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Spatial and frequency characteristics of equatorial enhancement of geomagnetic field variations

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Abstract

The spatial and frequency characteristics of the equatorial enhancement for several period bands from minutes range to Sq harmonics are established using geomagnetic data from upgraded/new networks that were operational during the International Equatorial Electrojet Year along the Indian and Brazilian sectors. In addition to the regular Sq harmonics and well-developed train of Pc5 pulsations, the periodic components in the period range of 20–160 min are isolated using the data adaptive singular spectrum analysis technique. Equatorial enhancement factor ranges between 3 and 5, both for magnetic fields associated with ionospheric dynamo or the processes that have their primary origin in magnetosphere. Examination of the spatial behavior of variations from equatorial to polar region revealed that magnetic fluctuations in equatorial region have bi-modal origin; related to the ionospheric dynamo and magnetospheric process, the latter resulting from almost instantaneous transmission of polar electric field to equatorial region. When these two sources operate independently, the magnetic fluctuations in equatorial belt in relation to that at low latitudes are enhanced roughly by a factor of 4 ± 1 due to enhanced Cowling conductivity. However, when the two mechanisms work in an interactive coupled manner, they may account for the variability of the equatorial enhancement seen in individual cases.

Keywords: Equatorial electrojet; Cowling conductivity; Ionospheric dynamo; Magnetic field variations; Singular spectral analysis

1. Introduction

It is well known that over the dip equator, effective Pedersen conductivity that supports the east–west dynamo currents is augmented due to the inhibition of the vertical Hall current (Baker and Martyn, 1953). A net consequence of this increased conductivity is that in a narrow latitude range, centered at the dip equator, eastward flow of dynamo current is amplified. This enhanced current is familiarly known as equatorial electrojet (EEJ). At the ground, the effect of this intense band of currents is manifested as an enhancement of solar quiet-day geomagnetic variations in horizontal component, Sq (H). In addition, a wide range of short period fluctuations in horizontal component is also enhanced. The dip equator enhancement of the class of short storm time fluctuations, e.g. sudden commencements (Kane, 1978; Araki, 1977), Pc5 (Trivedi et al., 1997), DP2 (Kikuchi et al., 1996), substorms (Nishida, 1971), etc., that have origin in magnetospheric processes, clearly signify the importance of ionospheric contribution in their global manifestations. It is generally believed that equatorial augmentation of these short-period magnetic fluctuations is caused by the penetration of magnetospheric electric field into the equatorial ionosphere through the polar ionosphere (Kikuchi and Araki, 1979). Although it is known that geomagnetic variations of different origins exhibit remarkable enhancement in the immediate vicinity of the dip equator, the extent and magnitude of enhancement for events of varying origin and factors responsible for its variability are still ambiguous. From a statistical study of the diurnal pattern, Kane (1978) showed that equatorial enhancement of storm sudden commencements (SSC) fluctuates over a wide range, not always commensurate with the EEJ strength. Precise knowledge of the agencies responsible for the variability in enhancement

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is still not available. Whether the purely ionospheric sources and/or some magnetospheric processes influence in deciding the factor of enhancement needs to be examined. Since the characterization of the equatorial enhancement holds key in understanding the nature of electrodynamic coupling processes between the high latitude and the equatorial regions, there is a renewed interest to quantify the spatial and frequency characteristics of equatorial enhancement for a variety of geomagnetic fluctuations (Matoba et al., 2002; Kobea et al., 2000). Further, the estimates of equatorial enhancement of geomagnetic variations can be important diagnostic tool in emphasizing the relative roles of Hall and Pedersen conductivity in the formation of EEJ. Taking advantage of the fact that the existing network of geomagnetic observatories were suitably augmented during International Equatorial Electrojet Year (IEEY), an attempt is made in the present paper to establish the nature of equatorial enhancement for a wide range of magnetic field variations under magnetically quiet or disturbed conditions.

2. Data analysis and results

To establish the spatial and frequency characteristics of equatorial enhancement under magnetically quiet and disturbed conditions, the geomagnetic data have been examined in the three different categories, as detailed below.

2.1. Sq variations

An analysis of the Sq variations was undertaken using data recorded by the network of geomagnetic observatories that was augmented during IEEY along the Indian sector (Fig. 1; Table 1). As a part of the IEEY program, five stations were added to the existing observatories in the peninsular India (Arora et al., 1993). The alignment of all observatories in a narrow longitude sector, with six stations right under the electrojet influence and other seven stations spanning low and mid-latitudes, extending well into the region of Sq focus, provide unique data set to investigate the spatial structures of the EEJ vis-à-vis global Sq.

