

Day-to-day variation of geomagnetic H field and equatorial ring current

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ABSTRACT

The paper describes the day-to-day fluctuations of the horizontal component of the geomagnetic field along Indo-Russian chain of stations during midday and midnight hours in relations to the corresponding variations of Dst index. The correlation between ΔH and Dst index is around 0.8 for all latitudes. The slope of the regression line is about 1.0 during daytime but during the nighttime hours the slope is only around 0.5. This suggests that the nighttime tail currents have almost equal contribution towards fluctuations of ΔH as due to the disturbance ring current. The equatorial electrojet current, designated by $\Delta H(\text{TRD}) - \Delta H(\text{ABG})$ has no correlation with Dst index because any variation of Dst are removed from ΔH at both stations and electrojet currents represents only the ionospheric current component.

INTRODUCTION

The first explanation for regular solar daily variation of the geomagnetic field was proposed by Stewart (1882), who had suggested the existence of currents in the upper atmosphere due to the movement of conductive air across the lines of force of earth's magnetic field, caused by the solar heating. Using Gauss spherical harmonic analysis, Schuster (1889) gave mathematical basis for the solar daily variation of the geomagnetic H field observed at ground. Later, Schuster (1908) and Chapman (1919) proposed that the lunar and solar tides as the cause of the air movement in upper atmosphere and established the atmospheric dynamo theory. Egedal (1947) discovered the abnormally large amplitude of solar daily variation in H field within a narrow latitude belt over equatorial region. The phenomenon was attributed to a band of eastward current over the magnetic equator during daytime, which was named as Equatorial Electrojet current (EEJ) by Chapman (1951). The equatorial electrojet was explained by Baker & Martyn (1953) as due to the considerable enhancement of the east-west ionospheric conductivity within a narrow latitude belt where the electric and magnetic fields are orthogonal to each other. Thus, the equatorial electrojet was considered to be an integral part of the mid-latitude Sq current system caused by atmospheric dynamo. It was expected that there should be a close correlation between the day-to-day variations in the daily range of H field at an equatorial station and that at low latitude station in the same longitude sector. Kane

(1971) reported that the daily range of H at Trivandrum, an equatorial electrojet station, was poorly related to the corresponding range of H at Alibag, a northern station outside the equatorial electrojet belt. Mann & Schlapp (1988) studied day-to-day variability of $Sq(H)$ at low latitude stations around the world. No definite relation between the electrojet and Sq current could be derived because of the mixing of effects due to the spatial variations and temporal variations. James, Tripathi & Rastogi (1996) studied the day-to-day variability in $Sq(H)$ at thirteen stations confined within a narrow longitude belt along Indo-Russian sector spread from equator to about 60°N dip latitude. Using the correlation coefficients of $Sq(H)$ between each pair of stations, they identified three latitude zones, where correlation were very high as (i) the equatorial electrojet latitudes (ii) latitudes midway between equator and Sq focus and (iii) latitudes poleward of Sq focus. They suggested that the observed solar daily range in H field for each day was the result of the interactions of these current systems over three different zones. The correlation of the daily range of H at different stations with that at Trivandrum decreases with increasing latitude, became zero around 15°N dip latitude, -0.3 around 30°N dip latitude, then increases towards the stations north of Sq focus. As an evidence for this, James, Rastogi & Rao (1997) identified a typical low latitude current system between the equator and Sq focus latitude on a partial counter electrojet day. As a further refinement of day-to-day variability analysis, James & Rastogi (2002) studied the day-to-day variations of the

deviations of midday H, midnight H and range H from their corresponding 27-day moving average, thereby removing long term trends. It was found that the fluctuations of H field among stations during midnight are very well correlated at all stations, with correlation coefficients of more than 0.9, suggesting that same sources are responsible for midnight fluctuations of H at different stations. During the midday hours, the correlation between the fluctuations of H field became poorer progressively with increasing distance from the equator. Further, they found that the day-to-day fluctuations are better correlated during magnetically disturbed days compared to quiet days, which indicates that fluctuations during magnetically disturbed days are more prominent and are affecting all latitudes almost equally. It was suggested that some additional sources of electric field generation in magnetosphere and certain high latitude phenomena do modulate the low latitude atmospheric dynamo current even on a day-to-day basis.

