On the Local Time Dependence of Annual and Semiannual Modulations of Geomagnetic Disturbance Field

B.R. Arora and G.K. Rangarajan

Indian Institute of Geomagnetism, Colaba, Bombay, India

(Received May 13, 1974; Revised September 27, 1974)

Amplitudes and phases of the annual and semiannual components in the geomagnetic disturbance field and its constituents are derived at each local hour of the day for Alibag and Hermanus. The annual variations at Alibag and Hermanus are nearly in phase. The variations at the same station for intervals 12 hr apart are nearly in phase opposition. It is shown that the local time variation in the annual component is predominantly due to the modulation in the asymmetric part (SD) and that in semiannual component is due primarily to the symmetric part (DR) of the disturbance field. The semiannual modulation of symmetric and asymmetric parts of the disturbance field are in phase opposition during morning hours and in phase in the evening hours leading to a marked forenoon/evening asymmetry in its amplitude. The results obtained here explain the local time variation in annual and semiannual modulations of horizontal intensity derived from observations on all days earlier by Bhargava (1972b, c).

1. Introduction

The presence of annual and semiannual variations in the earth’s magnetic field has been known for many years. Moos (1910) using monthly horizontal force inequalities at Colaba for each of the 24 local hours had pointed that periodic seasonal disturbance was mainly confined to hours when sun was above the horizon. During the night hours the seasonal progression was feeble and reverse of that observed during sunlit hours. Bhargava (1972a, b, c) from spectral analysis of horizontal intensity observations at low latitudes showed that amplitudes of the annual and semiannual components of earth’s magnetic field varied with local time. The power density corresponding to annual line assumed large magnitude twice a day, first a little after local noon and again in the evening-night sector. While the day-time component was shown to be of ionospheric origin, the component observed in late evening was indicated to be of magnetospheric origin. The semiannual component assumed its first maximum around 0800 hours LT and the secondary maximum was again in the late evening hours. Bhargava (1972c) and Bhargava et al. (1973) found that the day-time component of semiannual oscillation was largely associated with the modulation
of \( Sq \) currents. The secondary maximum appeared to be due to a modulation of the asymmetric ring current. As part of these modulations in low latitude horizontal intensity was clearly shown to have a link with the magnetosphere and the asymmetric ring current, it was considered worthwhile to study the local time variation in the amplitudes and phases of these in only the disturbance field. The disturbance field observed at the earth's surface is generally treated as a combination of an axially symmetric part, \( DR \), and an asymmetric part, \( SD \). Symmetric part of disturbance has long been attributed to a 'ring current'. While the mechanism responsible for \( SD \) is still ambiguous, its diurnal characteristics are well known. In low and middle latitudes it is a sinusoid with morning maximum and evening minimum (Sugiura and Chapman, 1958). The equivalent overhead current system for \( SD \) field at low and middle latitudes as given by Chapman (1935) has two symmetrical circuits; plane of symmetry separating these circuits is 0h–12h meridian which forms the line of demarcation of positive and negative \( \Delta H \) areas. The \( SD \) field is generally attributed to either the return currents from the auroral electrojet or to a partial ring current superposed on the symmetric ring current. Recently, Fukushima and Kamide (1973a) have interpreted the origin of \( SD \) field in terms of the appearance or intensification of partial ring current system consisting of three segments: the Birkeland currents in the magnetosphere, partial ring current in equatorial plane and the electric currents in the ionosphere and have concluded that primary contribution to \( SD \) comes from Birkeland currents. Irrespective of the mechanism responsible for \( SD \), its intensity will be related to the magnetic flux entering into the earth's magnetosphere through the tail (Piddington, 1968). In this communication an attempt is made to evaluate the annual and semiannual modulations of the disturbance field and its constituents \( DR \) and \( SD \) for two stations—Alibag in the northern hemisphere and Hermanus in the southern hemisphere.

2. Data Analysis

The data used in the analysis are the mean monthly hourly values of horizontal intensity for five international quiet and disturbed days of each month for the years 1936 to 1971. The mean daily variation of the disturbance field for each month is obtained by subtracting the monthly mean hourly values for quiet days from the corresponding values for disturbed days, wherein it is tacitly assumed that the strength of \( Sq \) field is preserved all through the month and is effectively removed by subtraction. The daily variation of disturbance field, \( D(t) \), for each month so derived can be represented as

\[
D(t) = DR + SD(t), \quad t = 1, 2, \ldots, 24.
\]

