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Low latitude ionosphere responses to solar wind forcing from GNSS data in March 2001

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Abstract

We employ Global Navigation Satellite Systems (GNSS) data to investigate the low latitude ionosphere variations over the African sector (Magnetic Latitude: 0.17°) during active and quiet magnetospheric conditions during solar maximum in March 2001. The relative Total Electron Content (rTEC) index is employed to detect the variations over the threshold of |rTEC| ≥ ±30%. We observe increases in the solar wind speed, the interplanetary magnetic field (IMF), and the geomagnetic SYM-H index during the abrupt changes detected in the ionosphere. On 9March 2001, an anomalous rTEC started at 5 h UT due to a short period of southward IMF Bz orientation. At 8h UT, a minimum SYM-H of -139nT was recorded under solar wind speed of 712 km/s, causing an rTEC disturbance. Results show that solar wind forcing during the prompt electric field drives positive storm-enhanced density and observed during early morning hours.

1. Introduction

The exact understanding of the ionosphere variability and its coupled variables and processes are very important for applications such as Global Navigation Satellite Systems (GNSS) navigation, positioning, and timing, radio communications, and Earth observation with remote sensing techniques (Calabia et al. 2021). Electrodynamic coupling between the magnetosphere and the high latitude ionosphere has significant impact on the low latitude ionosphere during geomagnetic storms (Sharma et al. 2020).

This phenomenon is attributed to F-region thermospheric equatorward winds, which result from momentum force and joule heating of the upper atmosphere (Richmond and Roble, 1979). In addition, thermospheric winds enhance total electron content and can change the global distribution of atmospheric chemistry (Ansari et al., 2019).

During geomagnetic storms, the low latitude electrodynamics are characterized by the disturbance dynamo electric field (DDEF) driving long-lasting effects on plasma distribution (Araki, 1985), and by the prompt penetration electric field (PPEF) that drives variations of shorter durations (Yamazaki and Kosch, 2015). The coupling between solar wind and the magnetosphere mainly occurs in the magnetic reconnection, and it results in ionospheric disturbances. However, the relationship between solar wind characteristics and the intensities of different geomagnetic storms is difficult to understand (Ji et al. 2010; Wang et al. 2003).

Here, we present the low latitude ionosphere responses to solar wind forcing during active and quiet geomagnetic conditions under the solar maximum period of March, 2001. We employ GNSS data and space weather indices to elucidate the possible interrelations between parameters; these are briefly introduced in section 2. In section 3 our results are provided, and section 4 summarizes our conclusions.

2. Method

We employ GNSS data from the ground-based GPS station of UNAVCO to study the ADIS station at the low latitude of the African continent. Specifically, the ADIS station is located in Ethiopia at a geographical latitude of 9.035° and longitude of 38.766°; the geomagnetic latitude (MLAT) is 0.17°. The data is available at the UNAVCO website (https://data.unavco.org) in RINEX format, where the slant total electron content (sTEC) is provided at 30s resolution. Here we convert sTEC to

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vertical TEC (vTEC) using the thin shell model of Seemala and Valladares (2011). Then, rTEC obtained with the following formula:

$$rTEC = (TEC_{storm} - TEC_{quiet})/TEC_{quiet} \quad (1)$$

The rTEC index in essential to exclude regular diurnal, seasonal, and solar-cycle effects (Pancheva et al. 2016). Daytime ionization is usualy associated with positive storms, and usually preceed the equatorial plasma fountain that is strengthen by the eastward prompt penetration of electric field (PPEF).

In order to study the geomagnetic activity, we employ SYM-H and ASY-H obtained from Service International des Indices Géomagnétiques (http://isgi.unistra.fr/oi_data_download.php). We also employ the solar wind velocity, the interplanetary magnetic field (IMF) Bz component, the IEF, the planetary Kp index, and the AE index. These indices are available at the OMNI website (https://omniweb.gsfc.nasa.gov).

3. Results

Figure 1 shows the space weather indices under quiet magnetospheric conditions on 26 March 2001. Figure 2 shows the space weather indices during storm conditions on 9 March 2001. The axes in both figures are arranged with the similar ranges in the y-axes. In figure 2, we observe rTEC enhancements are observed from 0 h to 2 h UT which lasted approximately 3 h. At 3 h UT, rTEC show strong decrease, which is coincident with the IMF Bz > 0 and the eastward orientation of Ey.

The minimum SYM-H reaches at 8 h UT with -139 nT, and the rTEC is 10%. The rTEC started to increase from 5 h UT reaching 30% limit at 10 hUT. At 12 h UT, the solar wind velocity shows a maximum of 741 km/s and the SYM-H is -115nT. Then, from 16-17 h UT, another clear positive anomaly is seen.

These positive fluctuations result from combined effects of thermospheric winds and electric fields observed during the time 19 h UT. At 8 h UT, rTEC reaches the-30% limit, showing a clear negative storm. This abrupt effect may be associated with changes in thermospheric composition.

TEC anomalies observed through the deviation of quiet from geomagnetic storm time causes magnetic field disturbances and likely occured during solar wind shockwaves that interects with Earth's magnetosphere.

The behavior of the ionosphere during the storm is determined by several electrodynamics and chemical actions and affected by solar wind forcing through magnetosphere-ionosphere coupling.

4. Discussion

The effect of IEF as motional electric field causes magnetospheric disturbance in the form of PPEF. This appears after electric fields are being inserted by solar wind forcing to the magnetosphere. The PPEF has eastward (westward) polarity during dayside/nightside and causes plasma enhancements/depletions.

We identified the horizontal disturbance of magnetic activity with Kp and the AE indices. Enhanced currents seem to flow below and within the auroral oval.

