Equatorial ionospheric responses to high-intensity long-duration auroral electrojet activity (HILDCAA)

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[1] The knowledge of the coupling processes between the magnetosphere and the equatorial ionosphere is of basic importance to the understanding of the near-Earth space weather. This study focuses on observational results of such coupling processes based on data collected during the phenomenon defined as high-intensity long-duration continuous AE activity (HILDCAA) which occurs outside the main phase of geomagnetic storms. The fact that the responses of the equatorial/low-latitude ionosphere to HILDCAA events have not been specifically focused so far is one of the motivations for this study. Ionosonde data on hmF2, h'F, and foF2 from three locations in Brazil (magnetic equatorial station São Luis (SL), subequatorial station Fortaleza (FZ), and low-latitude station Cachoeira Paulista (CP)) are analyzed together with ACE satellite data on solar wind and interplanetary magnetic and electric fields during three HILDCAA events that occurred in the years 2000 and 2001. The results did not indicate any presence of penetrating electric field disturbance during these events. However, they provided clear evidence of disturbance dynamo electric field and disturbance thermospheric winds, through F layer height changes that were similar but generally less intense than those observed during a typical storm event. The foF2 presented no particular disturbances that can be clearly attributed to the HILDCAA event. Previous extensive studies carried out by the authors on ionospheric storm effects for these same three stations clearly illustrate the much more intense F layer storm disturbances compared with HILDCAA events disturbances.

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1. Introduction

[2] The effects of the high-intensity long-duration continuous AE activity (henceforth referred to simply as HILDCAA) events on the equatorial ionosphere are poorly known. The purpose of this work is to investigate the existence of such effects in the Brazilian longitude sector (38-45W). The low-latitude ionospheric responses to magnetosphere-ionosphere coupling processes during storms have been extensively investigated in the Brazilian longitude sector (see, for example, Batista et al. [1991], Abdu [1997], Abdu et al. [1995, 1996, 1997, 1998], Sobral et al. [1997, 2001], and other earlier papers). The present study is an extension of these previous investigations in an attempt to understand the nature of the disturbance electric fields and thermospheric winds possibly triggered by the HILD-CAA events. The main storm effects on the equatorial ionosphere were found to be caused by prompt penetration

electric fields from the auroral region [Kelley et al., 1979; Spiro et al., 1988; Fejer and Scherliess, 1997] and disturbed dynamo electric fields and neutral winds (Blanc and Richmond [1980], Fejer and Scherliess [1995], Abdu [1997], Prölss [1995, 1997], Richmond et al. [2003], Richmond and Lu [2000], and many other papers). A large number of recent studies on magnetic storms have been carried out by means of satellite-borne detectors [Forbes et al., 1995; Scherliess and Fejer, 1998; Tsurutani et al., 2004; Zhang et al., 2004; Lin and Yeh, 2005; Mannucci et al., 2005], incoherent scatter technique [Gonzales et al., 1979; Kelley et al., 2003], OI 630nm airglow photometers and imagers [Sobral et al., 2002; Shiokawa et al., 2002; Abdu et al., 2003], ionosondes, magnetometers, and polarimeters [Abdu, 1997; Abdu et al., 1995, 1996, 1997, 1998; Sastri et al., 1992, 1997, 2000; Valladares et al., 1996; Kobea et al., 2000; Sobral et al., 1997, 2001], GPS receivers [Basu et al., 2001a, 2001b; Tsugawa et al., 2004], theory and modeling [Kelley et al., 1979; Blanc and Richmond, 1980; Tsunomura, 1999; Spiro et al., 1988, 1992; Wolf et al., 1982; Richmond et al., 2003; Peymirat et al., 2000; Fejer and Scherliess, 1997; Anderson et al., 2002]. The geomagnetic storms are primarily characterized by sudden and large intensifications in the auroral electrojet

