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Research Article

Major Ionospheric Effects on GPS Signals in East African Low-Latitude

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Abstract

Ionospheric irregularities are major components of space weather and have contributed to poor performance of Global Navigation Satellite System (GNSS), especially at equatorial and low latitudes. The variations of ionospheric parameters of Total electron Content (TEC), ionospheric delay and scintillation index (S4) have been investigated using GNSS data, to ascertain the contributions of location and time of the day on GNSS performance. Results obtained showed that variation in TEC and ionospheric delay are dependent on location and time of the day, with Addis Ababa station recording highest values and the least values recorded at Lagos station. Seasonal variation of ionospheric delay was observed, with equinox season having the highest values in all the stations, summer season recorded the least values. The observed scintillation index values of above 0.5 at Addis Ababa constitute major threat to GNSS users in the station. There was absent of scintillation at Lagos station and values less than 0.3 recorded at Cotonou station.

Keywords: Ionospheric Delay; Scintillation; Total Electron Content; GNSS

Introduction

Over the years, GNSS has played and still playing important roles in enhancing the efficiency of space-based technological systems used for precise positioning, timing and navigation. Ionospheric delay and scintillation occurrence, which are major components of space weather, in the other hand have been major challenge to this performance. The result of this analysis underpins the characteristic ionospheric delay, hence the electron density variation and scintillation effects at the EIA region, which pose a great deal of challenge to GNSS users in the continent during space weather events. The findings from the study therefore provide GNSS users, such as mobile phone networks, useful information on the sporadic nature and irregularities as well as their spatial temporal extent.

However, continuous investigation is recommended for proper mitigation of space weather effect on critical technologies, especially across the African longitude, where no much work has been carried out. Such investigation will require deployment of ionospheric delay error forcasting and mitigation services.

The effect of scintillation on some stations in low-latitude, including the African low latitude was investigated [1]. They observed that scintillation was dependent on location and condition of the ionosphere. Also, the equatorial anomaly regions experience the most significant activity, which most times results in loss of track of one or more satellite signals by GNSS receivers [2]. The occurrence of scintillations at a low latitude station was linked to the peak value of TEC during daytime [3].

Methodology

The GPS receivers installed at three low latitude stations of Addis Ababa, Ethiopia (8.98°N, 38.76°E), Lagos, Nigeria (6.52°N, 3.38°E) and Cotonou, Benin Republic (6.37°N, 2.39°E) recorded data in Rinex format. The data obtained from the separate stations comprise of code and phase pseudo ranges at two frequencies, L_1 and L_2. The additional parameters of the stations included the coordinates, satellites cutoff angle and value for signal differential delay of the receiver station. The analysis of the observational data, which include the code and phase measurements, detection and elimination of cyclic phase slips, smoothing code measurements with the phase ones was done using GPS-TEC application software developed by Gopi Seemela of the Institute of Geomagnetism. The analysis resulted in obtaining Total Electron Content (TEC) data, scintillation data (S_4 index), among other data. The TEC obtained after processing was the slant TEC (STEC), which was dependent on the elevation angle. The STEC was obtained according to [4,5] using the expression in equation (1).

$$STEC = \frac{1}{40.3} \times \left[\frac{1}{L_1^2} - \frac{1}{L_2^2}\right]^{-1} \times (P_1 - P_2) + TEC_{BE}. \quad \text{-------- (1)}$$

Where P_1 is pseudo range at L_1, P_2 is pseudo range at L_2 and TEC_{BE} is the bias error correction, which is different from satellite-receiver pairs [6]. The desire to obtain a TEC data, which was independent of elevation angle, was sort. This TEC (vertical TEC) was obtained by taking the projection from the slant to the vertical using the thin shell model, assuming a height of 350 km [7].

$$VTEC = STEC \times \cos\left[\sin^{-1}\left(\frac{R_Z \cos e}{R_E + h_{max}}\right)\right]. \quad \text{--------- (2)}$$

Where the radius of the Earth, the height to the pierce point, and Z = elevation angle at the station, as shown in figure 1.

