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# Observations of the F-region ionospheric irregularities in the South American sector during the October 2003 "Halloween Storms"

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**Abstract.** The response of the ionospheric F-region in the South American sector during the super geomagnetic storms on 29 and 30 October 2003 is studied in the present investigation.

In this paper, we present ionospheric sounding observations during the period 29–31 October 2003 obtained at Palmas (a near equatorial location) and Sao Jose dos Campos (a location under the southern crest of the equatorial ionospheric anomaly), Brazil, along with observations during the period 27–31 October 2003 from a chain of GPS stations covering the South American sector from Imperatriz, Brazil, to Rio Grande, Argentina. Also, complementary observations that include sequences of all-sky images of the OI 777.4 and 630.0 nm emissions observed at El Leoncito, Argentina, on the nights of 28–29 (geomagnetically quiet night) and 29–30 (geomagnetically disturbed night) October 2003, and ion densities observed in the South American sector by the DMSP F13, F14 and F15 satellites orbiting at about 800 km on 29 and 30 October 2003 are presented. In addition, global TEC maps derived from GPS observations collected from the global GPS network of International GPS Service (IGS) are presented, showing widespread and drastic TEC changes during the different phases of the geomagnetic disturbances. The observations indicate that the equatorial ionospheric irregularities or plasma bubbles extend to the Argentinean station Rawson (geom. Lat. 33.1° S) and map at the magnetic equator at an altitude of about 2500 km.

**Keywords.** Ionosphere (Ionosphere-magnetosphere interactions; Ionospheric disturbances; Ionospheric irregularities)

## 1 Introduction

Interactions between the magnetosphere and the ionosphere during intense geomagnetic storms continue to be an important subject related to space weather studies. Ionospheric storms are closely associated with geomagnetic storms. Buonosanto (1999) has indicated that ionospheric storms represent an extreme form of space weather with important effects on ground and space-based technological systems. As described by Gopalswamy et al. (2005) the solar-terrestrial events of late October and early November 2003, popularly referred as the Halloween storms, represent the best observed cases of extreme space weather activity observed to date and have generated research covering multiple aspects of solar eruptions and their space weather effects. Tsurutani et al. (2005) and Sahai et al. (2005) have mentioned that on 28 and 29 October launch of fast coronal mass ejections (CMEs) were associated with the solar flares and their impacts on the Earth's magnetosphere resulted in major geomagnetic storms on 29 and 30 October (Halloween storms). The geomagnetic storms on the 29 and 30 October (and their interplanetary causes) were discussed in greater detail by Wu et al. (2005) and Mannucci et al. (2005). Several investigators

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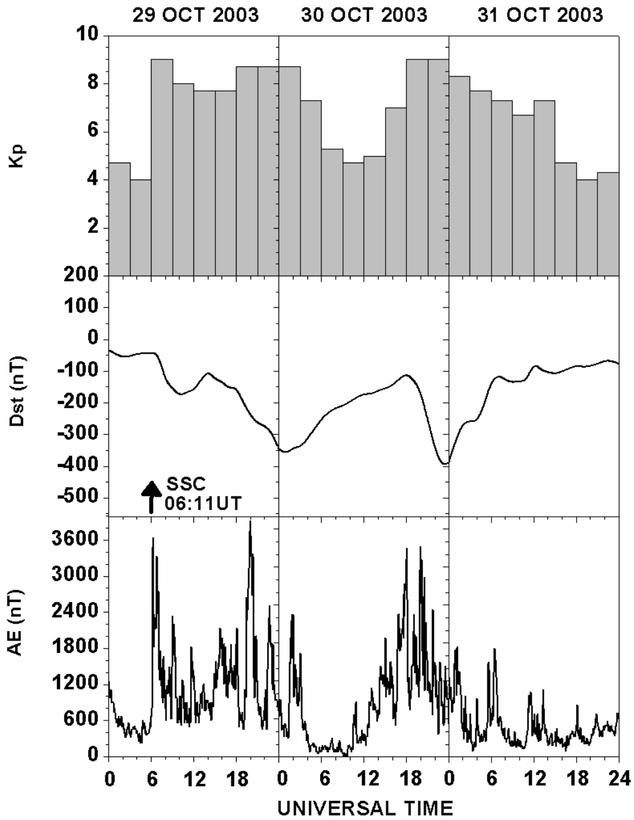


**Fig. 1.** Time variations of the $K_p$, $D_{st}$ and AE geomagnetic indices for the period 29 to 31 October 2003.

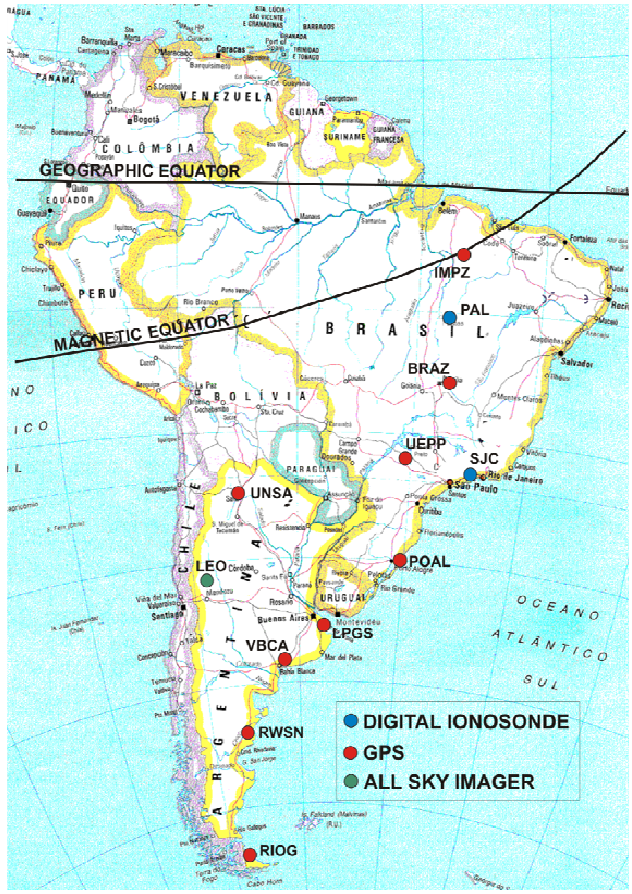


**Fig. 2.** Map showing the locations of the ionospheric sounding, all-sky nightglow imaging and GPS stations.

have studied the response of the ionospheric F-region in the equatorial and mid-latitude regions during the October 2003 Halloween storms (e.g., Basu et al., 2005, 2007; Foster and Rideout, 2005; Lin et al., 2005; Zhao et al., 2005; Sahai et al., 2005; Yizengaw et al., 2005; Chi et al., 2005; Batista et al., 2006; Garner et al., 2006; Abdu et al., 2007, 2008; Huang et al., 2007; Mannucci et al., 2008; Perevalova et al., 2008; Tsurutani et al., 2008; Verkhoglyadova et al., 2008).