Sq(H) variations, for each month of the year 1992, were derived using hourly values of selected quiet days with Ap $\leqslant 7$ where no single three-hourly Kp index exceeded 3_+. The number of quiet days used to derive monthly mean variation varied from 4 to 12 days in different months of the year 1992. The monthly mean Sq variations, after correcting for non-cyclic variation, were subjected to harmonic analysis to obtain amplitude and phase of the first four harmonics, corresponding to periods of 24-, 12-, 8- and 6-h, respectively. The first four harmonics collectively account for more than 95% of the monthly Sq variations. Fig. 2 shows the latitudinal profiles of the amplitude of the first four harmonics normalized with respect to the amplitude at low-latitude station Alibag (ABG). The amplitude–latitude profiles are shown for 4 months representing, respectively, winter (February), spring (March), summer (July) and fall (September) seasons. Consistent with the intense flow of eastward directed electrojet currents, amplitude of all harmonics of Sq (H) are enhanced in the vicinity of the dip equator in relation to the amplitudes at low latitudes. The latitudinal distribution of stations in Fig. 2 provides very limited coverage south of the dip equator, with just two stations. Despite this limitation, a clear amplitude peak roughly coincident with the dip equator is seen in the latitudinal plots of different harmonics for the equinoctial months. Perhaps due to the inter-hemispheric intrusion of either the northern or the southern Sq vortex across the dip equator, no peak is seen in the amplitude plots of certain harmonics during solstices (February and July). However, the EEJ—associated enhancement, confined to a narrow latitude range, can unambiguously be traced in plots of different harmonics and all months. Following a sharp drop in magnitude near the edge of the electrojet (4° dip latitude), the latitudinal progressions of amplitudes at low and mid-latitudes depict behavior expected from the conventional Sq vortex. The widely differing trend for the month of July may reflect complexity of the Sq variation near the Sq focus. In the vicinity of the dip equator, the amplitudes of different harmonics are enhanced by a factor ranging between 2 and 5 in relation to the amplitude at low latitudes. However, it is worth noting that both the latitudinal structure (width) and the dip equator enhancement (DEE) factors do not show any regular dependence on the periodicity. A moderate month-to-month variation in DEE factor can be attributed to the seasonal progression of ionospheric conductivity with maximum in equinoxes.

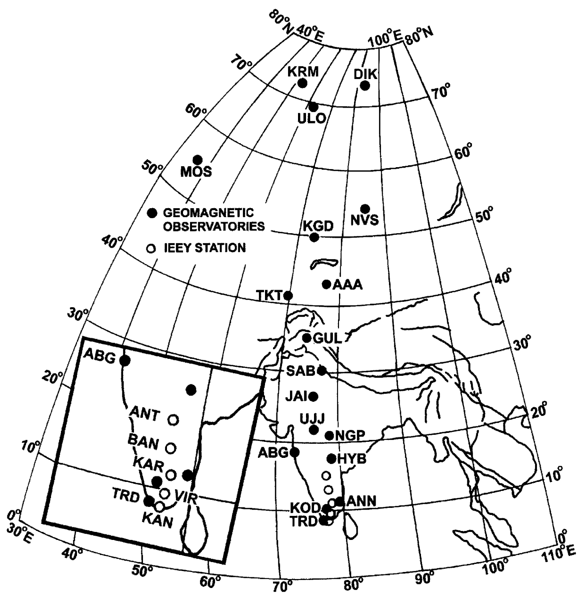

Fig. 1. Map showing the location of geomagnetic observatories along the Indo-Russian sector whose data are used in the present study. Inset shows the location and code of five temporary stations that were set up during the IEEY campaign.

Table 1
Geographic, geomagnetic co-ordinates and dip latitudes of geomagnetic observatories along 75°E meridian

Station name	Station code	Geographic		Geomagnetic		Dip lat.
		Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)	
Kanyakumari[a]	KAN	8.10	77.54	−1.21	148.98	−0.23
Trivandrum	TRD	8.48	76.95	−0.88	148.24	0.28
Virudunagar[a]	VIR	9.61	77.94	0.26	149.52	1.61
Karur[a]	KAR	11.01	78.09	1.64	149.80	3.32
Annamalainagar	ANN	11.40	79.68	1.77	151.20	3.67
Bangalore[a]	BAN	12.98	77.60	3.64	149.52	5.72
Anantapur[a]	ANT	14.67	77.63	5.32	149.71	7.83
Alibag	ABG	18.63	72.87	9.64	145.39	12.96
Nagpur	NAG	21.15	79.08	11.64	151.74	15.74
Ujjain	UJJ	23.02	75.78	13.50	147.00	18.42
Tashkent	TKT	41.33	69.62	32.51	145.52	41.50
Alma Ata	AAA	43.25	76.92	33.69	152.21	43.50
Novosibirsk	NVS	55.03	82.90	44.92	159.07	58.90
Moscow	MOS	55.48	37.32	50.79	121.62	54.92
Uloroski	ULO	69.8	60.80	65.00	137.70	71.40
Karmakuli	KRM	72.40	52.90	67.40	133.00	72.14
Dixon	DIK	73.55	80.57	63.36	162.45	78.36

[a]IEEY stations.

2.2. Geomagnetic pulsations

A globally coherent sequence of Pc5 pulsations occurred in association with the magnetic storm of March 24, 1991 (Fujitani et al., 1994; Trivedi et al., 1997). Due to the abnormally large amplitude, the event was well recorded by the worldwide observatories. The event was also recorded by the 10 stations of a magnetometer array that was operational in the equatorial region of the North Northeast Brazil between November 1990 and March 1991. Combining this data from the equatorial region with low- and high-latitude stations of Northern America, Trivedi et al. (1997) have examined the amplitude and polarization parameters of the Pc5 event right from the auroral oval to the equatorial belt. Fig. 3 shows the stacked plot of filtered data of X component for the interval of 1100–1400 UT when the pulsation sequence is well developed. It can be seen that amplitude of the pulsations is markedly enhanced at stations in the vicinity of the dip equator.

