Low-latitude Storm-time Ionospheric Correction Considering the Disturbance Electric Field

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Abstract

It is known that the equatorial electric field plays an important role in low-latitude ionospheric plasma distribution especially at disturbance time. In this study, we propose an empirical model for real-time ionospheric correction during storm time, based on the theory that the ionospheric disturbances during the initial and main phases are mainly caused by the zonal electric field disturbances. The performance of the model during three intense storms is evaluated and compared with another empirical correction model, STORM. The results show that some sharp increase of foF2 could be captured by our model. This indicates that the disturbance field should be included in low-latitude storm-time ionospheric corrections.

1 Introduction

Low-latitude ionosphere exhibits complex day-to-day and hour-to-hour variabilities, which leads to complex influences on short-wave communications and space-terrestrial and inter-satellite links. When interplanetary and geomagnetic disturbances happen, the ionospheric variation becomes more complicated, which could be attributed to different physical processes and/or their interactions such as the atmospheric dynamic process, the electromagnetic process and the chemical process.

Among these processes the zonal disturbance electric field or its resultant vertical plasma drift plays an important role in low-latitude storm-time ionospheric dynamics [1-3]. Both observations [4-6] and simulations [7, 8] show that the disturbance electric field can cause great enhancement or inhibition on the equatorial ionization anomaly (EIA), depending on its magnitude and direction. Generally speaking, locally eastward disturbance field conduces to increased plasma upward drift and excursion to higher latitude along the magnetic field line, thus results in poleward expansion of EIA. While westward field restrains the upward drift and so as to the poleward diffusion. Though the physical processes have been studied for several decades, there still leaves difficulty in their utilizations.

In this study, we propose an empirical model contained some affiliations between the ionospheric responses and their disturbance electric field origins during storm time, which helps to low-latitude storm-time ionospheric corrections real-timely. Other disturbance origins such as neutral winds and neutral composition changes are excluded.

2 Model Description

In a previous study [9], we obtained a series of coefficients on how to regress the relation between the ionospheric disturbances and their electric field origins. One can get more details from that paper. Here we only give a simple description.

In paper [9], historical data from two low-latitude ionosondes, namely Haikou (HK, with geomagnetic latitude of 8.6°N) and Chongqing (CQ, 18.1°N), during 50 storms are used to set up the model, as well as the disturbance electric field data deduced from an empirical model [10]. The ionospheric disturbance is

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Table 1: The fitting coefficients adopted by the model for each seasonal bin and station.

	Winter		Equinoxes		Summer	
	a_1	a_2	a_1	a_2	a_1	a_2
HK	0.014158	-0.000365	0.001893	0.000174	0.002242	-0.000428
CQ	0.002014	0.000498	0.001506	0.000265	-0.003220	-0.000262

depicted by

$$\Phi(t) = \mathrm{foF2}_{\mathrm{obs}}(t)/\mathrm{foF2}_{\mathrm{med}}(t), \tag{1}$$

where $\mathrm{foF2}_{\mathrm{obs}}$ is the measured data, and $\mathrm{foF2}_{\mathrm{med}}$ the medians of previous 27 days' observations at given time t, representing the quiet time behaviors. An weighted integral of the disturbance field (vertical drift)

$$X(t) = \sum_{\tau=0}^{\tau_N} v_d(t-\tau)\exp(-|\tau-\tau_0|) / \sum_{\tau=0}^{\tau_N} \exp(-|\tau-\tau_0|), \tag{2}$$

is adopted to designate the accumulative effect of previous historical disturbances, where v_d is the disturbance vertical drift defined by [10], $\tau_0 = 2$ and $\tau_N = 8$. All the data are separated into three seasonal bins, namely Winter (from November to February), Summer (from May to August) and Equinoxes.

Once the series of the integral of disturbance drifts X and the relevant ionospheric responses Φ are sorted, we bring forward an algorithm,

$$\Phi(t) = a_0 + a_1 X(t) + a_2 X^2(t), \tag{3}$$

to adapt the non-linear dependence of Φ to X, where $a_0 = 1$ to ensure that quiet-time ionosphere is corresponding to no disturbance drift, and the coefficients a_1 and a_2 could be adjusted by the non-linear least-square fitting technique.

Based on equations (1)-(3) and the coefficients (listed in Table 1), the empirical correction model of ionospheric foF2 at HK and CQ is established. The inputs are the median foF2 of the observations in previous 27 days and the current and eight previous equatorial disturbance zonal electric fields, and the output is the current corrected foF2.

3 Validation

To validate the empirical model and test its performance, three intense storm events are selected as examples, which occurred on October 29 2003, November 20 2003, and July 22 2004, respectively. Ionospheric observations and model outputs during from Oct 28 to Nov 3, 2003 for the two stations are shown in the middle and bottom panels of Figure 1, respectively. The "real line" denotes the observations Φ_{Obs}, and the "circle" for the proposed model outputs $\Phi_{E\times B}$. The results of STORM Φ_{STORM} [11] are also shown in the figure by "dotted line" for comparison. The Dst data is shown in the upper panel to denote the storm evolution.

