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Ionospheric Response on Radio Communication during Different Geomagnetic Conditions at Low-Latitude Stations

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***Abstract* - The ionospheric response on radio communication during different geomagnetic conditions in low-latitude ionosphere has been studied using ionospheric data. The different geomagnetic conditions of quiet, weak, moderate and intense were considered. The results obtained showed that the two ionospheric parameters of critical frequency of *F2* layer (*foF2*) and total electron content (TEC) vary with time of the day, latitude and geomagnetic conditions. The dependent of *foF2* on geomagnetic condition is such that high values of *foF2* correspond to high geomagnetic conditions. The highest value of *foF2* of 11.0 MHz and 12.0 MHz for Addis Ababa and Cotonou respectively was obtained during the intense geomagnetic condition. This corresponded to the *F2*-layer peak electron density of 1.40×10^{10} and 1.79×10^{10} for Addis Ababa and Cotonou respectively. The various peaks of *foF2* in the stations at different geomagnetic conditions reflect the highest frequency at which ionosphere above the stations was reflecting signals at 180^o. The observation of uncertainties in form of wave-like perturbations in TEC at the stations revealed the level of ionospheric irregularities developed as a result of storm events. Under suitable conditions, the ionosphere reflects long, medium and short waves, hence very useful for radio communication and navigation.**

Keywords: Critical frequency, TEC, Geomagnetic condition and Radio communication.

I. INTRODUCTION

The sun's energy leads to constant changing of the ionosphere due to particles ionization. The condition of the ionosphere at any particular time is subject to many factors, such as day and night, weather conditions, space weather and so on. Even, there are more unpredictable changes in the ionosphere caused by factors both from Earth below and space above, that makes it hard to know exactly what the ionosphere will be like at a given time. There are some known conditions as ascertained by some researchers. For example the ionosphere thins with night fall because the previously ionized particles relax and recombine back into neutral particles. However, continuous study of the ionosphere is required to unravel other features and in having more understanding of the complex nature of the ionosphere, especially the low-latitude.

The ionosphere also is home to many satellites. The implication is that these satellites can be affected by the constantly changing conditions of the ionosphere. The effects could include sudden swells of charged particles that increase drag on satellites and shorten their orbital lifetimes, or how long they can continue orbiting the Earth. Also, the signals of such satellites could suffer disruption due to the disturbances in the ionosphere. Simply put, ionosphere plays important role in our everyday communication and navigation systems.

Radio and GPS signals travel through the layer of ionosphere, or rely on bouncing off the ionosphere to reach their destination. For systems operating with radio waves, the knowledge of the critical frequency of the F2 layer (foF2)and the total electron content (TEC) is very important(Goodman, 2005). To ascertain to a high degree, the effect of ionosphere on these systems, one would know the state of the ionosphere at the bottom side, up to maximum height of the F2 layer (hmF2) and also the density of the electron in the height of high-altitude satellite. Such could be possible by TEC measurement. Eliminating the effects of ionosphere mean eliminating TEC. The most efficient method of eliminating TEC is to eliminate its effect by using signals in different frequencies. Similarly, the slab thickness of the ionosphere is closely linked with TEC and also the shape of the ionospheric electron density profile Ne(h). It is basically the ratio of the TEC to the F2-layer peak electron density (NmF2).

It has been shown by many researchers (e.g. Shuanggen et. al.,2007) thatτ,TEC and NmF2 vary diurnally and seasonally. They pointed out that the diurnal variation of τ may be due to the action of the thermospheric wind and the plasmaspheric flow into the F2-region.

In this study, the diurnal variation of foF2 and TEC during different geomagnetic conditions in two low-latitude

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stations has been investigated. This is to ascertain the effects of geomagnetic conditions on the parameters and also find out the extent of the effect of location on the parameters.

