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Variability of the Ionospheric Component of the Equatorial Geomagnetic Field

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Day-to-day variability in the ionospheric component of the equatorial electroject strength is not dependent on either the degree of magnetic disturbance or the polarity of interplanetary magnetic field except for the solar maximum year 1969. The time of maximum of equatorial electrojet field shifts to earlier part of the day with enhanced strength. The diurnal variations of the ionospheric component at low and equatorial latitudes are similar in pattern from month to month but the day-to-day variability at individual hours are negatively, though poorly, correlated.

1 Introduction

The geomagnetic daily variation on quiet days, $S_q(H)$, is largely due to overhead ionospheric current systems. The strength and centre of this system are known to undergo daily, seasonal and solar cycle changes. Day-to-day variability in $S_q(H)$ may be either in the amplitude or in the phase[1,2]. Close to the dip equator, day time enhanced electrojet currents play a crucial role and significantly change the features of the variability. It is still not clear whether the equatorial electrojet is merely an augmented S_q current or an additional current system[3]. Appreciable variability is also caused even on quiet days by disturbance field sources[4], but these effects will be of nearly the same magnitude at two locations in the same longitude zone separated only by about 10° in latitude. Taking advantage of this fact Kane[5] introduced a parameter *SDI* defined by

$$SDI(EQ) = H(EQ) - H(Q) + S_q(Q)$$

as an estimate of purely ionospheric part of the electrojet field where $H(Q)$ and $S_q(Q)$ represent the H field and average quiet-day field at a low latitude station outside the electrojet. He showed that *SDI* is a fairly good measure of the equatorial electrojet strength and is especially a very good indicator for the afternoon hours. Even on disturbed days *SDI* during night hours is very small clearly indicating that it is mostly of ionospheric origin.

The hourly difference in the H field between Trivandrum and Alibag may be considered to be a good measure of the strength of the equatorial electrojet in the Indian zone not augmented by planetary S_q. A similar approach defining electrojet strength has also been adopted by Rush and Richmond[6] and Rezhnenov and Feldshtyn[7]. Extending the same logic to a pair of stations such that one is at low latitude outside the jet influence and the other close to the focus of the overhead S_q current system, Kane[8] showed that S_q pattern due to ionospheric currents at low latitudes, denoted here as *SDI* (*LL*), can be obtained continuously for quiet and disturbed intervals. For these analyses Kane utilized magnetic data from Trivandrum (TRD) representative of electrojet station, Alibag (ABG) as a low latitude station and Sabhawala (SAB) as a station close to the focal latitude.

Hutton[9] while studying the day-to-day variability of $S_q(H)$ suggested that it may be preferable in many equatorial studies to consider the nature of the currents at a particular instant in time rather than to use average seasonal or annual values. Schlapp[10] using correlation techniques on hourly data clearly demonstrated the importance of hour-to-hour fluctuations in $S_q(H)$. Bhargava and Yacob[11] considered the variance for each hour as an index of the day-to-day variability of the H field at low and equatorial latitudes and studied the solar cycle change in the same. Yacob and Arora[12] followed up this study to examine the diurnal features of day-to-day variability in quiet day field at Alibag.

In these research efforts on variability contributions the parts from magnetospheric and ionospheric sources have not been distinguished. It is, therefore, considered worthwhile to carry out systematic study of the variability of the equatorial geomagnetic field arising mainly from ionospheric origin. The salient features are grouped into four major classes and discussed in this paper.

2 Data and Analysis

Mean hourly values of the horizontal intensity for the years 1968, 1969, 1975 and 1976 at TRD, ABG and SAB are utilized. The first two years are representative of solar maximum epoch and the latter two years of solar minimum epoch.

For each hour variance of the electrojet field, as the difference between H (TRD) and H (ABG), is computed. Also, the relationship between the time of maximum of the equatorial electrojet field and the strength of the jet as depicted by the jet range is computed through fitting of polynomials by least squares, for each of the four years. Correlations between $SDI(EQ)$ and $SDI(LL)$ restricting the data to 1 hr at a time are also computed. The average diurnal patterns of $SDI(EQ)$ and $SDI(LL)$ for each month are compared, again through correlations techniques. There was no subdivision according to degree of magnetic activity in the above categories. Results based on quiet days ($A_p \leq 7$) will be published separately.

It may be noted that the data are analyzed 1 yr at a time and therefore no correction for secular variation has been applied. During these four years the decreasing secular change in H was roughly about 20-30 nT per year at the three stations[13]. Differences in seasonal changes would also be present. The variances reported here will be contaminated by these two sources and hence they may be considered as an overestimate of genuine day-to-day variability.