Magnetic storm signals the arrival of high-energy plasma from sun following a flare or coronal mass ejection from the sun. The first signal of the storm is the compression of the magnetosphere by the solar plasma causing a sudden increase of the H field at all stations around the world almost simultaneously known as sudden commencement (Burlaga & Ogilvie 1960). These charged particles carried by the solar wind while entering the earth's magnetic field are turned by the Lorentz force $F = q V \times B$, where q is the charge of the particle, V is the velocity and B is the earth's dipole field, causing currents in the sunlit side of the magnetosphere. Later, some of these particles are trapped by the earth's magnetic field and spiral around the lines of force bouncing between high north and south latitudes. Further, these particles drift normal to the field lines, protons moving westward and electrons moving eastward, generating the disturbance equatorial ring current causing a large decreases of the H field at ground stations around the world. Suguira (1964) suggested an index of this ring current using the geomagnetic H data from midlatitude stations distributed uniformly around the world and called Dst index, as a measure of geomagnetic storms. It is now believed that there is equatorial ring current that exists all the time and is intensified on magnetic disturbed periods. An attempt has been made to examine the day-to-day variations of midday and midnight values of H field at all stations along Indo-Russian sector in relation to corresponding Dst index.

RESULTS

The annual mean daily variations of the H field on the five International Quiet Days of each month (SqH) together with the corresponding variations of the standard deviations for the four typical stations (i) Trivandrum (TRD) - an equatorial electrojet station (ii) Alibag (ABG) - a low latitude station outside the equatorial electrojet belt (iii) Sabhawala (SAB) - a station close to Sq focus and (iv) Novosibirsk (NVS) - a high latitude station equatorward of the auroral latitudes are shown in Fig. 1. At all stations the ΔH as well as the standard deviations of ΔH were largest around midday hours. At Trivandrum the midday value of ΔH was 88 nT with standard deviation of about 40 nT, this indicates a large day-to-day variations of ΔH . At the off-equatorial electrojet station ABG, the mean maximum was 48 nT with standard deviation of 20 nT. At SAB, a station situated near the Sq focus latitudes, the standard deviation is of the same order as the mean SqH, around 25 nT. At NVS, a station near the sub-auroral latitudes, the SqH variations is negative and the standard deviation is nearly of the order of SqH. This indicates that some sources do produce large day-to-day variations in H at all latitudes from the dip equator to the sub-auroral latitudes.

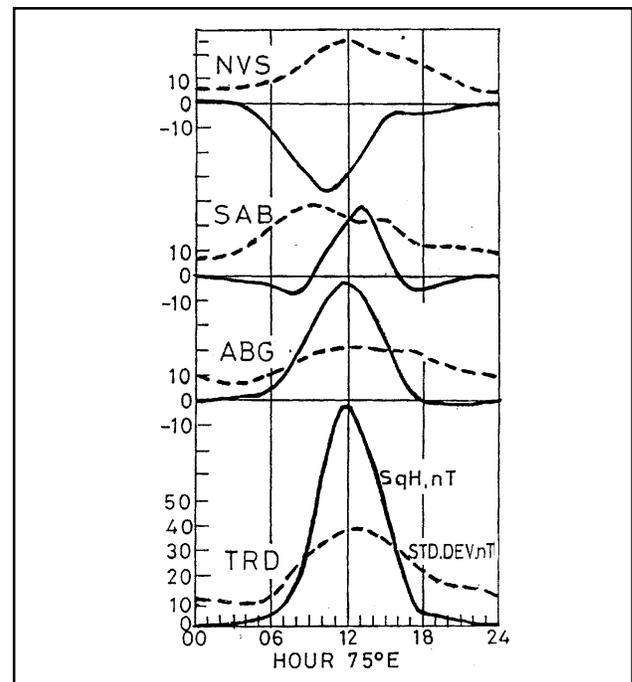


Figure 1. Annual mean daily variations of H field for five International Quiet days (SqH) and of the standard deviations in mean.

