On some new Features of the Semiannual Variation of the Geomagnetic Field

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Abstract. — Using a technique based upon computations from magnetic data restricted to selective daylight hours, which permits the estimation of the semiannual component of the field with an improved signal-to-noise ratio, it is shown that, this component is entirely «equinoctial». No «axial» mechanism is observed but a singularity in the field is noticed around September 6 with a half-width of about 5 days. This effect is confined to periods of peak solar activity and is insignificant during declining and low activity phases of the solar cycle. The nature of the semiannual componnent in the field also suggests an association with the preponderance of activity in the northern solar hemisphere over the southern hemisphere.

1. INTRODUCTION

The mechanism responsible for the semiannual increase in the magnetic activity has been discussed in the literature for many years. According to 'equinoctial' hypothesis (Bartels, 1932) the varying orientation of geomagnetic axis to the direction of the solar wind flow and consequent modulation of the geomagnetic cavity is responsible for the semiannual increase in the magnetic activity. In the 'axial' hypothesis, originally due to Cortie (1912), the cause has been ascribed to a $\pm 7.2^\circ$ variation of the heliographic latitude of the earth. A comprehensive review of the semiannual variation of the magnetic activity has been given by Wilcox (1968). Shapiro (1969) has suggested that the two hypotheses are not mutually exclusive and that a possibility exists of the alternate mechanism operating as a secondary effect. Russell and McPherron (1973) have proposed that the semiannual variation of geomagnetic activity is caused by a variation in the effective southward component of the interplanetary field. According to them, the southward field arises because the interplanetary field is ordered in the solar equatorial coordinate system, whereas the interaction with the magnetosphere is controlled by a magnetosphere system. Since the southward component of the interplanetary field as measured in solar magnetospheric coordinates is modulated by the tilt of the earth's rotation axis relative to the ecliptic pole and the tilt of the dipole axis to this rotation axis, as well as by the tilt of the Sun's axis of rotation to the ecliptic pole, the model of Russell and McPherron for the semiannual variation of geomagnetic activity is both an equinoctial and an axial hypothesis. Since the phases of the variation, based upon the two hypotheses, differ by only 16 days and because an appreciable 'noise' is present in the indices of magnetic activity from which the semiannual variation of the disturbance field has generally been derived, it has not been possible to abtain conclusive evidence in favour of one hypothesis or the other. Computations to derive the semiannual variation using data with a high signal-to-noise ratio can, however, be expected to yield more meaningful results. In a communication (Bhargava, 1971a), it has been shown that an exceedingly large semiannual variation existed around 08-09 LT in the horizontal intensity of the earth's field at Alibag. Confirmation of these findings came from spectral analysis of extensive data from Honolulu and San Juan (Bhargava, 1971b). In the present communication, using 45 years' data, we have derived the fine structure of the field restricting observations to those hours at which the semiannual variation is most markedly present and have discussed the main features of the variations.

2. Computations

The fine structure of the field has been derived from daily values of the horizontal intensity at 0800 and 0900 hrs LT from January 1, 1925 to December 31, 1969 at two low-latitude stations, Alibag (geomag. lat. 9.5°N) and Honolulu (geomag. lat. 21.1°N). The series of horizontal intensity for each of the two hours were subjected to a detrending procedure by applying to the mean intensity on each of the 365 days, a correction based upon the difference in the average values of the field during the first and last ten days of each year. The mean of each of the series was subtracted from the detrended series, yielding 365 daily «inequalities». Values on the 29th day of February in leap years were omitted from the analysis. The series, one each for 0800 and 0900 hrs, were combined into a single series by determining the algebraic mean. The inequalities were averaged over the 45 year period providing the fine structure of the field variations with an improved signal-to-noise ratio. Inequalities were also grouped according to phase of the solar activity cycle. The groups and years which constituted the groups are shown in Table 1.

