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Electrodynamical control of the ambient ionization near the equatorial anomaly crest in the Indian zone during counter electrojet days

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[1] The variability of ambient ionization near the crest of the equatorial anomaly on the days of counter electrojet (CEJ) is studied using a long-term (1980–1990) database of total electron content (TEC) obtained from Calcutta (geographic: longitude, 88.38°E; latitude, 22.58°N; dip: 32°N), situated virtually below the northern crest of the equatorial anomaly, in conjunction with the equatorial electrojet (EEJ) data of the Indian subcontinent and f_oF_2 data from the equatorial stations. On the days of CEJ events the diurnal variations of TEC exhibit deviations (decreases) from monthly mean values, but the feature is not regular throughout the observing period. A larger percentage of CEJ days show decreases in the descending phase (1980–1985) of solar cycle compared to the ascending one (1986–1990). During low to moderate solar activity years the ionosphere near the anomaly crest is found to be more susceptible to CEJ related equatorial electrodynamics than in the high solar activity periods. On the seasonal basis, though the solstitial months of ascending phase exhibit higher percentage occurrence of decreases, the feature is not so prominent in the descending epoch. An attempt is made to relate the decreases in TEC with the prevailing electrodynamics at the magnetic equator for which EEJ, under quiet geomagnetic conditions, may be treated as a proxy index. A statistical analysis reveals positive correlations of TEC decreases with strength and duration of CEJ but anticorrelations with rising slope, strength, and time-integrated value of EEJ as well as initiation time of CEJ. To represent better correspondence of the TEC variability with the equatorial electrodynamics a function combining various EEJ parameters has been generated, which seems to exhibit significant association with TEC decreases on the days of CEJ events.

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1. Introduction

[2] The daytime equatorial electrodynamics plays a dominant role in shaping the diurnal profile of ambient ionization in the low-latitude ionosphere. The three important features of the equatorial ionosphere, namely the equatorial electrojet (EEJ), the counter electrojet (CEJ) and the equatorial ionization anomaly (EIA) are mainly controlled by the electrodynamics at the magnetic equator. The horizontal configuration of Earth's magnetic field at the dip equator along with the global-scale daytime dynamo electric field, in the presence of non-conducting layers above and below the altitude where currents flow (100–140 km), lead to the inhibition of Hall current. The resulting increase in Cowling conductivity produces an enhancement of ionospheric current, in the narrow latitudinal belt around the dip equator (±5° dip width), known as EEJ [*Chapman*, 1951]. Intensification of ionospheric current near the magnetic equator due to EEJ is marked by the large perturbation in the solar daily variation of horizontal component (H) of geomagnetic field at the ground level. The EIA refers to double humped structure in the latitudinal distribution of ionization at low latitudes with a trough at the magnetic equator and two crests of enhanced ionization at ±15–

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20° dip latitudes. The vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift of plasma at the magnetic equator and subsequent diffusion along the magnetic field lines, collectively known as equatorial fountain, develop the EIA. The driving force of equatorial fountain is the same, as in the case of EEJ, E region dynamo related electric field communicated to the F layer altitude via highly conducting geomagnetic field lines. There is a high degree of correlation between the strength of EIA and EEJ [*Sethia et al.*, 1980]/integrated EEJ strength [*Raghavarao et al.*, 1978; *Rama Rao et al.*, 2006]. A good correspondence is noted between $\boldsymbol{E} \times \boldsymbol{B}$ vertical plasma drift at the magnetic equator and EEJ strength [*Anderson et al.*, 2002] which may be taken as a proxy index of equatorial fountain under quiet geomagnetic conditions.

[3] The CEJ event refers to the phenomenon of reversal of the EEJ current, manifested by the depression of H below its nighttime level, during morning and afternoon hours of the magnetically quiet days [*Gouin*, 1962; *Gouin and Mayaud*, 1967]. The reversal of ionospheric drifts from westward to eastward and disappearance of E_{sq} near dip equator are suggested to be the concomitant effects of CEJ [*Rastogi et al.*, 1971]. The event is also ascribed by the superposition of an additional semidiurnal field on normal quiet day EEJ field [*Bhargava and Sastri*, 1977]. The possible causes of this additional field/reversal of the field are suggested to be (1) lunar semidiurnal wave [*Hutton and Oyinloye*, 1970; *Rastogi*, 1975], (2) local interaction of height varying zonal wind with the EEJ plasma [*Reddy and Devasia*, 1981; *Raghavarao and Anandarao*, 1987; *Stening et al.*, 1996], and (3) abnormal combination of upper atmospheric tidal modes [*Stening*, 1977; *Rastogi*, 1994].

[4] Ionospheric total electron content (TEC) at any location is the integrated effect of production, loss and transport mechanisms. While production is mainly controlled by solar fluxes, transport at the low-latitude regions is dominated by equatorial fountain. As the effect of eastward electric field at the magnetic equator is to produce vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift of the plasma, appearance of an additional westward electric field during CEJ period, depending upon its strength/initiation time/duration, should modulate the drift to affect the development of the anomaly. The manifestation of the EIA by TEC and its variability caused by the day-to-day variability of equatorial dynamo electric field and neutral wind system were reported by several workers [*DasGupta and Basu*, 1973; *Huang et al.*, 1989; *Walker et al.*, 1994; *Yeh et al.*, 2001]. The absence of equatorial anomaly during CEJ days was recorded using both the ionosonde data [*Rajaram and Rastogi*, 1974] and TEC data [*Deshpande et al.*, 1977; *Chandra et al.*, 1979; *Rastogi et al.*, 1992].

[5] Although a large number of investigations on theoretical as well as experimental grounds are conducted to find and explain the characteristics of CEJ event, its causes and effects on the equatorial and off-equatorial ionosphere [*Rajaram and Rastogi*, 1974; *Deshpande et al.*, 1977; *Raghavarao and Anandarao*, 1987; *Alex and Mukherjee*, 2001; *Devasia et al.*, 2006], the effect of CEJ on diurnal variation of TEC near the anomaly crest region is yet to be fully explored. TEC is an important parameter to describe the state of ionosphere and significant for time delay/range error problems involving global positioning system (GPS) navigation. Globally the maximum ionization is observed around the equatorial anomaly crest region which is potentially more effective in creating perturbations to transionospheric communication/navigation links. The present paper attempts to investigate, using a long-term (1980–1990) database of TEC, the effects of CEJ event on the diurnal variation of TEC recorded at Calcutta (geographic: longitude, 88.38°E; latitude, 22.58°N; dip: 32°N), the location being very important with respect to the position of the anomaly crest. It is situated near the northern crest region around noontime but this is dependent on the day-to-day variability of primary zonal electric field at the magnetic equator and the subsequent variation of the diurnal movement of the anomaly crest. Under present investigation, attempts have been made to explain the variability of TEC associated with the CEJ events in terms of various EEJ parameters, considering it to be a proxy index of zonal electric field at the magnetic equator [*Stolle et al.*, 2008]. Such an extensive study of TEC variation in relation to equatorial electrodynamics on CEJ days is reported for the first time.