During the recent past several excellent reviews related to the effects of geomagnetic storms on the equatorial and mid-latitude ionospheric regions have been published (e.g., Schunk and Sojka, 1996; Abdu, 1997; Buonosanto, 1999; and Tsurutani et al., 2008). However, studies of magnetosphere-ionosphere interactions during intense geomagnetic storms at equatorial and mid-latitude regions continue to attract considerable attention of different investigating (both observational and modeling) groups. Case study for the ionospheric storm is still important to enrich our current understanding and to verify whether the observed storm effects can be explained by the established theories. The continued interest in these studies is related to the lack of understanding and our inability to predict well the space weather response of the thermospheric and ionospheric regions. It appears that there are several drivers of the ionospheric response during geomagnetic storms: electric fields (solar wind- magnetosphere dynamo (e.g., Senior and Blanc, 1984; Spiro et al., 1988; and Tsurutani et al., 2008), and ionospheric disturbance dynamo (e.g., Blanc and Richmond, 1980), winds (transport of energy from high latitude (Joule heating or Lorentz forcing) in the form of traveling atmospheric disturbances (TADs) (e.g., Buonosanto, 1999; Nicolls et al., 2004), and composition changes ($O/N_2$ ratio) (e.g., Zhang et al., 2003; Meier et al., 2005).

Figure 1 shows the $K_p$, $D_{st}$, and AE geomagnetic indices observed during the period 29–31 October 2003. Considering an intense geomagnetic storm with $|D_{st\,\max}| > 250$ nT as a superstorm, two superstorms were observed during the period 29–30 October. There was a storm sudden commencement (SSC) at 06:11 UT on 29 November and a sudden impulse at 10:29 on 30 October. The $|D_{st\,\max}|$ reached 363 nT at 01:00 UT and 401 nT at 23:00 UT on 30 October. The AE index variations show that this index attained several times values greater that 2500 nT during the period 29–30 October.

The principal objectives of this paper have been to use the multi-instrument, multi-site optical/radio techniques

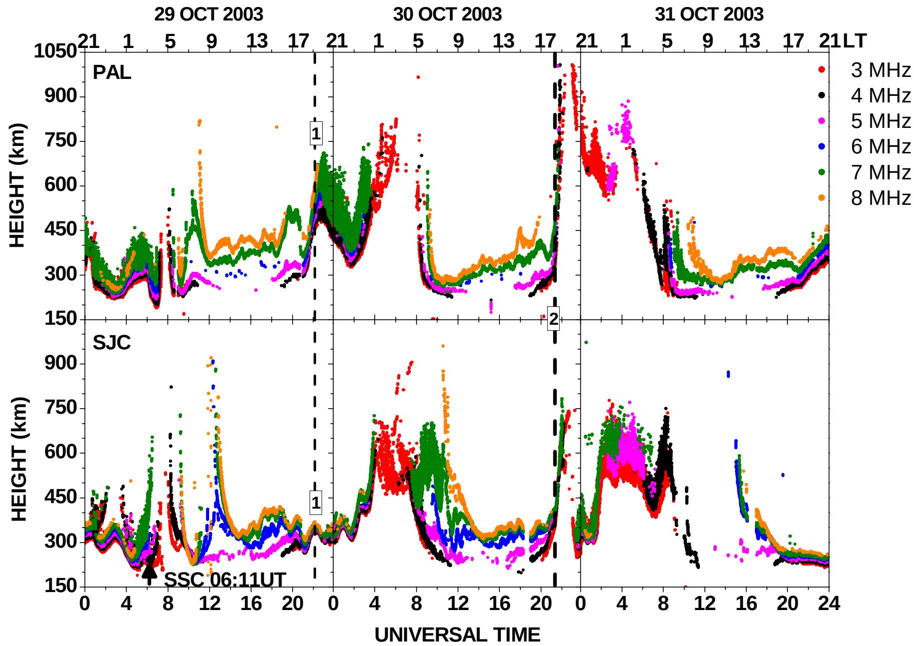


**Fig. 3.** Plots of the virtual height variations for six different frequencies (iso-frequency plots) observed at Palmas (top panel) and Sao Jose dos Campos (bottom panel), Brazil, for the UT days 29 to 31 October 2003. Also, the local time is shown at the top.

observation to investigate the generation and latitudinal extent of equatorial ionospheric irregularities, also known as equatorial spread-F (ESF), and ionospheric dynamics in the South American sector during the superstorms on 29 and 30 October. Of the late, the earlier view that a geomagnetic storm suppresses the generation of the ESF is no longer valid (e.g., Tsurutani et al., 2004; Becker-Guedes et al., 2004; Martinis et al., 2005; Chakrabarty et al., 2006). However, several investigators have reported ESF in post midnight period during geomagnetic disturbances earlier. Statistical analysis of ESF on geomagnetic quiet and disturbed days showed that ESF in the post midnight period could be more on disturbed days during low sunspot years and J-months (northern summer months) (Chandra and Rastogi, 1972). Rastogi et al. (1978) showed increase of ESF on disturbed days or high Kp days at Huancayo, Peru, in post midnight periods. A case study carried out by Rastogi and Woodman (1978) showed how ESF was triggered in the post midnight period due to sudden changes in IMF when F-region rises fast. Figure 2 and Table 1 show details of the ionospheric sounding, all-sky imaging, and GPS stations used in the present investigation. Also, some details of the apex point (dip latitude = 0) for different observing stations are given in Table 1. The apex height was calculated by tracing the geomagnetic field lines passing through the observed irregularities (altitude 300 km) using the International Geomagnetic Reference Field 2000 model (Mandea and Macmillan, 2000).

## 2 Observations

In this paper, several F-region observations carried out in the South American sector during the period 27–31 October 2003 are presented and discussed. Figure 3 shows the iso-frequency plots (virtual height variations of the ionospheric F-region at six frequencies obtained every 100 s) from ionospheric sounding observations using the Canadian Advanced Digital Ionosonde (CADI) (Grant et al., 1995; Abalde et al., 2001) operational at Palmas (10.2 S, 48.2 W; dip lat. 5.3 S; hereafter referred as PAL) and Sao Jose dos Campos (23.2 S, 45.9 W; dip lat. 17.2 S; hereafter referred as SJC), Brazil, on 29 and 30 October 2003. Figure 4 shows the sequences of the all-sky nightglow images (OI 630 nm and OI 777.4 nm emissions) obtained at El Leoncito (31.8 S, 69.3 W; dip lat. 17.0 S), Argentina (Martinis et al., 2006), on the night of 28–29 October 2003, a geomagnetically quiet night (ionospheric irregularities or plasma bubbles were observed between about 01:10 to 05:15 UT). Figure 5 shows the sequences of the all-sky nightglow images (OI 630 nm and OI 777.4 nm emissions) obtained at El Leoncito on the night of 29–30 October 2003, a geomagnetically disturbed night (ionospheric irregularities or plasma bubbles were observed between about 02:15 to 04:45 UT). It should be mentioned that due to the moon phase no airglow imaging observations were possible during the earlier parts of the nights on 28–29 and 29–30 October. Figures 6 and 7 show the variations of the ion density observed from the DMSP F13, F14 and F15 satellites orbiting at an altitude of about 840 km, passing through the South American sector, on the nights of

**Table 1.** Locations of the digital ionospheric (DI) sounding, all-sky airglow (OI 630 and 777.4 nm emissions) imaging and GPS stations. Also, apex point (dip latitude = 0) details are given.

