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Validation of the STORM model in IRI-2001 at a high latitude station

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Abstract

The International Reference Ionosphere IRI-2001 model contains geomagnetic activity dependence based on an empirical storm time ionospheric correction (STORM model). An extensive validation of the STORM model for the middle latitude region has been performed. In this paper the ability of the STORM model to predict foF2 values at high latitudes is analyzed. For this, ionosonde data obtained at Base Gral. San Martin (68.1°S, 293°E) are compared with those obtained by the IRI-2001 model with or without storm correction during four geomagnetic storms that occurred in 2000 ($Rz_{12} = 117$) and 2001 ($Rz_{12} = 111$). The results show that predicted values with the STORM model follow the behaviour of foF2 experimental data better than without the STORM model. The relative deviation between measured and predicted foF2 reaches values of up to 24% and 43% with and without the STORM model in IRI-2001, during the main phase of the storms. In order to explain increases of electron density that occurred prior to the storm onset and also decreases of electron density observed during the first part of the recovery of the storm, possible physical mechanisms are discussed.

Keywords: Geomagnetic storms; IRI model; Ionospheric storms

1. Introduction

The study of the ionospheric perturbations produced during geomagnetic storms is of practical interest since transionospheric radio communications and also satellite ephemeris are severely degraded during these events. Basically, the peak electron density of the F-region can either increase or decrease from its mean value during disturbed conditions (the so-called positive or negative ionospheric storms). However, although the ionospheric perturbations are studied since several decades ago, neither the morphology nor the physics of the changes is completely known. This is due to the great variability of this phenomenon and also to the many different processes at work (Prölss, 1995).

There are several empirical and semi-empirical models (e.g., Anderson, 1973; Barghausen et al., 1969; Bent et al., 1975; Llewellyn and Bent, 1973; Anderson et al., 1987; Bilitza, 1990) to predict the critical frequency of the F2-layer, foF2, during quiet magnetic conditions. One of the most widely used empirical models to predict ionospheric parameters during quiet conditions has been the International Reference Ionosphere, IRI (Bilitza, 1990, 2001) which provides median values of electron density, electron temperature, and ion composition as a function of height for a given location, time, and sunspot number. This model is being continuously revised and updated through an international cooperative effort sponsored by the Committee on Space Research and the International Union of Radio Science.

An empirical ionospheric storm correction model STORM (Araujo-Pradere and Fuller-Rowell, 2000) was included in the 2001 version of the IRI (Bilitza, 2001). It was designed to be dependent on the intensity of the storm (ap index over the 33 previous hours) and to be a function

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of latitude and season (Araujo-Pradere et al., 2004). A number of recent studies have compared the IRI-STORM predictions with ionosonde data at mid, low, and equatorial latitudes during storm time periods. In general, the results indicate a significant improvement of IRI-2001 with the STORM model over IRI-2001 without the STORM model (e.g., Araujo-Pradere and Fuller-Rowell, 2003; Araujo-Pradere et al., 2004; Mansilla et al., 2004; Miro Amarante et al., 2007; Mansilla and Mosert, 2007).

The objective of this paper is to evaluate this storm correction model at a high latitude station by comparing the foF2 values by the IRI-2001, with and without the STORM model, with those measured at Base Gral. San Martin (68.1°S, 293°E), a station not used in previous IRI-2001 validations. Data for four intense geomagnetic storms (peak Dst < −100 nT) occurring in the years 2000 ($Rz_{12} = 117$) and 2001 ($Rz_{12} = 111$) are considered.

2. Data

The data used in this evaluation are monthly median and hourly values of the critical frequency foF2 measured at the Antarctic station Base Gral. San Martin (68.1°S, 293°E). A basic difficulty with ionosonde data from high latitude stations is that in general no measurements are available during disturbed periods. For this reason only a few events with a reasonable amount of data were found.

The Dst geomagnetic index was used to represent the different phases of the storms. Hourly Dst and AE indices were obtained from the World Data Center at the University of Kyoto database: http://swdc.kugi.kyoto-u.ac.jp/dstdir. The storm dates, the time of sudden commencement (SC), the minimum Dst reached, and the UT of the minimum Dst of the storms considered are given in Table 1.

The IRI-2001 model can be run on-line at: http://modelweb.gsfc.nasa.gov/models/iri.html. It has two options to provide the critical frequency: foF2 with the STORM model turned on and foF2 with the STORM model turned off.

