

Equatorial electrojet in the African sector

R G Rastogi & H Chandra^{§,*}

Physical Research Laboratory, Ahmedabad 380 009, Gujarat, India

[§]E-mail: hchandra@prl.res.in

Received 30 July 2015; revised 27 November 2015; accepted 18 December 2015

Hourly values of the deviations in the geomagnetic X and Y field at two equatorial electrojet stations in Africa, viz. Freetown (FTN) on the western part and Addis Ababa (AAE) on the eastern part, are studied for three years 1962-64. The declination is almost along the geographic N-S at AAE and 14° towards west of the geographic N-S at FTN. The annual mean daily range in X is around 80 nT at FTN and 70 nT at AAE with peak around 1100 hrs LT. Deviations in Y at FTN show a broad minimum of about -20 nT around noon while the decrease is much smaller at AAE with a minimum of -5 nT at noon. Seasonal mean variations of the daily range in X show almost equal peaks during December solstice and equinox at FTN but at AAE it is highest during equinoctial months and lowest during June solstice. The seasonal asymmetry at FTN could be due to large declination. The equinoctial peak in March - April is higher than the peak in September - October at both the stations. Another notable feature at FTN is the steady increase in deviation in X from about -10 nT at 1800 hrs LT to 10 nT at 0600 hrs LT. The direction of the H vector is aligned almost along the geographic N-S for December solstice and equinox at AAE and along 12° W of north during June solstice. At FTN, it is aligned along about 5° W of north during D and E-months and to about 20° W of north during June solstice.

Keywords: Equatorial electrojet, Geomagnetic deviation

PACS Nos: 94.20.dt; 94.20Ss; 94.20Wh

1 Introduction

The enhancement of the daily range of H close to magnetic dip equator was explained by Chapman¹ as due to a narrow band of thin current sheet flowing eastward during the day time hours in the ionosphere (100 km) and named it equatorial electrojet (EEJ). The equatorial enhancement of the range in H was observed later in Nigeria², Peru³, India⁴ and Tchad⁵. Based on the observations during the IGY-IGC period (1957-59), Rastogi⁶ detected a longitudinal variation of EEJ, being strongest in American and weakest in Indian longitudes and suggested an inverse relationship between the conductivity in the equatorial region and the background magnetic field.

Gouin⁷ reported a depression of H on magnetogram at local noon at Addis Ababa well below the night level on a very quiet day. Later, Gouin & Mayaud⁸ named such events as counter equatorial electrojet (CEJ). Hutton & Oyinloye⁹ described the disappearance of Es-q during CEJ at Ibadan. Fambitakoye¹⁰ described the latitudinal profiles of ΔH and ΔZ along Central African longitudes on normal and counter electrojet days. On CEJ day, ΔH showed a minimum over the magnetic equator and the

latitudinal profile of ΔZ was reversed with respect to that during an EEJ day, with a maximum in northern and a minimum in southern fringe region of the electrojet.

Spaced receiver drift measurements at the equatorial electrojet station Thumba, near Trivandrum in India showed very good similarity with the deviations in H in the daily and the seasonal variations and also in the latitudinal variation (along with the data at other stations). The day-to-day changes in the midday drift speed at Thumba were found to be highly correlated with the deviations in H at Trivandrum and the correlation improved when the difference between the deviations in H at Trivandrum and at Alibag, a low latitude station away from the electrojet region, was used¹¹. Thus, the difference in the geomagnetic field at magnetic equator and at a low latitude station away from the magnetic equator can be used as an index of the electrojet current (or of the electric field in the E-region of the ionosphere near magnetic equator). Rastogi *et al.*¹² showed that the disappearance of Es-q and the CEJ at Kodaikanal, an equatorial electrojet station in India were concurrent with the reversal of ionospheric drift at

Thumba, confirming the reversal of ionospheric electric field during CEJ. Rastogi¹³ showed number of examples of the disappearances of Es-q at Huancayo and Kodaikanal during the depressions of ΔH on quiet as well as on disturbed days. Thus, the presence (or absence) of equatorial Es-q during daytime was found to be an alternate parameter to the presence of EEJ (or CEJ).

Fambitakoye *et al.*¹⁴ showed that the disappearance of Es-q is related to the inverted latitudinal profiles of ΔH and ΔZ and not necessarily when ΔH at the equatorial station alone decreases below the night time value, discovering the phenomenon of partial counter electrojet, P-CEJ event. The correct estimate of the EEJ or CEJ is not when ΔH at the station close to the dip equator is above or below the night time level, but from the difference of ΔH at an equatorial and off equatorial stations along the same longitude sector^{15,16}.

Rastogi¹⁷ suggested that the ΔH at any ground EEJ station is the combined effect of an eastward ionospheric current associated with the global Sq current system and a narrow band of electrojet current flowing eastward during normal and westward during counter electrojet period. Carter *et al.*¹⁸ detected simultaneous opposite flowing currents at different altitudes from radar measurements in Western Africa.

Equatorial electrojet has been extensively studied from ground, rocket and satellite based magnetometers, spaced receiver drift, VHF backscatter radar and theoretical studies¹⁹⁻²¹. Features of EEJ have been described for longitude regions of 75°W (Ref. 3), 15-19°E (Refs 22,23), 75°E (Refs 24,25), 5°W (Ref. 26), 45°W (Refs 27,28) and 60°W (Ref. 29).

The most important feature of the geomagnetic field in eastern Brazil is the deviation of the horizontal field by about 20° west of the geographic north and hence, large westward component of the geomagnetic field is observed. Kane & Trivedi^{30,31} compared the electrojet in Peru and Eusebio in east Brazil. Recent comparisons of the electrojet in eastern Brazil and Peru are by Shume *et al.*³² (Jicamarca and Sao Luiz) and Rastogi *et al.*³³ (Huancayo and Itinga).

Rastogi *et al.*³⁴ compared the equatorial electrojet at Sao Luiz in eastern Brazil (44.2°) and at Sikasso in the western African sector (5.7°W) where declination is 6.4°W.

In the present paper, the features of equatorial electrojet in the African sector are describe based on three years (1962-64) of data at Freetown (FTN, 8.4°N, 13°E, dip 0.9°N, declination 13°E) on the western part of Africa and Addis Ababa (AAE, 9°N, 38.7°E, dip 1.2°S, declination 0.4°W) on the eastern part of Africa. The coordinates and the geomagnetic field parameters of the two stations are given in Table 1. The declination is almost along the geographic N-S at AAE and 14° towards west of the geographic N-S at FTN. The total field intensity is 35772 nT at AAE and 31034 at FTN.

2 Data

Hourly values of the geomagnetic components X, Y and Z have been obtained from World Data Center for Geomagnetism, Kyoto, Japan. To derive the hourly deviations in the geomagnetic components, local midnight values have been subtracted from the hourly values of the geomagnetic components. Rastogi *et al.*²⁸ made quantitative estimate of the standard deviation and of the standard error in mean of ΔX , ΔY and ΔZ at each hour for the month of April 1993 for Sao Luiz (SLZ). There is large day-to-day variability in the daily variations of the geomagnetic field components. The daily range in X component varied between 60 nT and 160 nT with time, the maximum variation has been between 1100 and 1300 hrs LT. The daily plots of ΔY showed maximum negative values between 40 and 70 nT during 0900 – 1300 hrs LT. The standard deviations in ΔX and ΔY were maximum at noon. The standard error in mean in ΔX varied from around 8 nT at noon to 5 nT during evening - midnight hours and was least during midnight - morning hours (1-2 nT). The standard error in mean ΔY was maximum around noon with a value of about 5 nT. Based on the mean values and standard errors in mean of ΔX and ΔY at SLZ, the errors in the direction of H vector were computed. Error was very small (about a degree) between 0900 and 1500 hrs

Table 1 — Stations with geographic coordinates and geomagnetic field parameters

Station name	Station code	Latitude, °N	Longitude, °E	Declination, °W	Inclination, °N	Geomagnetic field, nT	X, nT	Y, nT
Addis Ababa	AAE	9	38.7	0.4	1.2	35772	35771	-249
Free Town	FTN	8.4	13.0	14.0	0.9	31034	30113	-7489

LT. The error was very high between sunset and sunrise hours due to low values of the deviations in ΔX and ΔY . The standard error in the monthly mean of ΔX , ΔY and ΔZ at the two stations FTN and AAE was of similar magnitude. The standard error in seasonal mean and annual mean were 50% and 30%, respectively of the errors in the monthly mean.

