Geomagnetic Spectrum Unbiased by Noise - 8 to 60 days

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Abstract—Power spectral estimates unbiased by noise of horizontal intensity observations from three low and middle latitude stations, well separated from each other, in the period range 8 to 60 days are obtained adopting a procedure described by Black (1970). Results confirm that amplitudes at different frequencies exhibit latitudinal dependence. A significantly determined peak corresponding to a period of 13.9 days and absence of its subharmonic near 28 days indicates the tendency for equi-distant spacing of solar active regions. Several other significant periodicities are also detected.

1. INTRODUCTION

Investigation of periodic magnetic variations concerns detection and estimation of lines in the spectrum in the presence of noise. High resolution power spectrum using long series of data is essential for detecting weak signals above the general noise level. With the advent of computationally efficient technique for calculating Fourier coefficients of geophysical time series by fast Fourier transforms (FFT) using the Cooley-Tukey algorithm, high resolution spectrum can now be obtained with highly increased computational efficiency. Black (1970) pointed out that spectrum based on auto-correlation functions of data was disadvantageous due to the lack of a good estimate of probable error to associate with the power estimates and biasing of the estimates by noise in the series. To obviate the drawbacks associated with the correlation-cosine transformation procedure, he developed a method based on discrete Fourier transform for detection and estimation of lines in the frequency spectrum. The method gives estimates, with error limits, of the amplitudes of sinusoidal variation in the data and these estimates are unbiased by noise. Brault and White (1971) also suggested that smooth spectra can be obtained by dividing a long time series into several short segments of equal length, computing power spectrum for each segment and averaging the set of spectra. Cooley et al. (1970) recommended that the data segments preferably overlap by one-half of the desired segment length which increases statistical stability as the number of spectra averaged together is doubled relative to that without overlap. Power spectra of geomagnetic field variations and indices of magnetic activity have been reported in a number of communications (Shapiro and Ward, 1966; Currie, 1966, 1972, 1974; Fraser-Smith, 1972; Abdel-Wahab and Goned, 1974 and others) but estimates of amplitudes unbiased by noise have generally been infrequent. In this communication power spectral estimates unbiased by noise, of low latitude horizontal intensity observations, in the period range 8 to 60 days are computed following the procedure outlined by Black (1970) and significant spectral lines are discussed.

2. DATA ANALYSIS

Data used for analysis are the mean daily values of horizontal intensity at Alibag, San Juan and Hermanus. Table 1 gives the coordinates of the stations, the span of data and the number of segments averaged together. The data series were detrended using a 201-weight high-pass digital filter with unit response for periods shorter than 62.5 days and cut-off period in excess of 167 days. Trend-free series were divided in blocks of four years with a two-year period common to successive segments. Using a version of fast Fourier transform based on the algorithm of Cooley and Tukey (1965) valid when the number of data points (N) is a power of 2 ($N = 2^n$), spectral estimates were obtained as outlined below:

Each of the segments was first weighted by a data window to avoid the inconsistency that arises because the effective signal has discontinuities at the ends due to finite data length. The window used was a 10% cosine bell weights for which are defined by Brault and White (1971). Following Singleton and Pulter (1967), each of the modified data series was transformed into an equivalent set of Fourier cosine and sine coefficients

$$a_k = \frac{2}{N} \sum_{j=0}^{N-1} x_j \cos (2\pi jk/_N)$$

$$k = 0, 1 \ldots\ldots, N/_2$$

$$b_k = \frac{2}{N} \sum_{j=0}^{N-1} x_j \sin (2\pi jk/_N)$$

$$k = 1, 2 \ldots\ldots, (N/_2 - 1)$$

and from these,

$$P_{kj} = (a_k{}^2 + b_k{}^2)/2 \quad k = 0, 1 \ldots . N/_2$$

were formed as the initial estimates of the spectral density function for the j-th segment. Since Black's procedure of separating noise from signal is based on amplitudes, the power densities were reduced to amplitudes A_{kj}. From A_{kj} for j different segments at each frequency k, the maximum likelihood estimates of amplitudes were obtained using equations C16 and C17 of Black (1970).

The power spectra, considered as square of the amplitudes and the variance for the estimates combined together, between frequencies 80 and 520 cycles/4096 days are shown in four sections in figures 1, 2 and 3 for Alibag, San Juan and Hermanus respectively. There is no signal shown at which the maximum likelihood equations had only zero as solution.

