Extreme changes in the equatorial electrojet under the influence of interplanetary electric field and the associated modification in the low-latitude *F* region plasma distribution

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[1] A case of the drastic effects of an eastward prompt penetration and a westward overshielding electric field successively affecting the daytime equatorial ionosphere during the space weather event that occurred on 24 November 2001 is presented. Under the influence of the strong eastward prompt penetration electric field starting from 11:25 Indian standard time (IST), the equatorial electrojet (EEJ) strength reached the maximum value of 225 nT at 12:42 IST, almost 7 times greater than the monthly quiet time mean at the same time. This peak EEJ value exceeds the maximum observed values during the month of November for the entire solar cycle by more than 100 nT, irrespective of quiet or disturbed conditions. Further, owing to an ensuing overshielding event that occurred during the main phase of the storm rather than the end of the main phase, this unusually large EEJ showed an equally strong polarity reversal along with a weakening of the sporadic *E* layer over the equator. The EEJ strength was reduced from +225 to −120 nT at ∼13:45 IST, resulting in a strong counter electrojet condition. The latitudinal variation of the *F* region electron density data from the CHAMP satellite reveal an ill-developed equatorial ionization anomaly at 17:00 IST (11:24 UT) over the Indian sector due to this significant weakening of the zonal electric field. These observations showcase the significant degree to which the low-latitude ionosphere can be affected by the interplanetary electric field.

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1. Introduction

[2] During space weather events, the equatorial and low-latitude ionosphere is subjected to the penetration of the interplanetary electric field (IEF) through the magnetosphere-ionosphere system. During a period of sudden southward turning of the Z component of the IMF (IMF Bz), the shielding effect at the inner edge of the ion population region of the ring current becomes partially ineffective and the Y component (dawn to dusk) of the interplanetary electric field (IEF) penetrates promptly. As a result of this, the effective electric fields and associated drifts at the magnetic dip equator are enhanced [e.g., *Fejer et al.*, 1990]. This penetration electric field has often eastward polarity in the day sector and westward polarity in the night sector [*Sastri*, 2002]. The dayside low- to middle-latitude ionospheric response to this prompt penetration (PP) effect includes enhancement in the total electron content (TEC) [e.g., *Maruyama et al.*, 2004; *Tsurutani et al.*, 2004]. In addition to this, the daytime equatorial ionization anomaly (EIA) is found to intensify in amplitude as well as in latitudinal extent in association with the prompt penetration electric field [e.g., *Lin et al.*, 2005; *Mannucci et al.*, 2005; *Zhao et al.*, 2005; *Balan et al.*, 2010]. Similarly, the prompt penetration of eastward interplanetary electric field occurring at the local sunset time can trigger equatorial spread *F* [e.g., *Chakrabarty et al.*, 2006; *Tulasi Ram et al.*, 2008; *Bagiya et al.*, 2011].

[3] On the other hand, during a period of rapid northward turning of the IMF Bz after a sustained southward polarity, the convection electric field is decreased abruptly, and an overshielding effect occurs [e.g., *Fejer et al.*, 1979; *Kelley et al.*, 1979] when the sluggish residual shielding electric field in the inner magnetosphere slowly decays and exerts an electric field influence in the low-latitude ionosphere with an opposite polarity [e.g., *Kelley et al.*, 1979; *Kikuchi et al.*, 2008]. The eastward overshielding electric field over the dip equatorial ionosphere can cause

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the resurrection of plasma plume structure during premidnight hours [e.g., *Chakrabarty et al.*, 2006], whereas the westward overshielding electric field can cause the suppression of the prereversal enhancement in the zonal electric field, which, in turn, leads to the stability of the postsunset *F* layer [*Abdu et al.*, 2009]. This westward overshielding electric field is also found to cause substantial decreases in the daytime zonal *E* region electric field and the EEJ current [e.g., *Rastogi*, 1977; *Kikuchi et al.*, 2000, 2003; *Sastri et al.*, 2003]. The reversal in the direction of the daytime eastward equatorial electrojet is termed as counter electrojet (CEJ) which is manifested as a depression in the magnetic field values below the nighttime level at the dip equatorial region [*Gouin and Mayaud*, 1967]. The causative mechanism for the quiet time CEJ is still being debated [e.g., *Raghavarao and Anandarao*, 1980; *Somayajulu et al.*, 1993, *Stening et al.*, 1996; *Gurubaran*, 2002]. Moreover, there have been observations that CEJ events can occur in association with the changes in the interplanetary electric field (IEF) during geomagnetic storms and substorms. It was observed that the northward turning of the IMFBz, after a sustained southward polarity, caused substantial decrease in the electric field and the EEJ at the dayside equator during a geomagnetic storm [*Rastogi*, 1977]. The VHF radar measurements showed the presence of a westward electric field in the daytime equatorial ionosphere [*Reddy et al.*, 1979, 1981] and a reversal in the electrojet current [*Kikuchi et al.*, 2003], during substorms. Recently, using the radar observations from São Luís, Brazil, *Shume et al.* [2011] reported the inhibition of large-, medium-, and short-scale electrojet plasma waves, along with occurrence of CEJs caused by the overshielding electric field. The evidence of a westward electric field, superimposed on the normal eastward Sq electric field, associated with polar substorm activity is also reported [*Kobea et al.*, 1998, 2000; *Kikuchi et al.*, 2000]. However, in general, the overshielding condition is known to be mostly generated when the auroral conductivity decreases abruptly near the end of the growth phase of the ring current [*Ebihara et al.*, 2004].

[4] The degree of influence of IEF on EEJ can vary from event to event. Here we provide an example of the prompt penetration of IEF_Y that enhanced the magnitude of EEJ drastically and a subsequent overshielding condition that reversed the polarity and generated a CEJ condition. There is a clear correspondence between the overshielding and the northward turning of the IMF. This type of overshielding has already been reported [*Rastogi*, 1977; *Kelley et al.*, 1979; *Fejer et al.*, 1979; *Kikuchi et al.*, 2003]. However, the uniqueness of this event is that the main phase continues even after the over shielding event (as evident from SYM-H). Hence, this overshielding event does not trigger the recovery of the storm, although there is a reduction in convection due to the northward turning of the IMF. Interestingly, the overshielding does trigger the recovery of the substorm, as evident from the variation of the AL (Figure 2). Moreover, we also investigate the impact of this overshielding event on the *F* region plasma distribution over low latitudes in the Indian region.