3 Results

3.1 Daily variations of ΔX and ΔY

The annual mean daily variations of the deviations in the geomagnetic field components X (ΔX) and Y (ΔY) at both the stations FTN and AAE for three years are shown in Fig. 1. The mean daily variations of ΔX show a peak around midday for both the stations with maximum value of about 80 nT at FTN and 70 nT at AAE. This longitudinal difference is consistent with the lower value of the geomagnetic field at FTN compared to that at AAE resulting in the higher Hall conductivity, hence stronger electrojet currents at FTN than AAE. Another notable difference seen is that at FTN, ΔX after attaining the minimum value after sunset, increases slowly up to sunrise. Almost similar feature (increase in ΔX from midnight to sunrise) is seen at the equatorial electrojet stations Itinga in Eastern Brazil³³ and Sikasso in Western Africa³⁴. Referring to the daily variations of ΔY , there is fairly large westward component of the deviation in the geomagnetic field at FTN. The daily variation of ΔY at FTN shows decrease after sunrise with a broad minimum of -20 nT at noon. The decrease is much smaller at AAE with minimum of

-5 nT at noon and changing to small positive peak (2-5 nT) in the afternoon.

Figure 2 shows the plots of hourly values of ΔX versus ΔY at both the stations for each of the three years. The straight lines represent the directions at -5°, -10° and -15°. The points for FTN lie along an elongated ellipse tilted towards west of north. The major axis of the ellipse is aligned towards -10°. It is interesting to note that the points representing 2200 to 0600 hrs LT lie along the geographic N-S, from 0700 to 0900 hrs LT lie towards east of geographic N-S and cross to west of geographic N-S at 1000 hrs LT. The points lie around 15° west of north at midday and more than 20° west of north in the early afternoon. The values in the evening and night hours are not significant due to large errors owing to small values of ΔX and ΔY . In contrast, the points for AAE lie along a highly elongated ellipse, almost a straight line and the major axis oriented along a direction less than 5° west of north. Thus, the electrojet current direction is not eastward during daytime but north of east by about few degrees at AAE and by almost 20° at FTN. The current direction is also dependent on local time.

The seasonal mean daily variations of ΔX and ΔY for the three seasons of December solstices (November to February), equinoxes (March, April, September and October) and June solstices (May to August) at both the stations are shown in Fig. 3 for each of the three years. The variation of ΔX for D-months at FTN shows a peak around 1100 hrs LT with value of about 90 nT for each of the years. During E-months, peak values at 1100 hrs LT vary

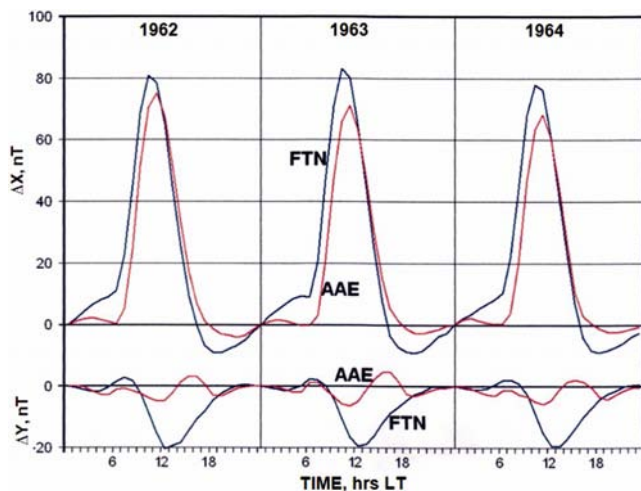


Fig. 1 — Annual mean daily variations of ΔX and ΔY at FTN and AAE for the years 1962 - 1964

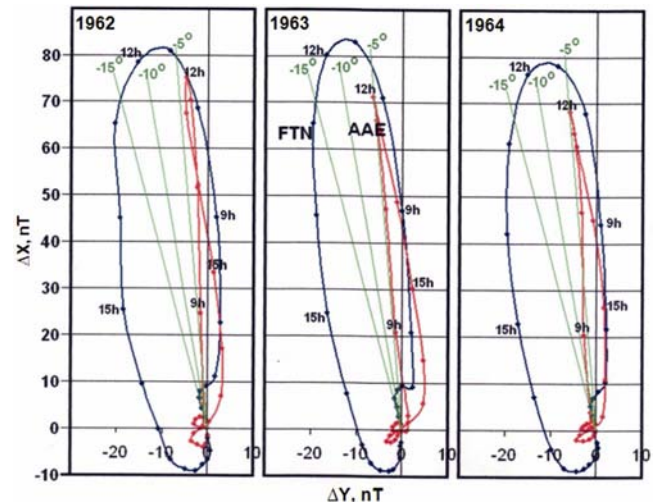


Fig. 2 — Diurnal plots of the annual mean values of ΔX versus ΔY at FTN and AAE for the years 1962 - 1964

