Simultaneous ionospheric sounding observations from the equatorial and low latitude regions in the Brazilian sector during the super geomagnetic storm on 20 November 2003

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Abstract

Digital ionosondes, of the type known as the Canadian Advanced Digital Ionosonde (CADI), have been in routine operation at São José dos Campos (low latitude region) and Palmas (equatorial region), Brazil, since August 2000 and April 2002, respectively. These CADIs are part of a new network established in a collaborative program between UNIVAP and CEULP/ULBRA. The main objective of the network is to study the equatorial and low-latitude ionospheric regions in the Brazilian sector during both quiet and geo-magnetically disturbed conditions. In this work we present the results of the ionospheric observations related to the superstorm ($|Dst|_{max}$ > 250 nT) on 20 November 2003 in the Brazilian sector, as evidenced by the ionospheric parameter changes from simultaneous ionospheric sounding observations carried out at São José dos Campos and Palmas. A comparison of the observed ionospheric response at the two stations, separated only by about 1460 km, shows considerable latitudinal differences associated with the geomagnetic disturbances. Both the stations show copious storm-time changes.

Introduction

The response of the ionosphere-thermosphere system in the equatorial and low latitude regions during super geomagnetic storms ($|Dst|_{max}$ > 250 nT) are important space weather issues. Geomagnetic storms are extreme form of space weather disturbances. The coronal mass ejection (CME) by sunspot 484 hurled into space on 18 November 2003 hit Earth's magnetic field on 20 November resulting in a super geomagnetic storm with storm sudden commencement (SSC) at 08:03 UT (20/11) and attaining $|Dst|_{max}$ = 472 nT at 20:00 UT (20/11). In this paper we present and discuss the simultaneous ionospheric sounding observations carried out from Palmas (10.2°S, 48.2°W; dip latitude 5.5°S; a near equatorial station and hereafter referred as PAL) and São José dos Campos (23.2°S, 45.9°W; dip latitude 17.6°S; station located under the crest of equatorial ionospheric anomaly and hereafter referred as SJC), Brazil, during this superstorm. The two stations are located nearly in the meridional (magnetic) direction separated by about 1460 km. During geomagnetic storms, the electric fields in the equatorial ionosphere could be affected by two different processes: (1) the solar wind - magnetosphere dynamo, associated with prompt or direct penetration of the magnetospheric convective electric field (e.g., Senior and Blanc, 1984; Spiro et al., 1988) and (2) the ionospheric disturbance dynamo, due to global thermospheric wind circulation associated with Joule heating at high latitude (e.g., Blanc and Richmond, 1980), however, sometimes a mixup of the two effects are possible (e.g. Reddi and Nishida, 1992).

Observations

Figure 1 shows the locations of the two ionospheric sounding stations. The two sounding stations have same local time, with UT = LT + 3 hours.

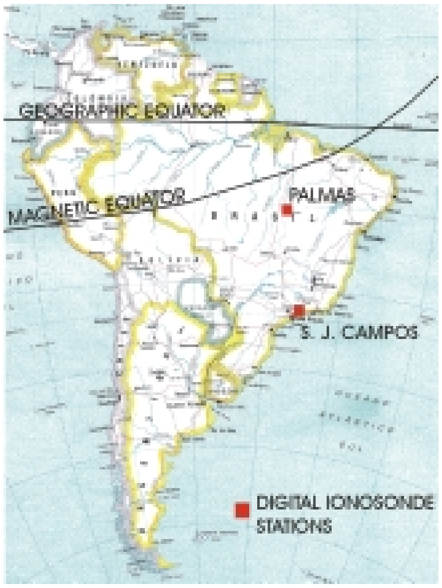

Figure 1 - Map of South America showing the locations of the ionospheric sounding stations and of the geographic and magnetic equators.

Figure 2 shows the UT variations in Kp (intensity of storms; 3-hourly values), Dst (intensity of the ring current; hourly values), SYM-H (1-minute resolution Dst values), and AE (intensity of the auroral electrojet; every 1 minute values) geomagnetic indices during the period 19-21 November 2003. As pointed out by Basu, Sa., et al.