TABLE 1

Group	period	No. of years	Fig. No. representing the fine structure
Entire period	1925-69	45	1(a)
Years of primarily sporadic activity	1925-30; 1935-41; 1945-49; 1955-61; 1965-69.	30	1(b)
Years of primarily recurrent activity	1931-34; 1942-44; 1950-54; 1962-64.	15	1(c)
Years of ascending solar activity	1925; 1934-36; 1944-46; 1955-56; 1965-66.	11	1(d)
Years of peak solar activity	1926-28; 1937-38; 1947-49; 1957-59; 1967-69.	14	1(e)
Years of declining solar activity	1929-31; 1939-42; 1950-53; 1960-63.	15	1(f)
Years of minimum solar activity	1932-33; 1943-44; 1953-54; 1964-65.	8	1(g)

TABLE 2. SEMIANNUAL DEPRESSION OF THE FIELD

Classified Group	VERNAL EQUINOX (March-April)			(Axial)		
	Presence	Date	Magnitude	Presence	Date	Magnitude in nT
ALIBAG						
Entire period	Absent	—	—	Present	6th Sept.	−17.2
Recurrent activity years	Absent	—	—	Not prominent	—	—
Sporadic activity years	Absent	—	—	Present	6th Sept.	−18.7
Ascending phase of solar activity	Absent	—	—	Present	4th Sept.	−13.2
Peak Solar activity	Absent	—	—	Present	6th Sept.	−28.1
Years of declining activity	Absent	—	—	Not prominent	—	—
Years of minimum activity	Absent	—	—	Present	2nd Sept.	−13.5
HONOLULU						
Entire period	Present	20th March	−10.8	Present	5th Sept.	−12.9
Recurrent activity years	Present	4th March	−14.7	Not prominent	—	—
Sporadic activity	Present	30th March	−14.0	Present	5th Sept.	−15.6

TABLE 2. SEMIANNUAL DEPRESSION OF THE FIELD

AUTUMNAL EQUINOX (September-October)			Maximum of the field		Remarks
Presence	Date	Magnitude in nT	Date	Magnitude in nT	
ALIBAG					
Present	24th Sept.	−18.2	22nd June	13.5	
Present	24th Sept.	−20.0	6th June	15.9	Magnitude of the field on 6th Sept. was −14.1 nT. This was marked in the main depression
Present	25th Sept.	−17.5	22nd June	14.1	
Present	18th Sept.	−15.9	5th June	12.7	On 27th Sept. −15.8 nT depression of the field was noticed
Present	25th Sept.	−20.8	19th June	22.8	
Present	21st Sept.	−24.7	12th June	17.7	Magnitude of the field on 5th Sept. was −13.9 nT This was not very striking as it was in other groups
Present	22nd Sept.	−13.7	6th June	19.7	Field values are more or less equal from 2nd to 6th Sept. with the average −12.5 nT
HONOLULU					
Present	1st Oct	−17.7	22nd June	11.0	
Present	23rd Sept. to 2nd Oct.	−15.5	20th July	12.1	Depression corresponding to 6th Sept. was not at all prominent
Present	1st Oct.	−18.3	22nd June	11.5	

