Different Behaviors of TEC and F2 Peak Electron Density at Midlatitudes During Geomagnetic Storms

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Abstract

We investigated behaviors of total electron content (TEC) and F2 peak electron density (NmF2) observed at midlatitudes during geomagnetic storms. Although TEC and NmF2 disturbances were similar during moderate storms, they were sometimes quite different during severe storms. By using numerical simulation, we suggest that different TEC and NmF2 disturbances can be caused by effects of F-region plasma dynamics enhanced when storm drivers operate suddenly or effects of more than one storm drivers operating simultaneously. Therefore, observations of such TEC and NmF2 disturbances include important information on the plasma dynamics in the F region and on the operating storm drivers.

1. Introduction

The F-region plasma density is strongly disturbed during magnetic storms due to various processes, such as penetration electric field from the magnetosphere, changes in the thermospheric composition and wind circulation, and traveling wave disturbances (see a review by Prolss [7]). The dominant storm drivers differ from storm to storm depending on the energy input to the magnetosphere from the disturbed solar wind and on the changes in the interplanetary magnetic field direction. They can even change during a storm event depending on the storm phase, location (local time and latitude), and season.

In this paper, we investigate behaviors of total electron content (TEC) and F2 peak electron density (NmF2) observed at midlatitudes during geomagnetic storms. The electron density in the F2 region is larger than other altitudes, so contributing in a large part to the vertical integral of TEC. Therefore, daily variations of TEC and NmF2 are similar during geomagnetically quiet times. On the other hand, the time variations and degrees of TEC and NmF2 disturbances are sometimes observed quite different during geomagnetic storms. We show several such observations and discuss possible causes for the differences. It is shown that observations of such different behaviors include information on the plasma dynamics in the F region and on the operating storm drivers. We use TEC data over Japan which is obtained through the method of Ma and Maruyama [4], and data obtained by the several ionosonde stations, Wakkanai (36.6°N magnetic latitude) and Kokubunji (26.8°N magnetic latitude). We also used a numerical model, the SAMI2 code developed at the U.S. Naval Research Laboratory [2], in order to investigate quantitatively the mechanism of TEC and NmF2 disturbances.

2. Observations

First, we discuss several TEC and NmF2 disturbances at midlatitudes during moderate geomagnetic storms. Figure 1a shows Dst index, vertical TEC, and NmF2 observed at Wakkanai from 17 to 23 April 2002. Two major negative storms were seen on 19 and 21 April, in response to a sequence of geomagnetic storms that began from 20 JST on 17 April. The TEC negative disturbances were quite similar to the NmF2 disturbances on the two days; both quantities decreased during the whole day with its negative deviation of 40-60% from the monthly median value. These negative disturbances occurred probably due to changes in the thermospheric composition (increase in the $[N_2]/[O]$, so the faster recombination rate). The CHAMP satellite observed larger total mass density at F-region height (410 km) during the same storm events than in the quiet time [1]. Another storm event that began from 14 April 2006 is shown in Figure 1b, in which positive TEC and NmF2 disturbances were observed. These positive disturbances can be caused due to direct electric field penetration from the magnetosphere or due to equatorward-strengthened thermospheric wind;

both storm drivers can uplift the ionospheric plasma transverse to or along the geomagnetic field line to higher altitudes where $[N_2]/[O]$ is smaller, so the recombination rate is smaller compared to the production rate. Also in this event, the temporal profile and degree of TEC and NmF2 disturbances were quite similar to each other.