Table 1. List of stations with their coordinates and magnetic field parameters for the year 1978

Observatory	Code	Geog. Lat. °N	Geog. Long. °E	Dip Lat. °N	Declination °E	H nT	Z nT
Trivandrum	TRD	8.5	77.0	-0.3	-2.8	39929	-532
Kodaikanal	KOD	10.2	77.5	1.6	-2.4	39318	2208
Annamalainagar	ANN	11.4	79.5	2.8	-2.6	40466	3946
Hyderabad	HYB	17.4	78.6	10.7	-1.6	38846	14956
Alibag	ABG	18.6	72.9	12.8	-0.8	38504	17489
Ujjain	UJJ	23.2	75.8	18.1	-0.5	37261	24281
Jaipur	JAI	26.9	75.8	22.4	-0.8	35941	29594
Sabhawala	SAB	30.4	77.8	26.9	0.4	33985	34417
Tashkent	TKT	41.3	69.6	41.0	4.6	25869	45300
Alma Ata	AAA	43.3	76.9	43.0	4.5	25485	47941
Karaganda	KGD	49.8	73.1	52.5	8.2	20269	52338
Novosobirsk	NVS	55.0	82.9	58.5	8.5	17302	56457

Hourly mean values of H during midday and midnight hours and the daily range of H (midday-midnight) at the chain of 12 geomagnetic observatories along Indo-Russian longitude sector extending from geomagnetic equator to about 60°N have been analyzed for the period January to December 1978. Details of selected stations are given in Table 1. The 27-day running average has been computed for midday H, midnight H and range H for all stations. These mean values were subtracted from the corresponding daily values of all the three parameters to derive the deviations of midnight H, midday H and range H for all stations for each day of the year 1978. These deviations from running means have been utilized for the present analysis. In order to compare these data with the magnetic disturbances, the hourly mean values of Dst index for midday and midnight for each station have been corrected for latitude to get Dst for the particular station using the simple relation

$$\text{Dst}(\lambda_m) = \text{Dst index} * \text{Cos}(\lambda_m)$$

where λ_m is the geomagnetic latitude of the station.

First the correlation between the deviations of midday H and midnight H with the corresponding values of Dst index for all the stations are studied. Deviation of range H has been compared with mean Dst for midday and midnight. Mass plots of deviations of midday-H and midnight-H against the corresponding Dst index along with trend line are shown in Fig.2 for the four typical stations. It is clear

from the figure that the midday H as well as midnight H values of all stations are highly correlated with the corresponding Dst index, indicating that the day-to-day fluctuations in daytime H as well as nighttime H are largely due to the corresponding fluctuations in the strength of equatorial ring current, represented by Dst index. The deviations in midday H with respect to Dst at all stations are comparatively larger than the deviations in midnight H. This suggests that besides the fluctuations in magnetospheric current, the day-to-day fluctuations in the ionospheric current do affect the observations of the day-to-day variations of the midday H.

The correlation coefficients and the slope of regression lines for ΔH versus Dst at the four typical stations calculated separately for the different groups of Dst indices (< 0, 0-25, 25-50, 50-75, 75-100, >100) are shown in Fig. 3. The number of points for each Dst groups is also shown in the figure to judge the significance of results. For low disturbance (Dst 0 - 50nT) the correlation coefficient is about 0.3 and slope is about 1.0. This suggests that some sources other than Dst significantly cause day-to-day fluctuations of ΔH at all latitudes. At higher magnetic activity, the slope is more than unity and the correlation coefficients are also higher. This range represents the magnetic storms when large changes of H field are observed associated with magnetospheric currents other than the ring current. However caution should

