1

G. K. RANGARAJAN

Some features of irregular geomagnetic activity at low latitudes. - Part I: Mean diurnal trends

---

Some features of irregular geomagnetic activity at low latitudes. - Part II: Mean seasonal trends and power spectra

Reprinted from
RIVISTA ITALIANA DI GEOFISICA
E SCIENZE AFFINI
Vol. IV (1977), *N. 1/2, pp. 80-87*

Some features of irregular geomagnetic activity at low latitudes. - Part I: Mean diurnal trends

G. K. Rangarajan (*)

Introduction.

The *K*-index is designed to measure the irregular variations observed on a standard magnetogram at a station and is intended to be a measure of the solar corpuscular radiation based on the intensity of geomagnetic activity. For a station, it represents regional conditions and will include local features such as the systematic diurnal variation at its location (Lincoln, 1967). For Alibag the following are the three-hour disturbance ranges in the horizontal component *H*, corresponding to *K* indices 0 to 9.

$K =$ 0 1 2 3 4 5 6 7 8 9
3 6 12 24 40 70 120 200 300γ

From an analysis of the irregular variations in middle and high latitudes extending upto the polar regions, Stagg (1935) showed that a strong local time dependence was observed over this range of latitudes and the time of peak disturbance exhibited shift with increasing latitude.

Nicholson & Wulf (1955; 1958; 1961 *a*, *b*; 1962) studied the *K*-indices of six low latitude stations well distributed in longitude and showed that apart from a prominent local time variation at each observatory, a universal time component was also present. The nocturnal prevalence of irregulat fluctuations were explained in terms of atmospheric turbulence in the ionosphere. They also showed that the LT component was more pronounced at low values of activity but the amplitude of the LT and UT components were comparable at higher values of activity. The local time component changed apparently with sunspot cycle which was attributed to changes in the lower ionosphere with solar cycle. McIntosh (1959) used the longest available series of *K*-indices for the Potsdam-Seddin-Niemegk Observatory to examine the characteristics of the diurnal and annual variations at that station as a function of the sunspot epochs. A progressive change in the form of the annual variation with rise in level of disturbance was clearly evident. From *K*-indices of 11 observatories distributed in latitude he also showed that the amplitude of semiannual component did not exhibit any marked latitude dependence. In actual force units however, this latitudinal dependence would be implied in view of the contraction in *K*-scale at lower latitudes. Gjellestad & Daleseide (1964) identified summer day time and winter night time maxima in the diurnal variation of geomagnetic activity at several stations in and on either side of the auroral zone. Earlier, Mayaud (1956) had noticed similar local time features at some high latitude stations.

Regular scaling and reporting of *K*-indices from Alibag Observatory (dipole lat. 9.5° N) began from 1946. In this communication we have reported results of an extensive analysis of the *K*-indices from a low latitude station, representative of a region which is well away from both auroral and equatorial electrojet effects. The results of analysis are presented and discussed. It is shown (Rangarajan, 1976) that the response of *K*-indices at Honolulu, San Juan and Alibag to the passage of boundary of interplanetary sector structure are quite alike. Results reported here can, hence be taken to be representative of the geomagnetic activity changes at low latitudes.

The years 1946 to 1974 were classified into three groups representative of

1) Minimum solar activity with mean Annual $Rz = 22$; 1953-1955, 1963-1966,
2) Declining solar activity with mean Annual $Rz = 60$; 1950-1952, 1960-1962, 1971-1974 and
3) Maximum solar activity with mean Annual $Rz = 130$; 1946-1949, 1956-1959, 1967-1970.

Since the increase of sunspot from minimum to maximum is quicker than the rate of decline from maximum and since the years in ascending phase of solar cycle were found to be usually less disturbed than the years of solar maximum or minimum (Bartels, 1963), the few years falling in the ascending part have been assimilated suitably in either of the two categories 1 or 3 above. It is fortuitous that the number of years in category 3 are more than that in other two due to which disturbance effects caused by sporadic solar flares during high activity are appreciably averaged out and persistent features are made more prominent.