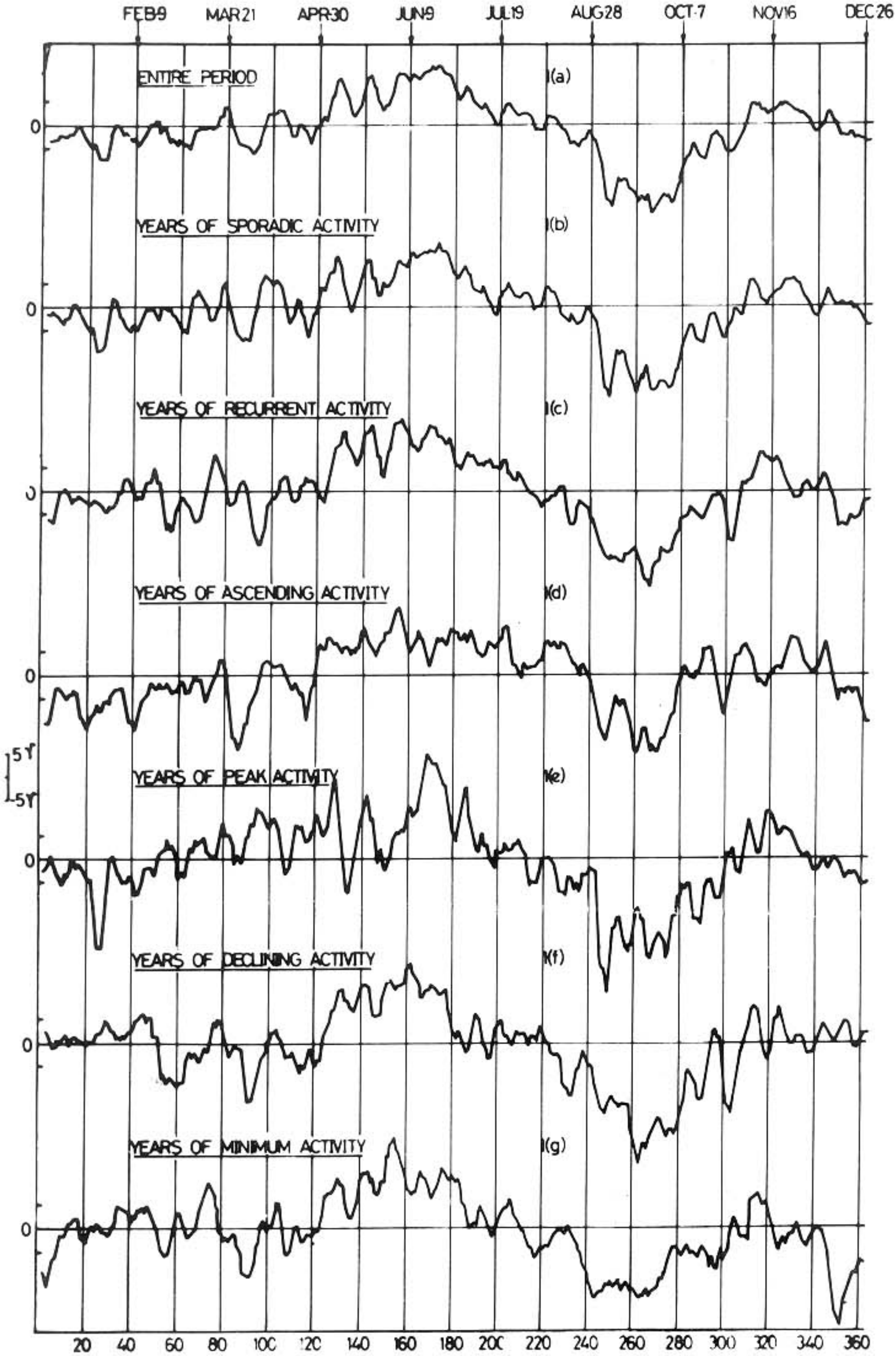

FIG. 1. Field variations from Alibag station corresponding to the seven solar activity groups defined in Table 1.