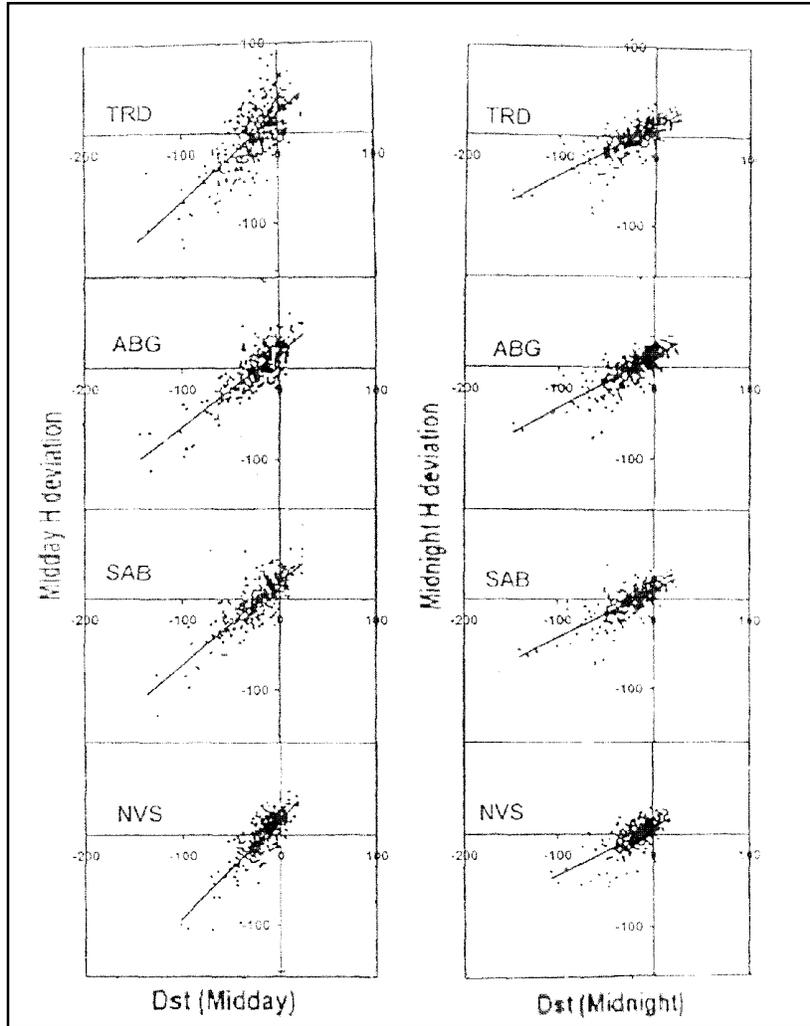


Figure 2. Mass plot of the midday-H and midnight-H with Dst Index.

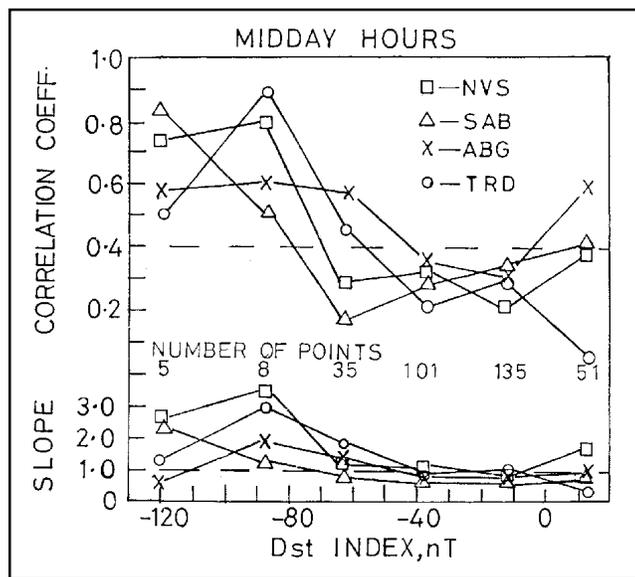


Figure 3. Correlation coefficients and slopes of regression lines for ΔH verses Dst for different groups of Dst indices.

be exercised to give importance of correlations at very low Dst values due to very few points. Latitudinal variation of the correlation between midday-H and midnight-H deviations shows that there is no significant latitudinal dependence suggesting that the source of these fluctuations are the result of some distant magnetospheric processes.

