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Time variations of Alibag *K*-indices (1946-1965)

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ABSTRACT. Results of analysis of time variations of Alibag *K*-indices for the period 1946 to 1965 confirm the occurrence of day-time maximum in summer and night-time maximum in the equinoxes and winter. Average magnitude of *K*-index at each of the 3-hour intervals, for which *K*-indices are scaled, depicts semi-annual trend with equinoctial maxima. This semi-annual variation is particularly prominent around midnight. Annual trends in equivalent daily range amplitude, A_k, for Alibag show clear equinoctial maxima for both IQ and ID days of the years 1952-54. No clear semi-annual variation in A_k is seen during sunspot active periods of 1955-57 and 1958-60. Power spectra of A_k depicts also rotation periodicities for the years around the sunspot minimum year 1954. This periodicity is much less prominent during the years around sunspot maximum. The observed features are discussed.

1. Introduction

For evaluating and standardizing the intensity of disturbance effects, superposed on daily magnetograms, many observatories employ the three-hour-range indices (*K*-indices) in the scale 0 to 9, first introduced by J. Bartels. The procedure is to scale the maximum ranges of geomagnetic disturbance superposed on the quiet-day trend of the geomagnetic field for periods of three hours— 0^h-3^h, 3^h-6^h, ...21^h-24^h UT. The scaling is done for the most disturbed geomagnetic field component. These three hour disturbance ranges are then assigned the indices 0 to 9 according to an increasing pre-determined magnitude-range scale for a particular observatory. For Alibag the following are the three-hour disturbance ranges in the horizontal component *H* corresponding to *K*-indices 0 to 9—

0	1	2	3	4
0-3γ	3-6	6-12	12-24	24-40
5	6	7	8	9
40-70	70-120	120-200	200-300	>300 γ

In the present communication an attempt has been made to analyse time variations of *K*-indices of Alibag for the period 1946 (when regular scaling was commenced) to 1965, to bring out the important characteristics pertaining to a region well away from both the auroral and equatorial electrojet belts. The geographic and geomagnetic co-ordinates of Alibag are —

Geographic	Lat. 18°38′N,	Long. 72°52′E
Geomagnetic	Lat. 9°28′N,	Long. 143°36′E

The results of analysis are presented and discussed under three separate heads, *viz.*, (1) Mean diurnal trends, (2) Mean annual trends and (3) Power spectra.

2. Mean diurnal trends

Examination of mean diurnal trends is aimed at identifying the summer day-time and the equinoctial as well as winter night-time maxima in the diurnal variations of geomagnetic activity at Alibag. These local-time characteristics of geomagnetic disturbance have been noticed for some high-latitude stations by Mayaud (1956), Lassen (1958), Nicholson and Wulf (1955, 1958, 1961 a, 1961 b, 1962) and Gjellestad and Dalseide (1964). The *K*-indices for each of the eight 3-hour intervals K_1, K_2, ... K_8 were averaged over the 20-year period (1946-65) for the three seasons — summer (May, Jun, Jul and Aug), equinoxes (Mar, Apr, Sep and Oct) and winter (Nov, Dec, Jan and Feb). The mean diurnal trends in magnitude of *K*-indices for the three seasons are shown in Fig. 1.

In summer, a broad maximum is seen to occur around local noon (K_2, K_3, K_4) in conformity with the finding of the same feature (*J*-effect) at several high and middle latitude stations by workers mentioned earlier. In winter and equinoxes, magnitude of *K*-index is maximum around local midnight (K_6, K_7). This agrees with the seasonal characteristics (*N*-effect) at higher latitudes. For all the seasons, the minimum occurs in interval K_1 corresponding to local hours 5-8.

Following Gjellestad and Dalseide (1964) mean annual variations of the *J* and *N*-effects are further examined to see if these effects really have the seasonal characteristics seen in Fig. 1. For this purpose *J* and *N* are defined as follows —