Fig. 4 shows the amplitude plot, determined by spectral analysis of the variations shown in Fig. 3, as a function of dip latitude. Apart from the expected sharp maximum near the auroral oval, the pulsation amplitude reduces to low value at mid- and low-latitudes but rises again in the equatorial belt. The amplitudes close to dip equator are enhanced roughly by a factor of 5, in comparison to the amplitude at low latitudes. The enhancement of the amplitudes near the dip equator clearly emphasizes the role of enhanced Cowling conductivity in the equatorial ionosphere. Such visualization is well supported by the nature of equatorial enhancement that falls off to a low value within ±4° dip latitude. As seen in Fig. 3, the train of Pc5 pulsations are best developed around 1300 UT. Along the Brazilian sector, this time interval is corresponds to 1000 h local time when the EEJ is known to peak and the amplitude of the pulsations are found to be strongest. For Japanese sector, located in the dark-hemisphere during the pulsation event, no equatorial enhancement was noticed at Guam (dip 11°N)—see Fig. 4—although pulsations with reduced amplitude were well traced out on the magnetograms for stations ranging up to 40° dip latitudes. These distinct differences between night and dayside highlight the role of ionospheric conductivity in the global manifestation of the Pc5 pulsations. Recently, Matoba et al. (2002) reported latitudinal distribution in the Pc5 amplitude similar to that presented here in Fig. 4, for the event of April 21, 1993 that appeared simultaneously in the dayside auroral, low and equatorial latitudes. The Pc5 amplitude decreased sharply away from the auroral oval but the amplitudes were enhanced by a factor of 4 near the equator in comparison to the low latitude. The global distribution of the equivalent current vectors associated with the Pc5 event resembled the large-scale twin-vortex current system (DP 2-type) produced by the pair of field-aligned currents flowing into and out of the polar ionosphere (Nishida, 1971). Based on the similarity of this current system with SSC model of Araki (1994), they explained the almost instantaneous transmission of the Pc5-related polar electric field to the equator by the zeroth-order transverse magnetic mode in

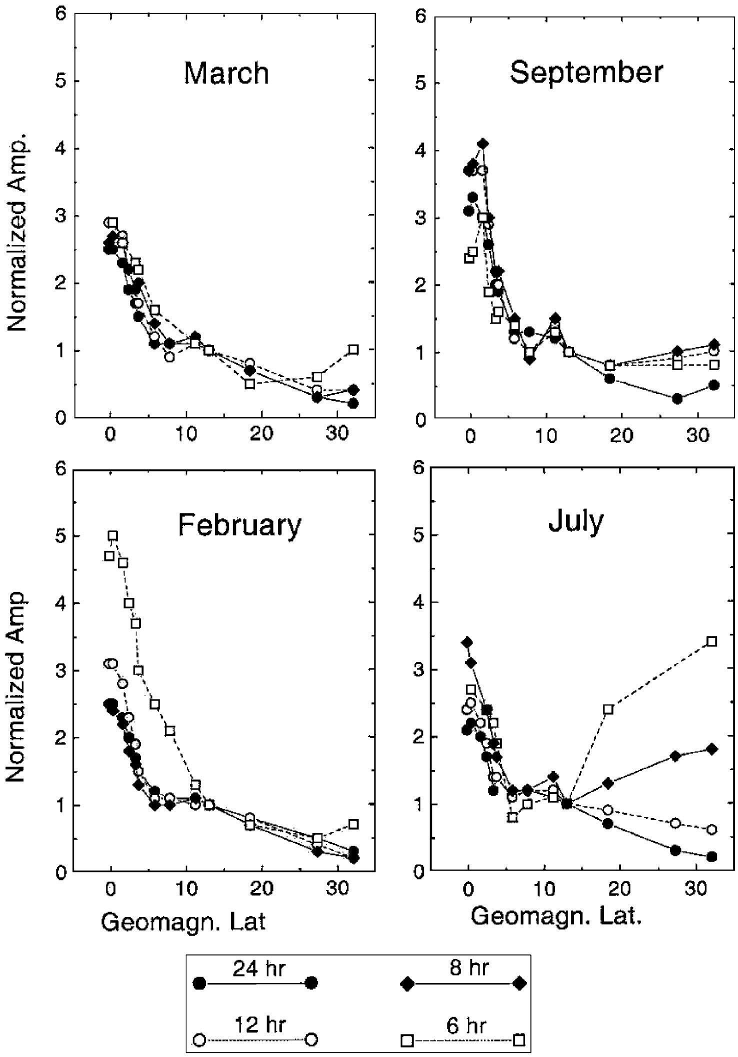

Fig. 2. Latitudinal plots of amplitude of the first four harmonics of quiet-day variations in H during different months. Amplitudes are normalized with respect to the value at ABG.

the insulating space between the earth and the ionosphere, as initially envisaged by Kikuchi and Araki (1979). Such hypothesis is also consistent with the results of numerical simulation of Tsunomura and Araki (1984). The calculations revealed that the amplitude of the polar electric field decreases as it propagates towards the equator but the current density is intensified on the dayside equator due to the increased Cowling conductivity.