3 Results and Discussion

3.1 Variability of the Electrojet Field as a Function of Magnetic Activity

Kane's analysis showed that when low latitude field values are subtracted from the equatorial jet field the night time field is small (only about 3 nT) with hardly any variability. Burrows *et al.*[14] found, from a rocket launched during the early main phase of a magnetic storm, that no large perturbations of the normal ionospheric current systems in the E-region occurred. Kane[8] also suggested that violent changes in the ionospheric F-region during geomagnetic disturbances do not seem to affect the E-region S_q currents.

It may, therefore, be expected that the variability pattern as a function of time need not be dependent on the magnitude of geomagnetic disturbance. To quantitatively establish this, we computed the variance for each hour dividing the yearly data into three categories based on the index A_p of magnetic activity, viz. (i) quiet ($A_p \leq 7$), (ii) moderately disturbed

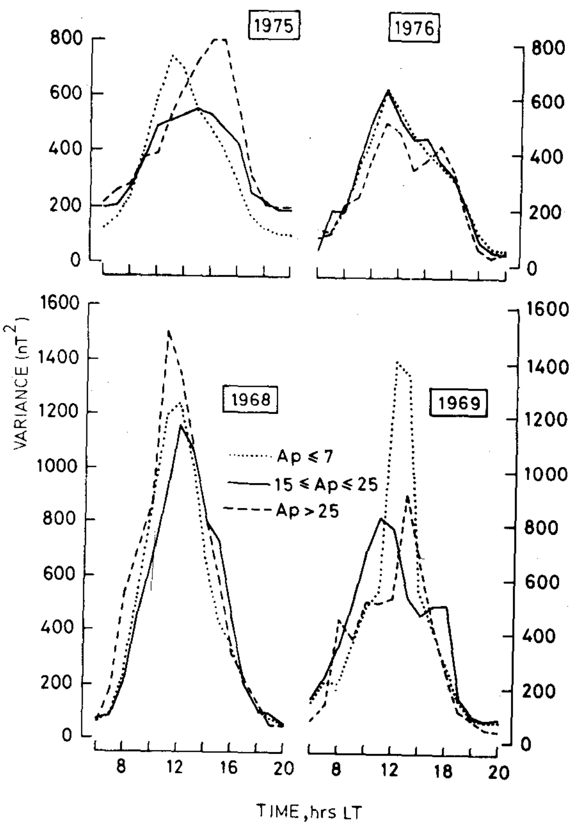

Fig. 1—Variability of equatorial electrojet strength (taken as the difference in H field at Trivandrum and Alibag) as a function of 75° EMT for solar maximum and minimum years (The variances are computed for three categories of magnetic activity).

($15 \leq A_p \leq 25$) and (iii) disturbed ($A_p > 25$). The variance for each year is shown in Fig. 1. It is clear that during years of solar minimum the peak variance is considerably lower and there is hardly any tendency for the variance to depend on magnetic activity. In solar maximum years, again, there is no clear dependence of the variance on the magnitude of disturbance. While largest variance is associated with the most disturbed category for 1968, quiet intervals have in contrast, largest variance for the year 1969 of comparable solar activity. In all the cases, for all the four years, the variability is largest close to local noon hours and the rise to peak and subsequent decline is in phase with the regular $S_q(H)$ pattern at equatorial stations. This suggests that most of the contribution to variability in electrojet strength arises from the corresponding changes in the amplitude rather than in phase. However, the plot for 1975 demonstrates clearly that phase variation in quiet day field can also be a source of hourly variability. This is consistent with the results of Brown and Williams[2] and Arora[15] who found that abnormal quiet days as identified from phase of $S_q(H)$ occur more frequently during solar minimum epoch.

3.2 Variability of Electrojet Field as a Function of IMF Polarity

The discovery of sector structure of the interplanetary magnetic field (IMF) by Wilcox and Ness[16] led to several subsequent studies on the IMF polarity effects on the geomagnetic field. At high latitudes the polarity influence is quite significant but at low latitudes the associated effects are subtle. Several aspects of IMF sector structure and low latitude geomagnetic fields have recently been reviewed[17,18]. Sastri *et al.*[19] looked for an association between the occurrence of equatorial counter-electrojet events and the IMF polarity but concluded that it is negligible. Of particular interest to the present study is the suggested polarity effects on S_q current focus location by Matsushita[20]. As the focal movement and its day-to-day variability is known to be related to electrojet strength[21,22] it is interesting to study the electrojet variability as function of IMF polarity.