3. Results

The top plot in Fig. 1 shows the evolution of the Dst geomagnetic index for the 5–8 April 2000 storm period. The SC occurred near local noon at this station (LT = UT − 4 h). The storm was characterized by a short duration main phase (until around 0 UT on 6 April), followed by a fast recovery. The middle plot of Fig. 1 presents the AE index in which a significant increase up to 1560 nT was simultaneously observed with the storm onset. The bottom part of Fig. 1 presents the behaviour of foF2 data (solid circles) and superimposed the monthly median values and also both the IRI-2001 predictions (with and without the STORM model). From the available data it can be seen that IRI-2001 with STORM model follows the foF2 variations better than IRI-2001 without the empirical storm correction model. STORM model predicts the negative storm effect (decrease of electron density) during the first part of the recovery and the subsequent positive storm effect (increase of electron density) but does not reproduce well the experimental values. Unfortunately the gap of data during the main phase prevents the determination of the accuracy of the model in this stage. There is a small overestimation during the recovery phase of the storm. The relative deviation between modelled and experimental values in this stage is lower than 40%.

Fig. 2 shows the variations of Dst and AE indices, and measured and predicted foF2 values for the 14–17 July

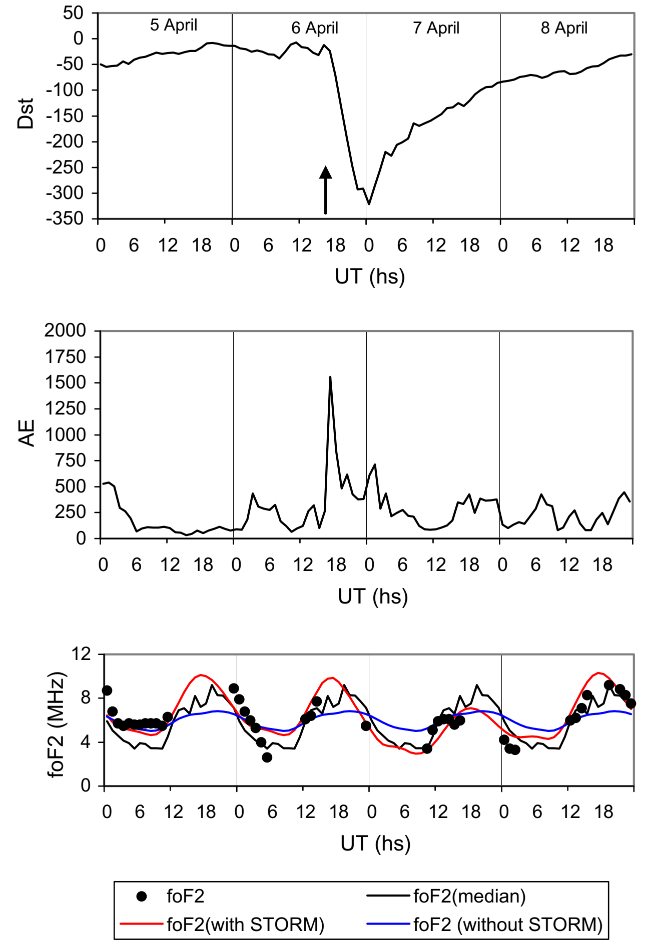

Fig. 1. Temporal variation of Dst index (upper panel), AE index (middle panel) and storm time foF2 data (solid circles), monthly median (full line) and outputs of the IRI-2001 model with and without STORM model (lower panel) for the 5–8 April 2000 storm period. The arrow indicates the sudden commencement (SC).

Table 1
Storm dates, sudden commencement, minimum Dst, and time of the minimum Dst of the storms used in this study.

Date	SC (UT)	Minimum Dst (nT)	Time of minimum Dst
6 April 2000	1639	−321	00 UT on 7 April
14–15 July 2000	1532–1437	−300	21 UT on 15 July
11 April 2001	1519	−256	23 UT on 11 April
21 April 2001	1601	−103	15 UT on 22 April

2000 storm in the same format as Fig. 1. In this storm period, two sudden commencements occurred: 1532 UT (SC1) and 1437 UT (SC2) on 14 and 15 July, respectively, in the daytime hours (peak Dst = −300 nT). The Dst decreased until its minimum value at 21 UT on 15 July. Thereafter, the storm activity subsided during the recovery phase. An enhancement of the AE index was observed in response to SC1 and after the SC2, when AE increased up to about 1900 nT at 18–19 UT on 15 July, after which began a rapid decrease. As before, STORM model captures the direction of the initial changes (positive storm effects) but underestimates the measured foF2 values during the entire disturbed period. The underestimation is of about 30% during the main phase and 25% during the recovery phase.

Fig. 3 presents the variations of Dst, AE, and foF2 for the 10–13 April 2001 storm period. Dst began to decrease at about 16 UT on April 11. The main phase lasted until around 23 UT, followed by a relatively rapid recovery. An irregular behaviour of AE was observed until the storm sudden commencement when AE started to increase significantly, reaching values near to 1400 nT at 14 UT on 11 April. The positive storm effect observed at the onset of the main phase is captured by the STORM model, but the predicted values underestimate the measurements (~16%).

