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Some ionospheric storm effects at an antarctic station

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Abstract

In this paper, the ionospheric response of a high latitude station to some intense geomagnetic storms occurred in 2000 and 2001 is analyzed. For that, data of the critical frequency of the F2-layer foF2 and the virtual height h′F measured at Base Gral. San Martín (68°08′S; 67°06′W) during the storms of April 6, 2000; May 23, 2000; March 31, 2001 and April 11, 2001 (high solar activity) are considered. In order to obtain the features of the disturbances, a comparison of the foF2 data with the outputs of the IRI-2001 model during quiet conditions is made. The results show in general negative storm effects (decreases of foF2 with respect to quiet conditions) following the storm commencement irrespective of the local time. Also, increases in foF2 prior to intense storms are sometimes observed. The h′F data show increases in association with the negative storm effects. The role of some physical mechanisms acting during the phases of the storms is analyzed.

Keywords: Geomagnetic storms; Ionospheric storms; High latitudes

1. Introduction

Perturbations of the terrestrial ionosphere in association with geomagnetic storms (called ionospheric storms) have been studied since more 80 years ago (Prölss et al., 1991). Numerous studies have pointed out the dynamic character of the ionosphere during geomagnetic storms. As a consequence of the variability of the ionospheric perturbations no definite morphology has emerged. Neither there is consensus about the physical mechanisms, which control the phenomenology of the ionosphere during geomagnetic storms.

The morphology patterns of ionospheric storms at middle and low latitudes are rather well known, and the dominant mechanisms responsible for them have been identified and modeled (Mendillo and Narvaez, 2009). Basically, during disturbed conditions the electron density can either increase or decrease relative to a background level, which are termed as positive or negative storm effects or positive or negative phases of the storm, respectively. Electric fields, thermospheric meridional winds, a “composition bulge”, among others, have been suggested as possible physical mechanisms to explain the ionospheric behavior during geomagnetic storms (see for example Fuller-Rowell et al., 1994; Prölss, 1995; Bounsanto, 1999; Danilov, 2001, 2013 and references therein).

The systematic study of ionospheric storms has been conducted primarily with ground-based data from the Northern Hemisphere. The ionospheric effects of geomagnetic storms at high latitudes have been less analyzed. Some studies have found that at high and subauroral

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latitudes negative phases almost always are produced (Kane, 2005). For example, analyzing the ionospheric storm effects during storm period December 7–8, 1982, Prölss et al. (1991) report negative storm effects at high latitudes of the Northern Hemisphere and the Southern Hemisphere (Antarctic station Argentine Is.) during the main and recovery phases of the storm, which were attributed to changes in the neutral gas composition. Analyzing the high-latitude ionosphere structure of the Northern hemisphere during March 22, 1979 geomagnetic storm for the different local time sectors, Karpachev et al. (2007) find decreases in NmF2 during the main phase and the recovery phase of the storm. Patowary et al. (2013) study the effect of geomagnetic storms on the F2 layer by calculating the deviation, DfoF2, of foF2 during 40 magnetic storms. They observe very pronounced negative effects at daytime in summer and in winter at high latitudes of the Northern Hemisphere.

Some storm time ionospheric models have also been developed. An example is the STORM model, which is included in the International Reference Ionosphere (IRI). Some evaluations at high latitudes show that the STORM model captures the direction of the changes in foF2 during magnetic storm events but in general it underestimates the observations during intense storms (Mansilla et al., 2009). The STORM model has problems even at middle latitudes (e.g., Buresova et al., 2010).

The use of the Global Positioning System (GPS) data to record irregularities at high latitudes has been the subject of other papers. Thus, several studies have used GPS observations from a single site or network to monitor TEC fluctuations and related irregularities in the high latitude ionosphere.

Intensive phase fluctuations (termed scintillation) are observed along GPS satellite passes at high latitudes during storms, which cause dramatic changes in the total electron content (TEC). For example, Aarons et al. (2000) observe increases in TEC when analyze storms occurred on January 10, April 10–11, and May 15, 1997 using measurements of phase fluctuations and total electron content taken for GPS satellites at high latitudes of the Northern hemisphere. Kinrade et al. (2012) report significant phase scintillation on Global Positioning System signals in Antarctica during the storm period 5–6 April 2010. By analyzing GPS measurements of the northern and southern high-latitude ionosphere during severe geomagnetic storms, Shagimuratov et al. (2012) report that maximum activity of the TEC fluctuations take place when the *D*st index sharply decrease observed. Case study comparing the GPS phase scintillations in Arctic and Antarctic was done by Prikryl et al. (2011). Tiwari et al. (2013) also observe strong phase scintillation during storms occurred in 2012 with a GPS receiver installed at high latitudes of the Northern Hemisphere. By using TEC measurements from GPS data to investigate the global ionospheric response to the March 31, 2001 magnetic storm, Fedrizzi et al. (2005) observe decreases in TEC between 60° and 70° (Southern Hemisphere) and from 25° to 70° (Northern Hemisphere), along the geographic longitude of 315° E.

Even though there are currently a large number of GPS receivers in continuous operation, they are unevenly distributed for ionosphere study purposes, being situated mostly in the Northern Hemisphere. There is relatively small number of GPS receivers located at the high latitudes of the Southern Hemisphere and, consequently, there is a reduced number of available TEC measurements and therefore limited studies. A comprehensive summary of the TEC storm phenomenon at different latitudes can be found in the paper by Mendillo (2006).

During geomagnetic storms, the majority of energy from the magnetosphere to the thermosphere is transferred in the high-latitude region. As consequence of that, there is a heating of the lower part of the thermosphere (100–140 km) in the auroral region. The main source of this heating is the Joule dissipation of the currents, but some input may be provided also by absorption of precipitating particles (Prölss, 1995).

The heating should lead to an immediate depletion of the atoms-to-molecules ratio throughout the entire thermosphere in the high-latitude region. Because the electron concentration in the peak of the F2 layer is, roughly speaking, directly proportional to the $[O]/[N_2]$ ratio (Rishbeth and Barron, 1960; Mikhailov et al.,1989, 1995), we should have a depletion of electron density (a negative phase) in all the regions where $[O]/[N_2]$ has been decreased at F-region heights. Satellite observations have shown the close relation between the $[O]/[N_2]$ ratio depletions and electron density decreases at several ionospheric sectors (e.g., Prölss and von Zahn, 1974; Prölss, 1980; Mansilla, 2008).

The aim of this paper is to provide a contribution to the understanding of the processes acting in the high latitude ionosphere during intense geomagnetic storms by using data of an Antarctic station not previously considered in ionospheric research. Although the study of individual storm effect in details is more basic in nature, reveals the inherent physical processes working in the Magnetospheri c–Ionospheric coupling.

For that, we use data of the critical frequency of the F2-layer foF2 and the virtual height $h'F$ measured at the Antarctic station Base Gral. San Martín (68°08′S; 67°06′W) to present the temporal evolution of these ionospheric characteristics during the storms occurred on April 6, 2000; May 23, 2000; March 31, 2001 and April 11, 2001 (high solar activity). The data were provided by the Argentine Antarctic Institute (Instituto Antártico Argentino).

To obtain the features of the disturbances, a comparison of the foF2 measurements with the outputs of the IRI-2001 model without the STORM model is made (that is, with the average variation during quiet conditions). There are lacks of foF2 measurements for magnetically quiet days during the months of the considered storms, which prevent to