Effects observed in the Latin American sector ionospheric *F* region during the intense geomagnetic disturbances in the early part of November 2004

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[1] The Sun was very active in the early part of November 2004. During the period of 8–10 November 2004, intense geomagnetic disturbances with two superstorms were observed. In this paper, we have investigated the generation and suppression of equatorial ionospheric irregularities and the daytime changes in the *F* region electron density in the Latin American sector during the period of intense geomagnetic disturbances. We present the ionospheric sounding observations carried out at Manaus and Sao Jose dos Campos, Brazil, during this geomagnetically disturbed period. Also, GPS observations obtained from several stations in Brazil, Argentina, and St. Croix, U.S. Virgin Islands, during the disturbed period are presented. During the main phase of the first superstorm, around the prereversal enhancement time (night of 7–8 November), prompt penetration of electric field was observed and the presence of equatorial ionospheric irregularities was detected from St. Croix, U.S. Virgin Islands (in the northern hemisphere) to Bahia Blanca, Argentina (in the southern hemisphere). The ionospheric sounding observations at Manaus indicate inhibition of prereversal enhancement on the nights of 9–10 and 10–11 November, possibly due to the disturbed thermospheric winds or disturbance electric fields. Virtually no phase fluctuations on the nights of 9–10 and 10–11 November were observed in the Latin American sector. During the daytime on 8 November, the vertical total electron content (VTEC) observations show a negative storm phase at Porto Alegre (Brazil) and Bahia Blanca (Argentina). Again during the daytime on 10 November, the VTEC observations show a negative storm phase from Brasilia (Brazil) to Bahia Blanca. These negative storm phases are associated with a decrease in the O/N_2 ratio. During the daytime on 9 November, the VTEC observations show a positive storm phase extending from St. Croix to Porto Alegre, and again on 10 November, VTEC observations show a positive storm phase. These positive storm phases observed are possibly due to changes in large-scale wind circulation and an increase in the O/N_2 ratio.

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1. Introduction

[2] Effects observed in the ionospheric *F* region during geomagnetic superstorms are important space weather issues. As discussed by *Trichtchenko et al.* [2007], during the early part of November 2004 the Sun was very active. During the period 1–7 November there were 11 M- and 2 X-class flares, and 9 CMEs (coronal mass ejections) forming two geoeffective interplanetary structures. During the period of 8–10 November, two superstorms (considering $|Dst|_{max} > 250$ nT for a superstorm) having $|Dst|_{max} = 373$ nT on 8 November at 0700 UT and $|Dst|_{max} = 289$ nT on 10 November between 1000 and 1100 UT were observed. The second superstorm on 10 November was preceded by

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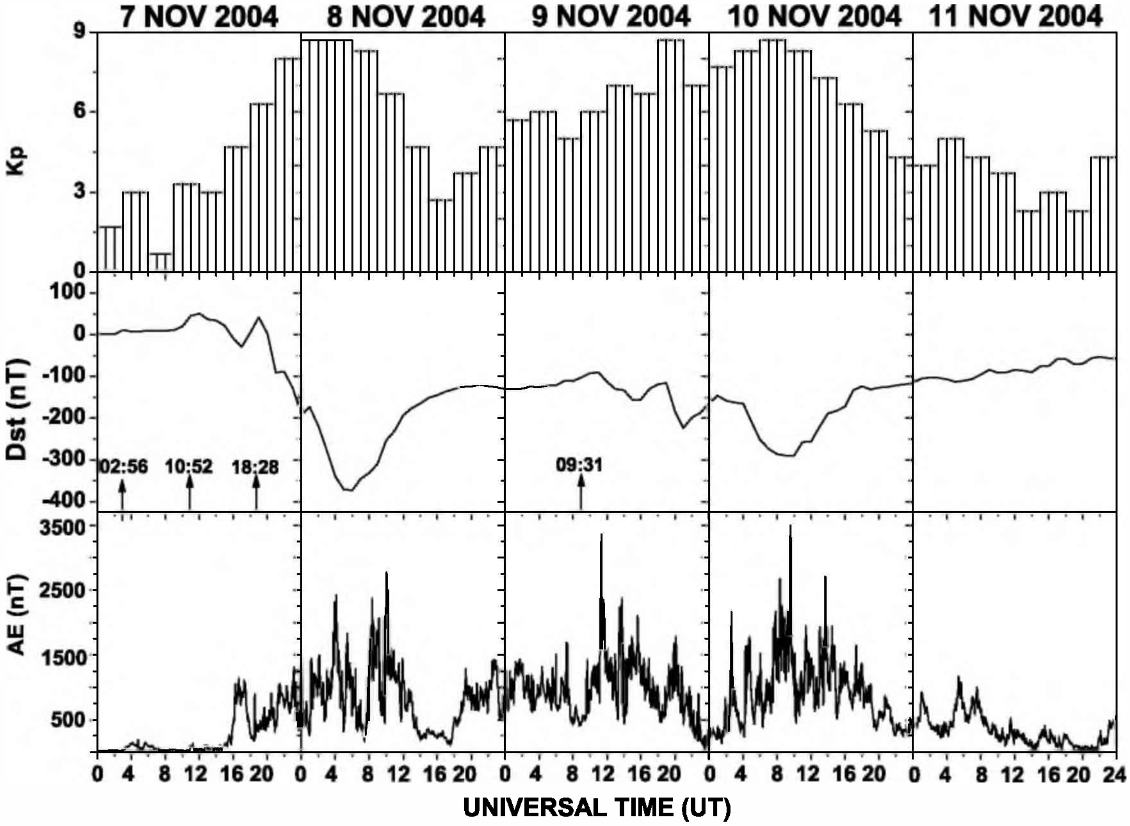

Figure 1. The variations of the *Kp*, *Dst*, and *AE* geomagnetic indices during the period 7–11 November 2004.

two storm enhancements at 1600 UT and at 2200 UT on 9 November.

[3] Figure 1 shows the time variations of the *Kp*, *Dst*, and *AE* geomagnetic indices for the period from 7 November to 11 November 2004. The *Dst* panel (middle) also shows the sudden commencement (SC) times with vertical arrows. These sudden commencements are related to increases in the solar wind density and/or solar wind velocity (not shown). The geomagnetic indices indicate an extended period of geomagnetic disturbances covering the period from 7 to 11 November 2004.

