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Ionospheric Time Delay Variations At An Equatorial Station During Low Solar Activity

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ABSTRACT

The greatest source of error in position estimate and precise time transfer using Global Positioning System (GPS) satellites is range delays, which degrade GPS signals as they propagate through the ionosphere. In order to improve the accuracy of GPS position fixing, it is important to have a good understanding of ionospheric time delay. In this paper, we have studied the diurnal and seasonal variations of ionospheric time delay of radio signals from GPS satellites and their dependence on solar flux (10.7 cm) index during low solar activity period (March 2008 to December 2009) over an equatorial station, Lagos, Nigeria (6.5°N, 3.4°E; magnetic latitude 3.03°S). It is found that diurnal variation of ionospheric time delay show maximum values around 14h00-16h00 LT during all the months considered. The study reveals that during low solar activity, the time delay values are high in equinox months, least during summer and moderate in winter. The correlation between average daytime peak ionospheric time delay and the solar F10.7 flux shows low positive correlation, with Correlation Coefficient of R = 0.31 for 2008 and R = 0.15 for 2009.

Keywords: *Ionospheric time delay, Total electron content (TEC), GPS, navigation.*

INTRODUCTION

The ionosphere, extending from a height of about 60 km to about 1000 km above the earth, is a region of free electrons and ions in sufficient quantities to affect propagation of radio signals from Global Positioning System (GPS) satellites. The advent of GPS has led to a major development in the worldwide navigation facilities. The major error source in position estimate of GPS is the range delays suffered by radio waves as they propagate through the ionosphere. The signal group velocity slows down and phase velocity speeds up (Kintner and Ledvina, 2005). In order to achieve better accuracy in GPS position fixing for navigation and geodesy applications, it is important to have a good estimation of ionospheric time delay.

Conventionally, ionospheric time delay on GPS signals can be reduced by using the dual-frequency receivers. Dual-frequency GPS receivers operate by comparing the time delay between the two GPS frequencies, f_1 = 1.57442 GHz and f_2 = 1.2276 GHz. Even though ∂t cannot be measured at single frequency with a standard receiver clock, the difference in ∂t at two different frequencies can be measured (Bhattacharya *et al.*, 2009). The difference in arrival time for two codes transmitted at identical times but at different frequencies can be given as:

$$\Delta(\partial t) = \frac{40.3 \times TEC}{c}\left(\frac{f_1^2 - f_2^2}{f_1^2 f_2^2}\right) \qquad 1$$

TEC is an important descriptive parameter of the ionosphere and it plays a major role in the time delay of ionospheric signals. It is the total number of electrons present along any path between the receiver and the satellite, with units of electrons per square meter, where 10^{16} electrons/m² = 1 TEC unit (TECU). Vertical total electron content (VTEC) is a very good indicator for the overall ionization of the Earth ionosphere. Eq. 1 shows that if the TEC is known or measured, a perfect correction to ionospheric time delay could be performed. This is important because the navigation concept requires that a user measures the time delay that satellite emitted signals experience in traversing the distance between satellite and user.

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Misra and Enge (2006) reported that the ionosphere is generally well behaved in the temperate zones but can fluctuate near the equator, where our station of interest is located. The region of highest ionospheric delay is within ±20° of the magnetic equator.

The effects of ionosphere on GPS receivers have been studied by various researchers (Conker *et al*., 2003; Aaron and Basu, 1994; Groves *et al*., 2000; Doherty *et al*., 2000; Bhattacharya *et al*., 2008). Bhattacharya *et al*. (2009) studied the diurnal and seasonal variations of ionospheric time delay during solar minimum period of January to December 2005. The study reveals that Equinox season shows maximum delay, moderate during Summer and minimum during Winter.. Bhattacharya *et al*. (2008) investigated the effect of magnetic activity on ionospheric time delay at low latitude station Bhopal (geom. lat. 23.2°N, geom. long. 77.6°E) using dual frequency mechanism. Their results showed that maximum delay was observed during quiet days in Equinox months while the delays of disturbed period are observed during the months of Winter. In the summer hemisphere at mid- and high latitudes, the negative storm effects can propagate to the low latitudes at post-midnight to the morning sector with a time delay of 4–7 h.

