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Daily variation of the geomagnetic field near the focus of Sq-current system in Indian longitude

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Abstract. The paper presents the first results on the behaviour of solar quiet-day variations of the geomagnetic field components at Gulmarg. Combining the data from Russian stations in the same longitude belt, the annual average daily variations are calculated which show, in the horizontal component (H), a reversal of phase between Gulmarg and Tashkent. Studying the Sq-variations at Gulmarg separately for the three seasons, the daily variation of H during *d*-months is predominantly diurnal in character with the maximum before noon. During *e*-months, and more so in *j*-months, daily variation of the H field is predominantly semi-diurnal in character with minimum around 08–09 hr LT and maximum around 14 hr LT consistently during 1978, 1979 and 1980. These features of the Sq at Gulmarg are suggested to be due to the deformations of the current loops caused by the changing latitude of focus during the course of the day.

Keywords. Solar quiet-day variation; overhead current system; Indian longitude; geomagnetic field.

1. Introduction

India has a long tradition of monitoring the geomagnetic field since early nineteenth century and had a regular magnetic observatory in Colaba for the years 1846 to 1907 which has been transferred to Alibag in 1905 and is still in continuous operation as the primary magnetic observatory of India. During the IGY two new magnetic observatories were established at Trivandrum and Annamalainagar which in conjunction with Kodaikanal have provided valuable data on equatorial electrojet since then. During the geomagnetic meridian project additional observatories were established at Ujjain and Jaipur. The latest addition to this network of 12 magnetic observatories in India is at Gulmarg (Geog. Lat. 34° 03′N; Long. 74° 24′E) being also the northernmost observatory in the Indian network. Until this latest addition, Sabhawala (Geog. Lat. 30° 22′N, Long. 77° 48′E) used to be the northernmost magnetic observatory in India.

Yacob and Rao (1970) studied the seasonal variations of the diurnal and semi-diurnal components of Sq in horizontal component (H) at low latitude observatories in India. Rastogi and Iyer (1976) studied the Sq(H) variations at Indian observatories from Trivandrum to Alibag. Srivastava and Prasad (1979) studied the solar (Sq) and lunar (L) variations at Hyderabad and Sabhawala and detected large amplitude of the second solar harmonic in H at Sabhawala during *e*- and *j*-months. Arora *et al* (1980) studied the solar and lunar tides in the geomagnetic field at all the magnetic observatories in India and confirmed the predominance of the second harmonic in S at Sabhawala. Rangarajan and Ahmed (1981) studied the geomagnetic H field at Sabhawala for the period 1964–78 and found that during January and December there is no appreciable variation indicating that during these months the Sq focal latitude is close to the station while the amplitude of second harmonic exceeds that of the first harmonic in summer and equinoxes. With this background information it was felt necessary to examine the geomagnetic data at Gulmarg to assess its position *vis-a-vis* the Sq-focus during different seasons.

2. Data treatment and results

In the present work, use is made of hourly values of geomagnetic field components, *viz* horizontal (H), declination (D) and the vertical (Z) components, from 13 magnetic stations whose data are available in common with Gulmarg. The names and locations of these stations are shown in figure 1. The mean pattern of daily variation in each of the components is obtained by averaging the hourly field values over all the international quiet (IQ) days of the year 1978. The hourly values for each IQ day have been corrected for non-cyclic variation before they are employed in the present analysis. The

