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Latitudinal extent of the equatorial electrojet effects in the Indian zone

R. G. Rastogi *

C.S.I.R. Emeritus Scientiest, Physical Research Laboratory, Ahmedabad 380 009, India

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Abstract. Using the H and Z components of the geomagnetic field at eight observatories in India, situated within a narrow longitudinal zone and spread from 0° to 25° dip latitudes, it has been shown that the effects at the ground during strong counter electrojet events can be seen over the entire latitudinal extent of the Indian zone, not only over the narrow zone near the dip equator. Some disturbances are shown to occur at low latitudes, causing simultaneous decrease of the equatorial electrojet current and increase of the Sq current. These abnormal changes in the low-latitudes geomagnetic field are suggested to be due to local modifications of the lunar and solar tides rather than due to the imposition of additional electric fields at only the equatorial stations.

Introduction

The early data on the daily range of the horizontal component of the geomagnetic field, H, at low latitudes had indicated the equatorial enhancement to be confined within a narrow belt of ±5° centered around the dip equator (Egedal, 1947). This was attributed to a strong eastward current in the dynamo region of the ionosphere and was named the Equatorial Electrojet by Chapman (1951). Using ground magnetic data from December 1956 to January 1957 Onwumechilli (1959) determined the half-width of the equatorial electrojet during midday hours to be 220 km in Nigeria.

The establishment of geomagnetic observatories at Chimbote, Chiclayo and Talara in Peru during the IGY-IGC period, together with the earlier existing observatory at Huancayo, provided data which clearly defined the electrojet to have width of 660 km centered on the magnetic equator (Forbush and Casaverde 1961). The observatories at Trivandrum and Annamalainagar, established during IGY and continuing since then, together with the observatory at Kodaikanal did not cover the complete belt of the electrojet in India. The model calculations using the data from these equatorial stations suggested the half width of the electrojet to be 290 km for the summer of 1958 (Yacob and Khanna, 1963). The establishment of six temporary observatories, together with three permanent observatories in Central Africa, formed a unique chain of nine observatories situated on either side of the dip equator spread over 3000 kms, and provided important data on the equatorial electrojet (Fambitakoye and Mayaud 1976 a, b).

Additional permanent geomagnetic observatories were established in India during IGY and later during the IQSY programmes. Today, a network of eleven observatories are operating in India between the latitudes of the centre of equatorial electrojet current and the focus of Sq current system. They form the only network of geomagnetic observatories along the same longitude sector for the simultaneous study of equatorial electrojet and Sq currents.

The regular daily variations of the D-, H- and Z-components of the geomagnetic field at the network of Indian observatories, together with observatories in the same longitude sector of the USSR, for the year 1978, have been discussed by Patil *et al.* (1983). The focus of Sq current was shown to lie between the latitudes of Gulmarg (Geog. 34.0°N, 74.4°E) in India and Tashkant (Geog. 41.3°N, 69.6°E) in the USSR. The H field reached a maximum around noon at all of the Indian observatories, the magnitude of the daily range decreased with increasing latitude all the way from Trivandrum to Gulmarg. The Z-component at all the observatories except Trivandrum showed a minimum around noon; the daily range was a maximum at Annamalainagar, a station near the half-width of the electrojet. The daily variation of the Z-component at all the observatories except Trivandrum showed a minimum around noon; the daily range was a maximum at Annalmalainagar, a station near the half-width of the electrojet. The daily variation of the Z-component at Trivandrum showed a maximum jet before

* Formerly Director, Indian Institute of Geomagnetism, Colaba, Bombay 400 005, India

noon and a minimum in the afternoon hours. This abnormal behaviour of Z at Trivandrum has been explained as due to an induced current in the sub-surface conducting underground layer in the Palk Strait between India and Sri Lanka (Singh *et al.* 1982).

Fambitakoye (1971) showed, for the first time, the latitudinal profiles of ΔH and ΔZ during the normal electrojet day (NEJ) and the counter electrojet day (CEJ). During the NEJ event, ΔH showed a maximum over the dip equator and ΔZ showed a minimum near the southern edge and a maximum near the northern edge of the electrojet belt. During the CEJ event, both the ΔH and ΔZ profiles were reversed. In the Indian sector the CEJ events cause a minimum of ΔH at Trivandrum and a maximum of ΔZ at Annamalainagar (Rastogi, 1974a).