The aim of this present study is to investigate the diurnal and seasonal variations of ionospheric time delay. The data used for the present investigation are the time delay measured by a dual frequency GPS receiver and solar flux (10.7 cm) index obtained during low solar activity period (March 2008 to December 2009) over an equatorial station, Lagos (6.5°N, 3.4°E; dip latitude 3.03°S) Nigeria. This study of diurnal and seasonal variation of time delay is expected to be included in ionospheric models such as the International Reference Ionosphere (IRI), so as to provide a more accurate way of eliminating this ionospheric delay effect.

DATA AND METHOD OF ANALYSIS

The VTEC data used for this research were obtained from the Low-latitude Ionospheric Sensor Network (LISN) (http://jro.igp.gob.pe/lisn). The RINEX observation files obtained from LISN were processed by the GPS-TEC analysis application software, developed by Gopi Seemala of the Institute for Scientific Research, Boston College, U.S.A. In order to minimize multipath effects on GPS data, elevation cut off of 20˚ was used. In addition to eliminating the errors from multipath, we also remove satellite and receiver biases from the TEC values used in this present study. The satellite and receiver bias values were obtained from the data center of Bern University, Switzerland. We have used daily values

of TEC from March 2008 to December 2009, based on the availability of data from the LISN website. The sunspot numbers for the months under consideration are given in Table 1. In this particular study time delay values were grouped into three seasons namely Equinox (March, April, September, October), June Solstice (May, June, July, August), and December Solstice (November, December, January, February).

RESULTS AND DISCUSSION

Diurnal Variation of time delay

The diurnal variation of ionospheric time delay difference is shown in Fig. 1-6. A significant diurnal variation is observed. The diurnal variation of time delay shows approximately the same trend during the whole day. Time delay decreases gradually from 00h00 to 06h00 LT where it reaches a minimum value. It is observed that, generally, ionospheric time delay increases from 06h00 LT and has its maximum value around 14h00-16h00 LT during all the months considered, after which it decreases until midnight. The mass plots of time delay show appreciable day to day variability. Since the magnitude of the time delay is a function of TEC, the day to day variability of time delay is caused by various parameters like Extreme Ultraviolet (EUV) flux, geomagnetic activity (Dabas *et al*., 1984), Electrojet strength and local atmospheric conditions in the thermosphere (Rao *et al*., 1980). As the sun rises, its UV radiation breaks up gas molecules (mainly H_2 and He at higher altitudes, and O_2 and N_2 at lower altitudes) into ions and free electrons. The TEC builds up, with peak around 14h00-16h00 LT, and then starts declining. During nighttime, there is no further ionization and the ions and electrons recombine, reducing the TEC and hence the time delay.

Seasonal variation of time delay

Fig. 7 shows the mean diurnal time delay variations during different seasons observed at Lagos for 2008 and 2009. The time delay values are high in Equinox, minimum in JUNSOLS and moderate in DECSOLS for the year 2008. However, the time delay values, in general, are high in JUNSOLS, minimum in DECSOLS and moderate in Equinox for the year 2009. In the work of Bhattacharya *et al*. (2009), the maximum ionospheric time delay for Bhopal (23.2^{o}N, 77.6^{o}E) during a low solar activity year (2005) occurred in Equinox, minimum in Winter and moderate in Summer.

Thermospheric neutral composition has a direct control on the seasonal variation of ionospheric time delay. The equator is hotter than the pole during the daytime; therefore the meridional wind flows toward the pole from the equator. This flow of thermospheric meridional wind changes the neutral composition and O/N_2 decreases at equatorial stations (Bagiya *et al*., 2009). This decrease is a maximum in equinox months. At the maximum height of the F2 layer, the decrease in O/N_2 ratio will result in higher electron density and therefore the time delay will be highest in equinox.

