Unusual early morning development of the equatorial anomaly in the Brazilian sector during the Halloween magnetic storm


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The solar events that occurred at the end of October 2003 gave rise to very strong geomagnetic disturbances that peaked twice with Dst values reaching $-345$ nT around 0000 UT on 30 October and $-400$ nT around 2300 UT, on the same day. Disturbances in several ionospheric parameters were observed over Brazil. This work will focus on the ionospheric response to the initial westward prompt penetration electric field and on the strong intensification of the equatorial ionization anomaly that occurred because of the electric field polarity reversal that followed in the early morning hours of 29 October. The $F$ layer peak height over the equator first decreased under the strong prompt penetration westward electric field, which was followed by significant height increase under eastward electric field. We have used Sheffield University Plasmasphere Ionosphere Model (SUPIM) with an intensified westward disturbed electric field in the presunrise hours, presumably due to prompt penetration from the magnetosphere, in order to study the effect of such a field in the ionosphere. The simulation results showed that prompt penetration of magnetospheric electric fields of westward polarity to the nightside equatorial region seems to be the most probable cause of the initial $F$ layer height decreases. The intensification of the equatorial ionization anomaly and the unusual enhancement on $F$ layer peak density, which was not modeled by the SUPIM, are explained as caused by the strong eastward electric field that followed the initial phase in combination with a highly variable disturbed meridional/transsequatorial wind system as inferred from the $F_2$ layer peak height variations. The highly dynamic wind pattern, with a short-term response (2–4 hours), is compatible with the predictions of some previous theoretical model calculations reported in the literature.


1. Introduction

The perturbations that occur at equatorial- and low-latitude ionosphere following magnetic disturbances result from modification in zonal electric field, meridional neutral winds and neutral gas temperature and composition [see, e.g., Rishbeth, 1975; Abdu, 1997; Buonsanto, 1999; Sasri et al., 2000; Fejer, 2002, and references therein] that occur during the disturbance process. The modification of the ionospheric zonal electric field can occur mainly owing to two factors. The first is the direct penetration of magnetospheric electric fields to equatorial latitudes, that is associated with sudden changes in interplanetary magnetic field (IMF) component Bz that are often accompanied by polar cap potential changes, auroral electrojet intensification, and symmetric/asymmetric ring current developments. This is a rapid and short-lived event in which the perturbations in magnetospheric convection electric fields can penetrate to low latitudes before they are opposed by the development of shielding charges in the inner magnetosphere. The second factor that modifies the equatorial zonal electric field results from the so called disturbance dynamo, which arises from global-scale changes in thermospheric general circulation resulting from storm energy deposition and heating of the high-latitude thermosphere-ionosphere system. Many authors have described drastic ionospheric effects at low latitudes related to strong magnetic storms, observed by various techniques such as ionosondes, optical measurements or satellite probes [see, e.g., Abdu et al., 2003; Basu

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A major solar flare took place on 28 October 2003, at 1110 UT, from a sunspot directly in line with the Earth. The X-ray flux associated with the event measured X17.0 on the astronomers’ Richter-like scale of magnitude, strong enough to be classified as one of the top three flares in the last few decades. Subsequently a coronal mass ejection (CME) was observed to leave the Sun in the direction of the Earth. The magnitude of the solar eruption was strong enough to temporarily disable spacecrafts. At 0611 UT of the following day a major magnetic storm started, with activity reaching the top of the geomagnetic K-scale measurement. Following the very disturbed period, the Sun significantly erupted again at 2049 UT on 29 October, and a second powerful CME impacted the Earth’s magnetosphere at around 1600 UT on 30 October. The Advanced Composition Explorer (ACE) spacecraft measured solar wind speed $>1850$ km/s and 1700 km/s, respectively, following these two CME events [Skoug et al., 2004].

During magnetic storm events that disturb the equatorial ionosphere, the equatorial ionization anomaly (EIA) can be drastically affected as well. The EIA development depends directly on the intensity (and direction) of the zonal electric field over the equator. The EIA development can undergo drastic modifications in the form of anomalous occurrence at local times outside that of its quiet time development, and anomalous inhibition or enhancement [see Abdu et al., 1991, and references therein]. In this paper we discuss a possibly asymmetric EIA that occurred in the early morning hours of 29 October with the aim of improving our understanding of the magnetosphere-thermosphere-ionosphere coupling process during these magnetic disturbances.

