.

In the solstices of June and December, the index S4 presents a variation that doesn't differ from 0000 to 2400 in general. The average of the index of scintillation is confined between 0 and 0.08.

The VTEC dependence on the season can be easily seen from figure which displays respectively the VTEC at equinoxes and Solstices.

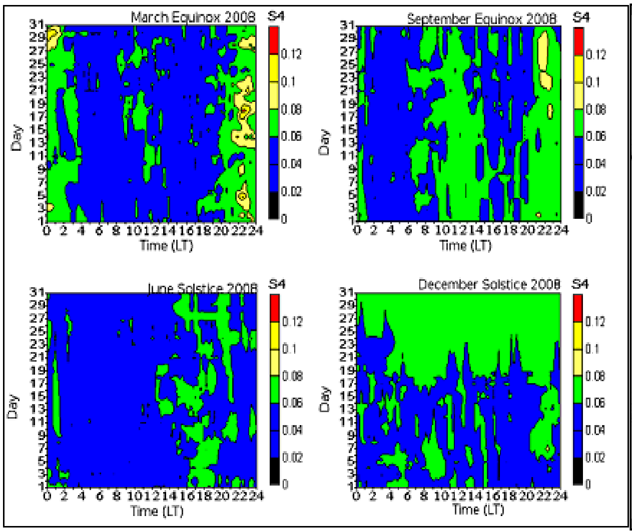

Figure 3: Index S4 seasonal variation at Equinoxes and Solstices 2008

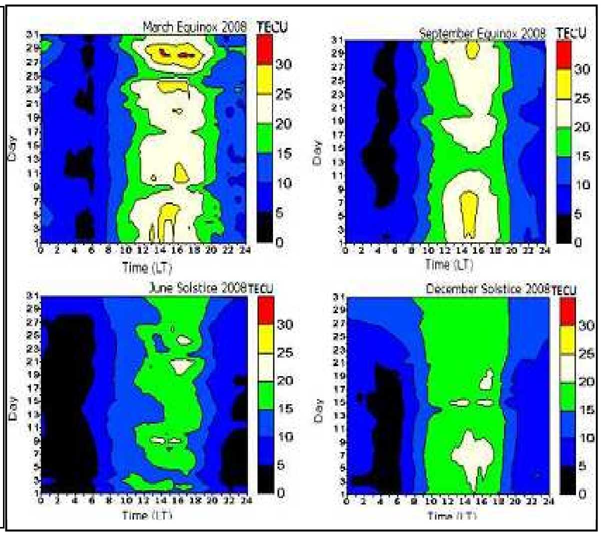

Figure 4: VTEC seasonal variation at Equinoxes and Solstices 2008

In equinox of March, we observe that the VTEC is generally lower than 20 TECU during the time intervals going from 0000 to 1100 and from 1800 to 2400. However, it is high from 1100 to 1800 with values of VTEC which oscillate between 20 and 35 TECU.
In equinox of September, we observe the same mode of variation with a light difference. During the time interval going from 1100 to 1800, the proportion of raised values of VTEC is less than this in equinox of Mars.
In the solstices of June and December, the VTEC presents a variation which almost doesn't differ from 0000 to 2400. The average of the VTEC is confined between 0 and 20 TECU with a fine proportion which varies between 20 and 25 TECU from 1200 to 1800.

3. Discussion and Conclusion

We have investigated on characteristics of ionospheric scintillations and TEC at solar minimum in a West African equatorial region using GPS receiver, precisely at Abidjan, Côte d'Ivoire during a period from January 2008 to January 2009.
In this study, our observational results show that GPS scintillations occurred from 2000 to 0000 and extend to 0200 in some cases where the greatest average value of scintillation index S4 is equal to 0.14. Largest values of VTEC appear from 1100 to 1800 where the maximum average value is equal to 35 TECU. The scintillation is thus primarily a nighttime effect while TEC is significant between after sunrise and before sunset [4, 7, 11].
The scintillation activity indicated by S4 has four categories i.e. $S4 \leq 0.25$ is quiet, $S4 > 0.25$ and $S4 \leq 0.5$ is moderate, $S4 > 0.5$ and $S4 \leq 1$ is disturbed, then $S4 > 1$ is severe [10]. Therefore, we obtain a low scintillation activity and TEC values in this minimum solar activity period.
We have also an equinoctial asymmetry in both the scintillation index S4 and the TEC [4, 8, 12].

All things considered, we can say that the scintillation is primarily a nighttime observed phenomenon while the TEC in general exhibits a diurnal variation as a function of the solar zenith angle. S4 and VTEC were more significant in equinoxes than in solstices with a higher rate of occurrence in equinox of Mars. At solar minimum solar epoch the scintillation phenomenon and the TEC values are relatively low effects.

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