Bhargava and Sastri (1977) gave a new insight to the CEJ phenomenon by computing the daily variations of ΔH on CEJ minus the same on NEJ days for Indian observatories, taking special care of selecting very quiet days for the two groups, equally distributed over the same period. The difference curve, ΔH on CEJ days minus ΔH on NEJ days showed a maximum around 0900 LT and a minimum around 1500 LT. This clearly suggests a strong

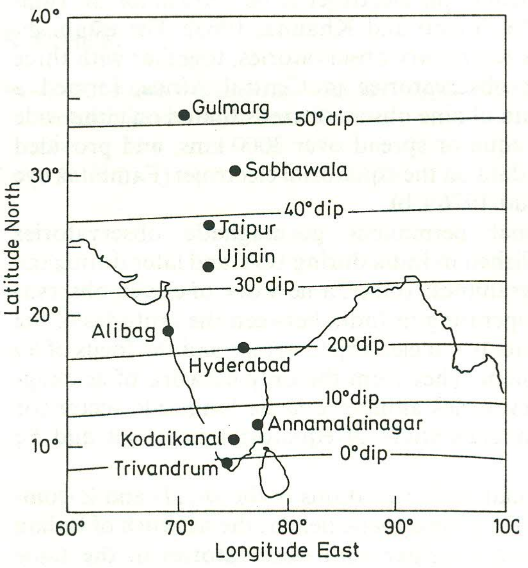


Fig. 1. The map showing the location of geomagnetic observatories in India situated within a small longitude

semi-diurnal component during the daylight hours superimposed on the daily variation of the H field at low latitudes on the days with afternoon CEJ events. Alex *et al.* (1986) suggested that this semi-diurnal wave was associated with the lunar semi-dirunal tide. Rastogi (1974b) has shown that the occurrence of the morning and afternoon CEJ events is correlated with the time of maximum negative effect of the lunar semi-diurnal magnetic variation.

In this paper, an attempt is made to study the daily variation and the latitudinal profiles of ΔH and ΔZ on CEJ days, utilizing the data from eight magnetic observatories in India, the locations of which are shown in Fig. 1. The geographic and magnetic coordinates of the observatories are given in Table 1.

Presentation of data

First, a day (4 January 1985) was chosen which was magnetically quiet and showed abnormally large CEJ features on the magnetogram at the equatorial station, Trivandrum. For comparison, another quiet day (18 January 1985) in the same month was chosen, which showed distinct NEJ features with a gradual rise of ΔH following sunrise, a maximum shortly before noon, and a gradual decrease until sunset without any depression below the base-line value. The magnetograms at Trivandrum on these days are reproduced in Fig. 2. Both these days were geomagnetically quiet and so the variations of geomagnetic field disturbance effects. The H magnetogram on 18 January 1985 showed an increase of the H field after sunrise, maximizing at about 1000 LT, followed by a gradual decrease until sunset, after which it remained fairly constant throughout the night; characteristics of a NEJ day. On 4 January 1985, the H field started increasing after sunrise, maximizing around 1000 LT after which is started decreasing, crossing the night-time level at about 1215 LT, reaching a minimum around 1345 LT, and returned to the night-time level by sunset. It is to be noted that the maximum negative excursion of the field in the afternoon was almost the same magnitude as the maximum positive excursion in the morning.

Figure 3 shows the daily variations of ΔH and ΔZ at different observatories on 4 and 18 January 1985. On the NEJ day, 18 January 1985, the H field showed a maximum around noon at all of the stations, with a systematic

Table 1. List of geomagnetic observatories with its IAGA code name, geographic, dipole coordinates and dip latitude, whose data are used in the present analyses

Observatory	Code	Geog.		Dipole		Dip latitude approx.
		Long. °E	Lat. °N	Long. °E	Lat. °N	
Trivandrum	TRD	77.0	8.5	146.4	−1.2	− 0.9
Kodaikanal	KOD	77.5	10.2	147.1	0.6	3.1
Annamalainagar	ANN	79.6	11.4	149.4	1.4	5.4
Hyderabad	HYD	78.6	17.4	148.9	7.6	20.5
Alibag	ABG	72.9	18.6	143.6	9.5	24.2
Ujjain	UJJ	75.8	23.2	147.0	13.5	32.7
Jaipur	JAI	75.6	26.9	147.4	17.3	39.4
Sabhawala	SAB	77.8	30.4	149.8	20.8	45.3