$$J = 2\,K^n - (K^{n-2} + K^{n+2}) \qquad (1)$$

$$N = 2\,K^m - (K^{m-2} + K^{m+2}) \qquad (2)$$

where K^n, K^m indicate the *K*-index for the n^{th}

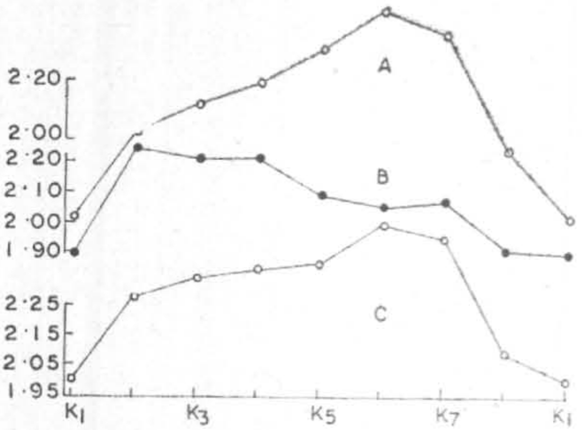

Fig. 1. Seasonal mean diurnal variation in average magnitude of K-index at Alibag for the period 1946–65

Winter—Curve A. Summer—Curve B. Equinoxes—Curve C
$K_1 K_2, \ldots K_8$ are 3-hr intervals 0-3, 3-6, ... ,21-24GMT day
Ordinates indicate magnitude of K-index

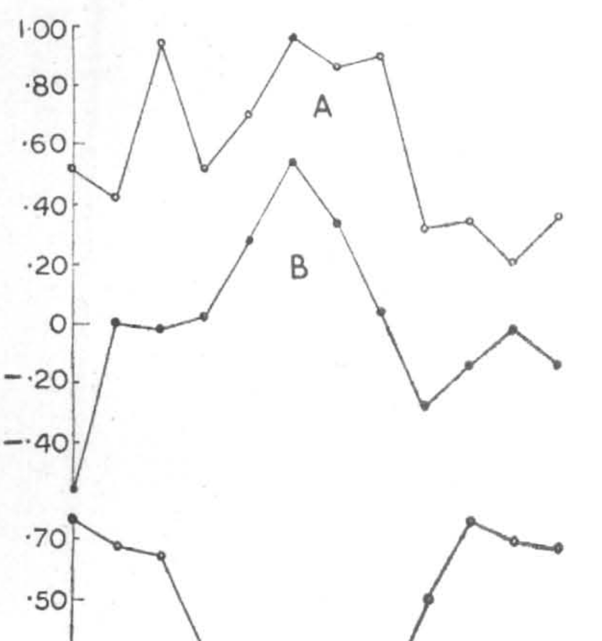

Fig. 2. Mean annual trends in J and N effects at Alibag

Curve A — J-effect for $n = 3$
Curve B — J-effect for $n = 4$
Curve C — N-effect for $m = 6$
Ordinates indicate mean magnitude of J and N

and m^{th} 3-hour intervals of the GMT day. In eqn. (1), K^n should correspond to the interval near local noon and in eqn. (2), K^m should be near local midnight. In case of Alibag, n can appropriately be given the values 3 or 4 and m the value 6. With these values J and N were computed for each day and averaged over the 20-year period separately for every month. Average J and N effects as defined were obtained in this way for each month of the year. These average values have been graphed in Fig. 2.

There is a tendency for J to be maximum during the summer months (curves A and B). This is markedly clear for J defined with $n = 4$ (curve B). In the case of N (curve C) prominent minimum appears in summer with broad maximum covering the winter and equinoctial months. These features corroborate the characteristics of seasonal differences in diurnal trends of K-indices seen in Fig. 1. It may, therefore, be stated with certainty that the J and N effects are both present at Alibag.

These features were noticed earlier by Narayanaswami (1941) in hourly disturbance ranges of H at Alibag for the years 1923-33. For days with character figure C = 2, he found that for the summer months disturbance ranges were maximum at noon and again around 17-18 hours L.T. For the equinoctial months the maximum range was at 21-22 hours with smaller peaks appearing near noon and around 17 hours. Likewise the maximum was around 22-23 hours for the winter months. He had indicated the occurrence of the minimum between 4 and 8 hours for all the seasons. In the case of K-indices also the minimum is found to be at the same period of the day for all seasons. The same feature is noticed in Fig. 1 of Gjellestad and Dalseide (1964) for some high latitude stations. The findings here regarding local time variation of geomagnetic disturbance, together with those of Narayanaswami (1941) add weight to the conclusion of Gjellestad and Dalseide (1964) that the J-effect is a global one. The N-effect also appears to be a widespread phenomenon since it is present at Alibag and at several high-latitude stations as indicated by earlier workers.