| Location Symbol (Network) | Obs. | Geog. Lat. | Geog. Long. | Dip Lat. | Declina | Local Time (LT) | Apex Point Altitude | Declina |
|---|---|---|---|---|---|---|---|---|
| Imperatriz IMPZ (RBMC) | GPS | 05.5° S | 47.5° W | 1.5° S | 18.9° W | LT=UT−3 h | 308.2 km | 18.6° W |
| Palmas PAL (UNIVAP) | DI | 10.2° S | 48.2° W | 5.3° S | 18.8° W | LT=UT−3 h | 366.7 km | 17.8° W |
| Brasilia BRAZ (RBMC) | GPS | 15.9° S | 47.9° W | 10.3° S | 18.6° W | LT=UT−3 h | 537.8 km | 16.8° W |
| Presidente Prudente UEPP (RBMC) | GPS | 22.3° S | 51.4° W | 13.8° S | 15.7° W | LT=UT−3 h | 749.6 km | 14.1° W |
| Sao Jose dos Campos SJC (UNIVAP) | DI | 23.2° S | 45.9° W | 17.2° S | 20.2° W | LT=UT−3 h | 973.7 km | 15.4° W |
| Salta UNSA (SIRGAS) | GPS | 24.7° S | 65.4° W | 11.6° S | 4.5° W | LT=UT−4 h | 630.0 km | 6.8° W |
| Porto Alegre POAL (RBMC) | GPS | 30.1° S | 51.1° W | 19.8° S | 13.5° W | LT=UT−3 h | 1311.7 km | 12.2° W |
| El Leoncito LEO (BU) | IMAGER | 31.8° S | 69.3° W | 17.0° S | 1.6° E | LT=UT−4 h | 1070.4 km | 4.3° W |
| La Plata LPGS (SIRGAS) | GPS | 34.9° S | 57.9° W | 20.9° S | 6.3° W | LT=UT−4 h | 1554.6 km | 8.9° W |
| Bahia Blanca VBCA (SIRGAS) | GPS | 38.7° S | 62.3° W | 22.6° S | 0.7° W | LT=UT−4 h | 1887.9 km | 6.8° W |
| Rawson RWSN (SIRGAS) | GPS | 43.3° S | 65.1° W | 25.3° S | 4.0° E | LT=UT−4 h | 2499.4 km | 5.4° W |
| Rio Grande RIOG (SIRGAS) | GPS | 53.8° S | 67.8° W | 31.8° S | 11.7° E | LT=UT−4 h | 4815.7 km | 4.0° W |

29–30 October 2003 and 30 October 2003 (UT). Figure 8 shows the time rate change of TEC (TECU/min), also known as phase fluctuations (Aarons et al., 1996), using data from different GPS stations. It should be pointed out that the phase fluctuations represent ionospheric irregularities of the order of kilometers (Aarons et al., 1997). Figure 9 shows the plot of the average vertical total electron content (VTEC) obtained using global positioning system (GPS) satellites (above 30-degree elevation) at several GPS receiving stations in the South American sector. The VTEC for calculating the average used the algorithm presented by Brunini et al. (2003). The red line is the day's data and the green line is for a quiet day before the storm-time for a comparison. Figure 10 shows eight "Global Ionospheric TEC (total electron content)" maps (Mannucci et al., 1998) from about 100 GPS receiver stations obtained between 29–31 October. Figure 11 shows six GPS-based TEC maps (obtained from the website http://cdaweb.gsfc.nasa.gov./sp_phys/) from the global GPS network for the same UT on geomagnetically quiet days (27–28 October; left column) and geomagnetically disturbed or recovery days (29–31 October; right column). The brief descriptions of the figures given in this section are discussed with more detail in the next section.

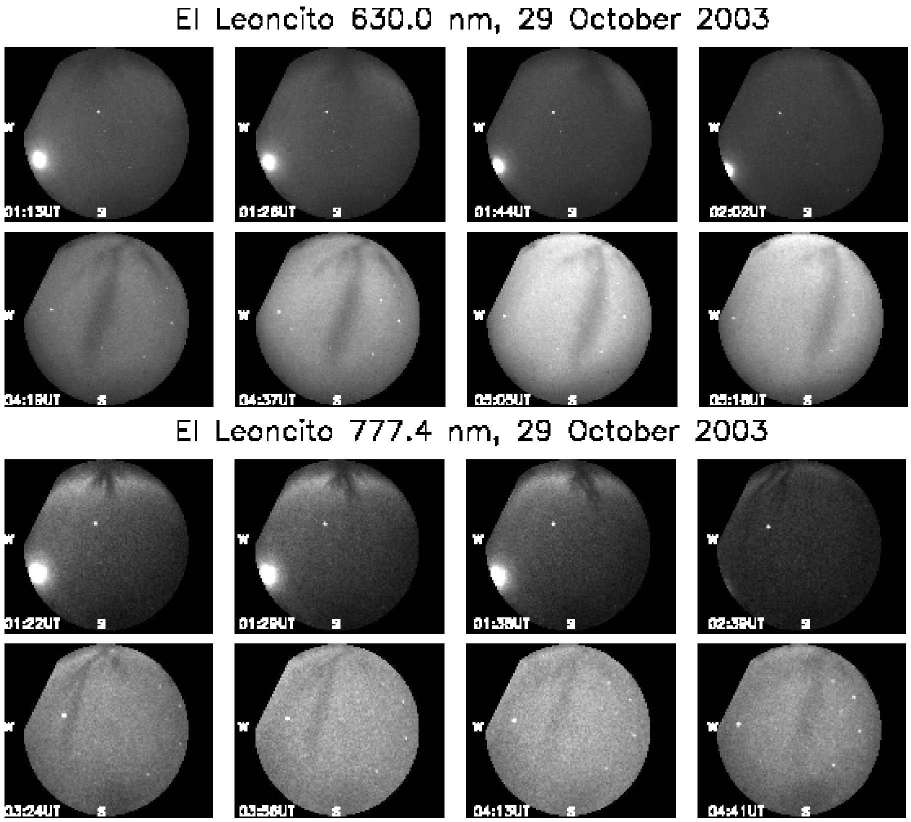


**Fig. 4.** A sequence of the F-region all-sky nightglow images obtained at El Leoncito, Argentina, on the night of 28–29 October 2003 (quiet night). The top panel shows the OI 630.0 nm emission images and the bottom panel shows the OI 777.4 nm emission images.

## 3 Results and discussion

An analysis of the ionospheric sounding, all-sky F-region nightglow imaging, and GPS observations obtained at several stations in the South American sector during the super geomagnetic storms on 29 and 30 October 2003 are presented and discussed. After the SSCs on 29 and 30 October, unusual uplifting of the F-layer, due to penetration electric fields, in the equatorial region during the pre-reversal enhancement periods on both days were observed (points 1 and 2; Fig. 3). As described by VanZandt et al. (1971; see also Sastri et al., 2002) the most direct and easily observed effects of $\boldsymbol{E} \times \boldsymbol{B}$ drift are changes in the height of the F-region. It should be mentioned that the geomagnetic $D_{st}$ index was decreasing rapidly during these periods and the eastward penetration electric field was particularly enhanced due to the global electric field. As mentioned by Basu et al. (2007), in the dusk sector, the eastward penetration electric field, associated with rapid $D_{st}$ decrease, adds to the post-sunset eastward E-field because of the F-region dynamo, and this enhanced E-field at dusk causes a rapid uplift of the ionosphere and sets off plasma instabilities.