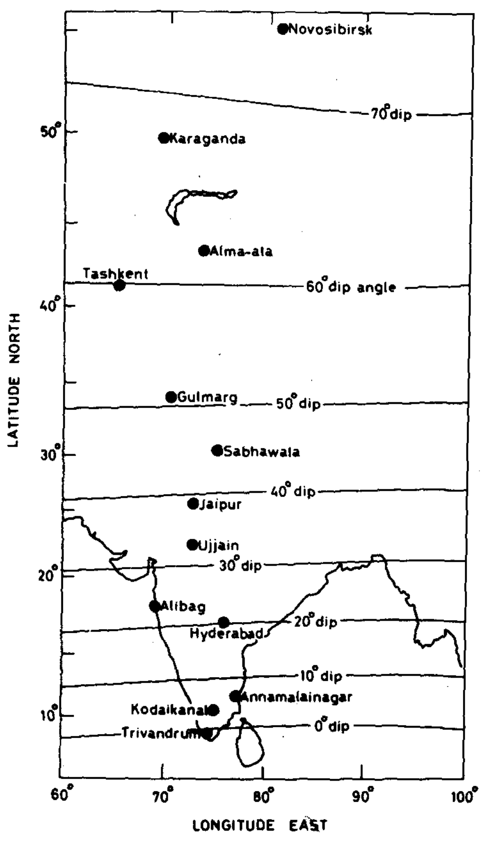

Figure 1. Map showing the locations of magnetic observatories whose data are used in the present analysis.

mean Sq-variation in D, H and Z for each of the stations are plotted as a function of 75° E time and are shown in figure 2. Figure 3 gives the latitudinal profile of the amplitude and phase of the diurnal and semi-diurnal terms obtained by the harmonic analysis of daily variations shown in figure 2. As the primary features of the latitudinal profile in this zone up to Sabhawala have already been discussed elsewhere (Rastogi and Iyer 1976; Arora *et al* 1980), prominent features having special reference to Gulmarg or indicating behaviour typical of the focal latitudes would only be emphasized.

Examination of figures 2 and 3 reveals that in regard to the pattern of DV (daily variation) as well as its latitudinal dependence, the variations at Gulmarg and at the adjoining stations broadly conform to the behaviour as revealed by global studies through spherical harmonic analysis (SHA) (*eg.* see Matsushita 1967). For example D and Z variations in their latitudinal progression attain maximum close to Gulmarg and H-variations are diminished in magnitude. The phase of the diurnal as well as semi-diurnal term in H shows a sharp jump between Gulmarg and Tashkent approximating to a reversal of the DV pattern. All these features lead to the inference that Sq-focus is located close to the latitude of Gulmarg. A noteworthy feature to emerge from figure 2 is that moving northward from Ujjain, the near-noon maximum of H-variatior

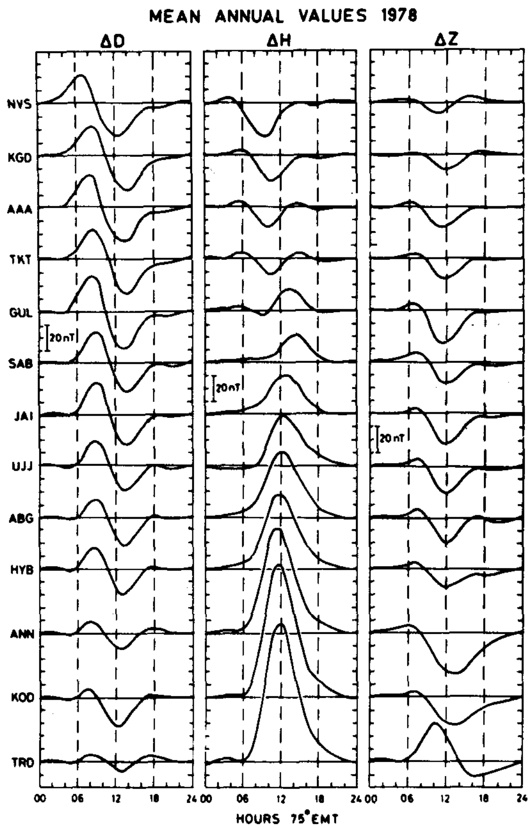

Figure 2. Solar quiet-day variations in geomagnetic field components, D, H and Z at magnetic observatories along Indian longitudinal belt for the year 1978.