2. Data

[6] Ionospheric TEC data obtained through Faraday rotation technique of plane polarized VHF (136.11 MHz) signal from geostationary satellite ETS-2 (130°E) for the period (1980–1990), including the descending (1980–1985) and ascending (1986–1990) phases of solar cycles, are used in the present analysis. The data were recorded at the Ionosphere Field Station, Haringhata (geographic: longitude, 88.38°E; latitude, 22.58°N; dip: 32°N), University of Calcutta with 400 km subionospheric point located at 21°N, 92.7°E (geographic), dip: 27°N. To avoid any contribution from magnetic disturbances, the days with $D_{st} > -50$ nT are only considered.

[7] For the measurement of EEJ/CEJ strength, the method suggested by *Chandra and Rastogi* [1974] is used. Accordingly, the hourly variations of the horizontal component of the geomagnetic field relative to its nighttime value at Alibag (ΔH_A) (geographic: latitude, 18.63°N; longitude, 72.87°E; dip: 23°N) are subtracted from those at Trivandrum (ΔH_T) (geographic: latitude, 8.29°N; longitude, 76.57°E; dip: 1.2°S) for the measurement of EEJ strength, ($\Delta H_T - \Delta H_A$). Trivandrum is an EEJ station while Alibag is located outside the EEJ belt.

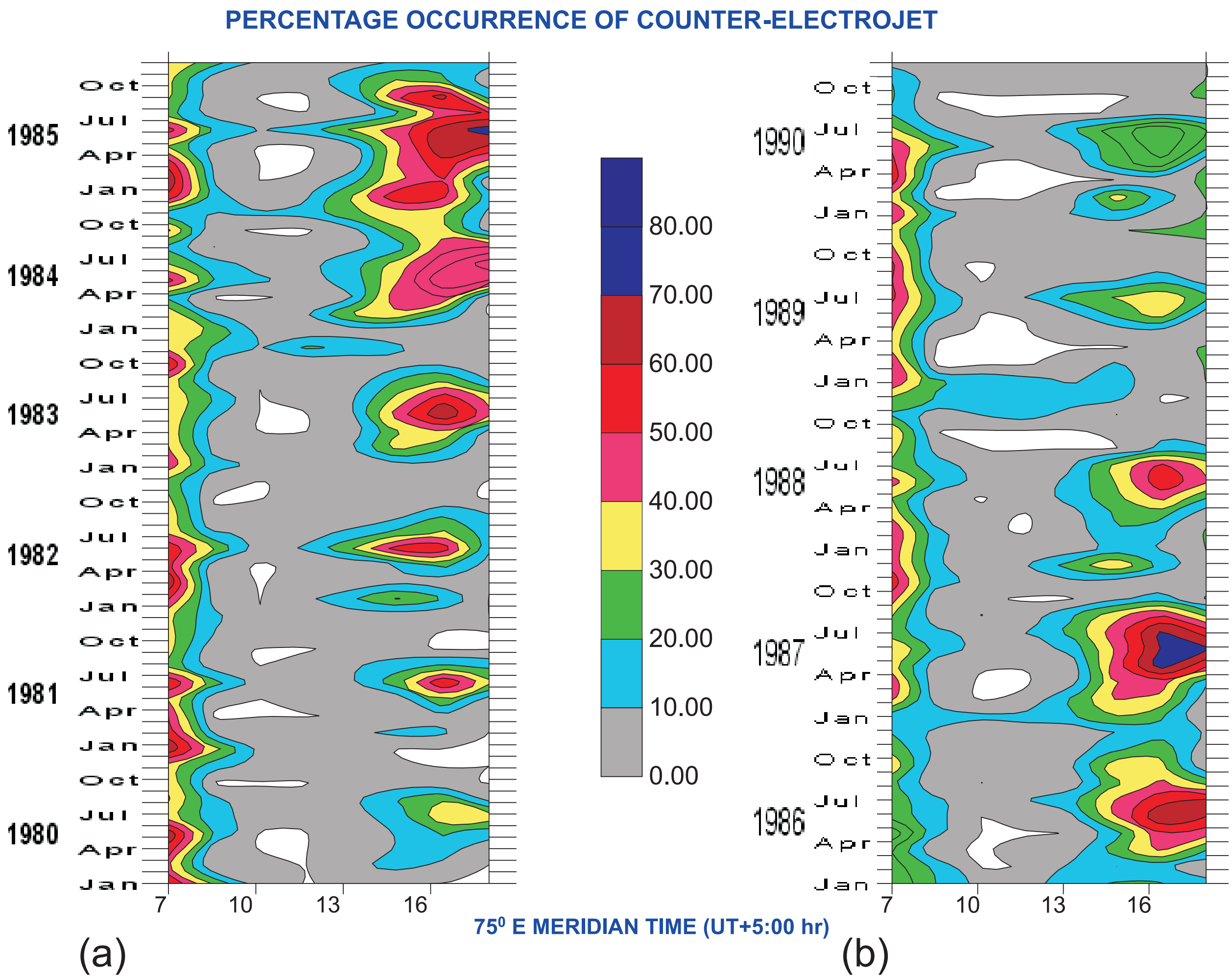

Figure 1. Contour plots of monthly percentage occurrence of CEJ events versus 75°E meridian local time (UT + 0500 h) for the period 1980–1990. (a) Descending phase (1980–1985) of 21st solar cycle. (b) Ascending phase (1986–1990) of 22nd solar cycle.

[8] To get an idea of the EIA strength the F_2 layer critical frequency (f_oF_2) data of Kodaikanal (geographic: latitude, 10.25°N; longitude, 77.5°E; dip: 4°N) and Ahmedabad (geographic: latitude, 23.01°N; longitude, 72.36°E; dip: 34°N), downloaded from website, are used. Kodaikanal is an equatorial station and Ahmedabad is situated near the equatorial anomaly crest. The f_oF_2 values are employed to estimate the maximum electron density (N_mF_2) of the layer.

3. Results and Discussions

3.1. Seasonal and Solar Cycle Variation of CEJ Events

[9] Figure 1 shows the contour plots of percentage occurrence of CEJ events for the entire period of observations (1980–1990), while Figure 2 pertains to seasonal features of the same. The CEJ events mainly occur in the morning and noon to afternoon hours. For the present investigation only the noon to afternoon (occurring after 1100 h IST) events are considered in detail. From Figures 1 and 2 the following morphological features in the occurrence of CEJ event emerge:

[10] 1. The number of noon to afternoon events shows a clear anticorrelation with solar activity level (Figure 1) with highest occurrence in low solar activity periods (1985–1986). No perceptible dependence on solar phase (ascending or descending) is detected. The events exhibit pronounced maximum of occurrence in J months (local summer) with secondary maximum in D months (local winter) (Figure 2).

