Observation and model comparisons of the traveling atmospheric disturbances over the Western Pacific region during the 6–7 April 2000 magnetic storm

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[1] The ionospheric features of traveling atmospheric disturbances (TADs) over the Western Pacific region have been observed by the Wuhan, NCU-DPS, and Cebu ionosondes and the ROCSAT-1 satellite during the 6–7 April 2000 magnetic storm. The nighttime observations are further compared with the simulation results of the Thermosphere-Ionosphere Electrodynamics General Circulation Model (TIEGCM). Both observation and model demonstrate that the TADs propagate equatorward with a phase speed of 610–650 m/s. The observations and corresponding TIEGCM simulations show a negative initial correlation between $N_m F_2$ and $H_m F_2$ caused by equatorward wind surges at various locations from midlatitudes to the equator. These qualitative agreements reveal that the TIEGCM is capable of simulating the TADs. The TIEGCM simulations of two locations located in the downwind hemisphere further show decreases in $N_m F_2$ and $H_m F_2$ mainly due to the enhanced transequatorial winds. After lowering the $F_2$ layer at the two locations, the $H_m F_2$ is raised for several hours and shows slightly enhanced $N_m F_2$ daytime values while the meridional wind is at background magnitude. We propose that this effect is caused by accumulation of plasma transported from northern latitudes. However, we also find that the $N_m F_2$, $H_m F_2$, and the lifetimes of $H_m F_2$ uplift phase and equatorial vertical drift in the model results are quantitatively inconsistent with that in the observed data. INDEX TERMS: 2435 Ionosphere: Ionospheric disturbances; 2415 Ionosphere: Equatorial ionosphere; 2788 Magnetospheric Physics: Storms and substorms; 2437 Ionosphere: Ionospheric dynamics; KEYWORDS: TADs, magnetic storm, TIEGCM


1. Introduction

[2] It is known that a large amount of energy is dissipated in the polar region during magnetic storms, which leads to profound changes in the global upper atmosphere [e.g., Fuller-Rowell et al., 1997; Prölls, 1997; Buonsanto, 1999]. These changes are accompanied by a substantial increase in the Joule and particle heating rates. Such heating in the high latitude expands the neutral atmosphere, it further enhances the equatorward winds. If the heating events are impulsive, the equatorward winds will take the form of traveling atmospheric disturbances (TADs) [Richmond and Matsushita, 1975; Prölls and Jung, 1978; Prölls, 1993; Bauske and Prölls, 1997; Lu et al., 2001; Lee et al., 2002]. The TADs, which are superposition of pulse-like or surge-like atmospheric waves, can propagate to the equatorial and low latitudes or even into the opposite hemisphere. Once the equatorward propagating TAD arrives at middle latitudes, the associated meridional wind causes an uplift in the F-peak height ($H_m F_2$), which in turn leads to an initial decrease followed by a subsequent increase in the F-peak density ($N_m F_2$) [Bauske and Prölls, 1997; Lu et al., 2001; Lee et al., 2002].

[3] Various researches on the TAD effects also reported about an associated negative correlation between $N_m F_2$ and $H_m F_2$ at lower latitudes. Fesen et al. [1989], using the thermospheric general circulation model (TIGCM), found a negative correlation of $N_m F_2$ and $H_m F_2$ at low latitudes during the 22 March 1979 storm. They proposed that a
transsequatorial wind generated by storm would deplete electron concentrations in the upwind hemisphere and enhance them in the downwind hemisphere. Bauske and Pro¨lss [1997] performed a model simulation of the ionospheric response to a daytime TAD and found a negative initial correlation at midlatitudes. Furthermore, Lu et al. [2001] demonstrated the presence of the negative correlation of these two ionospheric parameters in the January 1997 storm by a correlated study with ionosondes and the global Thermosphere-Ionosphere Electrodynamics General Circulation Model (TIEGCM). Recently, during the 6–7 April 2000 magnetic storm, an equatorward TAD traveling over the Western Pacific region was detected by Lee et al. [2002].