**2. Data Set**

We have analyzed quarter-hourly ionograms over the Brazilian stations, São Luís (2.6°S, 44.2°W, dip latitude 1.5°S) and Cachoeira Paulista (22.5°S, 45°W, dip latitude 17°S) registered by two Digisondes, DGS256, [Reinisch et al., 1989] and 10 minutes ionograms registered at Fortaleza (3.8°S, 38°W, dip latitude 6°S) by a DPS [Reinisch et al., 1997]. The ionospheric parameters, $\text{foF}_2$, $\text{hmF}_2$, the $F$ layer peak density $N_mF_2$, and $\text{h}'F$, the $F$ layer minimum virtual height, were
analyzed. The analysis is complemented by total electron content data from GPS receivers operated at 15 stations of the RBMC (Brazilian Network for Continuous Monitoring of GPS satellites) over the Brazilian territory and at 6 stations of the IGS (International GPS Service) network over South America. The combined data sets from the GPS receivers and from the Digisonde network have enabled us to evaluate the response features on the southern half of the EIA.

3. Results

[6] On 29 October 2003 an intense magnetic storm set in at 0611 UT, approximately 19 hours after the major solar flare and the CME that occurred on the previous day. This major magnetospheric disturbance developed in an already disturbed background, as can be noted in Figure 1, which shows the provisional auroral electrojet index AE, the symmetric/asymmetric ring current activities represented by the indices, ASY D, ASY H, SYM D and SYM H, the IMF component Bz, and theDst and Kp indices, for the period 28–29 October 2003. On 28 October the AE index reached values of the order of (and higher than) 500 nT for a long time period between 1600 and 2100 UT. After a short recovering period a new substorm started around 2200 UT, and AE values higher than 500 nT (sometimes even higher than 1000 nT) were observed until 0200 UT on 29 October. The auroral activity that started after 2200 UT on 28 October had not recovered completely when the magnetic storm started at 0611 UT on 29 October.

[7] Figure 2 shows the ionospheric parameters foF2 (left), hmF2 (middle), and h′F (right) for the three ionospheric stations São Luis (SL), Fortaleza (FZ), and Cachoeira Paulista (CP) on 29 October as compared to the quiet days mean for the same month. The ASY D, ASY H, SYM D, SYM H and Bz parameters are repeated on the top of each group of panels, to allow the identification of the disturbed periods. Significant deviations from the quiet day mean are observed at the three stations. The perturbations in the height parameters are more significant at the stations closer to magnetic equator (SL and FZ) and the perturbations in the peak density parameter (represented by foF2) are more significant at the station closer to the EIA crest (CP).

3.1. Perturbations in F Layer Heights

[8] The F layer height parameters, hmF2 and h′F, are shown in Figure 2. In the postmidnight and early morning hours, hmF2 was higher than the quiet day mean. Just after the storm onset at 0611 UT, it decreased rapidly over SL and FZ, but not over CP (at the same time foF2 decreased over the three locations). Over CP an increase in hmF2 was observed around one hour later (0715 UT). In the following two ionogram registers (0730/0745 UT for CP and SL, 0720/0730 UT for FZ) no F trace was observed at the three stations. It seems that the F layer critical frequency decreased below the minimum frequency threshold of 2 MHz (foF2 was rapidly decreasing at the three stations), but some uncertainty persists because of the presence of strong sporadic E layers at the three locations during this time period. When the F layer reappeared after the break its altitude over the equatorial stations was much higher than the values observed before the data gap. Over CP the F layer altitude did not show any significant discontinuity in relation to the values observed prior to the data gap, but after 0900 UT, hmF2 decreased to values well below the quiet days mean, while h′F2 did not vary significantly, indicating a compression of the F layer as will be described latter.

[9] Significant positive deviations (in relation to the quiet values) in hmF2 over the three stations and in h′F over SL were also observed in the afternoon and early evening hours, but in this work we will focus only on the event that occurred following the storm onset.