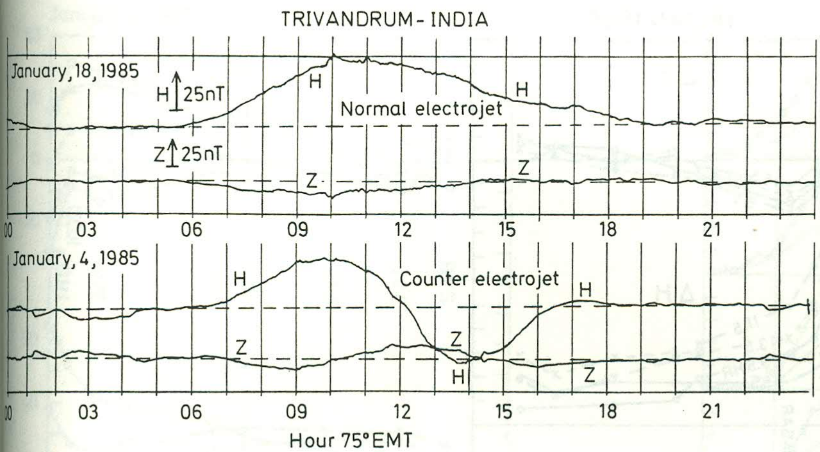
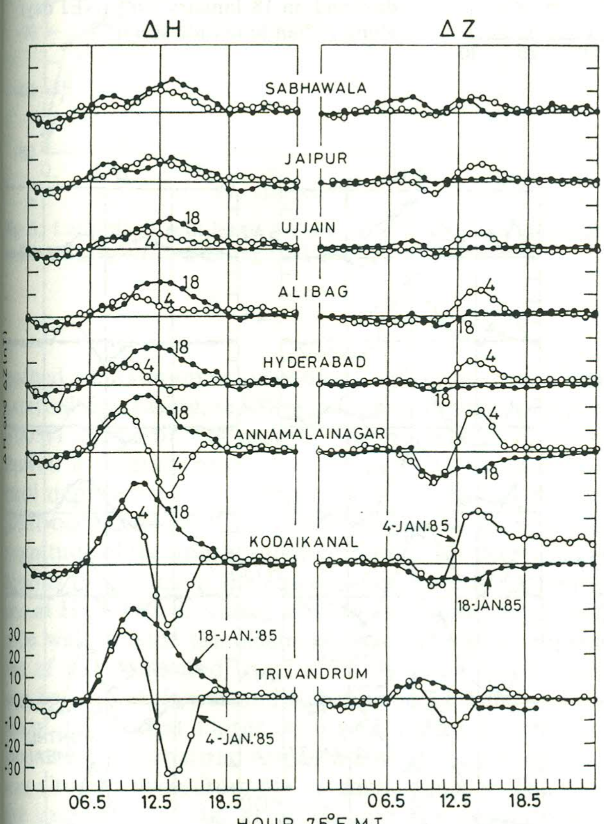


Fig. 2. The reproduction of the magnetogram at Trivandrum on 4 January 1985 showing a strong counter electrojet (CEJ) in the afternoon hours and on 18 January 1985, a normal electrojet (NEJ) day



ig. 3. Daily variations of the horizontal (ΔH) and the vertical (ΔZ) mponents of the geomagnetic field at Indian observatories on 4 nuary 1985 (a CEJ day) and on 18 January 1985 (a NEJ day)

ecrease of amplitude and an advancement of the time of aximum from 1000 LT to 1300 LT with increasing dip itude. The Z field showed a minimum around noon xcept at Trivandrum), and the amplitude was largest at nnamalainagar. From the H magnetogram only, it is ifficult to define the latitudinal extent of the equatorial ectrojet, because the amplitude of maximum ΔH decreases monotonously from the dip equator to the region f Sq focus.

On 4 January 1985, the CEJ day, H at Trivandrum showed an abnormally large decrease of about 65 nT around 1330 LT. As expected, the magnitude of the afternoon depression decreased with latitude and it was 55 nT at Kodaikanal and 40 nT at Annamalainagar. Note that there was very significant decrease of ΔH around the same time at Hyderabad, Alibag and even at Ujjain.