II. METHODOLOGY

The GPS data of two low-latitude stations of Addis Ababa (Lat 9.03°N and Long 38.760°E) and Cotonou in Benin Republic (Lat 6.37°N and Long 2.391°E) was assessed via Script Orbit and Array Center (SOPAC). The data obtained was in RINEX format, which was processed using TEC application software by Gopi Seemela of Institute of Geomagnetism, India. The software is such that all corrections, such as instrument bias, elevation effect, etc. has been affected. In the processing, a slant TEC which is dependent on elevation angle was first obtained. A more preferred TEC, vertical TEC, which is independent of elevation angle, was sort from equation 1.

$$V_{TEC} = STEC \times Cos\{sin^{-1}\left(\frac{R_E cos\beta}{R_E + h_{max}}\right)\} \quad (1)$$

R_E = 6378 km, β= elevation angle of GPS satellite at the ground station and h_{max} is the height of ionospheric penetration point (IPP) usually assumed to be 350 – 400 km.

The equation (1) is obtained by taking the projection from the slant to vertical using a thin shell model, assuming a height of 350 km following the techniques given by Klobuchar (1986), as depicted in Figure 1.

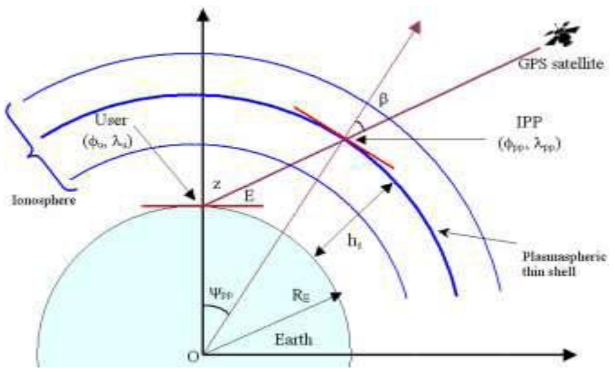

Figure 1: Geometry for the Conversion of Slant TEC to Vertical TEC (After Bolaji *et. al.*, 2015)

The critical frequency of F2 layer (foF2) was obtained from International Reference Ionosphere (IRI-2016) model. The data was used to calculate the electron density of F2 layer (NmF2) from the expression:

$$NmF2 = (foF2)^2 \times 1.24 \times 10^8 \quad (2)$$

The geomagnetic indices of Disturbance Storm Time (Dst) obtained from World Data Center (WDC) for geomagnetism, Kyoto, Japan, was used to classify the geomagnetic events. This classification was based on the work by Gonzalez *et al.*, 1994.

III. RESULTS AND DISCUSSION

Variation of foF2 during different geomagnetic conditions

The diurnal variations of foF2 during the geomagnetic quiet periods (Dst > -30nT) of August 1 – 10 and July 1 – 3 are represented in Figure 2. The figures showed three phases: steep increase in foF2 during the early hours of the day, afternoon maximum and sharp fall to minimum values. The afternoon maximum was marked with double peaks (bifurcation). It occurred between 7.00 – 18.00 UT in Addis Ababa and between 12.00 – 22.00 UT in Cotonou station. Observation also showed that the variation of foF2 in Addis Ababa lag that at Cotonou by about 6 hours during the three phases.

The maximum value of foF2 as observed in the month of August was about 10 MHz and 9.7 MHz for Addis Ababa and Cotonou respectively, while the minimum values were 3.5MHz and 4 MHz respectively. In the month of July, maximum values are 9.8 MHz and 10.0 MHz for Addis Ababa and Cotonou respectively.

During the geomagnetic weak period (-50 nT < Dst < -30 nT), same features as during the quiet period, with almost same magnitude of peaks and minimum values of foF2 as shown in Figure 3. The Figure is the diurnal variation of foF2 on August 17 – 20.

During the geomagnetic moderate periods (-100 nT < Dst < -50 nT) of November 1 – 7 and September 6 – 10 (Fig. 4), the peak values of foF2 increased to about 10.2 MHz and 10.7 MHz at Addis Ababa and Cootonou respectively.

During the geomagnetic intense periods (-250 nT < Dst < -100 nT) of December 20 – 22, October 7 – 10 and March 16 – 19, as shown in Figure 5, the maximum values of foF2 increased. On the month of December, the maximum values of 8.6 MHz and 9.0 MHz was observed for Addis Ababa and Cotonou respectively. On the month of October, the values are 11.0 MHz and 10.8 MHz for Addis Ababa and Cotonou respectively, while 11.0 MHz and 12.0 MHz for the month of March was observed for Addis Ababa and Cotonou respectively.