Mean diurnal trends.

K-indices for each 3 hour UT interval for each month have been averaged for the corresponding groups of years, according to the following scheme:

$$\overline{K}_{mi} = \frac{1}{D} \sum_{j} [\sum_{n} Kmi_{nj}].$$

(*) Indian Institute of Geomagnetism, *Colaba, Bombay* 400005, India.

The left side signifies the mean K-index for the UT interval i, for the month m.

The summation for n extends over the number of days of the month m, and that for j extends over the number of years according to the classification listed earlier. D is the total number of days so added.

In Fig. 1 are depicted the mean diurnal variation of magnetic activity for each month for the three categories of solar activity. The diurnal pattern is similar for the six months January to March and October to December with maximum corresponding to the 6th interval (15-17 UT). In contrast, for summer months a less well-defined maximum appears in the local day-light hours (2nd or 3rd UT interval). Due to the transitory nature of the diurnal variation between equinoxes and summer, the patterns for April, May and September are not well-defined and the ranges of variation are also comparatively small.

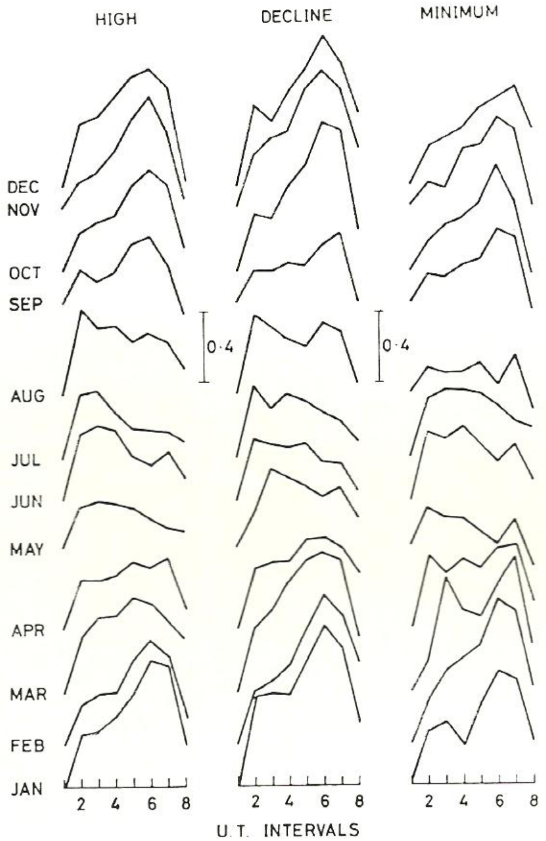

Fig. 1 - *Mean diurnal variation of irregular geomagnetic activity for each month during High, Declining and Minimum phases of solar cycle.*

While the epoch of maximum shows significant change with season, the minimum occurs corresponding to the first or the eighth UT interval always. This is in conformity with the earlier finding of NARAYANASWAMY (1941) and with the local time variation at several stations shown by NICHOLSON & WULF.

The amplitudes and phases of the diurnal and semidiurnal components of the variation for each month, obtained through harmonic analysis, are given in Table I. It can be seen that the phase of the solar activity does not appreciably influence the time of maximum of either the diurnal component or the semidiurnal component. Another interesting feature is that while the epoch of maximum of the diurnal component differs by about 6 hours between summer and winter, the semidiurnal component has its maxima at nearly the same time for all the 12 months. However, in comparison to the diurnal term, the amplitudes are less in most cases.