Solar activity dependence of time delay

Fig. 8 shows the correlation between average daytime peak ionospheric time delay and the solar F10.7 flux for both years. The ionospheric time delay data set covered a period of low solar flux variation from 2008 to 2009. The result shows that the low variation of solar flux does not permit an examination of the solar flux effects on ionospheric time delay. Fig. 8 shows low positive correlation, with Correlation Coefficient R = 0.31 for 2008 and R = 0.15 for 2009. However, Bagiya *et al*. (2009) reported a high positive correlation between daytime peak TEC and the solar F10.7 flux. Abdu *et al*. (2008) reported that the solar flux dependence of the TEC is a maximum during Equinoxes, especially for post-sunset TEC values at times when the latitudinal distribution is controlled by the equatorial evening plasma fountain processes. Kouris *et al*. (2008) showed that TEC is highly correlated with the latitude and solar activity, whereas the slab thickness is independent of both solar activity and latitude.

CONCLUSION

We have used GPS-TEC values recorded by a dual frequency GPS receiver installed at an equatorial station, Lagos, Nigeria (6.5^o N, 3.4^o E; magnetic latitude 3.03°S) to estimate ionospheric time delay difference on GPS signals. We have used values of TEC from March 2008 to December 2009 to evaluate the ionospheric time delay difference. The main features of this study are listed as follows: (1) The diurnal variation shows that the time delay decrease gradually from 00h00 to 06h00 LT where it reaches a minimum value. It is observed that, generally, ionospheric time delay increases from 06h00 LT with maximum value around 14h00-16h00 LT during all the months considered, after which it decreases until midnight. (2) The time delay values are generally high in Equinox, minimum in JUNSOLS and moderate in DECSOLS for the year 2008. However, the time delay values are generally high in JUNSOLS, minimum in DECSOLS and moderate in Equinox for the year 2009. (3) The result shows low positive correlation between average daytime peak ionospheric time delay and solar F10.7 flux.

The results from the present study can provide useful information that could support the construction of empirical ionospheric time delay correction models. Understanding of diurnal and seasonal variation of time delay will also aid space weather forecasting.

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Table 1: Sunspot number from March 2008 to December 2009.

Month	**2008**	**2009**
JAN		1.3
FEB		1.4
MAR	9.3	0.7
APR	2.9	0.8
MAY	3.2	2.9
JUN	3.4	2.9
JUL	0.5	3.2
AUG	0.5	0.0
SEP	1.1	4.3
OCT	2.9	4.6
NOV	4.1	4.2
DEC	0.8	10.6
AVERAGE	2.8	3.1

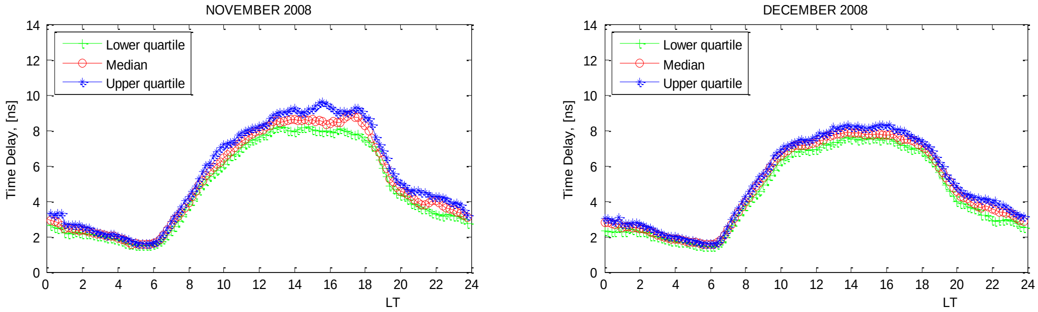


Figure 1: Plot of diurnal variation of ionospheric time delay during DECSOLS 2008