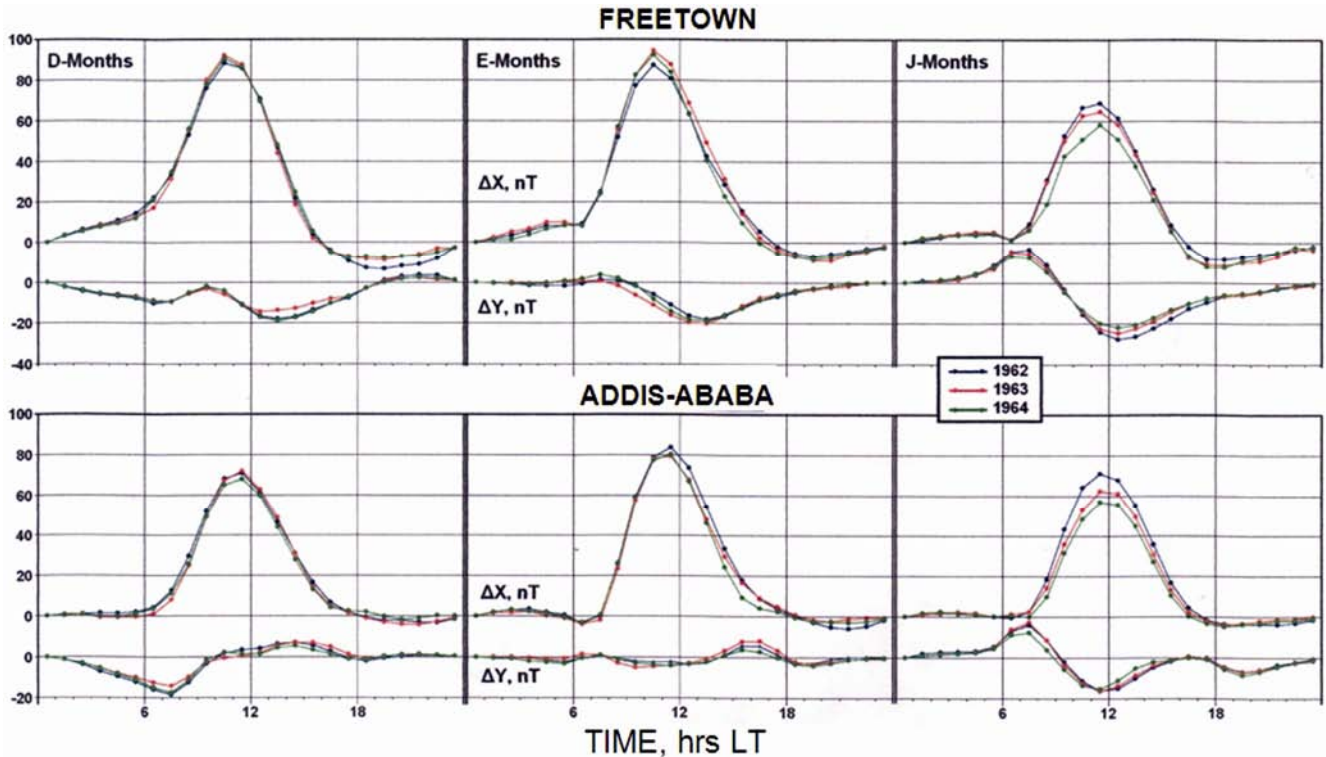


Fig. 3 — Seasonal mean daily variations of ΔX and ΔY during D-months, E-months and J-months at FTN for the years 1962 - 1964

between 87 and 95 nT for the three years. During J-months, peak values at 1100 hrs LT are between 58 nT and 70 nT, which are comparatively smaller than the other two seasons. As compared to FTN, the peak values of ΔX are smaller at AAE with values of around 70 nT during D-months and 90 nT during E-months. However, peak ΔX values between 58 nT and 70 nT during J-months at AAE are similar to the values at FTN.

Referring to the daily variations of ΔY at FTN, during D-months, it decreases from midnight to sunrise and reach a minimum of -10 nT. It shows an increase from 0800 hrs LT to reach a value close to zero at 1000 hrs LT and then decreases rapidly to about -20 nT around 1300 hrs LT. During E-months, ΔY remains almost constant from midnight to sunrise near zero level. It decreases to about -20 nT around 1300 hrs LT and later recovers to zero level by midnight. During J-months, the trend is very different. ΔY increases slowly from zero level at midnight to about 15 nT at 0800 hrs LT and then decreases rapidly from -20 to -28 nT around 1300 hrs LT. It slowly returns to zero level by midnight. The variations of ΔY at AAE are different in nature. During D-months, it decreases slowly from zero at midnight to -20 nT at 0800 hrs LT, increases to zero

level by 1000 hrs LT and then is almost constant later on, though there is an indication of a flat peak in the afternoon. There is hardly any variation during E-months but an indication of a minimum in the pre-noon and maximum in the late afternoon is clearly seen. During J-months, ΔY increases slowly from midnight to about 15 nT at 0800 hrs LT, decreases rapidly to -15 nT at midday and then increases again to zero level by 1700 hrs LT. Another dip is seen at 2000 hrs LT with value of -8 nT. Thus, there is some similarity in the nature of daily variations at the two stations season-wise. D-months show a decrease from midnight to sunrise, no variation in this period is seen during E-months and an increase is seen during J-months.

The vector plots of the hourly values of ΔX versus ΔY for each season at the two stations are shown in Fig. 4. For FTN, the points (day time) lie along ellipses with major axis oriented around 5 degrees west of north for D-months and E-months. However, during J-months, major axis is oriented along almost 20 degree west of north. For AEE, points (day time) lie almost along straight lines during D-months and E-months with orientation of the major axis along 2 degree and almost 15 degree west of north. During J-months, there is large scatter with points during

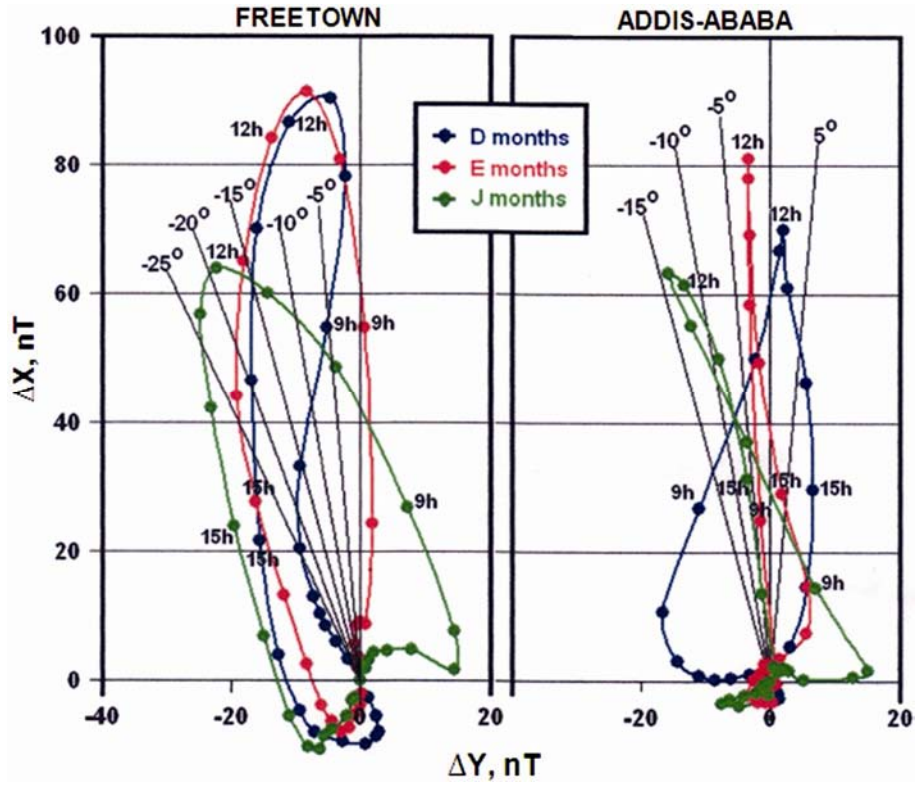


Fig. 4 — Diurnal plots of the seasonal mean values of ΔX versus ΔY at FTN and AAE for D-months, E-months and J-months averaged over the years 1962 - 1964

0900-1000 hrs LT lying west of north and during 1200-1500 hrs LT along east of north. The midday values (1100-1300 hrs LT) are almost towards north.

3.2 Seasonal variations of ΔX and ΔY

The month-to-month variations of the monthly mean midday values of ΔX and ΔY at the two stations FTN (blue) and AAE (red) for the entire three year period are shown in Fig. 5. The seasonal variations of ΔX at the two stations show equinoctial maxima and minimum during J-months. However, the peak in February-March with values of 100 nT at FTN and 80-90 nT at AAE is higher than the peak in October with values of 70-80 nT at FTN and 70-75 nT at AAE. Similar results were also observed for Trivandrum by Rastogi *et al.*³⁵ and at Sao Luiz in central Brazil³⁴.

The month-to-month variation of the monthly mean midday value of ΔY at the two stations show positive (or close to zero) values during D-months and maximum negative values of about -20 nT in J-months at AAE. At FTN, values are negative but again minimum negative values of about -10 nT are

seen in D-months and maximum negative values are seen in J-months. For all the three years, the values are most negative in May (-25 to -32 nT) and become less negative in June-July months.