For this purpose, the data for each year was grouped into two categories depending on the IMF being directed away from the sun (away) or toward the sun (toward). Svalgaard's[23] atlas of polarity of IMF was utilized for this purpose. The diurnal change in the variance for each of the four years as a function of IMF polarity is shown in Fig. 2. The most striking aspect of Fig. 2 is the significant difference in the peak variance for 1969 with away polarity being associated with much larger variability and toward polarity with lower than normal variance. There is some similarity to this result in the year 1976 also indicating that this feature is independent of phase of the solar cycle.

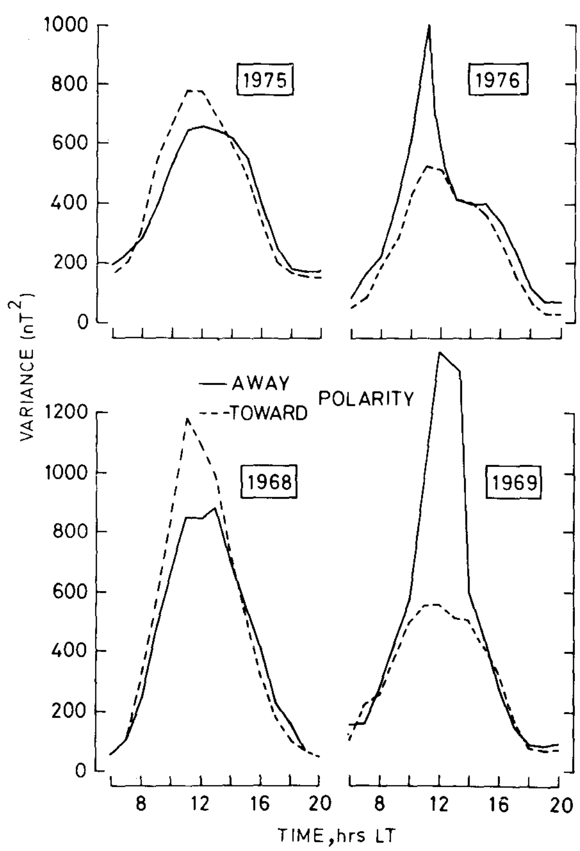

Fig. 2—Variability of equatorial electrojet strength as a function of 75° EMT for four years (The variances are computed for two categories based on polarity of the interplanetary magnetic field).

However, if polarity effects were to be unambiguously established, the other two years should also have shown similar tendency. The only possible inference can, therefore, be that if any day-to-day variability of the ionospheric currents responsible for equatorial geomagnetic field is attributable to the polarity of IMF, then the variability could be larger in away sector rather than in toward sector of IMF. In a way this is consistent with some recent findings of Butcher and Brown[24] who suggested that polarity-associated focal movement occurs only on abnormal quiet days and only when IMF is directed away from the sun. The years 1968-69 and 1975-76 may be considered to be representative of the years before and after the reversal in 1971 of the solar dipole magnetic field. As the IMF polarity is rooted to the solar magnetic field and the dominant polarity should follow the solar dipole field[25], we should anticipate reversal of the polarity dependence of the variability for the solar minimum and maximum epochs which is not observed. Based on these considerations it may be concluded that there is no clear dependence of variability of the equatorial electrojet field on IMF polarity. The striking dissimilarity of the diurnal change in variability for 1969, however, needs further careful examination.

3.3 Variability in the Form of Diurnal Variation and the Time of Peak Intensity

It has been well established that the equatorial magnetic field variation exhibits abnormal diurnal trends with depression of the field below the night time level more often during afternoon hours and occasionally during noon and morning hours[26]. These variations are termed 'counter-electrojets' and have been studied in great detail[27]. On days of counter-electrojet the phase of the diurnal variation also changes and semi-diurnal features become equally prominent[28]. The counter-electrojet features have been shown to have seasonal and solar cycle dependence with more frequent occurrence in summer and solar minimum[27]. The phase of the diurnal variation of H field at equatorial latitudes exhibits strong dependence on solar activity[29] and magnetic activity[30,31]. In this section we study the change in the time of maximum of the dirunal variation of the electrojet field with its strength taking the diurnal range as the index. The relative importance of the diurnal component of the daily jet variation as function of season is also studied.