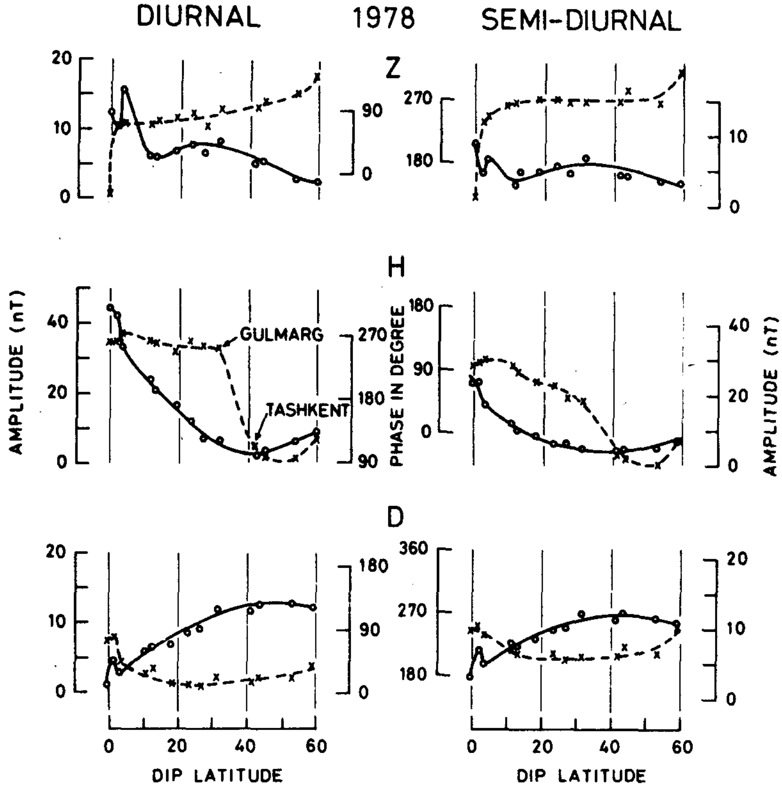

Figure 3. Latitudinal variations of the amplitude (solid line) and phase (broken line) of the diurnal and semi-diurnal terms of daily variations in the three geomagnetic components D, H and Z.

progressively shifts to a later hour until a reversed DV pattern is registered at Tashkent (TKT). However, this reversed H-variation at TKT is not completely out of phase as there exists a considerable time difference between the daily minimum at TKT and maximum at SAB. The pattern at Gulmarg is characterized by mixed features, showing a feeble minimum close to the time of TKT minimum and a pronounced maximum near the time of SAB maximum. Yet another feature of DV borne out by the harmonic analysis is that at latitudes close to the Sq-focus first and second harmonics of H-variation tend to be comparable in magnitude as against the dominance of the first harmonic at all other latitudes.

In order to have an insight into the stability or otherwise of DV pattern near Sq-focus with seasons, we have evaluated Sq-variations at Sabhawala, Gulmarg and Tashkent for the three seasons by grouping data for *d*-, *e*- and *j*-months of the year 1978. For *d*-months, four consecutive months, November 1977 to February 1978, are employed rather than combining data of January, February, November and December of the same year. The results are shown in figure 4. Apart from the regular seasonal changes in intensity, as implied by the strength of D-variation, the H-pattern depicts strong