Contour plots of monthly mean hourly values of ΔX and ΔY at FTN averaged over the three year period plotted on the grid of hour and month are shown in Fig. 6. The seasonal variation of ΔX shows clear equinoctial peaks around March and October and minimum around June. Diurnal variation shows peak around 1100 hrs LT. The contour plots of ΔY show positive values till 0900 hrs LT during April to October months. Negative values are seen throughout the year from 0900 to 1800 hrs LT. The peak positive value of about 15 nT around 0600 hrs LT and the peak negative value of -20 nT around noon both are seen centered around June.

The monthly mean daily variations of ΔX and ΔY for each month, averaged over the three years are shown in Fig. 7. The variation of ΔX at FTN shows clearly semi-annual variation with maxima in February - March and October - November. For AAE, the semi-annual peaks are seen during March - April and September - October. Other interesting point to

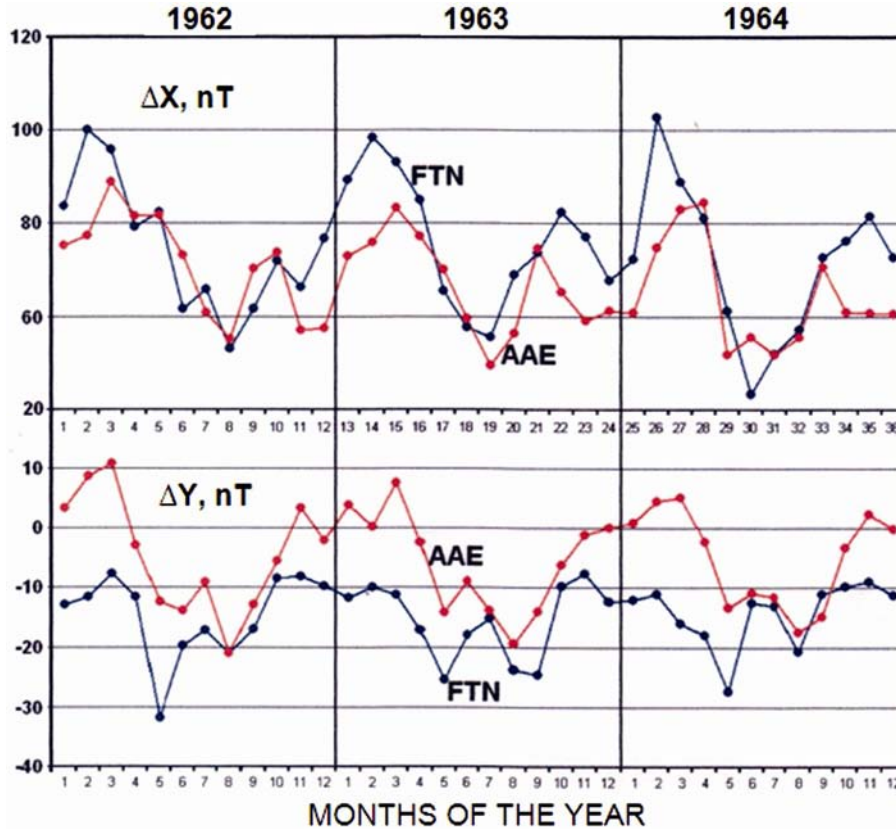


Fig. 5 — Monthly mean daily variations of ΔX and ΔY at FTN and AAE for each month of the years 1962 - 1964

note is that the midday peak values are higher at FTN than at AAE for the months of January - March and October - December. For the months of April - September, the two peaks are almost equal except for the month of June when the peak at AAE is higher than at FTN. The peak values are lowest during the months of June - August. This difference during the months of June solstices is again seen for the variations in ΔY . The daily variations of ΔY at the two stations for the months October - March is of one type and from April to September is different. Midday values of ΔY are positive at AAE for the months of October - March but negative during April - September. At FTN the values are negative at midday and positive close to zero at mid night for October - April. From May to September, there is a positive peak in the sunrise period, large negative value at midday.

3.3 Geomagnetic activity and Day-to-day variability

To study the day-to-day variability in terms of the geomagnetic activity, September-October 1963 period is chosen, which was marked by geomagnetic storms around 14 and 23 September 1963; and 24 and

30 October 1963. The daily variations of ΔX at AAE and FTN for each day of this two month period are shown in Fig. 8 (lower half) along with the Dst index. The daily variations of ΔY at the two stations and of the Dst index are shown in the upper half of the figure. The day-to-day variability in the variations in both ΔX and ΔY at both the stations is marked even when Dst index does not show much variation.

To study the variability as a function of Dst index, the correlation between the deviations in ΔX and ΔY and of Dst index is examined and the correlation coefficient (σ) and the slope (m) of the best-fit line is estimated from the hourly values of the deviations in ΔX and ΔY and of Dst index. The correlation between ΔY and Dst index along with the slope values for both the stations are shown in the scatter plot for midnight and midday in Fig. 9. For midday, there is no correlation between ΔY and Dst at FTN but a negative correlation of -0.52 is seen at AAE. For midnight, negative correlation is seen for both FTN and AAE with values of -0.50 and -0.84, respectively. Correlation coefficient and slope of the regression line between the hourly values of ΔX and Dst index for each hour at the two stations are plotted in Fig. 10.

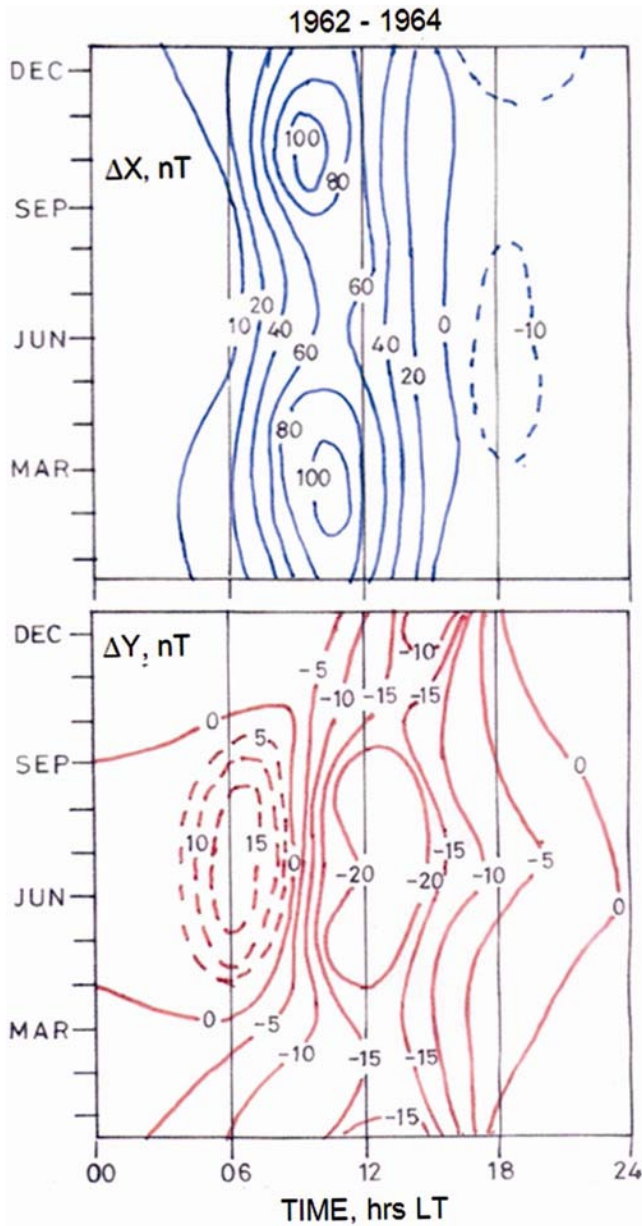


Fig. 6 — Contour plots of mean values of ΔX and ΔY averaged on the grid months versus hours over the period 1962 - 1964