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activity (AE) resulting in the AE indices variation of 100s to 1000s of nT and negative excursions of the Dst index, of the order of a few tens to a few hundreds of nT. In the absence of a geomagnetic storm, however, the rather intense HILDCAA event may occur transferring a significant amount of solar wind energy into the auroral ionosphere. The HILDCAA event was empirically defined by *Tsurutani and Gonzalez* [1987] as being high-intensity and long-duration AE activity, the duration varying from a couple of days to a few weeks. *Tsurutani and Gonzalez* [1987] claim that the HILDCAA events result from solar wind energy transfer into the magnetosphere between southward components of interplanetary Alfvén waves and the earth magnetic field, through the magnetic reconnection of the type proposed by *Dungey* [1961].

2. Experimental Data

[3] The ionospheric parameters used here are the F-layer electron density peak height hmF2, the virtual height of the F-layer bottomside h'F, and the F2 layer critical frequency foF2. The 15-min interval data of these parameters obtained from the three ionosonde stations São Luis (SL) (44.6W, 2.33S, dip angle 1.5S), Fortaleza (FZ) (38W, 3.8S, dip angle 10.8S), and Cachoeira Paulista (CP) (45W, 22.41S, dip angle 31.7S) are analyzed. These parameters during the HILDCAA days are compared with those of a reference day representing the average of a few quietest days taken during a 30-day interval centered on the HILDCAA period. The use of simultaneous data from the equatorial stations (FZ, SL) and from the low-latitude station (CP) can help identify the ionospheric response to prompt penetration electric field as distinct from the response to disturbance thermospheric winds [see Abdu et al., 1995; Sobral et al., 1997].

[4] The interplanetary data used in this study represent space weather parameters that are intrinsically related to the coupling processes of the magnetosphere and the equatorial ionosphere [see *Abdu et al.*, 1988, 1995; *Sobral et al.*, 1997, 2001]. They are dawn-to-dusk electric field E_Y (positive in the dawn-to-dusk direction), solar wind velocity V_H , particle concentration N_H , and temperature T_H that were obtained by the ACE satellite orbiting around the L1 libration point at a distance of ~1.5 × 10⁶ km from Earth. The auroral activity index AE presented here were obtained from the Kyoto site http://swdcwww.kugi.kyoto-u.ac.jp/wdc/Sec3.html.

3. Results and Discussion

[5] The results of this analysis are presented in Figures 1a and 1b to Figures 3a and 3b. The HILDCAA events presented here occurred on the following days: 2–6 April 2000, 27–31 March 2001, and 12–16 April 2001. We should point out that although most of the data correspond to HILDCAA period, indicated as such in the figures, there are days of extended auroral activity closer to the HILD-CAA period also included in these figures. The HILDCAA periods discussed here refer to periods of sustained AE index intensity that more closely approach the empirical definition of a HILDCAA event proposed by *Tsurutani and Gonzalez* [1987], who assumed that during the HILDCAA event the AE index should not range below 200 nT for more than 2 hours, should present peaks over 1000 nT and should

occur outside the main phases of magnetic storms. The HILDCAA events studied here do not strictly follow this definition since it did not reach 1000 nT, although it came close to it. These threshold values were arbitrarily established by *Tsurutani and Gonzalez* [1987] so that the present authors believe that the data considered here are suitable for the proposed investigation. The departures of the iono-spheric parameters from the reference day values, especially those exceeding the quiet days variance bars, are interpreted as being related to the HILDCAA events. Two episodes of magnetic storms, next to the HILDCAA events are also included and briefly discussed here.