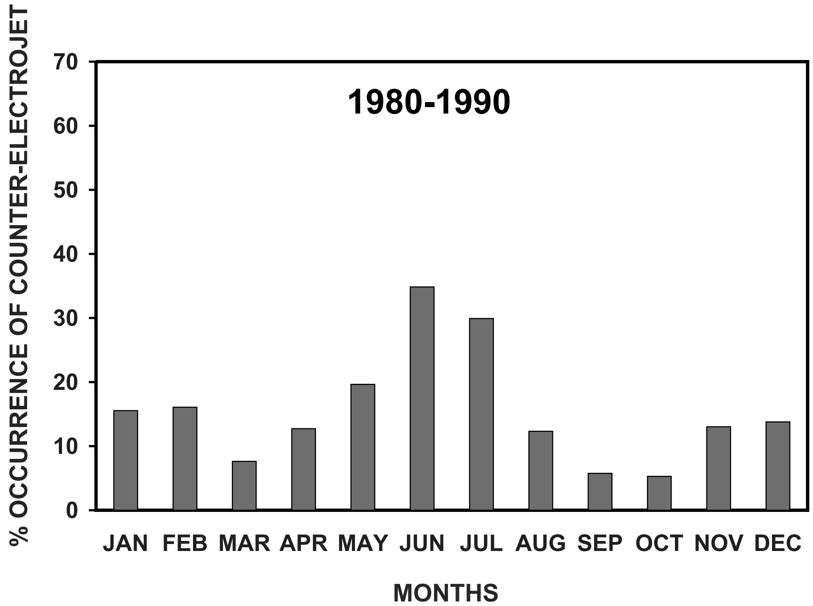

Figure 2. Seasonal variation of percentage occurrence of CEJ for the period 1980–1990.

[11] 2. A typical solar activity dependent feature of initiation times of CEJ events with earlier occurrences in low solar activity years than the higher ones is revealed through the analysis. The initiation time also differs from one solar epoch to the other by 1/2 to 1 h. On the seasonal basis initiation mostly occurs later in the local summer compared to other seasons.

[12] 3. The duration of CEJ events are observed to vary from 1 h to 8 h (approximately) with the highest number of longer-duration CEJ events recorded in the local summer months (J months).

[13] The solar activity as well as seasonal dependent features of the occurrence of the noon to afternoon CEJ events more or less follow the earlier results obtained from worldwide observations [*Gouin and Mayaud*, 1967; *Hutton and Oyinloye*, 1970; *Rastogi*, 1974]. From the seasonal distribution of CEJ events, signature of two sources centered on the month of January and the summer solstice, respectively, as suggested by *Mayaud* [1977], seems to be reflected in the present investigation. The weakening of EEJ current facilitates the electrodynamical processes responsible for occurrence of CEJ. The larger percentage occurrence of CEJ events observed in the local summer months of the low solar activity period supports the views of huge reduction in the noontime values of the jet field during the solstitial months of solar minimum periods compared to the solar maximum [*Rastogi*, 1974; *Devasia et al.*, 2006]. The seasonal variability (equinox to local summer) in occurrence of CEJ events is observed to be much larger (5–35%) compared to that (32–35%) reported from Addis Ababa (geographic: latitude, 9°N; longitude, 38.8°E; dip: 1°S) [*Mayaud*, 1977]. It may be due to limited longitudinal confinement nature of CEJ events – which is attributed to the local wind shear modifying the EEJ fields especially during noontime hours [*Alex and Mukherjee*, 2001]. The later occurrence of initiation time during J months is suggested to be related to the northward shifted position of the Sun with respect to the magnetic equator [*Rastogi*, 1974].

3.2. Counter Electrojet and Variability of TEC

[14] Since the location of observing station Calcutta is very critical with respect to the position of the northern crest of EIA, variability of TEC should be greatly influenced by the electrodynamical aspects of CEJ events. To study the effects on the level of ambient ionization, deviations of diurnal TEC, exceeding 1σ level, from the monthly average values are estimated. The deviations actually imply decreases (negative deviations) from the monthly mean (quiet days) values. A very complicated trend for the variation in diurnal TEC values is observed throughout the period (1980–1990) of investigation and a few cases are shown in Figure 3. For more or less same EEJ/CEJ strength, while no TEC decrease is recorded in Figure 3a, Figure 3b exhibits decreases from the averages. In both Figures 3a and 3b, levels of EEJ and CEJ strengths seem to be high. A high level of EEJ corresponds to strong equatorial fountain and this may lead to well developed anomaly. If the