The magnitude of the correlation coefficient varies from 0.75 around midday to 0.95 around midnight. The slope values vary from 0.55 to 1.45 at AAE and from 0.65 to 1.78 at FTN. The minimum values occur in the early morning hours (0200-0600 hrs LT) and maximum around 1200-1300 hrs LT. Thus, the fluctuations in the night time values of the deviations in ΔX are entirely due to the corresponding fluctuations of the ring current. Rastogi *et al.*³³ showed high correlation between the night time deviations in ΔX and Dst index at equatorial stations

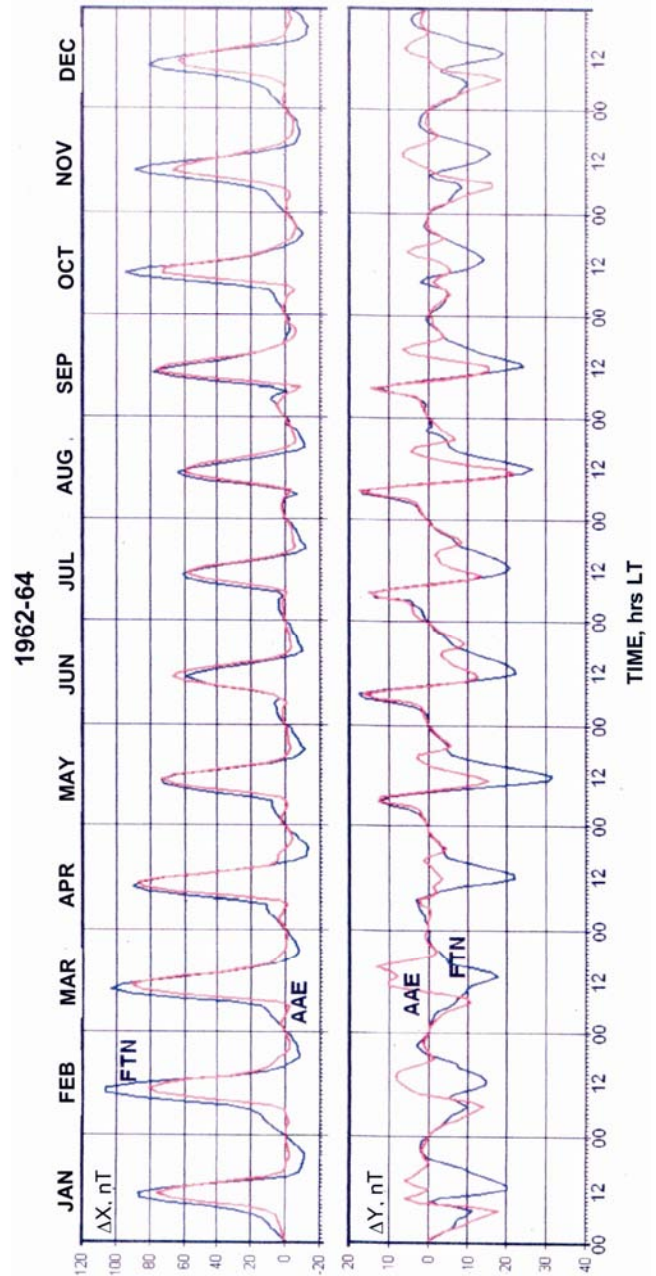


Fig. 7 — Monthly mean daily variations of ΔX and ΔY at FTN and AAE for each month averaged over the years 1962-1964

Huancayo in the western part of South America and Itinga in the eastern part.

There was a severe geomagnetic activity on 22-23 September 1963 with Dst decreasing to about -125 nT around 0600 hrs UT on 22 September followed by big decrease to about -235 nT around 0200 hrs UT on 23 September. The values of ΔX and ΔY along with Dst index during the 22-23 September are shown in Fig. 11. As expected, the decrease in ΔX follows the

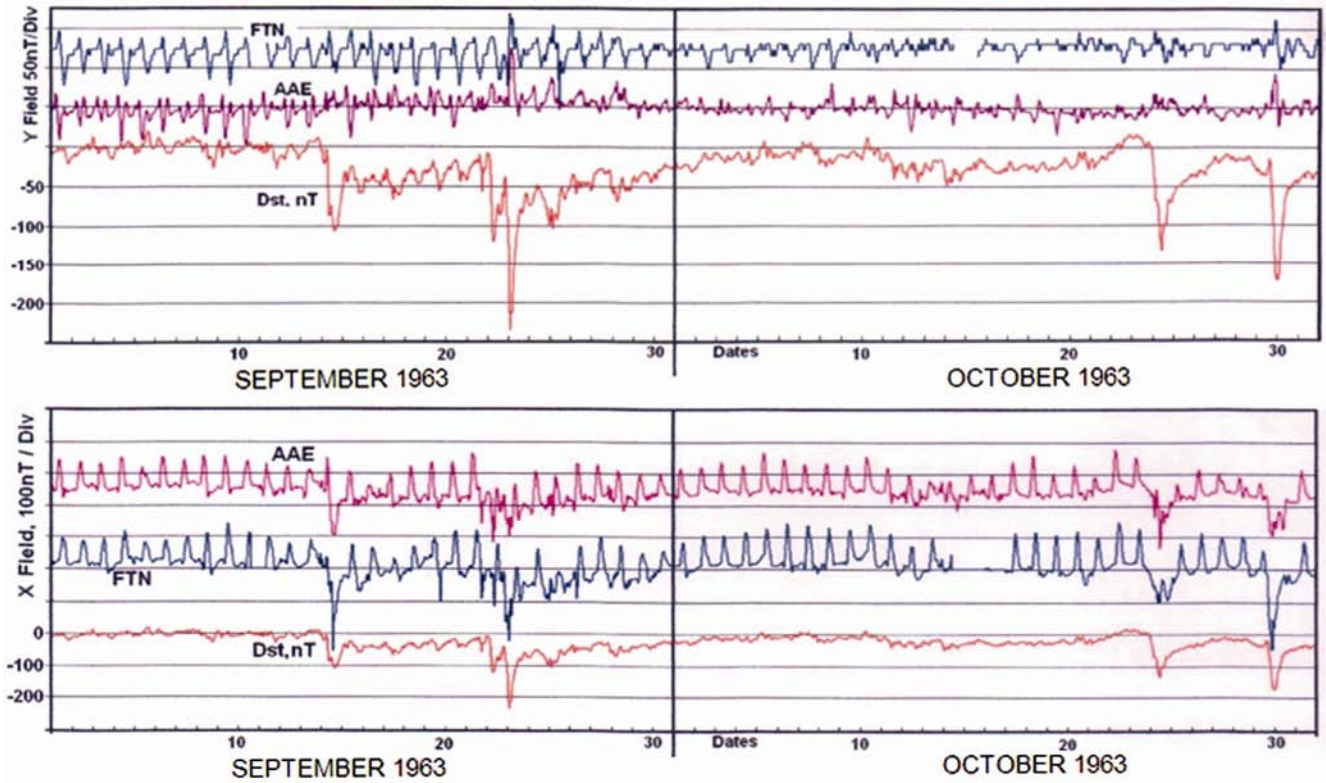


Fig. 8 — Daily variations of ΔX (bottom) and ΔY (top) at FTN and AAE and Dst index for each day during 1 September - 31 October 1963