[6] The variations in h'F provide a satisfactory estimation of the vertical velocity of the F-layer, provided that h'F is larger than \sim 300 km, as shown by Bittencourt and Abdu [1981]. Below 300 km, the plasma recombination causes an apparent vertical velocity whose effect increases with the layer descent due to increase of the recombination. We have used both the hmF2 and h'F to infer the vertical drift of the F layer and foF2 to infer possible composition effect on electron density changes during the HILDCAA events. We may note further that changes in hmF2 may arise not only from vertical electrodynamic drift of the plasma but also from other processes such as changes of shape of the electron density profiles arising from enhanced photoionization indicated by increases in the solar flux F10.7. However, the nighttime vertical drifts discussed here should always be considered as arising from vertical plasma drift [see Abdu, 1997, and references therein]. The systematic ionospheric responses observed here during the three HILD-CAA events can be classified as follows: (1) postsunset inhibitions of the ionospheric F-layer rises at the equatorial stations SL and FZ. (2) Inhibition of the range spread-F formation (3) hmF2 rises in the postmidnight period at SL, FZ, and CP. The results are presented in the following sequence: interplanetary/magnetospheric conditions, ionospheric responses, and summary of the observations.

3.1. Expected Effects From Disturbance Electric Fields and Winds During HILDCAAs

[7] As yet there is no model prediction specifically for the HILDCAA effects on the equatorial ionosphere. During magnetospheric and auroral substorm disturbances the highlatitude dawn-dusk electric fields promptly penetrate to equatorial latitudes due to the undershielding conditions presented by the region 2 current system. This PP electric field has a polarity local time dependence similar to that of the quiet time ionospheric dynamo electric field, as seen in the model simulation by Richmond et al. [2003]. At the end of a substorm the overshielding electric field presents an opposite polarity. In a follow-up phase the ion convection under the large high latitude electric field produces acceleration of the neutrals leading to setting up of winds propagating equatorward, which is followed by disturbance winds arising from Joule heating process. These disturbance winds produce dynamo electric field (disturbance dynamo (DD) electric field) that occurs at equatorial latitudes with a time delay of a few hours with respect to the initial high latitude energy input and therefore the onset of the PP electric field. The DD electric field has polarity local time dependence that is largely opposite to that of the PP electric field [Richmond et al., 2003]. The effects of these electric fields can be distinguished in the equatorial/



Figure 1a. The interplanetary ACE satellite data electric field E_Y (considered here to be positive in the dawn-to-dusk direction), velocity V_H , temperature T_H , density N_H , the NS component of the interplanetary magnetic field Bz, the Dst index, and auroral electrojet index AE. The HILDCAA period is indicated by a horizontal line.



Figure 1b

low-altitude response features during isolated and short duration storm events. A HILDCAA event represents an extended active period as compared to that of a typical storm, and as a result, the associated ionospheric responses corresponds to effects arising from concurrent electric fields (PP and DD electric fields) of nearly opposite polarities, the net results being ionospheric effects of significantly reduced intensity as is seen in the results of a recent analysis of ionospheric responses to extended AE activity presented by Abdu et al. [2006], which is in agreement also with the simulation results of Richmond et al. [2003]. On the other hand the disturbance winds arising from the auroral heating processes should be always present over the equatorial latitude during the general duration of a HILDCAA event. The intensity of such winds is expected to be similar to that occurring during magnetic storm subject to the hemispheric symmetry/asymmetry conditions of the auroral energy input.

[8] There are a number of model predictions for equatorial ionosphere-thermosphere disturbances during magnetic storms [*Spiro et al.*, 1988; *Fuller-Rowell et al.*, 1996; *Richmond et al.*, 1992, 2003; *Peymirat et al.*, 2000; *Fejer and Scherliess*, 1997, *Scherliess and Fejer*, 1997, 1999]. Observational results on the effects of disturbed thermospheric zonal and meridional winds and of PP and DD electric fields over the low-latitude and equatorial ionosphere over Brazil based on the ionospheric parameters hmF2, h'F, fo F2 are available in the literature [see, e.g., *Abdu*, 1997; *Abdu et al.*, 1995, 1996, 1997, 1998, 2003; *Sobral et al.*, 1997, 2001].