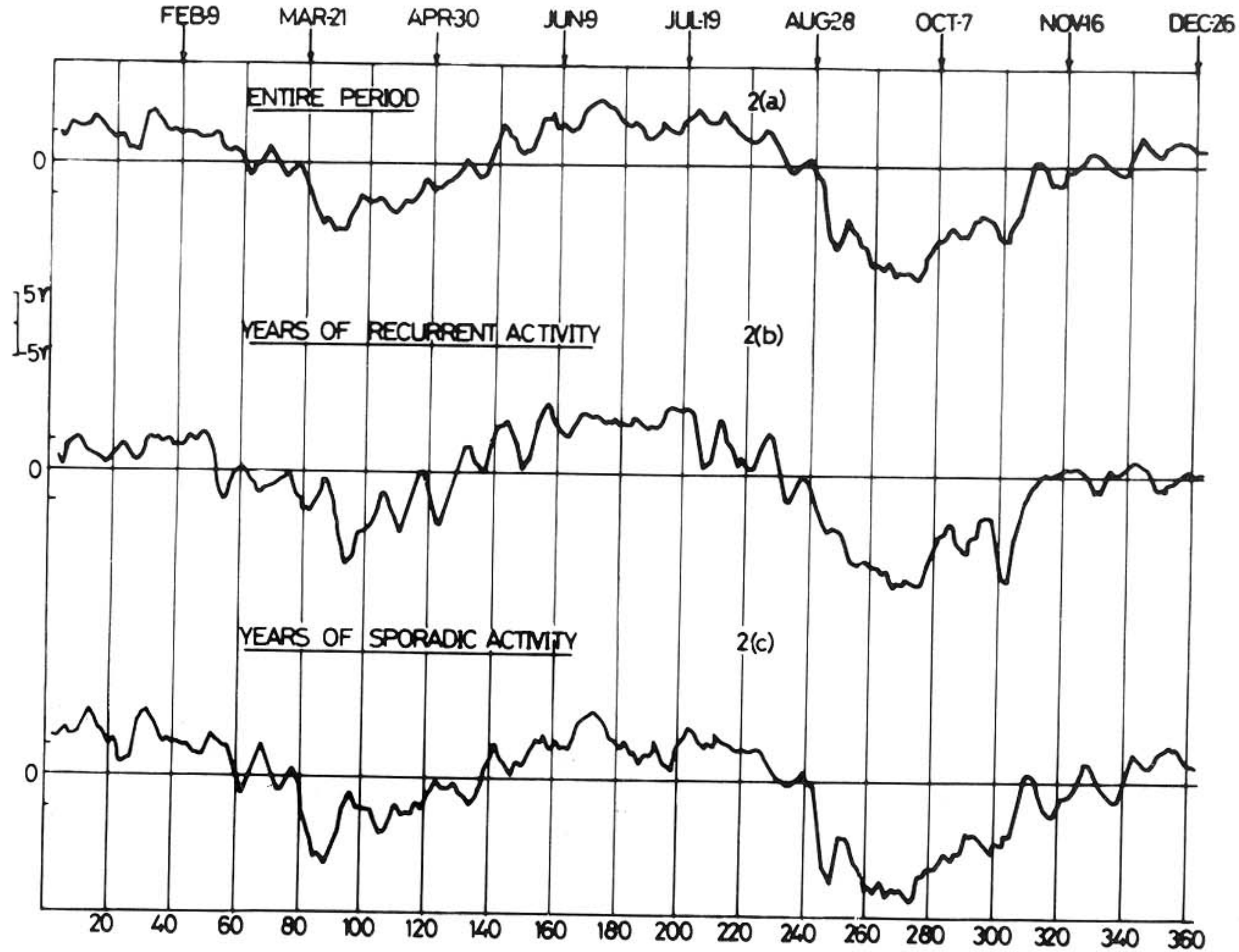

FIG. 2. Field variations from Honolulu station corresponding to (i) Entire period, (ii) Years of recurrent geomagnetic activity and (iii) Years of high and sporadic magnetic activity.

The 365 values were smoothed by computing 5-day overlappping means. Field variations derived from Alibag observations are shown in Fig. 1 for each of the seven groups of Table 1. The variations, derived from Honolulu observations at the same local time, 0800-0900 LT, are shown in Fig. 2 for three of the seven groups of Table 1, (i) for the entire 45 year period, (ii) years of recurrent geomagnetic activity and (iii) years of high and sporadic magnetic activity. The main features of the fine structure observed in Fig. 1 and 2, in so far as depression in the field predicted on the basis of equinoctial hypothesis and depression, if any, around March 6 and September 6, are summarised in Table 2. The main results are:

(i) Field depression with a frequency of 2 cy^{-1} is maximum around September 21, the date predicted on the basis of the equinoctial hypothesis and an analysis of Honolulu observations supports it.

(ii) In the autumnal equinoctial period during some years the field undergoes a sharp reduction of about 18 nT centred around September 6 with a half width of about 5 days. This depression is relatively large during years of high and sporadic solar activity and is small during the years of declining and low solar activity, an interval when recurrent magnetic storms are observed.

(iii) At Alibag as well as at Honolulu the field depression in the vernal equinox is much smaller than in the autumnal equinox.

(iv) Many of the smaller wave-length oscillations of the field superimposed on the semiannual variation observed both at Alibag and Honolulu are associated with the solar synodic rotation period (27-day).

3. Discussion

It is noticed from Fig. 1 and 2 that the depression of the field during the vernal equinox is insignificant in contrast to the larger depression during the autumnal equinox. Observing from the Sun, it can be considered that the earth is situated at a more southern heliographic latitude during vernal equinox and at more northern heliographic latitude during the autumnal equinox periods. The absence of field depressions in the vernal equinox period in all the groups and at both the stations, which are widely separated, can be attributed to the north-south asymmetry of solar activity. Excess of activity in the northern hemisphere of the sun over the southern hemisphere has been reported by Maunder (1922), Dodson and Hedeman (1969), Das Gupta and Sarkar (1970) and Waldmeier (1971).

Gold (1966), while commenting on the direction of the interplanetary field, has stated that it was not experimentally established whether the seasonal variation in the average 'frequency' and 'intensity' of magnetic storms is related to the periods of equinoxes or to the periods of maximum heliographic latitude of the earth. Magnetic storms would have their greatest intensity when the earth's dipole is most nearly perpendicular to the solar plasma flow. The existence of the field depressions around the dates of autumnal equinox in all the groups in Fig. 1 and 2 and the presence, in some groups, of a significant depression, very prominent in the autumnal equinox but with a half width of only about 5 days around the dates of axial hypothesis suggests that only the equinoctial hypothesis is operative; the axial mechanism does not contribute to the field over an extended period even as a secondary effect. This result may perhaps be undestood as follows: the intensity of the storms gradually increases from around June 21 and reaches a maximum around September 23 diminishing gradually to the solstices; the frequency of the storms is, however, largest in some phases of solar activity groups over a few days centred around about September 6.