3. DISCUSSION

The spectra for three observatories widely separated from each other are similar in many respects except for amplitudes, indicating that the generating mechanism responsible for significant oscillations of the field must be at large distance away from the earth, as shown by Banks (1969) who pointed out that the magnetic variation spectrum in the period range two days to six months is caused by fluctuations in the intensity of ring current. This suggests Sun as an important source for the field oscillations in the period range 8 to 60 days. It is also noticed from the figures that amplitudes at almost all the frequencies are largest at Alibag and least at Hermanus. This agrees with the finding of Gupta (1972) that amplitudes of 27-, 14- and 10-day lines in the magnetic spectrum were largest in equatorial and auroral zone and decreased on either side of these zones.

(a) Section of spectrum 65 to 190 c/4096d ($\sim$ 63 to 21.6 days)

A notable feature is that no significant line is detected in any of the spectra in the frequency range 65 to 82 c/4096d corresponding to periods of 63 to 50 days. Fraser-Smith (1972) detected a line at twice the average solar rotation period in the spectrum of index Ap of magnetic activity. In his extensive analysis of geomagnetic spectrum using mean daily values of H, Currie (1972) found a significant 54-day line in the data of 19 out of 28 observatories. The mean period calculated from 8 high resolution spectra was 53.8 days. Rangarajan and Bhargava (1974) also found a significant line corresponding to a period of 53.5 days in two samples of high resolution FFT spectra using 8192 values of mean daily H at Alibag. However, in a later communication reporting the results of spectra derived by a radically different approach using the concept of maximum entropy, Currie (1974) did not find any line corresponding to 54 days. Absence of any significant line beyond 50 days in the results by the present technique of analysis for three stations here lends support to Currie's modified view.

Significant periodicities found in this section of the spectra are around 45-49, 39-40, 29.5-36 days, a peak in the vicinity of 27.3 days, a spread of periods centred on 25.5 days and one near 22 days. It is interesting to note that 46 days is the eighth harmonic of the annual variation, 40 days the ninth and 36 days the tenth. Currie (1974) found that harmonics of the annual term upto ten or even more are detectable in geomagnetic spectrum and that there is a tendency for harmonics to be more evident at lower latitude stations. The 39-40 band is thus better observed at Alibag, located at a lower latitude than the other two stations. Wellknown periodicities in this range are the average solar rotation period of about 27.3 days and the lunar synodic rotation period of 29.53 days. A well-defined line corresponding to the period of 29.5 days (f = 139) appears in all the spectra. It appears well separated from the neighbouring peaks on either side for San Juan and Hermanus but not for Alibag. It appears that lunar effect on geomagnetic activity at a frequency corresponding to moon's synodic rotation period is detectable in low latitude field data. However, as suggested by Currie (1974) although synodic rotation periods of sunspots in different latitudes only vary from 26.4 to 28.7 days, (Chapman and Bartels 1940, p. 169) the mean speed of spots across the sun's visible disc when expressed in terms of a corresponding period of complete rotation leads to an extreme range of 24 to 31 days (p. 170). Rassbach et al. (1966) also noted that Kp correlation function showed that solar rotation contributes power to periods between 24 and 31 days. The lunar synodic rotation period falls well within this band and hence no firm conclusion can be drawn about detection of this periodicity in low latitude field except to state that there exists a line in the geomagnetic H spectrum corresponding to a period of 295 days. Both latitude variation and proper motion of sunspot could explain the spectral lines in periods range of 24 and 31 days. A noteworthy aspect of the spectra is that the line near 25.5 (f = 162) days is greater in amplitude than any other line in the vicinity of the average solar rotation period of 27-days. Banks and Bullard (1966) also detected a completely resolved line at 25.8 days in the spectrum of H at Abinger. A peak corresponding to 26.9 days observed by Olsen (1948) in polar geomagnetic field and by Fraser-Smith (1972) in Ap index is detected clearly in two of the three spectra presented here.