In Fig. 3, the dependence of time of maximum on jet range is shown for the four years separately. The curves are obtained as third degree polynomials of the best fits between the two parameters. While there is no clearly defined tendency relating the two, in general a slight decrease in peak occurrence time with enhanced electrojet strength may be seen, this being most marked during the solar minimum of 1976. In contrast during solar maximum of 1968 the relationship seems to be oscillatory, and does not conform to the patterns for the other three years.

In Fig. 4 we show the seasonal variation in the percentage accounted for by the diurnal component of the daily variation. This is obtained from harmonic analysis of the mean daily variation for individual months and later combining the percentages for four years monthwise. We could do this averaging process because it was noticed that the relative contribution of the diurnal term for any month was not significantly dependent on solar activity. A similar feature of the phase of lunar semi-monthly variation in electrojet has earlier been pointed out[32]. This plot clearly indicates a strong annual variation with diurnal term being less than 50% in importance during summer months. During this period the semi-diurnal term almost accounts for the rest so that its relative contribution has again an annual variation with winter minimum and June maximum. This result is consistent with the fact that counter-electrojets are more frequent in summer and that their presence ensures a significant semi-diurnal component in the daily variation. It is also noteworthy that counter-electrojets are not really rare phenomenon but occur fairly frequently[28].

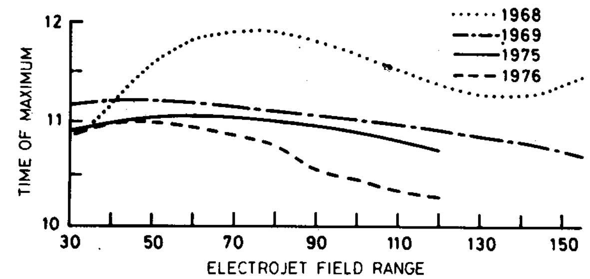

Fig. 3—Curves depicting the relationship between the time of peak intensity and strength of the equatorial electrojet for four years.

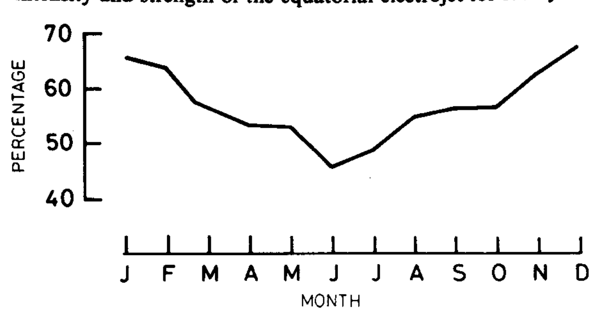

Fig. 4—Annual change in the percentage of variance accounted for by the diurnal term in the mean monthly daily variation curve (The values are averages for the four years).

3.4 Relationship between Ionospheric Component at Low Latitudes [*SDI*(*LL*)] and Close to Dip-Equator [*SDI*(*EQ*)]

Tarpley[33] suggested that the equinoctial maxima in the equatorial electrojet intensity are due to the alternate equatorward movement of the overhead S_q current system in the northern and southern hemisphere. Rajaram[22] recently found that the day-to-day variation of the latitude of S_q focus is highly correlated with electrojet intensity changes. Earlier, Kane[21] found that larger strengths of the planetary S_q seemed to be associated with equatorward shift of the focus. It may, therefore, be reasonably expected that the ionospheric component of the S_q at low latitudes as determined from Alibag and Sabhawala observations and that of equatorial electrojet as derived from Trivandrum and Alibag data may show some degree of correlation if electrojet current system is only an enhanced version of the planetary S_q. To verify the extent of the relationship we computed the correlation of *SDI*(*LL*) with *SDI*(*EQ*) (i) for each month using the 24 mean hourly values of *SDI*(*LL*) and *SDI*(*EQ*) and (ii) for each hour using the 365 hourly parameters for each year.

The seasonal dependence of the correlation between *SDI*(*LL*) and *SDI*(*EQ*) for the four years is shown in Fig. 5. For most of the months the correlation coefficient is quite high (~ 0.8) and significant. This suggests that even if there is significant change in amplitude of S_q and jet variation from month to month[29] the form of diurnal variation as depicted by $\partial H/\approx t$ is quite similar at low and equatorial latitudes. The most striking aspect is the perceptible drop in magnitude of correlation for September during solar minimum conditions. This can be explained in terms of the different amplitudes of the S_q field at Alibag and Trivandrum. During September the $S_q(H)$ amplitude at Alibag registers a clear minimum during low solar activity which is absent during solar maximum epoch[34]. In equatorial region, on the other hand, September is characterized by increased jet strength.