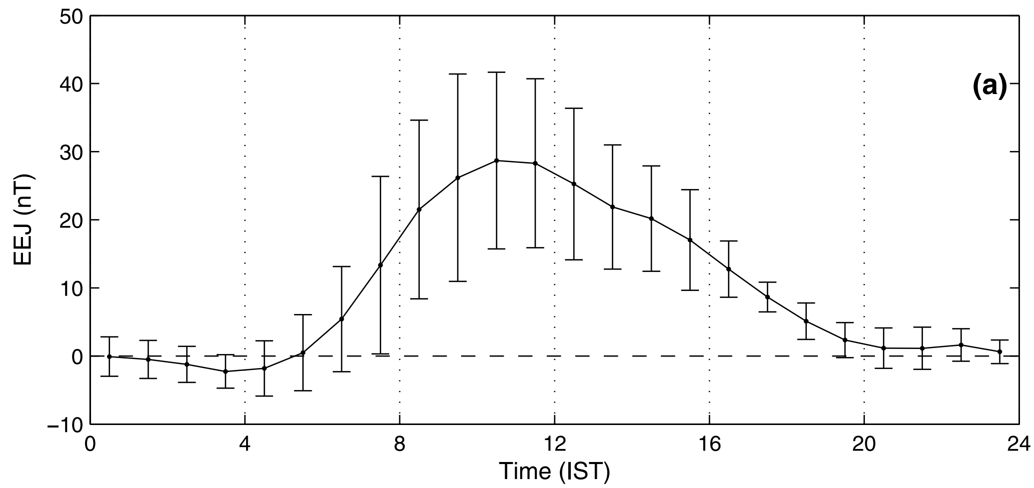
2. Data and Method of Analysis

[5] The response of the equatorial ionosphere in the Indian sector to a geomagnetic storm on 24 November 2001 (Ap = 104) is analyzed. The dawn-to-dusk component (Y component) of interplanetary electric field (IEF_Y) is calculated on the basis of the solar wind velocity and IMF measurements by the Advanced Composition Explorer (ACE) satellite located at the first libration point (L1 point) of the Sun-Earth system. The ACE data provided in the CDAWeb (http://cdaweb.gsfc.nasa.gov) are time shifted up to the nose of the bow shock. In order to have a meaningful comparison of the IEF_Y data with the ionospheric measurements, this IEF_Y time series is further shifted by the propagation lag up to the ionospheric observations. The same formalism for the calculation of propagation lag is adopted as described in detail by *Chakrabarty et al.* [2005]. In the present case the propagation lag from the bow shock nose to the ionospheric observations, during the interval of interest varies from a minimum of 4.8 min to a maximum of 13.8 min. The polar cap index (PC index), which is a proxy of the ionospheric electric field in the near-pole region [*Troshichev et al.*, 2000] and the high-resolution SYM-H (1 min) data are used to represent the magnetospheric ring current variations [*Iyemori and Rao*, 1996].

[6] The high-resolution (1 min) magnetic field data from Tirunelveli (8.3°N, 77.8°E, dip latitude 0.6°N) and Visakhapatnam (17.67°N, 83.32°E, dip latitude 9.8°N) are used to derive the EEJ strength. The EEJ values are obtained by subtracting the ΔH values of Visakhapatnam from that of Tirunelveli. Apart from this, the ionograms from Trivandrum are used to investigate the sporadic *E* layer characteristics. To study the EIA development based on the latitudinal variation of electron density, the data from the Planar Langmuir Probe (PLP) onboard CHAMP satellite ($\sim$400 km) are used.

3. Observations

[7] Figure 1a shows the mean temporal variation (hourly values) of EEJ during 14–23 November 2001. The error bars indicate the standard deviations which represent the variability within these 10 days prior to 24 November 2001, which is the event day. The mean EEJ strength shows a maximum of $\sim$28 $\pm$ 13 nT. It must be mentioned here that the "geomagnetically quietest day" was 3 November (Ap = 2), for which the maximum EEJ strength was $\sim$96 nT. Figure 1b shows the comparison of the mean EEJ variation with that on 24 November 2001, prior to the space weather event. One minute resolution data are used for this day. It can be seen that, prior to the space weather event (until 10:00 IST), the EEJ variation was normal, with values within the quiet time variability. Figures 2a–2d show the variations of the IEF_Y, polar cap index, SYM-H, and AL indices during 06:00–18:00 IST (Indian standard time = universal time (UT) + 5.5 h) on 24 November 2001. The sudden commencement of the storm (SSC) is indicated by the arrow in the SYM-H plot. IEF_Y first changed its polarity at $\sim$11:25 IST corresponding to the southward turning of the IMF Bz. Following this, IEF_Y changed from ~-15 mV/m to +34 mV/m in $\sim$50 min. At 12:42 IST, IEF_Y reversed again in response to the sudden northward turning of the IMFBz. IEF_Y changed from 34 mV/m to -15 mV/m within 10 min. The PC index showed corresponding enhancement during 11:25–12:42 IST and decrease thereafter (Figure 2b). Figure 2c shows the variation in the SYM-H values. It is



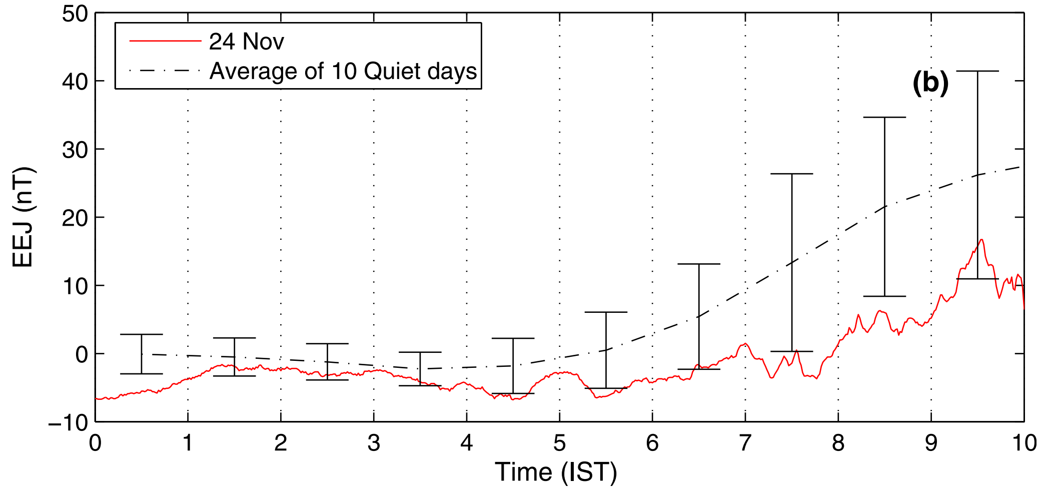


Figure 1. (a) Variation of equatorial electrojet (EEJ) during 10 quiet days in November 2001. The average values are plotted, where the error bars indicate the standard deviation. (b) Comparison of EEJ variation from 00:00 to 10:00 LT on 24 November 2001, with the quiet day values, before the prompt penetration event.

