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Seasonal Variations in the Intensity of S_q Current System & Its Focus Latitude over the Indian Region

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The signatures of solar quiet day (S_q) variation in the geomagnetic field components at Gulmarg and other midlatitude stations in the India-USSR region are used to determine the focus latitude and intensity of the S_q current system for each month of the year. The focus latitude in its annual progression shows a sharp southward shift in August and a northward shift in October and November. Intensity modulation of the current system is accompanied by significant deformation, particularly in the second half of the year. During summer and equinoxes, S_q focus appears to be in south of Gulmarg in the morning hours and moves back to north of Gulmarg in the afternoon.

1 Introduction

In an earlier paper Patil *et al.*[1] have examined the behaviour of solar quiet day (S_q) variation in the geomagnetic field components during the year 1978 at the newly commissioned observatory at Gulmarg. The form of the daily variation in the horizontal component at this station indicates that the focus of the northern overhead current system associated with S_q variation is located close to the latitude of Gulmarg. The various perturbations noted in the daily variation pattern during different seasons were qualitatively explained in terms of the magnetic effect brought about by some simple deformation of the overhead current system together with the latitudinal movement of the focus with season as well as in the course of a day.

In the present work, fine structure of the seasonal progression of S_q at Gulmarg is studied on a month-to-month basis. The signatures of daily variation pattern at Gulmarg and other midlatitude stations in India-USSR region are used to determine the focus latitude and intensity of the current system for each of the calendar months. This is one of the unique chains of geomagnetic stations extending from the dip equator to the auroral regions along the same longitudinal zone. The nature of the seasonal variations in the focus latitude as well as intensity over the region is examined and compared with those of West Pacific and American regions. Further, in the present work, the form of focus movement in the course of a day is identified, and the effect of intensity modulation and the effect of deformation of the overhead S_q current system are separated by comparing the daily variation pattern at Gulmarg with that at Alibag, a station far removed from the focal latitude.

2 Data Analysis

The basic data used in the present analysis are hourly values of the three geomagnetic field components, D, H and Z (declination and the horizontal and vertical intensities, respectively) at Gulmarg for the years 1978-80. The mean pattern of S_q variation for each of the calendar months is obtained by averaging hourly inequalities, measured above the local midnight level, of the respective components over 15 local quiet days, 5 quiet days per month from each of the years 1978, 1979 and 1980. The quiet days are selected such that they have maximum overlap with the international quiet days. The non-cyclic change was eliminated with a linear adjustment using the difference of the field between two successive midnight levels. The mean S_q variation in D, H and Z for each month from January to December is presented in Fig. 1.

2.1 Method for Focus and Intensity Determination

The form of S_q in H, i.e. $S_q(H)$ is known to reverse its sign across the latitude of S_q focus and as such $S_q(H)$ at midlatitudes hold information about the focus latitude of S_q current system. This property of H variation at the midlatitude stations has been often used to determine the focus latitude. Shiraki[2] has reviewed several simple methods employed to estimate the focus latitude and has proposed a new procedure wherein the influence of phase differences in the H variation at stations used in the computation of focus latitude is minimized. In the present work, we adopt the same method as detailed by Shiraki[2], where a parameter γ_1 is calculated from $S_q(H)$ for few midlatitude stations as follows.

$$\gamma_1 = \Sigma H \text{ (daytime)} - \Sigma H \text{ (nighttime)} \quad \ldots (1)$$

The first term on the right hand side of Eq. (1) indicates the algebraic sum of hourly values during daytime from 6 a.m. to 6 p.m. The second term is the sum of hourly values during nighttime from 6 p.m. to 6

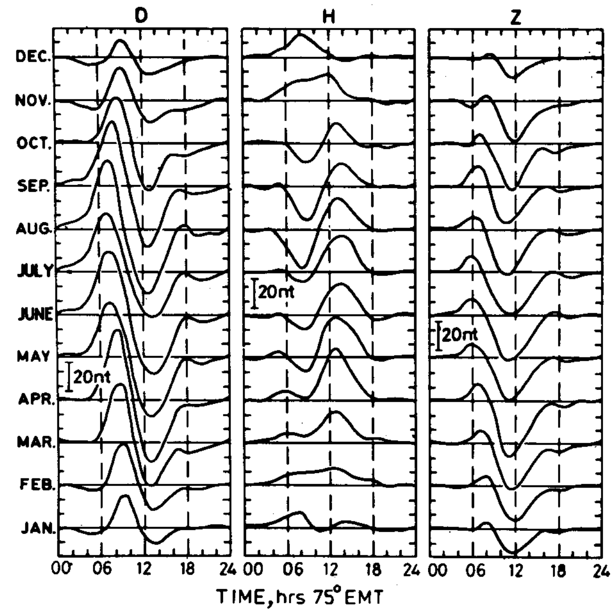

Fig. 1—Solar quiet day variations in geomagnetic field components, *D*, *H* and *Z* Gulmarg for each month, from January to December, averaged over the years 1978-80