Examining the variations of ΔZ on 4 January 1985, it is noted that at Kodaikanal ΔZ was a minimum in the morning and a maximum in the afternoon, opposite to the character of ΔH at the same station. At Annamalainagar there was also a minimum of ΔZ in the morning and a clear maximum (≈ 40 nT) in the afternoon. Rather unexpectedly, the ΔZ at Hyderabad also showed a minimum of about 8 nT in the morning and a maximm of +20 nT in the afternoon. The Z variation at Hyderabad was opposite to corresponding variations of ΔH, clearly indicating the effects of the CEJ at this station. The afternoon maximum and forenoon minimum of ΔZ was clearly seen at Jaipur and possibly at Sabhawala. Thus, the CEJ current seems to have been hidden within the Sq current almost at all the stations in Indian sector on 4 January 1985.

One of the tests of NEJ or CEJ effects in low latitudes geomagnetic field variations can be seen from the latitudinal profiles of ΔH and ΔZ at particular hours. Figure 4 shows the latitudinal profiles of ΔH and ΔZ at 9.5, 10.5, 11.5, and 13.5 hr on 18 and 4 January 1985. On 18 January 1985, the ΔH profile at 9.5 hr showed a slow increase towards from Alibag to Trivandrum. At 11.5 hr and 13.5 hr, ΔH decreased from the equator all the way to Jaipur. At 15.5 hr, the enhancement of ΔH was confined between Annamalainagar and Trivandrum. This suggests that, with the increasing strength of the electrojet currents, the latitudinal extent of the electrojet influence also increased. The latitudinal profiles of ΔZ show that it was negative at any of the daytime hours at Kodaikanal, Annamalainagar, and Hyderabad, with maximum deviations at Annamalainagar. These features are as expected for an eastward-flowing ribbon-type of current, except that the effects are seen at latitudes beyond the normally accepted latitude of 5° from the dip equator.

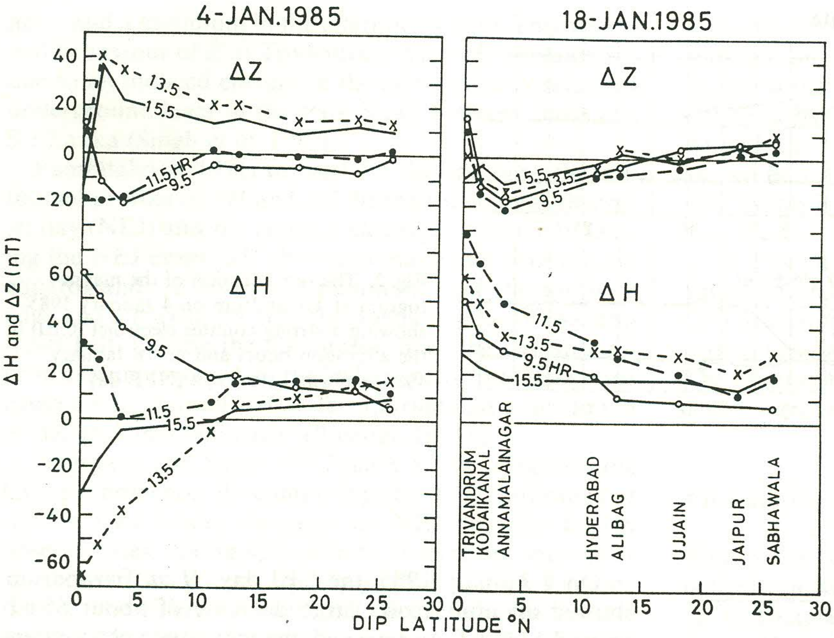


Fig. 4. Latitudinal profiles of ΔH and ΔZ at particular hours on 4 January 1985 (CEJ day) and on 18 January 1985 (NEJ day) along Indian longitude sector

The latitudinal profiles of ΔH and ΔZ on 4 January 1985 show that ΔH at 9.5 hr had decreased monotonously from Trivandrum up to Sabhawala. ΔZ was negative at all of the stations, with the maximum deviation at Annamalainagar, suggesting a very well extended normal equatorial electrojet at that particular hour. ΔH at 11.5 hr decreased from Trivandrum to Annamalainagar and increased monotonously from Annamalainagar to Sabhawala. The profile of ΔZ showed negative values at Kodaikanal and Annamalainagar and practically zero values at Kodaikanal and Annamalainagar and practically zero value of other stations, suggesting the developing effects of CEJ latitudes away from the equator. At 13.5 hr, the CEJ effects had developed fully and the value of ΔH increased monotonously from its value of −65 nT at Trivandrum, −38 nT at Annamalainagar, −5 nT at Hyderabad up to 27 nT at Sabhawala. The profile of ΔZ also showed peculiar behaviour: it decreased monotonously with latitude from 40 nT at Kodaikanal, +20 nT at Hyderabad and Alibag to +13 nT at Sabhawala; the ΔZ value was positive at all of the Indian stations. At 15.5 hr the intensity of CEJ had decreased, and ΔH showed monotonous increase with latitude, being −32 nT at Trivandrum, −1 nT at Hyderabad and −9 nT at Sabhawala. ΔZ profile at 15.5 hr showed a monotonous decrease with latitude from Kodaikanal to Sabhawala. These data clearly indicate that the effects of the CEJ current extend over a much larger latitude range than the classically accepted limit of about 5° North and 5° South.

