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The solar wind control of the equatorial ionosphere dynamics during geomagnetic storms

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Abstract

The interplanetary magnetic field, geomagnetic variations, virtual ionosphere height h′F, and the critical frequency foF2 data during the geomagnetic storms are studied to demonstrate relationships between these phenomena. We study 5-min ionospheric variations using the first Western Pacific Ionosphere Campaign (1998–1999) observations, 5-min interplanetary magnetic field (IMF) and 5-min auroral electrojets data during a moderate geomagnetic storm. These data allowed us to demonstrate that the auroral and the equatorial ionospheric phenomena are developed practically simultaneously. Hourly average of the ionospheric foF2 and h′F variations at near equatorial stations during a similar storm show the same behavior. We suppose this is due to interaction between electric fields of the auroral and the equatorial ionosphere during geomagnetic storms. It is shown that the low-latitude ionosphere dynamics during these moderate storms was defined by the southward direction of the B_z-component of the interplanetary magnetic field. A southward IMF produces the Region I and Region II field-aligned currents (FAC) and polar electrojet current systems. We assume that the short-term ionospheric variations during geomagnetic storms can be explained mainly by the electric field of the FAC. The electric fields of the field-aligned currents can penetrate throughout the mid-latitude ionosphere to the equator and may serve as a coupling agent between the auroral and the equatorial ionosphere.

Keywords: Ionosphere; Interplanetary magnetic field; Magnetosphere; Field-aligned currents

1. Introduction

Intensive magnetospheric and ionospheric currents during geomagnetic storms disturb the quiet ionosphere and cause the observed short-term variations of the ionospheric characteristics. The ionospheric wind dynamo is considered as an important and the main mechanism in generation of ionospheric electric currents and fields. The disturbed ionospheric wind dynamo can be the generator of the equatorial ionospheric electric currents during geomagnetic storms in the aftermath of strong auroral heating (Blank and Richmond, 1980). The magnetospheric electric field directly penetrating into the low-latitude ionosphere can be another source of electric field. Recent advances in solid earth sciences and remote sensing capabilities established the possibility of electromagnetic coupling between the boundary layer of the atmosphere and the ionosphere before strong earthquakes due to an increase in tectonic activity (Pulinets and Boyarchuk, 2004). So, even earthquakes can make one's contribution to ionospheric variations. During disturbed conditions as geomagnetic storms the critical frequency foF2, virtual height h′F, drift velocities, and other ionospheric characteristics are mainly defined by the state of the solar wind flowing around the Earth's magnetosphere. Magnetospheric electric fields disturb the auroral ionosphere forming auroral electrojets

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and by the high-latitude electric field and thermospheric disturbances penetrate to the equatorial ionosphere. That is the reason the equatorial ionospheric electric field variations like geomagnetic variations are complex and result of superposition of different disturbing agents. Numerous studies present the experimental and theoretical relations between the solar wind, geomagnetic variations, and the ionospheric parameters. The studies of Zmuda and Armstrong (1974), Iigima and Potemra (1978), Foster et al. (1989), and other authors led to the conclusion that the field-aligned currents constitute a major interconnection between the magnetosphere and the auroral ionosphere. However, the equatorial ionosphere has been assumed to be free from the influence of the field-aligned currents. As has been shown by Rastogi and Patel (1975) and Fejer et al. (1979), the interplanetary magnetic field (IMF) control of the ionosphere during geomagnetic disturbances is pronounced at the equatorial ionosphere as well. These authors explained the short-term equatorial ionospheric variations by action of the auroral sources. At present, the equatorial ionosphere processes are believed to be closely connected with the action of the field-aligned currents. Zakharov et al. (1989), Denisenko and Zamay (1992), Kikuchi et al. (1996, 2000), Sastri (2002) using geomagnetic data, Deminova (1995), Sizova and Pudovkin (2000) using ionospheric data, have shown that the electric fields from the high latitudes can penetrate into the equatorial ionosphere and may explain the equatorial electric field variations. The storm wind driven electric fields (Blank and Richmond, 1980) are responsible for the larger amplitudes and longer lifetimes of the drift perturbations following sudden decreases in convection compared to those associated with sudden convection enhancements (Fejer and Schrerliess, 1995). The ionospheric 5-min variations at the equatorial stations which allow calculating in detail time delays of the auroral and equatorial ionospheric phenomena are scantily known. Model simulations as disturbed ionospheric wind dynamo do not allow explaining a significant part of the experimental data. Additional investigations of the ionospheric characteristics are required to clear up the origin of the short-term equatorial ionospheric variations. The critical frequency foF2 and virtual heights h′F observed by the ionosondes are good indicators of the true layer heights and electron concentration and may provide information about the equatorial ionosphere dynamics. From the practical point of view, the relationships between the solar wind and the ionospheric parameters can be used for prediction of different ionospheric phenomena. For example, the changes of the ionosphere height may serve as a good measure for predictions of the spread F or intense ionospheric scintillations (Biktash, 2004).