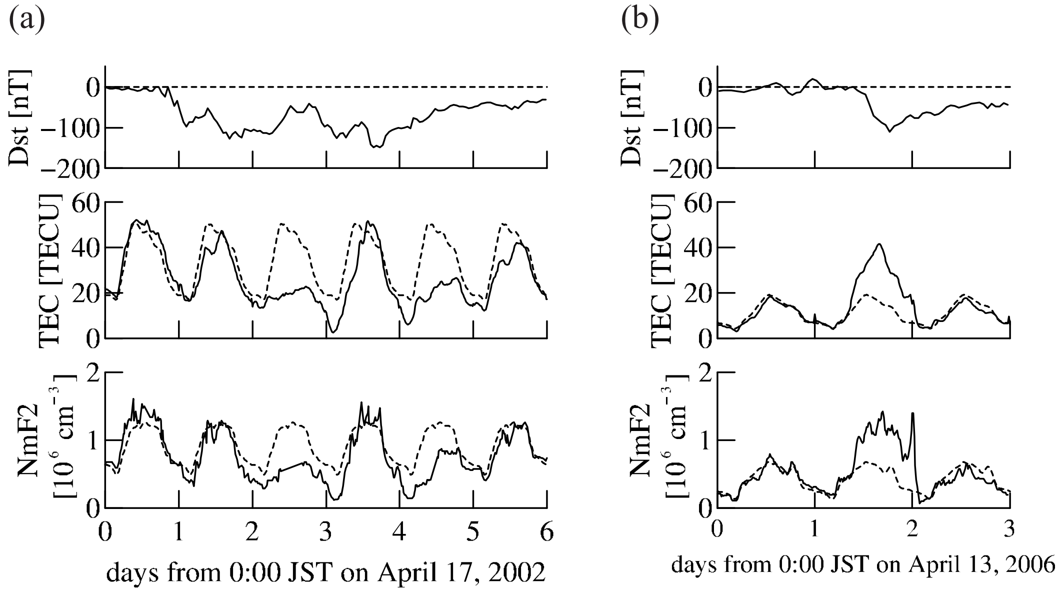

Figure 1: From the top panel, temporal profiles of Dst index, vertical TEC, and NmF2. (a) At Wakkanai, days from 17 to 23 April 2002. (b) At Kokubunji, from 13 to 16 April 2006. In the lower panels, the dashed curves represent monthly median values. Note that JST (Japanese standard time) corresponds to UT+9 hours.

Next, we discuss TEC and NmF2 disturbances at midlatitudes during intense geomagnetic storms. Figure 2 shows highly complicated TEC and NmF2 behaviors in response to a geomagnetic storm starting from 8 November 2004. The disturbances were quite different between Wakkanai and Kokubunji; two distinct positive TEC (NmF2) disturbances were seen in the afternoon and in the post sunset at Wakkanai, while the structure was not distinct at Kokubunji. The detail analysis of this event was carried out by Maruyama [6], who interpreted the later enhancement as low-latitude signatures of a storm enhanced density (SED). Discrepancies between TEC and NmF2 behaviors were also observed; TEC increased from the sunrise on 8 November, while the NmF2 decreased until 12 JST at Wakkanai (but increased at Kokubunji).

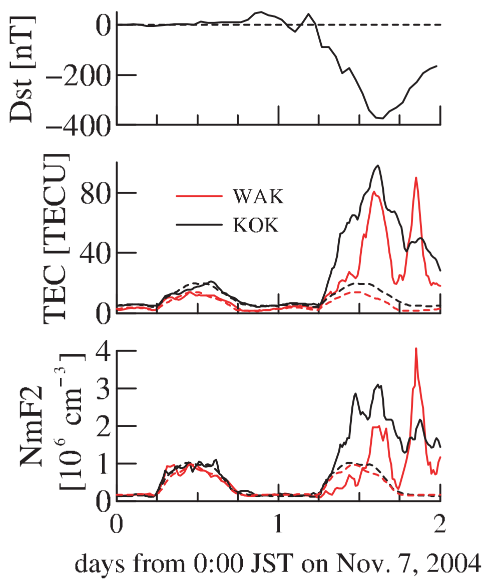

Figure 2: The same as Figure 1, but for days from November 7 to 9, 2004. The red curves represent Wakkanai, and the black curves represent Kokubunji.

The left panels of Figure 3 show Dst index, NmF2, the height of F2 peak (hmF2), and vertical TEC at Wakkanai for another intense geomagnetic storm that happened on November 6, 2001. The storm sudden commencement (SSC) occurred at 0151 UT (1051 JST), and the storm main phase began almost immediately, as indicated by the sudden decrease in the Dst index at around 11:00 JST. During the storm main phase, other observations of the same event suggested an anomalous development of equatorial ionospheric anomaly (EIA) -- there was an increase in TEC at the crest and a decrease at the magnetic equator [8], which indicates upward/poleward plasma transport and is strong evidence of eastward electric field penetration. In Figure 3, the ionospheric F-region was uplifted at 1100 JST, and the rate of TEC increase became higher. In contrast, NmF2 decreased for the subsequent 2 hours and then began to increase. In this event, TEC was observed to increase all over Japan (between 21 and 41 degrees in magnetic latitude) after SSC, and NmF2 also increased at other lower-latitude ionosonde stations in Japan [5].

3. Discussion

In the above, we showed TEC and NmF2 behaviors during moderate to severe geomagnetic storms. The temporal profile and degree of TEC and NmF2 disturbances were quite similar at midlatitudes during moderate storms (Figure 1). Note that behaviors of the two quantities can be different to some degrees even during weak to moderate storms, and at other latitudes. However, significant differences tend to occur during severe storms. In the followings, we discuss the main causes of the significant differences in TEC and NmF2 disturbances.