2.3. Irregular magnetic disturbances

Fig. 5 shows the magnetic variations on January 16, 1991, a magnetically disturbed day with Ap = 32, as recorded along the Indo-Russian chain of stations extending from the dip equator to the polar cap (see Fig. 1 for locations and Table 1 for geographic and geomagnetic co-ordinates). The 1 min field values are plotted after eliminating the Sq and other long period (>240 min) variations by numerical filtrations. An isolated bay-type (sub-storm) event is the distinct feature of the nighttime variations. This bay with near identical form and uniform amplitude persists at all latitudes right from the dip equator to Moscow (MOS). At the polar stations (DIK, ULO and KAM), the amplitude is enhanced by more than two orders and is in phase opposition to the rest of the stations. During daytime the plots distinctly show a range of short-period fluctuations. For magnetic latitude from equator to $\sim 30°$N, that is at least up to UJJ and TKT in Fig. 3, the fluctuations have highly coherent form and their amplitudes are conspicuously enhanced in the vicinity of the dip equator (KAN through ANN). The enhancement

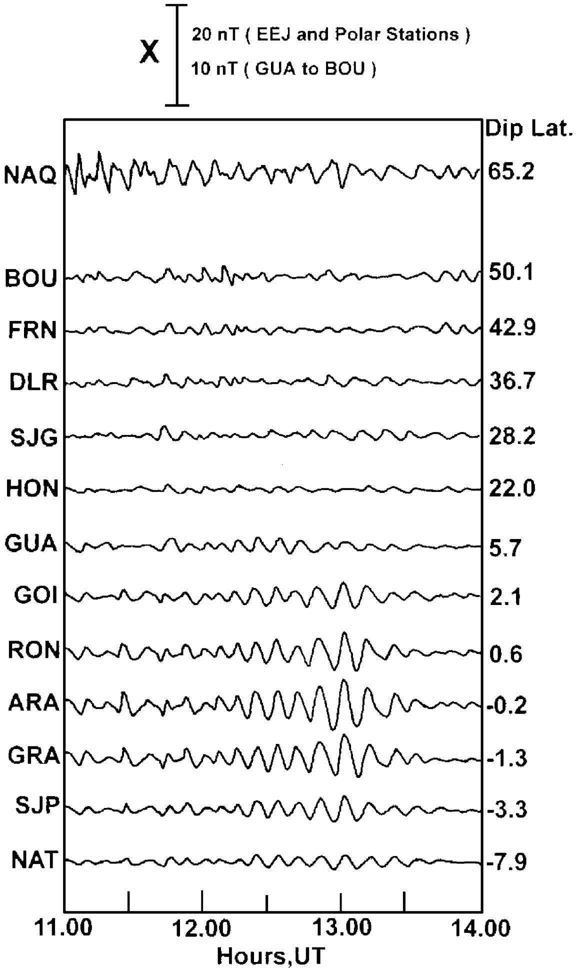

Fig. 3. Plots of filtered horizontal magnetic field (H) associated with the Pc5 pulsation event of March 24, 1991 (1100–1400 UT) for a chain of stations extending from dip equator to polar region along the American sector (modified from Trivedi et al., 1997).

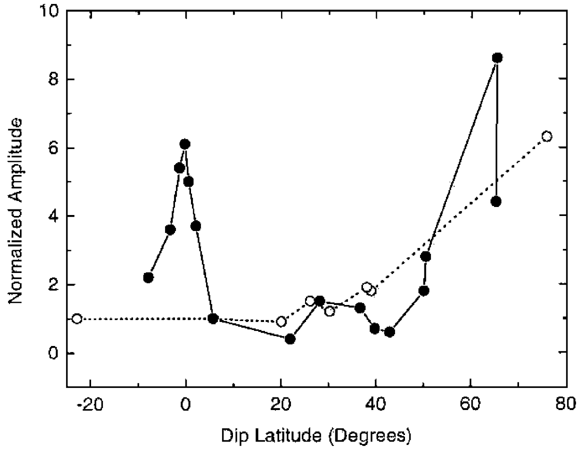

Fig. 4. Latitudinal plots of the amplitude of Pc5 geomagnetic pulsations for American (curve with solid circle) and Japanese (curve with open circle) sectors that respectively represent sunlit and dark hemispheres (daytime plots adopted from Trivedi et al., 1997).

is particularly marked in the time segment centered on local noon (0430–0900 UT). This confirms that main source for the amplification of the short-period magnetic fluctuations is due to the enhanced ionospheric conductivity associated with EEJ. This sequence of daytime short-period fluctuations at equatorial stations, however, shows only selective coherence with magnetic variations at high latitudes, e.g. DIK, ULO and KAM. In comparison to the clear anti-phase relationship between high and rest of the middle and equatorial latitudes, phase relations for daytime fluctuations between the equatorial and high latitudes is quite complex. However, in selective cases the fluctuations at all latitudes appear to be in phase. This tendency for varying phase relationship between equatorial and high-latitude magnetic variations during daytime and nighttime is consistent with the work of Kobea et al. (2000) who observed that short-period magnetic fluctuation in H at equatorial stations are positively correlated with high latitude variations in one longitude meridian but negatively correlated with other longitude meridian.