[4] Several investigators [e.g., *Schunk and Sojka*, 1996; *Abdu*, 1997; *Buonsanto*, 1999; *Danilov*, 2001] have recently reviewed the effects of ionospheric storms at high-, middle- and low-latitude regions. *Fuller-Rowell et al.* [1997] have reported model results to illustrate the response of the low-latitude thermosphere during quiet and geomagnetically disturbed conditions. As discussed in detail by *Buonsanto* [1999], ionospheric storms result from large energy inputs to the upper atmosphere associated with geomagnetic storms. This energy input is fairly variable and depends on the strength of the geomagnetic disturbance. As indicated by *Sahai et al.* [2004, 2005], the reason for the continued intense interest in ionospheric storms is related to (1) our poor understanding and (2) our inability to predict thermospheric and ionospheric space weather response. Intense geomagnetic storms are associated with a sudden increase in the solar wind speed accompanied by a large southward interplanetary magnetic field (IMF) impacting the magnetosphere causing sudden storm commencement (SSC). However, many storms start gradually and have gradual storm commencement (GSC). As discussed by *Campbell* [2000] SSC (or sometimes GSC) is followed by the main or growth phase, and finally a recovery phase. As pointed out by *Schunk and Sojka* [1996], during the main or growth phase the magnetospheric electric field and particle precipitation patterns expand. The electric fields become stronger and precipitation becomes more intense. The Joule and particle heating rates and the electrojet currents increase, providing maximum energy input to the upper atmosphere in high-latitude region, while during the recovery phase the geomagnetic activity and energy inputs decrease.

[5] In this paper, a study has been carried out related to the response of the equatorial, low-latitude and midlatitude ionospheric *F* region in the Latin American sector during the intense geomagnetic disturbances in the early period of November 2004. The objectives have been twofold. First, to study the generation or suppression of the equatorial ionospheric irregularities or equatorial spread *F* (ESF) during a period of intense geomagnetic disturbances, using the ionospheric sounding observations in the Brazilian sector and GPS observations in the Latin American sector. It should be pointed out the earlier view that a geomagnetic storm suppresses ESF generation is no longer valid [e.g., *Becker-Guedes et al.*, 2004; *Martinis et al.*, 2005]. Therefore, there is considerable interest in studying the ESF generation or suppression during an intense geomagnetically disturbed period. Second, another topic of considerable interest is to study the changes in the vertical total electron content (VTEC) obtained at several GPS stations in the

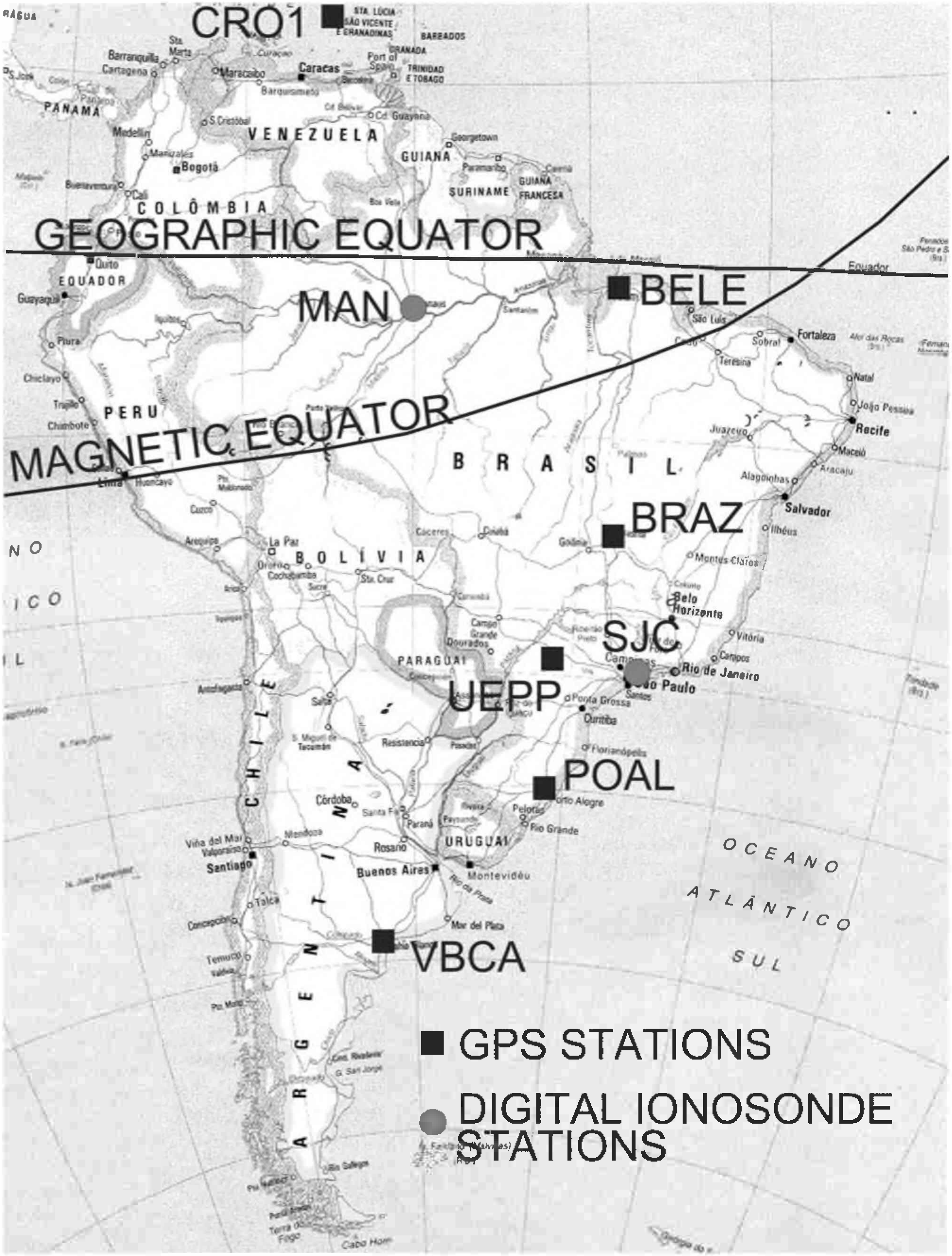

Figure 2. A map showing the locations of the digital ionosonde and GPS stations used in the present study. Also, the geographic and geomagnetic equators are shown.