Although the studies of TADs have clearly established the negative initial correlation between $NmF_2$ and $HmF_2$ during the passage of TADs at middle latitudes, the cause of the phenomenon has not been fully understood for lower latitudes. In this paper we attempt to explore the detailed features by revisiting the TAD event over the Western Pacific region during the 6–7 April 2000 magnetic storm. Our efforts are based on three sets of observation and simulation data: the ionogram data of three stations (Wuhan, NCU-DPS, and Cebu) along the 120°E sector, the plasma flow measurements at ~600 km from the ROCSAT-1, and the result of a global simulation with the TIEGCM. The $NmF_2$, $HmF_2$, ion drift, neutral wind, and neutral composition are then applied to describe the TAD features and the ionospheric plasma behaviors.

2. Geophysical Conditions and Experiment Setup

Figure 1 displays the Dst and Kp indices during the 6–7 April 2000 storm period. This storm was characterized by a pronounced sudden commencement (SSC) at 1640 UT on 6 April 2000. Then, the Dst amplitude started to decrease and reached a minimum value of ~321 nT at 0100 UT on 7 April (Figure 1a). After that the recovery phase continued into 8 April 2000. The maximum Kp value of 9- (Figure 1b) during 0000–0300 UT of 7 April categorized this event into the “severe” or “major” magnetic storm. Furthermore, in Figure 1c, the AE index started to increase at 1640 UT on 6 April and reached a maximum value of ~2500 nT at ~1750 UT of 6 April.

Three stations as shown in Figure 2 measured the ionosphere in the Western Pacific region at every 15-min interval. One station was at Wuhan Ionospheric Observatory (30.6°N, 114.4°E, geographic; 19.9°N, 185.8°E, geomagnetic; LT (local time) = UT (universal time) + 7 2/3 hours), using a digisonde (DGS). Near the crest of the equatorial ionization anomaly (EIA), a digisonde portable sounder (DPS) at National Central University (NCU-DPS, 24.9°N, 121.1°E, geographic; 14.5°N, 192.2°E, geomagnetic; LT = UT + 8 hours) was utilized. Furthermore, at Cebu (10.3°N, 123.9°E, geographic; 2.0°N, 195.6°E, geomagnetic; LT = UT + 8 1/3 hours), near to the geomagnetic equator, data from a portable FM/CW sounder was included. Notably, we

![Figure 1. Geomagnetic indices (a) Dst, (b) Kp, and (c) AE, as well as the two time-dependent driven inputs of TIEGCM, (d) the cross-polar-cap potential drop (CP) and (e) the hemispheric auroral precipitation power (HP) for 6–7 April 2000. The sudden commencement (SSC) onset is at 1640 UT on 6 April.](image1)

![Figure 2. Map showing the ionosonde stations and the ROCSAT-1 passes. The dots symbolize the locations of Wuhan, NCU-DPS, and Cebu ionosondes. The bold lines represent three ROCSAT-1 passes (A, B, and C) over this region during 1930–2306 UT on 6 April 2000.](image2)
applied the true height analysis programs ARTIST [Reinisch and Haung, 1983; Reinisch, 1996] and POLAN [Titheridge, 1985] on the Wuhan/NCU-DPS and Cebu ionograms, respectively.

[7] We also obtained the ion drift velocity from the drift meter (DM) and the retarding potential analyzer (RPA) of ROCSAT-1 orbiting at ~600 km orbit with a 35° inclination (see Yeh et al. [1999] for detail). Note that the accuracy of the DM measurement is ±10 m/s. To focus on the TAD behaviors in the Western Pacific region, we analyzed the satellite data during 1930–2306 UT on 6 April. During this period, ROCSAT-1 flew over this region with three consecutive orbits: passes A, B, and C (the bold lines in Figure 2).