(b) Section of spectrum 190 to 300 c/4096d (21.6 to 13.7 days)

Significant periodicities observed in this region of the spectra correspond to periods of 20, 16.8, 14.7, 14.3 and 13.9 days. Some of these may be the harmonics of the periodicities discussed in previous section. A 18.7-day line in Ap spectrum observed by Fraser-Smith (1972) is conspicuous in its absence. For all the three stations the line at 13.9 days is largest in amplitude among all the lines and this appears to be a fundamental, as no line is detected near 28 days. The earliest observations of 13.5 day oscillation (Moos, 1910) showed that when the mean daily values and range of H at Alibag were arranged in rows of 27 days and averaged the predominant wave appeared with a period of 13.5 days. Moos concluded that it was an independent wave. While some others concur with this view, in the opinion of others this line is a harmonic of the dominant 27-day line. From his Ap spectrum, Fraser-Smith (1972) indicated that a period of 14.1 days was possibly a fundamental period. The significantly determined periodicity of 13.9 days coupled with the absence of any equally significant line corresponding to period in the vicinity of 28 days leads to the suggestion that there exists a tendency for equi-distant spacing in longitude of solar active regions.

(c) Section of spectrum 300 to 520 c/4096d (13.7 to 8 days)

Significant periodicities observed in all the spectra correspond to 13.6, 13.4, 11.6, 9.4 and 9 days. Some of these are probably the harmonics of the signals detected in section (a). Spectral peaks corresponding to 13.6 and 9.4 days were observed in the Ap spectrum also by Fraser-Smith (1972), which suggests that these frequencies are of world-wide occurrence. In the higher frequency region of the spectra the amplitudes are appreciably less and the number of significantly determined periodicities also falls rapidly. If the spectrum in this range of frequencies was due to storm modulation as suggested by Ekhardt et al. (1963), then it would appear that the modulation with significant amplitude does not span the entire frequency range of this section.

Winch and Cunningham (1972) have listed several periodicities that are associated with moon's orbit. Several periods detected in sections (b) and (c) may be associated with some of the principal lunar magnetic tides (17.6, 16.8, 14.7 and 14.3 days) and nodal lunar magnetic tides (14.7, 14.2 and 13.6 days). Since these lines are also close in periodicity to significant oscillations of solar origin or their principal harmonics, it is not feasible to ascertain which of these detected periods are of lunar origin.

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TABLE 1

Station	Geographic		Dipole		Data Span	No.of seg-ments
	Lat.	Long.	Lat.	Long.		
Alibag	18°38'N	72°52'E	9.5°N	143°.6	1932-1971	19
San Juan	18°23'N	66°07'W	29.9°N	3°.2	1930-1969	19
Hermanus	34°25'S	19°13'E	33.3°S	80°.5	1934-1971	18