3.2. EIA Intensification in the Early Morning Hours

[10] As we can see from Figure 2, the most striking disturbance in foF2 was the strong enhancement over CP that occurred in the early morning hours. Between 0800 and 0900 UT, the foF2 was slowly increasing, following the quiet time mean variation (shown as the continuous thin line). From 0900 UT to 0945 UT foF2 increased by a factor larger than 3 (from 5.4 to 16.9 MHz), which corresponds to an increase in the F layer peak density of almost one order of magnitude (from 3.6 × 1010 to 3.5 × 1012 el cm−3). This rapid and remarkable increase was followed by a pronounced decrease that brought the critical frequency to values below its quiet time mean in approximately 1 hour. A similar but less intense behavior was observed over FZ, where the maximum in the foF2 occurred approximately one hour earlier than over CP.

[11] Figure 3 shows the vertical profiles of the electron densities over CP and during the remarkable increase in F layer peak density observed around 0945 UT (Figure 3, right). It should be mentioned that the topside densities of each profile are deduced from the knowledge of the bottomside distribution scale height according to the method of Reinisch and Huang [2001]. Equivalent profiles are shown for a quiet day ($\sum Kp = 3$) at the same month (Figure 3, left) for comparison purposes. A sequence of four profiles from 0845 to 1145 UT (0545 to 0845 LT), separated by one hour, is shown for each day. As we can see from Figure 3, on the quiet day the ionosphere shows the regular behavior expected around sunrise: The peak density is regularly increasing as the solar zenith angle decreases, owing to the increasing photoionization rate that mark these local times. The peak height variation is also smooth and regular. In contrast to this, the behavior on 29 October differs significantly. At 0845 UT (0545 LT) the peak electron density is similar on both disturbed and quiet days, although the peak heights and profile shapes are distinct. From 0845 to 0945 UT the peak density increased by a factor greater than 10 and the peak height decreased. The vertical profile was much narrower indicating a compression of the ionosphere. This drastic variation of the ionosphere was followed by a rapid decrease in electron density and a smooth decrease in height. At 1145 UT the disturbed layer peak height was about 70 km lower than the quiet day value for the same UT (the disturbed hmF2 was 243 km and the quiet day value was 316 km).

[12] Figure 4 shows the total electron content (TEC) derived from 21 GPS stations (15 - RBMC and 6 - IGS/South America) for 29 October 2003, between 0700 and 1100 UT (Figure 4, right) and for a reference quiet day in the same month (Figure 4, left). The color scale in the right
Figure 2. $F$ layer critical frequency ($f_0F_2$), peak height ($h_mF_2$), and virtual height of the $F$ layer base ($h'F$) for São Luís (SL), Fortaleza (FZ), and Cachoeira Paulista (CP) for 29 October 2003, and for the quiet days mean, for the same month. The top panels show the parameters ASY D, ASY H, SYM D, SYM H, and Bz, for comparison. The time (UT) is marked in the top panel, and the local time (LT) at the longitude sector under study is marked in the bottom panel.
gives the TEC in units of $10^{16}$ el m$^{-2}$. As we can see from Figure 4, on the disturbed day the TEC values were low between 0700 and 0800 UT (in fact the daily minimum TEC values occur around that time interval, which corresponds to 0400–0500 LT). In the following panel, TEC started to increase as expected from photoionization processes, but 1 hour later (0900–1000 UT panel) a strong intensification of the EIA was observed, which is coincident in time with the remarkable increase in NmF2 observed over CP. One hour later we can observe a retraction of the anomaly, again in agreement with the digisonde measurements over CP (Figures 2 and 3), in contrast to its continuous expansion and intensification observed in the reference quiet day.

4. Discussion

[13] Under regular ionospheric conditions the behavior of the ionospheric parameters (TEC and foF2) after sunrise, at the regions under consideration in this work, is a regular increase at all latitudes, due to the increase of the solar radiation. The EIA anomaly development will be smooth and regular and will start only after the F region plasma vertical drift becomes positive, around 0700 LT [see, e.g., Fejer et al., 1995]. In order to explain the anomalous behavior observed on 29 October (Figure 4), which shows an intensification of the equatorial anomaly between 0600 and 0700 UT (0900–1000 UT) a totally different vertical drift pattern and/or thermospheric wind configuration is needed. In Figure 5 we show a superposition of the ionospheric parameters at the three stations, for the time period from 0500 UT to 1200 UT, as well as the variations of ASY D, ASY H, SIM D, SIM H and Bz at the same time period. Local time at the longitude of CP (45°W) is marked in the bottom axis of Figure 5. Besides the already mentioned parameters foF2, hmF2 and h’F, we also show here dh’F/dt, derived from h’F over SL. For the purpose of this calculation, the missing points in the data set were interpolated following the tendency observed in h’F over FZ, at the same time interval. In the eighth panel we show the GPS derived TEC over Sáo José dos Campos (SJC) (23°S, 46°W), a location nearby CP. The magnetic storm started at 0611 UT. Almost at the same time (within the measurement resolution) the ionospheric F layer height started to decrease at SL and FZ, at a higher rate than during the quiet days mean. The F layer peak density (represented by foF2 in Figures 2 and 5) also decreased rapidly at the same stations, but with a delay of around 45 minutes. It seems that a westward disturbance electric field that penetrated from the magnetosphere to the equatorial region could be responsible for the observed disturbed downward $E \times B$ drift (negative values of dh’F/dt). This point will be investigated later through model simulation.