On the evening of 30 October, the uplifting was much stronger and was observed both at PAL and at SJC. At PAL, the uplifting was at a rate of about 170 m/s. As described by Huang (2008), the enhancement of the upward plasma drift driven by eastward penetration electric field was measured by the DMSP satellite. The increase of the vertical drift is about 180 m/s, consistent with the uplifting of 170 m/s estimated from the PAL digital ionosonde data. The unusual lifting of the F-layer in the equatorial region on 29 and 30 October during the pre-reversal period resulted in the generation of equatorial ionospheric irregularities and plasma bubbles in the Brazilian sector (Figs. 3 and 8). Also, Fig. 8 shows that the Argentinean stations (UNSA, LPGS, VBCA and RWSN), with geomagnetic field lines west of the Brazilian sector (see Table 1), have strong phase fluctuations close to the pre-reversal enhancement period (after local sunset) indicating the presence of equatorial ionospheric irregularities and plasma bubbles on the nights of 29–30 (ionospheric irregularities or plasma bubbles in the South American sector were observed between about 22:00 to 08:00 UT; see Fig. 8) and 30–31 October (ionospheric irregularities or plasma bubbles in the South American sector were observed between about 21:00 to 04:00 UT; see Fig. 8). Since the investigation

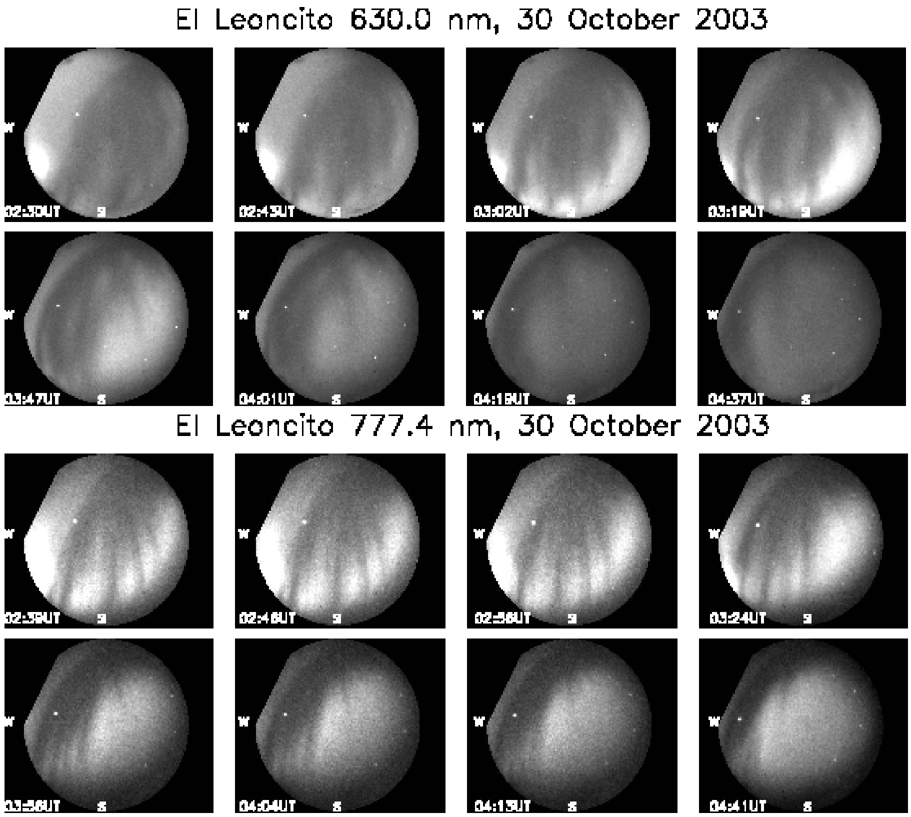


**Fig. 5.** A sequence of the F-region all-sky nightglow images obtained at El Leoncito, Argentina, on the night of 29–30 October 2003 (geomagnetically disturbed). The top panel shows the OI 630.0 nm emission images and the bottom panel shows the OI 777.4 nm emission images.

of ionospheric irregularities up to RWSN is based on phase fluctuations (Fig. 8), the scale size of the ionospheric irregularities is of the order of kilometers (Aarons et al., 1997). A perusal of Table 1 indicates that observed ionospheric irregularities or plasma bubbles at the Argentinean station RWSN will map at the magnetic equator at an altitude of about 2500 km. This is in conformity with Sahai et al. (1994), where it was indicated that the plasma bubbles attain very high apex altitudes. Figures 4 and 5 showing the F-region all-sky imaging observations also indicate that the observed plasma bubbles are well within the observational field of view on the geomagnetically quiet night of 28–29 October, whereas on the night of 29–30 October with geomagnetic disturbance, the observed plasma bubbles cut across the field of view. These observations are also in line with Sahai et al. (1994). On the nights before the geomagnetic storms viz., 26-27 (ionospheric irregularities or plasma bubbles in the Brazilian sector were observed between about 00:00 to 04:00 UT; see Fig. 8), 27–28 (ionospheric irregularities or plasma bubbles in the South American sector were observed between about 23:00 to 06:00 UT; see Fig. 8), and 28–29 October (ionospheric irregularities or plasma bubbles in the South American sector were observed between about 22:00 to 06:00 UT; see Fig. 8). Figure 8 shows that the ionospheric irregularities extend to POAL on the night of 27–28 October but is limited up to UEPP on the night of 26–27 October. The ionospheric sounding observations at PAL and SJC on these nights indicate this could be associated with the day-to-day variability in the evening height rise of the F-region.

The Argentinean station RIOG (dip lat. 31.8; geomag. lat. 43.6 S), a high mid-latitude station, shows very low VTEC (see Fig. 9) with very low VTEC fluctuations close to the sunset time on the nights of 29–30 and 30–31 October but accompanied with very large phase fluctuations after about 22:00 UT on both the nights. The large phase fluctuations observed are associated with mid-latitude spread-F during geomagnetic activity as described by Bowman (1984). The station RIOG could be within the sub-auroral polarization streams (SAPS) (Huang and Foster, 2007) region or even southward of the SAPS region during the intense geomagnetic storms. When the station is in or close to the SAPS region, the VTEC must be very low. Also, ionospheric sounding observations at Port Stanley (51.6 S, 57.9 W), close to Rio Grande, show the presence of spread F on the ionograms