seen that SYM-H increased abruptly with the southward turning of the IMFBz at 11:25 IST revealing the SSC. This increase in the SYM-H is indeed caused by an increase in the solar wind dynamic pressure. The main phase of a geomagnetic storm ensued after the SSC. Figure 2d shows the temporal variation in the westward auroral electrojet for which AL is a proxy. Significant substorm activities were found to occur during the post-SSC period. There is a clear correspondence between the overshielding and the northward turning of the IMF, and hence there is a reduction of the convection electric field. This triggers the recovery of the substorm (as evident from the variation of AL, shown in Figure 2b). It is verified (not shown) that the period 14–23 November did not have any major storm, which actually rules out the possibility of the presence of any effect due to a disturbance dynamo mechanism on 24 November 2001.

[8] In order to facilitate comparison, a blown-up version of Figure 2a is reproduced as Figure 3a wherein the variation of IEF_Y is shown. The temporal variation in EEJ during 06:00–18:00 IST is shown in Figure 3b. The four distinct phases of the IEF_Y variations on 24 November are marked as 1–4 in Figure 3a. Phase 1 is the absolute quiet period wherein IEF_Y remains almost close to zero. SSC occurs around 11:25 IST, as indicated by the arrow and this is marked as phase 2. The IEF_Y increases to +34 mV/m in the next ~50 min, which is termed as phase 3. The overshielding event is marked as the phase 4 in the IEF_Y variation. The temporal variation of EEJ on this day and the mean EEJ variation for the previous 10 quiet days in this month on the same scale as 24 November (green line) and also on a separate scale (pink line) are shown in Figure 3b. The four distinct phases of the EEJ variations on 24 November are marked as 1–4. During phase 1, the EEJ strength was comparable with the quiet time values, as already shown in the Figure 1b. This phase lasted till the prompt penetration took place. The EEJ enhanced almost by 40 nT starting at ~11:25 IST, almost simultaneous with the enhancement in the IEF_Y (phase 2). The penetration electric field enhanced the EEJ strength to significantly higher values,

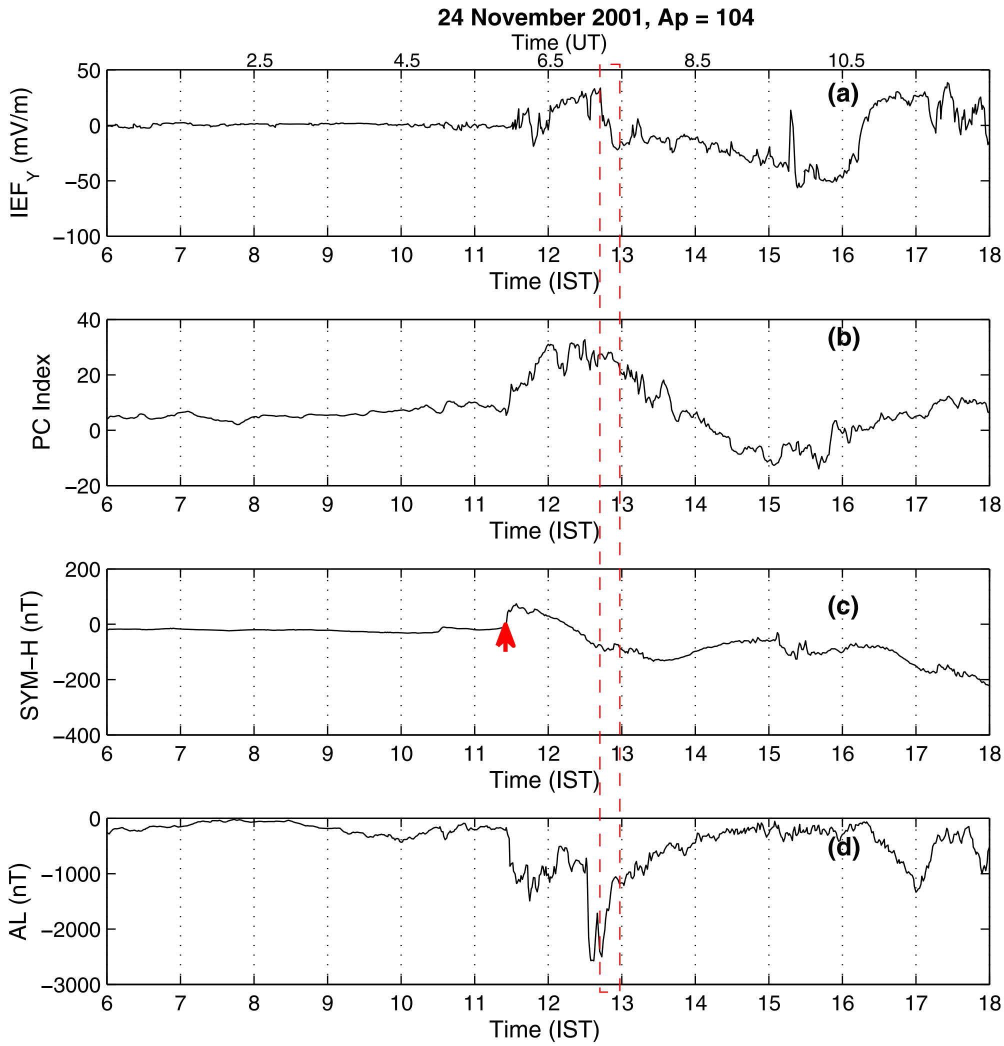


Figure 2. Variation of Interplanetary parameters on 24 November 2001.

compared to the quiet time values. The EEJ strength reached its maximum at 12:40 IST (phase 3), and started to decrease afterward. The observed EEJ maximum of ∼220 nT, is significantly higher than the corresponding quiet time maximum during the previous 10 days. Nonetheless, this peak EEJ value is one of the highest values observed during the entire solar cycle. This aspect will be discussed in section 4.2. The EEJ responds almost instantaneously to the polarity change of the IEF$_Y$ (overshielding) that started at 12:42 IST. The EEJ current drops from around 12:43 IST (phase 4) and reaches the negative maximum at 13:30 IST (maximum CEJ strength), then recovers gradually. It is to be mentioned here that this magnitude of CEJ strength is also an example of a drastic change. It must be mentioned here that the 1 min averages of the 210 Magnetic Meridian magnetic field data (http://center.stelab.nagoya-u.ac.jp/web1/sramp/eng/datact03/srmdb21.html) clearly show that similar changes are seen at all the stations from the equatorial to polar region, and hence it corroborate with our findings.