Table 1. Details of the Global Positioning System and Digital Ionosonde Sites Used in the Present Study

Location	Symbol Used (Network)	Observations[a]	Geog. Lat.	Geog. Long.	Dip Lat.	Local Time (LT)
St. Croix (U.S. Virgin Islands)	CRO1 (IGS)	GPS	17.4°N	64.3°W	25.4°N	LT = UT − 4 h
Manaus, Brazil	MAN (UNIVAP)	DI	02.9°S	60.0°W	06.4°N	LT = UT − 4 h
Belem, Brazil	BELE (RBMC)	GPS	01.5°S	48.5°W	01.2°N	LT = UT − 3 h
Brasilia, Brazil	BRAZ (RBMC)	GPS	15.9°S	47.9°W	11.7°S	LT = UT − 3 h
Presidente Prudente, Brazil	UEPP (RBMC)	GPS	22.1°S	51.4°W	14.9°S	LT = UT − 3 h
Sao Jose dos Campos, Brazil	SJC (UNIVAP)	DI	23.2°S	45.9°W	17.6°S	LT = UT − 3 h
Porto Alegre, Brazil	POAL (RBMC)	GPS	30.1°S	51.1°W	20.7°S	LT = UT − 3 h
Bahia Blanca, Argentina	VBCA (SIRGAS)	GPS	38.7°S	62.3°W	22.4°S	LT = UT − 4 h

[a]GPS, global positioning system; DI, digital ionosonde.

Latin American sector during the period of this intense geomagnetic disturbance in comparison with quiet period.

[6] The ionospheric sounding observations, using digital ionosondes (DI), carried out at Manaus (2.9 S, 60.0 W, hereafter referred as MAN) and Sao Jose dos Campos (23.2 S, 45.9 W, hereafter referred as SJC), Brazil, obtained during the period 6–11 November 2004 (mostly nighttime (between 1800 UT to 1200 UT) as the main interest is related to ESF studies) are presented and discussed in this paper. It should be mentioned that the measurements at MAN and SJC are representative of the equatorial and low-latitude regions, respectively. However, it should be pointed out that MAN and SJC are located in different geomagnetic hemispheres but same geographic hemisphere. Unfortunately, the ionospheric sounding station at Palmas (10.2 S, 48.2 W), Brazil, was not operational during this period owing to some technical problem. In addition, VTEC and phase fluctuations [*Aarons et al.*, 1996] from the Global Positioning System (GPS) observations obtained in Brazil, Argentina, and St. Croix, U.S. Virgin Islands, are presented for the period of 6–11 November 2004. The data from the GPS stations are related to observations from the midlatitude region in the northern hemisphere (St. Croix) to midlatitude region in the southern hemisphere (Bahia Blanca). Figure 2 and Table 1 provide the details of the GPS and DI sites used in the present study.

2. Observations

[7] The two ionospheric sounding stations (MAN and SJC) are equipped with the Canadian Advanced Digital Ionosonde (CADI) [*Grant et al.*, 1995] and have local times differing by one hour (MAN: UT = LT + 4 h; SJC: UT = LT + 3 h). All the GPS stations in Brazil used in the present study belong to the "Rede Brasileira de Monitoramento Continuo (RBMC; Brazilian Network for Continuous GPS Monitoring)" operated by the "Instituto Brasileiro de Geografia e Estatística" (IBGE; Brazilian Institute of Geography and Statistics). The station St. Croix, U.S. Virgin Islands, belongs to the International GPS Service (IGS) for Geodynamics, and station Bahia Blanca, Argentina, is operated in cooperation between the Deutsches Geodaetisches Forschungsinstitut (Germany) and the Universidad Nacional del Sur (Argentina).

[8] Figures 3a and 3b show the variations of the ionospheric parameters, minimum virtual height ($h'F$; black line) and critical frequency (f_oF_2; black line) of the *F* layer, observed at MAN and SJC, respectively, covering the nights (between 1800 UT and 1200 UT) on 6–7, 7–8, 8–9, 9–10, and 10–11 November 2004. The ionospheric parameters $h'F$, f_oF_2 reported here were obtained every 15 min from the ionograms obtained at MAN and SJC. Also, Figures 3a and 3b show the times where the presence of spread *F* is determined (both frequency and/or range type) from each of the respective ionograms. The ionospheric sounding observations presented start a few hours before the sunset and continue until a few hours after the sunrise. The thick red line in Figures 3a and 3b is the average of six geomagnetically quiet days (three before the geomagnetic disturbances and three after). The thin red lines in Figures 3a and 3b are ±1 standard deviation of the average quiet day values.

[9] Figure 4 shows the phase fluctuations (rate of change of TEC, TECU/min) [*Aarons et al.*, 1996] from GPS signals obtained from different satellites at 6 receiving stations. It should be pointed out that the phase fluctuations as obtained from the observations in standard "Receiver Independent Exchange (RINEX)" data measure large-scale irregularity structures of the order of kilometers [*Aarons et al.*, 1997]. As described by *Mendillo et al.* [2000], amplitude scintillation is a scattering phenomena, and it may be confined to a narrow range of altitudes, while the TEC changes (Figure 4) may originate from nearly anywhere along the line of sight from the ground station to the GPS spacecraft.

[10] Figures 5a and 5b show the variations of virtual heights at six fixed reflection frequencies (electron densities), with measurements every 100 s (iso-frequency plots), observed at MAN (top panel) and SJC (bottom panel) on UT days from 6 to 11 November 2004 (6 November is a quiet day). Figures 5a and 5b have been included to show the differences in height fluctuations at different frequencies in the *F* region at MAN and SJC during the geomagnetically disturbed period. Also, Figures 5a and 5b nicely show the presence or absence of ESF on different nights during post-PRE periods at MAN and SJC.

[11] Figure 6 shows the average (every 5 min) VTEC variations from GPS observations (satellites above 30° elevation angle) in UT at 6 receiving stations (Figure 2 and Table 1) during the period from 6 to 11 November 2004, with quiet day (6 November) to recovery phase (11 November). The black vertical dashed lines indicate the times of SSCs. The red lines are observations on the respective day and green lines are observations on the quiet day (6 November) repeated for all the subsequent days to allow a comparative study between quiet and disturbed days.

