The Response of Ethiopian Ionosphere to the Magnetic Storm of 11 October 2008

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Abstract

IGS network GPS measurements were used to study the ionospheric effect of 10-12 October 2008 magnetic storms on Ethiopian regions. The GPS data from three equatorial stations, Arbaminch (6.02^0N, 37.33^0E), Nazrate (8.33^0N, 39.09^0E), and Robe (7.51^0N, 39.38^0E), of Ethiopia were applied to create Total Electron Content (TEC) maps over Ethiopia. On sudden storm commencement, the TEC in all of the stations under consideration showed enhancement with percentage deviation of 40 in armi, 32 in nazr and 35 in robe respectively, *i.e.* the difference between monthly average TEC values and TEC on the disturbed day. We were capable to observe the positive effect (phase) of the storm during the 10-12 October 2008 storm period in all of the three stations; however, a slight negative effect of the storm has been observed from armi station with percentage deviation of 18 in magnitude.

Keywords: Equatorial ionosphere, TEC, Magnetic storm.

Resumen

De la red IGS de mediciones GSP se utiliza para estudiar el efecto de la ionósfera de 10-12 de Octubre de 2008 las tormentas magnéticas en las regiones de Etiopía. Los datos GSP desde tres estaciones ecuatoriales, Arbaminch (6.02^0N, 37.33^0E), Nazrate (8.33^0N, 39.09^0E) y Robe (7.51^0N, 39.38^0E), de Etiopía donde se han aplicado para crear el Contenido Total de Electrones (TEC) en los mapas de Etiopía. En el comienzo de una atormenta repentina, la TEC en todas las estaciones bajo consideración mostraron realce con la desviación porcentual de 40 en armi, 32 en nazr y 35 en robe respectivamente, es decir, la diferencia entre el promedio mensual TEC y los valores TEC en el día alterado. Fuimos capaces de observar el efecto positivo (fase) de la tormenta durante el periodo del 10-12 de Octubre de 2008 de toda la tormenta de las tres estaciones; sin embargo, un ligero efecto negativo de la tormenta se ha observado desde la estación armi con el porcentaje de desviación de 18 en magnitud.

Palabras clave: Ionósfera Ecuatorial, TEC, Tormenta magnética.

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I. INTRODUCTION

The quiet time ionosphere can be perturbed by the injection of energy at high latitudes that is associated with geomagnetic storms. The corresponding global changes in the composition and dynamics of the ionosphere and thermosphere can produce both increases and decreases in electron densities and TEC [1]. The observed increases and decreases in ionosphere F region electron densities and TEC are referred to as positive and negative storm effects. Parameters such as latitude, local time and phase of the storm are crucial for determining the occurrence and magnitude of the positive and negative storm effects. Many observational and modeling studies have showed the mechanisms that are responsible for these storm time effects. Even though many attempts are going on, there remain gaps in the present understanding of how the ionosphere responds to geomagnetic storms. Thus, investigations of geomagnetic storms and impacts on ionosphere are of great interest of space weather research.

The existence of major geomagnetic storms is associated with the earth directed coronal mass ejections (CMEs) from the sun particularly under the condition of southward interplanetary magnetic field (IMF) B_Z. Interaction between the solar wind and magnetosphere produces electric fields at the magnetosphere heights that may penetrate up to the equatorial latitude. These fields are termed as prompt penetration electric fields, PPEF [1, 2] at low latitudes, which are eastward during the day and westward during the nighttime. In the recent study [2] it has been shown that the PPEF may sustain up to several hours. In more detail sense, the increase in radiation and consequent joule heating of the high latitude plasma, which may launch equatorial ward wind, is responsible to generate disturbance dynamo fields (PPEF in low-latitude). This mid-latitude storm time winds may drive an F-region dynamo. The resultant electric field leak immediately to the equator.

Many studies, including [2] and [3], reported another interesting phenomena that occurs during geomagnetic storms, the traveling ionspheric disturbances (TIDs). TIDs may result due to the excessive and impulsive energy input at high latitude during the storms that travel from high latitude towards the equator with high speed. The TIDs lift the ionized plasma along the magnetic field lines to higher altitudes where it stays for longer time due to lower recombination rate.