The range error (RE) data was obtained from the expression:

$$RE = 40.3 \times \frac{VTEC}{f^2}. \quad \text{---------- (3)}$$

Where the frequency

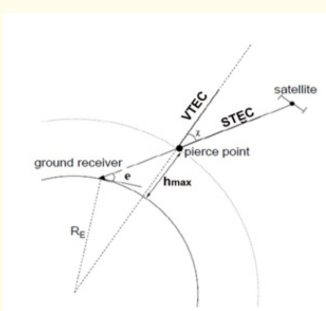


Figure 1: Geometry for the Conversion of Slant TEC to Vertical TEC (Modified from [7]).

Results and Discussion

TEC variation

Figure 2 and 3 represent the typical TEC plots for all pseudo Random Numbers (PRNs) in the three stations for March 17 and June 23, representing highly disturbed days in 2015, with minimum Dst of -223 nT and -204 nT respectively. The legend in the figures shows the graduation of the (geo) magnetic latitude (MLAT) of satellite pass. The diurnal variation in TEC measured by satellites to the geomagnetic north of the stations are in blue and green, while that measured by satellites to the geomagnetic south of the stations are in yellow and orange.

The diurnal patterns in the two days for the different stations are similar and exhibit the characteristics typical to low-latitude, such as TEC minimum at pre-dawn and gradual increase with the time of the day, attaining a maximum in the afternoon and gradual decrease after sunset.

On 17 March, there were multiple peaks during the daytime maximum in Addis Ababa station, with the highest peak of about 78 TECu at about 11:00 UT. In Cotonou station, the peak of about 90 TECu occurred at about 16:00 UT, while Lagos recorded peak value of about 70 TECu at about 17:00 UT.

On 23 June, the peak TEC values are about 55, 50 and 20 TECu for Addis Ababa, Cotonou and Lagos stations respectively. In general, the typical TEC values were dependent on the location, the time of the day and the magnitude of the storm.

Ionospheric delay

The variations of range error with the time of the day during the different seasons of the year in the three stations are shown in figure 4. During the Equinox season, Addis Ababa recorded a maximum range error value of about at about 12:00 noon, followed by Cotonou station, with value of about at about 15:00 UT. The delay experienced at the Lagos station was least, about at about 14:00 UT.

In summer, Addis Ababa and Cotonou recorded almost same values of range error of about, though at different time of the day. Lagos latitude recorded least value of about during the daytime plateau.

During winter, Addis Ababa and Cotonou recorded a maximum value of about and respectively, while Lagos recorded about during the daytime maximum.

From the observation, equinox season recorded the maximum values of range error in all the stations, followed by winter and least during summer. It was also obvious that the occurrence time of peak values differ, with Cotonou registering peak at later time, followed by Lagos and then Addis Ababa.

Scintillation occurrence during disturbed periods

Figure 5 represents the variation in scintillation index (S_4), TEC and Elevation angle for the three stations for different PRNs during disturbed periods. Emphasis is on scintillation index. From Figure 5(a), the scintillation in Addis Ababa varied and registered high values from 0.5 and above spontaneously. Some periods of the day did not register any scintillation. This was different from the observation at Cotonou station, where scintillation occurrence was all through the period of the days considered. The maximum S_4 index registered was generally less than 0.5 (Figure 5 (b)). There was no scintillation at all at Lagos station during the period under consideration (Figure 5 (c)).

When scintillation is severe, just like that registered at Addis Ababa station, it could affect radio signals ranging from 10 MHz to 10 GHz. From the observation therefore, scintillation occurrence is dependent on location, which is also in agreement with [1].

Impacts of ionospheric irregularities on GNSS

TEC provides overall description of the ionization in the ionosphere and also have practical applications on radio wave propagation. TEC is very much useful for single frequency users, as its measurements are used to correct their signals, owing to the relationship it has with radio signal delay that a GPS signal experiences in the ionosphere. From the results of the investigation, TEC as well as range error in all the stations varies with time of the day and location. Addis Ababa and Cotonou stations experience more of the variations in TEC and range error, and so will be the negative impacts on GNSS. The results of very low variations in Lagos station is an indication that the GNSS users there are not at risks with their systems.

Triggered scintillation can increase navigation errors, or even cause navigation failure. In this investigation, the GNSS users in Addis Ababa stand the risk of registering navigation errors or even failures or 'loss of lock'. No threat of any kind for GNSS users in Lagos station.