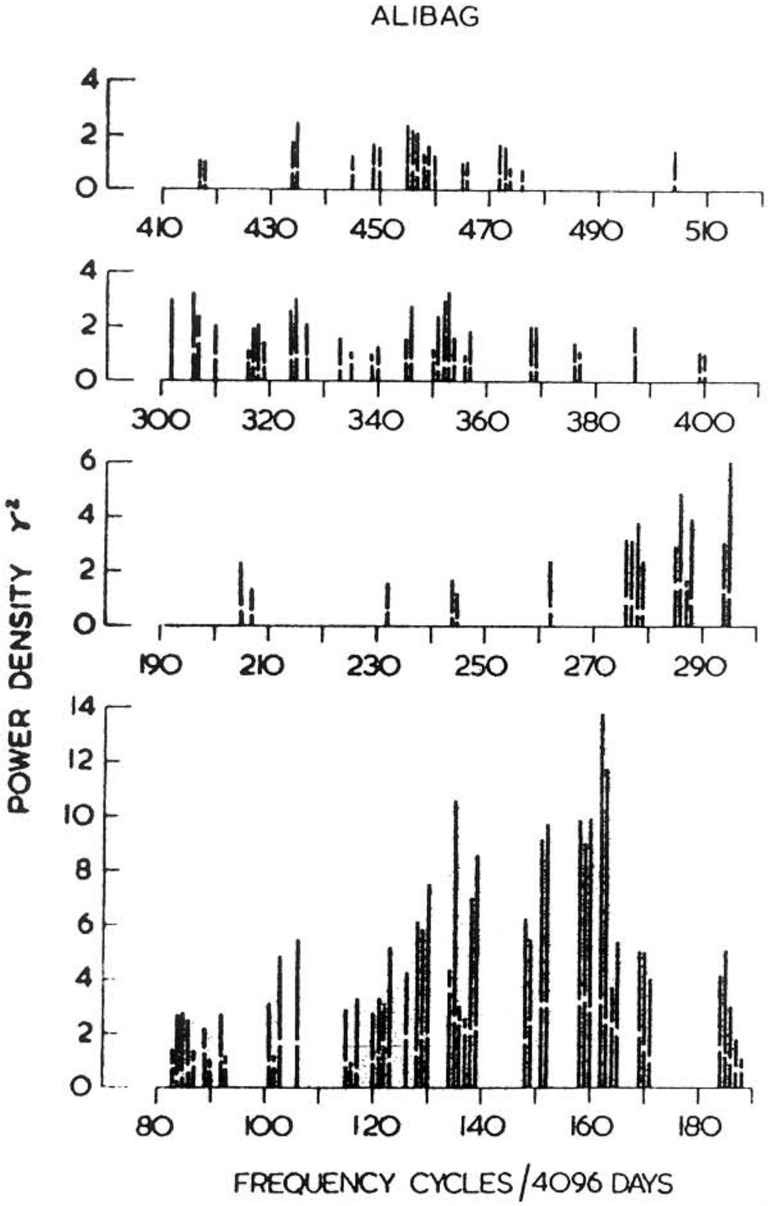

Fig. 1. Power spectrum of geomagnetic horizontal intensity at Alibag. The bar across each column is the height of the variance of the estimates of power density.