a.m. Considering the latitudinal change of $S_q(H)$, the value of γ_1 at stations equatorward of the focus would be positive whereas it would become negative for stations poleward of the focus. Near the focus latitude, the value of γ_1 will be almost zero. Therefore, given the values of γ_1 at some midlatitude stations, the relation between γ_1 and latitude, φ, can be evaluated. Focus latitude, φ_f, is then defined by the latitude where $\gamma_1 = 0$. In the present computations, five stations of the India-USSR chain, encompassing the latitude of focus, were selected. The details of these stations are given in Table 1. Using the $S_q(H)$ pattern obtained from the data of 1978, as that alone were available in common with Gulmarg, γ_1 values were calculated for each station and for each of the calendar months. Next, focus latitude for each month is determined by the least square method from these γ_1 values assuming a linear relationship between γ_1 and φ. The φ_f values were also determined by fitting a second degree curve between γ_1 and φ. However, the differences between the two cases were very small, suggesting that the assumption of a linear relation between γ_1 and φ is quite adequate. The analyses were made separately using the two latitude systems, namely, geographic and dip latitude. In both the cases, month-to-month changes were nearly equal. The monthly values of φ_f derived by using geographic latitude system are shown in Fig. 2. It is of interest to note that in the definition of γ_1, all the hourly values, rather than any instantaneous maximum or minimum, are employed and hence the effect of any short term focus movement during the course of a day is averaged out. The focus position thus determined will indicate the mean position of the focus during the course of a day.

Shiraki[2] also notes that since γ_1 contains the effect of both the intensity changes of the current system and of the focus movement, parameter $|d\gamma_1/d\varphi|$ (i.e. slope in the linear relation between γ_1 and φ which is readily available in the computation of φ_f) forms an index of the intensity of the S_q current system. The monthly changes noted in this parameter are presented in Fig. 2. The daily variation in *D* in its latitudinal progression attains its maximum amplitude near the focus latitude. Therefore, the range of daily variation in *D* at a station located close to the focus latitude can be taken as a measure of the intensity of the S_q current system. The

Table 1—The Locations of Magnetic Observatories

Station	Geographic Lat deg	Geographic E. Long deg	Geomagnetic Lat deg	Geomagnetic E. Long deg
Alibag (ABG)	18.4	72.5	11.8	142.7
Sabhawala (SAB)	30.3	77.8	25.2	148.0
Gulmarg (GUL)	34.0	74.4	28.0	146.2
Tashkent (TKT)	41.3	69.6	37.2	139.6
Alma-Ata (AAA)	43.2	76.9	39.2	146.9
Karaganda (KGD)	49.8	73.1	46.0	143.3

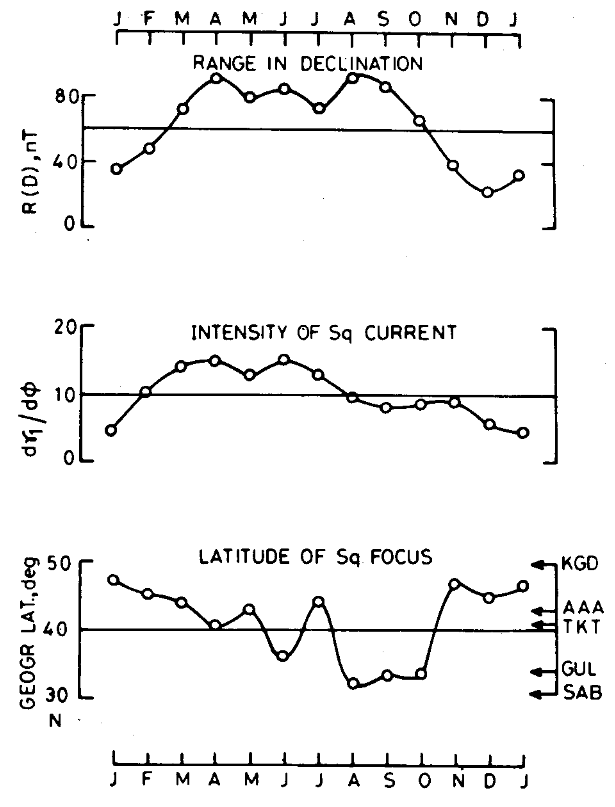

Fig. 2—Annual progression in the focus latitude, S_q intensity index $|d\gamma_1/d\varphi|$ as well as the solar daily ranges in declination during the year 1978

annual progression in the daily range of D, i.e. $R(D)$, during the year 1978 is also included in Fig. 2.