The rTEC values clearly show and detectthe anomalies above selected thershold (30%). The solar wind forcing along with the other variables are clearlydrivers of TEC anomalies.

The PPEF during IMF Bz < 0 strengts ionospheric zonal electric fields and weakens during Bz > 0.

PPEF as phenomenon of electric fields transmissions to the motion of particles in the magnetosphere, the auroral electroject (AE) and neutral atmosphere motions by DDEF has remained the equatorial ionosphere electrodynamic coupling with the high latitude ionosphere during geomagnetic storms.

The short-term changes in the Earth's magnetic field are largely impose by solar wind and can have direct response. It is likely seen that electric currents in space dominate in storms and serves as one major factor for vertical electrodynamics drift that influnces the growth rate of Rayleigh-Taylor Instability observed mainly during morning hour in this present analysis.

The main results of this study showed that small variations in magnetic field due to the forcing of solar wind are able to modify the dynamics of the low latitude ionsopere.

5. Conclusion

We have investigated ionospheric TEC anomalies during the storm of 9 March 2001 using the rTEC index and space weather indices. We employ relative TEC to study solar wind forcing to the low latitude ionosphere during both storm and quiet conditions. Our findings are summarized as follows:

- The rTEC anomaly was observed early morning hours and that corresponds to the eastward PPEF that indicates dayside plasma uplift.
- rTEC enhancements and depletions are difficult to separate from the effect of PPEF and DDEF and needs further investigation.
- Solar wind forcing indicated major driver of TEC during both storm and quiet conditions.
- At 8h UT a minimum SYM-H of -139nT was recorded under solar wind speed of 712 km/s, causing an rTEC disturbance.

The relations between solar wind and its interaction with different variables under different geomagnetic stormsrequire further investigation to observe the effects in the ionosphere.

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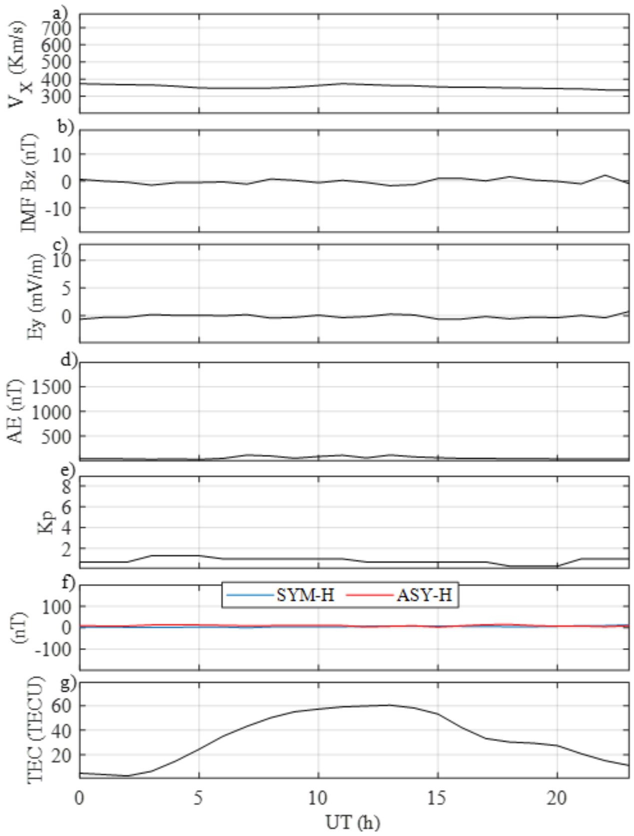

Figure 1. Space weather indices (a-f) and TEC (g) under magnetospheric quiet conditions (26 March 2001). Ranges in y-axes are set to be compared with Figure 2.

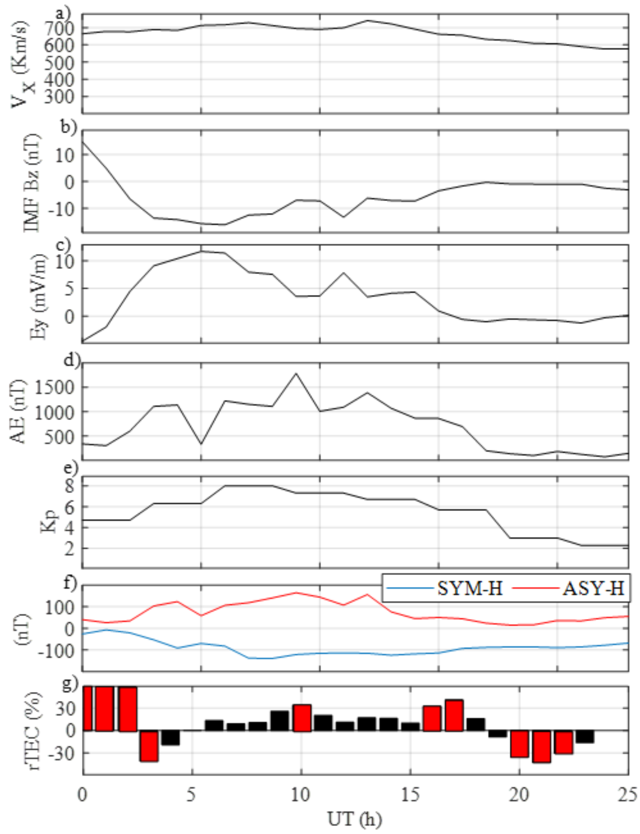

Figure 2. Space weather indices (a-f) and rTEC (g) under magnetospheric storm conditions (9 March 2001). Ranges in y-axes are set to be compared with Figure 1.

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