(2005), abrupt decreases in the SYM-H index signify the prompt penetration of high latitude electric fields to low latitude. A perusal of Figure 2 indicates that during the period at about 17:00-18:00 UT, there is a fast decrease in the SYM-H index.

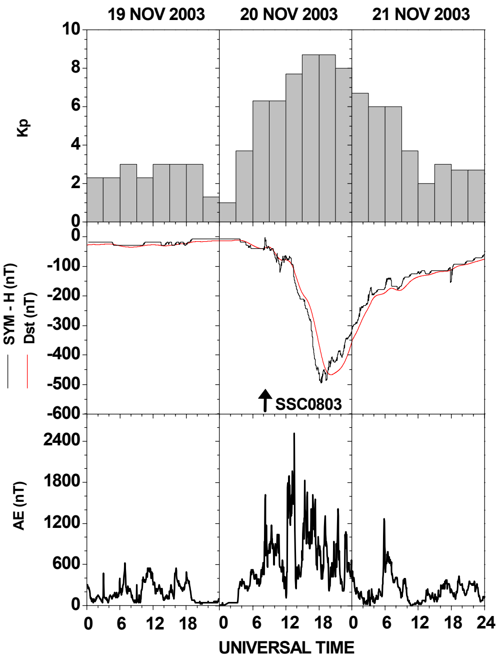

Figure 2 - The variations of the Kp, Dst, SYM-H and AE geomagnetic indices during the period 19-21 November, 2003 16-20, 2002.

Figure 3 shows variations of the ionospheric parameters (minimum virtual height of the F-layer (h′F), critical frequency foF2, and hpF2 (the virtual heights at 0.834 foF2; a proxy for the peak F-layer height (hmF2)) for a period of 24 hours from 12:00 UT on 20 November to 12:00 UT on 21 November. The values reported were obtained every 15 minutes. As pointed out by Danilov and Morozova (1985) the determination of the peak F-layer height (hmF2) using hpF2 is less reliable during the daytime (the altitude hp is overestimated with respect to the true altitude of the maximum of the layer hmF2) than at nightime where hpF2 ≈ hmF2. The quiet time average diurnal patterns of h’F, and foF2 presented in Figure 3 were obtained for each station from several quiet day observations (every 15 minutes) during the month of November 2003.

Results and Discussion

Ionospheric storms have been reviewed by several investigators (e.g., Danilov and Morozova, 1985; Schunk and Sojka, 1996; Abdu, 1997; Buonsanto, 1999). As pointed out by Sastri et al., (2002), the F-region height (e.g. h’F and hpF2) changes during geomagnetic storms are good indicators of vertical electromagnetic drifts. Also, an increase of foF2 from the quiet time average values indicates positive ionospheric storm or phase, whereas decrease indicates negative ionospheric storm or phase and these are important diagnostics for storm-time effects.