In general, critical frequency of the F2 layer is dependent on the geomagnetic condition, with higher values corresponding to higher geomagnetic activities. This enhancement during high geomagnetic conditions could be attributed to wavelike disturbances which originates from the auroral region and propagate toward the equator (Tsagouri and

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Belehaki, 2002). From the observation also, it can be said that foF2 is dependent on seasons. This was so owing to decreased values of foF2 during the winter compared to increased values observed in equinoxes with same geomagnetic activities.The dependent of foF2 on the time of the day, with peak during the daytime is attributed to the ionization of particles in this layer, which is highest during the day, when the Sun is above the horizon (MacNamara, 1994).

The various peak values of foF2 during different geomagnetic condition reflect the highest frequency at which ionosphere above the station was reflecting signal at 180^o. The effect of station on the variation of foF2 was obvious, as Addis Ababa recorded higher values compared to Cotonou station.

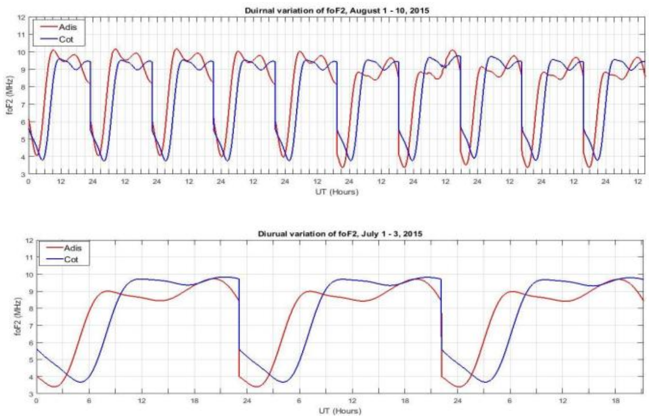

Figure 2: Diurnal Variation of foF2 during the Quiet Geomagnetic Period of August 1 – 10 and July 1 – 3, 2015

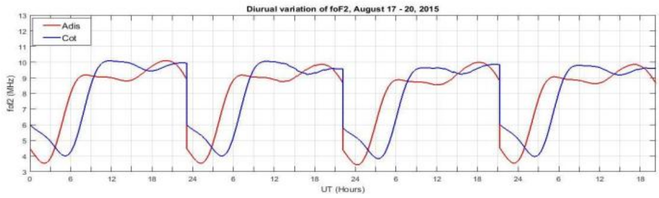

Figure 3: Diurnal Variation of foF2 during the Weak Geomagnetic Period of August 17-20, 2015

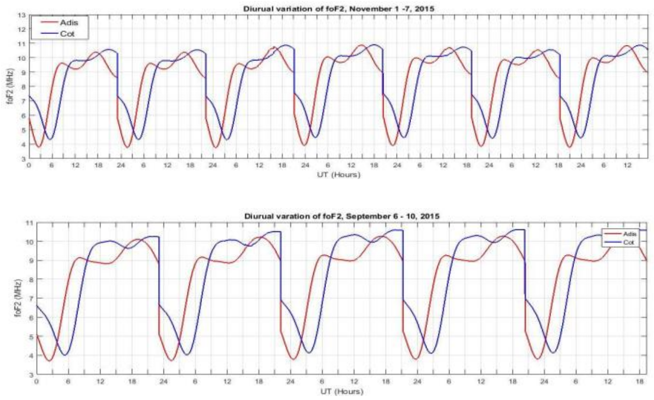

Figure 4: Diurnal Variation of foF2 during the Moderate Geomagnetic Period of November 1-7, and September 6-10, 2015