3. Annual trends

For each of the eight 3-hour intervals of the GMT day, K-indices were averaged for every month over the 20-year period according to the following scheme —

$$\overline{K}^n_m = \frac{1}{D}\sum_{d=1}^{d} K^n_{m,d}$$

where the superscript n indicates the interval 1 to 8 and the subscripts, m and d the month and day respectively. D is the total number of days in the 20-year period for month, m. For each value of $n = 1$ to 8, m takes the value 1 to 12. In Fig. 3 the values of $\overline{K}_m^n$ have been graphed for each of the eight 3-hour intervals, *e.g.*, $K_1 = 03$ GMT.

For all the 3-hour intervals the annual trends in the magnitude of K-index are markedly similar. The familiar semi-annual variation in geomagnetic activity with equinoctial maxima is clearly seen for all the intervals. The semi-annual oscillation is, however, more prominent for the intervals around midnight ($n = 5, 6, 7$).

It is of interest to examine the type of annual variation in geomagnetic activity for quiet and disturbed days during different epochs of the solar cycle. For this purpose three-year periods 1952-54 (period prior to and including the minimum year), 1955-57 (period prior to and including the maximum year) and 1958-60 (period following the maximum year) were considered. The quasi-logarithmic K-indices were converted into the linear equivalent amplitudes, a_k, using the standard conversion scale in the unit 2γ. The average of the 8 a_k's per day is then obtained to give the equivalent daily range-amplitude, A_k. These were then summed for every month over the above different 3-year periods, separately for the IQ and ID days. Their annual trends are shown in Figs. 4, 5 and 6. For comparison the daily planetary equivalent range amplitude, A_p, summed for the same days of the three periods are also shown in the figure. A_k (Alibag) and A_p variations for both IQ and ID days of all the three periods are fairly similar, indicating the representative character of Alibag K-indices as an index of world-wide geomagnetic activity.

Semi-annual variation with equinoctial maxima is clearly seen for both IQ and ID days only for the period 1952-54 (Fig. 4). Some semblance of a semi-annual variation is observed for ID days of 1955-57 (Fig. 5A) with a third peak in November. The variations for IQ days of 1955-57 and for IQ and ID days of 1958-60 (Fig. 6) do not depict clear semi-annual variation.

The difference seen in the character of annual variation of Alibag A_k as well as A_p for the period 1952-54 and the periods 1955-57 and 1958-60 must be on account of the different types of geomagnetic disturbance prevailing during these periods. The epoch 1952-54 was a period of declining sunspot activity, reaching the minimum in 1954. During this period, especially in 1952 and 1953 recurrent geomagnetic disturbance, from solar M-regions, was particularly strong. 1955-57 was a period of increasing sunspot activity reaching its maximum in 1957 while 1958-60 was a period immediately after sunspot maximum, when solar activity continued to be fairly strong. These two periods were marked by intense sporadic geomagnetic distubance, from flare-active sunspot regions of the sun. The geomagntic disturbances during 1952-54 were thus distinctly different from those that occurred during 1955-57 and during 1958-60, both in regard to their source and their occurrence characteristics. The solar latitudes of M-regions during 1952-54 have been inferred as higher than 7° (Bhargava and Naqvi 1954; Tandon 1956) and as about 34° (Bhargava *et al.* 1967). The solar latitudes of the

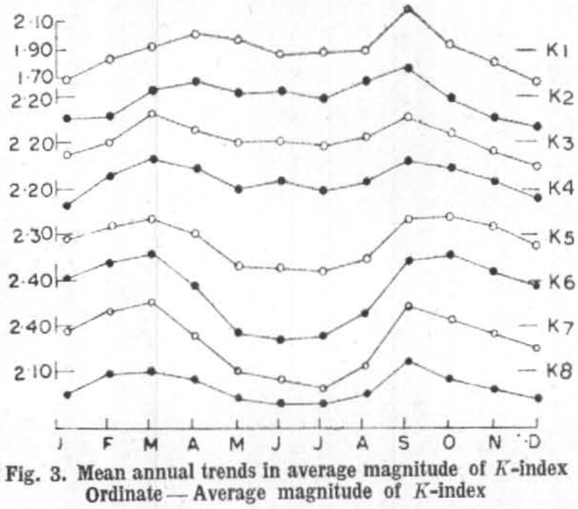

Fig. 3. Mean annual trends in average magnitude of K-index Ordinate — Average magnitude of K-index