[9] Over the magnetic equatorial location of Trivandrum, the sporadic *E* (E_{Sq}) layer is strongly associated with the daytime EEJ, which is generated by the eastward electric field. Hence we checked the time sequence of ionograms at Trivandrum to see the E_{Sq} features. Figure 4 shows the ionograms at 12:30 IST (before the northward turning of the IMF) and 13:30 IST, 14:15 IST (during the CEJ phase) and at 1630 (after the CEJ event). The trace at 12:30 IST is showing the normal E_{Sq} feature. However, there is a weakening of the E_{Sq} trace over equator, associated with CEJ onset. This weakening of E_{Sq} in association with CEJ has been earlier reported [*Rastogi and Patel*, 1975; *Rastogi*, 1997]. In the present case, the weakening of the E_{Sq} layer is seen in the ionograms from 13:30 IST onward. At 14:45 IST, the electrojet current polarity is still westward (though the maximum westward phase is over) and hence, even though the Es trace shows a slight spread, the E_{Sq} signature is still weak and not very clear. Similarly, the ionograms at 15:00 IST, 15:30 IST, etc., also shows the presence of Es layer, without much spread. The clear E_{Sq} feature reappears around 16:30 IST, when the EEJ current polarity recovered back to eastward.

[10] It must be remembered that the same east-west electric field over the low-latitude *E* region, maps to the equatorial *F* region, causes the fountain effect and the formation of EIA. The CEJ occurrence and the E_{Sq} weakening over the

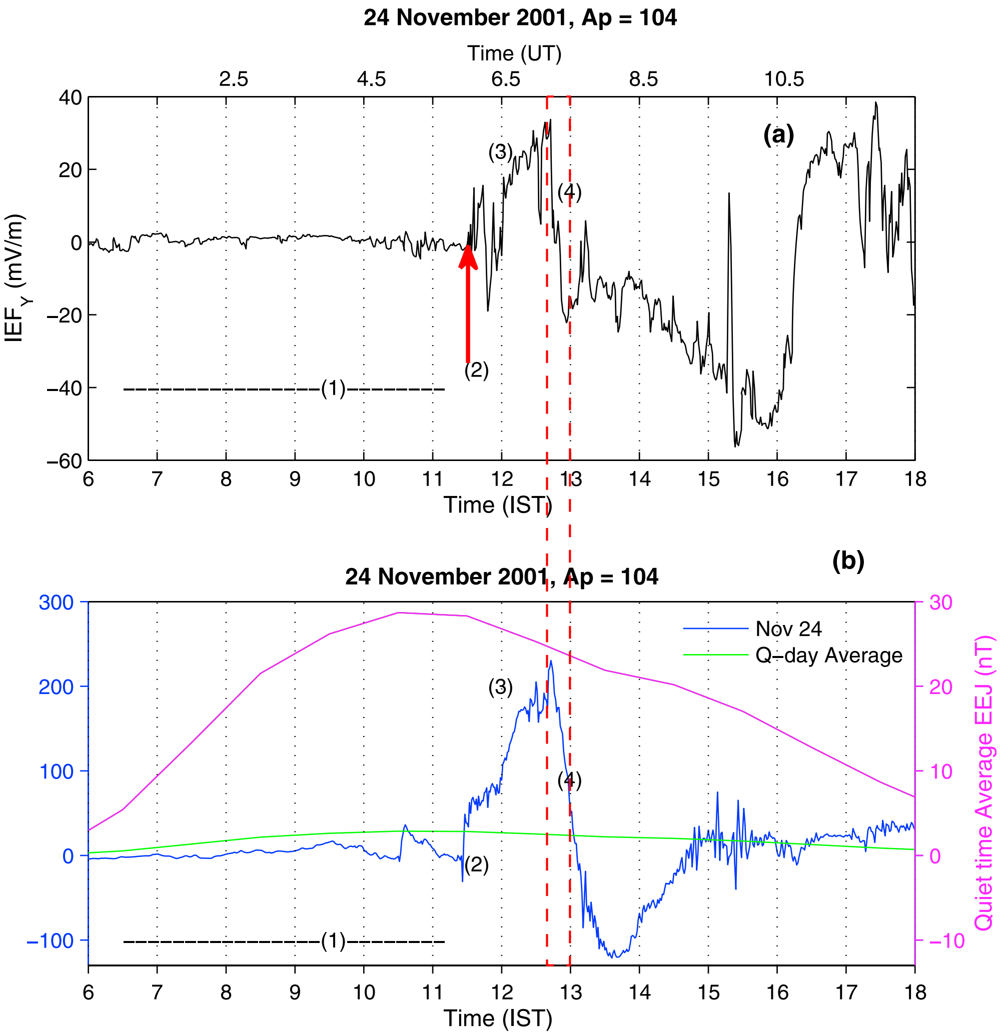


Figure 3. (a) Variation of IEF$_Y$ on 24 November 2001. The red arrow indicates the prompt penetration, and the dashed rectangle indicates the overshielding event. The different phases of IEF$_Y$ variation are marked with numbers 1–4. (b) Variation of EEJ on 24 November 2001, along with the quiet day variation for comparison. The quiet day mean values are plotted using hourly values, and they are plotted both on the same scale as that for 24 November (left *y* axis; quiet day mean is plotted in green) and on an expanded scale (right *y* axis; quiet day mean is plotted in pink). The standard deviations of the quiet day mean values are shown in Figure 1.

dip equator suggests the possibility of the influence of a significantly large westward overshielding electric field over the Indian low-latitude region which, in turn, can affect the development of EIA on this day [*Veenadhari et al.*, 2010]. To check this aspect, we have plotted CHAMP electron density profile on this day and compared it with another quiet day of the same month. The observations are in the 84–89°E longitude sector. Figure 5 shows the latitudinal evolution of electron density for the storm day of 24 November 24 2001 and for a quiet day of 14 November 2001 (Ap = 3). On the quiet day, a clear EIA is seen with reduced electron densities near dip equator and enhanced electron densities near ±15°–20° latitude regions, which is expected at 12:30 UT in the 84°E sector (18:08 LT). But the EIA pattern is totally distorted during the storm day and the crests are completely subdued. The observation is at 11:24 UT in the 89°E longitude sector (17:02 LT). A corresponding increase of electron density in the trough region, compared to the quiet day, again confirming the reduced EIA on this day.