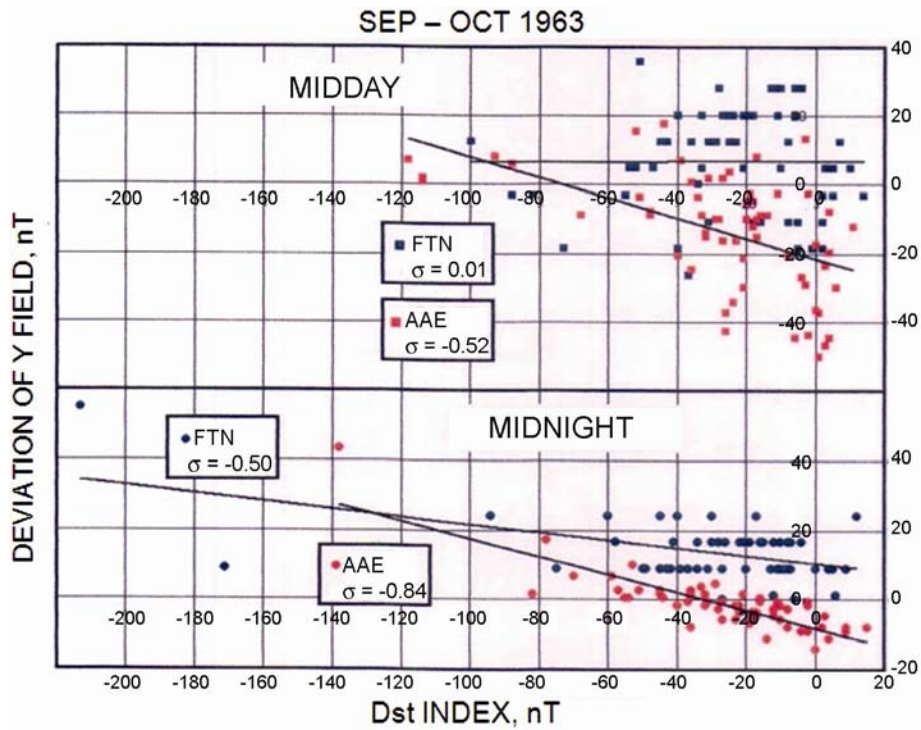


Fig. 9 — Scatter plot of the deviations in Y versus Dst index at FTN and AAE for: (top) midday; and (bottom) midnight, during September - October 1963 [the best-fit regression lines along with the correlation coefficient (σ) and slope of the line (m) are also shown]

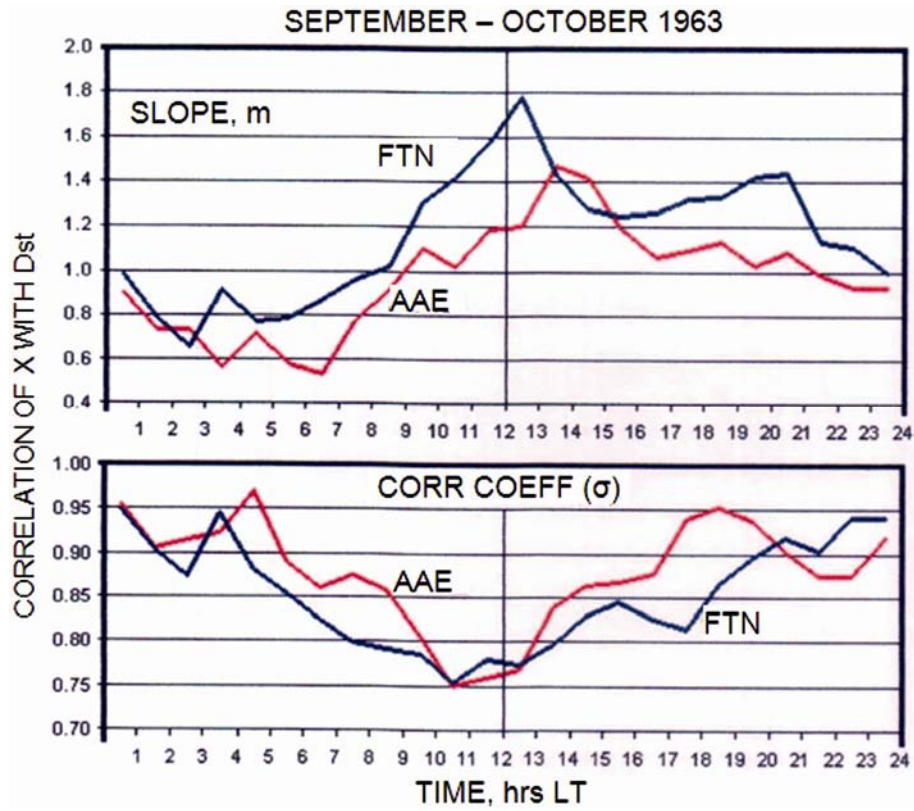


Fig. 10 — Daily variation of the correlation coefficient between ΔX and Dst index and the slope of the regression line at FTN and AAE based on data for September - October 1963

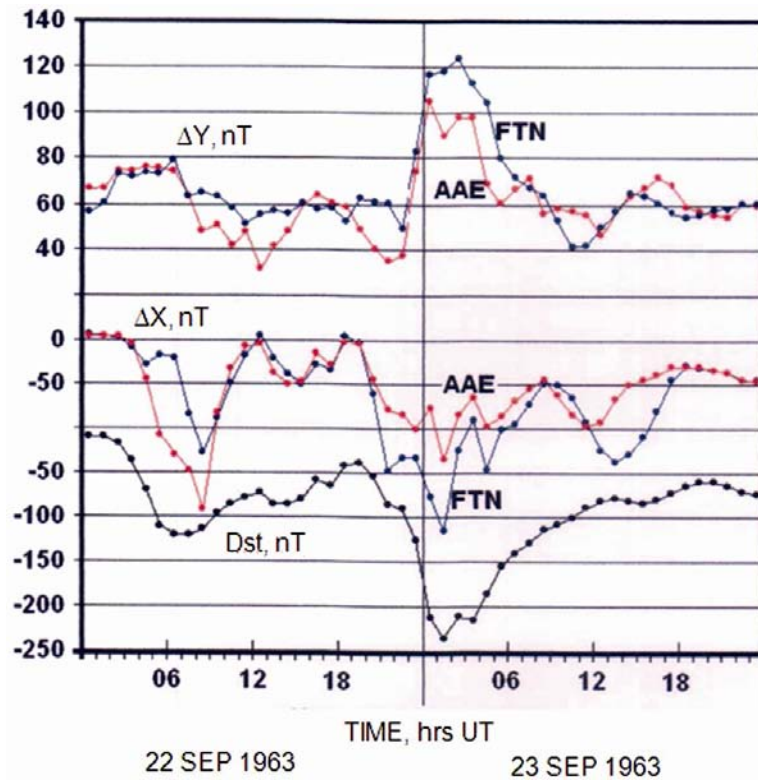


Fig. 11 — Daily variations of ΔX and ΔY at FTN and AAE and Dst index for 22 and 23 September 1963

decrease in Dst index at both the stations. However, there is increase in ΔY with the decrease in Dst. Thus, the current direction is not close to eastward (EEJ) or westward (CEJ) as the case for the equatorial electrojet current direction.