Unlike the two class of variations discussed in the earlier sections, the generating mechanisms for the irregular magnetic variations shown in Fig. 5 are less certain, perhaps both penetrating polar electric fields associated with magnetospheric processes as well as atmospheric processes appear to be contributing to the variations. In order to investigate their spatial frequency characteristics, the periodic/quasi-periodic components are isolated by subjecting the time series to the data adaptive filtering technique of singular spectral analysis (SSA), as described in detail by Vautard et al. (1992). The important computational steps involve calculations of lagged auto-correlations for an optimal number of lags (M). The auto-correlation functions are organized into a Toeplitz matrix structure, which is then subjected to an eigenanalysis to get the eigenvalues in descending order and their corresponding eigenvectors. The magnitude of each eigenvalue gives the contribution by the corresponding component to the total variance. If quasi-periodic oscillations are present, they correspond to pairs of nearly equal eigenvalues with eigenvectors in phase quadrature. In this regard SSA, is a form of principal component analysis wherein the entire time series can be represented/recreated by a limited number of principal components.

The greatest advantage of SSA is that using the significant eigenvectors as data adaptive filters on the time series, the time evolution of the selected component can be retrieved. Here we take advantage of this property in studying local time–space behavior of any periodic component. The application of SSA to the data shown in Fig. 5 indicated that six or seven dominant periodic components,

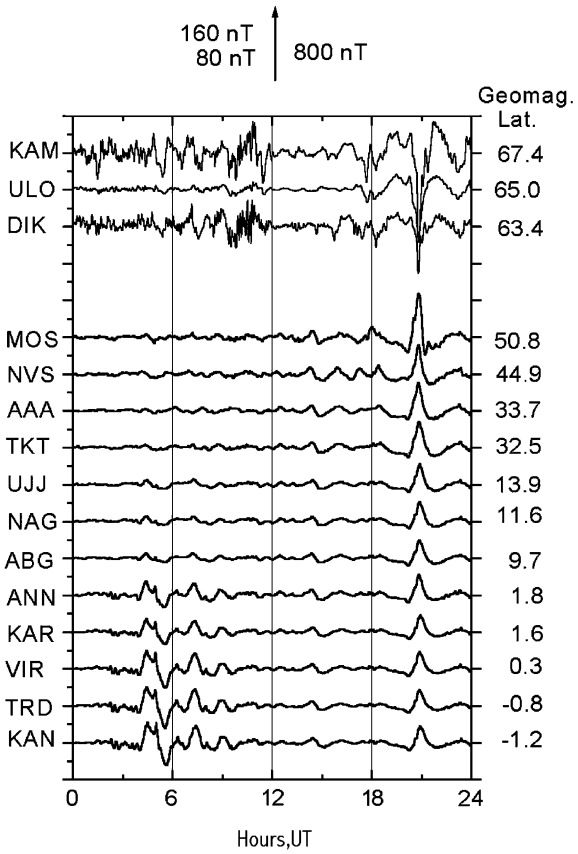

Fig. 5. Irregular geomagnetic disturbance variations in H on January 16, 1992 for a chain of stations extending from dip equator to polar region along the 75°E meridian (LT = UT + 5.5 h). Plots for stations KAN to MOS are all on the same scale of 80 nT/bar length whereas fields at polar stations (DIK, ULO and KAM) are plotted on different scales for daytime (~ 0000–1200 UT) and nighttime (1200–2400 UT), as indicated on the top.

common to all stations, can account for the major features of Fig. 5. Fig. 6 shows the reconstructed time series corresponding to periodic components of (a) 37 min and (b) 57 min. The plots bring out the quasi-periodic nature of the signals that occur in burst punctuated by quiet intervals. Each burst sequence can be treated as an independent event. Time evolution of quasi-periodic components in each event shows large similarity among stations but their amplitudes have distinct latitudinal dependence during day and night hours. For the time variations shown in Fig. 6, the first half (first 720 points) and latter half, respectively, correspond to daytime and nighttime of the local day. The data of these two segments were separately subjected to FFT to obtain the amplitude and phase of the periodic components. The latitudinal plots of the amplitude, normalized with respect to the average amplitude at the low-latitude stations (ABG, NAG and UJJ), are shown in Fig. 7 for all isolated quasi-periodic components, covering the period range of 27–159 min. As seen in Fig. 6a, amplitude of the isolated periodic component reduces to a very small value just outside the equatorial belt (e.g. at ABG for 37 min). The use of these fields as a normalizing factor can bias the correct estimation of the DEE. To minimize this bias, the DEE is worked out by normalizing the station's amplitude by the average amplitude at all low-latitude stations. During the daytime, the amplitudes in all period bands are enhanced within the equatorial belt. The factor of the equatorial enhancement varies from 3 to 6, although no clear dependence on period can be inferred in these DEE factors. Also within the spatial resolution of stations, latitudinal extent of equatorial enhancement falls off to the background level with ±4° latitude. In contrast to these daytime features, the equatorial values during nighttime, in all period bands, are uniformly low despite the high level of activity in polar region. This suggests that high- low-latitude coupling is weak or absent during nighttime because of the low ionospheric conductivities.