[8] Additionally, we utilized the result from a simulation model, TIEGCM, on this storm event. The TIEGCM, with a 5° × 5° resolution in latitude-longitude grid, is well suited for the study of the F region/upper atmosphere during the moderate and disturbed geomagnetic conditions. This model has 29 constant pressure levels usually extending from ~97 to ~600 km in altitude [Richmond et al., 1992]. Notably, in this study the altitudes of the 29th pressure level (upper boundary) are ~800 km at low latitudes. Through a self-consistent calculation, it models the thermospheric/ionospheric conditions, i.e., plasma density, electric fields, neutral winds, etc. In this work we modified two time-dependent driven inputs to TIEGCM in order to simulate the geomagnetic storm: one is the cross-polar-cap potential drop (CP); the other is the hemispheric auroral precipitation power (HP). As moderate condition, we selected a CP of 60 kV and a HP of 25 GW. To simulate the disturbed condition, we varied CP from tens of kV to over 150 kV (Figure 1d) and HP from a few of GW to ~80 GW (Figure 1e). The upper boundary conditions of O+ flux are upward (+1.5 × 10^8 cm^-3 s^-1) by day and downward (−1.5 × 10^8 cm^-3 s^-1) at night during both moderate and disturbed conditions. This flux is assumed invariant with longitude and local time; it varies sinusoidally with geographic latitude from zero at equator to a maximum at 60°N. Owing to the TIEGCM resolution, the model result at a location close to the station is selected to compare with the observed data.

3. Results
3.1. Comparison of NmF₂ and HmF₂ Between Ionosonde and TIEGCM

[9] Figure 3 illustrates the NmF₂ and HmF₂ of the DGS (Figures 3a–3b) and TIEGCM (Figures 3c–3d) over Wuhan during 6–7 April 2000. The bold lines represent the observation and model data of 6–7 April, while the thin lines are the observed monthly median value of April 2000 and the moderate condition result of TIEGCM. Notably, there are some gaps in the Wuhan data at 0430–0515 UT and 0645 UT of 6 April, as well as at 0800–0845 UT and 2145 UT of 7 April. A sudden rise of ~200 km in HmF₂ during 1830 UT of 6 April to 0030 UT of 7 April is noticed in Figure 3b. Meanwhile, a decrease of ~3 × 10³/cm³ in NmF₂ (Figure 3a) initiates from 1830 UT of 6 April. Later,
HmF$_2$ increases to reach a maximum at 0030 UT of 7 April and decreases again afterward. Likewise, similar variations are shown in TIEGCM results (Figures 3c–3d), where a sharp rise in HmF$_2$ ($\sim$100 km) accompanied with a decrease in NmF$_2$ ($\sim$1.5 $\times$ 10$^5$/cm$^3$) simultaneously appear between 1830 UT of 6 April and 0230 UT of 7 April. According to Lee et al. [2002], such behavior has been characterized to the TAD effects [Proßl, 1993; Bauske and Proßl, 1997] that cause a rise in HmF$_2$ and an initial decrease in NmF$_2$.

[10] In Figure 4 the observed data and the TIEGCM results over NCU-DPS demonstrate that this TAD also affects the ionosphere near the EIA crest. Figure 4b displays a sudden increase by $\sim$200 km in HmF$_2$ between 1845 UT of 6 April and 0100 UT of 7 April. During the uplifting phase, the NmF$_2$ (Figure 4a) decreases ($\sim$4 $\times$ 10$^5$/cm$^3$) rapidly and then recovers to reach its maximum at $\sim$0000 UT of 7 April. Again, the TIEGCM results of TAD behaviors at a near location (22.5$^\circ$N, 120$^\circ$E) are shown in Figures 4c–4d. An uplifted HmF$_2$ ($\sim$140 km) and an NmF$_2$ decrease ($\sim$1.6 $\times$ 10$^5$/cm$^3$) concurrently appear from 1900 UT of 6 April to 0230 UT of 7 April.

