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Response of equatorial, low- and mid-latitude F-region in the American sector during the intense geomagnetic storm on 24–25 October 2011

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Abstract

In this paper, we present and discuss the response of the ionospheric F-region in the American sector during the intense geomagnetic storm which occurred on 24–25 October 2011. In this investigation ionospheric sounding data obtained of 23, 24, 25, and 26 October 2011 at Puerto Rico (United States), Jicamarca (Peru), Palmas, São José dos Campos (Brazil), and Port Stanley, are presented. Also, the GPS observations obtained at 12 stations in the equatorial, low-, mid- and high-mid-latitude regions in the American sector are presented. During the fast decrease of Dst (about ∼54 nT/h between 23:00 and 01:00 UT) on the night of 24–25 October (main phase), there is a prompt penetration of electric field of magnetospheric origin resulting an unusual uplifting of the F region at equatorial stations. On the night of 24–25 October 2011 (recovery phase) equatorial, low- and mid-latitude stations show h′F variations much larger than the average variations possibly associated with traveling ionospheric disturbances (TIDs) caused by Joule heating at high latitudes. The foF2 variations at mid-latitude stations and the GPS-VTEC observations at mid- and low-latitude stations show a positive ionospheric storm on the night of 24–25 October, possibly due to changes in the large-scale wind circulation. The foF2 observations at mid-latitude station and the GPS-VTEC observations at mid- and high-mid-latitude stations show a negative ionospheric storm on the night of 24–25 October, probably associated with an increase in the density of molecular nitrogen. During the daytime on 25 October, the variations in foF2 at mid-latitude stations show large negative ionospheric storm, possibly due to changes in the O/N2 ratio. On the night of 24–25, ionospheric plasma bubbles (equatorial irregularities that extended to the low- and mid-latitude regions) are observed at equatorial, low- and mid-latitude stations. Also, on the night of 25–26, ionospheric plasma bubbles are observed at equatorial and low-latitude regions.

Keywords: Space weather; Geomagnetic storm; Ionosphere; Ionospheric irregularities

1. Introduction

During geomagnetic storms the upper atmosphere can be drastically changed due to the imposition of adverse space weather conditions (Buonsanto, 1999). As described by Dungey (1961), geomagnetic storms are related to the penetration of solar wind energy in the Earth's magnetosphere by reconnection process. The reconnection process occurs when there is an interconnection between the lines of the interplanetary magnetic field (southward) and the geomagnetic field lines (northward) on the day side, carrying the energy of the solar wind on the polar cap toward the tail of the magnetosphere where a new reconnection occurs, and solar wind energy is injected into the magnetosphere (Dungey, 1961; Tsurutani et al., 1997).

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A large amount of energy is dissipated at high latitudes during the geomagnetic storms, and can generate traveling atmospheric disturbances (TADs) that produce ionospheric disturbances (Lee et al., 2002, 2004; Sahai et al., 2009a; de Jesus et al., 2012). The TADs can propagate to regions of mid- and low-latitudes. It should be mentioned that when the TADs propagate through the ionosphere are called traveling ionospheric disturbances (TIDs). As discussed by Abdu (1997), major changes in the equatorial ionosphere–thermosphere system during magnetospheric disturbances are produced due to: (1) prompt equatorward penetration of the magnetospheric electric fields, (2) disturbance dynamo driven by enhanced global thermospheric circulation (resulting from energy injected at high latitudes), and (3) disturbance winds (meridional and zonal) modifying the equatorial thermospheric dynamics. When the electron density in the F region shows an increase during geomagnetic storm relative to geomagnetically quiet period, results in ionospheric disturbances called positive ionospheric storm or positive phase of ionospheric storm (Sahai et al., 2007a; de Jesus et al., 2010; de Abreu et al., 2010a). As described by Ngwira et al. (2012), a long-duration positive ionospheric storm (over 6 h of enhancement) is often associated the equatorward neutral wind of large-scale thermospheric circulation. Also, during geomagnetic storms can occur decrease of the ionospheric electron density as compared with quiet periods, which results in ionospheric disturbances called negative ionospheric storm or negative phase of ionospheric storm (Sahai et al., 2005, 2009c; de Abreu et al., 2011). According to Prolss, (1980), negative ionospheric storms are related to the change in composition of the neutral gas which increases the ratio of N_2/O at high- and mid-latitude during geomagnetic storms.