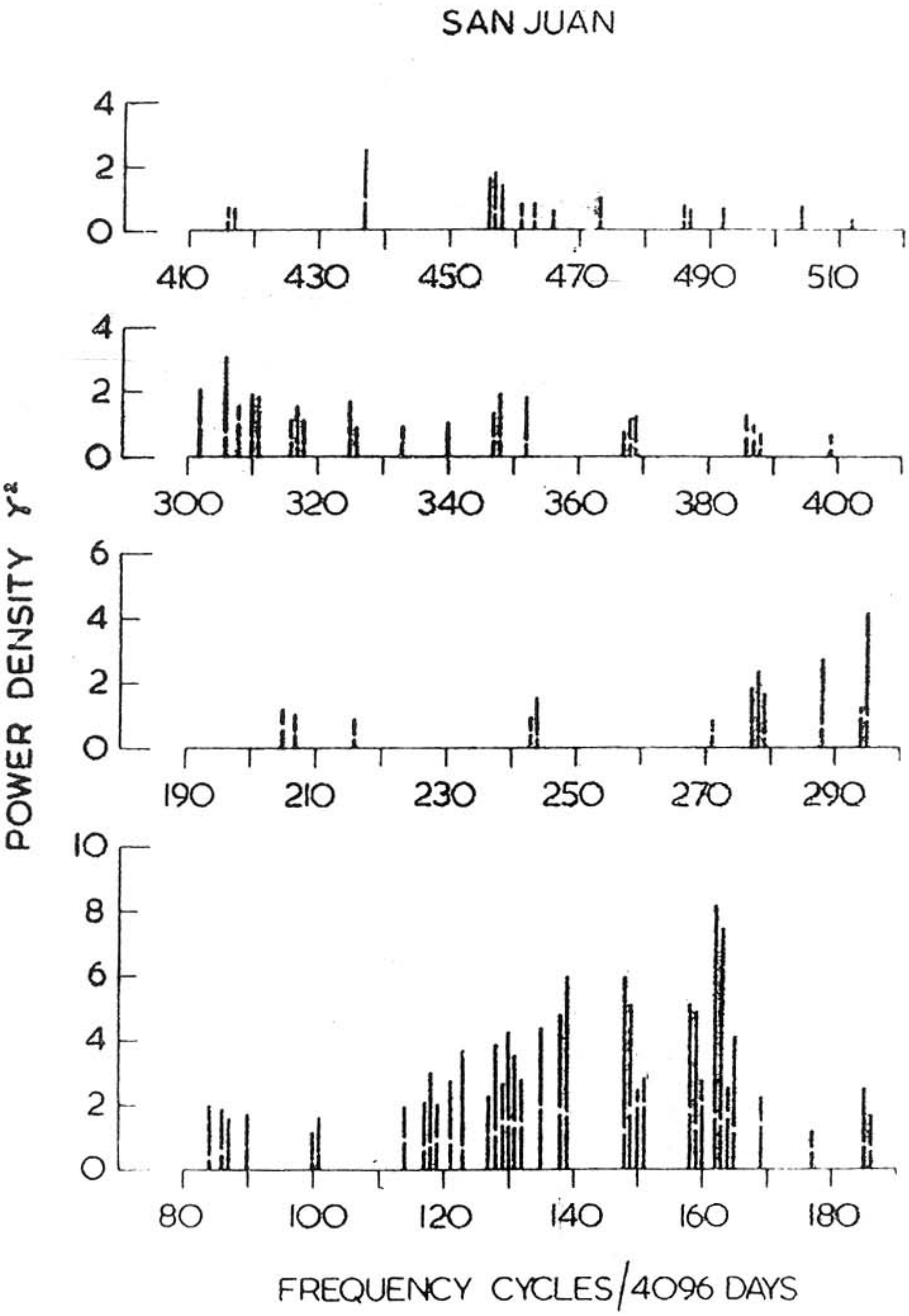

Fig. 2. Power spectrum of geomagnetic horizontal intensity at San Juan. The bar across each column is the height of the variance of the estimates of power density.

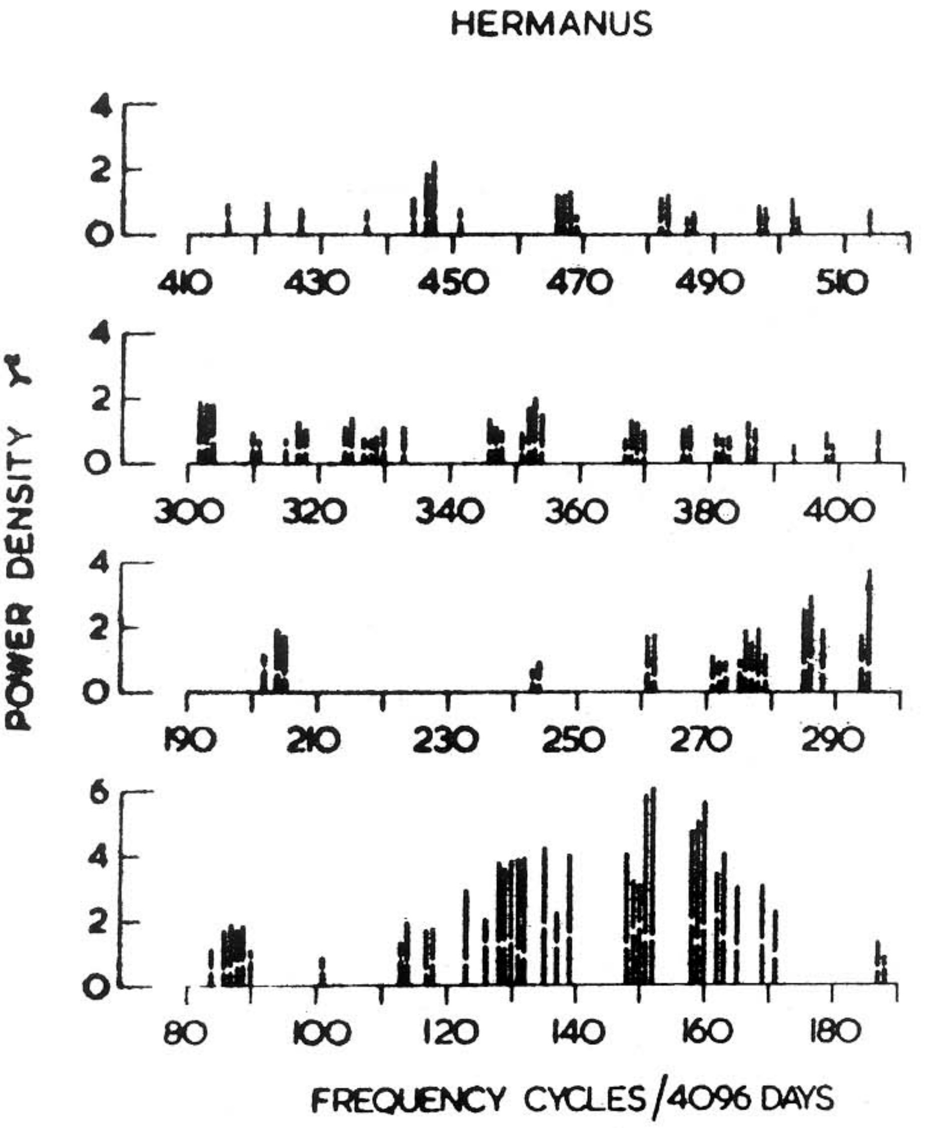

Fig. 3. Power spectrum of geomagnetic horizontal intensity at Hermanus. The bar across each column is the height of the variance of the estimates of power density.