[12] Figure 7 shows four global maps of thermospheric O/N_2 ratios, determined from the Global Ultraviolet Imager (GUVI) flown on board the TIMED satellite, observed on

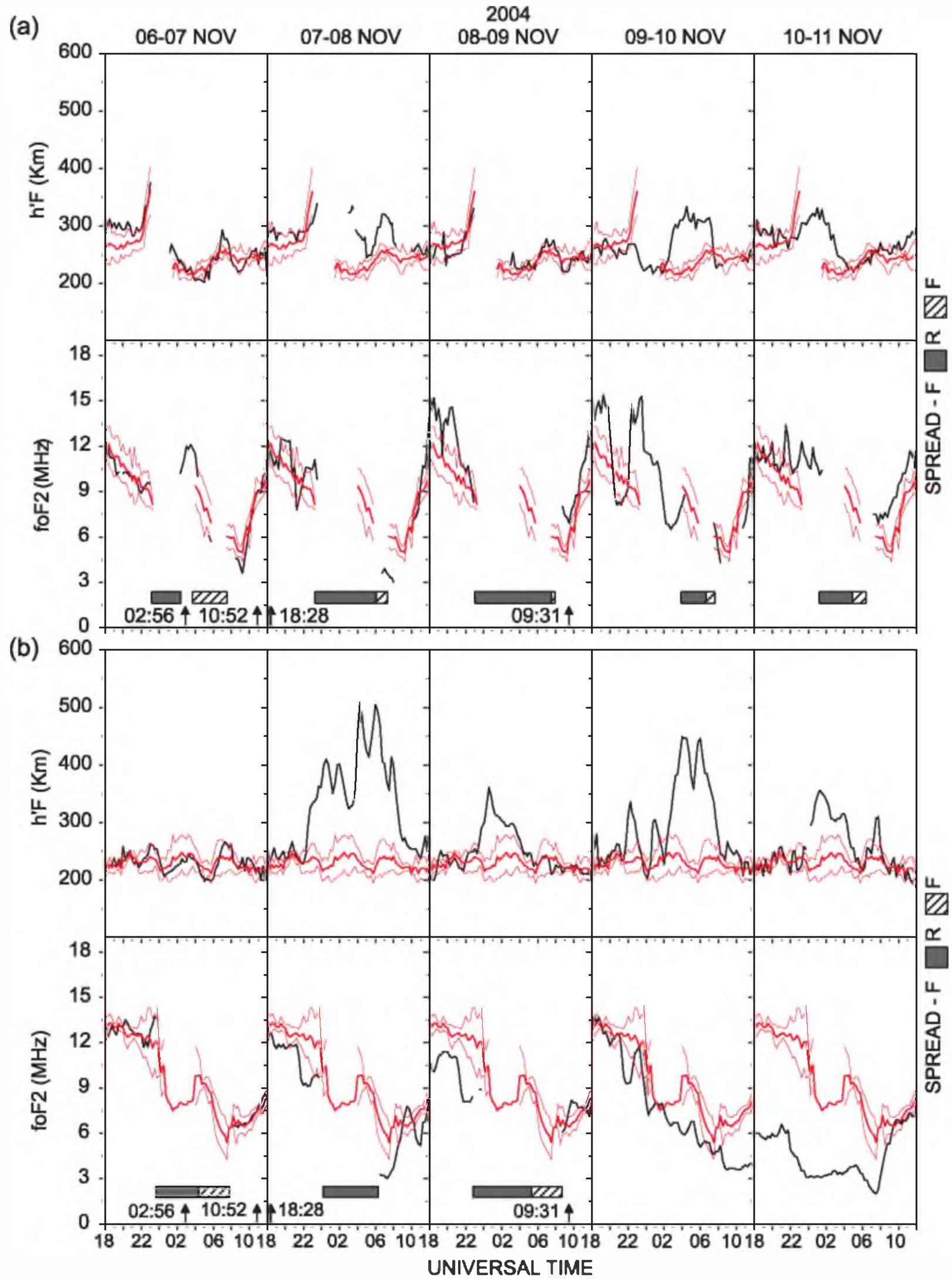

Figure 3. (a) The variations in $h'F$ and f_oF_2 (black line) on the nights of 6–7, 7–8, 8–9, 9–10, and 10–11 November 2004 observed at Manaus (MAN), Brazil. The average quiet day variations in $h'F$ and f_oF_2 are shown as thick red lines. The thin red lines indicate ±1 standard deviation. Horizontal bars indicate spread *F* observed on different nights. The vertical arrows indicate the times of sudden commencements (SCs). (b) Same as in Figure 3a, but for Sao Jose dos Campos (SJC), Brazil.

6 November 2004 (quiet day) and 8, 9, and 10 November 2004 (geomagnetically disturbed days).

3. Results and Discussion

[13] The important aspects of space weather studies are how variable the ionospheric *F* region responses (changes in the *F* layer height and peak height electron density, and generation and suppression of ionospheric irregularities) could be during the geomagnetic disturbances compared with the quiet period, and what are the drivers. It appears there are three major drivers for the ionospheric *F* region response: electric fields, winds, and composition changes. As mentioned by *Sastri et al.* [2002], the solar wind-