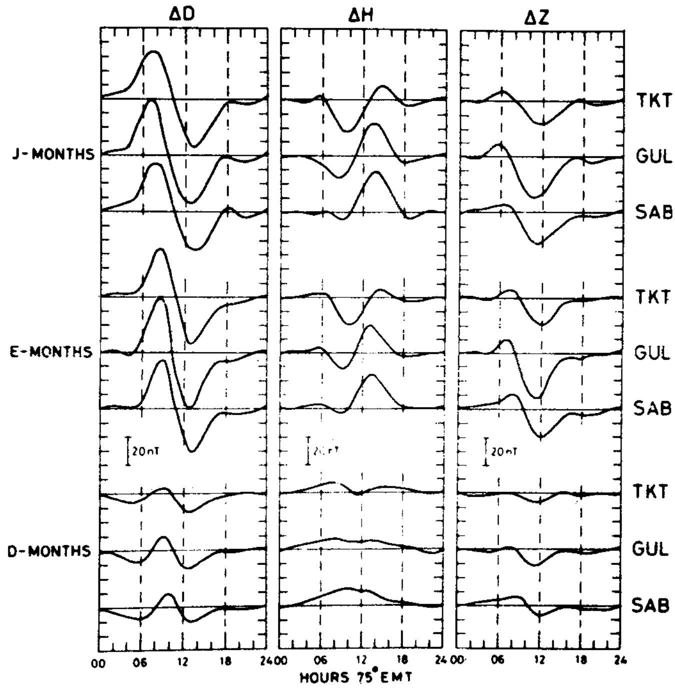

Figure 4. Mean seasonal quiet-day variations in D, H and Z at Sabhawala, Gulmarg and Tashkent for the year 1978.

seasonal variability of form, leading to the conjecture that overhead current system undergoes large seasonal variation both in shape and intensity. Figure 5 illustrates the mean seasonal and annual variation at Gulmarg separately for the years 1978, 1979 and 1980. The similarity of seasonal DV patterns among the three years, further suggests that seasonal progressions are stable and repetitive in nature.

The most striking aspect of the DV during *j*- and *e*-months as noticed from figures 4 and 5, is the absence of normal pattern in H-variation at Gulmarg, *i.e.* absence of a single maximum or a minimum close to the local noon. In contrast, the DV has a pronounced minimum around 9–10 hr LT and a maximum around 13–14 hr LT. Both the maximum and the minimum have equal prominence in DV pattern at Gulmarg. However, the behaviour differs markedly at stations immediately north (TKT) and south (SAB) of Gulmarg. While at Sabhawala the strength of the maximum in the early afternoon tends to be greater than that of the minimum in the forenoon, more or less reversed features are seen in the diurnal variation at Tashkent. In the *d*-months, Gulmarg H-variation is primarily made up of inverted V-type variation with positive (northerly) field during daylight hours suggesting that the Sq-focus is located further north of Gulmarg in this season. An interesting feature of winter H-variation is the presence of a depression, close to the local noon, in the northerly field variation giving the appearance of a secondary minimum included in the main northerly variation. This feature is more prominently registered at TKT than at GUL and SAB (figure 4) and stands out more clearly in the winters of 1978, 1979 than in 1980 (figure 5).