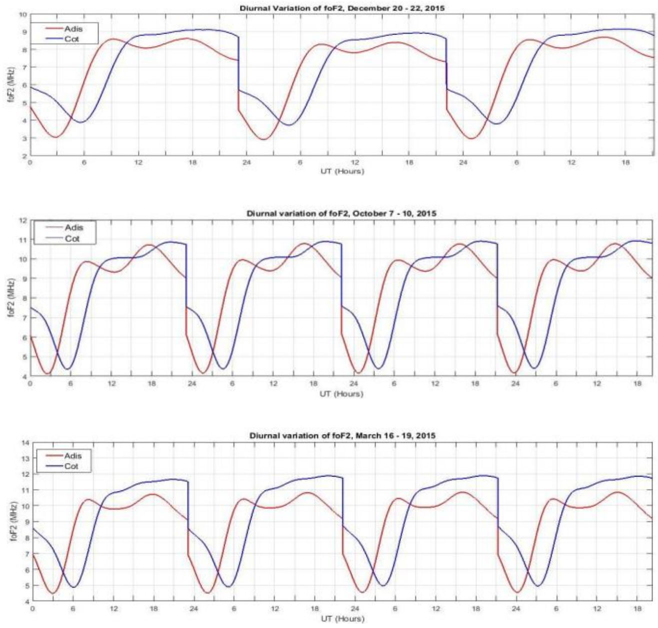

Figure 5: Diurnal Variation of foF2 during the Intense Period of December 20 – 22, October 7-10, and March 16 – 19, 2015

Variation of TEC during Different Geomagnetic conditions

The diurnal variations of TEC as seen in the figures exhibit the three segments expected of low latitude: the build-up region, daytime plateau and the decay region (Bagiya *et. al*., 2009).

Observation in all the TEC figures also showed some uncertainties in the plots in form of wave-like perturbations. This may be as a result of ionospheric irregularities developed as a result of the storm events. TEC values also vary from station to station and attained maximum values at different times. This is evidence of dependence of TEC on latitude and the different times of occurrence of the maximum TEC could be attributed to the westward drift of current. Tsurutani *et al*. (2004) and Mannucci *et al*. (2005) revealed the dependence of TEC during geomagnetic storms to geographic location of the receiver, and the strength and local time of occurrence of the storm.

In Figure 6 representing the quiet geomagnetic condition, the maximum TEC values were about 40 TECu in the two stations. As the geomagnetic condition increases, enhancement in both TEC and wave-like perturbation were observed. The maximum TEC values of about 50 TECu and 43 TECu were observed in Addis Ababa and Cotonou respectively during the moderate geomagnetic condition (Figure 7). During the intense geomagnetic conditions (Figure 8), the maximum TEC value was about 59 TECu at Cotonou and about 44 TECu at Addis Ababa on December 20 (the day of the storm). However, on March 17, the maximum TEC

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values were about 82 TECu at Cotonou and about 72 TECu at Addis Ababa. Obviously, season affects TEC variation, one would expect the TEC maximum during the intense storm event that occurred in December to be high just like that that occurred in March. Also, observation showed that Cotonou station is more affected by increased storm events than the Addis Ababa station. The TEC maximum during quiet periods in Addis Ababa was consistently high compared to that at Cotonou station, which was actually expected since Addis Ababa was at higher latitude.