3. Discussion

The examination of latitudinal structure of geomagnetic variations of different origin and covering wide period bands from a few minutes to Sq harmonics has shown unambiguous enhancement of amplitudes during daytime in the vicinity of dip equator. Although factor of the equatorial enhancement varied from 3 to 5, no systematic dependence on period is seen. Similarly, no visible change in the latitudinal width (spatial structure) with period is seen; essentially DEE is confined to a narrow latitude range of ±4°. This is in variance with the earlier observations of Mason (1963) who noted that the effective width decreases with decreasing periods, resulting in greater concentration towards the center of the electrojet. As against the present dense network of stations spreading uniformly from the equatorial belt to low latitudes, the earlier inference on the period-dependence of electrojet width/intensity were drawn from three sparsely distributed island stations. It was pointed by Mason (1963) that the apparent decrease in the latitudinal width of the electrojet at short periods might well arise from the induction effects in the ocean. Recently, Arora et al. (2001) have shown that the presence of anomalous induction effects can introduce bias in the source characterization of equatorial enhancement. It is shown here that for Sq harmonics, the mean equatorial enhancement factor is about 3. Since these variations have their origin in ionospheric dynamo electric fields, the DEE could be directly associated with the Cowling effect, i.e. the Hall electric field set up by the vertical polarization in conjunction with northerly horizontal ambient magnetic field induce eastward Hall current that augments the original eastward Pedersen current. The effective Cowling conductivity (σ_c) supporting enhanced electric current (field) is related to Hall (σ_h) and Pedersen (σ_p) conductivity

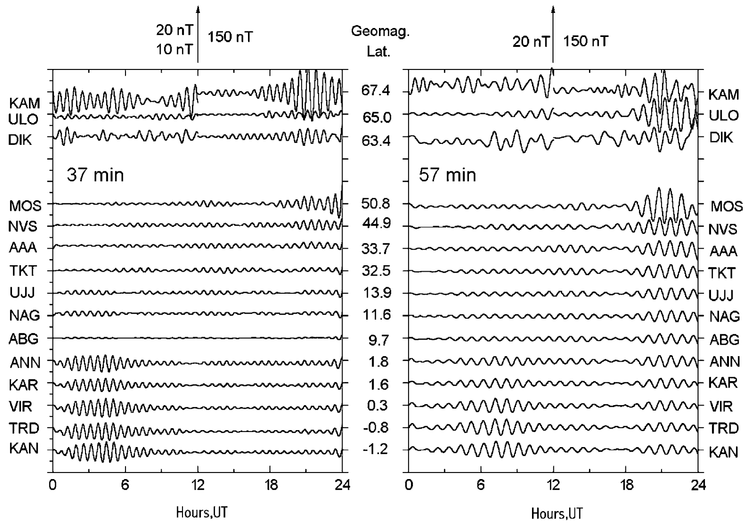

Fig. 6. Time-evolution of reconstructed geomagnetic variations corresponding to period of (a) 37 min and (b) 57 min on January 16, 1992 at widely distributed stations extending from dip equator to polar latitudes. Plots for stations KAN to MOS are all on the same scale of 10 nT/bar length whereas fields at polar stations (DIK, ULO and KAM) are plotted on different scales for daytime ($\sim$ 0000–1200 UT) and nighttime (1200–2400 UT), as indicated on the top.

as follows:

$$\sigma_c = \sigma_p + \frac{\sigma_h^2}{\sigma_p},$$

$$\frac{\sigma_c}{\sigma_p} = \left[1 + \left(\frac{\sigma_h}{\sigma_p}\right)^2\right]. \tag{1}$$

Just outside the electrojet belt, the strength of the dominant east–west dynamo currents is determined by the Pedersen conductivity and, therefore, the ratio of Cowling conductivity at the dip equator to the Pedersen conductivity at low latitude is a measure of the DEE. Electron and ion Pedersen mobilities expected in the electrojet region on the basis of collision models yield a value of $\sim$ 20 for the ratio of Hall conductivity to the Pedersen conductivity. In an independent approach, Bhattacharyya (1995), using the observationally derived parameters of electrojet irregularities, arrived at the conclusion that effective Hall conductivity to be about five times the effective Pedersen conductivity in the electrojet region. Both theoretical and observationally deduced ratios indicate effective Cowling conductivity and hence, DEE to be much higher than inferred from the magnetic field variations. Takeda (1991), studying the effects of the Hall conductivity on ionospheric dynamo, observed that the ratio of magnetic field line integrated Hall conductivity to Pedersen conductivity at low latitude is about 1.3. From Eq. (1) it follows that effective enhancement of Cowling conductivity effect would be about 2.7, a value close to the average enhancement observed for the Sq harmonics.