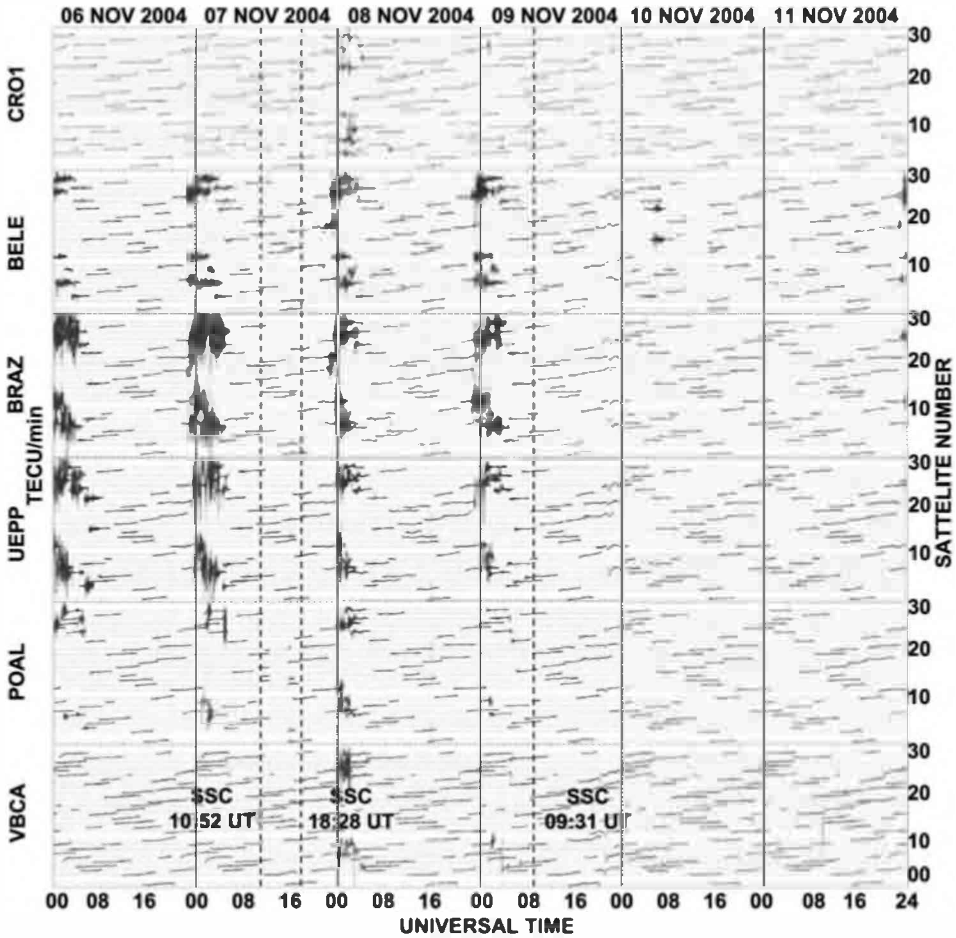

Figure 4. The phase fluctuations (rate of change of TEC (TEC/min)) from GPS signals obtained from different satellites at six receiving stations (Figure 2 and Table 1) during the period 6–11 November 2004.

magnetosphere dynamo [*Senior and Blanc*, 1984; *Spiro et al.*, 1988] and the ionospheric disturbance dynamo [*Blanc and Richmond*, 1980] are considered responsible for the storm time behavior of the equatorial electric fields (plasma drifts). The solar wind-magnetosphere dynamo results in prompt or direct penetration of the magnetospheric convective electric field leading to short-lived (a few hours) disturbances, whereas the ionospheric disturbance dynamo results from global thermospheric wind circulation due to Joule heating at high latitude leading to long-lived (several hours) disturbances. Recently, *Fejer et al.* [2007] have pointed out that low-latitude ionospheric plasma perturbations during geomagnetically active times are due mostly to the combined effects of relatively short-lived prompt penetration and longer-lasting ionospheric disturbance dynamo electric fields. As mentioned by *Schunk and Nagy* [2004], during a storm, the large amount of energy deposited into the ionosphere-thermosphere system at high latitude results in changes in neutral composition, increase in thermospheric wind speeds and excitation of equatorward propagating gravity waves. The gravity waves traveling within the thermosphere interact with the ionosphere to produce large-scale traveling ionospheric disturbances [*Richmond and Roble*, 1979]. Several investigators [e.g., *Greenspan et al.*, 1991; *Zhang et al.*, 2003; *Meier et al.*, 2005] have indicated changes in the thermosphere composition (O/N_2) ratio during geomagnetic storms.

[14] As mentioned by *VanZandt et al.* [1971], during a storm the most direct and easily observed effects of electromagnetic or plasma drift are changes in the height of the *F* region (e.g., $h'F$). In addition, if the electron density increases because of storm dynamics, it is called a ‘positive ionospheric storm’, while a decrease in electron density is called a ‘negative ionospheric storm’ [e.g., *Danilov and Morozova*, 1985; *Schunk and Sojka*, 1996]. Another aspect, which has drawn considerable attention in the recent past, is the onset and suppression of equatorial ionospheric irregularities during geomagnetic disturbances. These are the important diagnostics for storm time effects. As discussed by *Danilov and Morozova* [1985], the negative phase is linked to Joule heating in the region of the auroral oval, which gives rise to a decrease in the ratio O/N_2 and correspondingly a decrease in f_oF_2. However, for the positive phase [see also *Tanaka*, 1979] several mechanisms are proposed. Recently, *Prolss* [1997] has pointed out that long-duration positive storms are due to changes in the