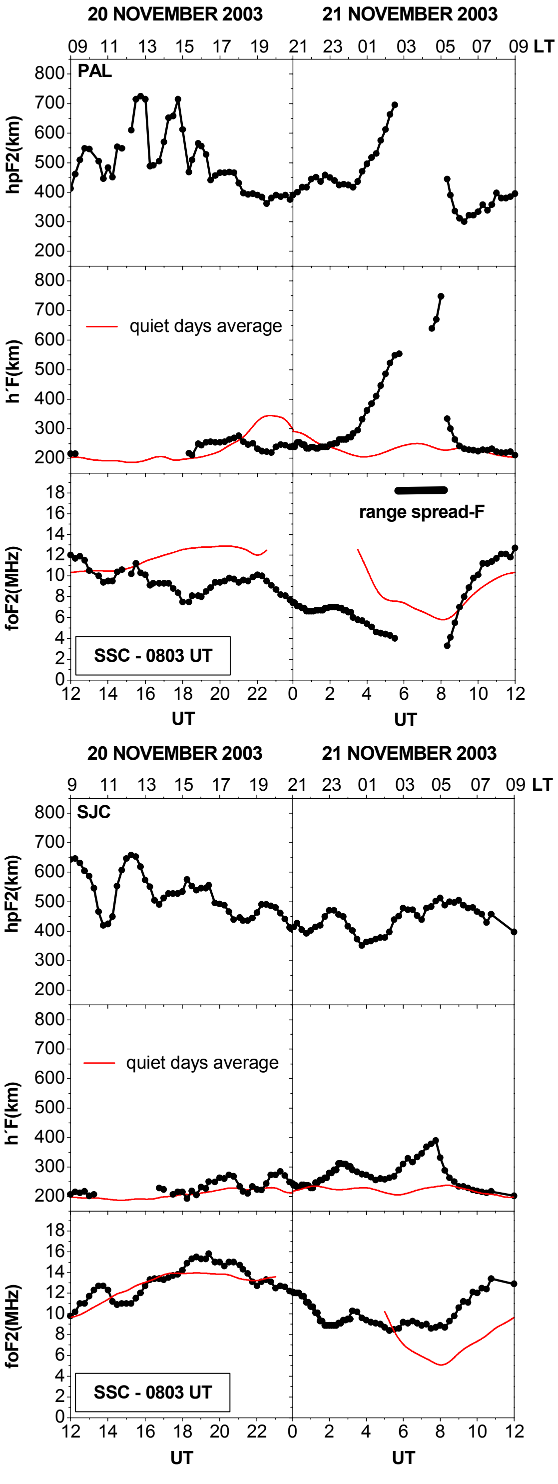

Figure 3 - The variations of h’F, foF2 and hpF2 (dots with line) during 12:00 UT on 20 November to 12:00 UT on 21 November observed at PAL (top) and SJC (bottom). The average quiet-day variations of h’F and foF2 (red line) are also shown.

The main features in the quiet time variations of foF2 shown in Figure 3 are the noon-time bite out at PAL and the equatorial ionospheric anomaly maximizing at about 19:00 UT at SJC. Also, the absence of foF2 values in the pre-midnight period at both PAL and SJC is due the presence of frequent spread-F at these stations. The variations in h′F at PAL shows prominent post-sunset pre-reversal enhancement. The variations in h′F show absence of data during the daytime between about 12:30 to 18:00 UT at PAL and 13:30 to 16:30 UT at SJC due to absorption of radio waves in the equatorial ionosphere (< 7 MHz at PAL and < 5 MHz at SJC). Figure 4 shows the variations of virtual heights at some fixed reflection frequencies (electron densities; iso-frequency plots), observed during the period 19-21 November at PAL and SJC. It is seen in Figure 4 that the absorption of radio waves similar to 20 November are also present on 19 November (quiet day) and 21 November (period of recovery) (Figure 2). Therefore, it appears low frequency absorption of radio waves seen in Figure 3 is not associated with the storm-time effects.

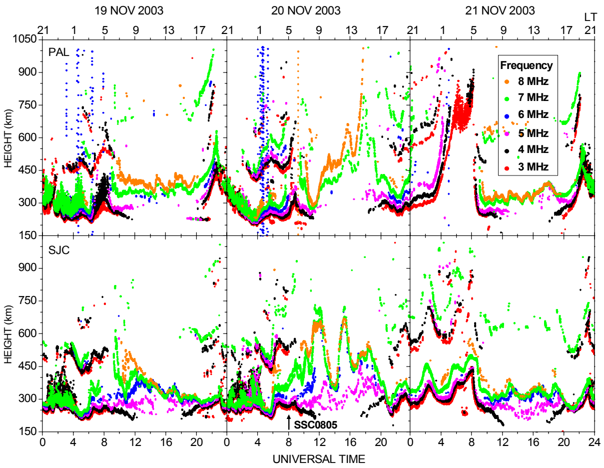

Figure 4 - Virtual height variation plots for different fixed frequencies (iso-frequencies) for the period 19 to 21 November, 2003, observed at PAL (top) and SJC (bottom).