J- *and* N-*Effects in diurnal trends.*

GJELLESTAD & DALESEIDE (1964) defined two parameters, called *J*-effect (*J* for « Jour ») and *N*-effect (*N* for « Nuit »), to demarcate the two main types of irregular magnetic activity, one having its maximum near local noon in summer and the second having maximum at local night in equinoxes and winter. According to them, the semi logarithmic scale of the *K*-indices are convenient for the study of these effects. The mean annual variations of the *J*- and N-effects can be computed using the definition given by them:

$$2 J = 2 K_n - (K_n - 2 + K_n + 2)$$
$$2 N = 2 K_m - (K_m - 2 + K_m + 2)$$

where K_n, K_m indicate the K-index for the *nth* and *m*th 3-hour interval of the UT day. The two intervals separated by 6 hours on either side can be considered as the most neutral intervals and the effect is measured with respect to their mean as the base. For Alibag (75° E) n should correspond to interval 3 or 4 (near local noon) and m should correspond to interval 6 or 7. With these values, J and N were computed and averaged separately for the three classes of solar activity. The results corresponding to $n = 4$ and $m = 6$, depicted in Fig. 2 show the smoothest annual variation in comparison to the other combinations of n and m (not shown here). The annual variation in the parameter J has a maximum in summer and that of N has a prominent minimum, as is to be expected.

GJELLESTAD & DALESEIDE (1964) were able to trace these effects from Bear Island (dipole lat. 71°) through Tromso (67.1°) and Dombas (62.3°) to Lovo (58°). NICHOLSON & WULF showed that the J effect was present between 18 and 36° N. The J and N effects observed for Alibag conclusively show that these local time features of diurnal variation are global in nature.

Following are some of the main features that can be observed in Fig. 2:

1) The amplitude of the annual variation in N is considerably larger than that observed in J;

2) During minimum and declining periods, a superposed semiannual variation can be clearly seen for the *J*-effect, which is absent during periods of high activity;

TABLE I: *Results of harmonic analysis of mean diurnal trends for each month during three phases of solar activity.* (Amplitudes in 10^{-3} units of K).

Month	Amp.	*Minimum* Phase hrs.	Accounted variance per cent	Amp.	*Decline* Phase hrs.	Accounted variance per cent	Amp.	*High* Phase hrs.	Accounted variance per cent
Diurnal Component									
Jan	205	16.0	58	299	14.9	64	268	15.5	73
Feb	310	15.5	78	321	15.9	82	228	15.1	78
Mar	229	14.6	45	329	14.5	82	201	14.5	63
Apr	134	13.6	40	188	13.9	69	140	13.8	60
May	96	8.5	44	150	12.1	65	106	10.3	75
Jun	137	10.5	54	161	9.6	57	141	9.7	52
Jul	180	9.5	85	136	10.5	58	132	8.5	55
Aug	95	12.1	37	117	11.4	29	128	10.6	40
Sep	159	14.8	56	122	14.7	46	161	13.7	65
Oct	229	14.4	72	321	15.4	79	230	14.9	81
Nov	227	15.0	76	300	15.2	82	316	14.6	84
Dec	236	15.5	76	287	15.3	72	260	14.3	79
Semidiurnal Component									
Jan	168	6.0	39	202	6.1	29	153	6.2	24
Feb	161	6.7	21	123	6.5	12	116	5.8	20
Mar	246	7.3	52	133	6.7	14	127	7.2	25
Apr	136	6.3	45	105	6.2	21	89	6.4	24
May	69	6.2	24	104	7.8	31	40	6.9	11
Jun	85	7.0	21	111	6.0	27	116	7.3	35
Jul	57	6.7	9	70	5.7	13	103	6.6	34
Aug	79	6.3	25	172	5.9	62	121	6.2	36
Sep	124	5.6	35	114	6.2	40	113	4.5	32
Oct	138	5.5	26	152	5.9	17	106	5.9	17
Nov	93	5.5	13	125	6.3	14	129	5.7	14
Dec	128	6.2	22	133	6.1	15	112	6.2	15