3.2. Event of 2–6 April 2000

3.2.1. Interplanetary/Magnetospheric Weather

[9] The interplanetary parameters and AE index for the period of 2-6 April 2000 are presented in Figure 1a. The HILDCAA period as per the definition by Tsurutani and Gonzalez [1987] is 2 April, 0000 LT to 5 April, 0300 LT, which is indicated in the figure. A storm onset may be noted on the last day 6 April at \sim 1800 UT followed by a Dst decrease of ~ 280 nT. The solar wind velocity, V_H, density, $N_{\rm H}$, and temperature, $T_{\rm H}$, behaved smoothly throughout the HILDCAA days up to the storm onset on 6 April, except for a small decrease in Dst of magnitude ~ -50 nT seen on 3 April, 2100 LT caused by a northward turning of Bz. The eastward interplanetary electric field, Ey, also showed a drop to negative intensity (dusk-to-dawn direction) at this time. The Dst decrease of 50 nT is not expected to produce any detectable disturbance effects in the equatorial ionosphere based on our previous studies [see, e.g., Sobral et al., 1997]. The solar wind speed varied between \sim 350 km/s and 480 km/s. While the Dst index presented mostly a steady amplitude of ~ -50 nT during all days the Bz presented high frequency oscillations that are possible signatures of Alfvén waves [Tsurutani and Gonzalez, 1987]. The average

F10.7 values representative of the reference day curve was 215.2 and that of the HILDCAA days was 202.

3.2.2. Ionospheric Effects

[10] São Luis: The ionospheric parameters hmF2, h'F and foF2 for SL and CP for 2-6 April 2000, are shown in the upper part of Figure 1b. No ionosonde data is available for Fortaleza for these days. The horizontal dashed rectangles shown below the hmF2 curves represent the time range of spread-F occurrence. The daily Kp sum (ΣK_P) for the days 2 to 6 April are 23, 17⁺, 27⁻, 15⁺, and 38⁻, respectively. The ionospheric parameters shown by continuous lines represent the reference curve (the average for the three quietest days, that is, 20 March (ΣK_P 24 hours = 10), 21 March $(\Sigma K_P 24 \text{ hours} = 7^+)$, and 27 March $(\Sigma K_P 24 \text{ hours} = 8^-)$ 2000). Variance bars are shown at hourly interval only. Spread-F was observed on 2 and 3 April during the HILD-CAA period. On 4 April, still during the HILDCAA period, however, the evening h'F rise was strongly inhibited while the hmF2 rise closely matched the average hmF2. The combination of the inhibited h'F rise with the uninhibited rise of hmF2 suggests the establishment of smaller electron density height gradients that, together with the reduced h'F seems to be responsible for the total suppression of spread-F formation. This is the only day that did not present spread-F over SL during the period considered in this figure. Notice that the AE index was quite high for approximately 6 hours preceding the h'F inhibition. The h'F increase centered around midnight over CP would suggest that equatorward propagating winds were present in the night of 4 April as a consequence of the HILDCAA event. During the following postmidnight hours simultaneous increase of hmF2 and h'F are present till \sim 0500 LT which corresponds to the typical patterns of disturbance dynamo eastward electric field effects as extensively reported before for the equatorial stations in Brazil [Abdu et al., 1995, 1996; Sobral et al., 2001]. On 5 April, hmF2 closely matched the quiet hmF2, but a short duration (\sim 2 hours) spread-F is still detected. The parameter foF2 was slightly above the average during daytime on 2, 4, 5, and 6 April, which may not represent a conclusive HILDCAA effect.

[11] Cachoeira Paulista: Equatorward disturbance winds of auroral origin during geomagnetic storms have been reported to lift the ionospheric F-layer over CP [*Abdu et al.*, 1995, 1996; *Pincheira et al.*, 2002; *Sastri et al.*, 1997; *Sobral et al.*, 1997, 2001]. In the premidnight period of 4 April, both hmF2 and h'F were lifted up to higher than their quiettime averages, suggesting the role of disturbed equatorward winds. This fact suggests that the sustained high intensity AE activity during the HILDCAA period can generate disturbance equatorward winds similar to those observed during geomagnetic storms. The parameter foF2 presented no particular disturbance that can be clearly attributed to the HILDCAA event.