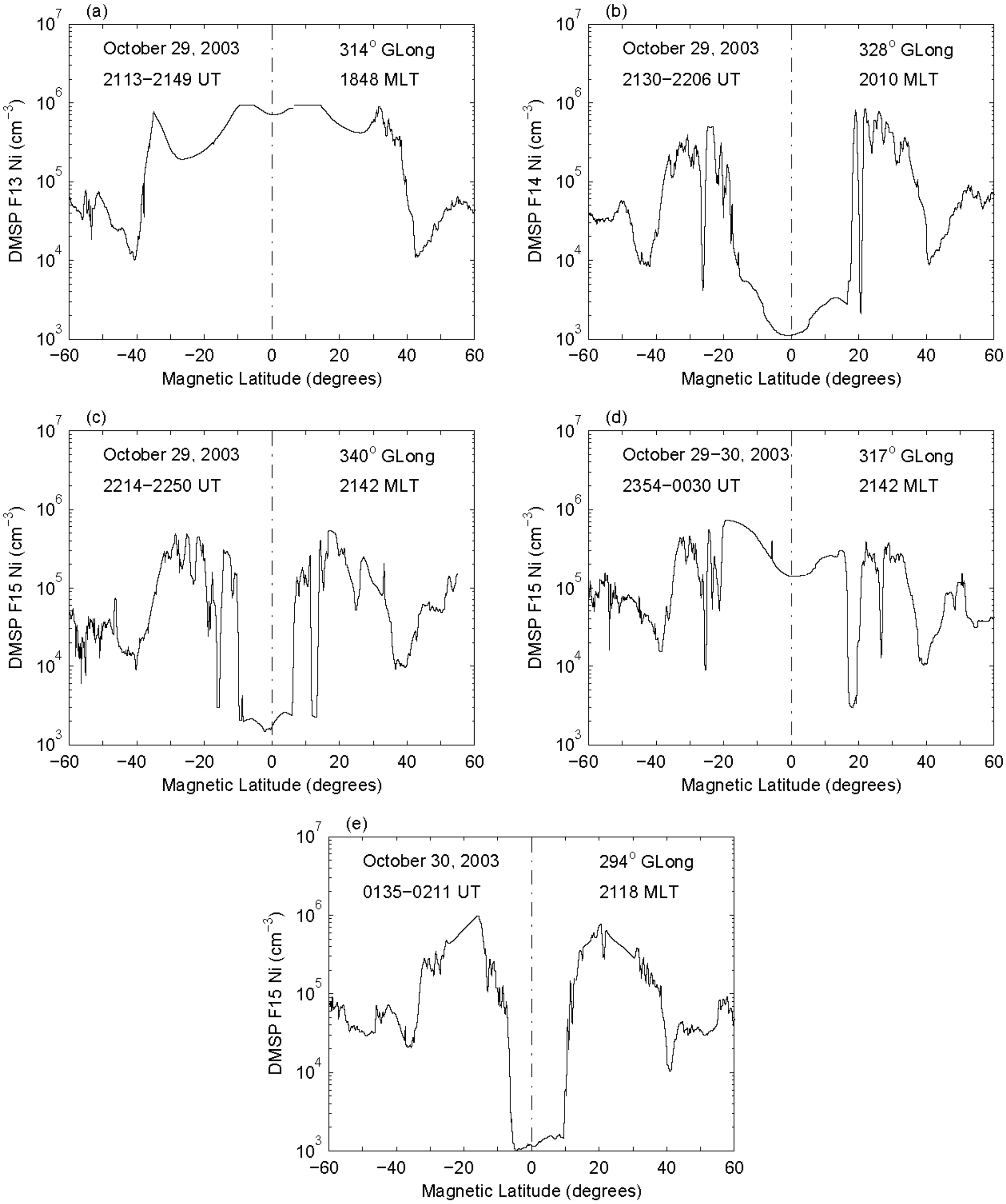


**Fig. 6.** Variations of the ion density observed from the DMSP F13, F14 and F15 satellites orbiting at an altitude of about 840 km in the South American sector on the night of 29–30 October 2003 (UT).

on both the nights of 29–30 and 30–31 October. No spread-F was observed at Port Stanley on the night of 28–29 October (a geomagnetically quiet night). It should be pointed out that because the station Rio Grande could be within in the SAPS region, the ionospheric behavior at this station is very different from other stations.

Figure 4 shows the sequences of the all-sky nightglow images from the F-region OI 630 nm and OI 777.4 emissions, obtained at El Leoncito, Argentina (Martinis et al., 2006), on the night of 28–29 October 2003 (a geomagnetically quiet night). Figure 5 shows similar sequences of the all-sky nightglow images (OI 630 nm and OI 777.4 nm emissions) obtained at El Leoncito on the night of 29–30 October 2003 (a geomagnetically disturbed night). Also, the ray-like structures seen clearly with the 777.4 nm emission are due to very small life time of this emission as described in detail by Abalde et al. (2001). A perusal of the OI 630 nm images shown in Fig. 4 clearly indicates that between 04:06 UT (00:06 LT) and 05:36 UT (01:36 LT) plasma bubbles are drifting toward east on this geomagnetically quiet

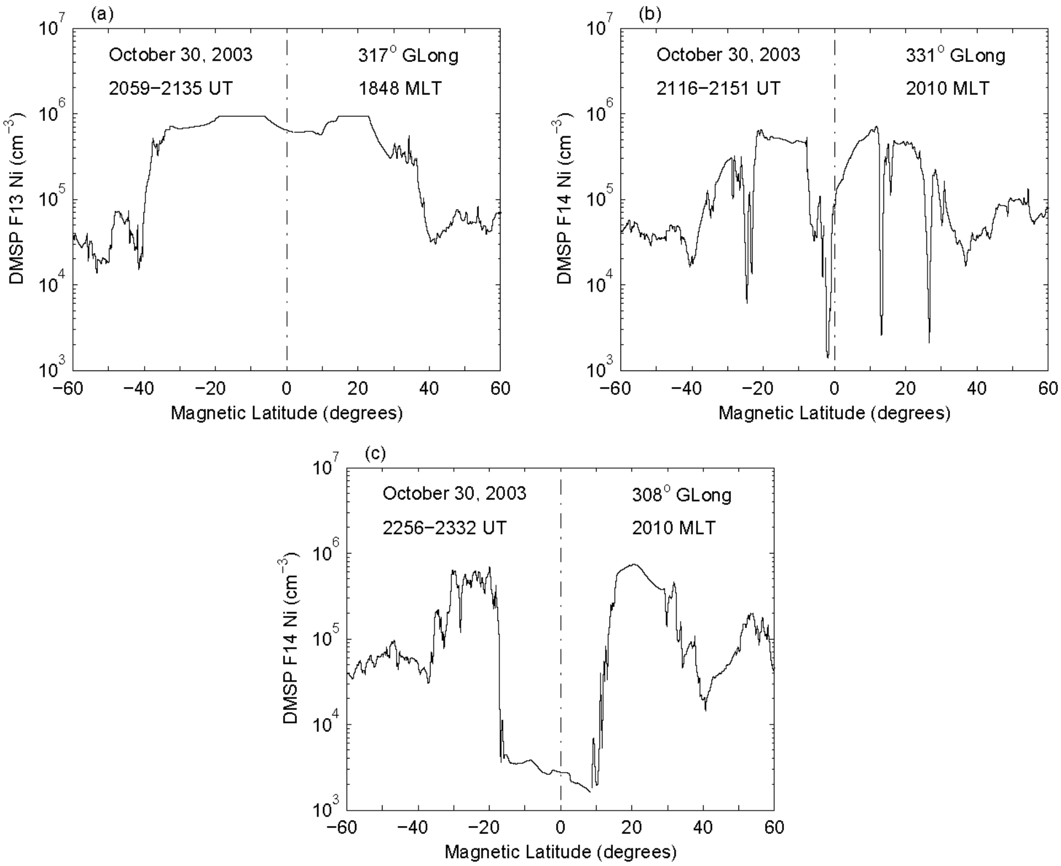


**Fig. 7.** Variations of the ion density observed from the DMSP F13 and F14 satellites orbiting at an altitude of about 840 km in the South American sector on the night of 30 October 2003 (UT).

night. At 05:05 UT (01:05 LT) the OI 630 nm image shows strong increase in intensity nearly in the full field of view indicating that possibly the F-layer came down at this time. The all-sky imaging observations of the OI 777.4 nm and OI 630.0 nm emissions on the night of 28–29 October (quiet night) show ionospheric plasma bubbles drifting to east (normal), whereas on the geomagnetically disturbed night of 29–30 October, both the emissions show that the plasma bubbles drift towards west (not normal). The present results during the geomagnetic disturbance are similar to the observations in the Brazilian sector reported by Abdu et al. (2003) during the major magnetic storm of 26 August 1998. As mentioned by Abdu et al. (2003) the results point out to the dominant role of a disturbance dynamo associated westward thermospheric wind to maintain the plasma irregularity drift increasingly westward going into postmidnight local time.