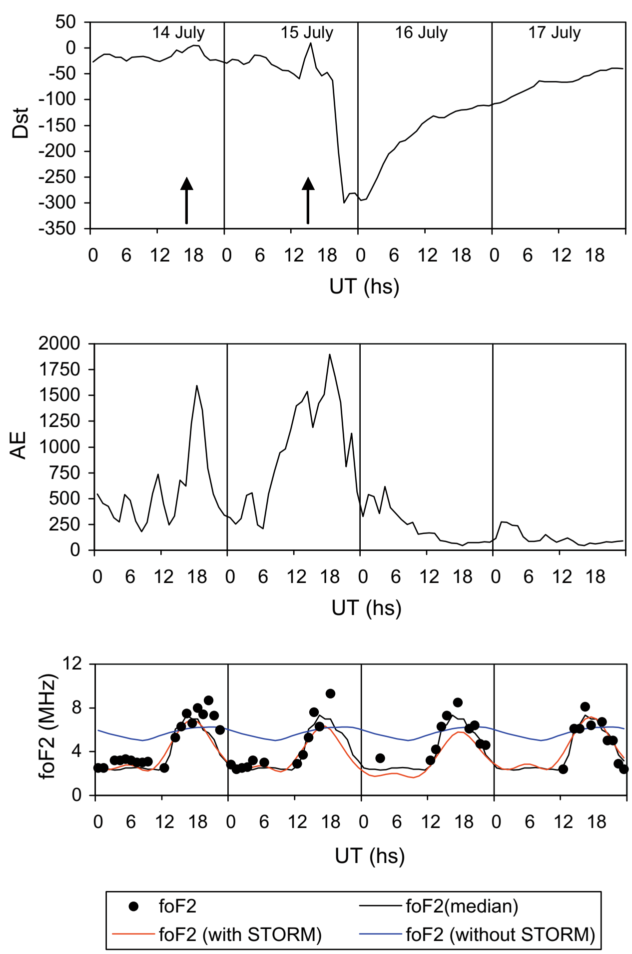

Fig. 2. Same as Fig. 1, but for the 14–17 July 2000 storm period.

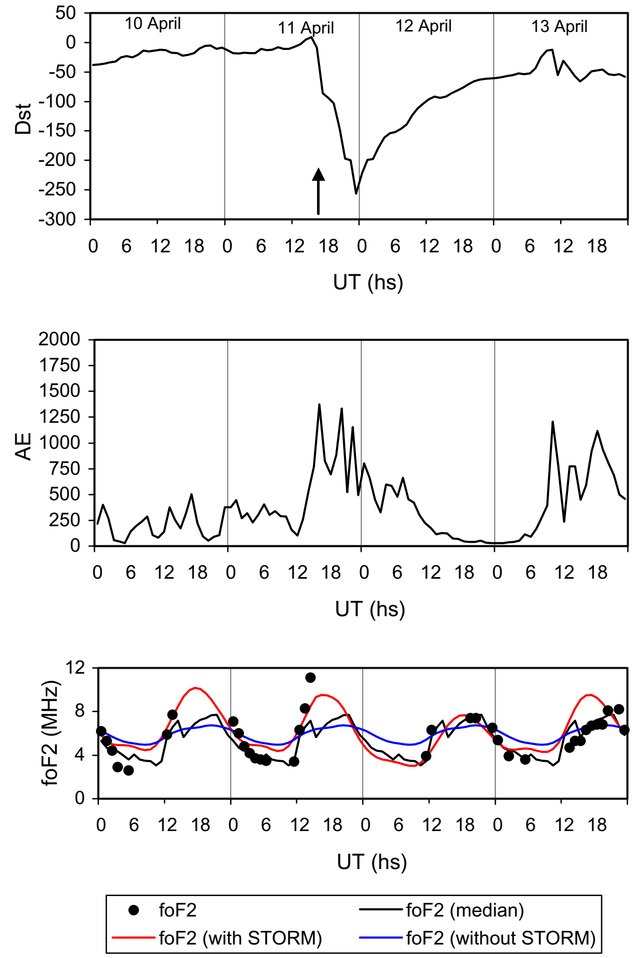

Fig. 3. Same as Fig. 1, but for the 10–13 April 2001 storm period.

During the end of the main phase modelled values are close to the experimental ones. IRI-2001 without the storm correction model follows reasonably well the monthly median values.

