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Some ionospheric storm effects at equatorial and low latitudes

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Abstract

In this paper, the response of the equatorial and low latitude ionosphere to three intense geomagnetic storms occurred in 2002 and 2003 is reported. For that, critical frequency of F2-layer foF2 and the peak height hmF2 hmF2 for the stations Jicamarca (11.9°S), Ascension Is (7.92°S) and Tucuman (26.9°S) are used. The results show a "smoothing" of the Equatorial Anomaly structure during the development of the storms. Noticeable features are the increases in foF2 before the storm sudden commencement (SC) at equatorial latitudes and the southern crest of the Equatorial Anomaly. In some cases nearly simultaneous increases in foF2 are observed in response to the storm, which are attributed to the prompt electric field. Also, positive effects observed at equatorial and low latitudes during the development of the storm seem to be caused by the disturbance dynamo electric field due to the storm-time circulation. Increases in foF2 above the equator and simultaneous decreases in foF2 at the south crest near to the end of a long-duration main phase are attributed to equatorward-directed meridional winds. Decreases in foF2 observed during the recovery phase of storms are believed to be caused by composition changes. The results indicate that the prompt penetration electric field on the EA is important but their effect is of short lived. More significant ionospheric effects are the produced by the disturbance dynamo electric field. The role of storm-time winds is important because they modify the "fountain effect" and transport the composition changes toward low latitudes.

Keywords: Geomagnetic storms; Equatorial anomaly; Ionosphere

1. Introduction

It is well known that during quiet magnetically conditions the F2 layer in the magnetic equator is characterized by a depression in the electron density or "trough" and two peaks (crests) at about 15°–20° latitude (Stening, 1982). This is the so-called Appleton or equatorial anomaly (EA).

Changes in the mentioned structure are produced in association with geomagnetic storms (usually referred as ionospheric storms), which have been a topic of extensive studies for many decades. However, in spite of large number of case studies and a few morphological studies on the storm related changes of various ionospheric parameters, our understanding of the ionospheric storms at the EA area still remains unsatisfactory (e.g. Abdu et al., 1991; Zhao et al., 2005).

The studies of the response of the ionosphere to geomagnetic storms are important for understanding the energy coupling process between the Sun and the Earth and for forecasting space weather changes.

Geomagnetic storms are caused mainly by solar wind transients from the coronal mass ejections (CMEs) and solar flares or by the corotating interaction regions (CIRs) formed during the interaction between the high and low speed streams (Rawat et al., 2009). Occurrence frequency and intensity of transient solar emissions vary with different phases of the solar cycle characterized by the number

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of sunspots on the photosphere. Solar maximum is dominated by powerful solar eruptions, like solar flares and CMEs.

Most dominant mechanism for transfer of solar wind energy into the magnetosphere to produce the geomagnetic storms is magnetic reconnection between southwardly oriented IMF Bz component and the antiparallel geomagnetic field lines (see e.g. Rawat et al., 2009 and references therein).

So, a southward IMF condition is generally accepted as the most fundamental precondition for a storm or substorm to occur. However, some storms have been considered "anomalous" because the main phase storm occurred during the northward excursion of the Bz component of IMF. Such is the case of the storm occurred on 22 January 2005 in which minimum Dst reached −105 nT at 07UT (Sahai et al., 2011).

During the main phase of a geomagnetic storm at daytime the ionosphere above the geomagnetic equator presents generally an increase in the critical frequency foF2 with respect to median or quiet time values (the so-called positive ionospheric storms). Decreases in foF2 (the so-called negative ionospheric storms) are also observed during intense storms. Decreases of the peak electron density at low latitude stations occur in association with the increases observed at stations located below the trough of EA.

Electric field disturbances have been suggested as the most important contributor mechanism to explain the initial F2-region response to geomagnetic storms during daytime (see, for example, Abdu, 1997; Abdu et al., 2003, 2007, 2008; Batista et al., 2012 and references therein). This is possibly because the structure and dynamics of the quiet time equatorial ionosphere is determined by an eastward electric field in conjunction with the geomagnetic field.

Besides of perturbations of electrodynamic origin several other physical mechanisms (e.g., neutral wind effects, composition changes) seem to be operative at equatorial and low latitudes during storm periods (e.g., Prölss, 1995; Buonsanto, 1999; Danilov, 2001, and references therein).

One should expect a hemispheric asymmetry in the low latitude ionospheric response to a geomagnetic storm due possibly to the presence of different mechanisms along the various latitudinal regions during the disturbed period. As an example of that, analyzing Total electron Content (TEC) variations during the storm occurred on 7 September 2002, de Abreu et al. (2010) found that TEC variations at midlatitude stations in both hemispheres showed an *F* region positive storm phase. However, during the recovery phase, a strong hemispheric asymmetry was observed in the ionospheric response. While a TID was observed to propagate in the Southern American sector, no TID activity was seen in the Northern American sector. Also, in the Southern Hemisphere, the TEC variations were less affected by the geomagnetic storm. A perusal of TEC phase fluctuations and equatorial spread-F (ESF) ionospheric sounding data indicates that, on the disturbed night of 7–8 September, some stations showed the occurrence of ESF starting at about 0000UT (2000LT) on 8 September, whereas other stations showed that the ESF occurrence started much later, at about 0800UT (0500LT).

This paper analyses the ionospheric response during the periods of three severe magnetic storms events of 2002 and 2003 covering the magnetic equator and southern crest of the equatorial anomaly around 7.2 W-82 E magnetic longitudes. For that, the critical frequency foF2 and the peak height of F layer hmF2 of Jicamarca (equatorial station), Ascension Is and Tucuman (close to the southern crest of the EA) are used. Furthermore, possible physical mechanisms to explain the ionospheric effects of the storms are considered. The coordinates of the stations used are given in Table 1.

The goal of this paper is to present unusual observational results and try to analyze them with the current theories, showing some associations between foF2 and hmF2, which have not been frequently reported.

2. Results

The ground-based hourly foF2 and hmF2 data were provide by the Center for Atmospheric Research (University of Massachusetts-Lowell) website.

The strength of magnetic storms is determined by the variation in Dst geomagnetic index, thus the different phases of storms namely main phase and recovery phase were identified according to the distribution of Dst. Hourly values of Dst and AE indexes were obtained from the World Data Center at the University of Kyoto database: http://swdc.kugi.kyoto-u.ac.jp/dstdir.

As an index of ionospheric disturbance, the relative deviation of critical frequencies from the quiet level at each station was calculated as follows:

$$\mathrm{DfoF2} = [(\mathrm{foF2} - \mathrm{foF2(q)})/\mathrm{foF2(q)}] \times 100$$

where foF2 is the hourly perturbed critical frequency and foF2(q) represents the reference level (average value of five quiet days of the month of the storm). We use the average of five quiet days, instead of only one day taken as reference, because improves the representativity of the ionospheric behavior (Sobral et al., 2001). A similar expression in used for hmF2.

Positive and negative DfoF2 values correspond to positive and negative ionospheric storm effects.

The ionospheric response of three intense magnetic storms are presented in Figs. 1–3. The top plot of the figures shows the time evolution of Dst and AE for the storm

Table 1
Coordinates of the stations.

	Latitude	Longitude	Dip latitude
Jicamarca	11.9°S	283.2°E	0.64°
Ascension Is	7.9°S	345.6°E	−37.8°
Tucuman	26.5°S	294.8°E	−26.2°