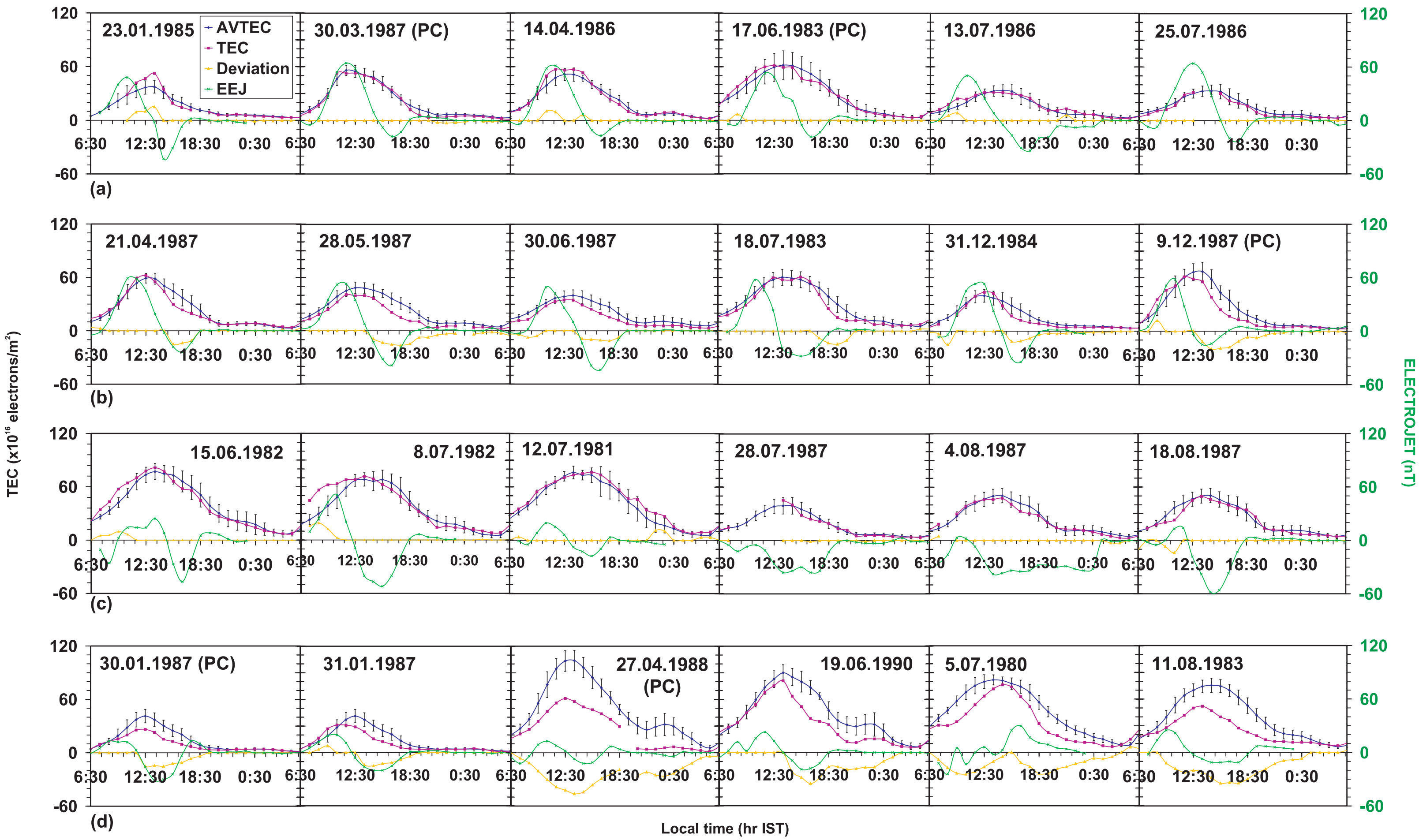

Figure 3. Diurnal variation of monthly mean values (AVTEC) of TEC, TEC for the dates mentioned, deviation of diurnal values from monthly mean (deviation) along with electrojet strength (EEJ). Deviations are calculated for the periods when diurnal values exceed 1σ level of monthly mean. One TEC unit is equal to 10^{16} electrons m^{-2}. EEJ strength is expressed in nT. PC indicates partial CEJ days. (a and b) Levels of EEJ and CEJ strengths seem to be high. (c and d) Mostly longer-duration CEJ events are shown.

reverse fountain effect related to CEJ events is not sufficient enough to disturb the cumulative effects of the forward ones, no decrease is expected. Although such an explanation may justify the features detected in Figure 3a, it seems to be redundant for Figure 3b.

[15] In Figures 3c and 3d mostly longer-duration CEJ events are shown: sometimes CEJ events continue throughout the day while amplitude of prenoon EEJ is remarkably less. For a similar type of prevailing background at the magnetic equator there is appreciable decrease from the monthly average TEC in Figure 3d, but no such trend is detected in Figure 3c. In the last four plots of Figure 3d, pertaining to moderate and high solar activity periods, the diurnal TEC values depart appreciably from the monthly mean. It may be noted that solar fluxes are not responsible for lower values of diurnal TEC as solar fluxes were not abnormally low on these dates compared to neighboring ones. These types of conflicting features are recorded throughout the period of observation (1980–1990).

[16] To study the correspondence between occurrence of CEJ events and decreases in diurnal TEC, a statistical analysis has been made. The CEJ days are separated into two groups: (1) partial counter electrojet (PC) days, i.e., days for which H field near the magnetic equator (ΔH_T) does not fall below the nighttime level but ($\Delta H_T - \Delta H_A$) exhibits negative values [*Rastogi*, 1974], and (2) complete counter electrojet (C) days when both the indices fall below the respective nighttime levels.

[17] The number of CEJ days studied for the descending phase (1980–1985) of 21st solar cycle is 112 (C = 84, PC = 28) while the same for the ascending epoch (1986–1990) of 22nd solar cycle is counted to be 87 (C = 65, PC = 22). The percentage of CEJ days exhibiting TEC decrease is noted to be higher during the descending phase (68% of the observed 112 CEJ days) than in the ascending epoch (44% of 87 days). In both solstitial months of ascending epoch larger number of days (60%) show TEC decreases compared to the equinoctial months (16–30%) while in the descending phase not only solstitial months but equinoctial months also exhibit comparable number of days (70–90%) involving TEC decreases. Clearly, a prominent solar epoch dependent feature for the days with TEC decreases is revealed.

[18] When separated on the basis of complete (C) and partial CEJ (PC) days, the same percentage (68%) for TEC decreases is recorded on the two categories of CEJ events in the descending phase while for the ascending epoch larger number of days (68%) show TEC decrease for PC days in comparison to CEJ days (~35%). TEC variability at the present location, thus, seems to be susceptible to the changes in the strength of EEJ represented by ($\Delta H_T - \Delta H_A$) alone rather than to the combined (S_q + EEJ) strength given by ΔH_T. Using ionograms and VHF backscatter echoes from stations near the magnetic equator the importance of the difference field was also reported by *Rastogi et al.* [1977, 1992].

[19] Such an extensive study of TEC variability is important, as stated earlier, in the context of ionospheric range error problem. A variable depth of decrease in the diurnal TEC during CEJ events, ranging from 1.4 to 35 TEC unit, is recorded and the associated range errors at GPS L1 (1.57542 GHz) frequency are estimated. A minimum range error of 25 cm and maximum of 6 m resulting from the TEC decreases are detected. The TEC variability during CEJ days leads to significant uncertainty in detecting the diurnal range around the equatorial anomaly crest region. It may be noted that under present investigation equivalent vertical TEC, measured by Faraday rotation technique have been used while at GPS observations slant TEC measured along the raypath are converted to vertical one by multiplying a geometric factor.

3.3. CEJ Events and Variation of N_mF_2

[20] To relate the variability of TEC near the anomaly crest location with the prevailing features of the equatorial ionosphere around the period of CEJ, the N_mF_2 data of Kodaikanal (geographic: latitude, 10.25°N; longitude, 77.5°E; dip: 4°N) and from Ahmedabad (geographic: latitude, 23.01°N; longitude, 72.36°E; dip: 34°N) are studied. Irrespective of the decreases in TEC on the CEJ days N_mF_2 values at Kodaikanal during the period are observed to be somewhat higher than those on the neighboring normal EEJ days. In most of the cases the diurnal N_mF_2 variations, for the days exhibiting TEC decreases, are characterized by a steeper slope of rise, much higher values of diurnal peaks and remarkable diurnal differences compared to the neighboring normal EEJ days. Much larger values of N_mF_2, contrary to the normal feature, indicate increased electron density at the magnetic equator on the CEJ days – which may be attributed to the perturbed fountain effect. A sharper slope may resemble faster increase in density at the magnetic equator. For some days noontime bite-out in N_mF_2 at Kodaikanal started before the initiation of CEJ event and a decreasing trend is observed during the CEJ period. The features may be attributed to the well developed equatorial fountain resulting in no depression of TEC around the crest location.