In October 2008, a moderate storm (with Dst=-55nT and Ap=35nT) occurred at 12:00UT, which caused the magnetic field and ionosphere TEC disturbances. [4] investigated the effect of this storm based on TEC and the rate of change of TEC (TECR) whose data was observed from GPS during the storm periods at locations of Maitri (70.65^{0}N, 11.45^{0}E), Trivandrum (8.5^{0}N, 77^{0}E), and Delhi (28^{0}N, 77^{0}E). According to his investigations, during sudden storm commencement, the TEC at high latitude (Maitri) showed enhancement and the rate of change of TEC (TECR) showed variations but at both stations equatorial (Trivandrum) and low latitude (Dehli) the variation of TEC and the TECR didn't show any enhancement during the 10-12 October storm. Moreover, he could observe both the positive and the negative effects of the storm on TEC at higher latitudes.

In the present paper, we investigate the storm effect during the October, 2008 storm using ground-based GPS observations from three equatorial stations, Arbaminch (6.02^{0}N, 37.33^{0}E), Nazrate (8.33^{0}N, 39.09^{0}E), and Robe (7.51^{0}N, 39.38 ^{0}E), in Ethiopian sector. We intended to investigate this particular storm effect because there is no reported document that demonstrates the effect of 10-12 October 2008 magnetic storm on Ethiopian Ionosphere.

II. DATA AND METHOD OF ANALYSIS

TEC derived from GPS signals is a powerful method of studying the ionospheric response to geomagnetic storms. TEC data obtained from dual frequency GPS receiver is used to study the ionospheric variability during moderate magnetic storm. For the present study, GPS data has been obtained from Arbaminch (6.02^{0}N, 37.33^{0}E), Nazrate (8.33^{0}N, 39.09^{0}E), and Robe (7.51^{0}N, 39.38 ^{0}E), which are among GPS stations in Ethiopia. The TEC data are corrected for receiver and satellite (instrumental) biases. The variability of the ionosphere can be estimated by different ways [5] but the changes in the ionosphere are more evident in TEC deviation from the quiet day TEC. The disturbance degree was estimated by the deviation from the quiet day TEC as

$$\Delta TEC = \frac{TEC_{observed} - TEC_{average}}{TEC_{average}}. \quad (1)$$

According to [5] "the geomagnetic storm is an interval of time when a sufficiently intense and long lasting interplanetary convection electric field leads, through a substantial energy in the magnetosphere-ionosphere system, to an intensified ring current sufficiently strong to exceed some threshold of the quantifying storm time Dst index". This index is a quantitative measure of the ring current forming around the earth during geomagnetic storm. It is commonly agreed that the magnetic storm can develop when Dst index exceeds the threshold -50nT (which corresponds to the interplanetary magnetic field B_Z component -5nT) and stays over this threshold at least 2 hours.

III. OBSERVED STORM INDICATORS

The observations from Arbaminch, Nazrate and Robe confirmed that October 2008 has had a few magnetic active periods during low solar activity. For the time being, we need to concentrate on the intensive disturbance of 10-12, October 2008. The sudden storm commencement was observed at 12:00UT on 11 October 2008.

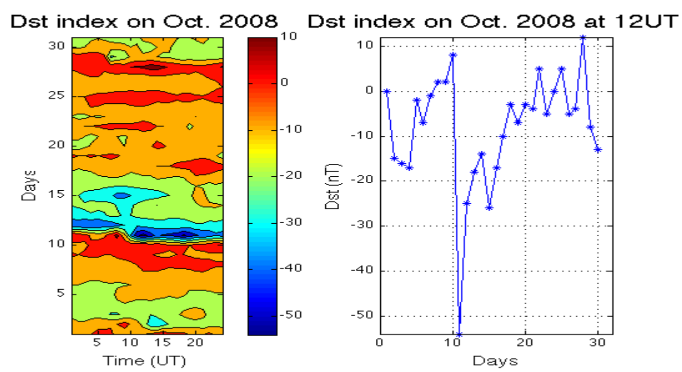

FIGURE 1. Dst index on October 2008.

The geomagnetic conditions present in Figs. 1 and 2 were observed during the storm period. The left panel of Fig. 1 illustrates the temporal and daily variations of Dst index and the right panel shows the daily variation of Dst index at a particular time, 12UT. Moreover Fig. 2 demonstrates the daily variations of average planetary index, Ap in comparison with the Dst index. Both indices are indicators for the existence of magnetic storm. Based on these initials, we are going to show the effect of 10-12 October 2008 storm on Ethiopian Ionosphere. Data related to solar wind and interplanetary magnetic field (IMF) during the development of the storm is presented by Table I.