3 Results and Discussion

3.1 Fine Structure of Seasonal Variation in S_q at Gulmarg

An examination of Fig. 1 reveals that S_q variations in H undergo large variability both in amplitude and form. The $S_q(H)$ during winter months is primarily made up of northerly (positive) variation over all the daylight hours. January curve in Fig. 1 shows the presence of a deep depression around local noon in the otherwise dominant northerly field variation. Such signatures were also prominently noticed on the mean winter $S_q(H)$ variations at Gulmarg separately in the years 1978, 1979 and 1980 (Fig. 5 of Ref. 1). It has been explained by Patil *et al.*[1] that this secondary minimum in the northerly field variation results from a deformation of the S_q current system such that the current contours in the overhead current system appear closer on the equatorside of the focus than on the poleward side. In other words, focus appears eccentric with respect to the current contours. Such deformation in the current system conforms to F_l model of S_q proposed by Mayaud[3].

The $S_q(H)$ variations in summer and equinoctial months are composed of northerly (positive) variation in the afternoon hours and southerly (negative) variation in the forenoon hours. In general, northerly variation attains its maximum at around 1300-1400 hrs LT whereas strongest southerly (minimum) variation is registered around 0900-1000 hrs LT. Both the maximum and minimum are conspicuous features in all the *j*- and *e*-months but their relative prominence varies from month to month. While the strength of maximum tends to be greater than that of minimum during the months of April through July, the forenoon minimum appears to be the dominant feature in the daily variation pattern of August, Sepatember and October. Since the H variations at the middle latitudes are prone to the changes in the latitude of focus, $S_q(H)$ at Gulmarg, having both southerly and northerly fields, suggests movement of the focus across the latitude of Gulmarg in the course of a day during *j*- and *e*-months.

The S_q in D and Z components conform to the pattern expected for a northern hemispheric midlatitude station. In contrast to H variation, D and Z variations have consistent form in all the months of the year, clearly permitting an inference that any deformation of the S_q current system does not have any discernible influence on the form of D and Z variations. However, large month-to-month changes in the amplitude of D and Z are indicative of the intensity modulation of the overhead current system.

3.2 Latitudinal Variation in the S_q Focus

Fig. 2, which gives the latitudinal position of the S_q focus during different months of the year 1978, suggests that there is not much of a monthly variation in the focal latitude from January to July but from July to December the changes are strikingly prominent. The focus position shows an abrupt equatorward (southward) shift from July to August which is followed by an equally sharp northward (poleward) movement during October-November. During August-October, the focus with its average position around 30°N is located well south of Gulmarg. In the remaining months, the focus is consistently north of Gulmarg. The above noted seasonal variation in focus movement over the India-Russia region was earlier qualitatively inferred by Yacob and Rao[4] from the nature of annual progression in the phase angles of diurnal and semi-diurnal components of monthly mean $S_q(H)$ at Alibag (geogr. lat. 18°38′N; long. 72°52′E). They also showed that this character of the annual progression remained the same for both the solar maximum and minimum epochs, suggesting an atmospheric tidal origin for the phenomenon. More quantitative studies on the focus position during different months of the year by Gupta[5], Shiraki[6] and Tarpley[7] indicated that a relatively constant position of the northern S_q focus in the first six months of the year, followed by an equatorward movement in the fall equinoctial season and a poleward movement during December solstice, were the characteristic features for the American and West Pacific regions. Tarpley has also shown that annual movements of the foci are complementary in the northern and southern hemispheres. Tarpley[7] and Shiraki[6] consider the likely cause for the movement of S_q focus to be related to the variation in the winds driving the ionospheric dynamo, rather than the fluctuations in the ionospheric electrical conductivity or magnetospheric effects. Considering that the behaviour of focus movement is related to the local seasons in both the hemispheres[7], the wind variations may be related to the local season. The similarity of seasonal variation in the focus movement in different longitudinal regions further suggests the variation in the wind pattern to be a global feature rather than a regional characteristic.