Figure 5 shows the daily variations of ΔH and ΔZ at Indian observatories on a strong afternoon CEJ day, 21 January 1977, compared with the corresponding monthly mean variations. Figure 6 shows the latitudinal profiles of ΔH and ΔZ at some fixed hours of 21 January 1977. ΔH at Trivandrum started increasing after sunrise,

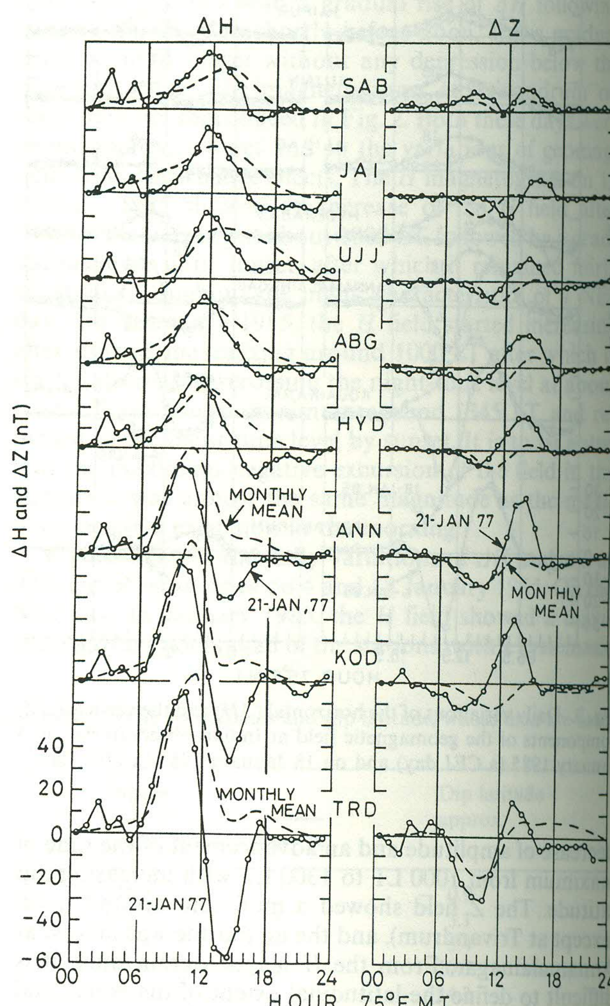


Fig. 5. Daily variations of ΔH and ΔZ at Indian magnetic observatories on a strong CEJ day (21 January 1977) compared to the monthly mean variations

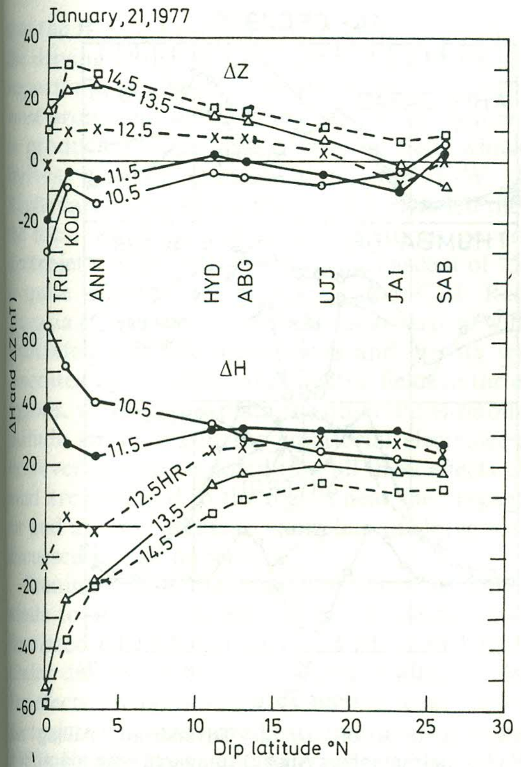


Fig. 6. Latitudinal profiles of ΔH and ΔZ along Indian longitudes on 21 January 1977, a strong CEJ day