[21] Figure 4 shows the diurnal variations in the ratios of N_mF_2 values at Ahmedabad and Kodaikanal. After the occurrence of CEJ event a lower value (<1) of the ratio may be an indication of less developed anomaly [*Rajaram and Rastogi*, 1974]. The level of N_mF_2 near the crest (Ahmedabad) on 12.06.1985 is almost compar-

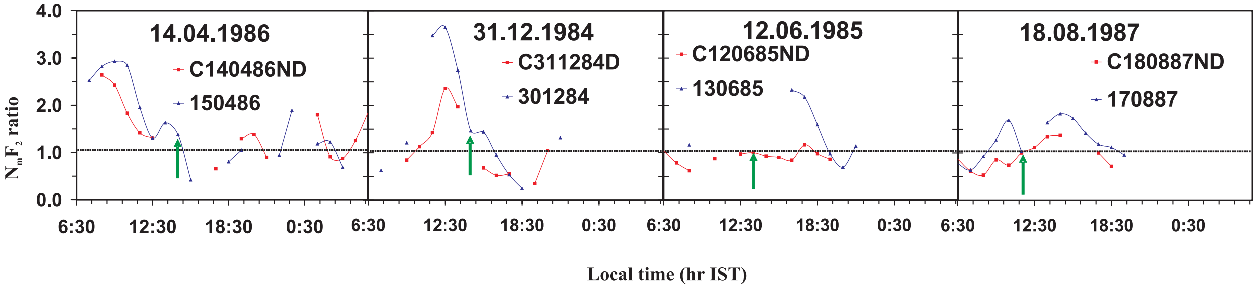

Figure 4. Diurnal variations of the ratio of N_mF_2 from Ahmedabad and Kodaikanal for CEJ days and also for the normal EEJ days. C indicates CEJ dates, and dates without C pertain to normal EEJ days. D and ND represent dates with and without deviations in TEC, respectively. Vertical arrows indicate initiation times of CEJ events.

able to that at the equator (Kodaikanal). On 18.08.1987, an increase in the ratio is observed after the initiation of CEJ event. The anomaly strength may be assumed to remain constant in the former case while the later case may be the signature of strengthen anomaly resulting in no TEC decreases. On 31.12.1984, a somewhat decreasing trend in anomaly strength may lead to TEC decrease. The combined study on N_mF_2 and TEC may thus reveal that TEC variability near the anomaly crest location is basically the manifestation of the variation in EIA during the CEJ days also. It may be noted that simultaneous unavailability of the f_oF_2 data from both the stations makes the analysis somewhat incomplete.

3.4. Association Between TEC Variability Near the Anomaly Crest and Different Parameters of Diurnal EEJ

[22] The zonal electric field, for which the strength of EEJ may be considered as a proxy index [*Stolle et al.*, 2008], primarily controls the EIA through the equatorial electrodynamics (fountain mechanism). A causative connection between TEC variability near the anomaly crest and the electrodynamics at the magnetic equator may be investigated by considering different parameters of the EEJ/CEJ. The parameters considered are (1) the rising slope of EEJ preceding CEJ, (∂EEJ/∂t), (2) the strengths of EEJ and CEJ, $|\Delta H_T - \Delta H_A|$max, (3) the initiation time of CEJ (IT), (4) the duration of CEJ (D), and (5) the time-integrated value of the EEJ (IEJ) preceding the CEJ events. The cases of TEC decreases which occur after the initiation of CEJ with a time lag of 1 to 2 h are mainly considered under the present investigation. The partial CEJ days are excluded. The results are presented chronologically in the following sections.

3.4.1. Rising Slope of EEJ and TEC Variability

[23] It is observed that when the rising slope of EEJ (∂EEJ/∂t) is not too sharp ($\leq$14 nT h^{-1}), number of days exhibiting decrease in TEC is 52% of the total CEJ days while for higher values of ∂EEJ/∂t the same is reduced to 33% (Figure 5a).

[24] When the magnitudes of TEC decrease ($|TEC_{dec}|$) are studied in relation to ∂EEJ/∂t (Figure 5b), a decreasing trend with higher correlation coefficient (0.6–0.7) during equinox and local summer (J months) than the local winter months (D months) of low to moderate solar activity years mark the seasonal TEC variability.

[25] The slope of EEJ curve may be taken as a measure of the rapidity with which vertical drift of plasma at the magnetic equator varies [*Anderson et al.*, 2002]. The large value of ∂EEJ/∂t implies vertical acceleration of the equatorial plasma that may facilitate the development of equatorial anomaly through the mechanism proposed by *Martyn* [1955]. The faster rate of growth of anomaly on CEJ days may mask the possible influence of the westward electric field on the ambient level near the crest region resulting in negligible depth of decrease in TEC. The effect should be modulated by the initiation time of CEJ events and strengths of EEJ and CEJ.

3.4.2. Strengths of EEJ and CEJ Versus TEC Variability

[26] Investigations on the strength of EEJ/CEJ reveal that when EEJ strength $\geq$ 30 nT (normal EEJ strength ~20–25 nT), i.e., for strong/moderate prenoon EEJ, the strength of CEJ, $|(\Delta H_T - \Delta H_A)|$max seems to play a major role for observing decreases in TEC. For the descending solar epoch (1980–1985), 25 nT may be taken as a critical value of CEJ strength for exhibiting decrease in TEC while the same is found to be 30 nT for the ascending phase (1986–1990). For stronger CEJ, 77% (57%) of CEJ days of descending (ascending) epoch exhibit decreases, while the number reduces to 42% (22%) when CEJ amplitude is less than 25 nT (30 nT). A test of significance reveals high degree of association in the descending solar epoch. Clearly strong