[11] Furthermore, at the geomagnetic equator, the ionosphere over Cebu is changed during this TAD event (Figure 5). Ignoring the two data gaps during 1200–1745 UT on 7 April, a NmF$_2$ decrease ($\sim$5 $\times$ 10$^5$/cm$^3$) and an HmF$_2$ rise ($\sim$100 km) coincidently exist between 1900 and 2300 UT of 6 April (Figures 5a–5b). Similarly, such variations appeared in the TIEGCM results (Figures 5c–5d), a decrease in NmF$_2$ ($\sim$2 $\times$ 10$^5$/cm$^3$) and an uplift in HmF$_2$ ($\sim$110 km), between 1915 UT of 6 April and 0200 UT of 7 April. Notably, the decreases in NmF$_2$ of observation and simulation data start slightly before the increases in HmF$_2$, and there is a depression of HmF$_2$ compared with quiet time values directly before the uplifting. Moreover, during the daytime, the simulation results for both NmF$_2$ and HmF$_2$ are inconsistent with the Cebu data during 2300 UT of 6 April to 0800 UT of 7 April (0720–1620 LT of 7 April).}

3.2. TAD Propagation of TIEGCM

[12] The ionosonde and model results in Figures 3–5 indicate that the TIEGCM underestimates NmF$_2$ but overestimates HmF$_2$ all the time. Furthermore, at Wuhan and NCU-DPS (Figures 3–4), the period of the uplift phase of HmF$_2$ in observation ($\sim$5–6 hours) is shorter than that in simulation ($\sim$7–8 hours). At Cebu (Figure 5) the period in simulation ($\sim$7 hours) is much longer than that in observation (4 hours). Nevertheless, the TIEGCM results still have a qualitative agreement with the observed data during the nighttime. It is remarkable that the negative initial correlation between NmF$_2$ and HmF$_2$ (shown as the gray areas in Figures 3–5), which is one of the TAD characteristics, simultaneously appears in the observations and model results.

Figure 4. NmF$_2$ and HmF$_2$ variations of observation (a–b) and TIEGCM (c–d) over Chung-Li. The bold lines are the observed data and the model result during 6–7 April 2000. The thin lines are the monthly median value of April 2000 for observation and the model result under moderate condition for TIEGCM. The vertical lines and the gray areas indicate the negative initial correlation between HmF$_2$ and NmF$_2$. 

Figure 4.
TIEGCM at 120°E. In Figure 6a we show the meridional wind perturbations at a 400 km altitude between 1200 UT of 6 April and 1200 UT of 7 April. The solid and dashed contours denote the northward and southward perturbation winds, respectively. As seen in the figure, one TAD (highlighted by the heavy dashed line) originated from 1640 UT in the Northern Hemisphere and reached 7.5°S geographic latitude at 2100 UT on 6 April, indicating a propagation speed of ~610 m/s. Meanwhile, another one departed from 80°S at 1640 UT in the Southern Hemisphere and arrived at 7.5°S at ~1930 UT on 6 April, indicating a propagation speed of ~650 m/s. It is found that the southern TAD is faster than the northern one. Moreover, only the northern TAD crosses the dip equator and penetrates into the opposite hemisphere. Notice that the difference in the meridional wind equals zero at 7.5°S latitude.

Additionally, the TADs also perturb the HmF. Figure 6b shows the difference in HmF along the 120°E sector. The solid and dashed contours represent the uplift and drop in HmF, respectively. It is clear that the northern TAD lifts the HmF between ~80° and 7.5°N (upwind hemisphere) but lowers the F-peak height between ~2.5°N and 7.5°S geographic latitudes (downwind hemisphere). The other TAD, in the Southern Hemisphere, lifts the HmF between ~80° and 7.5°S geographic latitudes.