Mass plots of the daily range (midday-midnight) of H at the four stations against the mean of midday and midnight Dst index value are shown in Fig.4. It can be seen that the daily range of H do not seem to correlate with corresponding variations of Dst index as the midday H or midnight H field do. The points are uniformly scattered within a circular patch except for large magnetic storms. This suggests that the day-to-day variations of the electrojet component of the equatorial ionospheric currents are not correlated with the magnetospheric ring currents. Only during large magnetic storm the electrojet is reduced in relation to the decrease of Dst. It is interesting to find that the range of H do not show any significant correlation with Dst for any station as well as for any level of magnetic disturbances. The correlation coefficients are too low to have any statistical significance and the slope of the regression lines is too small. The general conclusion from this analysis is that the lifetime of fluctuations of the magnetospheric current is less than 12 hours, when the equatorial disturbance ring current strength is taken as the calibrating parameter.

The latitudinal variations of the correlation coefficients and the slope of the ΔH versus Dst for the midday and midnight hours are shown in Fig.5. The average correlation coefficient for the midday and midnight hours is independent of latitude and is about 0.8. The slope too is independent of latitude and the magnitude is about 0.9 for the midday but only about 0.5 during the nighttime hours. It is rather unexpected that the equatorial ring current has only 50% contribution to day-to-day variations of H during the nighttime hours, when one does not expect any ionospheric current due to very low ionospheric conductivities. Thus, magnetospheric currents such as tail current significantly contribute towards the day-to-day variations of ΔH .

Next, analysis has been carried out for three different levels of geomagnetic activity such as (i) positive Dst ($Dst > 0nT$), (ii) low negative Dst ($0 > Dst > -50nT$) (iii) high negative Dst ($Dst < -50nT$). The variation of correlation coefficient with latitude for the daytime and the nighttime periods for each groups of Dst days are shown in Fig.6(a). The corresponding curves for the slope of the regression lines are shown in Fig.6(b).