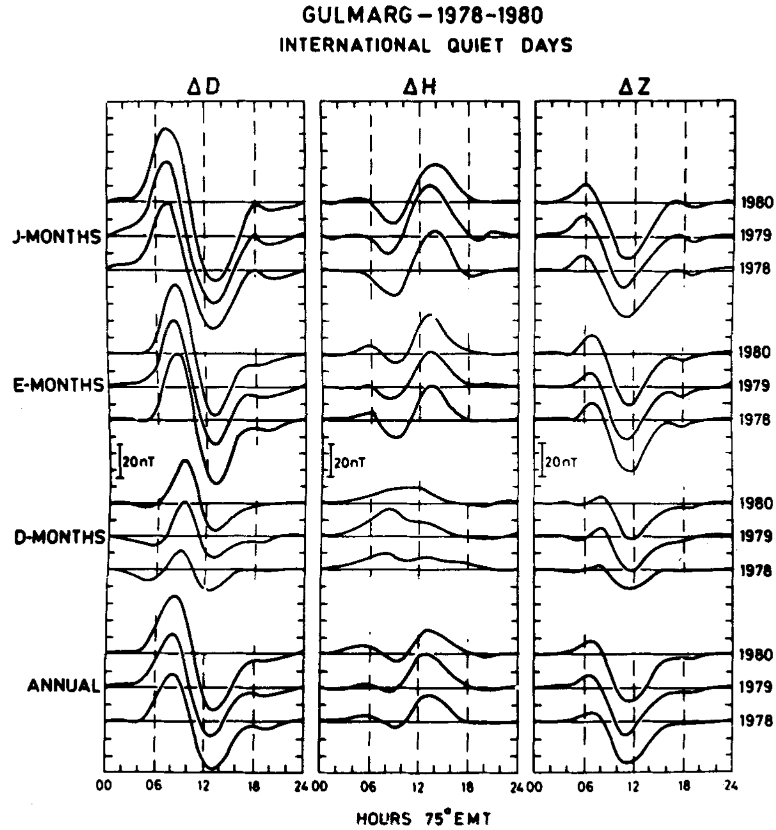

Figure 5. Mean seasonal and annual quiet-day variations in D, H and Z of Gulmarg during the years 1978, 1979 and 1980.

3. Discussion

Mayaud (1967) has visualised some schematic models of Sq-current system which individually or in combination bring out various patterns of DV registered near the focal latitudes. The basic model, termed the rectilinear model, includes an elliptical-shaped current vortex in the overhead current system responsible for DV in geomagnetic component. The other two models, called tilt (T) and deformed (F) models, are obtained by giving some simple deformation to the rectilinear model. In the tilt model, current vortex is deformed in such a manner that the currents are shifted towards either higher (*h*) or lower (*l*) latitudes in the morning (*m*) hours. These two possible forms are named T_h^m or T_l^m models. In other words, in the *T* model a kind of 'skewing' of the current vortex in the clockwise or anti-clockwise sense with respect to the axis parallel to latitude is implied. At the latitude of the focus or very close to it, the DV in H associated with T_l^m model is made up of a minimum and a maximum, similar to the pattern depicted in the DV pattern at Gulmarg during *j*- and *e*-months. Thus, it may be inferred that during *j*- and *e*-months northern hemispheric current vortex as it passes over the Indian region tends to have a tilted shape wherein current lines are shifted towards low latitudes in the morning hours. It may also be added that DV near the Sq-focus are very prone to the changes in the latitude of focus, and, therefore, it is likely that H-variation, both with southerly and northerly fields, may result from latitudinal movement of focus during the course of a day.

In the deformation model discussed by Mayaud (1967), the focus is shifted either to higher or lower latitudes such that current contours tend to be closer on the poleward side than on the equatorward side or *vice-versa*, the inherent assumption being that current vortex does not move as a rigid body and the focus appears eccentric with respect to current contours. For such a model where the focus has moved to a lower latitude, called F_1 model, the daily variation in H at latitudes little lower than the focus consists of a secondary minimum included in the broad day-time maximum, a signature well-marked in the DV pattern of H at Gulmarg and Tashkent during *d*-months (figures 4 and 5). The fact that no anomaly is seen in D variation associated with this secondary minimum in H-variation lends further support to the interpretation that secondary minimum has resulted from the concentration of current lines towards the equator side of the focus as such concentration of lines would not produce any discernible influence on the form of D-variation (Mayaud 1967). The secondary effect is more pronounced in the winter months of 1978, 1979 than in the winter of 1980. The relative sunspot numbers during the winter season of these three years were 92.5, 131.2 and 168.5 respectively. This leads to a conjecture that the phenomenon of the deformation of sq-current vortex associated with the secondary effect has a measure of dependence on solar activity.

4. Conclusions

It follows from the above discussion that various perturbations from the normal pattern (as observed at low latitudes) noticed in the daily variation plots at Gulmarg and other neighbouring stations can reasonably be understood in terms of the effects arising from some simple deformations in the overhead currents system. The typical signatures noted suggest that during *j*- and *e*-months, current vortex appears tilted in an anti-clockwise sense with respect to the latitudinal axis whereas during the *d*-months focus is shifted to lower latitudes resulting in a greater concentration of contours towards *lower* latitudes.

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