Figure 6c demonstrates the corresponding perturbation of the N2/O ratio. The solid and dashed contours represent the increase and decrease in N2/O ratio, respectively. Comparing Figure 6c with Figures 1d–1e, the change in the N2/O ratio at high latitudes coincides with the simulated time variations of CP and HP in the disturbed condition, as can be expected from the model. At middle and high latitudes the direction of the N2/O maximum enhancement zone with respect to latitude and time differs from the direction of the TAD propagation. The zone of increased N2/O ratio stretches in both hemispheres towards the equator. It is delayed with respect to the TAD propagation with different delays in north and south hemisphere. Therefore it is difficult to conclude from Figure 6c whether and how much the TADs affect the change in the N2/O ratio at lower latitudes. Moreover, the increase in N2/O seems too small to have a significant impact on the simulated ion density values between ~20°N and ~32.5°S. At 22.5 and 32.5°N, the simulated ion density decrease starts more than 2 hours before the N2/O density increase. Therefore composition changes are not the prime cause of the negative storm effects seen in the nighttime simulation results for the three stations.

The TIEGCM results show that the TADs with meridional wind surges apparently modulated the HmF. These TADs also cause a slight westward enhancement (~15%) in the zonal wind (not shown here). This westward enhancement in the zonal wind may be due to the action of Coriolis force on the enhanced equatorward winds [e.g., Fuller-Rowell et al., 2002].

3.3. Ion Drift Velocity of ROCSAT-1

We further examine the ion drift velocities to understand the plasma motions during this TAD period. The ion velocities are observed by ROCSAT-1 at ~600 km, while
the $HmF_2$ are in the uplifting phase over the three stations during 1930–2306 UT on 6 April.

Figure 7 demonstrates the $V_\parallel$ (solid line) and $V_M^\parallel$ (dashed line) flow components from the ROCSAT-1. The bold and thin lines represent the observed and background values, respectively. The $V_\parallel$ is the parallel-to-field component of the ion drift velocity; the positive values represent the northward plasma flows. The $V_M^\parallel$ represents the ion drift component in the magnetic meridian plane, which is perpendicular to the geomagnetic field; the positive values are the outward plasma flows (see Su et al. [2002] for reference). It can be seen that the absolute values of $V_\parallel$ and $V_M^\parallel$ which are almost negative, are greater than the background values along all three passes. The enhancement of $V_\parallel$ indicates that the ions are dragged by the enhanced meridional wind, which in turn causes a southward movement of plasma along the magnetic field line during the $HmF_2$ uplifting phase. Furthermore, the enhanced $V_M^\parallel$ denotes that the inward plasma flow increased. This increased $V_M^\parallel$ could be due to a westward electric field that is generated by an equatorward wind. It is noted that the $V_\parallel$ has twice the magnitude of $V_M^\parallel$.

4. Discussion and Conclusion

[19] Previous investigators proposed two basic mechanisms to explain the variations in ionospheric height at equatorial latitudes during storm times. One is the short-lived (~1 hour) prompt penetration electric field [Spiro et al., 1988; Fejer and Scherliess, 1997], and the other is the longer-lasting (1–12 hours) disturbance dynamo electric field [Blanc and Richmond, 1980; Scherliess and Fejer, 1997]. To look for the major mechanism in this storm event, we examine the TIEGCM results at the dip equator ($7.5^\circ$N, $120^\circ$E, geographical). Figure 8 displays the $HmF_2$ and vertical $E \times B$ drift at the dip equator during 6–7 April 2000. Both the $HmF_2$ and the vertical $E \times B$ drift concurrently decrease between 1645 and 2118 UT on 6 April. During 1645–1710 UT (0045–0110 LT), the enhancement of the downward $E \times B$ drift is similar to the penetration effects of Fejer and Scherliess [1997], which proposed that the vertical drift is downward in the postmidnight for the storm time of 7.5–30 min. Notice that the storm time of zero is the SSC onset. However, Fejer and Scherliess [1997] showed the average exponential decay time constant is ~70 min for the storm time of 30–75 min. Such kind of decay is inconsistent with our simulation result where the downward velocity is increasing for more than 3 hours. On
the other hand, the enhanced downward drifts during 1740–2240 UT (0140–0640 LT) are also contrary to the results of the disturbance dynamo by Scherliess and Fejer [1997], which suggested that for the storm time of 1–6 hours, the vertical drift is upward in this period. Note that the TIEGCM overestimates the duration of the $HmF_2$ rising in Figure 5 by several hours, which indicates that it may also overestimate the duration of the downward $E/C_2B$ drift in Figure 8. At Cebu, based on the downward $E \times B$ drift in the simulation and on the appearance of $NmF_2$ decrease before $HmF_2$ rise in data, we assume that prompt penetration (or other electric field effects) is likely to affect the $F_2$ layer before arrival of the TAD. However, the downward $E \times B$ drift in the simulation and the rapid changes of $HmF_2$ with time in the data rule out the disturbance dynamo as prime cause of the effects seen in Figure 5 between 1740 and 2240 UT of 6 April. Therefore we expect other processes in the equatorial ionosphere to be more important during this storm.