[14] Between 0700 and 0715 UT the F layer height at CP started to increase. Between 0730 (0430) and 0745 UT (0445 LT) the F layer was not visible in the ionograms of SL and CP (0720 and 0730 for FZ). It seems that the F layer critical frequency decreased below the minimum frequency threshold of 2 MHz, but some uncertainty persists because of the presence of strong sporadic E layers at the three stations. When the F layer traces became visible again in the SL and FZ ionograms, they were at altitudes much higher than the previous registered data. For the equatorial stations SL, the F layer peak jumped from 267 km at 0715 UT to 495 km at 0800 UT, a difference of almost 230 km in less than one hour. When we analyze the behavior of the F layer peak at FZ, we observe that the highest value of F layer peak was attained at 0750 UT, so it is highly probable that over SL a higher value was also attained around the same time, but this cannot be confirmed because of the time resolution of 15 min for the sounding at that station. According to FZ data, between 0740 and 0750 UT the layer height was increasing till the descent started, just after that.

Figure 3. Electron density profiles over Cachoeira Paulista for a quiet day (11 October 2003) and for the disturbed day (29 October 2003). The number identifying each curve represents the time (UT) at which the profile was measured.
A little more than one hour later, the unusual increase in $F$ layer peak density started at CP. As we can see in the seventh and eighth panels of Figure 5, both the peak density (represented by $f_0F_2$) and the TEC increased simultaneously, confirming the intensification of the EIA at the latitudes of CP/SJC.

4.1. Perturbations in $F$ Layer Heights and SUPIM Simulations

[15] We believe that the fast height decrease observed at the equatorial stations SL and FZ just after the start of the magnetic storm was produced by a disturbed westward electric field that penetrated from the magnetosphere to the ionosphere.
the low-latitude ionosphere, associated to a sudden increase in the polar cap potential. The negative Bz values between 0600 and 0700 UT give support to this assumption. Such prompt penetration electric fields are westward (downward drift) at night and eastward (upward drift) during the day, occurring in phase with the quiet time pattern, with larger amplitudes in the postmidnight period [see, e.g., Sastri et al., 2003, and references therein]. In order to investigate this hypothesis, we have used the Sheffield University Plasmasphere Ionosphere Model (SUPIM) [Bailey et al., 1993; Bailey and Balan, 1996] that solves the coupled time-dependent equations of the continuity, momentum, and energy balance (see also Souza et al. [2000a, 2000b] for applications of the model to low latitudes over Brazil). For the present work the input model used for the neutral wind was the Horizontal Wind Model 1990 (HWM90) [Hedin et al., 1991], and the quiet $E \times B$ plasma drift was taken from the empirical model of Scherliees and Fejer [1999]. A disturbance downward vertical drift (resembling the drift caused by a prompt penetration westward electric field) was introduced in the model as a function similar to a step function (see first panel of Figure 6), with constant drift values from 0700 to 0800 UT (0400 to 0500 LT), a sharp decrease between 0600 and 0700 UT (0300 and 0400 LT) and a sharp increase between 0800 and 0900 UT (0500 and 0600 LT), with respect to the quiet time plasma drift pattern, that was used at the other times. This disturbance electric field model was based on the difference ($\Delta H$) between the horizontal magnetic field components measured at Jicamarca and Piura, Peru, which are located at the magnetic equator and at low latitude outside the magnetic equator, respectively. The disturbed vertical drift model is also in accordance with the ROCSAT measurements at 70°W, scaled to 300 km, presented by Lin et al. [2005]. In fact the drift amplitudes and temporal variation agree very well, but they present a phase displacement of about one hour. The $F$ layer critical frequency and peak height ($foF2$ and $hmF2$) that resulted from the model calculations are shown in Figure 6, in comparison with the observed values at the three locations SL, FZ and CP. The quiet time results from SUPIM are also shown (dashed line), for comparison. As we can see, the rapid $F$ layer height decrease and the subsequent sharp increase at SL and FZ (Figure 6, right) are well reproduced by the model. The rapid decrease in density (represented by $foF2$ in Figure 6, left) that occurred following this sharp height descent is also well simulated by SUPIM. The recombination processes that are more effective at the lower heights must be responsible for the low $foF2$ values. Around 0500 LT (0800 UT) the ionization starts to increase again, because of the photoionization process that starts to take over at the $F$ region heights. Over CP the model also reproduces well the layer height increase around 0700 UT (0400 LT), but did not simulate the decrease that started at ~0915 UT, before the maximum of the $F$ layer compression. In summary, the results of the simulation show that the proposed westward electric field can explain reasonably the main features in height and density that occurred at the stations closer to the magnetic equator, that are more sensitive to electric field effects, but is not enough to explain the main anomalous features observed at CP, such as the EIA enhancement and the compression of the layer. A discussion about this topic follows.