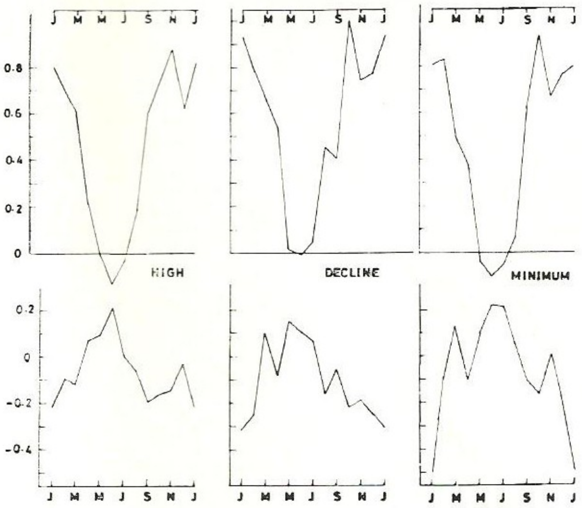

Fig. 2 – *Mean annual variation of* J-*effect (bottom) and* N-*effect (top) at Alibag during High, Declining and Minimum phases of solar cycle.*

3) While the amplitudes of annual variation in N is not related to the phase of the solar cycle the amplitude of J shows an inverse correspondence with solar activity.

This last feature is brought out clearly in Fig. 3 where the amplitude of annual variation of J and N defined as:

$$A_J = (J_5 + J_6 + J_7 + J_8) - (J_1 + J_2 + J_{11} + J_{12})$$
$$A_N = (N_1 + N_2 + N_{11} + N_{12}) - (N_5 + N_6 + N_7 + N_8)$$

are plotted as a function of mean annual Rz for the corresponding group. All the three points A_J lie very close to a straight line of best fit with insignificant departures whereas the three points A_N do not show any sensible relation with Rz. This strongly suggests that the physical causes of the J and N effects observed at low latitudes are not the same. The night-time magnetic activity was associated with the turbulence in ionospheric F layer by NICHOLSON & WULF. The day-time maximum in summer may have its origin in the Universal Time component dependent on ϕ_3 (section on UT component of this chapter may please be seen) having maximum amplitude in June solstice and minimum in December solstice. A solar cycle variation in the local time component was indicated by NICHOLSON & WULF in data confined to either quiet days or disturbed days. They also found that the amplitude of local time variation with day

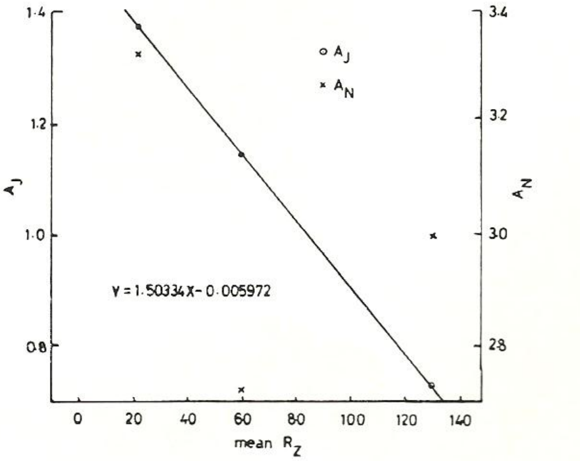

Fig. 3 – *Relation of the amplitudes of* J- *and* N-*effects with relative sunspot number*, R_z. *The equation of straight line of best fit given in the figure pertains to* (R_z, A_J).

time maximum increased with sunspot number whereas the night time maximum observed during disturbed periods decreased with increasing sunspots.

Universal Time Component in Geomagnetic Activity.

Lewis & McIntosh (1953) first proposed a method of deriving the universal time component of diurnal variation in magnetic-activity taking into consideration three parameters which are the angles between dipole axis and

(*i*) the plane of the ecliptic (ϕ_1)

(*ii*) the solar equatorial plane (ϕ_2)

(*iii*) the sun-earth line (ϕ_3).