[20] Figure 5 shows that the negative initial correlation between $NmF_2$ and $HmF_2$ appears in the Cebu ionosphere, which agrees with the main feature of the TAD proposed by Bauske and Prölls [1997] and Lee et al. [2002]. According to Bauske and Prölls [1997], the height variation of the meridional wind could form the negative initial correlation at midlatitudes. Here, we examine the height variation of the meridional winds at the time of the maximum perturbation of the TIEGCM results at 22.5° and 7.5°N along 120°E (as shown in Figure 9). In Figure 9a the enhanced meridional wind velocity (bold line) at 22.5°N increases with height; this is similar to the TAD model results of Bauske and Prölls [1997, Figure 2]. At 7.5°N (Figure 9b) the enhanced meridional wind velocity (bold line) also increases with height. This suggests that the vertical gradient of the meridional wind might be a reason for the negative initial correlation of the TAD at the dip equator. Furthermore, the perturbation of Cebu $HmF_2$ begins at the time after ~2.5 hours of the storm onset. This result is similar to those reported by Prölls [1993] and Fuller-Rowell et al. [2002], where they found that the arrival time of TADs at the equator is 2–4 hours after the storm onset. Thus the equatorial ionosphere seems to be modulated primarily by the TAD. Moreover, this TAD affects the ionosphere over Wuhan and NCU-DPS (Figures 3–4), as found by Lee et al.

**Figure 7.** $V_h$ (solid line) and $V_M$ (dashed line) at ~600 km obtained by ROCSAT-1 along three passes. The bold and thin lines represent the observed and background values, respectively. The $V_h$ is one parallel-to-field component of ion drift velocity, positive value is northward. The $V_M$ is one component of ion drift velocity in the magnetic meridian plane of perpendicular-to-field, positive value is outward. The data of passes A, B, and C are displayed in the upper, middle, and lower panels, respectively. The arrow indicates the time when the ROCSAT-1 passed close to the ionosonde station.

**Figure 8.** The (a) $HmF_2$ and (b) vertical ion drift of TIEGCM at 7.5°N and 120.0°E during 6–7 April 2000. The bold lines represent the model result during 6–7 April 2000, while the thin lines are the model result under moderate condition.
Previous works have shown that the meridional wind is important for the thermospheric responses to a storm. Prölls [1993] and Bauske and Proß [1997] suggested the propagation speed of a TAD to be 600–750 m/s, respectively. Recently, Lu et al. [2001] used TIEGCM to show a TAD with a phase speed of 750 m/s along 70°W during the January 1997 storm. Lee et al. [2002] found that the TAD speed is 600–750 m/s, respectively. Comparing the timing of the wind shear (Figure 4) with the timing of the wind shear (Figure 10), it seems that the positive (negative) disturbance of NmF2 is very well correlated with the negative (positive) value of the wind shear. We should be noted again that the nighttime TADs is well simulated by the TIEGCM, but the daytime model results of HmF2 and NmF2 shown in Figure 10 disagree with the data presented earlier in Figure 4.