4. Discussion

[11] An undershielding (prompt penetration)/overshielding mechanism has been proposed for a long time to explain how the interplanetary/magnetospheric electric field penetrates to the low-latitude ionosphere [*Vasyliunas*, 1972; *Jaggi and Wolf*, 1973; *Wolf*, 1974; *Southwood*, 1977]. The present case study is an example of the extreme and successive variations in the equatorial and low-latitude electric field caused by prompt penetration (PP) and overshielding. In the context of the shielding and overshielding phenomena, this event is important because the overshielding occurred during the storm main phase. As we know, the overshielding events are known to trigger recovery phase of

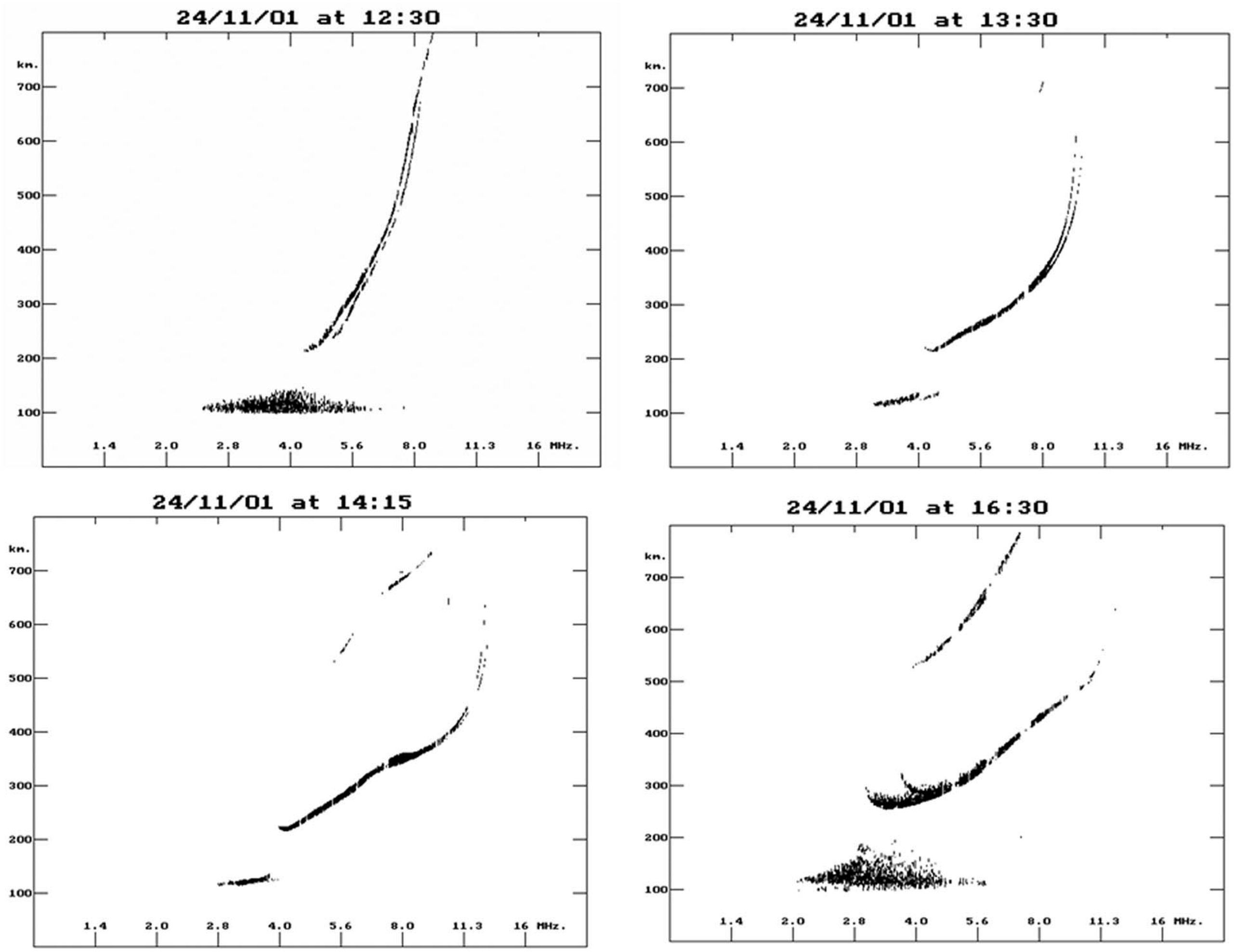


Figure 4. Ionograms from Trivandrum, showing the E_{Sq} layer variations.

the geomagnetic storms and trigger the substorms, or trigger the recovery of substorms [e.g., *Chakrabarty et al.*, 2008; *Kikuchi et al.*, 2008; *Veenadhari et al.*, 2010]. Unlike this, the event reported here occurs in the main phase of the storm, and the main phase continues even after the overshielding event. Hence, this overshielding event does not trigger the recovery of the storm, although there is a reduction in the convection due to the northward turning of the IMF Bz. Interestingly, the overshielding does trigger the recovery of the substorm, as evident from the variation of the AL (Figure 2). Hence, this event is uniquely different and poses a very important question on what sustains the storm even when conditions are not favorable.