Since the direction of the earth's rotational axis and of the ecliptic and solar equatorial planes are fixed in space, ϕ_1 and ϕ_2 vary diurnally between limits which are constant throughout the year. Any UT variation depending on ϕ_1 and ϕ_2 can be obtained significantly by considering the difference of the daily variations for periods 6 months apart. ϕ_1 and ϕ_2 attain their diurnal maximum at 1030 UT in March, at 2230 UT in September, 0340 UT in June and 1630 UT in December respectively. In contrast, ϕ_3 undergoes seasonal change which could cause significant changes in geomagnetic activity leading to the semiannual variation in view of the fact that geomagnetic activity would be larger when the sun-earth line is nearer normal to the dipole axis. ϕ_3 is near 90^0 at 0430 UT in June and at 1630 UT in December. At equinoxes it attains 90^0 both at 1030 and at 2230 UT. McIntosh (1959) has given in detail the method of evaluating the UT component in geomagnetic activity depending on either of the three angles. Mayaud (1970) has shown that the a_m index, devised by him to characterise the daily magnetic activity, clearly exhibits the UT component depending on ϕ_3 with maximum at the predicted time.

Arora (1974) analysed the long series of horizontal intensity observations at two low latitude stations and discussed the UT variations observable in the disturbance field. He found that contrary to expectation the ϕ_3 dependent component was larger in magnitude in September than in March. As the analysis of McIntosh (1959) was based on only short span of data and as discussed in previous section we have computed the mean diurnal variation for each month for three levels of solar activity, we derive the universal time component at solstices and equinoxes, compare with earlier results and discuss their behaviour with change in phase of solar cycle.

Here we follow the scheme of analysis of McIntosh to identify the UT components. It must be noted, however, that no direct method is available to reveal a UT component, at a station, uncontaminated by LT effects. Only analysis of indices of magnetic activity of several stations well distributed in longitude (such that $\Sigma \sin \lambda = 0$) can reveal clearly such a component. According to McIntosh (1959), ϕ_1- or ϕ_2-dependent component would have a variation, in « March minus September », with maximum either at 1030 or at 2230 UT. In the « June minus December » curves, ϕ_1-, ϕ_2- and ϕ_3-dependent components are all additive but the main contribution would apparently be from ϕ_3 as the magnetic disturbance dependence on the angles ϕ_1 or ϕ_2 would be small. The « June-December » curve represents entirely residual LT effects. The « March + September » curve is an admixture of residual LT effect and a ϕ_3-component, in UT variations at equinoxes. Their difference should then correspond to a measure of the ϕ_3-component of disturbance at equinoxes.

The diurnal variation in geomagnetic activity, for each of the five cases, are depicted in figure for three levels of solar activity, in Fig. 4 *a*, *b*, *c*, *d* and *e*.

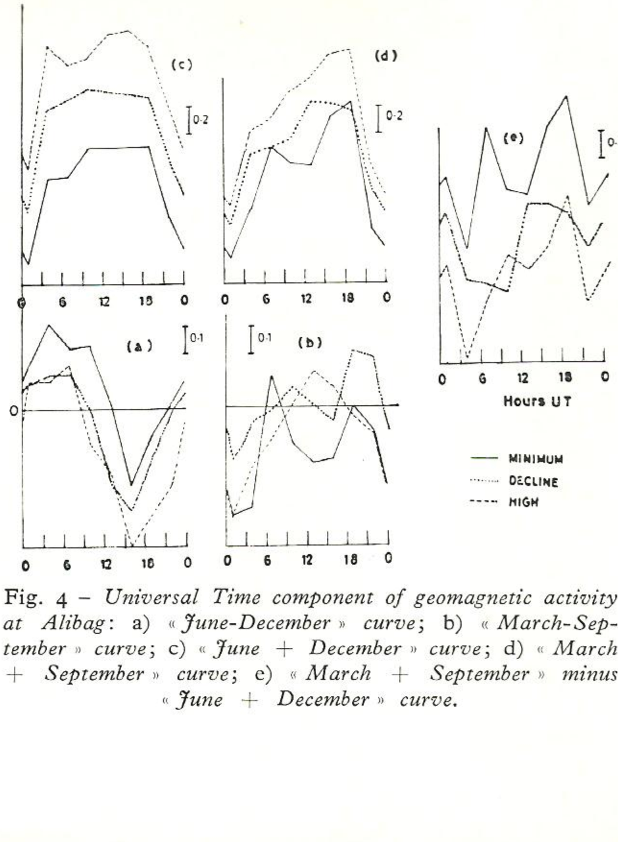

Fig. 4 – *Universal Time component of geomagnetic activity at Alibag*: a) « *June-December* » *curve*; b) « *March-September* » *curve*; c) « *June* + *December* » *curve*; d) « *March* + *September* » *curve*; e) « *March* + *September* » *minus* « *June* + *December* » *curve.*