Figure 1b. The ionospheric parameters hmF2, h'F, and foF2 for the stations as indicated, where h'F is the virtual height of the base of the F-layer, hmF2 is the height of the peak of the F-layer and foF2 is the F-region critical frequency. The daily F10.7cm flux and the AE index are shown on the top and bottom of the figure, respectively. The horizontal dashed rectangles shown below the first hmF2 curve on the top represent time range of spread-F occurrence. The days are indicated on the top of the figure. Notice that although the continuous curves were made out of 15-min data points, their variance bars were placed every hour only in order to preserve legibility of the figure. A horizontal line at 300 km is included in the figure for reference.

[12] Storm of 6 April: The solar wind characteristics in Figure 1a indicated the occurrence of a shock at ~1450 UT that promptly initiated an intense storm with the Dst decreasing to ~-300 nT within ~5 hours. The AE index jumped over 1200 nT just at the interplanetary shock initiation. Ionospheric uplift was registered starting at ~1800–1900 LT at São Luis and CP. The large increase of hmF2 and h'F observed over CP suggested the presence of strong equatorward wind which seems to have taken ~4 hours from the storm onset. The increase of the height over São Luis appears to have been the result of changing AE activity and associated PP electric field which seems to have contributed to the generation of spread F seen over both SL and CP.

[13] Summary of the observations: In the night of 4-5April, the h'F rise was remarkably inhibited during the premidnight period while the hmF2 rise was not inhibited. The lower h'F values and the reduced density gradient were consistent with the observed total suppression of spread-F on that day. The enhanced AE activity during ~ 6 hours preceding the h'F increase over CP on the same night suggests that equatorward disturbed winds occurred during the HILDCAA period. The increases during the postmidnight hours in hmF2 and h'F over SL and CP suggest the presence of DD electric field similar to that observed during storm activity. The spread-F occurrence at São Luis during the first and second days indicate that the auroral activity was not strong enough to generate disturbance dynamo electric field to inhibit the spread-F formation as occurs during intense storms.

3.3. Event of 27–31 March 2001

3.3.1. Interplanetary/Magnetospheric Weather

[14] The interplanetary parameters and AE index for the period of 27-31 March 2001 are shown in Figure 2a. The HILDCAA period considered here is 28 March, 1500 LT to 30 March, \sim 2200 LT, during which the AE index varied from 200 nT to 700 nT, and the solar wind velocity $V_{\rm H}$ continuously decreased from 600 km/s to \sim 400 km/s. E_y, $V_{\rm H}$, $T_{\rm H}$ and the Dst index behaved quietly (except for two minor drops in the Dst intensity of the order of 50 nT on 27 March at 1800 LT and 28 March at \sim 1000 LT) until the storm onset on 31 March, at ~0200 LT. The stormtime Dst index reached a minimum of ~ -400 nT. Bz presented typical high frequency oscillations of Alfvén waves for much of the time [Tsurutani and Gonzalez, 1987; Tsurutani et al., 1990]. The average F10.7 value for the quiet days was 138.0, which is considerably smaller than the average value for HILDCAA period, 262.2.