Storm-time h′F and foF2 Variations

The principal features observed during the super geomagnetic storm on 20 November are presented and discussed in this section. A perusal of Figure 3 indicates that, in general, the variations of foF2 during the storm period follow closely the quiet-day average (median values) variations at SJC, with some oscillations over the quiet day average, till about 06:00 UT on 21 November and then show a strong positive storm phase. The foF2 variations at PAL (Figure 3) show a strong negative phase starting at about 15:30 UT (20/11) to about 08:00 UT (21/11) when the foF2 starts increasing as the F-layer goes down. Therefore, both positive and negative effects in foF2 are observed during the storm-time. The formation of the positive and negative storm phases are linked to different magnetosphere-ionosphere interaction channels (Danilov and Morozova,1985). A possible explanation for positive storm effects at low latitudes is electrodynamic lifting (upward drift of ionization) (Prolss and Najita, 1975), whereas negative storm effects are almost certainly caused by changes in neutral composition due to atmospheric disturbances originating in the polar zones (increase in recombination rate).

As mentioned earlier Figure 2 indicates that during the period between about 17:00-18:00 UT, there is a fast decrease in the SYM-H index, providing conditions for the prompt penetration of high latitude electric field to low latitude (Basu, Sa., et al. 2005). However, during this period the Brazilian sector is in daytime and, as discussed by Reddy and Nishida (1992), it is difficult to recognize F-region height variations during daytime. The effect of the prompt penetration of high latitude electric field on November 20 was clearly observed in the ionospheric observations in the African sector, which was in the dusk period (Basu, Su., private communication 2005).

Figure 1 shows that the enhancement of the auroral electrojet index (AE) started soon after the SSC. A perusal of Figures 3 and 4 indicates that after a few hours (2-3 hours) from the SSCs on 20 November, the variations of foF2 and hpF2, at both stations, show near concurrent wave-like disturbances, propagating from SJC toward PAL, during the daytime, possibly associated with high velocity traveling atmospheric disturbances (TADs). Turunen and Mukunda Rao (1980) have reported wave-like disturbances in foF2 at an equatorial station after a few hours of the onset of intense geomagnetic disturbances in the daytime. The observed wave-like disturbances during daytime could be associated with high velocity traveling atmospheric disturbances. As reported by Killeen et al. (1984) and Hajkowicz (1990), sometimes TIDs with velocities in excess of 1200m/sec are generated.

The Joule heating in the auroral region possibly sets up an equatorward neutral wind reaching the equatorial and low latitude regions in the Brazilian sector by the dusk time. Figure 3 shows that the disturbance wind suppressed the post-sunset pre-reversal enhancement at PAL and no spread-F was observed at PAL in the pre-midnight period. The wave-like structures seen at SJC in the F-region heights (Figures 3 and 4) during the period 22:00 to 08:00 UT are possibly associated with the disturbance winds. These structures are not seen at PAL.

A perusal of Figures 3 and 4 indicate that PAL show strong uplifting (indicating the prompt penetration of electric field) of the F-layer (h′f and hpF2) starting at about 03:00 UT (21/11), possibly associated with the isolated substorm starting at about the same time and peaking at about 06:00 UT (21/11). This was followed by spread-F at PAL. The station SJC neither shows uplifting nor spread-F. Possibly SJC was under the influence of strong disturbance winds. The positive storm phase at SJC from about 05:30 UT is possibly associated with the unusual uplifting of the F-layer observed at PAL resulting in transport of plasma to low latitude region due to fountain process.

Conclusions

In this paper we have presented the simultaneous ionospheric sounding observations from to stations Palmas (PAL) and São José dos Campos (SJC), located in the Brazilian sector, during the super geomagnetic storm on 20 November, 2003. Some of the salient features associated with these observations are summarized below.

1. Soon after the SSC on 20 November, the observations at both SJC and PAL exhibited wave-like disturbances both in foF2 and F-region heights during daytime.

2. At PAL, the variations in h′F show considerable reduction in the post-sunset pre-reversal enhancement.
3. The nighttime variations in h'F, at SJC, show strong oscillations on the night of 20-21 November. No such variations were observed at PAL.
4. During the early morning hours of 20 November (UT), the observations at PAL show unusual lifting of the F-region followed by spread-F. No uplifting and spread-F are observed at SJC.
5. Both positive and negative effects in foF2 are observed during the storm-time at PAL and SJC.

Acknowledgments

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