It is now widely accepted that equatorial enhancement of a class of short-period fluctuations (SSC, PC5, DP2, etc.) that are primarily associated with magnetospheric processes, is the result of strong electrodynamic coupling between the daytime equator and high latitudes. The physical model proposed by Kikuchi and Araki (1979) successfully explains how the electric field imposed on the polar region can be transmitted instantaneously to the low latitude and magnetic equator. At the magnetic equator, the penetrating electric field, though only a fraction as strong as the high-latitude field, can have a major impact on the ionosphere through the vertical drift they create (Richmond and Lu, 2000). The vertical drifts set up their own polarization field, which by extended Cowling mechanism, similar to the ionospheric dynamo, would augment the electric current in the equatorial belt from the polar region. The present observation that Pc5 pulsations in the equatorial region have amplitude that is a large fraction of the peak amplitude in the auroral region clearly signifies the importance of vertical polarization field set up in the equatorial region by the penetrating electric field. It is also a common observation that daytime DP2 fluctuations have comparable amplitude both in subauroral and equatorial stations (Nishida, 1971; Abdu et al., 1998). The equatorial augmentation of the amplitude of Pc5 pulsations suggests that penetrating polar electric field to electrojet region are amplified by a factor of 4 ± 1, close to the enhancement factor for Sq harmonics. This agreement favors the inference that the equatorial enhancement of both dynamo generated as well as polar penetrating electric fields can be successfully explained by the Cowling effect.

The amplitudes of quasi-periodic magnetic fluctuations in period intervals of 40–160 min, isolated by the technique of the SSA, indicate enhancement in the equatorial belt roughly

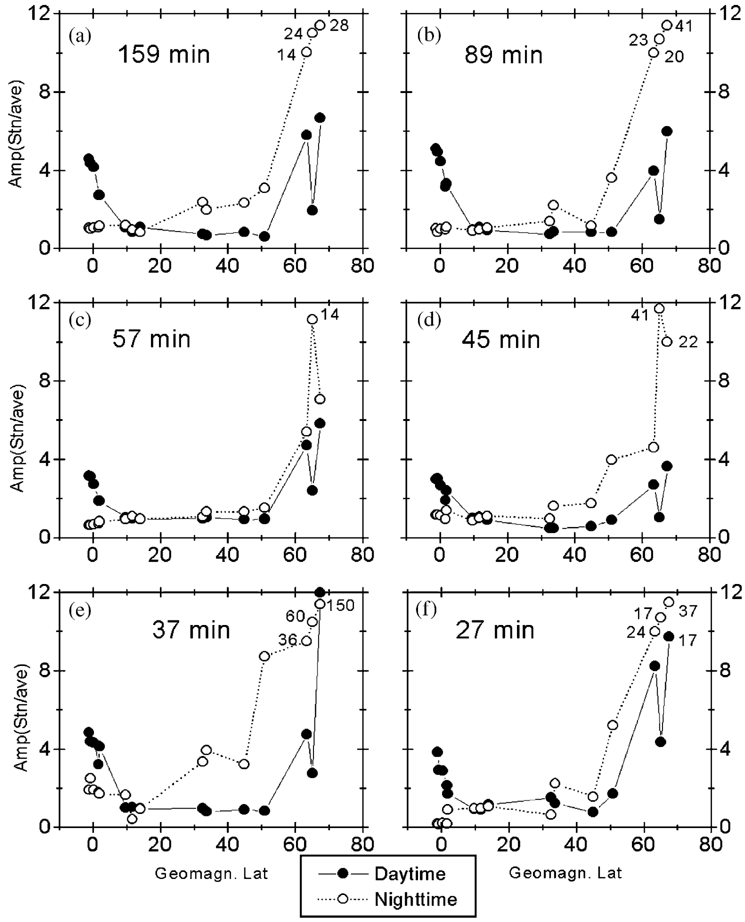

Fig. 7. Latitudinal plots of normalized amplitude of dominant periodic components in the horizontal magnetic variations, separately for daytime and nighttime conditions. The normalized amplitudes at polar stations—DIK, ULO and KAM are not to scale, the number along side the curves indicate actual normalized amplitudes.