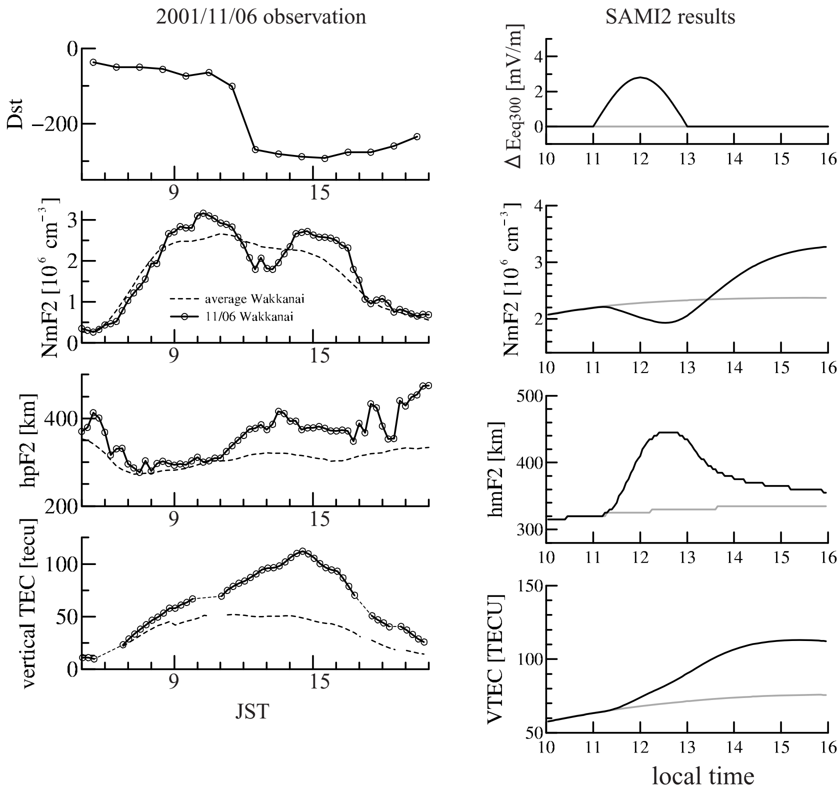

Figure 3: In the left panels, temporal profiles of (from the top) Dst index, NmF2, hpF2, and vertical TEC observed at Wakkanai, while in the right panels, (from the top) the input perturbation electric field (measured at the equator at the 300 km height: positive means eastward), and the model results of NmF2, hmF2, and vertical TEC.

One possible cause can be effects of F-region plasma dynamics enhanced when storm drivers operate strongly and suddenly. The right panels of Figure 3 show the SAMI2 simulation results. The simulation method including the input parameters and conditions was given by Jin and Maruyama [3]. The panels show the assumed temporal profile of disturbed eastward electric field at 300 km altitude at the equator, and the time development of vertical TEC, NmF2, and hmF2 at the same longitude and latitude of the observation shown in the left panels. The hmF2 increased relative to the quiet case after 11 LT, and, at the same time, NmF2 started to decrease and TEC started to increase. After the temporary decrease, NmF2 began increasing. The simulated TEC and NmF2 behaviors are similar to those of the observations in the left panels. Jin and Maruyama [3] analyzed the simulation results and found that the decrease of NmF2 occurred both due to an increased diffusion flux in the topside ionosphere caused by the layer uplift and due to a flux tube expansion (plasma dilution) caused by the EXB motion towards an outer L shell region. Figure 4 shows the altitude profiles of electron density and upward diffusion flux immediately after the electric field penetration, showing the enhancement of diffusion flux. On the other hand, the TEC increase was largely due to the continuing photochemical plasma production below the uplifted F-region ionosphere (Figure 4a).

Another possible cause for the TEC and NmF2 different behaviors can be effects of more than one storm drivers operating at the same time. The geomagnetic storm on 8 November 2004 (Figure 2) may be such a case. In this event, both TEC and NmF2 increased significantly from the sunrise at lower latitudes in Japan (e.g., Kokubunji in Figure 2), which is likely caused by penetration eastward electric fields during the storm main phase. On the other hand, NmF2 decreased from the sunrise at higher latitudes (e.g., Wakkanai), which can be caused by molecular-rich air (larger $[N_2]/[O]$) once enhanced in the polar region and moving towards midlatitudes. At Wakkanai, plasma density may have increased above the F2 peak in spite of the decrease in NmF2, due to the transport from the lower latitudes by the EXB drift, and therefore vertical TEC increased there. Thus, the different TEC and NmF2 behaviors in this case may indicate

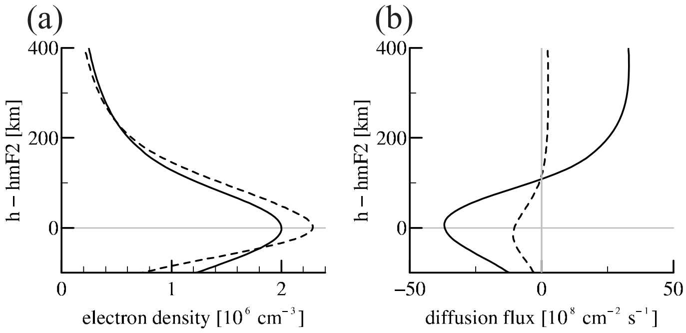

Figure 4: Altitude profiles of (a) electron density and (b) upward diffusion flux immediately after the electric field penetration. Solid curves represent the storm case and the dashed the quiet case.

different storm drivers operating simultaneously. These processes can also be examined quantitatively through the modeling work.

4. Conclusion

We suggested that different TEC and NmF2 disturbances observed during intense geomagnetic storms can be caused by effects of F-region plasma dynamics enhanced when storm drivers operate suddenly or effects of more than one storm drivers operating simultaneously. Therefore, observations of such TEC and NmF2 disturbances include important and useful information which can help us to understand the plasma dynamics in the F region and to identify operating storm drivers which are sometimes not evident from TEC or ionosonde observation alone especially for the case of intense storms.

5. Acknowledgments

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6. References

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