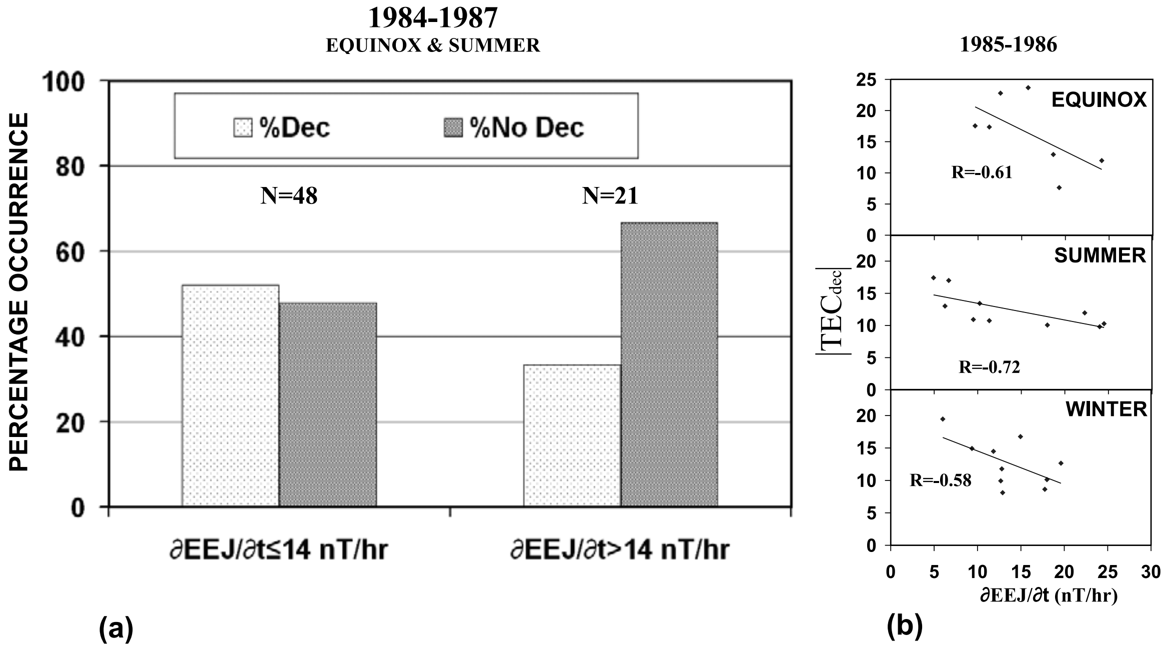

Figure 5. (a) Histograms for percentage occurrence of days with and without decrease in TEC when rising slope of EEJ is less than or exceeds the value 14 nT h^{-1}, respectively, for the low solar activity period. N indicates total number of CEJ days. (b) Magnitude of TEC decreases versus rising slope of EEJ. For different seasons the value of correlation coefficient (R) is shown in each plot.

EEJ should be followed by intense CEJ for TEC decrease to be observed near the anomaly crest.

[27] In case of low EEJ strength (<30 nT), overall occurrence of TEC decrease is more frequent (81% and 43% of total CEJ days of descending and ascending solar epochs, respectively) than the case when EEJ amplitude is high ($\geq$30 nT) (60% and 34%, respectively). For the days with weak prenoon EEJ no consistent feature of dependence of TEC decrease on the strength of CEJ is noted.

[28] When the variation of $|TEC_{dec}|$ is considered in relation to the strengths of EEJ and CEJ (Figure 6) for different seasons of low solar activity years (1984–1985/1986–1987), appreciably high correlation coefficients during all the three seasons with high levels of significance (0.5% to 2.5%) mark the CEJ related TEC variability.

[29] A strong EEJ adduces an enhanced eastward electric field (***E***). This may produce large $\boldsymbol{E} \times \boldsymbol{B}$ vertical drift resulting in a great height rise of the plasma at the magnetic equator. Owing to negligible frequency of collisions with neutrals at these heights and rapid diffusion along the geomagnetic field lines, a large amount of plasma is transported to the crest location [*Rajaram and Rastogi*, 1974]. To compete with this strong fountain effect, westward electric field of comparable magnitude may be required. On the other hand, low values of prenoon EEJ strength may result in shorter-duration and weakly developed anomaly [*Baxter and Kendall*, 1968; *Yeh et al.*, 2001] which may be perturbed by CEJ related electric field of comparatively less magnitude.

3.4.3. Initiation Time of CEJ Versus TEC Variability

[30] The ionization distribution at the anomaly crest region is reported to be dependent on the time of maximization or reversal of upward electrodynamic drift at the equator [*Rush*, 1972]. On the days of afternoon CEJ events weakening of the zonal electric field strength begins around 1200–1330 h IST (normal time 1400–1500 h IST). This may lead to less supply of ionization to the crest region by the fountain effect from noontime onward. For the days with earlier CEJ events the fountain effect becomes weak at the developing phase itself leading to much change in rate of supply of plasma over the low-latitude region.

[31] A statistical analysis made with the initiation time of CEJ and decreases in TEC reveals that early initiation of CEJ events corresponds to larger probability of TEC decrease. For high solar activity years (1980–1981) ~90% of the days exhibit decrease in TEC for CEJ events initiating at or before 1230 h IST while the same

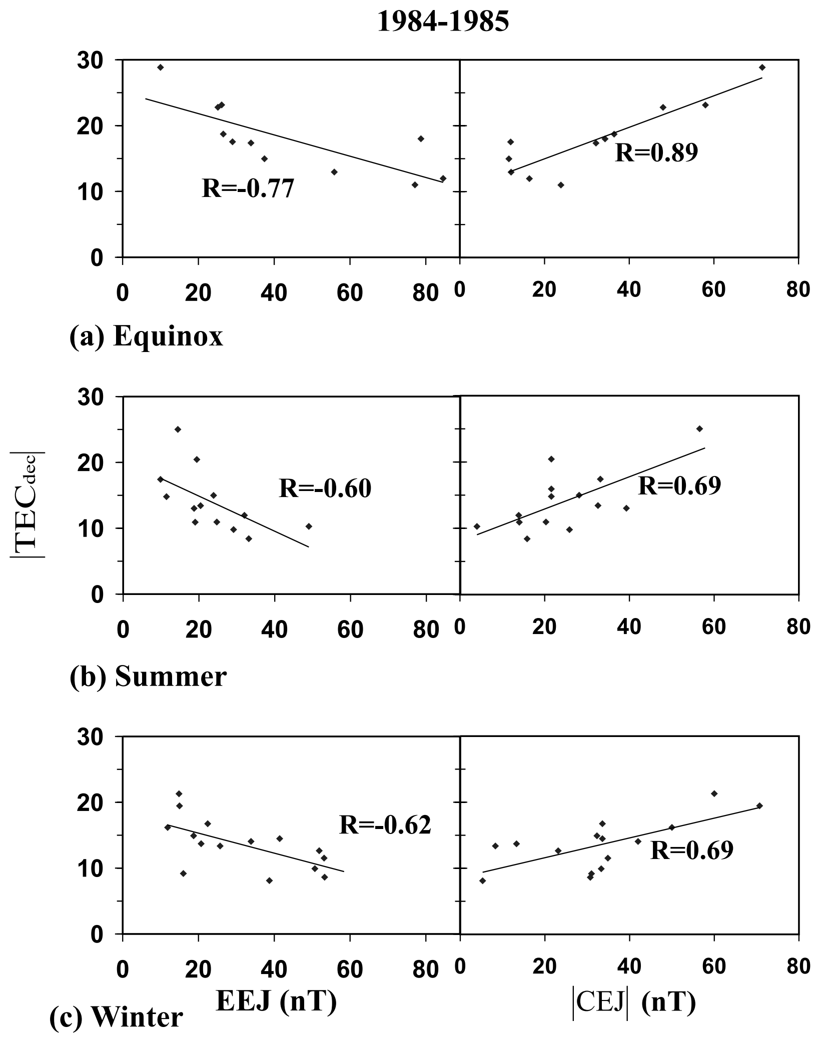

Figure 6. Variations of magnitude of TEC decreases with (left) EEJ strength and (right) CEJ strength for different seasons. The correlation coefficients (R) of linear fit are shown in each case.