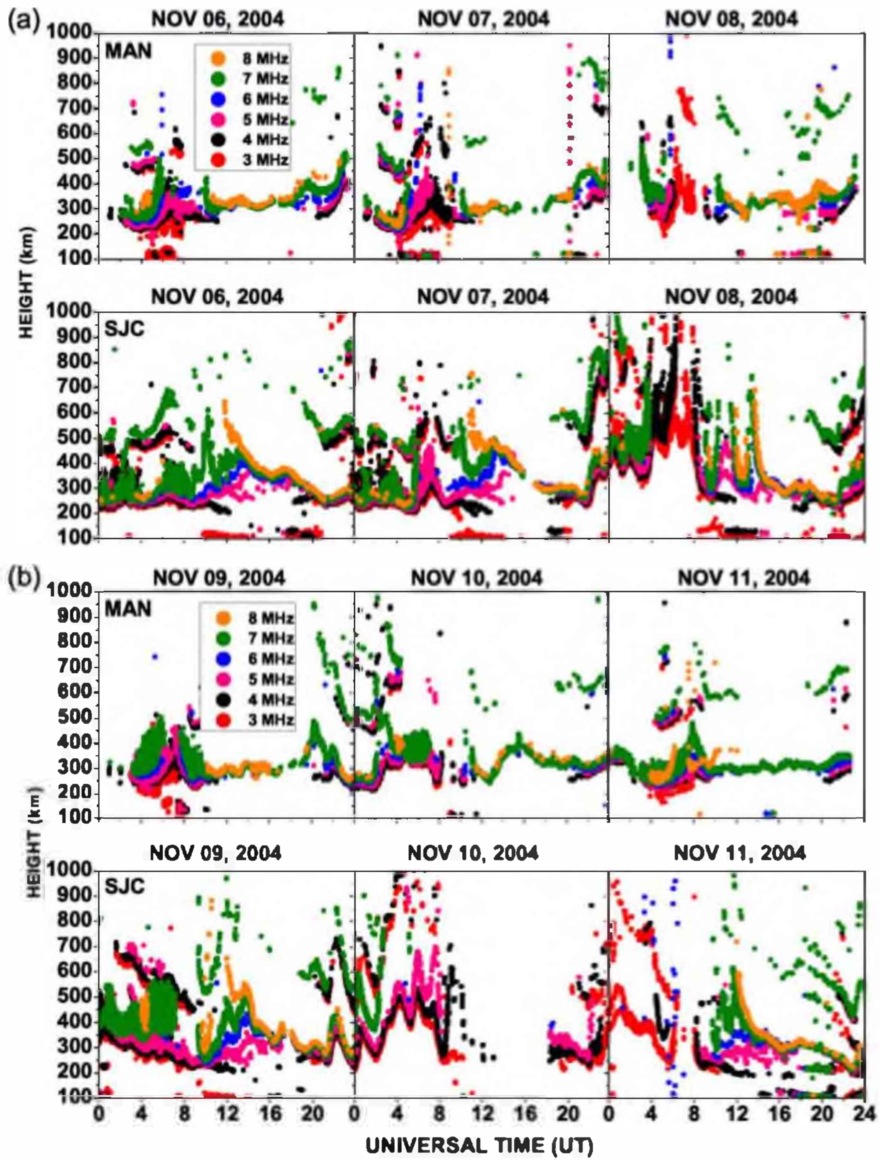

Figure 5. (a) Virtual height variation plots for different fixed frequencies (iso-frequencies) for the period 6 to 8 November 2004 observed at (top) MAN and (bottom) SJC. (b) Same as in Figure 5a, but for the period 9–11 November 2004.

large-scale wind circulation. Another topic presented and discussed in this paper is related to the equatorial spread *F* during this intense geomagnetic disturbance period. It should be mentioned that recently *Kelley et al.* [2006] have described equatorial spread *F* in terms of convective ionospheric storms, which they see as a major space weather problem.

[15] The main features observed in the ionospheric *F* region parameters during the intense geomagnetic disturbances in the early part of November 2004 (starting on 7 November) are presented and discussed in this section. At the outset it should be pointed out that the occurrence rate of equatorial ionospheric plasma bubbles in the Brazilian sector is generally large during the period of October to March [*Sahai et al.*, 2000]. Therefore, the intense geomagnetic disturbances during November 2004 provided us an excellent opportunity to investigate the onset or suppression of equatorial spread *F* during geomagnetic storms. As discussed by *Whalen* [2002], a necessary condition for plasma bubble formation is the presence of bottomside spread *F* (BSSF) near the dip equator (in the present study MAN), and macroscopic bubbles (spread *F*) measured at the equatorial ionospheric anomaly (in the present study SJC).

3.1. ESF During Intense Geomagnetic Disturbance

[16] Figures 3a and 3b show the $h'F$ and f_oF_2 variations, and presence of spread *F* at MAN and SJC, respectively, for the nights of 6–7, 7–8, 8–9, 9–10, and 10–11 November. Figures 5a and 5b show iso-frequency plots observed at MAN and SJC in the same time frame. Figure 3a shows that around prereversal enhancement (PRE) time the variations in $h'F$ at MAN on the nights of 6–7 (quiet), 7–8 (initial storm phase), and 8–9 (recovery phase of the first superstorm) November followed the average quiet day variations.

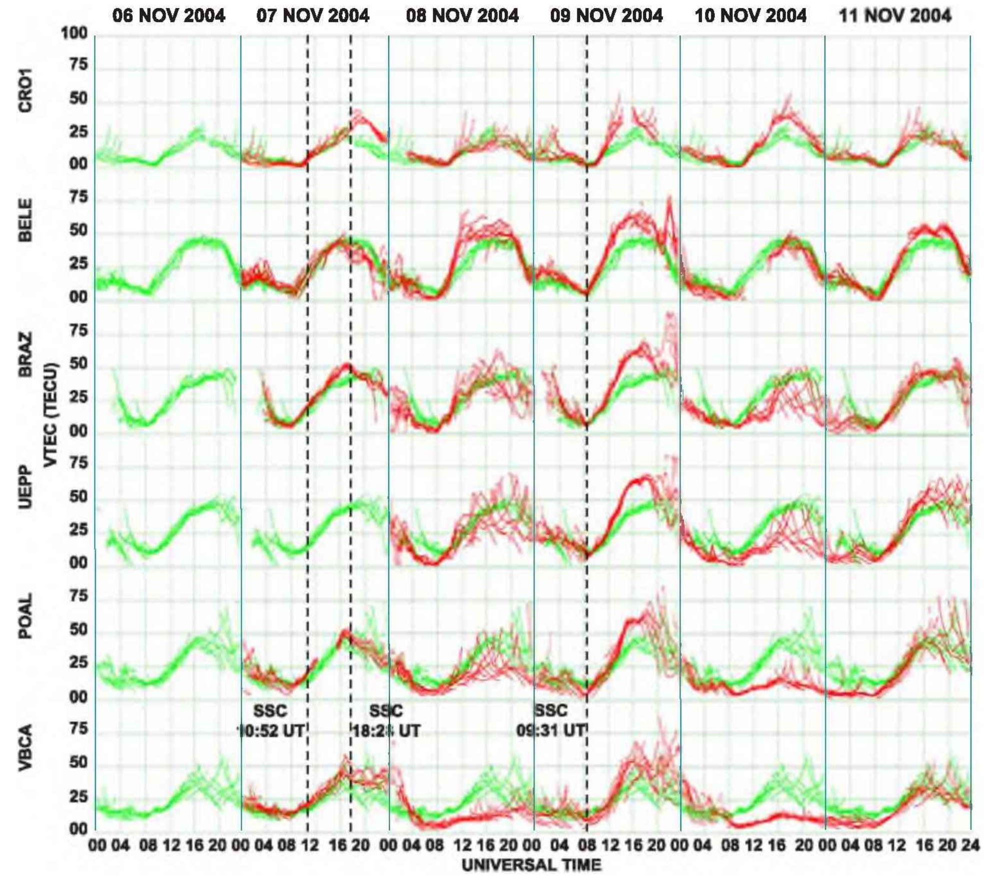

Figure 6. The vertical total electron content (VTEC) variations from GPS observations (satellites above 30° elevation angle) at six receiving stations (Figure 2 and Table 1) during the period 6–11 November 2004. The red lines are observations on the respective day, and green lines are observations on the quiet day (6 November) repeated for all the subsequent days to allow a comparative study between quiet and disturbed days.