by a factor of 4 ± 1 in comparison to that at the low latitude. The latitudinal profiles of amplitudes for this class of magnetic fields are similar to that of the amplitude of Pc5 magnetic pulsations presented here and reported by Matoba et al. (2002). The relatively large amplitude of the magnetic variations in the auroral oval (Fig. 7) may support the idea that equatorial fluctuations are associated with the penetration of high-latitude disturbance electric field. However, such a mechanism requires almost simultaneous appearance of fluctuations in auroral oval and at equator. Figs. 5 and 6 reveal waveforms of the certain well-developed sequence of aperiodic fluctuations at equatorial stations that are either not accompanied or show only selective coherence with polar magnetic variations. The lack of correlation between auroral and equatorial fields for these long period oscillations is consistent with the theoretical models of coupled magnetosphere/ionosphere that predict damping of the penetrating polar electric fields to low latitudes on the time scale of the order of ∼ 30 min by the establishment of shielding layer at the inner edge of the magnetospheric ring current (Blanc and Richmond, 1980; Richmond, 1995). In fact, sequence of short-period fluctuations in the time window of 180–540 min in Fig. 5 are most conspicuous only in the equatorial records; it seems that the sources of such fluctuations may have their primary origin in the local winds in the equatorial region or extending to mid latitudes utmost. The short-period magnetic fluctuations from a few minutes to several tens of minutes are the characteristics of the equatorial fields, even during magnetically quiet conditions. This was known from the time of the establishment of geomagnetic observatory at Huancayo (Chapman and Bartels, 1940). Since these fluctuations were conspicuous only in the equatorial records, the sources of such fluctuations were believed to be located in the equatorial ionosphere, associated with local wind pattern. However, a doubt prevailed that the absence of concurrent fluctuations at stations outside the electrojet belt was due to the low conductivity outside the electrojet belt (Onwumechili, 1997). The presence of short-period fluctuations in the zonal electric field in the equatorial dynamo region has now been unequivocally indicated by the changes in plasma drift measured by backscatter radar (Viswanathan et al., 1987; 1993). The work of Vikramkumar et al. (1987) demonstrated that magnetic effects calculated from the zonal electric field at Trivandrum (dip lat. 0.28°N) correlated well with the horizontal magnetic fluctuations of 15 min to 4 h duration, both under quiet and disturbed intervals. From the cross-correlation of zonal electric field at Jicamarca, (11.95°S, 77.86°W) under EEJ and Arecibo (18.3°N; 66.75°W) in the tropical zone, Gonzales et al. (1983) arrived at the conclusion that electric field at equatorial zone has bi-modal origin i.e. (i) atmospheric origin and (ii) magnetospheric origin, the latter occurring simultaneously both at auroral and equatorial zones and accompanied by globally coherent ΔH fluctuations. Establishing criteria to distinguish between electric field fluctuations of magnetospheric and atmospheric origins, Earle and Kelley (1987) associated the atmospheric electric field to atmospheric gravity source. In recent years, in situ measurements of neutral winds by MF radar at equatorial station Tirunelvelli (dip lat. 0.18°N) have confirmed the presence of gravity waves in the period range of 30–120 min (Gurubaran and Rajaram, 2001). However, the precise nature of the link between these gravity waves with electric and related magnetic fields is yet to be established conclusively.

Given that electric and magnetic fields in the equatorial region have bi-modal origin it is possible that these two modes operate independent of each other. For example, when only the ionospheric dynamo is operative, as in the case of Sq harmonics, the DEE is found to be in the range of 3–4. Nearly same enhancement would result if short magnetic fluctuations are produced by the ionospheric dynamo driven by gravity or other local equatorial winds. On the other hand, when the penetrating polar fields are the primary source contributing to the equatorial electric/magnetic fields, as in the case of SSC, Pc5, and DP2, the DEE is again found to be in the range of 4 ± 1. During the disturbed conditions, both modes may operate concurrently and the overall behavior of magnetic fluctuations in equatorial region and, hence the DEE, would be controlled by the relative strengths and phases of local ionospheric dynamo currents and penetrating electric fields. Blanc and Richmond (1980) have shown that direct penetration of electric fields from the polar region is not the only source of disturbance equatorial fields. The Joule heating at high latitude can alter the global thermospheric winds. The changed wind system generates electric fields by ionospheric dynamo that extend down to equator and were considered a potential mechanism for the propagation of the polar electric field to the equator at long periods of 2–3 h. Simulation models (Blanc and Richmond, 1980) have indicated that these 'disturbance dynamo' electric fields at the equator generally tend to be opposite in direction to that of the penetration electric field as well as to the equatorial quiet-day electric fields. Low-latitude observation of the electrojet electric fields sometime supports the contribution of disturbance dynamo (Spiro et al., 1988; Fejer et al., 1990) but there are also many examples that show no clear effect following magnetic storms (Kane, 1978; Sastri, 1988). The dynamo disturbance fields, when present, will partially annul the combined effects of quiet-day dynamo and penetrating polar electric fields and may account for the reduced magnitude of equatorial enhancement, below the average value of 4 ± 1. Further, as the polar penetrating electric fields are independent of the local EEJ conditions, the observed EEJ enhancement factor in individual events may not be always commensurate with the strength of the electrojet, as reported by Kane (1978).

4. Conclusions

It is shown that geomagnetic variations whether they are produced by ionospheric dynamo or result from the almost instantaneous transmission of the polar electric field are enhanced during daytime in the vicinity of the dip equator. The DEE is confined to a narrow latitude range of $\pm 4°$ dip latitude and the does not show any systematic dependence on the period of fluctuating fields. It is also seen that when ionospheric dynamo or polar penetrating field alone control the nature of fluctuating electic/magnetic fields, the equatorial enhancement factor is close to 4 ± 1 and can be directly associated with the Cowling effect. However, the multi-modal origin of the equatorial magnetic/electric fields is able to explain the variability of DEE in individual cases, although an accurate quantification of the contribution of different modes in individual event is not easy. The direct measurements of local/global winds and in situ electric field, both at high latitudes and in the equatorial region would be critical. Since these measurements are now feasible with the introduction of MST/MF radar in equatorial regions as well as VHF radar and satellite mapping of polar electric field, it is opportune time to undertake these studies in a coordinated manner to understand and quantify the variability of EEJ in terms of basic parameters.

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