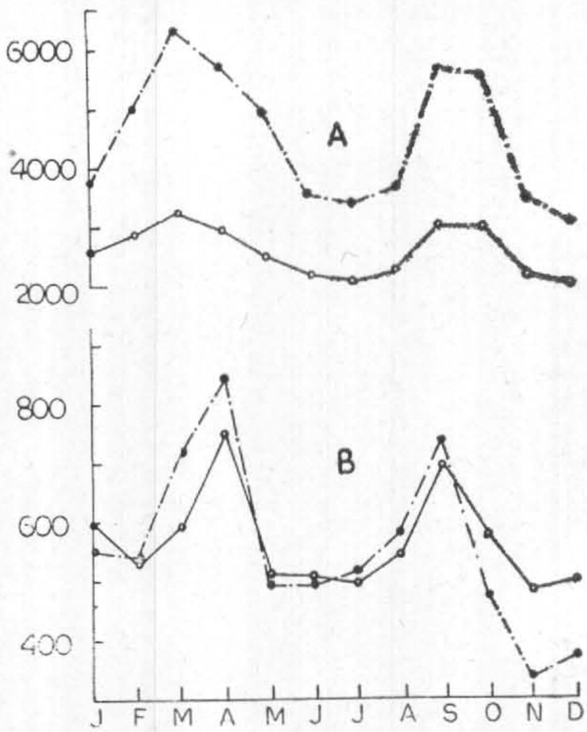

Fig. 4. Annual trends in the sum of A_k and A_p for ID and IQ days (5 days for each month for 1952–54)

A–ID, B–IQ days, A_k – Continuous lines; A_p – Broken lines, Ordinates indicate summed A_k or A_p in units of 2γ

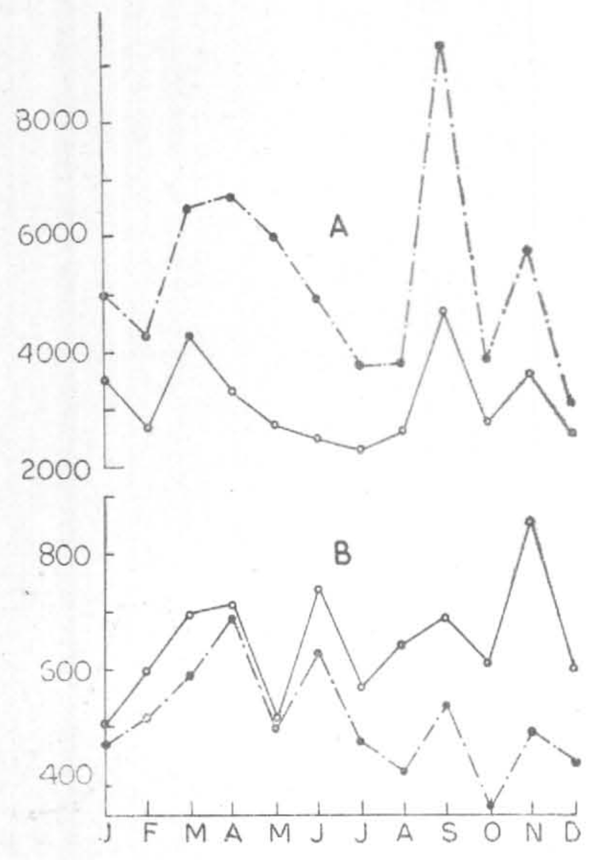

Fig. 5. Annual trends (1955–57)

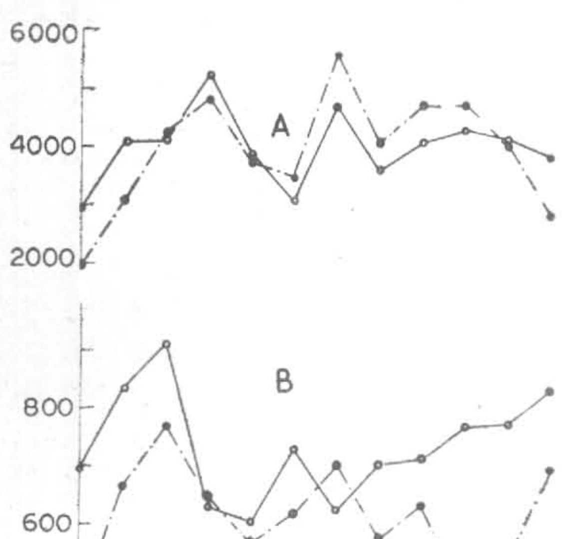

Fig. 6. Annual trends (1958-60)