However, the prereversal uplifting of the *F* layer on the nights of 9–10 and 10–11 (during intense second part of geomagnetic disturbances and its recovery phase) is inhibited. As discussed by *Abdu* [1997] the inhibitions could be associated with the disturbance winds (always inhibit) or disturbance electric fields (enhanced development or inhibition). Figure 4 of *Fejer et al.* [2007] indicates a negative vertical plasma drift during the PRE time at Jicamarca (11.9 S, 76.8 W), Peru, and a station located on the west (about 15 degrees W from MAN) of the Brazilian sector, on 9–10 November. This disturbance electric field could inhibit the PRE in the Brazilian sector as well. During the prereversal enhancement time on 8–9 November, in the recovery phase of the first superstorm, no suppression has been observed. A perusal of the $h'F$ variations in Figures 3a and 3b, and height changes in different frequencies in Figure 5a (iso-frequency plots of both MAN and SJC) shows rapid uplifting of the *F* layer during the prereversal time (around 2200 UT) on the night of 7–8 (during the main phase of the first superstorm) November. Uplift during the prereversal time is usually normal, and indeed at MAN the $h'F$ parameter looks similar to other nights. It is the higher-latitude station (SJC) that shows the most remarkable effect. This indicates storm time prompt penetration of magnetospheric electric field to low latitudes. It should be mentioned that the penetrating electric field is global and Figure 5a shows simultaneous rapid uplifting of the *F* layer at both MAN and SJC around 2200 UT on 7 November. As pointed out by *Wygant et al.* [1998] and *Basu et al.* [2001, 2005], when rapid changes of the *Dst* occur during the main phase of a storm, penetration electric fields of magnetospheric origin affect the ionospheric dynamics at low latitudes. During the rapid uplifting observed in the present study on 7 November, *Dst* decreased rapidly, by −40 nT/h.

[17] Figure 3a shows an unusual rapid uplifting on the night of 9–10 November around 0200 UT and generation of spread *F* afterward. This uplifting of the *F* layer at MAN is due to the storm time vertical plasma drift (Figure 5b shows simultaneous uplifting at this time at both SJC and MAN) during an increase in the *AE* index in the recovery phase of the magnetic storm (Figure 1) [*Fejer and Emmert*, 2003; *Keskinen et al.*, 2006]. Also, Figure 4 of *Fejer et al.* [2007] indicates a strong positive vertical plasma drift around the same time at Jicamarca, Peru. On the night of 10–11 November, Figure 3a again shows uplifting of the *F* layer with generation of spread *F* afterward, due to the disturbance electric field (both SJC and PAL show uplifting of the *F* layer). On the nights of 9–10 and 10–11 November, no spread *F* is observed at SJC, indicating that on these nights spread *F* was generated only near the dip equator.

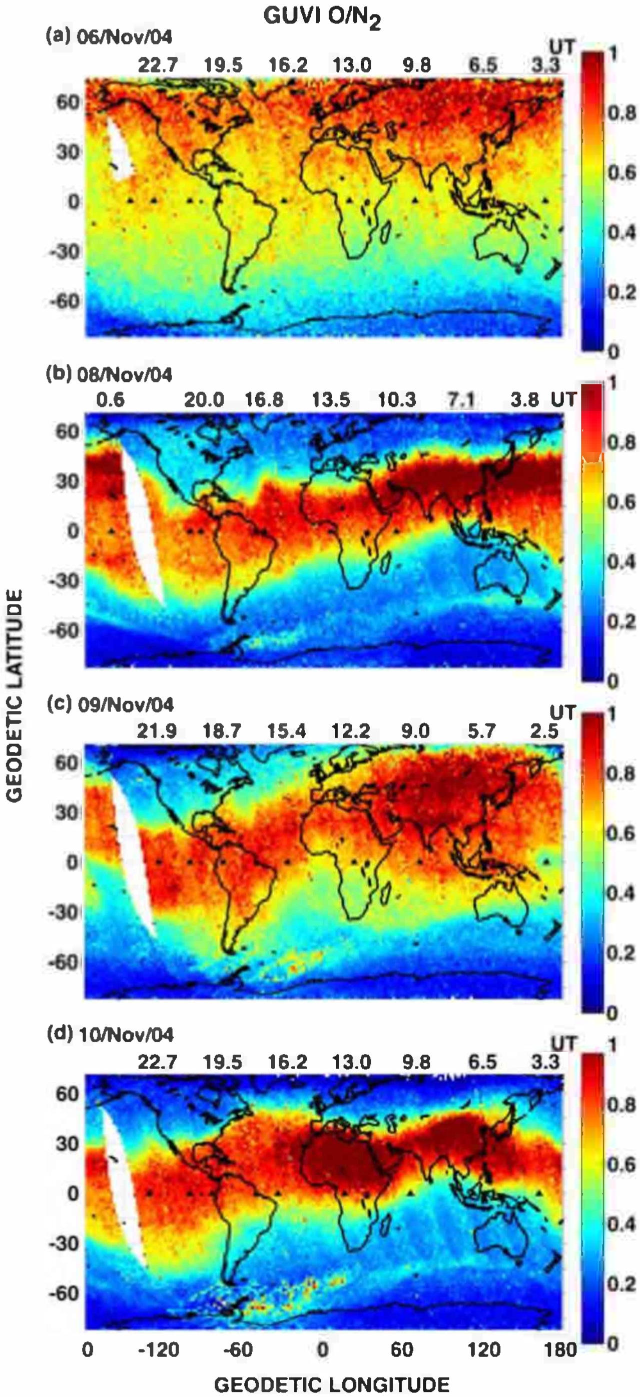

Figure 7. "Global maps" of the ratio O/N_2 obtained from the GUVI experiment flown on the TIMED satellite for the days (a) 311 (6 November), (b) 313 (8 November), (c) 314 (9 November), and (d) 315 (10 November), 2004.

[18] Figure 4 shows the phase fluctuations (kilometer-scale irregularities) [*Aarons et al.*, 1997] observed at different GPS stations during the period 6 November to 11 November. It is observed that on the nights of 5–6, 6–7, and 8–9 November, the phase fluctuations are limited between BELE to POAL (normal spread *F* with plasma bubbles covering the region from near the magnetic equator to about dip lat. 20°S). However, on the night of 7–8 November, when a prompt penetration electric field is observed around prereversal period, the phase fluctuations are seen from St. Croix, U.S. Virgin Islands (apex height close to 2300 km) to Bahia Blanca, Argentina (apex height close to 2100 km). This indicates unusual latitudinal extension of plasma bubbles to nearly midlatitude regions in both hemispheres associated with uplifting of the *F* layer in the equatorial region due to storm time effect. In contrast to the observations mentioned above, there are no phase fluctuations observed on the nights of 9–10 and 10–11 November in the Latin American sector, likely due to inhibition of PRE.