(i) *June-December curves.*

For all the three categories representing minimum, declining and maximum phases of solar activity, the variational pattern, as seen in Fig. 4*a*, is same with maximum between 3 and 6 UT and minimum between 15 and 18 UT. These times of extrema are in close agreement with the prediction based on ϕ_3 variations and clearly indicate that the ϕ_3-dependent UT component, although contamined by ϕ_1 and ϕ_2 effects, is neither vitiated by sporadic flare activity during solar maximum years nor it is missing during quiet sun years. The amplitude of the diurnal component of this variation is found to be largest during the declining phase of the solar cycle.

March-September curves.

McIntosh (1959) found that no significant UT variation was detected in the *K* daily variation computed as equinoctial differences for 12 observatories and concluded that there was no discernible dependence of magnetic activity on ϕ_1 or ϕ_2. In contrast, Arora (1974) found a distinct ϕ_1- or ϕ_2-dependent component in low latitude disturbance field whose diurnal component had maximum near the predicted time of geomagnetic sunrise. He also indicated a significant ϕ_3-dependent component with unequal amplitudes in the two equinoxes.

Fig. 4*b* shows that when the data were divided into three classes, according to solar activity, the diurnal variation patterns are not comparable among themselves both in amplitude and phase. This is in striking contrast to the June-December variations and leads to the conclusion that no systematic UT variation dependent on ϕ_1 or ϕ_2 could be obtained in the low latitude disturbance field. However, maximum near the predicted time corresponding to geomagnetic sunset (22 30 UT) could be seen during low and declining phases of solar activity.

June + December curves.

For all the phases of solar cycle the residual LT effects, depicted in the curves of Fig. 4*c*, are quite alike and are similar to that shown by McIntosh (1959) (his Fig. 15*a*). The large amplitudes strengthen the earlier remark that LT effects cannot be effectively eliminated at a single station. It may also be seen that the change in solar activity has no appreciable influence on the amplitude of the residual LT variations at Alibag.

March + September curves.

The nature of the diurnal variation depicted in Fig. 4*d* is again similar for all the three categories and is comparable to that obtained by McIntosh. A suggestion of a solar activity dependence in amplitude with maximum in declining phase can be noticed. Similarly a slight displacement of the time of maximum from low to high solar activity is also noticed.

(March + September) - (June + December) curve.

In contrast to the expected semidiurnal variation which should be in phase with the daily variation of ϕ_3 (McIntosh 1959, Fig. 15*d*), diurnal variation with different characteristics of phase are observed for the three categories. Only during periods of low solar activity there seems to be a semidiurnal variation, nearly in phase with ϕ_3 variation. A maximum of geomagnetic activity, near the predicted time of geomagnetic sunset is discernible.

REFERENCES

B. R. Arora (1974): Pageoph, 112, 456. — J. Bartels (1963): Ann. Géophys., 19, 1. — G. Gjellestad & H. Daleseide (1964): Astrophys. Norveg., 9, 123. — R. P. W. Lewis & D. H. McIntosh (1953): J. atmos. terr. Phys., 4, 78. — J. V. Lincoln (1967): *Physics of the geomagnetic phenomena,* Vol. I. — P. N. Mayaud (1956): Ann. Géophys., 12, 84. — P. N. Mayaud (1970): Ann. Géophys., 26, 313. — D. H. McIntosh (1959): Phil. Trans. Roy. Soc. London, *A*251, 525. — R. Narayanaswamy (1941): Terr. Magn. Atmos. Elec., 46, 147. — S. B. Nicholson & O. R. Wulf (1955): J. Geophys. Res., 60, 389. — S. B. Nicholson & O. R. Wulf (1958): J. Geophys. Res., 63, 803. — S. B. Nicholson & O. R. Wulf (1961*a*): J. Geophys. Res., 66, 1139. — S. B. Nicholson & O. R. Wulf (1961*b*): J. Geophys. Res., 66, 2399. — S. B. Nicholson & O. R. Wulf (1962): J. Geophys. Res., 67, 4593. — G. K. Rangarajan (1976): Planet. Space Sci. (in press). — J. M. Stagg (1935): Proc. Roy. Soc. London, A149, 298.