4.2. Interpretation for the EIA Intensification in the Morning Hours

[16] Following the period of intensified westward electric field, a remarkable increase in $foF2$ over CP occurred simultaneously with the compression of the layer (layer thickness decrease), as noted from the $F$ region profile shape at 0945 UT on 29 October 2003 (Figure 3). This remarkable increase in $foF2$ is part of the intensification of the EIA also seen in TEC in the Brazilian region around 0900–1000 UT (Figure 4). The SUPIM simulation that used a disturbed westward electric field (shown in Figure 6) as one of the input parameters does not reproduce this behavior. Another peculiar feature during the disturbed period refers to the relative behavior of the $F$ layer height at the three stations, just before the density increase over CP. Between 0830 and 0930 UT (0530 and 0630 LT) the $F$ layer peak height is higher over CP than over SL and FZ (see Figure 5). This behavior could be explained by the presence of an enhanced meridional wind blowing equatorward during this local time period. The effect of such a wind in the layer height will be more significant over CP (larger dip angle) than over FZ and SL (closer to the magnetic equator).
However, from ~0915 UT the hmF2 over CP started decreasing and by 1000 UT (0700 LT) the relative tendency is inverted; that is, the hmF2 became lower over CP and higher over the equatorial stations (Figure 5), providing thereby an evidence of an inversion in the wind pattern starting at 0915 UT.

[17] The large upward vertical drift, represented by dh'F/dt (Figure 5, sixth panel), seems to indicate the presence of a disturbance eastward electric field (that followed the initial westward electric field marking the storm onset), which could be the responsible for the development/initiation of the EIA. The polarity reversal of the electric field from west to east coincides with a sudden inversion of the IMF to northward (Figure 5, third panel), indicating an association with the overshielding mechanism [e.g., Richmond et al., 2003]. The eastward electric field showed increase till around 0445 LT after which the sunrise effect seems to have contributed in its rapid decrease, thereby introducing some uncertainty on the precise time of the peak upward drift velocity. The drift variation seems to suggest a time delay of ~2 hours between the large vertical drift over São Luís and that of the foF2 over CP which is consistent with the EIA response time to an imposed perturbation electric field as observed from previous studies [Abdu et al., 1990]. However, the abnormally large foF2 (17 MHz) over CP is unlikely to be explained by this anomalous fountain effect alone. The cause of such large foF2 can be attributed to the dynamic changes in the meridional/transequatorial winds suggested by the hmF2 variations over CP as commented above. The inversion of the wind pattern near 0915 UT suggests the onset of a strong poleward wind over CP that steadily brought down the F layer peak height, at the same time causing a compression of the layer (decrease of the layer thickness) which seems to have contributed to the large increase of the foF2 over this station. The steady decrease of the hmF2 (under the action of the intense poleward wind) soon began to cause recombination decay of the plasma seen as a rapid decrease in the foF2 starting at ~1000 UT that continued till about 1230 UT by which time the disturbance wind seems to have turned equatorward (see Figure 2, middle, sixth panel). Thus we need to recognize the combined roles of a disturbance eastward electric field and a rather strong disturbance transequatorial wind with changing directions as the driving forces that can qualita-

Figure 6. SUPIM simulation of F layer critical frequency (foF2) and peak height (hmF2) compared with the observations over SL, FZ, and CP. The dashed curves represent the quiet day reference values. The solid line and dots represent the SUPIM simulation and observational data, respectively.
tively explain the anomalous EIA development with unusually large anomaly crest foF2.