During highly disturbed period ($Dst < -50nT$),

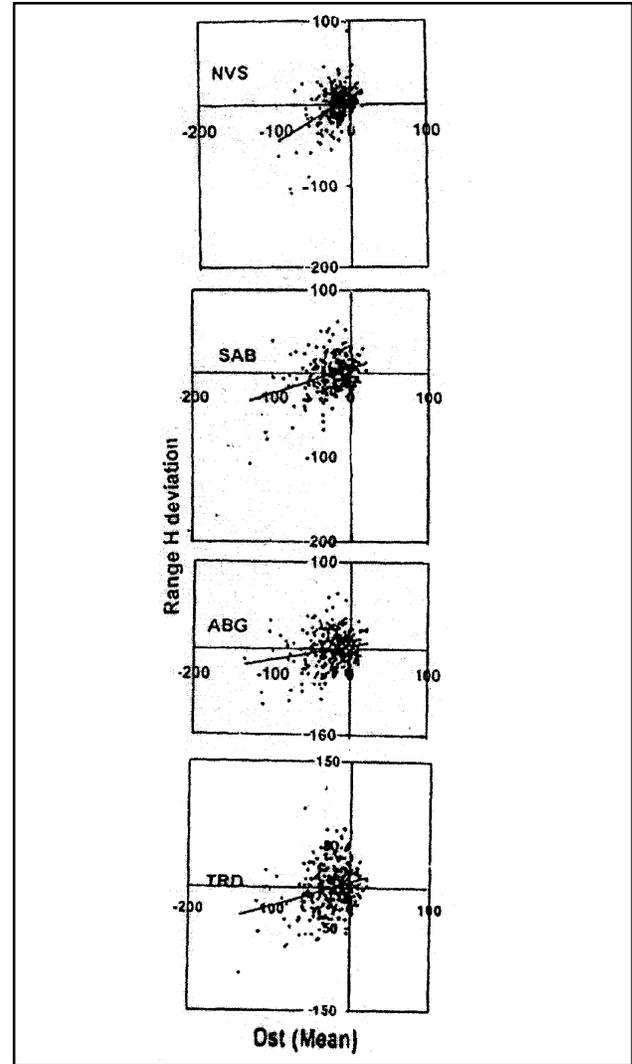


Figure 4. Mass plot of the daily range of H against mean Dst index.

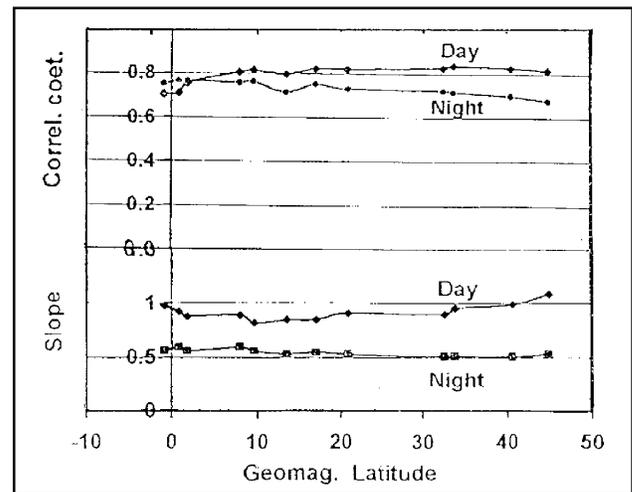


Figure 5. Latitudinal variation of correlation coefficients and slope of ΔH verses Dst for midday and midnight.

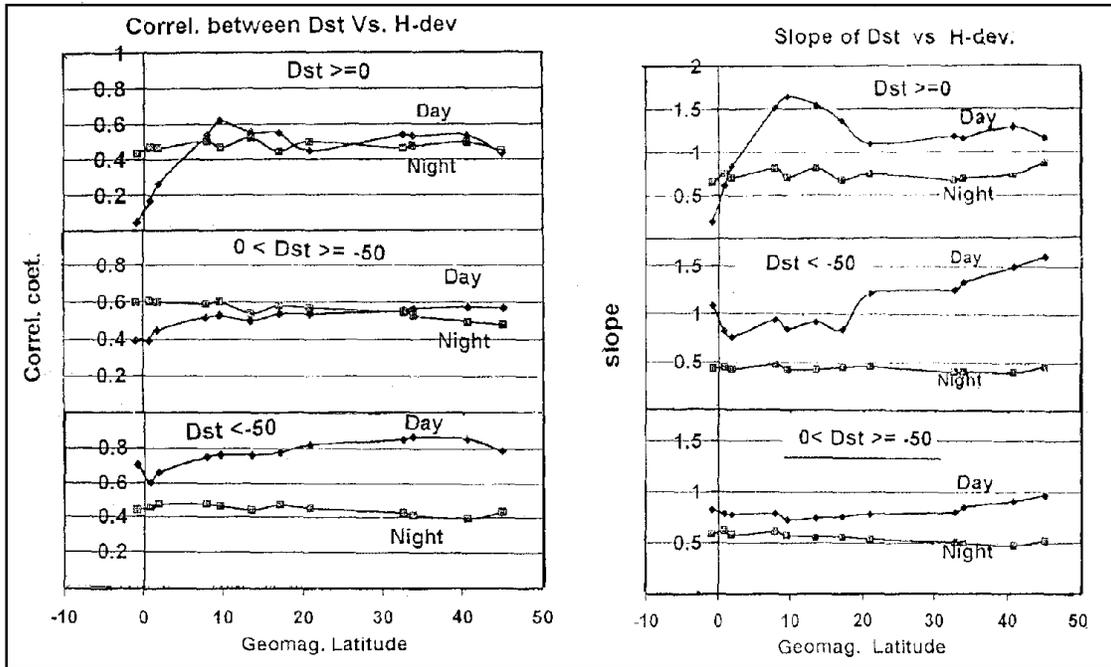


Figure 6. Latitudinal variation of correlation coefficients and slope of ΔH verses Dst for midday and midnight for different Dst groups.