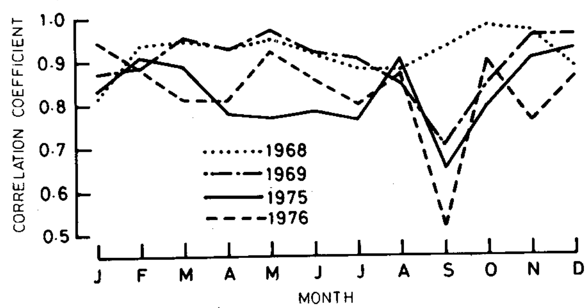

Fig. 5—Annual pattern of the correlation between ionospheric part of daily variation at equator [*SDI*(*EQ*)] and at low latitudes [*SDI*(*LL*)].

During vernal equinoctial period both Alibag and Trivandrum H field and consequently their ionospheric parts show maximum and, therefore, have high degree of correlation in their form of daily variation.

In Fig. 6 are shown the correlation pattern for the four years under study, between $SDI(LL)$ and $SDI(EQ)$ as also for the pair $SDI(LL)$ and electrojet strength. The correlations are necessarily restricted to the daylight hours as all the parameters are close to base level during night hours and, therefore, are not correlated. It is to be noted here that the computation is carried out using 365 (or 366) pairs of values for each hour and the correlation coefficient is significant at 99% if the value exceeds 0.25 even for 100 pairs. There is a discernible difference in the local time progression of the correlation coefficient for the two parameters, viz. $SDI(EQ)$, wherein allowance for planetary S_q field is provided by adding average $S_q(H)$ at Alibag for each hour, and the electrojet strength which is only a difference field at each hour. The electrojet strength is poorly correlated with the ionospheric component at Alibag close to noon hours but the correlations

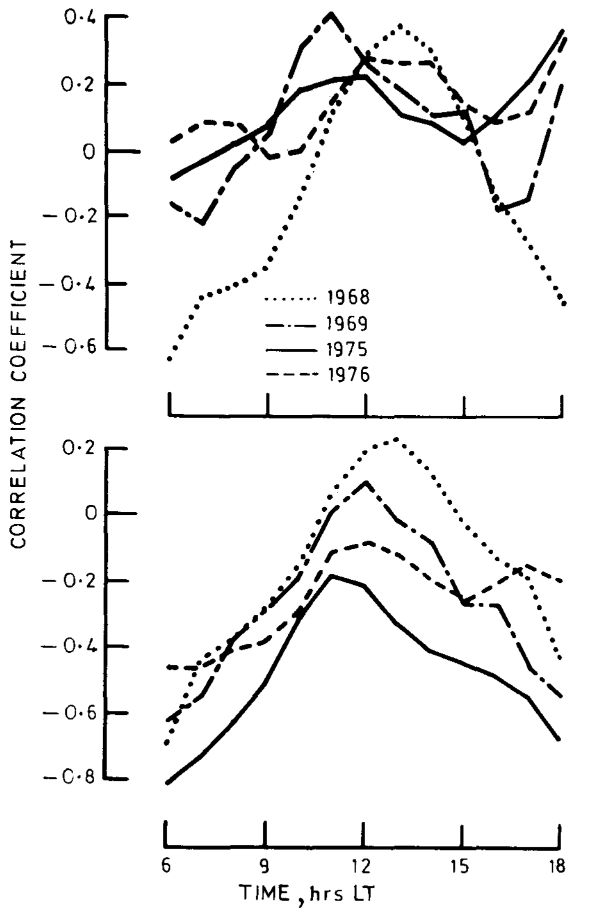

Fig. 6—Local time dependence of the correlation between ionospheric part of the daily variation at low latitude [$SDI(LL)$] and (i) $SDI(EQ)$ (top) and (ii) Electrojet strength (bottom) for four years [It may be noted that the correlation coefficient is computed using 365 (366) values for each year.]

improve and became significantly negative for the other hours. On the other hand, except 1968, correlation for which is similar to the earlier result, the correlation coefficient is not significant for all the daylight hours when $SDI(EQ)$ is utilized.

It, therefore, appears that equatorial electrojet field may be caused by some independent current system but whose variability is somehow linked to the planetary S_q in such a way that enhancement in strength from one day to another of S_q is accompanied by a reduction in the jet strength and vice versa.

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