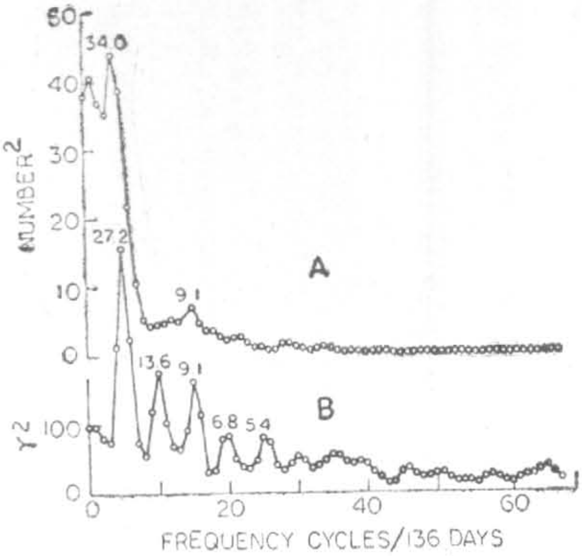

Fig. 7. Power spectra of A_k (B) and daily Zurich sunspot number (A) for 1953

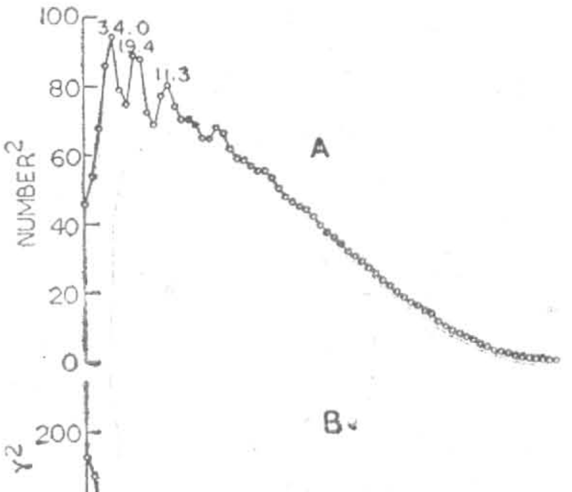

Fig. 8. Power spectra for 1954

flare-active sunspnt regions of 1955-57 and 1958-60 were around 10°. On the assumption that the equinoctial maxima in geomagnetic activity arises from the annual oscillation of the earth's heliographic latitude (maxima of 7·2°N and S in 7 Sep and 5 Mar respectively), it is apparent that disturbances originating from about 34° solar latitude are more likely to cause the semi-annual variation