Summary — The local time variation of the irregular geomagnetic disturbances at low latitudes exhibits marked phase difference between summer and winter. Day-time maximum is significant in summer months while in equinox and winter months, the maximum occurs at local night hours. The semidiurnal component, on the other hand, exhibits no phase difference. Increased solar activity does not modify the nature of the diurnal variation of *K*-indices. *J*- and *N*-effects identified earlier at some high latitude stations are shown to exist at Alibag, confirming the effect to be global. From the dependence of *J*-effect on phase of the solar activity and the independence of *N*-effect, it can be firmly concluded that the physical causes for the two phenomena are different. A U.T. component of disturbance diurnal variation due to the change in the angle ϕ_3 is clearly discernible at solstices but not evident in equinoxes. ϕ_1- or ϕ_2-dependent component of disturbance in UT diurnal variation is not detectable.

Some features of irregular geomagnetic activity at low latitudes. - Part II: Mean seasonal trends and power spectra

G. K. RANGARAJAN (*)

In Part I of this paper, the characteristics of mean diurnal variation of the *K*-index at Alibag, representative of low latitude magnetic stations, was discussed. In this note, we derive the mean seasonal trends in irregular geomagnetic variations for individual 3-hour UT intervals. The periodic oscillations of the low latitude *K*-indices are considered from a new approach of spectral analysis of the equivalent daily amplitude *Ak*, for conditions representative of low, declining and high solar activity.

Mean Seasonal Trends.

For each of the eight 3-hour intervals of the UT day, *K*-indices were averaged, for every month covering the three categories of solar activity as shown below:

$$\overline{K^n}_m = \frac{1}{D} \sum_d K^n_{md}$$

where

n: denotes one of the 8 intervals,

m: one of the 12 months and

D: the total number of days for all the years of a class of solar activity.

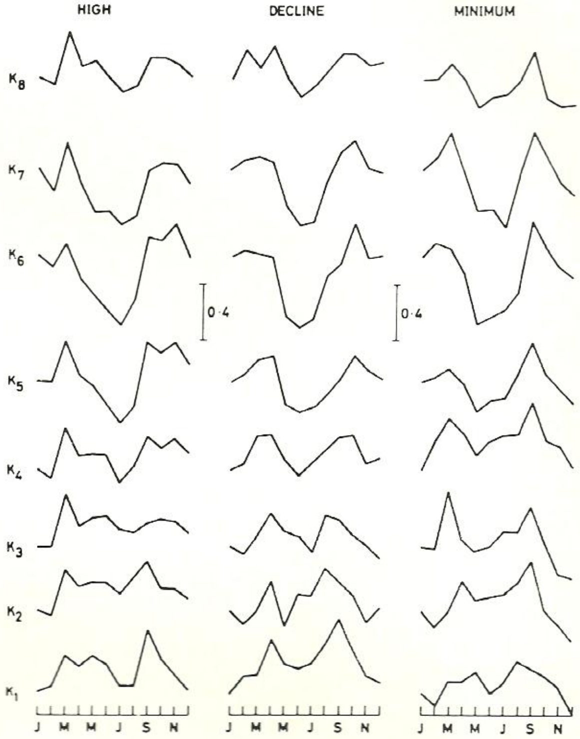

Fig. 1 - *Mean seasonal trends in average magnitude of* K-*index for each 3 hour UT interval during High, Declining and Minimum phases of solar cycle.*