For estimating the dependence of the annual and semiannual modulations of disturbance field on local time, 24 series of monthly mean disturbance values,
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$D(t)$, are derived, following Bhargava (1972a), from observations at each local hour of the day. To obtain the amplitudes and phases of the oscillations at frequencies of 1 and 2 cycle/year, 432 mean monthly values for each hour was subjected to spectrum analysis using the computationally efficient method of fast Fourier transform (FFT) based on Cooley-Tukey algorithm valid when the total number of data points ($N$) in the series is a power of 2. Suitable number of zeroes were added to one end of the series to make the data points equal to 1024. A 10% cosine-bell data window, weights for which are defined by Brault and White (1971), was applied to avoid the undesirable effects due to finite length of the data sample, before the discrete Fourier transforms were obtained. From the Fourier cosine and sine coefficients, $a_k$ and $b_k$ at each frequency $k$ ($k=0, 1, \ldots, N/2$), the raw spectral estimates $(a_k^2 + b_k^2)/2$ were computed which were then smoothed by application of weights 0.25, 0.5 and 0.25 (Singleton and Poulter, 1967). Amplitudes are derived from the relation $2^{1/2}$. While both the amplitude and phase of the annual component show considerable variation over the 24 local hours, the phase of the semiannual component is nearly same at all houes of the day. Since the hourly values are arranged in local time without particular reference to the commencement of storms in the derivation of $D(t)$, the average of 24 mean hourly values of $D(t)$ may well represent the mean monthly level of $DR$ component and the hourly departures from this mean will determine the strength of $SD(t)$. A fresh set of 24 series of monthly inequalities, $SD(t)$, one for each hour, are subjected to FFT similar to the series, $D(t)$. The annual and semiannual components of the symmetric part of disturbance are also computed from the monthly values of $DR$. The modulation of $DR$ field is predominantly semiannual. The change in amplitude and phase of the annual component of $D(t)$ and $SD(t)$ during the course of the day are almost alike. The amplitudes of semiannual component of $SD(t)$ and its variation over 24 local hours is comparatively smaller than that of $D(t)$.

3. Results and Discussion

3.1 Annual component of disturbance field

The amplitudes of the annual component of $DR$ at Alibag and Hermanus are only 2.1$\gamma$ and 1.4$\gamma$ and the epoch of maximum is in early April. Amplitudes and phases of the annual component of $SD(t)$ for different hours are shown by harmonic dial in Fig. 1. The line OP represents the annual component of $DR$. Amplitudes of $SD$ at most of the hours are greater than that of $DR$. Hence the amplitudes computed for $D(t)$ is primarily determined by $SD$ and a close similarity in the trends of changes of amplitudes and phases of $D(t)$ and $SD(t)$ should be expected.

It is seen from Fig. 1 that the modulation at a frequency of 1 cycle/year of asymmetric disturbance field at Alibag has a first maximum around 1200 hr $LT$.
and another around 2000–2100 hr LT. At Hermanus, the largest amplitudes occur around 1100 hr and 1700 hr LT, with greater amplitude for the evening component in contrast to Alibag where both amplitudes are comparable. The amplitudes are, in general, greater at Alibag than at Hermanus. The harmonic dial is oval in shape and is smoothly varying in a clockwise sense at both the stations. There is, however, an anti-clockwise loop from 2200 to 0300 hr LT at Hermanus. A striking feature in Fig. 1 is that around the hours when annual component registers its maximum amplitude, the phases for periods 12 hr apart are in opposition. It can also be noticed from the figure that the annual variations at Alibag and Hermanus are nearly in phase around the hours when the amplitudes are maximum. These two features can be explained as follows: Any change in the intensity of flux in the magnetospheric tail will also manifest as a change in the overhead current system responsible for SD. As the overhead currents in middle and low latitudes are eastward over the sunlit hemisphere and westward over the night hemisphere, any modulation in these currents at a frequency of 1 cycle/year will have opposite effect in the two halves of the day leading to a phase difference of nearly 180° at a station as observed here. Since these currents have the same direction for the same local hour at two stations in opposite hemisphere, any variations in the intensity of these currents will have similar effects at both the stations resulting in similarity of phase as observed here. FUKUSHIMA and KAMIDE (1973b), while computing the contribution of individual component of the model partial ring current system to SD, showed that the total magnitude of SD decreases with increasing latitude. It may, then, be reasonably assumed that the amplitude of the annual modulation of SD also has a latitudinal dependence. The differences in the amplitudes of annual component at Hermanus compared to Alibag may, hence, arise from the difference
in the location of stations with respect to the overhead current system.