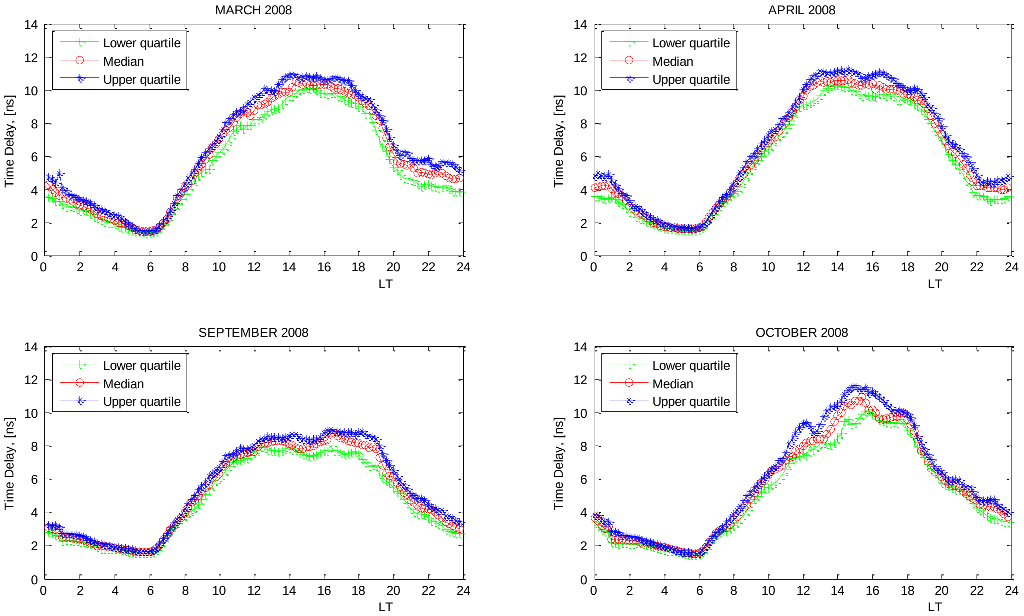


Figure 2: Plot of diurnal variation of ionospheric time delay during Equinox 2008

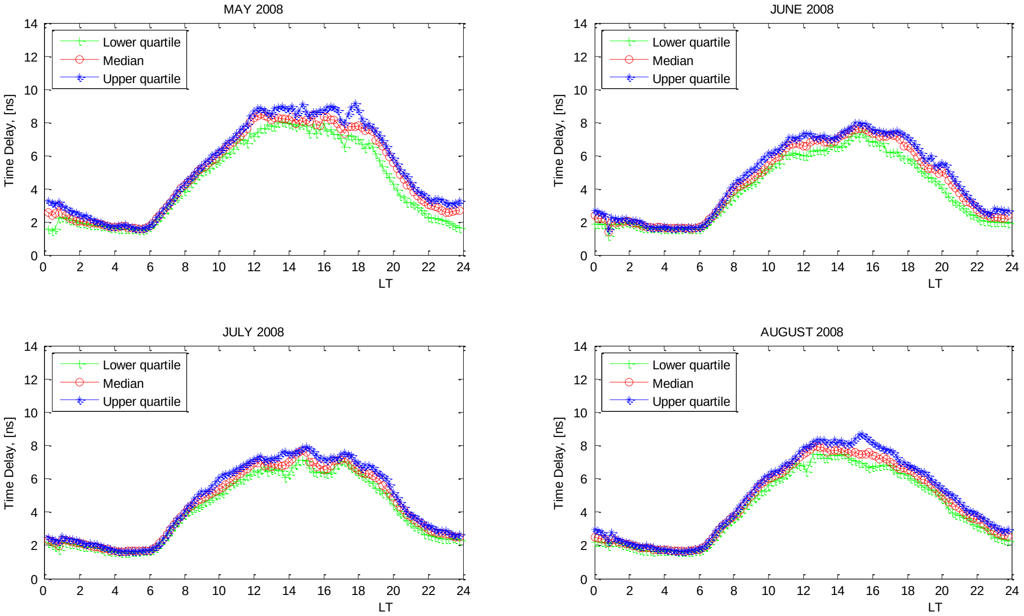


Figure 3: Plot of diurnal variation of ionospheric time delay during JUNSOLS 2008