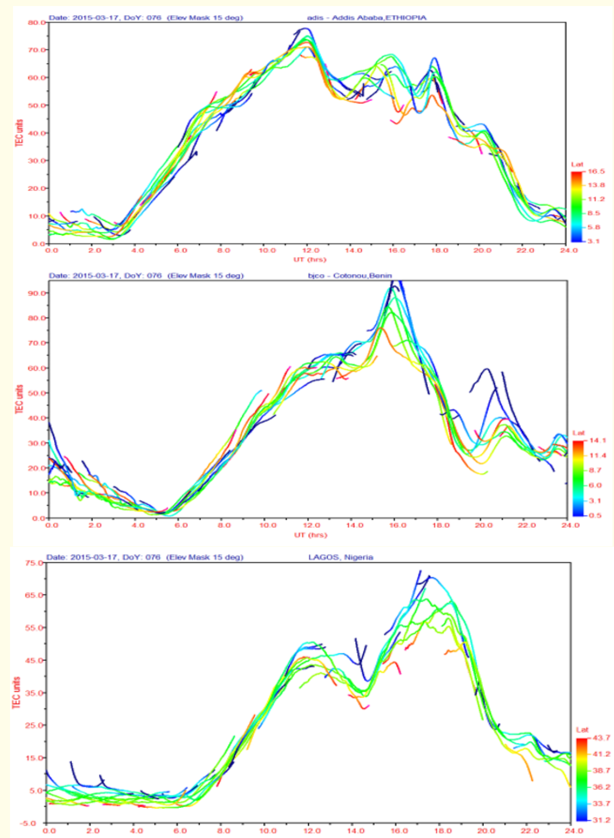


Figure 2: Typical TEC Plots for all PRNs during the Disturbed Period on March 17, 2015.

Conclusion

The study of major ionospheric effects on three low-latitude stations revealed that the propagation speed of radio waves along their path through the ionosphere was dependent on electron density variation. This variation was also proportional to the range error. In terms of time of the day, Addis Ababa consistently lagged the other two stations by more than two hours. The seasonal variation of range error showed that the maximum range error recorded at Addis Ababa and Cotonou at all seasons can cause degradation to the GNSS in the stations. The very low values of TEC and range error at Lagos station is noteworthy compared to Cotonou station, which is located very near to the Lagos station.

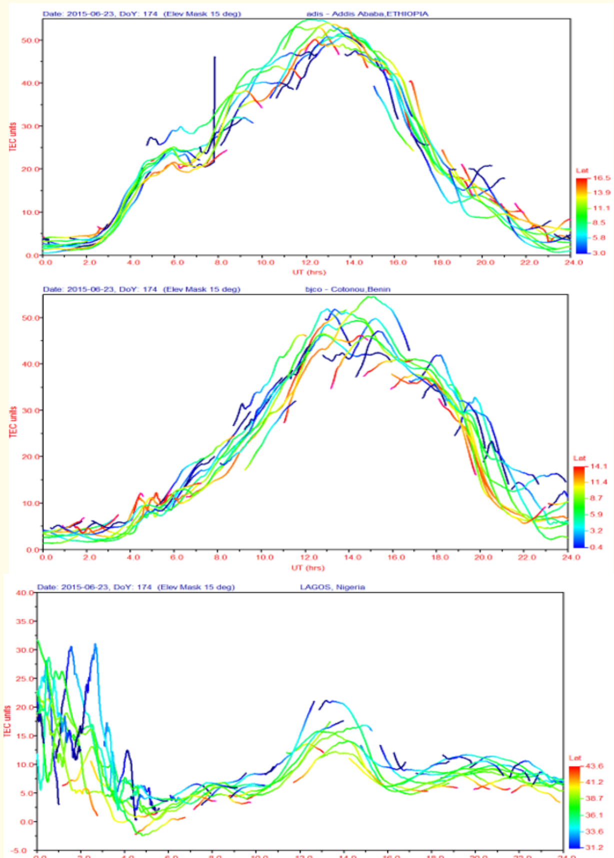
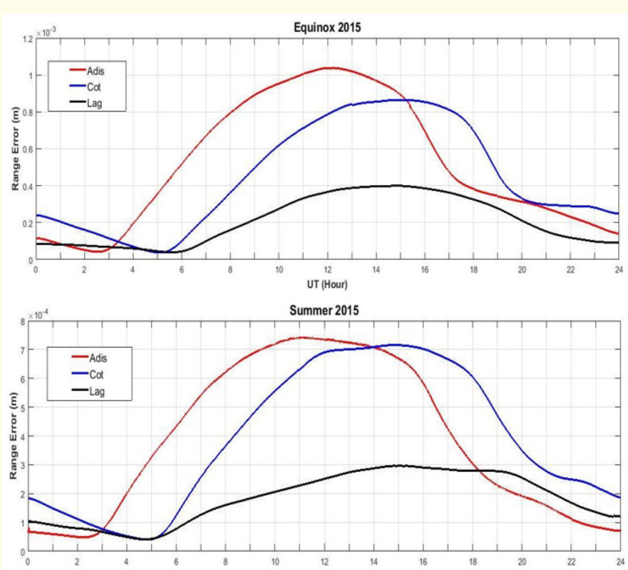