During the past several excellent reviews on ionospheric storms covering low-, mid- and high-latitude regions have been provided by Schunk and Sojka (1996), Abdu (1997) and Buonosanto (1999). However, individual studies of magnetosphere–ionosphere interactions at equatorial, low-, mid-, and high-latitude regions during geomagnetic storms use both observational (Pirog et al., 2007; Sahai et al., 2009b; de Jesus et al., 2010; Balan et al., 2010) and modeling (Balan et al., 2009; Balan et al., 2010; Lu et al., 2008; Lin et al., 2009a; Lin et al., 2009b; Klimenko et al., 2011a,b; Klimenko and Klimenko, 2012) results continue to be published. Klimenko and Klimenko (2012) have reported that, the prompt penetration electric field occurs in the early stages of geomagnetic storm with an increase of geomagnetic activity and results in equatorial ionization anomaly intensification. Balan et al. (2009), Balan et al. (2010) and Klimenko et al. (2011a,b) have shown that the additional eastward electric field (during geomagnetic storms) such as prompt penetration electric field on its own is unlikely to cause positive ionospheric storms. According to Balan et al. (2009), Balan et al. (2010) an equatorward neutral wind is necessary to produce positive ionospheric storms. As mentioned by Lu et al. (2008) and Klimenko et al. (2011a,b), positive ionospheric storms are caused by the meridional component of thermosphere wind velocity. As discussed by Lin et al. (2009b), the storm time meridional neutral wind is important to produce an additional ionospheric layer underneath the equatorial ionization anomaly crest during an intense geomagnetic storm. As described by Lin et al. (2009a), theoretical model simulations for an intense geomagnetic storm have shown the generation of a low-latitude electron density arch aligned along the geomagnetic field generated by an unusual uplifting of the F_2-region that is driven by the penetration electric field.

Effects observed in the ionospheric F-region during intense geomagnetic storms remain an important issue related to space weather studies. In this investigation, we present and discuss the response of the ionospheric F-region in the equatorial, low-, mid- and high-mid-latitude regions in the American sector during the intense geomagnetic storm which occurred on 24–25 October 2011, using ionospheric sounding data (5 ionosonde stations) and Global Positioning System (GPS) (12 GPS stations) observations. The principal objectives of this paper have been to study the generation or inhibition of equatorial ionospheric irregularities (ESF) (Martinis et al., 2005), and ionospheric dynamics in the American sector during the geomagnetic storm on 24–25 October 2011.

2. Observations

In this investigation we present ionospheric sounding data F-region critical frequency (foF2) and minimum F-region virtual height (h′F) obtained at the five stations located in the American sector, Puerto Rico (hereafter referred as PTR; 18.5°N, 67.2°W, dip latitude 26.5°N; every 30 min), United States; Jicamarca (hereafter referred as JIC; 12.0°S, 76.8°W, dip latitude 0.13°S; every 30 min), Peru; Palmas (hereafter referred as PAL; 10.2°S, 48.2°W; dip latitude 7.2°S; every 15 min), São José dos Campos (hereafter referred as SJC; 23.2°S, 45.9°W; dip latitude 19.1°S; every 15 min), Brazil; and Port Stanley (hereafter referred as PST; 51.6°S, 57.9°W, dip latitude 31.5°S; every 30 min), on 23, 24, 25 and 26 October 2011. The ionospheric parameters (h′F and foF2) at PAL (a near equatorial station) and SJC (low-latitude station located under the southern crest of equatorial ionization anomaly) were obtained from the ionograms (manually scaled data), using the software UDIDA (UNIVAP Digital Ionosonde Data Analysis) (Sahai et al., 2007b; de Abreu et al., 2010b; de Jesus et al., 2011). The PTR (mid-latitude station) ionospheric parameters (auto-scaled data) were obtained from the Space Physics Interactive Data Resource (SPIDR Home) by the site http://spidr.ngdc.noaa.gov/spidr/. The JIC (equatorial station) and PST (mid-latitude station) ionospheric parameters (manually scaled data) were obtained from the Digital Ionogram DataBase (DIDBase) by the site http://ulcar.uml.edu/DIDBase/.

The complementary Global Positioning System (GPS) observations from 12 receiving stations in American (see