[12] As mentioned earlier, the effects of PP and overshielding over the equatorial ionosphere are reported by *Kikuchi et al.* [2008]. They have shown the penetration of the magnetospheric electric field to the equatorial ionosphere during the geomagnetic storm on 6 November 2001, by analyzing the difference in magnitude of the geomagnetic storm recorded at the dayside geomagnetic equator, Yap (0.3°S magnetic latitude) and low latitude, Okinawa (14.47°N magnetic latitude). The penetrated electric field caused eastward currents during the main phase of the storm, while the overshielding currents, i.e., westward currents dominated during the recovery phase. In contrast to this, the event on 24 November 2001 is an example of the successive eastward and westward currents, both during the main phase. In the context of the ionospheric response, this event showcases (1) the extremely high EEJ peak values as a

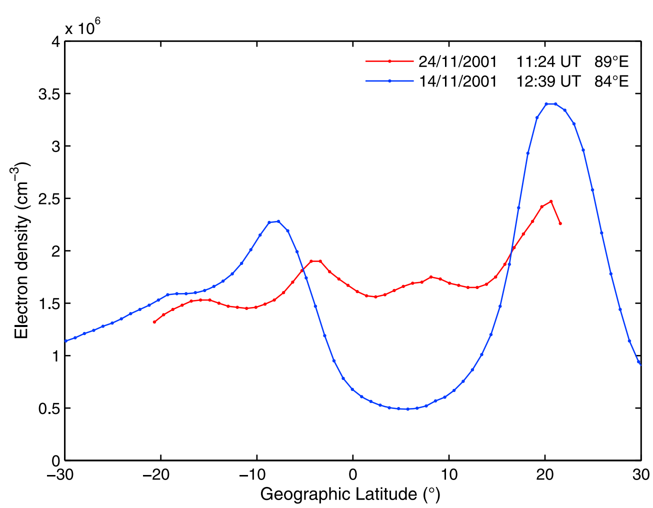


Figure 5. Latitudinal variation of electron density obtained from CHAMP for 24 November 2001 and 14 November 2001.

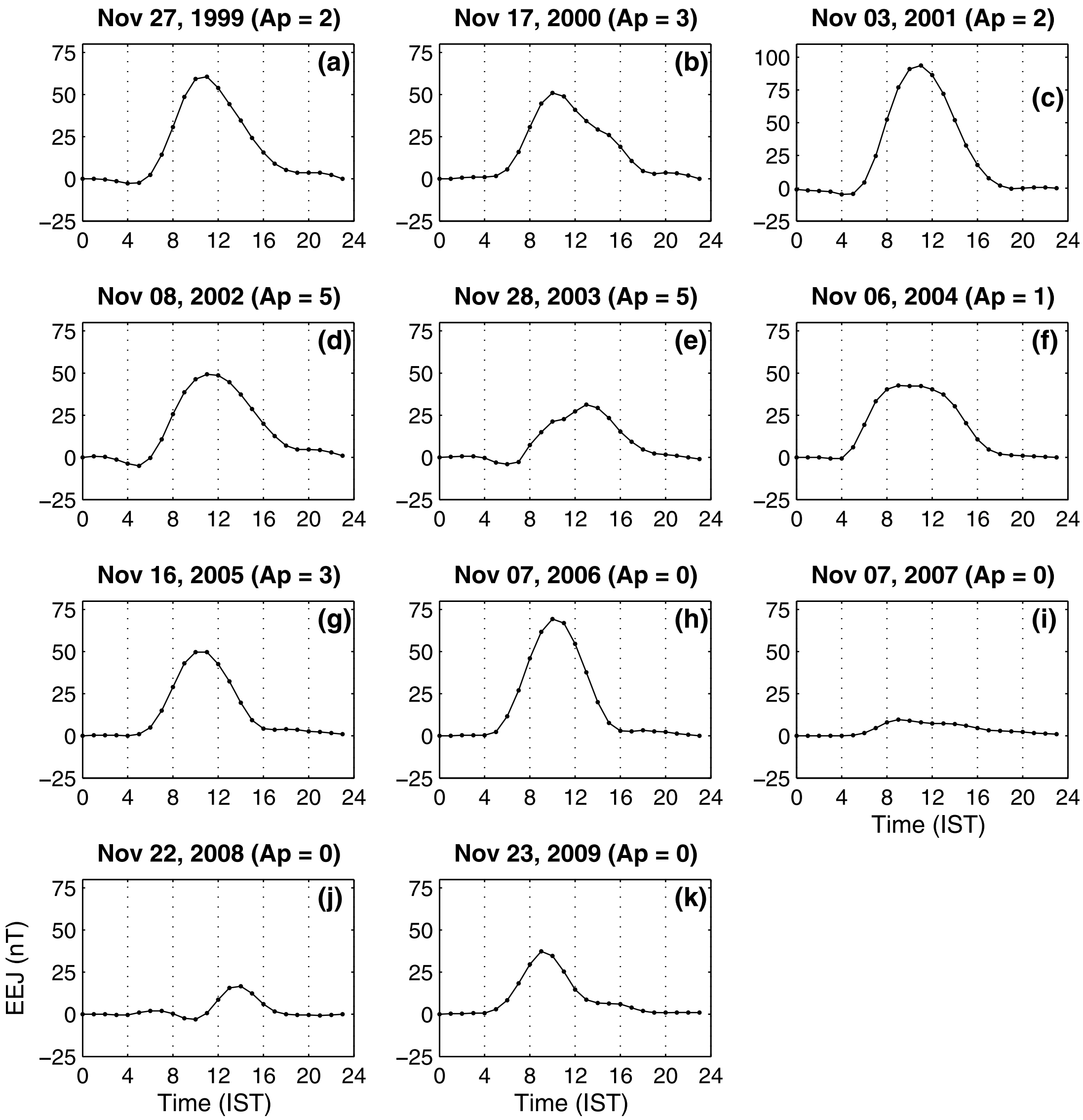


Figure 6. EEJ variation during the quietest days in November for the entire solar cycle.

result of the enhancement in the eastward electric field due to prompt penetration and (2) the very strong CEJ caused by the overshielding event happened nearly 1 h and 17 min after the prompt penetration.

4.1. Extremely High Magnitudes of Peak EEJ Current Under Penetration Electric Field

[13] During a period of southward IMF, the convection electric field can penetrate to the low-latitude ionosphere [*Vasyliunas*, 1972; *Jaggi and Wolf*, 1973; *Crooker and Siscoe*, 1981; *Senior and Blanc*, 1984; *Kikuchi et al.*, 2000]. Direct penetration of the interplanetary electric field can cause enhancement in the equatorial daytime eastward electric field, which, in turn, can result in an increase in the EEJ current over the equator, almost simultaneously. Although the time constant for the shielding effect being effective at low latitudes was found to be 17–20 min theoretically [*Senior and Blanc*, 1984] and observationally [*Somayajulu et al.*, 1987; *Kikuchi et al.*, 2000], there are ample cases when long duration penetration events are found to take place [e.g., *Kelley et al.*, 2003; *Huang et al.*, 2005]. In this case, the prompt penetration caused an enhancement in eastward electric field and as a result of this the peak electrojet strength reach unusually high value of ∼225 nT. It must be mentioned here that, these are the highest magnitudes of EEJ peak strength for November, for the entire solar cycle. Figure 6 depicts the EEJ variation (hourly values) during the quietest days in November, for the entire solar cycle. The days are chosen from the “international quiet days” published by WDC for Geomagnetism, Kyoto University (http://wdc.kugi.kyoto-u.ac.jp/qddays/index.html). It can be seen that the maximum EEJ strength observed was on 3 November 2001 (the quietest day in November 2001), which was still less than 100 nT, as compared to 24 November 2001. Apart from this, the peak EEJ strength during November varied between ∼27 nT and 62 nT, except for the years 2007 and 2008. For these 2 years during the “deep solar minimum period” the EEJ values also showed very low peak values. The important point to be noted here is that EEJ peak values never exceeded 100 nT for both the