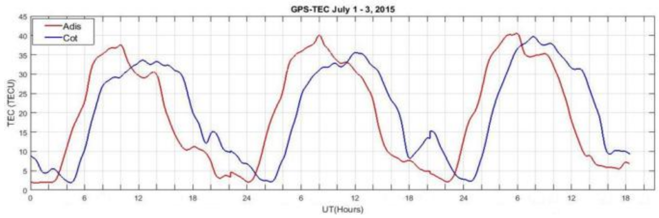

Figure 6: TEC Variation during Geomagnetic Quiet Period of July 1 – 3, 2015

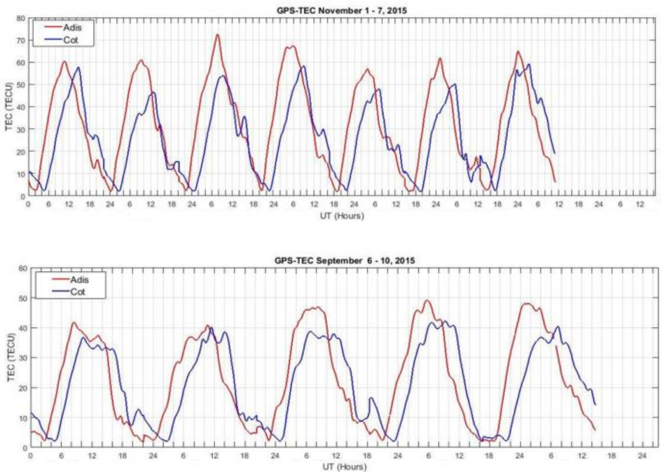

Figure 7: TEC Variation During Geomagnetic Moderate Period of November 1 – 7 and September 6 - 10, 2015

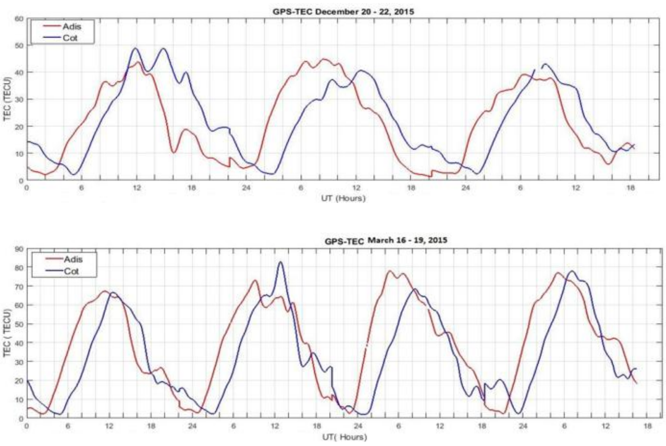

Figure 8: TEC Variation during Geomagnetic Intense Period of December 20 – 22 and March 16 - 19, 2015

Effects of the Variations on Radio Communication

Here, the effects of electron density and frequency of propagation is considered. Under suitable conditions of the ionosphere, charged particles (electrons) can remove energy from an electromagnetic wave and thus attenuate the signal. Also, a wave travelling from one place to another in which the electron density is different will undergo a change in its direction of propagation, due to the effect of free electrons on the velocity of a radio wave. When a radio wave enters the ionosphere and encounters a significant concentration of free electrons, some energy of the radio wave is transferred to the electrons, which are thus set into oscillation at the same frequency as that of the radio waves. The electrons can lose some of this energy as a result of collisions with neutral particles (atoms or molecules) in the upper atmosphere and it results in attenuation of radio waves when passing through the ionosphere. But, if there are no such collisions, the oscillating electrons will reradiate electromagnetic waves at the same frequency and restore the original radio waves without loss. In addition, collision frequency of electrons with neutral particles is inversely proportional to the square of the frequency of the radio waves and hence attenuation is greater with the lower frequency, i.e., the longer the wavelength.

The maximum frequency when transmitted vertically and reflected back from a particular region of the ionosphere is called the critical frequency of that region. In long-distance radio communication via ionosphere only high frequency (HF) band (3 to 30 MHz frequencies) is normally used. This is because of the fact that the radio waves of lower frequency are too greatly attenuated in passing through the D region, whereas those of higher frequency will not be reflected because the maximum critical frequency, i.e. for the F2 region is exceeded.

IV. CONCLUSION

In this study, critical frequency of F2-layer and GPS data obtained for two independent stations located at equatorial ionosphere have been used to study the ionospheric response on radio communication during different geomagnetic conditions. Results showed that both foF2 and TEC play significant role in everyday communication and navigation. This is affirmed by increased variation and perturbation of both parameters with increased geomagnetic conditions. The contribution of location was also investigated. Addis Ababa station stands a higher risk of negative ionospheric effects on communication compared to Cotonou station. Under suitable conditions, the ionosphere reflects long, medium and short radio waves and is used for radio communication and navigation. Since electron density of the ionosphere varies with factors such as, local time, season, latitude and

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geomagnetic condition, it becomes imperative to keep studying these changes because it affects the long distance radio communications applications through ionosphere.

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