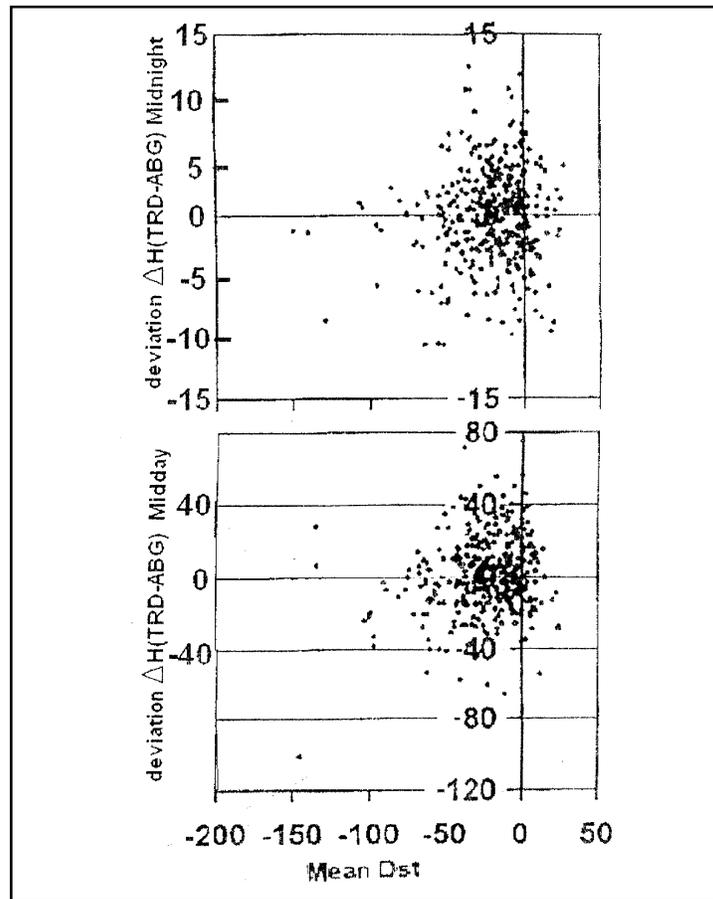


Figure 7. Mass plot of difference between deviations of H values at Trivandrum and Alibag for midday and midnight as a function of mean value of Dst.

there is a clear distinction between daytime correlation and nighttime correlation. The daytime correlation values of about 0.7 to 0.8 are almost similar to those for mean conditions. However for nighttime correlation has been reduced to about half. The slope between $\Delta H(\text{day})$ and Dst increased progressively from the equator to high latitudes; such that at stations north of Sq focus, variation in ΔH was much larger than the corresponding variation of Dst Index. But for nighttime slopes were only about 0.5, and there is no significant latitudinal variation. For moderately disturbed periods, the correlation coefficients as well the slope values decreased at all latitudes as compared to the same for highly disturbed periods for daytime.

The positive Dst means either a much weaker westward ring current on that day compared to the normal model calculated current for that environmental conditions or existence of some magnetospheric conditions causing an eastward electric field during that day. To our knowledge, no significant studies are made to explain these phenomena. For days with positive Dst, the correlation and slope of ΔH versus Dst are same for all latitude for the nighttime. But the daytime correlation become almost negligible at equatorial electrojet stations, similarly, the variation of slope suggests that the ΔH variation is very small compared to the Dst index variation. This phenomenon needs explanation and further close studies are suggested.