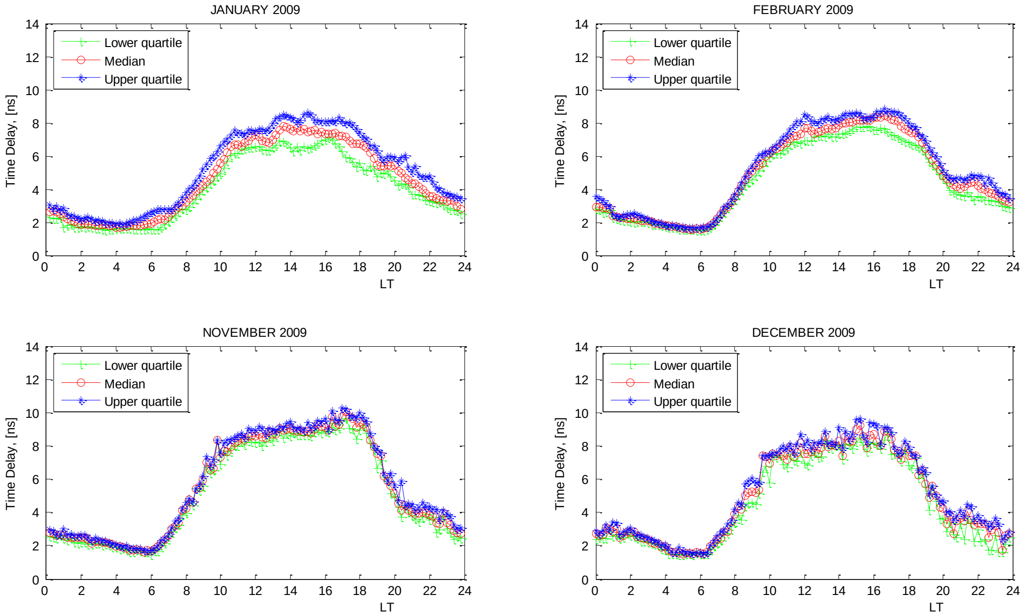


Figure 4: Plot of diurnal variation of ionospheric time delay during DECSOLS 2009

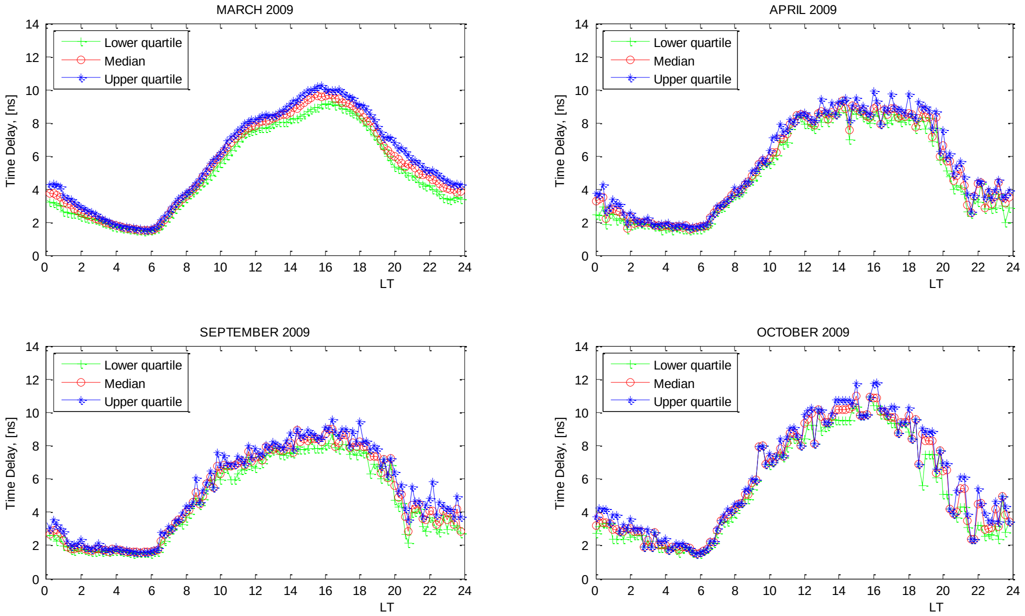


Figure 5: Plot of diurnal variation of ionospheric time delay during Equinox 2009