4 Discussion

The present study complements the earlier studies of the equatorial electrojet at different longitude regions, especially in and around the anomalous region in South America where the geomagnetic declination is up to $20^\circ W$ of the geographic N-S. Out of the two stations, the declination is almost close to the geographic N-S at Addis Ababa and $14^\circ W$ of N-S at Free Town. The mean daily range of the X component for the period 1962-64 is about 80 nT at Free Town and 70 nT at Addis Ababa. The strength of the equatorial electrojet varies with the longitude due to the lower value of the geomagnetic field in the South Atlantic region and results in the higher values of the Hall conductivity of ionosphere. The mean deviations in the Y component are very small (less than 5 nT) at Addis Ababa, and show a peak value of -20 nT at Free Town around noon. There is some similarity in the nature of daily variations at the two stations season-wise. D-months show a decrease from midnight to sunrise while an increase is seen during J-months. Similar seasonal difference is also noted at Sao Luiz in eastern Brazil and Sikasso in western Africa³⁴ with higher values at Sao Luiz.

There is large day-to-day variability in equatorial electrojet. The solar cycle variations are largely due to the changes in the electron density in E-region while the day-to-day variability is primarily caused by the changes in the electric field³⁶. On geomagnetic quiet days, the variability in electric field is mainly due to the changes in neutral atmospheric winds but on geomagnetic disturbed days, the variability is mainly due to the currents/electric fields of magnetospheric origin. Changes in the solar wind parameters and interplanetary magnetic field largely contribute to the variability during geomagnetic disturbed conditions. Yamazaki *et al.*³⁷ studied the day-to-day variability in equatorial electrojet and compared those in neutral winds at various altitudes, latitudes and longitudes. The day-to-day variation in equatorial electrojet is found to be dominated by the zonal winds at 100-120 km altitudes near the magnetic equator. Thus, the response of the zonal polarization electric field to variable zonal winds is shown to be the main

cause of the day-to-day variation in the equatorial electrojet during quiet periods.

Rastogi *et al.*¹² studied the day-to-day variations of the daily range in H at Ancon (ANC) and Sao Luiz (SLZ) for the period January - June 1993. For Ancon, the daily range in H varied mostly from 100 to more than 200 nT during March - April and from 50 to 150 nT during other months. For Sao Luiz, most of the values ranged from 50 to 150 nT. There were few negative or close to zero values on geomagnetic disturbed periods. Rastogi *et al.*³³ showed midday deviations in ΔX at Huancayo varying from about 50 to 200 nT during November - December 1990. The day-to-day variations in the midday values of ΔX at Buriticupa in N-E Brazil are shown to vary between 40 and 180 nT from 16 selected quiet days during November 1990 - March 1991 (Ref. 38).

Due to high conductivity, electrojet strength during daytime is very sensitive to the electric field changes. Since equatorial ionosphere is largely controlled by electric field, electrojet strength can be used to model the features of the equatorial ionosphere, like the ionization anomaly and the equatorial spread-F. Relationships have been shown between the Jicamarca incoherent scatter radar drift and the magnetometer data in Peru in the American sector and also from data in the Philippine longitude sector^{39,40}. Venkatesh *et al.*⁴¹ studied the day-to-day variability in the equatorial electrojet in the Indian and Brazilian sectors and its role in the ionization anomaly from the chain of GPS receivers. Significant day-to-day variability is seen in the equatorial electrojet. Total electron content also showed similar day-to-day variability, which is maximum near the anomaly crest.

Month-to-month variation of the mean daily range of X at both the stations shows equinoctial maxima with the values for March - April higher than September - October. Similar result is also reported in the Indian region based on 40 years of data at Trivandrum³⁵ and at Sao Luiz in central Brazil³⁴. Chandra & Rastogi⁴² showed maximum daytime E-region horizontal drift velocity averaged over the years 1964-67 from spaced receiver drift measurements from Thumba near Trivandrum to be higher in March - April than during September - October. Thus, the higher values of the electrojet during March - April are due to higher values of the electric field as compared to during September - October.

Another feature noted is the slow increase of the mean deviation in X at Free Town from about -10 nT

at 1800 hrs LT to about 10 nT at 0600 hrs LT. This feature is similar to the rise of deviation in X after midnight to morning reported earlier in the South American sector²⁷⁻²⁹.

The deviations in the geomagnetic X component in the night time are highly correlated with the Dst index^{33, 43, 44}. As expected, negative correlation is seen between Dst index and the hourly values of the deviations in X for the geomagnetic active period of September – October 1963. The magnitude of the correlation coefficient varied from 0.75 around midday to 0.95 around midnight. Rastogi *et al.*³³ found correlation of 0.90 at Itinga in East Brazil and 0.98 at Huancayo in Peru between Dst index and midnight values of the deviations in X. Thus, the fluctuations in the night time values of X are almost entirely due to the corresponding changes in the ring current index. The correlation values were found to be much less with values of 0.67 at Itinga and 0.40 at Huancayo during midday.

5 Conclusion

The present study shows the following :

- (i) The geomagnetic X and Y components at equatorial electrojet stations, Freetown on the western part and Addis Ababa on the eastern part of Africa, are studied for three years 1962-64. The annual average daily mean range in the geomagnetic X component at Freetown and Addis Ababa are 80 nT and 70 nT, respectively with peak at 1100 hrs LT.
- (ii) The equinoctial peak of the daily range in X during March – April is higher than the peak in September - October. This has been reported earlier for the Indian and Brazilian stations.
- (iii) A steady increase in the mean deviation in the X component is seen at Freetown from -10 nT at 1800 hrs LT to 10 nT at 0600 hrs LT.
- (iv) The annual average deviations in Y component at Freetown show a minimum of about -20 nT around noon while the values are much smaller at Addis Ababa.
- (v) The deviations in the night time values of the X component are highly correlated with the Dst index, thus almost entirely due to the fluctuations in the ring current.

Acknowledgement

Thanks are due to the Director, Physical research Laboratory, Ahmedabad for the facilities provided to the authors.