In this paper, we examine the solar wind conditions and the equatorial ionosphere response to illustrate what kind of solar wind conditions during the geomagnetic storms leads to short-term variations of the critical frequency foF2 and virtual height at the equator.

2. Analysis of the experimental data

The critical frequency foF2 and virtual ionosphere height h′F variations for Cebu Island (10.3 °N, 124 °E), Raratonga (21.2 °S, 159.8 °W), Tahiti (17.7 °S, 149.3 °W), Maui (20.8 °N, 156 °W), and Manila (14.7 °N, 121.1 °E) as well as the solar wind conditions OMNI data are examined. Ionospheric observations at Cebu Island station during the first Western Pacific Ionosphere Campaign (WestPac) were conducted every 5 min from March 2 to 12, 1998. On March 10, 1998 a moderate geomagnetic storm has occurred. This storm was chosen as an example of a high-speed solar wind driven storm. The solar wind velocity was around 550 km/s. A stream–stream interaction region observed by the WIND spacecraft from 12 to 24 UT, March 10, 1998, triggered off a magnetic storm which peaked within few hours at $D_{st} = -126$ nT and $K_p = 7+$. During the main phase of the storm the B_z-component of the IMF was great and negative (−15 nT). The interplanetary medium on March 10 is further characterized by the following features: high dynamic pressure of ~8 nPa, low Alfven Mach number of ~5, and high Pointing flux into the magnetosphere of ~0.08 mW/m^2. After that, a 5-day Alfven wave train on the faster stream in which B_z fluctuated about zero with a peak-to-peak amplitude of ~6 nT led to a lower level activity with an average $D_{st} = -50$ nT. Then a recovery phase of the storm took place (description of IMF conditions from V. Jordonova at http://www.ssc.igpp.ucla.edu/gem). The mean hourly

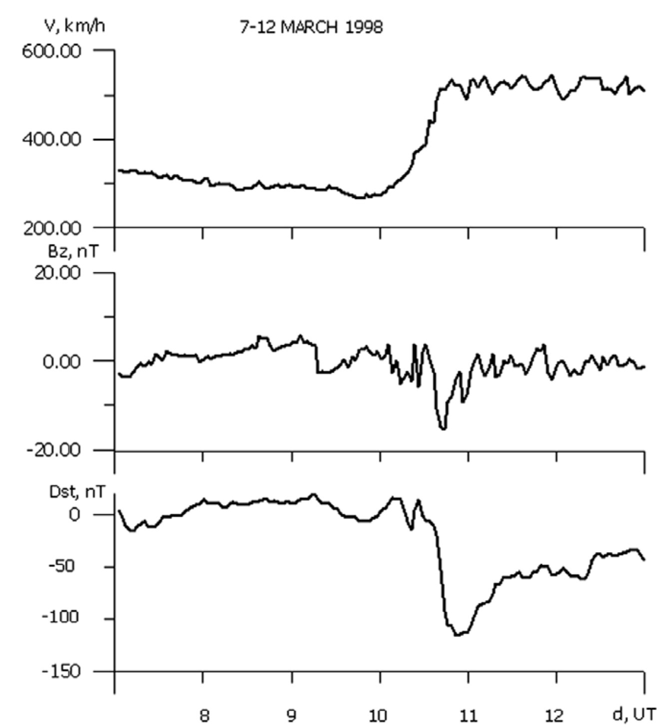

Fig. 1. Hourly average variations of the solar wind velocity, V (km/s); the IMF B_z-component, B_z (nT); and D_{st}-field in nT on March 10, 1998 geomagnetic storm.