Figures 6 and 7 show the variations of the ion density observed from the DMSP F13, F14 and F15 satellites (e.g. Basu et al., 2005, 2007; Huang et al., 2007; Huang, 2008) orbiting at an altitude of about 840 km, passing through the South American sector, on the nights of 29–30 October 2003 and 30 October 2003 (UT). The DMSP satellite moves from east to west and from the Southern to Northern Hemisphere in the evening sector. The time given in Fig. 6a, such as 21:13–21:49 UT, is the time interval during which the satellite moves from -60 to 60 degrees magnetic latitudes. Again, in Fig. 6a, 314° Glong refers to the longitude for the magnetic equator crossing and 18:48 MLT refers to the magnetic local time at the magnetic equator. This MLT should be very close to LT in the equatorial and low latitude regions. All the plots in Figs. 6 and 7 show a dip in ion density close to 40 degrees north 40 degrees south magnetic latitude during this geomagnetically disturbed period. This possibly indicates that the plasmapause moved to lower magnetic latitudes during this intense geomagnetic disturbance (Huang and Foster, 2007; Horvath and Lovell, 2008). The low density region at ∼40 magnetic latitudes is the region of the sub-auroral polarization streams (SAPS), and this region coincides with the mid-latitude trough during the intense geomagnetic storms. Figures 6 and 7 show large equatorial plasma depletions during several passages. These have been referred to as storm-induced big bubbles (SIBBs) (Kil et al., 2006).

Mendillo (2006) has recently reviewed storms in the ionosphere, patterns and processes for total electron content. Figure 9 shows average GPS-TEC observations (red lines) and indicate that several hours after the SSC on 29 October,