3.3.2. Ionospheric Effects

[15] São Luis: The ionospheric parameters hmF2, h'F and foF2 for SL are shown in the upper part of Figure 2b. The ΣK_P values for the days 27 to 31 are 28, 35, 28, 21, and 61, respectively. The continuous line superposed with the variance bars represents the quiet day reference curves taken as the average of two quiet days, 15 March (ΣK_P 24 hours = 4⁻) and 16 March (ΣK_P 24 hours = 4⁻) 2001. In general, during this HILDCAA period, hmF2 remained considerably higher than the quiet days average during both daytime and for most of the nighttime both at SL, FZ, and CP. Notice that the hmF2 rises at SL and FZ above the average curve are consistent with each other, that is, they present similar time progress of amplitude variations on all days shown, the rises over SL being often larger in magnitude than those over FZ. During the postsunset F-layer descents on 28, 29, and 30 March the difference between the quiet values and the HILDCAA days values were often larger at FZ and CP than at SL, both for hmF2 and h'F. This effect is very similar of those observed for equatorward wind effects at those same three stations during storms, pushing the ionosphere up with more efficiency at increased latitudes [*Abdu et al.*, 1995, 1996; *Sobral et al.*, 2001], which suggests that the equatorward winds during the HILDCAA days are associated with such discrepancies.

[16] On the other the hand, during the HILDCAA days the F10.7cm fluxes were much higher than those of the quiet days. Therefore the photoionization rates and consequently the plasma densities are expected to be higher as indicated by the larger foF2 on these days. The evening sunset electric field also should be higher for increased solar flux which seems to responsible for the higher hmF2 during the HILDCAA days after sunset. The higher photoionization rates also contribute to the observed higher daytime hmF2 in Figure 2b. So that the elevated F layer heights observed during this HILDCAA is mostly an effect of the higher F10.7cm rather than the coupling processes associated with the HILDCAA event. Spread F did not occur on 27 and 30 March, but it occurred on 28 and 29 March.

[17] Fortaleza: The hmF2, h'F and foF2 responses during the HILDCAA period were similar to those of São Luis described above. Spread F occurred on the days 27 to 30 March and inhibited on 31 March due to a severe inhibition of the height rise during the magnetic storm. As in the case of SL, the elevated hmF2 observed during the HILDCAA days is a direct effect of the higher F10.7cm rather than a HILDCAA effect.

[18] Cachoeira Paulista: Height rises, both in hmF2 and h'F, in relation to the quiet day values were higher over CP as compared to SL and FZ, which seems to be a result of the equatorward disturbance winds due to HILDCAA effect. This is similar to the strong equatorward winds needed to explain the sharp rise of hmF2 and h'F over CP caused by the storm of 31 March at 0300 LT that followed the HILDCAA period. Spread-F at CP was observed only in the night of 29–30 March which indicates that the associated bubble did not rise up enough over equator to be observable as spread F over CP on the other nights.

[19] Storm of 31 March: the initiation of a large Dst decrease that occurred at ~0100 LT on 31 March lags the interplanetary shock (2200 LT) signatures in $V_{H_z} E_{Y_z}$ and T_{H} by about 3 hours. The ionospheric h'F and hmF2 uplifts responses lag the interplanetary shock by 5 hours at CP, ~6.5 hours both at FZ and SL. The storm effects on the hmF2 and h'F parameters are dramatically higher than those due to the HILDCAA events at all three stations.

[20] Summary of the observations: The larger difference in the heights between the HILDCAA days and quiet days during the postsunset descent on 28-30 March seen over FZ and CP as compared to that over SL is consistent with the effect of equatorward winds in lifting the ionosphere up at CP and FZ but not at SL. The generally elevated values of hmF2, h'F and foF2 observed at all three stations appear to be a result of the considerably higher F10.7 flux that happened to be present during this HILDCAA period.





Figure 2a. Same as Figure 1a, except for the dates.



Figure 2b. Same as Figure 1b, except for the dates.



Figure 3a. Same as Figure 1a except for the dates.



Figure 3b. Same as Figure 1b, except for the dates.