[19] Figure 3b shows the ionospheric *F* region observed at SJC. A few hours after the SSC at 1828 UT on 7 November, the $h'F$ variations show strong oscillations on the nights of 7–8 and 9–10 November (after the second disturbance phase). In addition, some uplifting in the *F* region is observed on the nights of 8–9 and 10–11 November. As mentioned earlier regarding prompt penetration at MAN, a part of the variations observed at SJC on the nights of 7–8 and 9–10 is associated with the disturbance electric field. However, most of the oscillatory behavior and uplifting observed on the nights 7–8, 8–9, 9–10, and 10–11 November at SJC is possibly associated with the disturbance thermospheric winds. In addition, a perusal of iso-frequency plots at MAN (Figure 5a) and SJC (Figure 5b) show that the strong oscillations observed on the nights of 7–8 and 9–10 November at SJC are not observed at MAN. In this connection, it should be mentioned that MAN is a near equatorial station, whereas SJC is a station located in the equatorial ionospheric anomaly region. Regarding this behavior at MAN and SJC, as discussed by *Sastri et al.* [2002], during geomagnetically disturbed conditions, close to the magnetic equator, the vertical plasma drift is essentially due to zonal electric field, whereas meridional winds gain importance only with increase of dip angle.

3.2. Daytime *F* Region Electron Density Changes During Intense Geomagnetic Disturbance

[20] Figure 3b shows a strong negative storm phase at SJC on the night of 10–11 November. It should be mentioned that during the daytime on 10 November, the ionospheric sounding observations at SJC also show a strong negative storm phase (not shown). No such behavior is observed at MAN. A perusal of VTEC data obtained at different Latin American stations in Figure 6 indicates that negative storm phase during the daytime was observed on 8 November at POAL and VBCA, with larger effect at VBCA. As described by *Prolss* [1997], the negative storm phase is associated with a decrease in the ratio O/N_2. In addition, on 10 November during daytime, no change was observed at BELE (near equatorial station), whereas negative storm phase was observed at BRAZ, UEPP, POAL and VBCA (southern hemisphere). The effect of negative storm phase increases with latitude in the southern hemisphere and is associated with decrease in the ratio O/N2. During the daytime on 9 November strong positive storm phase is observed from CRO1 to POAL. Also, positive storm phase is observed at CRO1 on 10 November. As mentioned by *Prolss* [1997], the long-duration positive storms are due to changes in the large-scale wind circulation.

[21] Figure 7 shows the global maps of the ratio O/N_2 obtained from the global ultraviolet imager (GUVI) [*Paxton et al.*, 2004] flown on the TIMED satellite for days 311 (6 November), 2004 and days 313 (8 November), 314 (9 November), and 315 (10 November), 2004. In all the four maps, the Latin American sector is approximately at 1400 h. Figure 7 shows the ratio of O/N_2 on four days: 311 (ΣKp = 1+) (geomagnetically quiet) and 313 (ΣKp = 50o), 314 (ΣKp = 52o), and 315 (ΣKp = 56+) (with intense geomagnetic disturbances). The larger O/N_2 ratios on the three geomagnetically disturbed days are located away from the high-latitude regions and are driven largely by disturbance winds resulting in composition changes. A perusal of the ratio of O/N_2 on the days 313 and 315 indicates a decrease in the ratio of O/N_2 and a negative storm phase is observed in the Brazilian and Argentinean sectors. Figure 7 also indicates that the effects in global composition changes on the days 313 and 315 are not exactly the same in the Brazilian and Argentinean sectors. This appears to explain the differences in the VTEC (Figure 6) variations observed during the two intense geomagnetically disturbed days as discussed earlier. The larger O/N_2 ratio structure observed on the day 314 (9 November) in the Latin American sector is different from the days 313 and 315. Also, it appears from Figure 7 that at least a part of positive storm phase observed (VTEC; Figure 6) on day 314 at different stations and at CRO1 on day 315 could be associated with increase in the O/N_2 ratio due to changes in the large-scale wind circulation [*Prolss*, 1997].

4. Conclusions

[22] In this paper, we have presented the simultaneous ionospheric sounding observations from two stations: Manaus (MAN) and Sao Jose dos Campos (SJC), both located in the Brazilian sector, during the intense geomagnetic disturbances in the early part of November 2004. Data from several GPS receiving stations from the Latin American sector during the disturbed period are also presented. Some of the salient features associated with these observations are summarized below.

[23] 1. During the main phase of the first superstorm around the prereversal enhancement time (night of 7–8 November), prompt penetration of electric field is observed, along with the rapid uplifting of the *F* layer in the equatorial region which results in the presence of phase fluctuations (equatorial ionospheric irregularities with kilometers scale size) up to St. Croix, U.S. Virgin Islands, in the northern hemisphere, and Bahia Blanca, Argentina, in the southern hemisphere.

[24] 2. During the daytime on 8 November, a negative storm phase is observed at Porto Alegre (Brazil) and Bahia Blanca (Argentina), possibly associated with the decrease in the ratio O/N_2.

[25] 3. During the second phase of intense geomagnetic disturbances, the ionospheric sounding observations at MAN indicates inhibition of prereversal enhancement on the nights of 9–10 and 10–11 November, possibly due to the disturbed thermospheric winds or disturbance electric fields. However, on these two nights only spread *F* was observed at MAN, a near equatorial station, during the later part of the nights.

[26] 4. No spread *F* echoes (phase fluctuations) on the nights of 9–10 and 10–11 November were observed in the Latin American sector investigated, except for some small phase fluctuations at BELE around 0400 UT.

[27] 5. On the nights of 7–8 and 9–10 November (both having intense geomagnetic disturbances), the ionospheric sounding observations at SJC show strong oscillations in the height of the bottomside of the *F* layer, possibly associated with the disturbed thermospheric winds.

[28] 6. During the recovery phase on the night of 10–11 November, a strong negative storm phase is observed at SJC but not at MAN.

[29] 7. The VTEC observations during the daytime on 8 and 10 November show a negative storm phase from POAL to VBCA and from BRAZ to VBCA, respectively, due to changes in the ratio O/N_2 in the southern hemisphere.

[30] 8. The VTEC observations during the daytime on 9 November shows a positive storm phase from CRO1 to POAL, likely due to changes in the large-scale wind circulation and changes in the ratio O/N_2 in the northern and southern hemispheres.

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