Africa mid and low latitude ionosphere response observed during the geomagnetic storms of July 15 and 9 March 2012 using GPS

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Abstract. In this paper, the initial and recovery phases of July 15 and March 9, 2012 geomagnetic storms in African mid and low latitudes ionosphere has been studied using GPS. We employ relative total electron content (rTEC) variations using 2 stations from the Africa Geodetic Reference Frame (AFREF) to characterize African sector ionosphere responses during both storms. To characterize rTEC, we employ 15-day median-average sliding-window during the storm. Both storms lasted 18 h with Dst minima -139 nT for July 15 and -145 nT for March 9, when solar plasma wind speed recorded 545 km/s and 712 km/s respectively. The recovery phase lasted 48 h for -139 nT storm and 46 h for -145 nT when solar plasma wind speed recorded 485 km/s and 428 km/s respectively. It may be attributed that storm recovery phases do not depend on storm severity but the response of ionosphere during storms. Results show Positive storm dominates during the recovery phase and interplanetary electric field and solar plasma wind speed contribute to storm enhanced density. Ionospheric disturbances observed due to prompt penetration electric field shaped the magnetic field and prompted pre-storm rTEC enhancement. Plasma convection at mid-latitudes of African sector observed rTEC enhancements which did not appear in other studied sector results. Further observations should be carried out using other storms.

1. Introduction

Study of ionosphere during geomagnetic disturbed periods has magnified the importance of Global Navigation Satellite Systems [1]. Ionosphere as ionized region of Earth’s upper atmosphere houses sufficient ions and free electrons that interpose radio signals propagation. The magnetospheric current injection perturbs electromagnetic properties of the ionosphere. It is worth to know that ionosphere is a smooth varying media and plasma follows the magnetic field lines during geomagnetic disturbances.

Equatorial Ionosphere Anomaly (EIA), Equatorial Plasma Bubbles and Storm Enhanced Density (SED) as ionospheric phenomena have helped to understand complex structure of the ionosphere, and its variability majorly during disturbed periods [2]. The effect on GNSS and radio wave signal propagation during storm has been outlined [3][4].

Wang et al. 2013 [5] studied July 15 storm at North China and results showed noontime and sunset 60% TEC enhancements. Liu et al. (2014) identified EIA as plasma uplift phenomenon during storm.
recovery phase in Asian/Australian sector. Unfortunately, recent studies by Ren et al. 2020 [7] and Astafyeva et al. 2020 [8] have noticed TEC knowledge gap during storm recovery phase. This paper presents Africa sector TEC anomalies during storm main and recovery phases.

2. Data and method

GNSS data on sTEC from African Geodetic Reference Frame network (AFREF) were retrieved to study Africa sector ionosphere during both storms. Data stored in Receiver Independent Exchange (RINEX) format in 30 s cadences were processed using GPS-TEC analysis application software into vTEC and averaged to 1 h for easy analysis with space weather indices.

Obtain hourly values of disturbance storm time (Dst), Interplanetary Magnetic Field (IMF), Interplanetary Electric Field (IEF Ey), Solar wind plasma speed, Kp index, solar flux at 10.7 cm (F10.7), the auroral AE and AL indices using One-third (1/3) Dst threshold suggested by Yermolaev et al. 2012 [9] is used to classify fully recovered phase of the storm. 15-day median-average sliding-window was used to obtain relative TEC (rTEC) which is suitable for ionospheric TEC analysis. Interplanetary and geomagnetic indices were obtained from NASA-OMNIweb (http://omniweb.gsfc.nasa.gov/) and vTEC data from AFREF (http://afrefdata.org).

3. Results and Discussion

Listed as top 50 geomagnetic storms that have occurred since cycle 23, both storms occurred during the ascending solar level of cycle 24 with Dst minima -139 nT for July 15 and -145 nT for March 9, 2012. Figure 1 shows space weather indices during storm of July 15 where sudden commencement of the storm started at 00:00 UT, DOY=197 and preceded with main phase that lasted 18 h.