3.4. Event of 12–16 April 2001

3.4.1. Interplanetary/Magnetospheric Weather

[21] The interplanetary parameters and the AE index for the period of 12–16 April 2001 are shown in Figure 3a. Shock signatures on E_Y , V_H and T_H occurred on 13 April ~0400 LT and a few hours later Dst suffered a decrease to about 75 nT at ~0700–1300 LT. The solar wind speed decreased from ~600 km/s on 14 April, 2100 LT to 400 km/s on 16 April, 2400 LT. The AE index reached 1600 nT soon after the shock and then progressively decreased until ~200 nT where it remained until the end of 16 April. The average 10.7 cm flux values for the quiet days was 171.9 and for the HILDCAA days it was 136.5. This difference of flux does not seem to have produced any perceivable effect on the ionospheric parameters during the HILDCAA period as we will see below. **3.4.2. Ionospheric Effects**

[22] The results are presented in Figure 3b. The daily ΣK_P values from 12 to 16 April 2001, are 32^+ , 34^- , 26, 21^+ , and 15^+ , respectively. The continuous lines represent average values of the ionospheric parameters for the three quiet days 19 April ($\Sigma K_P = 12^+$), 20 April ($\Sigma K_P = 12^+$), and 27 April ($\Sigma K_P = 9^-$) 2001. Decreases in hmF2 and h'F were observed at SL on 15 April, after the prereversal enhancement. Such a decrease was less pronounced over FZ probably due to the presence of equatorward winds. Equatorward wind was present over CP as well but mainly during the postmidnight period. Large increases in hmF2 observed in the night of 14–15 April are unlikely to be an ionospheric effect. It may be caused by the presence of spread F that must have been for some reason stronger on this night than on other nights.

[23] Summary of the observations: Decreases in hmF2 and h'F were clearly observed at SL on the evening of 15 April, which suggested the presence of a DD electric field. Similar effects with reduced intensity over FZ suggested the presences of equatorward disturbance winds as well. Equatorward winds were present over CP during the postmidnight period of the same day. As in the two previous cases of 2-6 April 2000 and 27-31 March 2001, the parameter foF2 presented no particular disturbances at all three stations that can be clearly attributable to the HILDCAA event.

4. Conclusions

[24] The behavior of the ionospheric parameters h'F, hmF2, and foF2 over three equatorial-low-latitude stations in the 38-45W longitude range in the South American sector is studied here during the occurrence of three events of high intensity long-duration continuous AE activity (HILDCAA). The results of this analysis show significant coupling processes between the auroral zone and the equatorial ionosphere during the HILDCAA events through equatorward propagating disturbance winds in a similar way but less intense than those that occur during typical storms. No F-layer rises simultaneously at all the three stations were observed here indicating no noticeable penetrating electric field disturbances. During the first HILD-CAA period (2-6 April 2001) there was a clear inhibition of the layer rise and consequent suppression of the spread F over São Luis, in the night of 4 April, which suggested the presence of coupling processes associated with the HILD-CAA event. During the second HILDCAA period (2731 March 2001) the descent after the prereversal enhancement over SL, FZ, and CP, occurred with hmF2 and h'F parameters higher during the HILDCAA days than on quiet days, the difference being larger at stations farther away from the equator, which suggested a significant role of equatorward disturbance winds as a HILDCAA effect, which was similar to the results observed previously over these stations during storms. During the third HILDCAA interval (12-16 April 2001), the hmF2 and h'F decreases over SL in the night of 15 April that were remarkably smaller in magnitude over FZ also suggested the presence of equatorward disturbance winds. Over CP indications of such winds were present during the postmidnight hours only. The parameter foF2 presented no particular disturbances during the course of the three events reported here at all the three stations that could be clearly attributed to the HILDCAA event. The ionospheric responses of two cases of intense geomagnetic storms that followed the HILDCAA events of April 2000 and March 2001, which showed significantly more intense F layer height changes, and therefore disturbance electric fields as compared to those resulting from the HILDCAA events. The effects on spread F development processes due to the HILDCAA effects are not clear and systematic from the present analysis. However, in one case, in the night of 4 April 2000, disturbance dynamo electric field in the presence of equatorward disturbance winds stemming from the auroral zone seem to have contributed to the total suppression of spread-F/plasma bubble formation at SL. Further studies with more intense HILDCAA events are being planned to investigate the possibility of electric field penetration in the absence of magnetic storms.

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