Referring to the latitudinal variations of the slope of the regression lines of daytime-H, nighttime- H with different levels of Dst index, it is seen that the slope of the trend line is nearly unity for midday-H but it is only about 0.5 for midnight-H indicating that for the same amount of the change of Dst, the change in ΔH is more during the day than during night time hours. The daytime ΔH being affected by ionospheric as well as by magnetosphere currents but the nighttime variations are contributed mostly due to magnetosphere currents. The latter can only be affected if some westward electric field is imposed on the low and middle latitude regions during the daytime hours simultaneously with the increase of Dst index. The possible sources of this westward electric field may be auroral electric field of magnetospheric origin.

The mass plots of the difference between deviations of H values at Trivandrum and Alibag for midday-H and midnight-H are presented in Fig. 7. It may be noted that the scale of $\Delta H(\text{TRD} - \text{ABG})$ are very different for the two cases. The deviations of $\Delta H(\text{TRD} - \text{ABG})$ are much smaller during the night than during the daytime hours. Although both the parameters are fairly well correlated with the

corresponding Dst separately for both stations, the differences of deviations (TRD-ABG) are not correlated with Dst for all three cases. If we confine our attention to strong storms only, designated by Dst < -50 nT then we find that during the daytime hours $\Delta H(\text{TRD} - \text{ABG})$ have significantly negative values and in some cases the change in electrojet current is larger than in the Dst index. Rastogi (2006) has shown that during large storm the changes in the H field at ground are largest at stations close to the magnetic equator and at midday longitudes. The cause of this special storm time effect was suggested to be due to additional westward electric field imposed due to the interaction of solar wind with IMF. The differences of range H at Trivandrum and at Alibag were related with the electrojet component of the equatorial ionospheric current (Rastogi & Patil 1986). The electrojet component of ionospheric current is suggested to be driven by electric fields from high latitudes due to the magnetospheric dynamo (Rastogi 1975). Further, it has been shown that the equatorial electric field decreases with increase of magnetic disturbance activity indicated by Kp index [Rastogi, Chandra & Misra (1971)]. The randomness in this difference parameter suggests that fluctuations are caused by some factors in addition to the ring current.

The present analysis shows that the association of equatorial electrojet with magnetic activity is not through the equatorial ring current alone but also through the westward electric field of some other magnetospheric processes.

DISCUSSION

Sarabhai & Nair (1971) have suggested that the daily variation of the horizontal component of H field at low latitude stations is caused by various factors such as (i) the atmospheric dynamo current at ionospheric E-region (ii) the surface current at the magnetopause (iii) the tail current, the symmetrical equatorial ring current, eccentric ring current and the partial ring current in the magnetosphere. The magnetopause currents due to the corpuscular flux have been shown to be same during the nighttime at the surface of earth (Mead 1962).

Siscoe & Cummings (1969) have reported that the tangential stress at the magnetopause increases the magnetic energy stored in the tail, which results in the increase of tail radius and the movement of inner edge of the neutral sheet close to the earth. Axford, Petschek & Siscoe (1965) and Williams & Mead (1965) have shown that the effect of neutral sheet and the Q type current system in the tail is equivalent to a magnetic dipole of opposite magnetic moment to that

of the main geomagnetic field. This would result in the decrease of the H field at low latitude during the nighttime.

The symmetric ring current events on quiet days contribute to a decrease of about 28 nT in H field at the surface of earth (Schield 1969a, b). The contours of B in the equatorial plane are nearer to the earth in the anti-solar direction compared to the sub-solar direction (Fairfield 1968). This eccentricity of the B contours is enhanced when the solar wind pressure is more. Therefore, the decrease of H field due to the eccentric ring current is more during the nighttime than during the daytime.

During the geomagnetic disturbed days, the protons drift closer to the earth than the electrons, even though they have the same energy in the tail (Freeman & Magure 1967, Cummings, Barfield & Coleman 1968). Therefore, the currents produced by the protons, which drift towards dusk are stronger than those produced by the electrons (Kavanagh et al., 1968), causing a larger decrease of H field in the late evening hours.

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