is observed to be only 13% of the days with later occurrence of CEJ events. For moderate to low solar activity years, no such significant association is noted. However, there exists a good correlation between $|TEC_{dec}|$ and initiation time of CEJ in the early hours for equinox and J months of the low solar activity years (1984–1987). It should be mentioned that no suitable threshold initiation time of CEJ event sufficient for TEC decreases can be inferred.

3.4.4. Duration of CEJ and TEC Variability

[32] During longer-duration CEJ events the prevailing westward field disturbs the normal fountain mechanism inhibiting the transport of plasma for a long time interval. This may increase the probability as well as the depth of decrease in TEC at the present location.

[33] For both the phases of solar cycles, the percentage of days involving decreases in TEC increases with the increase in duration of CEJ up to 7 h (Figure 7). For longer-duration CEJ events, it remains more or less constant (75%) during descending part of solar cycle, while a slightly lower percentage occurrence marked the ascending epoch. From the histogram distribution a most probable duration of 6–7 h of CEJ necessary for decrease in the ambient level around the present location may be suggested.

[34] Again, a positive correspondence with high level of significance between $|TEC_{dec}|$ and the duration of CEJ event is noted during the equinox and J months of descending phase (1980–1985). But the feature is not so prominent in the ascending epoch (1986–1990).

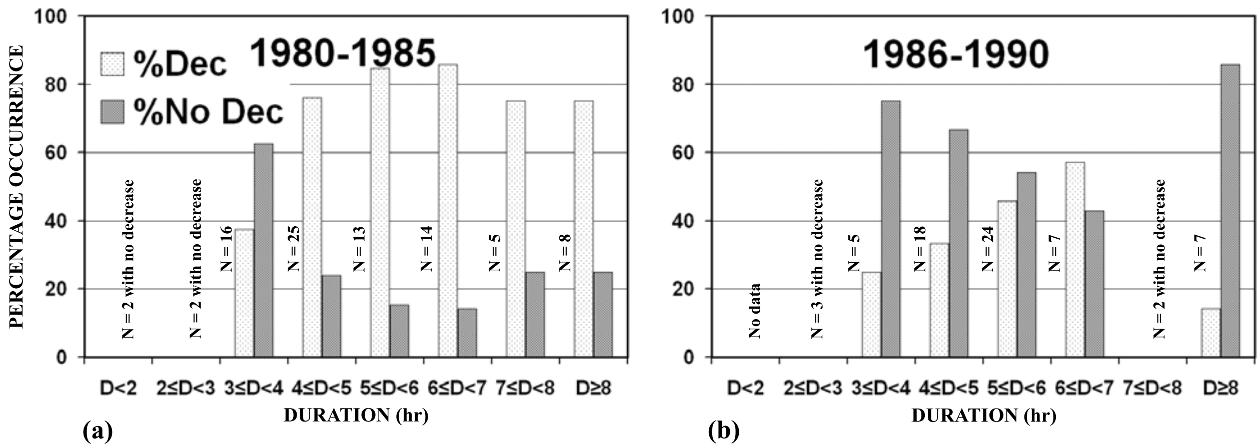

Figure 7. (a) Histograms exhibiting dependence of the percentage occurrences of days with and without decreases in TEC on duration (D) of CEJ events. Figure 7a pertains to descending phase (1980–1985) of solar cycle. N indicates total number of CEJ days considered. (b) Same as Figure 7a for ascending phase (1986–1990) of solar cycle.

3.4.5. Integrated EEJ Versus TEC Variability

[35] On CEJ days the time-integrated values (in the unit of nT h^{-1}) of EEJ (IEJ) preceding the CEJ events are evaluated. The probability of TEC decrease seems to gradually diminish with increase in IEJ strength throughout the low solar activity period (1984–1987) of the equinox and J months. The estimated correlation coefficients between $|TEC_{dec}|$ and IEJ strength for equinox and J months are found to be high (∼0.7–0.9) with high level of significance. A slightly less correlation at 5% significance level marked the local winter months. The results for the moderate to high solar activity periods are observed to be less consistent.

[36] A low value of IEJ may be attributed to weak EEJ strength or short duration of EEJ or both. It may imply poor supply of plasma to the crest location resulting in larger probability and amplitude of decrease in TEC on the days of CEJ events.

[37] A slightly less correspondence detected in the TEC variability with the EEJ parameters during local winter for all the levels of solar activity and during all the seasons of high solar activity years (except the initiation time of CEJ that shows good control during high solar activity years) may be attributed to, other than electric field, neutral wind, tides and waves, composition changes, etc. The meridional component of neutral wind, blowing toward the pole during the day and toward the equator at night [*Kohl and King*, 1967] and having typical temporal dependence of occurrence of its peak [*Igi et al.*, 1999], controls decisively the appearance, strength and duration of the anomaly. TEC observations made at Calcutta, situated virtually below the northern crest of the equatorial anomaly, are expected to be affected by the said variables.