reached a maximum value of 65 nT at 10.5 hr, after which it started decreasing, reaching a minimum value of about −60 nT at 14.5 hr. The monthly mean ΔH at Trivandrum showed a positive peak of 73 nT at 11.5 hr and only a small depression in the afternoon hours due to the frequent occurrence of CEJ events during the month. The magnitude of the afternoon minimum of ΔH decreased at stations further from the equator but it could be clearly seen at Hyderabad, Alibag and Ujjain, stations supposed to be well outside the electrojet belt. Afternoon depression of ΔH compared to its monthly mean value could even be seen at Jaipur and Sabhawala. The daily variation of ΔZ showed a large positive deviation in the afternoon at Kodaikanal and Annamalainagar, equatorial stations situated away from the magnetic equator. The positive excursion of ΔZ at KOD and ANN confirms a strong westward current over the dip equator. It is interesting to note that the positive peak of ΔZ is evident at other non-equatorial stations in India.

Figure 6 clearly shows and equatorial enhancement of ΔH at 10.5 hr. At 11.5 hr, ΔH increased at Hyderabad and other non-equatorial stations but decreased at Trivandrum, Kodaikanal and Annamalainagar, and there was an enhancement of ΔH near the dip equator. The ΔZ profiles at 10.5 hr and 11.5 hr showed negative values at all stations. At 12.5, 13.5 and 14.5 hours the ΔH profile showed a systematically decreasing magnitude with decreasing latitude; ΔZ profiles at these hours showed positive values at all stations, with the maximum value at Kodaikanal/Annamalainaga. This case again shows that

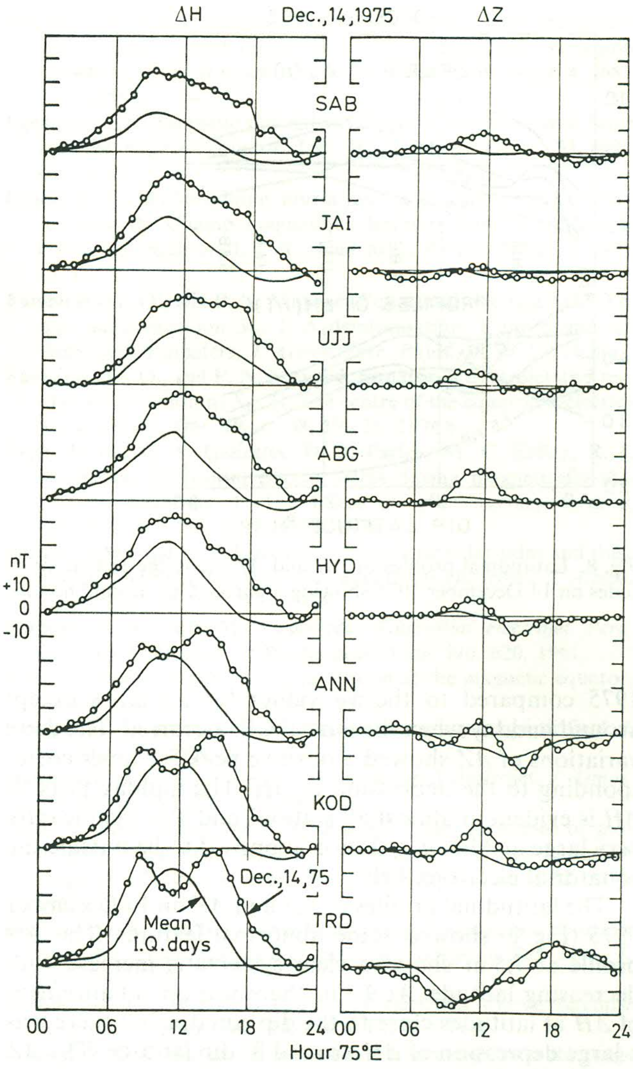


Fig. 7. Daily variations of ΔH and ΔZ along the Indian longitudes on 14 December 1975 showing a partial CEJ around midday

during strong afternoon CEJ events at the equator, the effect of the reversed current is seen at all low latitudes even up to the Sq focus.