This multi-step developed storm initiated at 05UT, October 29, with two Dst peaks -353nT and -383nT at 01UT and 23UT, October 30. Two positive ionospheric disturbances around the Dst peaks at HK are captured by our model (denoted by D1 and D2), whereas STORM exhibits nearly no improvement over the monthly medians. This could be partly explained by that the latter relies on that negative disturbances are due to neutral composition changes, thus it was helpless to those caused by disturbance electric fields. However, the model results are not satisfied at CQ. Observation shows that the ionosphere suffers a sharply negative disturbance followed by a sharply positive one in relation to the Dst peak -353nT, while the corrected results from the $E \times B$ drift theory only give an overestimated positive perturbation (D3). As for another result D4, our model even gives an opposite corrections. This implies that the intricate interactions between penetration field and disturbance dynamo [12], and/or between disturbance field and neutral wind [13] and

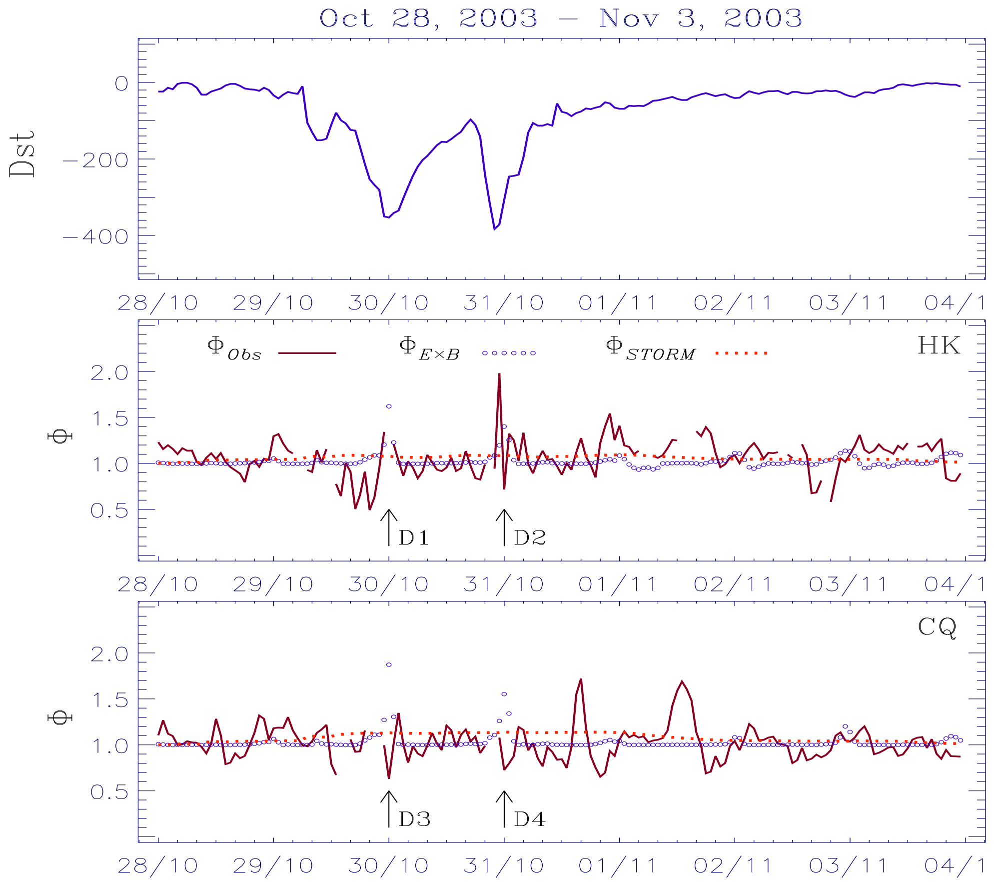

Figure 1: Observations and model outputs during Oct 28-Nov 3, 2003. The upper panel shows the storm evolution by Dst data, and the middle and bottom panels show the results at two stations. The real line denotes the observations Φ_{Obs}, the "circle" for our model outputs $\Phi_{E\times B}$, and the dotted line for STORM.

other possible precesses lead to complex variations in the ionosphere and make it difficult to describe by a simple empirical model.

The performances of the empirical model have similar results in the other two storms, which are not included in this paper because of limited space. From the morphological results, we summarized that some sharp disturbances during the initial and main phases of the storms were captured by our model, while seldom in the recovery phases. This could be partly attributed to that only data during these two phases are used in constructing the model.

4 Conclusion

In this paper we establish an empirical model for low-latitude storm-time ionospheric foF2 corrections, based on the theory that the equatorial zonal disturbance electric field could cause enhancement or inhibition on the equatorial ionization anomaly (EIA). Data from fifty storms between 1978-1995 at two low-latitude ionosondes, namely Haikou and Chongqing, are used to construct the model. The previous eight disturbance electric fields obtained from an empirical model [10] are used as inputs, and the output is current corrected coefficient comparing with quiet-time ionosphere. Data from three storms during 2003-2004 are used to validate the model. The results show that part of shapely disturbed ionospheric peaks during the initial and main phases of the storms could be predicted by the model. Comparing with another empirical model, STORM, which only gives the probable estimations, our model exhibits more energetic in capturing the short-term disturbances. This study provides a new possibility to low-latitude storm-time ionospheric corrections real-timely.

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