Next, we examine the meridional wind at a 400 km altitude, HmF2, and NmF2 at 22.5°N, 12.5°N, 2.5°S, and 7.5°S along 120°E as shown in Figures 11–14. It is found that when the wind is enhanced, the HmF2 are rising at 22.5 and 12.5°N altitudes (Figures 11–12) and lowering at 2.5°S latitude (Figure 13). Figure 13 seems to indicate that the wind enhancement has nothing to do with the decreases in HmF2 and NmF2, because the latter two start earlier. However, the difference of the meridional wind in Figure 6 during 2115–2330 UT indicates that the chosen location is under influence of the TAD coming from North. At 7.5°S latitude (Figure 12) the wind is close to the moderate value, but the HmF2 is enhanced from 2300 UT of 6 April to 1330 UT of 7 April. NmF2 is slightly decreased before 0600 UT but later increased until 1530 UT of 7 April.

Consequently, we utilize a sketch to explain how the meridional winds may modulate the ionosphere at different latitudes (Figure 15). The large arrow represents

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**Figure 9.** The height variation of the meridional winds at the time of the maximum perturbation of the TIEGCM results at (a) 22.5°N and (b) 7.5°N along 120°E. The bold lines represent the model result, while the thin lines are the model result under moderate condition. The negative value represents the southward wind.

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**Figure 10.** Variations of HmF2 (solid line), meridional wind at HmF2 (dotted thin solid line), and the vertical shear of meridional wind at HmF2 (dashed line) of TIEGCM at 22.5°N and 120°E during 6–7 April 2000. The positive meridional wind indicates the northward wind. The vertical lines remark the period of uplifting phase in HmF2.

...are generally negative during this period. Lu et al. [2001] found that zero crossings of the wind shear roughly correspond to the reversals of HmF2 time derivative (their Figure 6b), but in Figure 10 of the current manuscript the wind shear seems uncorrelated to HmF2. Thus here our results disagree with the results given by Lu et al. [2001]. On the other hand, Lu et al. [2001] also found that positive and negative wind shears contribute to the increase and decrease of NmF2, respectively. Comparing the timing of NmF2 (Figure 4) with the timing of the wind shear (Figure 10), it seems that the positive (negative) disturbance of NmF2 is very well correlated with the negative (positive) value of the wind shear. It should be noted again that the nighttime TADs is well simulated by the TIEGCM, but the daytime model results of HmF2 and NmF2 shown in Figure 10 disagree with the data presented earlier in Figure 4.
Figure 11. (a) The meridional wind at 400 km altitude, (b) $HmF_2$, and (c) $NmF_2$ of TIEGCM at 22.5°N and 120°E during 6–7 April 2000. The bold lines represent the model result during 6–7 April 2000, while the thin lines are the model result under moderate condition. The positive meridional wind indicates the northward wind. The vertical lines remark the period of uplifting phase in $HmF_2$.

Figure 12. (a) The meridional wind at 400 km altitude, (b) $HmF_2$, and (c) $NmF_2$ of TIEGCM at 12.5°N and 120°E during 6–7 April 2000. The bold lines represent the model result during 6–7 April 2000, while the thin lines are the model result under moderate condition. The positive meridional wind indicates the northward wind. The vertical lines remark the period of uplifting phase in $HmF_2$. 
Figure 13. (a) The meridional wind at 400 km altitude, (b) $HmF_2$, and (c) $NmF_2$ of TIEGCM at 2.5°S and 120°E during 6–7 April 2000. The bold lines represent the model result during 6–7 April 2000, while the thin lines are the model result under moderate condition. The positive meridional wind indicates the northward wind. The vertical lines remark the enhancement in the meridional wind.