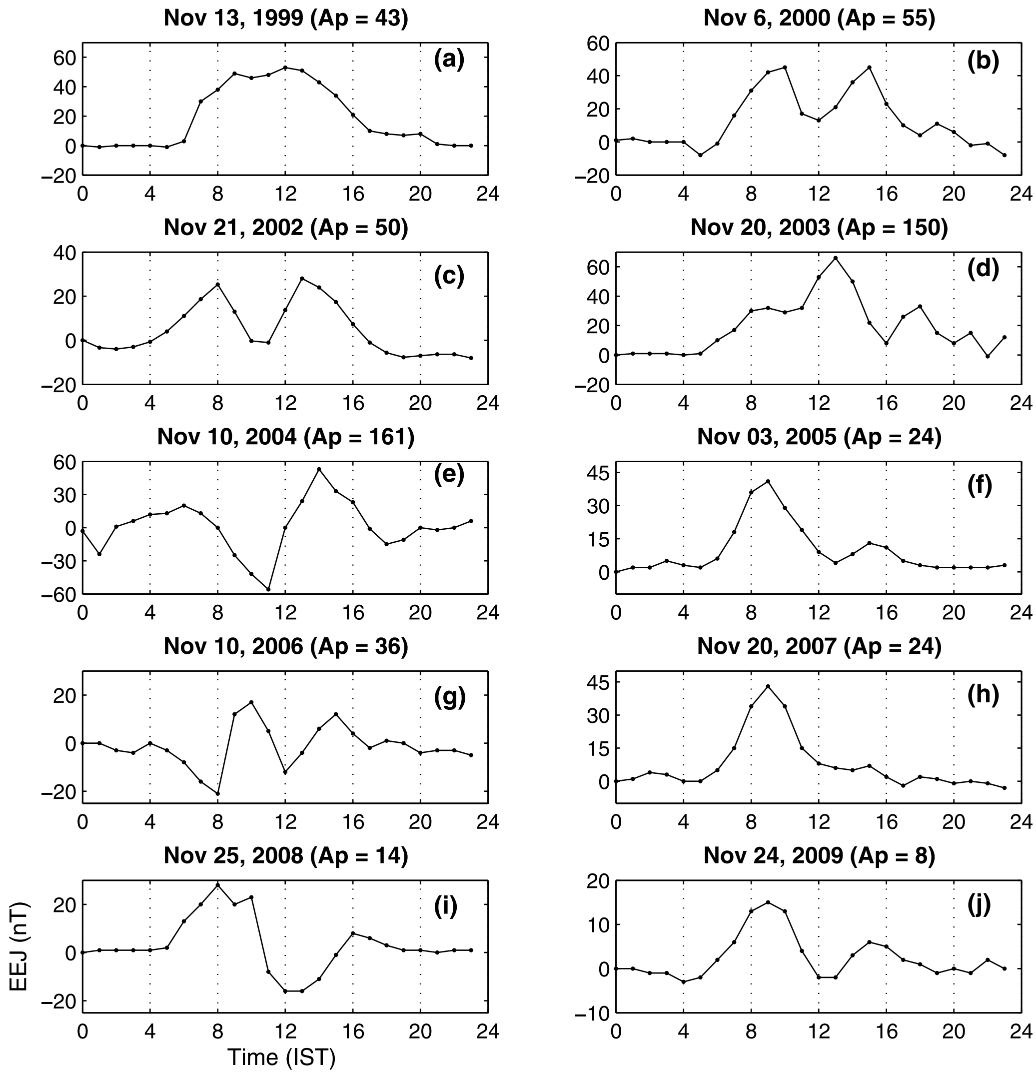


Figure 7. EEJ variation during the most disturbed days in November for the other years in the solar cycle. Note that the scale of the *y* axis is not the same in all plots.

quietest and most disturbed days during November, for the entire solar cycle. Figure 7 depicts the EEJ variation during the "most disturbed" days in November, for the other years of this solar cycle. These days are also chosen from the WDC for Geomagnetism, Kyoto University. It is to be noted that, we have not considered factors like the phase of the disturbance, and the EEJ variation shown here could be reflecting the response to different processes during space weather events. However, it is very clear that, the maximum EEJ value never exceeded 75 nT (which was observed on November 20, 2003), and the maximum CEJ was only ∼−60 nT (prenoon CEJ, 10 November 2004). The most disturbed day in November 2001 was 6 November (Ap = 142). Though Ap was less on 24 November, the 3-hourly indices during the day (Ap) were up to 179, which is quiet significant; 6 November became most disturbed day because disturbance was severe during the night hours (3-hourly Ap = 300). So the disturbance did not have any effect on daytime EEJ. Hence, the event on 24 November 2001 is really an example of one of the extreme changes recorded in the entire solar cycle because of the PP electric field.

[14] It must be mentioned here that by selecting the quietest and most disturbed days does not ensure that the largest EEJ or CEJ is captured, as the variability of these are also governed by other factors, which contribute toward the day-to-day variation. However, the variations on a quietest day could very well represent the typical local time variation of EEJ. The typical quiet time day-to-day variability could contribute a variation of even ± 20 or ± 30 nT (as seen in Figure 1). Similarly, there could be some underestimation of the EEJ magnitude because we are taking the hourly averages. However, on 24 November, the EEJ strength reached the maximum value of 225 nT which is almost 7 times greater than the monthly quiet time mean at the same time. This enhancement is far greater than the differences that could be caused by the usual quiet time day-to-day variations due to other factors and the averaging procedure. Similarly, just by choosing the most disturbed days, it is not certain that the highest EEJ or CEJ is captured, because the ionospheric response to the space weather event depends on local time and the phase of the disturbance (SSC or main

phase or recovery phase). The curves presented here only show the variations during few most disturbed days, and the 24 November event shows changes with far greater magnitudes. Therefore, the present investigation is not about the selection of the most extreme event but about the nature of the response of the equatorial ionosphere given the extreme nature of the event.