The disturbed wind pattern and many of the features observed in foF2/NmF2 and hmF2 at the three stations analyzed in this work are in accordance with the model results of Fesen et al. [1989], who used the National Center for Atmospheric Research Thermospheric General Circulation Model (TGCM) to investigate the response of the equatorial ionosphere to the neutral atmosphere perturbation produced by a magnetic storm. They have found that wavelike perturbations generated by the storm propagate away from the polar regions producing large-scale perturbation in neutral atmosphere. According to that simulation, the waves could reach the equatorial latitudes in about 2 hours and cause significant disturbances in the ionosphere [see also Fuller-Rowell et al., 2002]. The thermosphere/ionosphere response to the perturbation was predicted to be longitude/local time dependent. In the simulation by Fesen et al. [1989] the perturbation was predicted to have a maximum in the longitude sector in which the substorm onset occurred in the postmidnight/predawn local times. According to their model, the meridional wind can show a very disturbed pattern at low latitudes during the first hours following the magnetic storm onset, in such a way that rapid reversals from northward to southward can occur in time intervals shorter that two hours, and strong transequatorial winds can be occasionally generated [see Fesen et al., 1989, Figure 5]. Lin et al. [2005], using SUPIM model with atmospheric parameters generated by the Thermosphere Ionosphere General Circulation Model (TIEGCM) for the October 2003 superstorm, showed that the storm-generated equatorward neutral winds play an important role in producing TEC enhancements at low latitudes and midlatitudes.

Similar early morning EIA enhancements during disturbed periods were reported in previous works by Abdu et al. [1990] and Sastri et al. [2000]. Abdu et al. [1990] attributed the EIA enhancement to the intensification of the fountain effect that occurred in association with intensified eastward electric fields. Sastri et al. [2000] reported an anomalous and striking occurrence of the EIA in the Indian low latitudes that developed under counter electrojet conditions. In that case the abnormal EIA development is attributed to the possible presence of a poleward surge in transequatorial winds and to the associated large-scale atmospheric gravity waves. In the present work we have shown that a westward electric field that penetrated from the magnetosphere could be responsible for the anomalous behavior of the F region heights over Brazilian equatorial regions just after the onset of the magnetic storm. Such response features were soon followed by disturbance eastward electric field with associated plasma fountain that seems to have produced an apparently asymmetric EIA under the action of possibly strong transequatorial winds that seems to have caused also very large foF2 increase over the southern anomaly crest location CP.

5. Conclusions

The severe geomagnetic storm that started at 0611 UT on 29 October produced remarkable effects in the ionosphere over Brazilian longitudes, starting with the storm onset time. Following the disturbance onset, a wave-like variation in foF2 and hmF2 was observed at the three Brazilian stations (but more evident over CP and FZ than over SL).

Just after the storm onset, unusual variations in ionospheric densities and heights were observed at the Brazilian low-latitude stations, coinciding with negative IMF Bz. Those anomalous height and density behavior were well explained by the presence of a westward electric field (downward vertical drift) in the simulation using SUPIM. The amplitude of the electric field/vertical drift used as input for the present simulation is in good agreement with the ROCSAT measurements at 70°W [Lin et al., 2005] although they are displaced in phase by one hour.

The most remarkable effect of the storm after the initial westward electric field disturbances, as a subsequent phase, was the unusual increase in low-latitude NmF2 indicating an intensification of the southern EIA crest, at local time when it is not normally developed. The SUPIM was not run to simulate this latter phase of the storm effects, because of the uncertainty in our knowledge of highly varying disturbance electric and wind fields that characterize this storm phase. A peculiar disturbed meridional (transequatorial) wind pattern, that inverts from northward to southward and then to northward again in a short time interval, seems to be the most probable cause of this disturbed F region effect that was initiated by a disturbance eastward electric field. The wind configuration we have invoked is in accordance with the TGCM model predictions of Fesen et al. [1989].

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