The hours of maximum of the annual component of $D(t)$ and $SD(t)$ in the course of a day are nearly the same as obtained by BHARGAVA (1972b) from observations of horizontal intensity on all days at Alibag. The amplitude of the secondary peak observed in the late evening hours by him is comparable to that of $SD(t)$, suggesting that the peak observed in the evening hours in the series of horizontal intensity observations derived from all days has its origin in disturbance field. However, the amplitudes of annual wave in $SD(t)$ or $D(t)$ near local noon is less than the corresponding amplitude in the spectrum of horizontal intensity and does not show any phase difference across the hemisphere in contrast to the phase difference of about $160^\circ$ corresponding to the annual line for stations in northern and southern hemispheres as shown by CURRIE (1966). It thus appears that the annual modulation of horizontal intensity around local noon consists of two parts. One may be associated with the annual modulation of $Sq$ with its maximum in summer and yielding a phase difference of $180^\circ$ at stations in the northern and southern hemisphere. The other which is in phase in both hemispheres with maximum around January is likely to be associated with the modulation in $SD(t)$. The exact magnitude and phase of the annual component of horizontal intensity derived from observations on all days will then depend upon the relative contributions of the ‘out of phase’ component associated with $Sq$ modulation and ‘in phase’ component due to $SD$ field.

### 3.2 Semiannual component of disturbance field

Figure 2b shows the amplitude of semiannual component in disturbance field, $D(t)$, as a function of local time. The epoch of maximum depression, derived from phase angle, is in equinoctial months and is nearly constant over the 24 hr. The component associated with $Sq$ is removed in deriving the disturbance field analysed here. The absence of a peak around 0800 hr $LT$ in the series for $D(t)$ corroborates the conclusion of BHARGAVA (1972c) and BHARGAVA et al. (1973) that the forenoon maximum observed by them is due to semiannual modulation of currents responsible for $Sq$.

The amplitudes of the semiannual component of $SD(t)$ at different local hours are shown in Fig. 2a. At both stations there is a maximum around 0400 hr $LT$ and another around 1700–1800 hr $LT$. Figure 3 shows the harmonic dials of the semiannual component of $SD(t)$ for Alibag and Hermanus. Unlike $D(t)$, the phase of $SD(t)$ shows large changes from hour to hour as can be seen from Fig. 3. The line OP in Fig. 3 marks the direction for the epoch of maximum of $DR$ component. The semiannual component of $DR$ has magnitude of 11.5$\gamma$ and 8.4$\gamma$ at Alibag and Hermanus respectively with epochs of maxima in the beginning of June and December i.e. the epochs of maximum depressions are in March and September. An outstanding feature seen from Fig. 3 is that $SD(t)$ and $DR$ are in phase opposition during morning hours and in phase in the
Fig. 2. Amplitude of semiannual component, as a function of local time, of (a) $SD$ and (b) $D$.

Fig. 3. Hourly change in amplitude and phase of the semiannual component of $SD$. OP represents the amplitude and epoch of maximum of semiannual component of $DR$. 
evening hours. This will lead to a marked forenoon/evening asymmetry in the amplitude of \( D(t) \) as noticed in Fig. 2b. Since the semiannual component of \( SD(t) \) with changing phase is considerably smaller than that of \( DR \), its contribution to the phase of the resultant field \( D(t) \), predominantly controlled by \( DR \), will be negligible.

It is interesting to note that the hours of maximum amplitude of annual component are close to noon-midnight plane separating the equivalent overhead current circuits for \( SD \). Vestine and Chapman (1938) showed that the plane of symmetry often did not coincide with the noon-midnight meridian and changed during the course of the storm. Noncoincidence of this plane with noon-midnight meridian has also been indicated by Fukushima and Oguti (1953). The maxima in amplitude of annual modulation around hours close to noon-midnight meridian may be explained by the longitudinal oscillation of the plane of symmetry with a period of 1 cycle/year so that hours close to noon are under the influence of eastward currents in one half of the year and under westward currents in the other half of the year and vice versa for hours around midnight. The hours of maximum amplitude of semiannual component are nearer to times when \( SD \) attain maximum and minimum values in its diurnal variation viz. near crest and trough of the \( SD \) sinusoid, suggesting that the semiannual modulation of the disturbance field may be the result of only the periodic intensification of the overhead currents responsible for \( SD \). A further study of the overhead current system with particular reference to the position of plane of symmetry in different seasons is expected to suggest a clue for precise understanding of annual modulation of \( SD \) around noon-midnight meridian.

The authors wish to thank Prof. B.N. Bhargava, Director, Indian Institute of Geomagnetism, Bombay, for his guidance during the course of this work and to Mr. A. Yacob and Dr. D.R.K. Rao for their helpful suggestions.

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