References

- 1 Chapman S, The equatorial electrojet as detected from the abnormal electric current distribution above Huancayo, Peru and elsewhere, *Arch Meterol Geophys Bioclimatol (Austria)*, A4 (1951) pp 368-390.
- 2 Onwumechilli C A, Variations in the geomagnetic field at Ibadan, Nigeria I: Solar variations, *J Atmos Terr Phys (UK)*, 13 (1959) pp 106-114.
- 3 Forbush S E & Casaverde M, in *Equatorial electrojet in Peru*, Carnigie Instn, Washington Pub No 620 (Carnigie Instn, Washington DC), 1961.
- 4 Yacob A & Khanna K B, Geomagnetic Sq variations and parameters of the Indian electrojet for 1958 and 1959, *Indian J Meteorol Geophys*, 14 (1963) pp 47-477.
- 5 Gadivier R & Crenn Y, Equatorial electrojet in Tschad, *Ann Geophys (France)*, 2 (1965) pp143-155.
- 6 Rastogi R G, Longitudinal variation in the equatorial electrojet, *J Atmos Terr Phys (UK)*, 24 (1962) pp 1031-1040.
- 7 Gouin P, Reversal of the magnetic daily variation at Addis Ababa, *Nature (UK)*, 193 (1962) pp 1145-1146.
- 8 Gouin P & Mayaud P N, A proposal for the possible existence of a counter electrojet at magnetic equatorial latitudes, *Ann Geophys (France)*, 23 (1967) pp 41-47.
- 9 Hutton R & Oyinloye J O, The counter electrojet in Nigeria, *Ann Geophys (France)*, 26 (1970) pp 921-926.
- 10 Fambitkoye O, Variabilite jour a jour de la variation journaliere reguliere du champs magnetique terrestre dans la region de l'electrojet equatorial, *C R Acad Sci Ser B (France)*, 272 (1971) pp 637-640.
- 11 Chandra H, Misra R K & Rastogi R G, Equatorial ionospheric drift and the electrojet, *Planet Space Sci (UK)*, 19 (1971) pp 1497-1503.
- 12 Rastogi R G, Chandra H, Chakraborty D, Kitamura K & Yumoto K, Day-to-day correlation of equatorial electrojet at two locations separated by 2000 km, *Ann Geophys (France)*, 25 (2007) pp 875-880.
- 13 Rastogi R G, Sudden disappearance of Es-q and the reversal of equatorial electric fields, *Ann Geophys (France)*, 28 (1972) pp 717-728.
- 14 Fambitakoye O, Rastogi R G, Tabbagh J & Vila P, Counter electrojet and Esq disappearance, *J Atmos Terr Phys (UK)*, 35 (1973) pp 1119-1126.
- 15 Rastogi R G, Westward equatorial electrojet during the day time hours, *J Geophys Res (USA)*, 79 (1974) pp 1503-1512.
- 16 Rastogi R G, Fejer B G & Woodman R F, Sudden disappearance of VHF radar echoes from equatorial E region irregularities, *Indian J Radio Space Phys*, 6 (1977) pp 39-43.
- 17 Rastogi R G, On the simultaneous existence of eastward and westward flowing equatorial electrojet currents, *Proc Indian Acad Sci*, 78 (1975) pp 80-92.
- 18 Carter D A, Balsley B B & Eckerlund W L, VHF Doppler radar observations of the African equatorial electrojet, *J Geophys Res (USA)*, 81 (1976) pp 2786-2794.
- 19 Forbes J M, The equatorial electrojet, *Rev Geophys Space Phys (USA)*, 19 (1981) pp 469-504.
- 20 Reddy C A, The equatorial electrojet, *Pure Appl Geophys (Switzerland)*, 131 (1989) pp 485-508.
- 21 Rastogi R G, *The equatorial electrojet: Magnetic and ionospheric effects in geomagnetism V 3*, Ed: J Jacobs (Academic Press, London), 1989, pp 461-525.

- 22 Fambitakoye O & Mayaud P N, Equatorial electrojet and regular daily variations, SR I: A determination of equatorial electrojet parameters, *J Atmos Terr Phys (UK)*, 38 (1976a) pp 1-17.
- 23 Fambitakoye O & Mayaud P N, Equatorial electrojet and regular daily variations SR II: The Centre of the equatorial electrojet, *J Atmos Terr Phys (UK)*, 38 (1976b) pp 19-26.
- 24 Arora B R., Mahashabde M V & Kalra R, Indian IEEY geomagnetic observational program and some preliminary results, *Rev Brazil Geophys (Brazil)*, 11 (1993) pp 365-385.
- 25 Rastogi R G, Ionospheric current system in Indo-Russian longitude sector, *Sci Cult (India)*, 65 (1999) pp 269-282.
- 26 Doumouya V, Vassal J, Cohen Y, Fambitakoye O & Menvielle M, Equatorial electrojet at African longitudes: first results from magnetic measurements, *Ann Geophys (France)*, 16 (1998) pp 658-676.
- 27 Rastogi R G & Trivedi N B, Asymmetries in the equatorial electrojet around N-E Brazil sector, *Ann Geophys (France)*, 27 (2009) pp 1-17.
- 28 Rastogi R G, Chandra H & Yumoto Y, Equatorial electrojet in East Brazil longitudes, *J Earth Sys Sci (India)*, 119 (2010) pp 497-505.
- 29 Rastogi R G, Chandra H, James M E, Kitamura K & Yumoto, Characteristics of equatorial electrojet in the central region of South America, *Earth, Planet Space (Japan)*, 60 (2008) pp 623-632.
- 30 Kane R P & Trivedi N B, Comparison of equatorial electrojet characteristics at Huancayo and Eusebio (Fortaleza) in the south American region, *J Atmos Terr Phys (UK)*, 44 (1982) pp 785-792.
- 31 Kane R P & Trivedi N B, Equatorial electrojet movements at Huancayo and Eusebio (Fortaleza) on selected quiet days, *J Geomagn Geoelectr (Japan)*, 37 (1985) pp 1-9.
- 32 Shume E B, Denardini C M, de Paula E R & Trivedi N B, Variabilities of the equatorial electrojet in Brazil and Peru, *J Geophys Res (USA)*, 115 (2010) A06306, doi: 10.1029/2009JA014984.
- 33 Rastogi R G, Chandra H, Shah Rahul, Trivedi N B & Fontes S L, A comparison of equatorial electrojet in Peru and East Brazil, *Open Atmos Sci J (China)*, 7 (2013) pp 29-36.
- 34 Rastogi R G, Chandra H, Trivedi N B & Doumbya V, Equatorial electrojet in the South Atlantic anomaly region, *J Earth Sys Sci (India)*, 120 (2011) pp 301-310.
- 35 Rastogi R G, Chandra H, Janardhan P & Shah Rahul, Equatorial and mid-latitude ionospheric currents in India based on 40 years of data at Trivandrum and Alibag, *Indian J Radio Space Phys*, 43 (2014) pp 274-283.
- 36 Rastogi R G, Geomagnetic field variations at low latitudes and ionospheric electric field, *J Atmos Terr Phys (UK)*, 55 (1993) pp 1375-1382.
- 37 Yamazaki Y, Richmond A D, Maute A, Liu H L, Pedatella N & Sasi F, On the day-to-day variation of the equatorial electrojet during quiet periods, *J Geophys Res (USA)*, 119 (2014), doi: 10.1002/2014JA020243.
- 38 Rastogi R G & Trivedi N B, Asymmetries in the equatorial electrojet around N-E Brazil sector, *Ann Geophys (France)*, 27 (2009) pp 1-17.
- 39 Anderson D, Anghel A, Yumoto K, Ishitsuka M & Kudeki E, Estimating daytime vertical E×B drift velocities in the equatorial F-region using ground-based magnetometer observations, *Geophys Res Lett (USA)*, 29 (2002) pp 1596, doi: 10/1029GLO14562.
- 40 Anderson D, Anghel A, Chau J L & Yumoto K, Global, low-latitude, vertical E×B drift velocities inferred from daytime magnetometer observations, *Space Weath (USA)*, 4 (2006), doi: 10.1029/2005SW000193.
- 41 Venkatesh K, Fagundes P R, Prasad D S V V D, Denardini C M, de Abreu A J, de Jesus R & Gende M, Day-to-day variability of equatorial electrojet and its role on the day-to-day characteristics of the equatorial ionization anomaly over the Indian and Brazilian sectors, *J Geophys Res (USA)*, doi: 10.1002/2015JA021307.
- 42 Chandra H & Rastogi R G, Horizontal drifts in the E- and F-regions over Thumba, during day-time, *J Atmos Terr Phys (UK)*, 31 (1969) pp 1205-1215.
- 43 Uozumi T, Yumoto K, Kitamura K, A new index to monitor temporal and long-term variations of the equatorial electrojet by MAGDAS/CPMN real-time data: EE index, *Earth, Planet Space (Japan)*, 60 (2008) pp 785-790.
- 44 James M E, Rastogi R G & Chandra H, Day-to-day variation of geomagnetic H field and equatorial ring current, *J Indian Geophys Union*, 12 (2008) pp 69-78.