Yacob and Bhargava (1971), who examined extensive daily magnetic data of Alibag, have shown two significant singularities one around September 4-5 and the other on October 28. Around September 5 they have shown a singularity in the geomagnetic activity index Ap also. Here both at Alibag and Honolulu in the recurrent activity groups, as well as in the group of declining phase of solar activity cycle at Alibag, the depression corresponding to the date of axial hypothesis is not significant over the background 'noise'. Recurrence pattern can be hypothesized due to the «M-regions». Basler (1966) found that the recurrence pattern is more pronounced during the later half of the declining phase of the sunspot cycle. Identical behaviour of these two groups is, therefore, expected. In fact some years included in these two groups are common.

From basic measurements of the twin Vela 3 spacecraft suppplementing those of Vela 2 and 4, evidence was presented by Hundhausen et al. (1971) for semiannual variations in the density and flow speed of the solar wind. The semiannual variations in both solar wind density and flow speed are approximately correlated with the heliographic latitude of observations during the Vela 2 to Vela 4 period. The conditions of low average density and high average flow speed were observed by the spacecraft near the extremes of the heliographic latitude excursion. During periods of high activity phases of solar cycles the terrestrial magnetic activity is largely due to plasma from impulsive events. Following these events, the interplanetary space is generally not free of solar particles and the propagation of flare particles is known to be considerably influenced by interplanetary plasma and magnetic fields. The sharp depression of the field centred around September 6 suggests that the 7.2° tilt of the solar equator to the plane of the ecliptic facilitates the trapping of plasma from solar impulsive events in a greater measure and, for a few days around the dates of extremes of heliographic latitude of the earth, the frequency of storms and their geoeffectiveness (magnitude) is appreciably enhanced. Cage and Zawalick (1972) have listed the dates on which the planetary index Kp was equal to 7- or more for one or more three hourly intervals from January 1, 1957 through December 31, 1971. The data shows that during high activity years, 1957-1960, Kp equalled or exceeded 7- on 27 occasions between September 2 and 5, as compared to 13 occasions between September 21 and 23. Further, while during low activity years 1962-65, Kp equal to 7- or more was not observed at all between September 2 and 5, there were 9 occasions between September 21 and 23 when Kp was 7- or more during these years. These figures support the contention that during high solar activity the response of the magnetosphere to solar wind plasma is rendered more effective in the first week of September perhaps through a more efficient reconnection of interplanetary field lines to the geomagnetic field (Dungey, 1961). The figures also suggest that M-region plasma is more geoeffective during the period around September 22 when the earth's dipole field is most nearly perpendicular to the solar plasma flow.

REFERENCES

Bartels, J. (1932): Terrest. Magnetims, *37*, 1.

Basler, R. P. (1966): Planet Space Sci., *14*, 1193.

Bhargava, B. N. (1971a): Planet Space Sci., *20*, 423.

Bhargava, B. N. (1971b): Indian J. Radio Space Phys., *1*, 9.

Cage, A. L. and Zawalick, E. J. (1972): AFCRL Environmental Research Papers, No. 423.

Cortie, A. L. (1912): Mon. Not. R. Astr. Soc., *73*, 52.

Das Gupta, M. K. and Sarkar, S. K. (1970): J. Geophys. Res., 75, 7250.

Dodson, H. W. and Hademan, E. R. (1969): IQSY 43 1969 Solar Terrestrial Physics MIT Press, Cambridge.

Dungey, J. W. (1961): Phys. Rev. Lett., *6*, 47.

Gold, T. (1966): 'The Solar Wind', Pergamon Press.

Hundhausen, A. J., Bame, S. J. and Montgomery, M. D. (1971): J. Geophys. Res., *76*, 5145.

Maunder, E. W. (1922): Month. Not. Royal Astronoms., *82*, 1922.

Russell, C. T. and McPherron, R. L. (1973): J. Geophys. Res., *78*, 92.

Shapiro, R. J. (1969): J. Geophys. Res., *74*, 2356.

Waldmeier, M. (1971): Solar Physics, *20*, 332.

Wilcox, J. M. (1968): Space Sci. Reviews, *8*, 258.

Yacob, A. and Bhargava, B. N. (1971): Gerlands Beitrage Zur. Geophysik, *80*, 503.