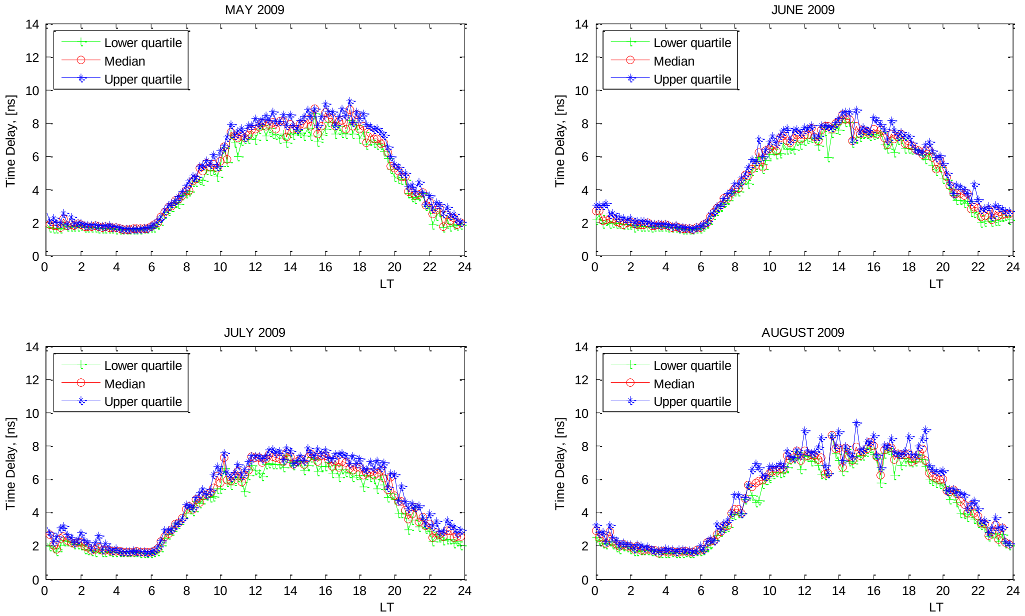


Figure 6: Plot of diurnal variation of ionospheric time delay during JUNSOLS 2009