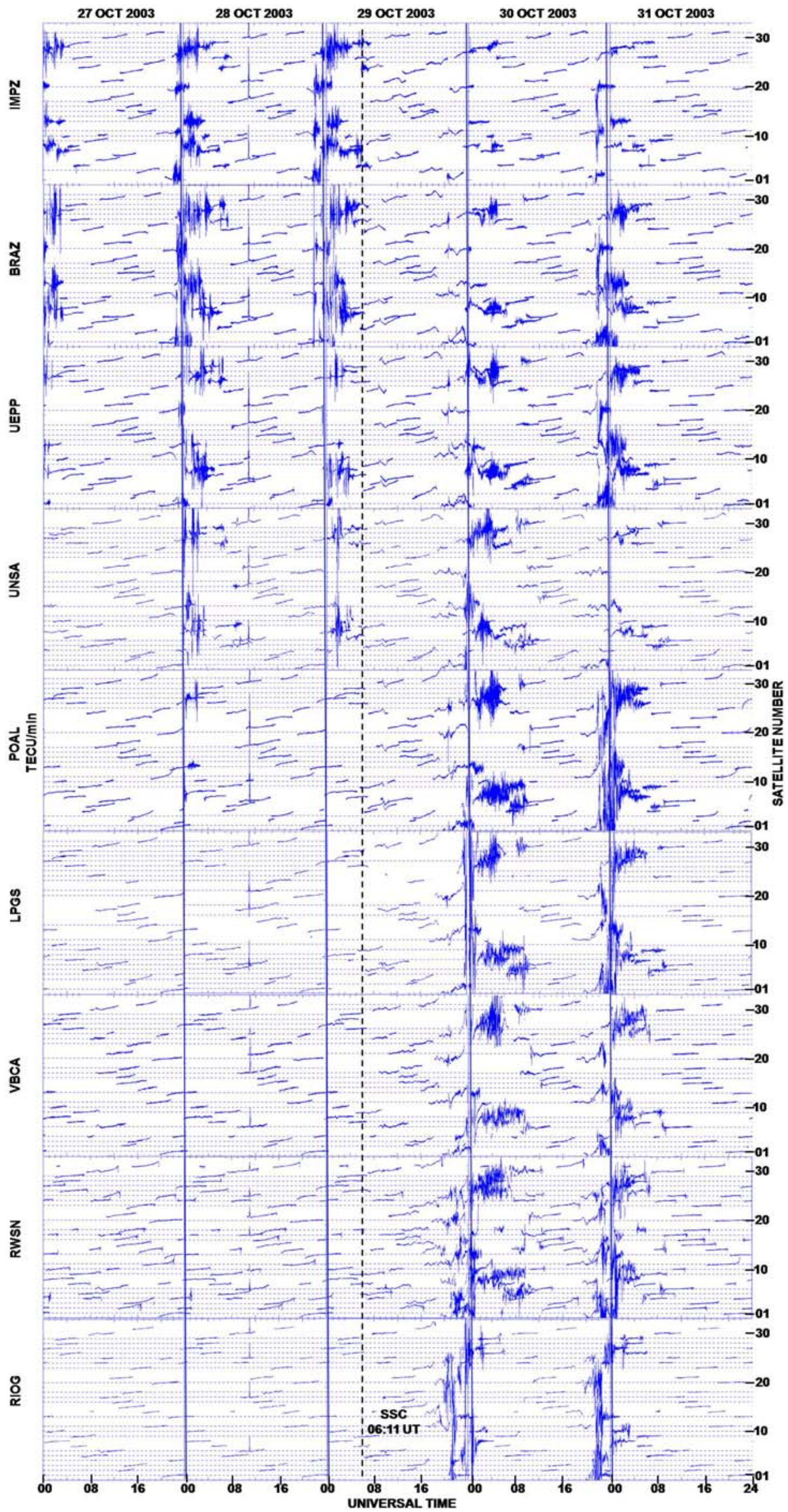


**Fig. 8.** The time rate change of TEC (TECU/min) measured at different GPS stations.

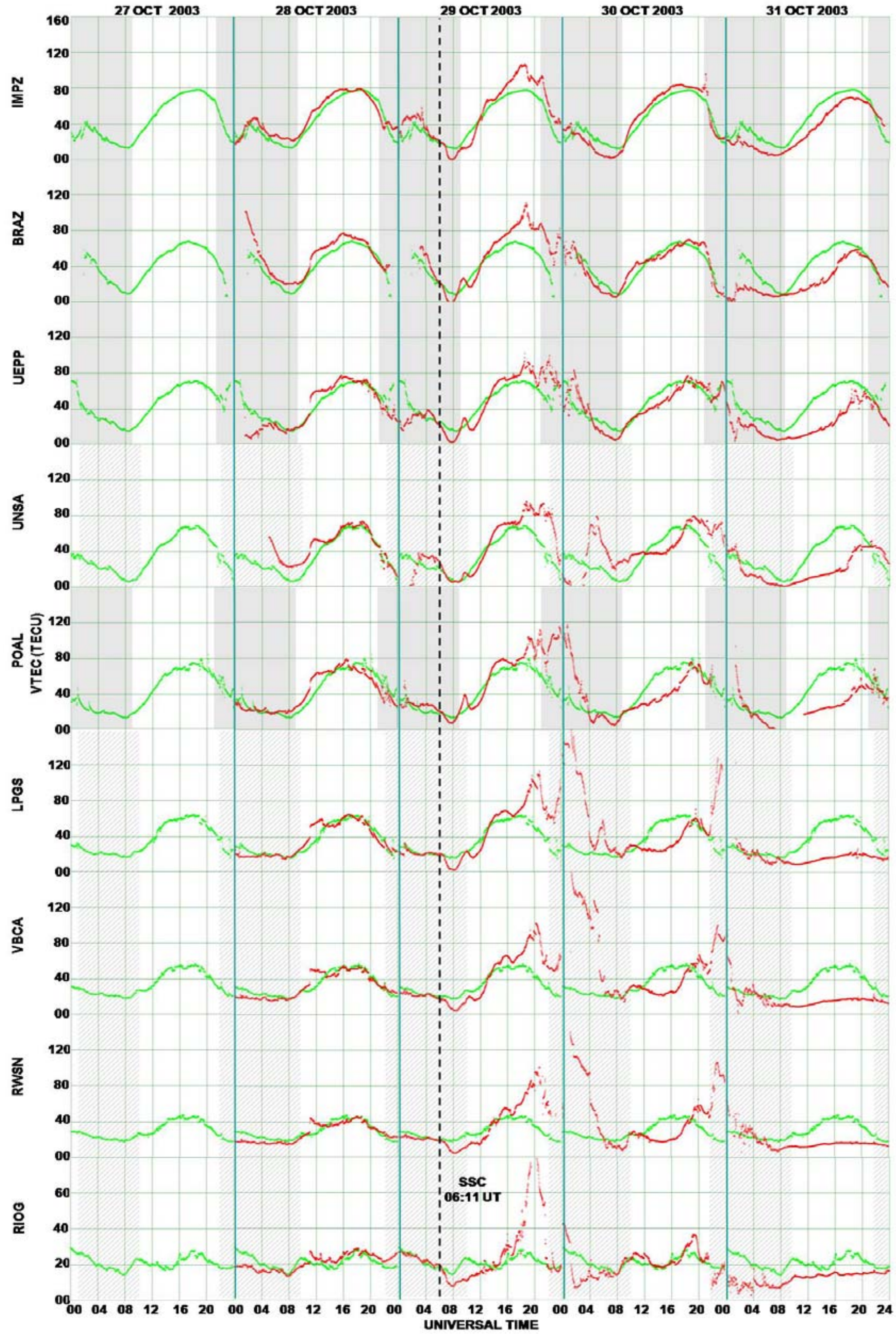


**Fig. 9.** The average vertical electron content (VTEC) measured using different satellites (above 30 degrees elevation) at several GPS stations in the South American sector. The red line is the day's data and the green line is for a quiet day before the storm.

the TEC variations undergo drastic enhancements. During the daytime, associated with heating in the southern auroral zone, large enhancement is observed at RIOG, propagating to lower latitudes up to LPGS on 29 October. Similar but smaller enhancements are seen during the daytime on 30 October extending to POAL. However, the enhancements on 30 October are preceded by negative storm phase from RWSN to POAL. Again, negative storm phase starting after midnight on 31 October (recovery phase) and continuing throughout the daytime is seen from IMPZ to RIOG. The negative phase of the storm is due to composition ($O/N_2$ ratio) changes. During the pre-reversal time on 29 and 30 October, the geomagnetic storm electric fields cause the crests of the Appleton anomaly to move much further south (Mannucci et

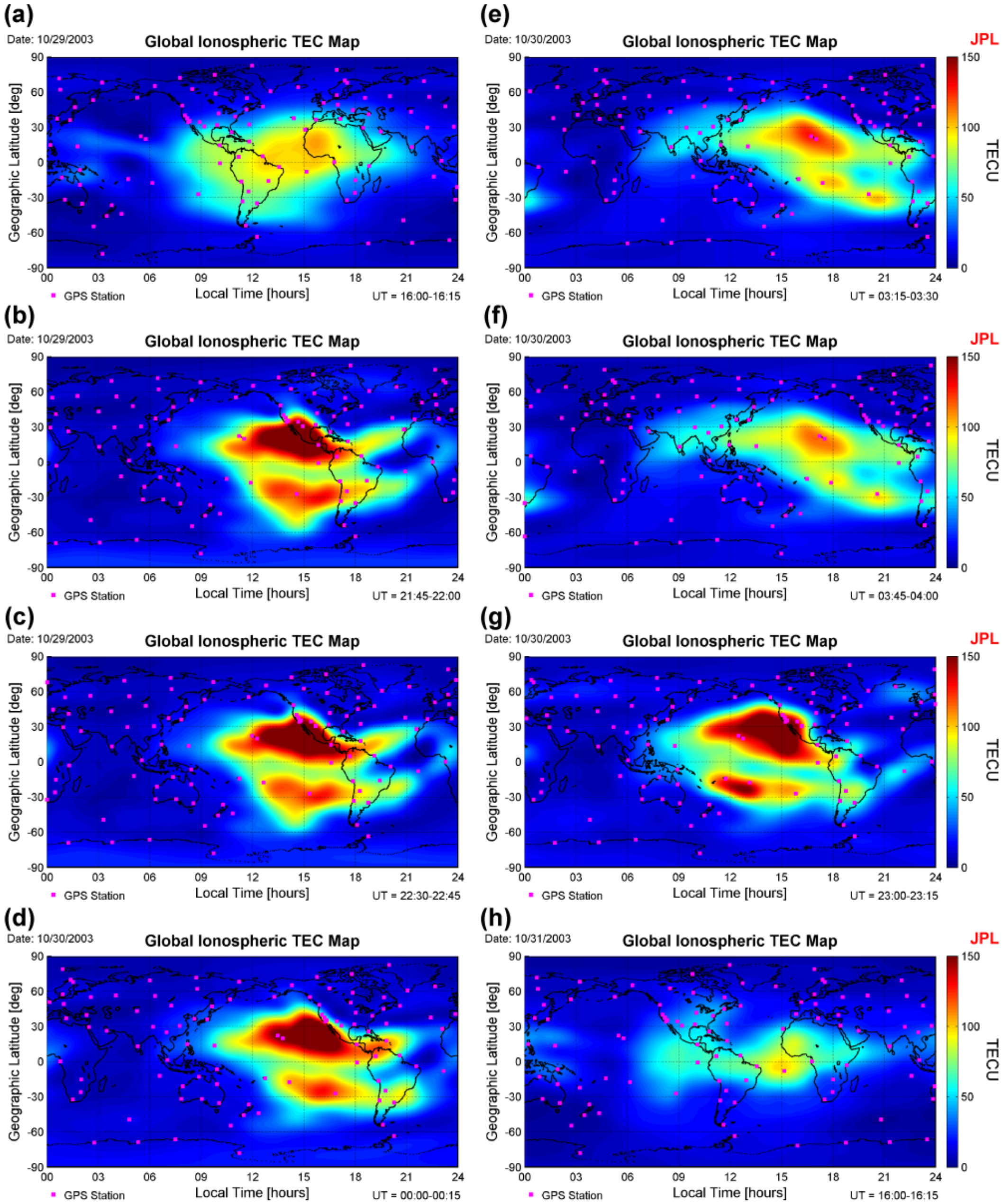


**Fig. 10.** Eight global TEC maps, with 15-min resolution, produced at the Jet Propulsion Laboratory using GPS observations collected from the IGS global GPS network. The red dots denote the locations of GPS stations.