Figure 14. (a) The meridional wind at 400 km altitude, (b) $HmF_2$, and (c) $NmF_2$ of TIEGCM at 7.5°S and 120°E during 6–7 April 2000. The bold lines represent the model result during 6–7 April 2000, while the thin lines are the model result under moderate condition. The positive meridional wind indicates the northward wind. The vertical lines remark the uplifting phase.
the difference in meridional wind with respect to the moderate condition from the TIEGCM at 120°E. The solid arrows indicate that the ions are dragged to other latitudes along the field line by the enhanced wind. Recall that the V// is more important than V_M and that the negative V// appearing in ROCSAT-1 data denotes that the plasma flows are southward (Figure 7). This indicates that the enhanced southward wind (and the associated vertical gradient of wind) not only causes the HmF_2 rising (and NmF_2 decreasing) [Bauske and Proß, 1997] but also blows the plasma in the upwind hemisphere to south latitudes and higher altitudes. In the downwind hemisphere, the decreases in both HmF_2 and NmF_2 exist at where the wind is still enhanced (at 2.5°S latitude) because the wind blows the plasma to southern latitudes and lower altitudes. This decreasing NmF_2 does not agree with Fesen et al. [1989], which suggested the transsequatorial winds will enhance electron concentrations in the downwind hemisphere.

[25] At 7.5°S, finally, the enhancement in the southward wind becomes zero and any wind controlled plasma transport along the field line comes to its end, with the result that we would expect plasma to accumulate in the topside ionosphere (shown as shadow area in Figure 15). Here, we examine the electron profiles at 7.5°S in simulation during 2300 UT of 6 April to 1330 UT of 7 April. The plasma increases in the topside ionosphere at 7.5°S and in turn forms a rising in HmF_2 at 0200 UT of 7 April (Figure 16a). Then, at 0700 UT of 7 April (Figure 16b), more plasma accumulates in the topside ionosphere and leads to the NmF_2 increasing. These results indicate that the plasma in altitudes of ~450–800 km in the downwind hemisphere (~2.5°N to 2.5°S) can be still transported (diffused) to the topside ionosphere at 7.5°S, while the enhanced wind is at the background values. Note that in these model results, the plasma accumulation cannot be transported from the upwind hemisphere because the apex height of the magnetic field line at 400 km altitude at 7.5°S is more than 800 km. It is remarkable that the decrease in N_2/O ratio (0.15 to 0.13) at this location during 0600–1530 UT of 7 April (shown in Figure 6c) seems too small to significantly affect the NmF_2 values.

[26] In summary, we have investigated the TAD features over the Western Pacific region during the 6–7 April magnetic storm using the ionosondes, ROCSAT-1, and TIEGCM. The results of observations and simulation demonstrate that the TIEGCM successfully models the nighttime TADs, which propagate from high to low latitudes with phase speed of ~610–650 m/s. The transsequatorial meridional winds raise and lower the HmF_2 in the upwind and downwind hemispheres, respectively. Besides, the wind transports the plasma to other latitudes along the field line and causes the nighttime decreases in NmF_2 in both hemi-

Figure 15. A sketch of the difference in meridional wind and V// along 120°E under the TAD condition. The large arrow is the difference in wind, while the solid arrows represent the V//. Notice that the difference in wind is equal to 0 at 7.5°S. The thin lines are the geomagnetic field lines. The shadow area represents the region where the plasma cumulates.

Figure 16. The electron profile of TIEGCM at 7.5°S and 120°E at (a) 0200 UT and (b) 0700 UT of 7 April 2000. The bold lines represent the model result in 7 April 2000, while the thin lines are the model result under moderate condition.
spheres. Furthermore, the plasma accumulates in the topside ionosphere where the difference in wind is approximately equal to zero. However, in this present work, the $HmF_2$ overestimate, the $NmF_2$ underestimate, and the longer lifetimes of $HmF_2$ uplift phase and equatorial vertical drift are simulated by the TIEGCM. Moreover, the simulation results disagree with the observation data during the daytime at Cebu. These inconsistencies might be due to the propriety of our two input parameters (HP and CP). To approximate the actual features, the other models, e.g., the assimilative mapping of ionospheric electrodynamics (AMIE) procedure [Richmond and Kamide, 1988], should be included in future works.

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### References


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