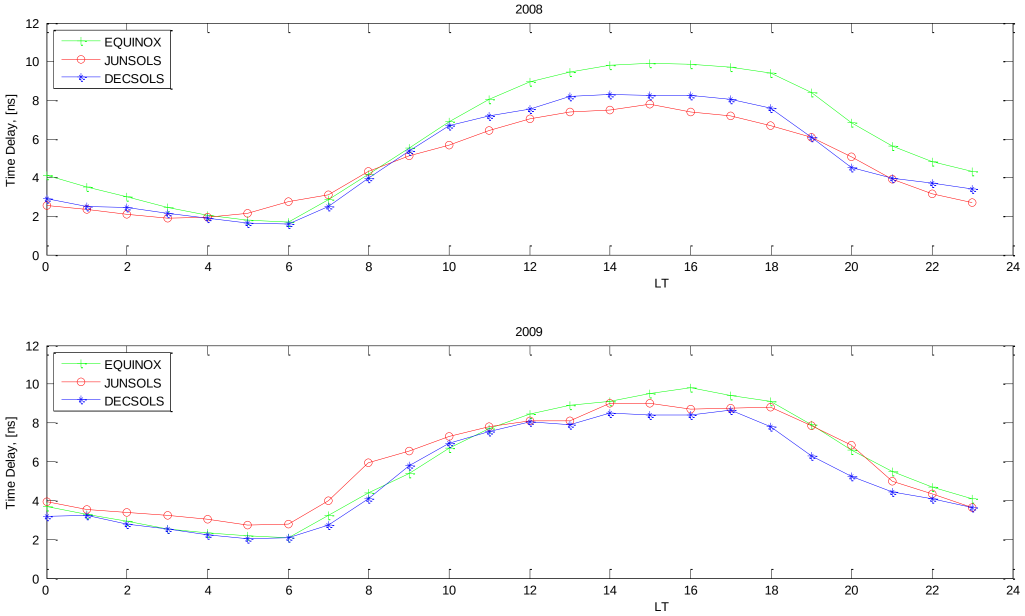
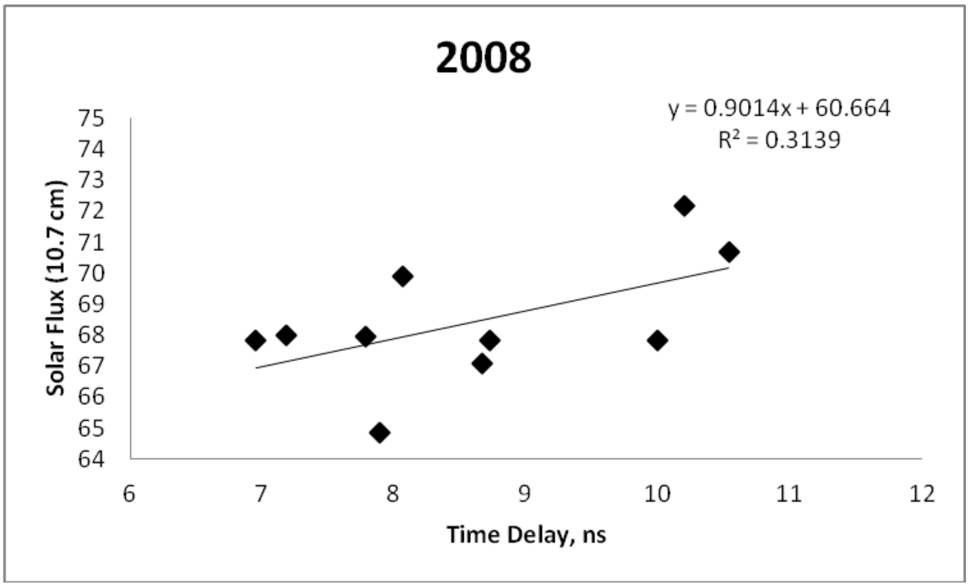
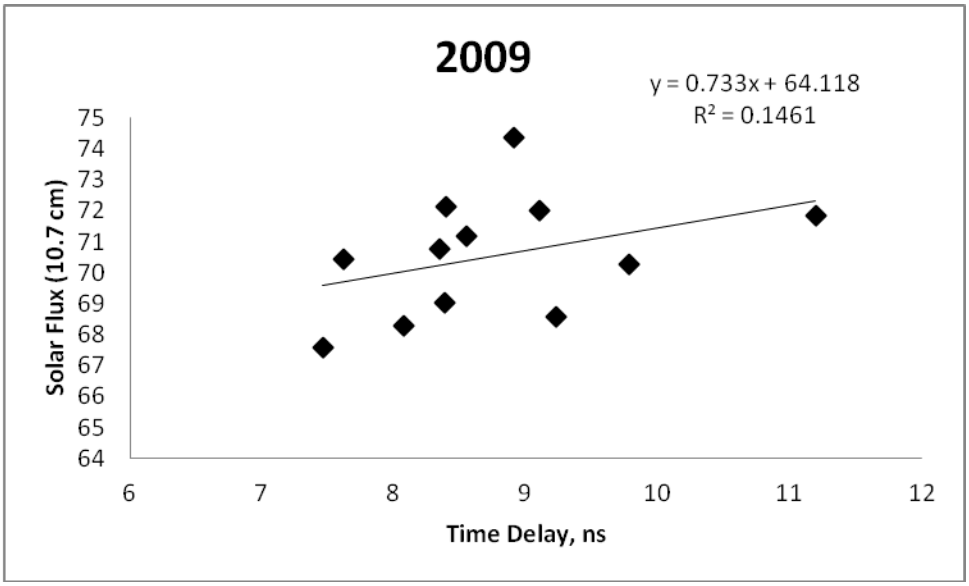


Figure 7: Seasonal mean diurnal variation of ionospheric time delay difference (a) 2008 and (b) 2009 at Lagos.



(a)



(b)

Figure 8: Time delay vs solar flux