al., 2005). The large gradients observed in the VTEC in the southern Brazil and some of the Argentinean stations are due to the geomagnetic storm that has moved the plasma away from the magnetic equator. Lin et al. (2005) have reported similar results during the October–November 2003 super-storm periods. They have reported from the GPS-TEC measurements that the equatorial ionospheric anomaly (EIA) expanded to very high latitudes with large increases of TEC after the storm started. The present results are in conformity with Mendillo (2006).

Figure 10 shows global TEC maps, produced at the Jet Propulsion Laboratory with 15-min resolution using GPS observations collected from the IGS global GPS network, for several periods. The first map (Fig. 10a) between 16:00–16:15 UT is before the unusual pre-reversal uplifting in the equatorial region on 29 October. Figure 10b to d and g shows clearly that during the storms of 29 and 30 October prompt penetrating electric fields (PPEFs) in the dayside ionosphere caused extreme $\boldsymbol{E} \times \boldsymbol{B}$ uplift of the equatorial ionospheric anomalies (EIAs) (Verkhoglyadova et al., 2008). In addition,

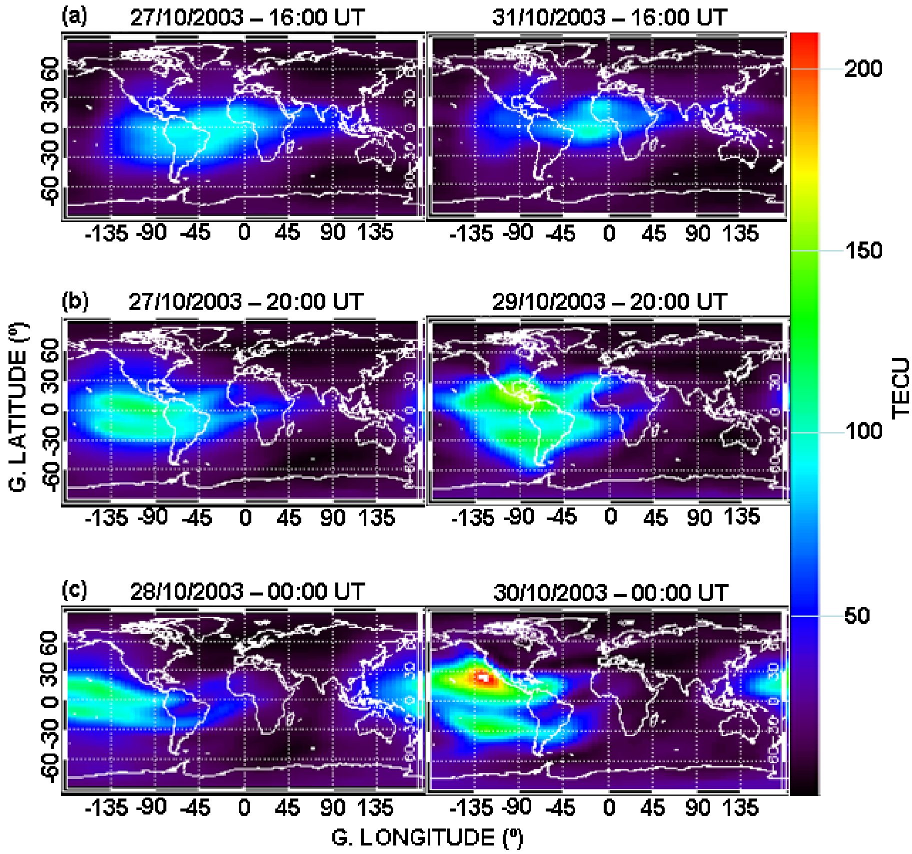


**Fig. 11.** Six GPS-derived global TEC maps also produced at the Jet Propulsion Laboratory, with 2-h resolution, for geomagnetically quiet (left hand column) and disturbed (right hand column) conditions.

Fig. 10b to f shows the global evolution of TEC after the unusual uplifting in the equatorial region in the American sector. Figure 10b to d very clearly indicates the intensification and expansion of the EIA to higher latitudes in the South American sector. Again, Fig. 10g shows the EIA after the unusual pre-reversal enhancement on 30 October. Figure 10h shows the daytime TEC variation on 31 October indicating a strong negative storm phase in the South American sector as described earlier.

Figure 11 shows GPS-TEC maps for the same UT observed on a geomagnetically quiet day 27 or 29 October; left hand column) and geomagnetically disturbed or recovery phase day (29–31 October; right hand column). A widespread and drastic TEC changes during the different phases of the geomagnetic disturbances in the South American sector is evident. Figure 11a refers to the daytime comparison during the recovery phase and a strong negative storm phase in the South American sector is observed. Again, Fig. 11b and c shows the development and intensification of the EIA on 29–30 October (UT).

## 4 Conclusions

We have analyzed and presented observations of the ionospheric sounding, all-sky F-region nightglow imaging, and GPS observations obtained at several stations in the South American sector during the super geomagnetic storms on 29 and 30 October 2003. The main results are as follows:

It should be noted that there was uplifting of the F-layer prior to the pre-reversal enhancements. The uplift was enhanced at dusk due to neutral wind effects. The uplifting of the F-layer in the equatorial region during the pre-reversal enhancement period on 29 and 30 October resulted in the generation of strong equatorial ionospheric irregularities (plasma bubbles) in the Brazilian sector (IMPZ to POAL), seen as phase fluctuations (indicating km scale ionospheric irregularities). In addition, the Argentinean stations (UNSA, LPGS, VBCA and RWSN), with geomagnetic field lines west of the Brazilian sector (see Table 1) also show strong phase fluctuations close to the pre-reversal enhancement period (after local sunset) indicating the presence of equatorial ionospheric irregularities on the nights of 29–30 and 30–31 October.

The DMSP satellites plots orbiting at an altitude of about 840 km are the passages over the South American sector and show large ion density (Ni) fluctuations including unusual depletions close to the magnetic equator. All the DMSP plots show a dip in Ni close to 40 north and 40 south magnetic latitude during this disturbed period. This possibly indicates that the plasmapause moved to lower magnetic latitudes during the intense geomagnetic disturbance.

The southernmost Argentinean station Rio Grande shows very low VTEC (in general) with very low VTEC fluctuations close to the sunset time but accompanied with very large phase fluctuations. This station could be within the SAPS region or even southward of the SAPS region during this intense magnetic storms.

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