The average latitudinal positions of the S_q focus in different seasons obtained by analyzing seasonal S_q patterns are given in Table 2 together with simultaneously obtained intensity parameters. Similar values reported by Shiraki[2] for West Pacific and American regions are also included in Table 2. The values presented for these regions correspond to that group of years whose mean sunspot number is close to that of 1978, a period for which the data are analyzed for a direct comparison. In India-Russia region the

Table 2—Focus Latitude (φ-geogr) and Intensity Index $|d\gamma_1/d\varphi|$ during Different Seasons for the Indian, West Pacific and North American Regions

Season	Indian region		West Pacific region		North American region	
	φ_f deg.	Intensity index nT deg^{-1}	φ_f deg.	Intensity index nT deg^{-1}	φ_f deg.	Intensity index nT deg^{-1}
Winter	47.0	4.5	37.6	7.7	25.5	8.9
Equinox	38.2	11.5	34.9	12.2	24.7	12.2
Summer	38.6	12.5	34.6	14.8	28.3	9.7
Annual	40.1	10.5	35.5	11.8	26.1	10.2

focus is found to be at a higher latitude in local winter than in local summer and equinoxes. This behaviour of focus movement with season is same for West Pacific and Indian region, but is different from that observed for the American region where the focus in its annual progression attains highest latitude in the summer months.

One interesting feature that emerges from an examination of Table 2 is that the latitudinal position of the focus in different seasons is closest to the geographic equator in the American region and farthest in Indian region. The position of the dip equator is south of the geographic equator in the American region but north of geographic equator in the Indian sector. While in the former, distance between dip and geographic equators is largest, it is the smallest in the latter sector. Taking the direction and magnitude of separation between the two equators, it emerges that the distance between the focus latitude and dip equator is nearly the same in all the three longitudinal sectors. The result corroborates the findings of Price and Stone[8] and Gupta[5], viz. the variation in the latitude of focus with geographic longitude follows the same variation as the magnetic dip equator with respect to the geographic equator.

3.3 Seasonal Variation in the Intensity of S_q Current System

It is evident from Fig. 2 that $|d\gamma_1/d\varphi|$, reckoned as a measure of the intensity of S_q current system, undergoes marked variation from month-to-month. This intensity index shows three maxima and three minima in a year; maxima occur in March-April, June and November, whereas minima occur in January, May and September. Comparison of this annual variation pattern for the Indian region with that of the other regions, as reported by Shiraki[2], reveals that seasonal variation in the intensity of S_q current system is more or less identical for Indian and West Pacific regions, but is markedly different for the American sector. In the American sector, the intensity index shows maxima in the equinoctial months and minima in the summer and winter months. This inequality of seasonal variation in the intensity of S_q in different longitudinal sectors is also quite evident in the seasonally averaged values of $|d\gamma_1/d\varphi|$ (see Table 2). Both in the Indian and the West Pacific sectors, the intensity index is larger in summer than in winter whereas in the American sector equinox values far exceed the summer and winter values. The extent of seasonal modulation, indicated by the ratio of maximum to minimum $|d\gamma_1/d\varphi|$ values, is smallest in the American sector and largest in the Indian region.

The seasonal variation in the intensity index $|d\gamma_1/d\varphi|$ as well as in the monthly mean values of quiet day range in declination, $R(D)$, at Gulmarg shows fair resemblance in the first half of the year but differs markedly in the later half of the year. The $R(D)$ values show strong maximum in September whereas the intensity index shows a minimum around September. As stated earlier, the parameter γ_1, in addition to intensity changes, is also sensitive to the deformation of S_q current systems. Since the S_q focus is shown to shift to lower latitude during August-October it seems likely that the value of γ_1 and also $|d\gamma_1/d\varphi|$ is controlled more by the deformation effect than the intensity changes. As the D variations are found to be less prone to deformation effect, S_q range in D at a station close to the latitude of focus provides a better measure of the intensity of S_q current system. However, the large differences in the seasonal behaviour of $R(D)$ and $|d\gamma_1/d\varphi|$ could serve as a useful index to indicate whether the intensity modulation is accompanied by significant deformation of overhead current system or not.

3.4 Nature of Focus Movement in the Course of a Day

With a view to studying the nature of focus movement in the course of a day and to examine the nature of deformation of S_q current system through the behaviour of daily variation pattern at Gulmarg, contour charts are obtained by plotting the monthly mean hourly inequalities of S_q in D, H and Z at Gulmarg as a function of local time. The charts constructed using data averaged over 1978-80 are shown in Fig. 3. Similar contour charts using data of Alibag are also shown in Fig. 3. Alibag being far from the latitude of S_q focus, daily variations at that station are likely to be less affected by the focus movement and hence comparison of Gulmarg and Alibag charts would enable one to isolate the effects arising from intensity modulation and focus movement or from the deformation of current system.