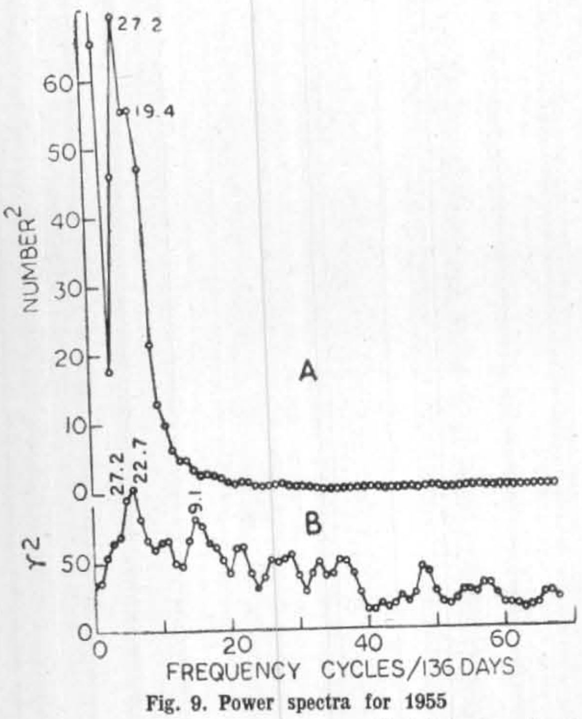

Fig. 9. Power spectra for 1955

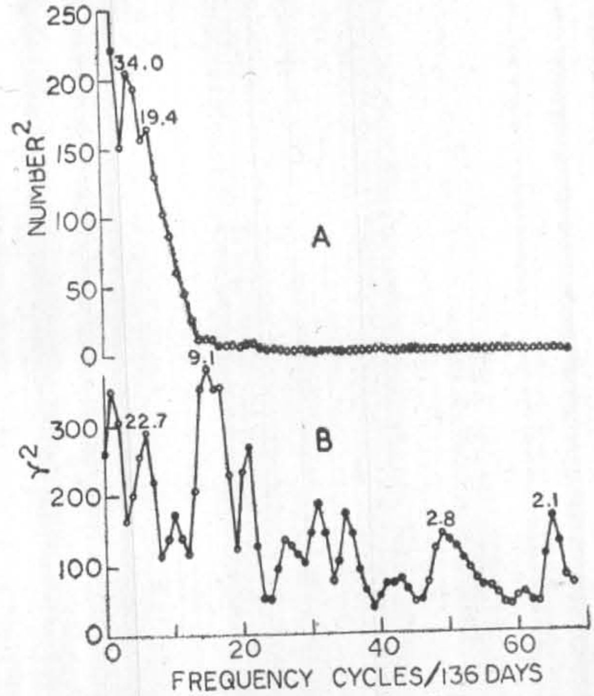

Fig. 10. Power spectra for 1957

· Periods in days shown at prominent spectral peaks

in geomagnetic activity than those emanating from regions around 10°. This must be the reason for the clear semi-annual variation in A_k and A_p seen for 1952-54 for both IQ and ID days.

4. Power spectra

For each of the years 1953, 1954, 1955, 1957 and 1959 (representing sunspot epochs prior to minimum, minimum, after minimum, maximum and after maximum) 365 A_k (Alibag) values were subjected to power-spectrum analysis after the method of Blackman and Tukey (1959). Cosine transforms of the autocorrelation function up to 68 lags were computed and smoothed spectral estimates were then obtained. For comparison the daily sunspot number, R, as given by Waldmeier (1961) for the same years were also similarly analysed. The computations were carried out using CDC 3600-160A Computer of the Tata Institute of Fundamental Research, Bombay. The power spectra obtained for the different years are shown in Figs. 7, 8, 9, 10 and 11.

In 1953, a year with strong recurrent geomagnetic activity, both A_k and R (Fig. 7) show well-defined periodicity close to the solar rotation period. This period for R is, however, greater than that for A_k which is close to 27 days. Sub-harmonics with periods around 13·6, 9·1, 6·8 and 5·4 days appear significant in A_k but not in R, except the one at period 9·1 days.

In 1954, a year of sunspot minimum, peaks at 27·2 and 9·1 days are seen for A_k (Fig. 8) but they are definitely less significant compared to those in 1953. The power spectrum of R for this year does not show any peak close to the 27-day period. What appears to be important is the 34-day period, since its sub-harmonics also happen to be prominent.

In 1955, fairly prominent peaks are seen (Fig. 9) in A_k at periods between 27·2 and 22·7 days and 9·1 and 8·0. days. R has high power for periods between 27·2 and 19·4, days. It is interesting to note that both A_k and R have prominent power for spectral components with solar rotation periods ≤ 27 days. During this year the power spectrum of A_k has many small peaks down to small periods which, unlike in the years 1953 and 1954, appear significant.

The power spectra for A_k for the years 1957 and 1959 (Figs. 10 and 11) are similar to that in 1955, depicting peaks down to small periods. Further, the most prominent peaks (9·1 days in 1957 and 15·1 days in 1959) are not close to solar-rotation periods. In the case of R some power is depicted at high solar rotation period between 34·0 and 27·2 days during 1957. In 1959, on the other hand, there is quite a significant power near 27 days, since the sub-harmonic (13·6 days) of this is also seen in the spectrum.