3.5. Combined Effect of Different Parameters on TEC Distribution

[38] From the previous sections it is apparent that the decrease in TEC on CEJ days has definite qualitative as well as quantitative dependences on different electrodynamical parameters related to EEJ/CEJ. In quantitative point of view, the magnitude of TEC variability ($|TEC_{dec}|$) may be assumed to decrease with the increases in rising slope of EEJ ($\partial EEJ/\partial t$), strength of EEJ, integrated value of EEJ (IEJ) preceding the CEJ event. On the other hand, a positive correspondence of $|TEC_{dec}|$ with the strength ($|CEJ|$) and duration (D) of CEJ is observed. The correlation coefficients between $|TEC_{dec}|$ and each of these parameters are noted to be appreciably high (∼0.6 or higher) with high level of significance during equinoctial and J months of moderate to low solar activity years. $|TEC_{dec}|$ may, thus, be expressed in terms of these parameters in the following ways:

$$|TEC_{dec}| \propto \frac{1}{\frac{\partial EEJ}{\partial t}} \quad (1)$$

$$\propto \frac{1}{EEJ} \quad (2)$$

$$\propto |CEJ| \quad (3)$$

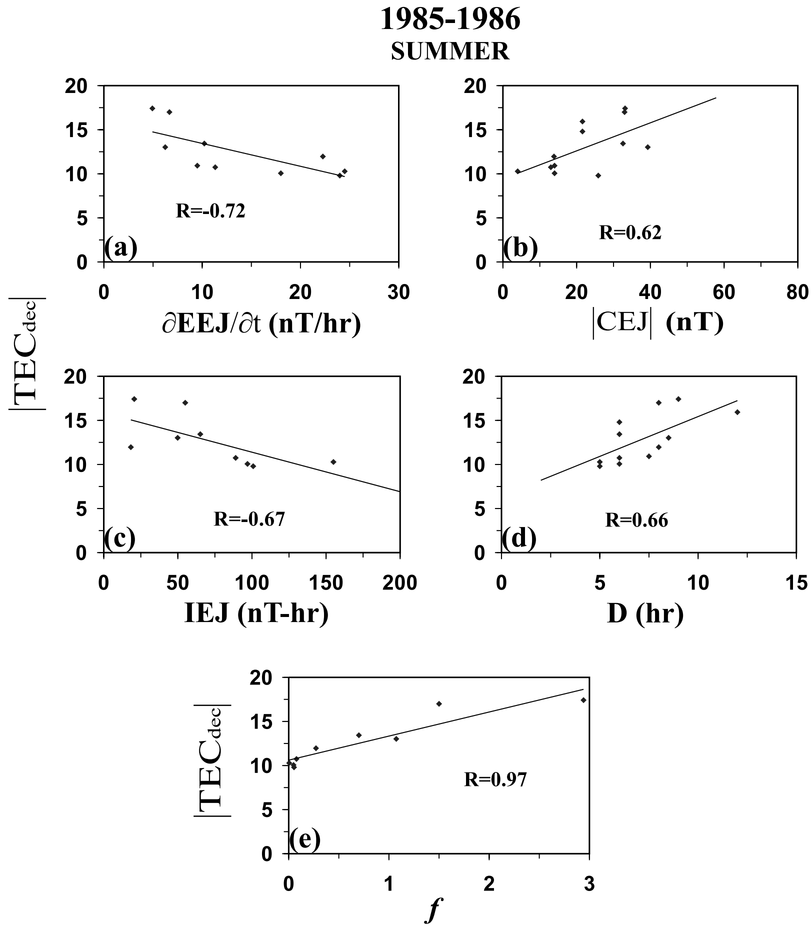

Figure 8. For the local summer months (J months), dependences of the amplitude of TEC decrease ($|TEC_{dec}|$) on the parameters, (a) rising slope of EEJ ($\partial EEJ/\partial t$), (b) strength of CEJ ($|CEJ|$), (c) time-integrated value of EEJ (IEJ) preceding the CEJ event, and (d) duration of CEJ (D). (e) The variation of $|TEC_{dec}|$ with the combined function f (D,$|CEJ|$, IEJ, $\partial EEJ/\partial t$) for the same period.

$$\propto D \tag{4}$$

$$\propto \frac{1}{IEJ} \tag{5}$$

The variation of $|TEC_{dec}|$ with the rising slope of prenoon EEJ (Figure 5b) may be represented by an equation of the form

$$|TECdec| = -m \times \left(\frac{\partial EEJ}{\partial t}\right) + c, \tag{6}$$

where m and c are some positive constants. The constant c actually arises due to the contributions of the parameters other than $\partial EEJ/\partial t$. When only the effect of $\partial EEJ/\partial t$ is taken into account, c can be considered as a 'base level' above which the contribution of $\partial EEJ/\partial t$ develops. Moreover, the leniency of one parameter on the other is yet to be ascertained.

[39] Using the above relations $|TEC_{dec}|$ may be written as a function of combined effect of $\partial EEJ/\partial t$, EEJ, $|CEJ|$, D, and IEJ by the following relation

$$|TEC_{dec}| \propto f \tag{7}$$

where

$$f = \frac{D \times |CEJ|}{IEJ \times \left(\frac{\partial EEJ}{\partial t}\right)} \tag{8}$$

The term EEJ is excluded as the effect of EEJ strength is already included in its integrated value (IEJ).

[40] The functional relationship between this combined function (*f*) and $|TEC_{dec}|$ has been validated for different seasons of the low solar activity years. For all the three seasons correlation coefficients are estimated to be remarkably high (∼0.7–0.9) which was not so evident for the individual cases (Figure 8). A test of significance also reveals high degree of association between $|TEC_{dec}|$ and *f*. The functional relation suggests that, other than the individual parameters, the combined function *f* may have a better correspondence with the variability of TEC around the anomaly crest region during CEJ periods and in effect, may give an estimate of TEC decrease.

4. Summary

[41] A long-term (1980–1990) study relating to the effects of equatorial electrodynamics on the distribution of TEC around the equatorial anomaly crest location (Calcutta) during CEJ events may be summarized as follows:

[42] 1. During the descending phase of solar cycle the ionosphere near the anomaly crest seems to be more susceptible to CEJ related equatorial electrodynamics than the ascending one.

[43] 2. For the days with higher values of prenoon EEJ strength (≥30 nT), amplitude of CEJ plays dominant role in dictating TEC decrease. But no consistent feature of dependence on CEJ strength is observed during the days of lower values of prenoon EEJ strength (<30 nT).

[44] 3. In spite of detected associations between TEC variability and various EEJ/CEJ parameters, namely rising slope, strength and time-integrated value of prenoon EEJ preceding the CEJ events, and initiation time, strength, duration of CEJ events during local summer (J months) and equinoxes of moderate to low solar activity years, no threshold value of any of the parameters (except the CEJ strength on the days of strong/moderate prenoon EEJ) necessary for decreases in TEC may be suggested. The combined function *f* (D, |CEJ|, IEJ, ∂EEJ/∂t) is observed to be significantly correlated with the depth of decrease in TEC ($|TEC_{dec}|$) during all the three seasons of low solar activity years.

[45] 4. Categorization of complete and partial CEJ days reveals the sensitiveness of the TEC distribution at the present location to the EEJ strength represented by ($\Delta H_T - \Delta H_A$) alone rather than to the combined (S_q + EEJ) strength given by ΔH_T.

[46] It should be mentioned that TEC data from single station (Calcutta) near the anomaly crest have been considered for the present investigation. If the data from other locations along the same meridian, situated in between the magnetic equator and EIA crest would have been available, more realistic picture of the control of electrodynamics on the distribution of ionization in the equatorial ionosphere could be developed.

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