Figure 7 shows the daily variations of ΔH and ΔZ on 14 December 1975, showing a partial CEJ at midday, compared with the corresponding monthly mean Sq variations. This class of events show a strong depression in ΔH but the minimum value of ΔH is very significantly larger than the night-time base level. These partial CEJ events are shown to be associated with the reversal of ionospheric drifts, the disappearance of the equatorial sporadic layer, and the cessation of upward uplifting of the F-layer over the equator (Rastogi 1974a), confirming the reversal of the electric field in the E region over the equator. The midday depression in ΔH was confined to three equatorial stations, Trivandrum, Kodaikanal and Annamalainagar, while at all other stations the ΔH values were much larger on 14 December 1975 compared to the corresponding monthly mean value. Further, the values of ΔH at equatorial stations was larger on 14 December

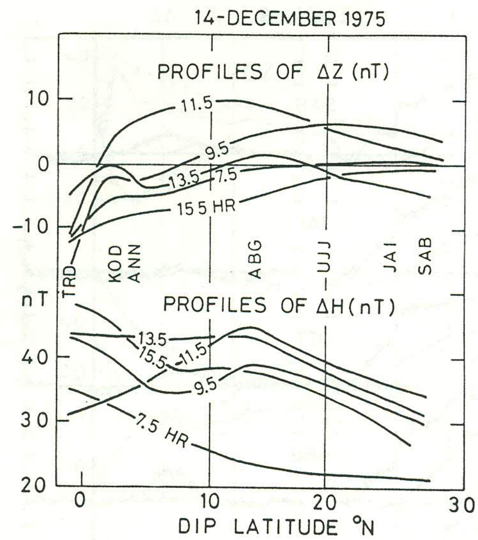


Fig. 8. Latitudinal profiles of ΔH and ΔZ along the Indian longitudes on 14 December 1975 showing a partial CEJ around midday

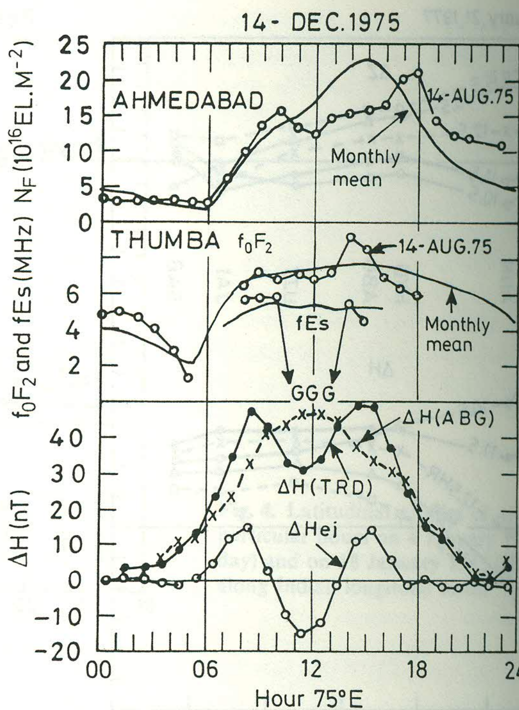


Fig. 9. Daily variations of ΔH at Trivandrum, Alibag and $\Delta H_{ej} = \Delta H$ (Trivandrum minus Alibag) compared with ionospheric parameters of fE_s and foE_2 at Kodaikanal and of ionospheric electron content NF at Ahmedabad on 14 December 1975

1975 compared to the *Sq* values for all times except around midday when the partial CEJ occurred. The daily variations of ΔZ showed a positive peak for times corresponding to the depression of ΔH. The midday peak in ΔH is evident at almost all stations and was significantly very large at Alibag, a station supposed to be outside the equatorial electrojet belt.

The latitudinal profiles of ΔH and ΔZ on 14 December 1975 (Fig. 8) showed some abnormal features. The ΔH profile at 7.5 hr shows a clear systematic increase with decreasing latitude. At 9.5 hr there was an enhancement of ΔH at latitudes close to the dip equator but there was a large depression of ΔH around 8° dip latitude. The ΔZ profiles showed negative values at low latitudes and positive values at higher latitudes. At 11.5 hr, there was a systematic decrease of ΔH with decreasing latitude equatorward of 11°. The corresponding ΔZ profiles showed strong positive values with a maximum around 10° latitude. At 13.5 hr, ΔH had almost constant magnitude from 0° to 11° latitude. At 15.5 hr there was an equatorial enhancement of ΔH, with a distinct depression around 9° latitude.