[15] Another example of an extremely high value for peak EEJ during the 15 May 2005 space weather event is reported by *Bagiya et al.* [2011]. During this event the prompt penetration was of similar magnitudes, IEF_Y reached up to ~40 mV/m, and as a result of this the EEJ current enhanced, and the peak EEJ strength reached up to ~220 nT. During both these events IEF_Y magnitude was extremely subdued, till the prompt penetration occurred. A CEJ was also observed during this event. Nonetheless, they have not addressed the variations of EEJ vis-à-vis IEF_Y changes. Rather, the focus of their work was on the changes in the total electron content and neutral composition. In the present case, an overshielding event occurred near the beginning of the main phase of the storm rather than the end of the main phase, and we clearly show that under the influence of this overshielding electric field, strong polarity reversal of the EEJ, along with a weakening of E_{Sq} is observed over equator, and the fountain mechanism over the low latitudes is inhibited.

4.2. Overshielding and Its Effects on the Low-Latitude Electric Field

[16] Overshielding occurs when the shielding electric field becomes dominant over the convection electric field. Such a situation occurs when the IMF suddenly turns northward after a prolonged southward orientation because the magnitude of the pressure gradients in the inner magnetosphere remains strong for a while after the sudden decrease in the convection electric field [*Spiro et al.*, 1988; *Peymirat et al.*, 2000; *Ebihara et al.*, 2008]. With the sudden northward turning of the IMF, the convection electric field would weaken rather rapidly, whereas the region 2 current would persist for some time. Then, the electric field generated by this current (overshielding electric field) would dominate over the convection electric field [*Ebihara et al.*, 2008]. *Kelley et al.* [1979] concluded that the causal relationship between the *F* region electric field fluctuations over the dip equator and the sudden northward turning of the IMF Bz [*Rastogi and Patel*, 1975; *Fejer et al.*, 1979] is through this overshielding electric field. The evening time westward overshielding electric field can cause the suppression of the ESF irregularities [*Abdu et al.*, 2009] whereas the premidnight eastward overshielding electric field over the dip equatorial ionosphere can cause the resurrection of ESF irregularities [*Chakrabarty et al.*, 2006].

[17] The equatorial CEJs are also seen to be associated with the northward turning of IMF, which was also related to the rapid decrease in the equatorial electric field measured at Jicamarca incoherent radar as well as to a decrease the polar cap potential [*Kikuchi et al.*, 2003]. This was identified as a substorm related CEJ, caused by the dominant region 2 field aligned currents, when the region 1 field aligned currents decrease abruptly because of the northward turning of the IMF. It was suggested that the equatorial CEJs are most likely to occur during substorms, and the northward turning of the IMF and the resultant decrease in the polar cap potential are important under overshielding conditions with well-developed region 2 field aligned currents [*Kikuchi et al.*, 2003].

[18] Overshielding electric field is generally found to be important during substorm activity [*Kikuchi et al.*, 2003] and also when the auroral conductivity decreases rapidly near the end of the growth phase of the ring current, triggering the recovery phase [*Ebihara et al.*, 2004]. However, the overshielding event presented here is associated with the northward turning of the IMF during the main phase of the storm and during daytime over the Indian sector. In other words, the overshielding event presented here does not trigger the recovery phase of the geomagnetic storm although the recovery phase of the substorm is found to be concomitant with it. The westward overshielding electric field was effective from 12:42 IST, and the maximum CEJ was observed around 13:30 IST, when the electric field was maximum westward. The equatorial electric field continued to be westward till 15:00 IST. It must be remembered that the decay time of the overshielding electric field can be 30 min to more than 1.5 h [*Peymirat et al.*, 2000], which corroborate with these observations. The disappearance of E_{Sq} in the ionograms, CEJ and the reversal of the daytime ionospheric drift are understood to be concurrent phenomena [*Rastogi et al.*, 1971]. The weakening of the E_{Sq} layer, further confirms the decrease in the eastward electric field during daytime. The effect of the overshielding electric field is felt over the low-latitude *E* region as well (which gets mapped into the *F* region altitudes over equator causing the fountain effect), and this resulted in the inhibition of the equatorial ionization anomaly (EIA). While it comes to the manifestation as EIA, there is a characteristic time delay associated with the changes the electric field to manifest in the EIA crest density [*Raghavarao et al.*, 1978; *Sastri*, 1990]. Usually a lag of ~2 h for the change in the electric field to be manifested in the EIA crest densities is quite expected [*Rush and Richmond*, 1973; *Raghavarao et al.*, 1978]. Hence, the reduction in the EIA at ~17:00 LT confirms the presence of the westward electric field (which is responsible for the CEJ), which inhibited the fountain, and suppressed the formation of EIA crests. Considering the fact that the electric field was still westward at ~14:45 LT, the suppression of EIA at 17:00 LT is quite expected. It must be noted here that, it is not the instantaneous value of EEJ, but the integrated EEJ strength which is related to the EIA strength [*Raghavarao et al.*, 1978]. Hence the westward electric field from about 13:30 LT would have turned off the fountain mechanism. This also confirms that the CEJ condition was indeed caused by the overshielding electric field of magnetospheric origin. The present event of CEJ occurred just after the noon time when the conductivity is high. It is a subject matter of further investigation whether overshielding electric fields are equally efficient in causing CEJ at different local times especially during morning hours.

5. Summary

[19] In this work, we have presented the significant effects of the successive eastward prompt penetration and westward overshielding electric fields on the daytime equatorial ionospheric processes. The strong eastward prompt

penetration electric field caused an unusual increase in the EEJ current with the maximum EEJ strength as measured by the magnetic field values exceeding 200 nT, one of the extreme values recorded during November month, for the entire solar cycle. Following this, an overshielding event occurred, during the main phase of the geomagnetic disturbance. The effects of this overshielding electric field are seen on the *E* and *F* region processes over the equatorial and low-latitude regions. The EEJ current showed a strong polarity reversal, along with a weakening of the sporadic *E* layer over equator. The *F* region electron densities showed an increase over the equator, with substantial inhibition of EIA crests over low-latitude region. All these vindicate the reversal of the daytime eastward electric field over the equator, as a result of the overshielding electric field.

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