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Unusual nighttime impulsive *fo*F2 enhancements at low latitudes: Phenomenology and possible explanations

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Abstract

This paper is focused on unusual nighttime impulsive electron density enhancements that are rarely observed at low latitudes on a wide region of South America, under quiet and medium/high geomagnetic conditions. The phenomenon under investigation is very peculiar because besides being of brief duration, it is characterized by a pronounced compression of the ionosphere. The phenomenon was studied and analyzed using both the F2 layer critical frequency (*fo*F2) and the virtual height of the base of the F region (*h*′F) values recorded at five ionospheric stations widely distributed in space, namely: Jicamarca (−12.0°, −76.8°, magnetic latitude −2.0°), Peru; Sao Luis (−2.6°, −44.2°, magnetic latitude +6.2°), Cachoeira Paulista (−22.4°, −44.6°, magnetic latitude −13.4°), and São José dos Campos (−23.2°, −45.9°, magnetic latitude −14.1°), Brazil; Tucumán (−26.9°, −65.4°, magnetic latitude −16.8°), Argentina. In a more restricted region over Tucumán, the phenomenon was also investigated by the total electron content (TEC) maps computed by using measurements from 12 GPS receivers. A detailed analysis of isoheight ionosonde plots suggests that traveling ionospheric disturbances (TIDs) caused by gravity wave (GW) propagation could play a significant role in causing the phenomenon both for quiet and for medium/high geomagnetic activity; in the latter case however a recharging of the fountain effect, due to electric fields penetrating from the magnetosphere, joins the TID propagation and plays an as much significant role in causing impulsive electron density enhancements.

Keywords: Equatorial ionosphere; Electron density enhancement; Traveling ionospheric disturbance; Fountain effect; TEC

1. Introduction

The ionospheric F2 layer presents a significant day-to-day variability. The F2 layer characteristics, such as the F2 layer critical frequency (*fo*F2), the electron density maximum (*Nm*F2) (*fo*F2 is related to *Nm*F2 as $1.24 \times 10^{10} \cdot (foF2)^2$, where the units of *Nm*F2 and *fo*F2 are electrons/m^3 and MHz, respectively) and the height of *Nm*F2 (*hm*F2) often show significant deviation from long-term values. Many studies have been made to disclose any trends of these F2-layer characteristics as a function of local time, season, and solar/geomagnetic activity (e.g. Liu et al., 2009, 2011, 2012; Liu et al., 2010; Akala et al., 2010; Borries and Hoffmann, 2010; Chen and Liu, 2010; David and Sojka, 2010; Lin et al., 2010; Hall et al., 2011; He et al., 2011; Lee et al., 2011; Burns et al., 2012;

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Chen et al., 2012; Meza et al., 2012; Mikhailov et al., 2012; Pavlov, 2012; Pietrella et al., 2012), that are essential for developing empirical ionospheric models (e.g. Bilitza and Reinisch, 2008; Gulyaeva, 2012; Hoque and Jakowski, 2012).

Even though usually F2 layer disturbances have been linked to solar and geomagnetic activity variations, there are disturbances, termed "meteorological" by Rishbeth and Mendillo (2001), appearing from the lower part of the atmosphere and hence considered different from those caused by the solar/geomagnetic activity. Mikhailov et al. (2004) suggested the term "Q disturbances" to indicate *Nm*F2 deviations (positive or negative) greater than 40% if all 3 hourly A_p indices were $\leqslant 7$ for the previous 24 h.

Nighttime values of *fo*F2 and total electron content (TEC) do not always decrease smoothly. With regard to this issue, many statistical studies have been performed on *Nm*F2 and TEC nighttime enhancements at mid and low latitudes (e.g. Mikhailov et al., 2000a; Farelo et al., 2002; Pavlov and Pavlova, 2007; Luan et al., 2008).

Recently, Pezzopane et al. (2011) have investigated a very unusual event which they have called "impulsive enhancement", because a sudden large increase in electron density is immediately followed by an equally rapid recovery phase. The phenomenon occurred on a wide region of South America, below the southern crest of the equatorial anomaly, for low solar/geomagnetic activity. The event was very distinctive, because the impulsive enhancement corresponded to a pronounced compression of the ionosphere. Their analysis showed that the propagation of traveling ionospheric disturbances (TIDs) could be considered as the main mechanism responsible for the observed phenomenology.