The clear difference in period for A_k and R in 1953 in respect of their spectral components, corresponding to solar rotation periods, suggest that the average solar latitudes of sunspots and of

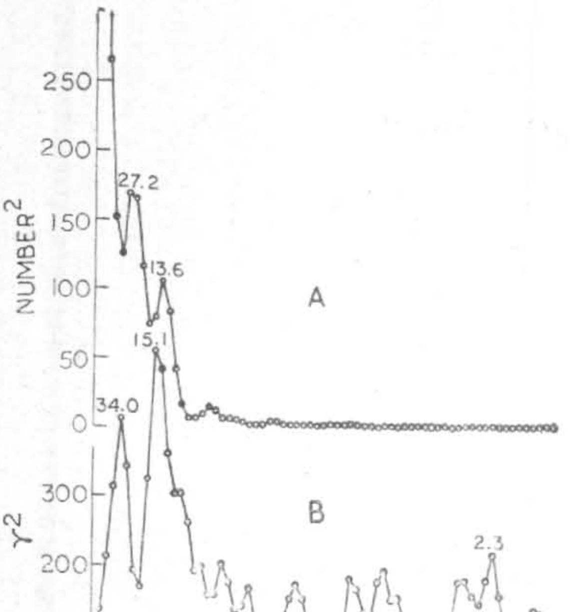

Fig. 11. Power spectra of A_k at Alibag (B) and daily Zurich sunspot number (A) for 1959

Periods in days shown at prominent spectral peaks

the sources of geomagnetic disturbance (*M*-regions) during the year were different. In accordance with the known increase in solar rotation period with latitude (Allen 1962), the smaller period for A_k indicates that the *M*-regions were located at latitudes lower than those of long-lived sunspots. Since the sharp peak for A_k is close to 27 days it may be inferred that *M*-regions were at solar latitudes of about 30°. The peak near 34 days for *R* suggests that long-lived sunspots were at solar-latitudes >30°. These conclusions are in conformity with the finding of Allen (1944) that *M*-regions tend to avoid active centres and that of Waldmeier (1950, 1962) that *M*-regions are very old and dead centres of activity devoid of sunspots. The conclusion regarding location of *M*-regions also agrees with the indication by Naqvi and Bhargava (1954) and Tandon (1956) that regions responsible for recurrent geomagnetic activity are in solar latitudes higher than 7°.2.

The recurrence periodicity for both A_k and *R* during 1955 being about 23 to 27 days is an indication that long-lived sunspots and sources of recurring geomagnetic activity were now in lower and about the same solar latitudes. Evidently, geomagnetic disturbance during the year emanated from persistent sunspot active centres.

The appearance of significant peaks in A_k down to small periods for the years 1955, 1957 and 1959 must be due to sporadic fluctuations in solar wind with sources in active centres with small longitudinal separations from each other. Concentration of power close to infinite period (0 frequency) in the spectra of *R* for the same years is a consequence of trend (increase in *R* during 1955 and 1957 and decrease in *R* during 1959) in the data.

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REFERENCES

Allen, C. W. 1944 *Mon. Not. R. astr. Soc.*, **104**, p. 13.
1962 Astrophysical Quantities, Second Edition, p. 179, The Athlone Press, University of London.
Bhargava, B. N. and Naqvi, A. M. 1954 *Nature, Lond.*, **173**, p. 498.
Bhargava, B. N. and Yacob, A. and Rao, D. R. K. 1968 *Indian J. Met. Geophys.*, **19**, 4.
Blackman, R. B. and Tukey, J. W. 1959 The Measurement of Power Spectra, Dover Publications, Inc., New York.
Gjellestad, G. and Dalseide, H. 1964 *Astrophys. Norveg.*, **9**, 123.
Lassen, K. 1958 *Publ. danske met. Inst. Comm.magn.*, No. 23.
Narayanaswami, R. 1941 *Terr. Mag. atmos. Elect.*, **46**, p. 147.
Mayaud, P. N. 1956 *Ann. Geophys.*, **12**, p. 84.
Nicholson, S. B. and Wulf, O. R. 1955 *J. geophys. Res.*, **60**, 389.
1958 *Ibid.*, **63**, 803.
1961a *Ibid.* **66**, 1139.
1961b *Ibid.* **66**, 2399.
1962 *Ibid.*, **67**, 4593.
Tandon, J. N. 1956 *Ibid.*, **61**, p. 211.
Waldmeier, M. 1950 *Z. Astrophys.*, **27**, p. 42.
1961 The Sunspot Activity in the years 1610-1960, Zurich Schulthess Co., A.G.
1962 *J. Phys. Soc. Japan*, 17, Suppl. A-II, p. 238.