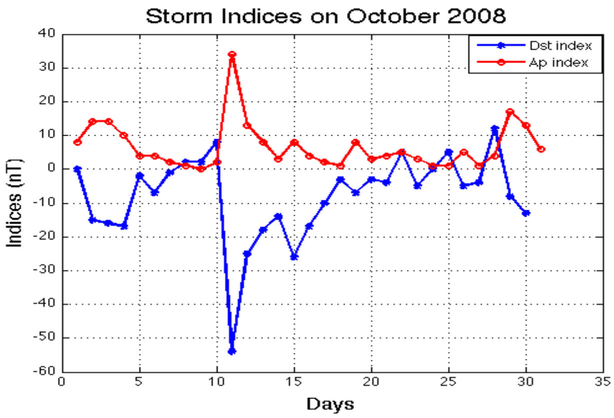

FIGURE 2. Dst and Ap indices on October 2008.

TABLE I. Solar wind and IMF on October 10-12, 2008 (from Spaceweather.com).

Days	*Solar wind speed (km/s)*	*B_z (nT)*	*Condition*
Oct. 10, 2008	333.6	3.0 North	Quiet
Oct. 11, 2008	533.9	1.0 South	Storm
Oct. 12, 2008	523.8	-	Unsettled

IV. RESULTS AND CONCLUSIONS

Over the Arbaminch (armi), Nazrate (nazr) and robe stations, the storm started at 12 UT on 10 October 2008 and sustained for 3 days. During this storm, the ionosphere was disturbed for longer hours, as seen from the left panel of Fig. 1 and the ionosphere TEC was affected by this magnetic disturbance. The solar energetic particles enter in the earth's magnetic field and produced electric current in Polar Regions. This current creates a disturbance in magnetosphere and ionosphere. During this disturbance, the TEC showed an enhancement.

According to a report by [4], the variation of TEC and the rate of change of TEC (TECR) didn't show any enhancement during the 11 October 2008 storm on ionospheres of both low (Delhi, 28^0N) and equatorial (Trivndrum, 8.5^0N) stations. Contrary to this result, our investigation showed that there were TEC variations with percentage deviation of 40 in armi, 32 in nazr and 35 in robe (See Fig. 8). Thus, this contradiction requires further investigation. Besides, the effect was significantly observed during the start of the recovery phase of the storm, *i.e.* on 12 October 2008.

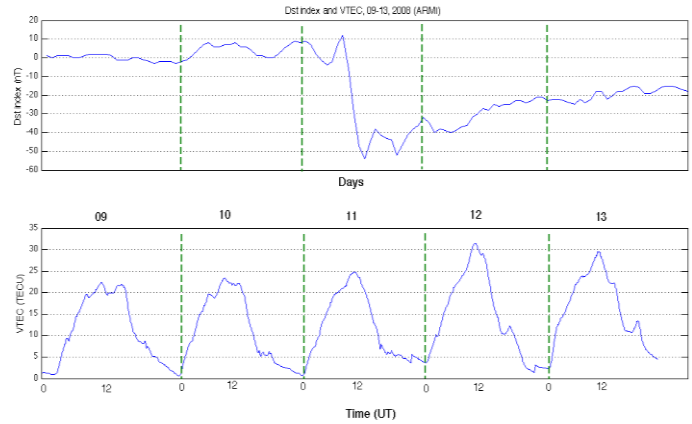

FIGURE 3. VTEC on October 09-13, 2008 at armi station.

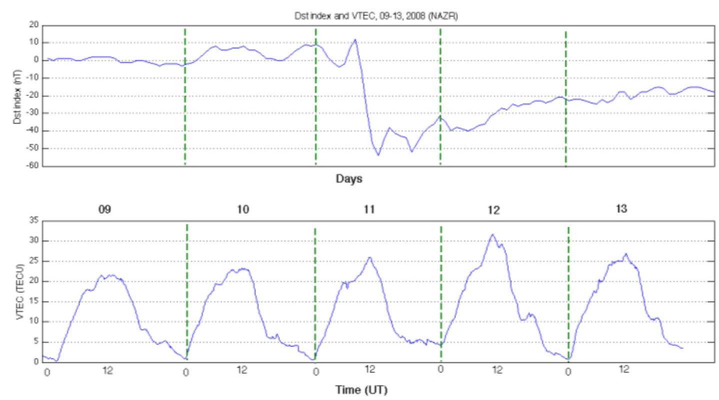

FIGURE 4. VTEC on October 09-13, 2008 at nazr station.