Fig. 4 presents the variations of Dst, AE, and foF2 between 21 and 23 April 2001. A long-duration main phase occurred (~23 h) until around 15 UT on 22 April when Dst reached its minimum value, followed by an irregular recovery phase. The AE index increased a few hours after the storm onset, reaching values of the order of 950 nT near the end of main phase, after which began the descending stage. The STORM model captures the positive effect produced during the initial stage of the storm with predicted values close to the experimental ones. During the end of the main phase and the first part of the recovery the storm correction model overestimates the foF2 data, the overestimation is about 60%. As expected, the IRI model without magnetic dependence presents good agreement with the median values.

4. Discussion and conclusions

The foF2 measurements from a high latitude station (Base Gral. San Martin: 68.1°S, 293°E) have been com-

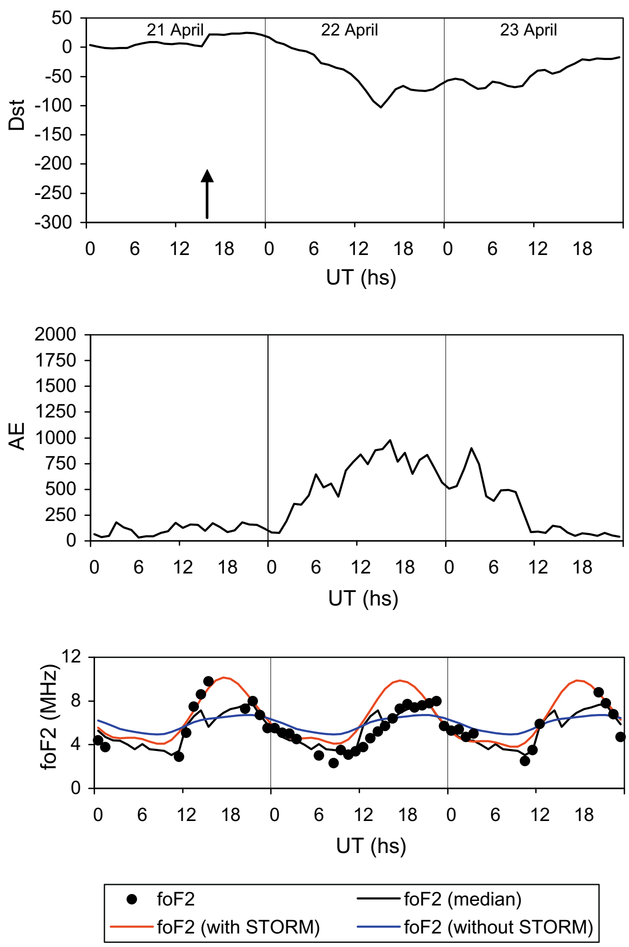

Fig. 4. The same as in Fig. 1, but for the 21–23 April 2001 storm period.

pared with the outputs of IRI-2001, with and without the STORM model, during four intense geomagnetic storms that occurred in years 2000 and 2001. The results indicate that the STORM model at high latitudes captures quite well the directions of the changes of the experimental data (positive or negative storm effects) but does not well reproduce the measured values. In the three more active storms (during the main phase and first stage of the recovery) there is an underestimation of the measured values and an overestimation in the less intense geomagnetic storm. Possibly at high latitudes a better correlation between the model predictions and magnetic activity is necessary. However, more cases studies must be done to give a definitive conclusion.

Sometimes significant increases of the electron density are observed a few tens of hours before the beginning of the magnetic storm (e.g., on the 5 April 2000 storm and to some degree during the 14 July 2000 storm). These effects cannot be explained in terms of the classical mechanisms because there are still neither storm induced circulation nor composition changes. Possibly they could be the effect of particle precipitation in the high latitude region. Supporting this explanation is the earlier (before SC) enhancement of the AE index, indicating high energy input to the high latitude region. That implies that energetic particles might precipitate into this region leading to the ionization enhancement.

Positive storm effects also occur during the first stage of the storms in association with a simultaneous increase in AE index. Possibly, the mentioned mechanism may contribute to produce these initial storm effects. The cause of the initial increase of the electron density with no significant variations of AE index is not clear at the moment but they could be attributed to a polar electric field, which produces strong horizontal transport of ionization. However, further studies are required to find the possible causes of these positive storm effects.

In regards to negative storm effects observed during the recovery phases, is believed that they are caused by neutral composition changes, as in middle latitudes. Thus, increases in the nitrogen molecular to atomic oxygen N_2/O ratio are a permanent feature of the high latitude thermosphere (e.g., Prölss, 1995 and references therein for details).

In brief, in these few analyzed cases, it is found that the STORM model captures the direction of the changes in foF2 at high latitudes during magnetic storm events, that is, it predicts the positive storm effects generally observed in the initial stage and main phase of the storms, and the negative ones observed during the recovery; but in general it underestimates the observations during the most intense storms. However, the results emphasize the need to make more validation studies using more stations and also different geomagnetic storm periods in order to try to refine the representation of the observations at different latitudes and also during different seasons.

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