This event suggests that some disturbances had been generated around 10° latitude which later affected all low latitude stations, generating a CEJ event overriding a strong *Sq* current system.

To confirm the reversal of electric field at midday, the daily variations of some of the ionospheric parameters are shown in Fig. 9. It is seen that ΔH (TRD) was less than ΔH (ABG) between 10.5 and 13.5 hr. The equatorial sporadic layer at Thumba, a station close to Kodaikanal, disappeared around midday, confirming the westward electric field at 100 km altitude over the dip equator. This had stopped the equatorial fountain of *F*-region plasma, consequently the ionospheric electron content at Ahmedabad decreased in the afternoon of 14 December 1975 due to the absence of plasma transported along the geomagnetic lines of force.

Discussions

Rastogi *et al.* (1971) showed that CEJ events at Kodaikanal and Trivandrum on geomagnetically quiet or disturbed days are associated with simultaneous reversal of ionospheric drifts at Thumba. Hence the CEJ electrojets, were confirmed to be associated with the westward electric field over the equator during the daytime. Rastogi and Patel (1975) identified the reversal of electrojet currents over Huancayo during disturbed days with the rapid reversal of the latitude of Interplanetary magnetic field (IMF), i.e. the B_Z component of IMF is directed from south to north. Alex *et al.* (1986) discussed the various dilemma presented for the relationship of CEJ and IMF by Kane (1978) and by Fejer *et al.* (1979). It was shown that their conclusions for the lack of correlation between CEJ and IMF was due to the use of improper data. The IMF was shown to be effective only during the periods of a compressed magnetosphere and a rapid change of IMF (B_Z) is required.

Rastogi (1981) classified the electrojet equatorial CEJ into different groups. One type, with high forenoon peaks of H followed by slow and smooth depression of ΔH in the afternoon occurring on a succession of quiet days, were ascribed to luni-solar tidal effects. The other type of events, due to a sudden reversal of the B_Z component of IMF from south to north, show fast and short period variations in H and occurred at any time on some isolated days.

Kato (1973) calculated the effect of horizontal wind motion under magnetic equatorial condition and showed hat the $W \times B_0$ field at the equator directly contributes to he driving of the equatorial electrojet. He suggested the mportance of the (1, 3) mode of the solar diurnal tide, most prominent in the lower part of the dynamo region, n producing large vertical electric field which further lerives a Hall current along the E-W direction. Raghavarao and Anandarao (1980) included the effect of he local winds in solving the equations governing the lectrojet and showed that a vertical ascent of 15–20 m/s s quite effective in producing the CEJ. Reddy and Davasia (1981) showed that the local vertical wind shears ssociated with the local winds and gravity waves can enerates significantly large electric fields in the electrojet egions, which can explain the observed variability in the atitude structures in the equatorial electrojet currents. However, it is to be noted that all these effects of neutral ind are localised to the region near the magnetic equa- or and are not adequate to explain the large scale effects liscussed in this paper.

Stening (1969) discussed the effects of various tidal inds to the *Sq* current system. Schieldge *et al.* (1973) imulated the observed geomagnetic variations on a par- icular day by combining different modes of tidal winds. The electrodynamic effects of various wind profiles on the lectrojet structure have been investigated by Richmond 1973), Fambitakoye and Mayaud (1976 a, b) and Forbes nd Lindzen (1976). Stening (1977) suggested that the eomagnetic variations at low latitudes are hard to ex- lain in terms of the combination of tidal wind modes hen the deviation is confined to a narrow strip round he dip equator. Due to insufficient density of the geo- nagnetic observatories at low latitudes it has been diffi- ult to identify the extent of the effects of equatorial elec- rojet currents. The data presented in this paper show hat the effects of normal or reverse equatorial electrojet re not confined only to within 5° from the dip equator ut extent over the whole low latitude *Sq* current lati- udes. If the *Sq* current can be simulated by the combina- on of different modes of tidal winds, there is no reason hy the afternoon CEJ on quiet days cannot be consid- red as the effect of lunar/solar tides on the low latitude inds on these particular days.

The proposed network of mesospheric wind radar sta- ons by Indian Institute of Geomagnetism, coupled with e excellent network of geomagnetic observatories ould go a long way in understanding the complexities of w latitude *Sq* and electrojet currents.

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