The event analyzed by Pezzopane et al. (2011) was the only occurred from August 2007, when an Advanced Ionospheric Sounder by Istituto Nazionale di Geofisica e Vulcanologia (AIS-INGV) ionosonde was installed at Tucumán (TUC) (−26.9°, −65.4°, magnetic latitude −16.8°), Argentina (Pezzopane et al., 2007), to July 2010. This paper is focused on the analysis of all the other similar events occurred from August 2010 to January 2012 both for quiet and disturbed geomagnetic conditions. The aim of this work is on the one hand to confirm for a larger dataset of events what it was already found by Pezzopane et al. (2011) for quiet geomagnetic conditions, and on the other hand to look into the differences between the events occurred for quiet and disturbed geomagnetic conditions.

2. Data sets

In order to detect the peculiar *fo*F2 nighttime impulsive enhancements that occurred from August 2010 to January 2012, reference was made to the autoscaling visualization feature of the electronic Space Weather upper atmosphere (eSWua) database (http://www.eswua.ingv.it/) (Romano et al., 2008), simply by checking the daily *fo*F2 plots computed on the basis of the values produced automatically as output by Autoscala (Pezzopane and Scotto, 2007) from the ionograms recorded at Tucumán.

The analysis was then based on data recorded from additional four ionosondes: Sao Luis (SL) (−2.6°, −44.2°, magnetic latitude +6.2°), Cachoeira Paulista (CP) (−22.4°, −44.6°, magnetic latitude −13.4°), São José dos Campos (SJC) (−23.2°, −45.9°, magnetic latitude −14.1°), Brazil, and Jicamarca (JIC) (−12.0°, −76.8°, magnetic latitude −2.0°), Peru. The ionospheric station at SJC is equipped with a Canadian Advanced Digital Ionosonde (CADI) (MacDougall et al., 1993). The ionospheric stations at JIC, SL and CP are equipped with a Digisonde (Bibl and Reinisch, 1978). JIC, SL, and CP data were downloaded from the Global Ionospheric Radio Observatory web portal (Galkin et al., 2012).

Twelve GPS receivers located in South America (see Table 1 for the corresponding locations) were also considered to compute TEC values in a region extending in latitude from 0° to −40° and in longitude from −50° to −80°. The GPS data were obtained from the International Global Navigation Satellite System Service (IGS) database (Dow et al., 2009).

The International Geomagnetic Reference Field 11 (Finlay et al., 2010) was used to calculate the geomagnetic latitude from the corresponding geographical coordinates of the ionosonde and the GPS receivers' stations (http://wdc.kugi.kyoto-u.ac.jp/igrf/gggm/index.html).

The level of geomagnetic activity characterizing the events under study is indicated by the 3 hourly-K_p, *AE*, and *Dst* indices, which were downloaded from the World Data Center for Geomagnetism, Kyoto, Japan from the Web site http://wdc.kugi.kyoto-u.ac.jp/.

Equatorial zonal electric field data recorded on September and November 2010 by the Communications/Navigation Outage Forecasting System (C/NOFS) satellite, developed by the Air Force Research Laboratory Space Vehicles Directorate, were also taken into account and downloaded from the NASA Space Physics Data Facility section reachable through the site http://cdaweb.gsfc.nasa.gov/istp_public/.

3. Results

Fig. 1 shows nine atypical *fo*F2 enhancements that were recorded at Tucumán on 8 and 9 September 2010, 2 and 5 November 2010, 19 March 2011, 7 April 2011, 24 June 2011, 26 and 31 January 2012. In particular, all the ionograms recorded for all the month including each event were considered and validated according to the International Union of Radio Science (URSI) standard (Wakai et al., 1987). Once the scaled *fo*F2 values had been obtained, the corresponding monthly mean (green[1] curve in Fig. 1) and standard deviation (red and blue curves in Fig. 1

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.