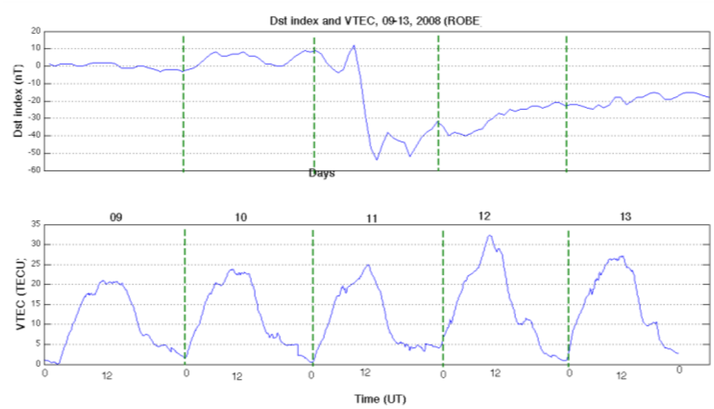

FIGURE 5. VTEC on October 09-13, 2008 at robe station.

From our investigations, we inferred two factors, which are responsible for the variability of TEC. The first is a strong solar wind (see Table I), which results in an enhancement in ionization and the second is the transport of additional plasma from high latitude towards equatorial and low-latitude region. Magnetic storm is usually intense near aurora zone, which is supposed to move towards equatorial and low-latitude region during sever storm. Thus in the 11 October 2008 situation, the intensity of solar wind was significantly high enough to push the energetic particles toward equator and low-latitude region so that ionosphere TEC showed significant variation or enhancement in equatorial and low-latitude (see Table I).

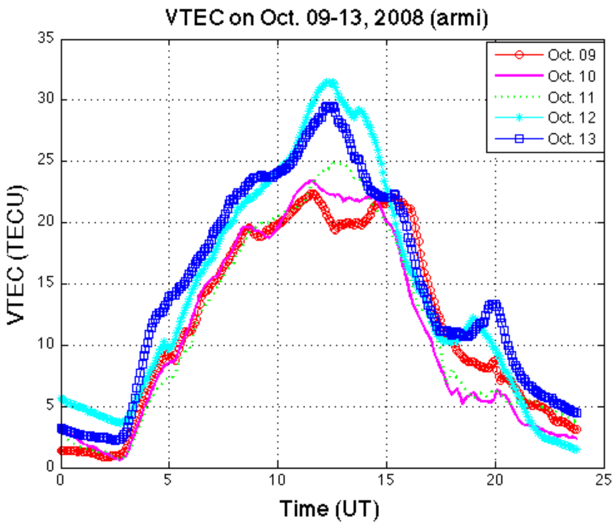

FIGURE 6. VTEC on October 09-13, 2008 at armi station.

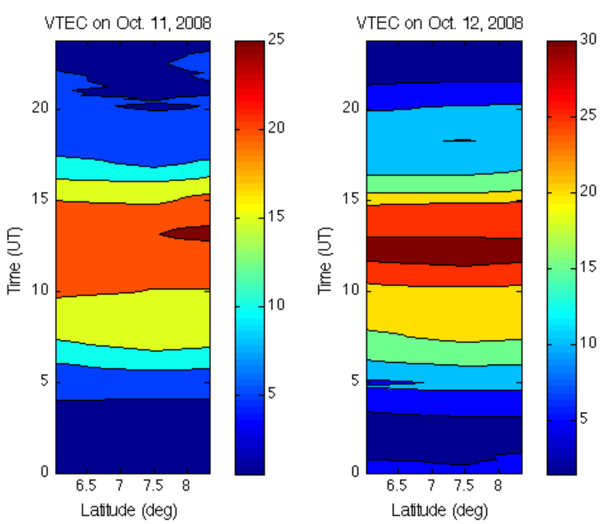

FIGURE 7. Spatial variation of the storm effect on Oct. 2008.