Southward decrease of IMF Bz recorded -15.2 nT with Kp > 5 (70) during storm commencement when solar wind plasma speed and IEF Ey recorded values 545 km/s and 8.83 mV/m respectively. In Figure 2, March 9 storm with minimum Dst -145 nT records sudden commencement at 11:00 UT, DOY=68 and preceded with main phase that lasted 18 h when solar plasma wind speed of 712 km/s and Kp > 5 (80) is observed. IMF Bz southward orientation -12.1 nT with aurora indices (AE and AL) 0f 1109 nT and -997 nT shows storm severity.

Figure 1. Observed space weather indices during the storm of July 15, 2012.
Figure 2. Observed space weather indices during the storm of March 9, 2012.

Figure 3. Mid latitude (HARB, MLAT: -36.32) TEC anomaly for July 15 storm (a) Dst -139 nT (b) Daily and 15-Day median average (c) absolute TEC during the initial and recovery phases [black line shows decrease and increase threshold], (d) relative TEC percentage anomaly during the initial and recovery phases.
Figure 3 shows mid-latitude early hours rTEC depletion observed during storm initial phase that lasted 6 h followed by daytime rTEC enhancements that lasted 7 h. The arrow marked (1) shows this display when traced to panel (d) of the figure. The arrowhead indicated (1) should appear vertical like arrow 2, where arrow 1 shows start time rTEC and arrow 2 shows one-third (33.3%) Dst threshold and rTEC recovery enhancements. The arrow is rightly placed in the commencement of the disturbed day. We selected two days before the storm and three days after the storm for a clear feature. Recovery phase of the storm lasted 5 h with nighttime rTEC depletion, followed by rTEC enhancements as indicated by arrow (2). It is seen that daytime ionospheric uplift is caused by PPEFs leading to rTEC enhancements. Disturbances of the ionosphere due to prompt electric field penetration initiate pre-storm rTEC enhancements [10]. Low latitude early hours rTEC enhancements were observed (Figure 4).

The magnetic storms are used as an example of PPEF effects, where different directions of IMF will create different magnetospheric and ionospheric PPEFs. PPEF associates with positive storm with joule heating sustaining negative storm.

Figure 4. Low latitude (MAL2, MLAT: -12.42) TEC anomaly for July 15 storm (a) Dst -139 nT (b) Daily and 15-Day median average (c) absolute TEC during the initial and recovery phases [black line shows decrease and increase threshold], (d) relative TEC percentage anomaly during the initial and recovery phases.
Figure 5 shows March 9 mid-latitude anomaly during the storm. Plasma distribution effect on equatorward wind is seen in figure 5 during post-storm effect. In order to get this feature, we selected two days before the storm and three days after. Morning hour’s rTEC depression is observed that lasted 6 h, where positive storms dominate during storm initial and recovery phases.

Figure 6 shows low latitude plasma drift to mid-latitudes. Negative storm dominates and supports traveling ionospheric disturbance [11].

4. Conclusion
Both storms severity and TEC variations have been studied over Africa sector during cycle 24 ascending phase. The study findings are summarized as follows:

1. Positive rTEC dominates during both storms recovery phase and may be attributed that IEF Ey and solar plasma wind speed contributes to storm enhanced density.
2. To characterize drivers of geomagnetic storm during the period, we observed that different directions of IMF Bz create different magnetospheric and ionospheric PPEFs.
3. PPEF shapes the magnetic field and plasma forced to follow the line where pre-storm rTEC enhancements are observed. At this period, enhanced PPEF develops pre-reversal enhancement that governs sunset mid-latitude ionosphere upward plasma seen during the initial phase of March 9 storm. PPEF as interplanetary motional electric field appears after electric fields are converted by solar wind to the magnetosphere.
4. rTEC anomalies depends on ionosphere response during storm and not storm severity.
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C.M.A. provided the main ideas, developed the methodology model, conceived and performed the comparison experiments, and analyzed the results; F.N.O and K.C.O provided supervision and mentorship.

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