Figure 3: Typical TEC Plots for all PRNs during the Disturbed Period on June 23, 2015.



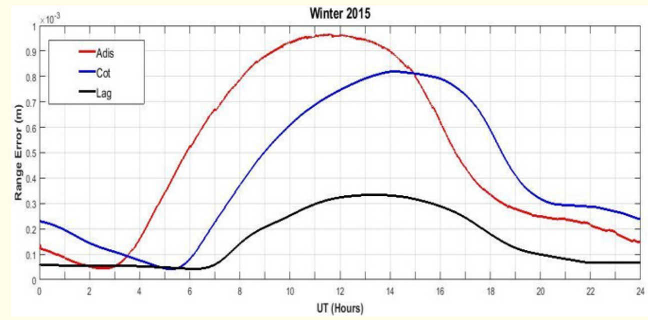


Figure 4: Seasonal Variation of Range Error with Time of the Day.

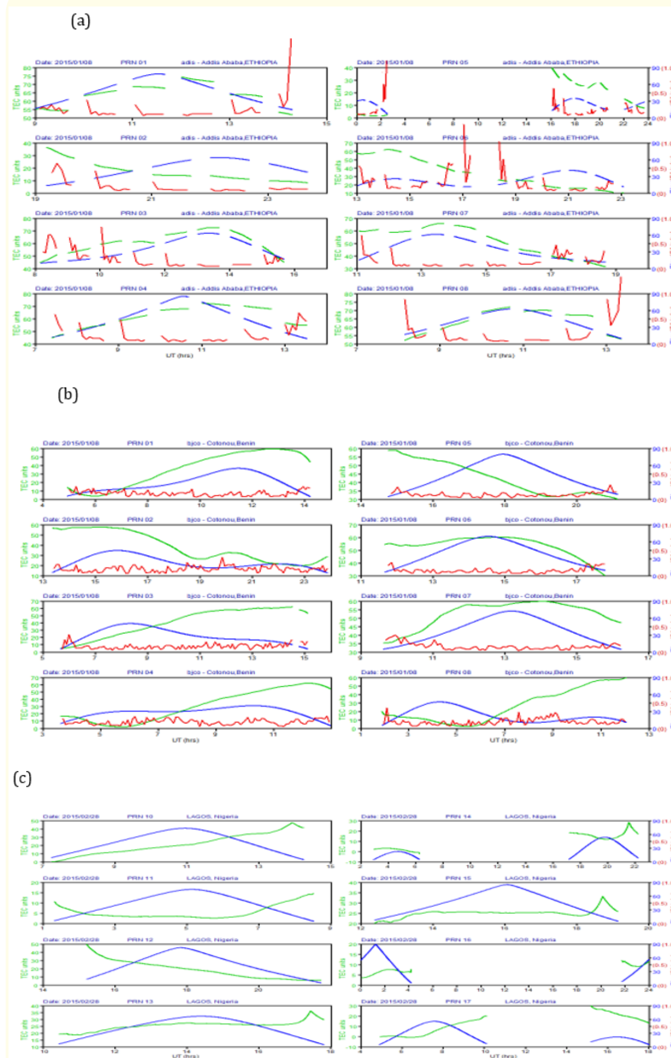


Figure 5: Variation in Scintillation Index during Disturbed Periods: (a) Addis Ababa, (b) Cotonou and (c) Lagos Stations.

High scintillation occurrence in Addis Ababa station poses major threat to GNSS users in that station. The results of this study will be useful to adjust the existing scintillation and other ionospheric models in low latitudes.

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