The forms of contour plots for D and Z components are nearly similar at the two stations. The higher values of contoured vortices in D and Z at Gulmarg, compared to Alibag, conform to the latitudinal

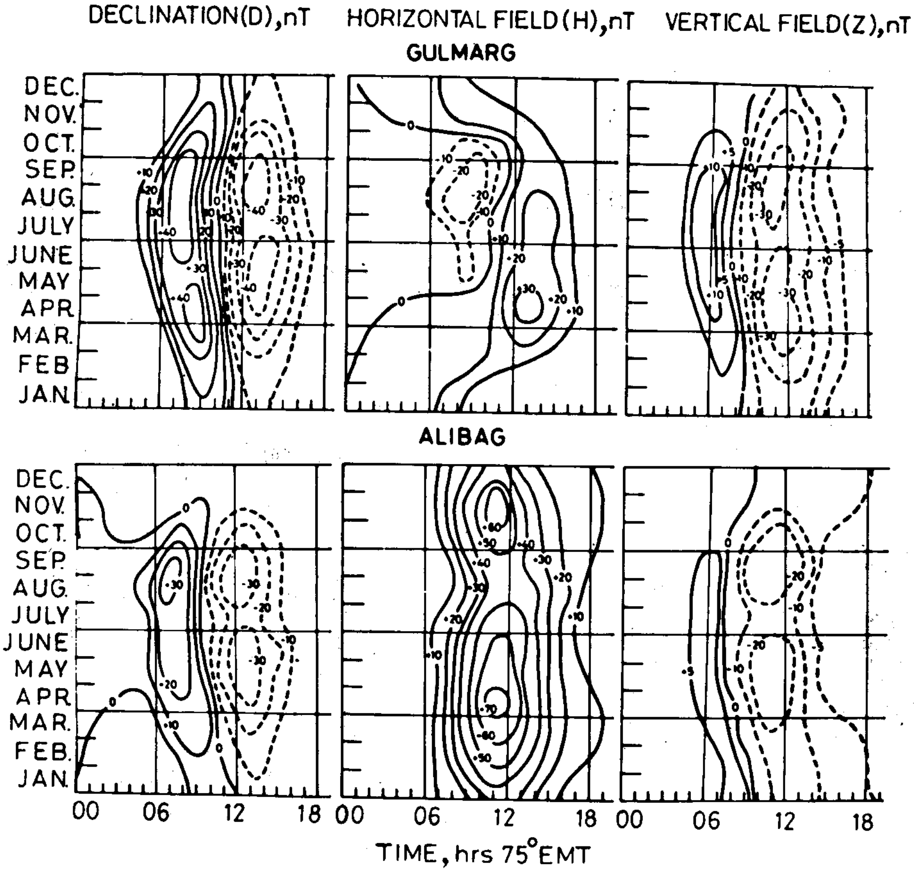

Fig. 3—Contour diagrams showing annual progression of solar quiet day variations at Gulmarg and Alibag for the years 1978-80

behaviour of S_q variation. The H plots reveal striking differences between Alibag and Gulmarg. Alibag plot is simple in form with northerly (positive) variation in all the months. Clearly, the strongest variations are registered around 1100 hrs LT during March-April and October-November. This pattern of H plot for Alibag is consistent with that resulting from semi-annual modulation in the intensity of normal S_q^p current system. As against the simple form of Alibag plot, H plot for Gulmarg is quite complex. Gulmarg plots in the first half of the year exhibit northerly (positive) field with diurnal maximum around 1300-1400 hrs LT and have the highest strength during March-April. Alibag plot for this part of the year shows similar feature except that the diurnal maximum is reached well before the local noon. This large difference in the phase of the daily variation in H at Alibag and Gulmarg suggests that the focus longitude of S_q current vortex does not pass over the two stations at the same local time, perhaps due to the skewing of the elliptically shaped current vortex. The occurrence of diurnal maximum at Gulmarg later than at Alibag is consistent with that resulting from Mayaud's T_l^m-model of S_q. In such a model, northern hemispheric current vortex, as it passes over the station, tends to have tilted (T) shape wherein current lines are shifted towards low (l) latitudes in the morning (m) hours. The contour pattern in the second half of the year shows that the daily variations are composed of both northerly and southerly variation. The southerly (negative) values in the forenoon and northerly (positive) values in the afternoon hours suggest that the S_q focus has shifted south of Gulmarg in the morning hours but migrates back to the north of Gulmarg in the afternoon.

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