Diurnal variation of TEC during the storm: Day-by-day diurnal variations of TEC can be used to deduce the general idea of storm development. Figs. 3, 4 and 5 show VTEC variations over three stations in Ethiopia during the storm time. The TEC behavior at armi, nazr and robe stations is very similar and the main feature of the storm under consideration is a significant positive effect during daytime on 11 and 12 October 2008. This series of TEC enhancement is probably related to the feature of development of magnetic storm, which included the sequence of IMF (Fig. 1 and Table I). Moreover a slight negative effect of the storm has been observed in armi station with percentage deviation of 18 magnitudes, as illustrated by Fig. 8.

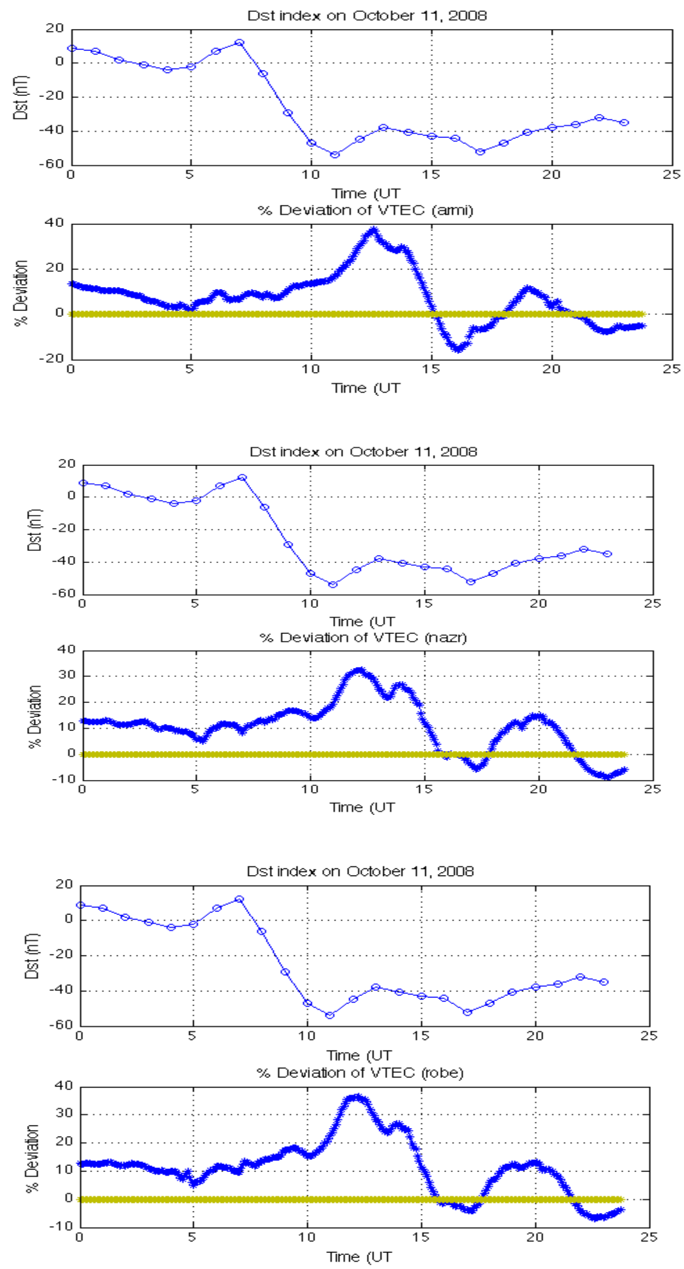

FIGURE 8. Deviation between monthly average VTEC and disturbed day TEC of the 10-12 October 2008 storm.

Spatial variation of TEC during the storm: As it is displayed by Fig., the storm development during the main phase (October 11) was dominantly observed at Nazr station and it was expanded to the other stations *i.e.* armi and robe. Otherwise, during the recovery phase of the storm (October 12), the storm effect was significantly observed in all latitudes that we considered. On October 12, the VTEC has enhanced with percentage deviation of 40 in armi, 32 in nazr and 35 in robe. Moreover, the negative effect of the storm was observed only at armi stations, as it is demonstrated by Fig. 8 The storm was pronounced on the initial phase (Oct. 10) in both nazr and robe stations, however, in armi station, the storm was significantly observed starting from Oct. 11, 2008. This might be due to the propagation of the storm from relatively high latitude towards the equatorial regions.

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