In Fig. 1, the values of $\overline{K^n}_m$ have been graphed for each of the eight intervals for the three phases. It can be noticed that while all the intervals depict similarity of annual variation, there exist substantial differences in the amplitude of variation both with change in local time during a particular phase of the solar cycle and with change in phase of solar cycle for a given local time. To bring out the characteristics of the annual variation, each of these curves has been harmonically analyzed. The amplitudes, the times of maximum computed from the phases and the percentage variance accounted for by the annual and semiannual components are given in Table I. The amplitude of the semiannual component is larger than that of the annual component, a feature only to be expected in seasonal variation of disturbance. However, what is more striking is the fact that the amplitudes of both components show local time variation with maximum near local nights and minimum in day time. This feature is observable during all phases of the solar activity. The amplitudes, however, change with increasing solar activity, with a corresponding increase for the annual component and a decrease for the semiannual component. The epochs of maximum for the annual component, indicate that the variation for the intervals covering 17 to 01 LT are nearly in phase opposition to the other intervals. In contrast, the phase is independent of local time for the semiannual component and interestingly the epoch of maximum tends to shift to latter part of the equinoctial months with increased solar activity.

Local time variation of the amplitude of the annual and semiannual components in horizontal intensity of low latitudes during quiet and disturbed periods has been examined in great detail by BHARGAVA (1972 *a*, *b*) who showed that the semiannual component of the field assumed large magnitude twice a day, first between 7 and 10 hrs LT and again during evening-night sector. During quiet periods, the nighttime component vanished. BHARGAVA *et al.* (1973) concluded that in low latitudes the day-time compo-

---

(*) Indian Institute of Geomagnetism, *Colaba, Bombay* 400005, India.

TABLE I: *Results of harmonic analysis of mean seasonal trends for each UT interval for three phases of solar activity.* (Amplitudes in 10^{-3} units of K)

UT int.	Amp.	*Minimum* Phase		Accounted variance per cent	Amp.	*Decline* Phase		Accounted variance per cent	Amp.	*High* Phase		Accounted variance per cent
Annual Component												
1	136	Aug	10	39	133	Aug	3	41	51	Jul	25	8
2	156	Jul	11	52	113	Aug	31	38	86	Jul	23	33
3	90	Jun	11	14	76	Aug	2	27	47	Jun	28	10
4	86	Jul	17	20	16	Sep	27	1	29	Nov	19	3
5	66	Oct	22	13	123	Jan	3	40	163	Dec	16	38
6	201	Dec	12	41	248	Dec	17	62	248	Dec	12	64
7	119	Jan	4	17	182	Dec	15	45	186	Dec	31	48
8	12	Mar	31	1	73	Dec	23	23	36	Feb	14	5
Semiannual Component												
1	130	Mar	21	36	133	Mar	26	41	145	Apr	6	61
2	94	Mar	15	20	70	Mar	5	15	83	Apr	5	31
3	182	Mar	8	60	94	Mar	29	41	90	Apr	11	38
4	149	Mar	17	60	132	Mar	28	80	117	Apr	17	51
5	156	Mar	10	74	137	Mar	31	50	182	Apr	10	47
6	216	Mar	14	47	172	Mar	23	30	157	Apr	8	26
7	235	Mar	13	67	195	Mar	24	52	151	Apr	5	32
8	146	Mar	3	74	109	Mar	27	50	125	Apr	10	60

nent is largely associated with modulation of *Sq* currents and the amplitudes show significant equatorial enhancement. The secondary component observed in the night hours is associated with the modulation of ring current by disturbance. Considering only the disturbance component of horizontal intensity at each local hour, ARORA & RANGARAJAN (1974) showed that the local time variation of amplitudes of semiannual variation exhibited only a late-evening maximum and they explained the features observed by BHARGAVA as due to the phase opposition of the asymmetric (*SD*) and symmetric (*DR*) parts of the disturbance in the morning hours and phase coherence in the evening hours. In regard to the annual component of horizontal intensity variations, BHARGAVA (1972*c*) established that the day-time component with peak amplitude near 13 hours LT was purely of ionospheric origin and that the component observed during late evening hours was likely to be of magnetospheric origin.

Since, in derivation of the *K*-indices, the *Sq* variations are nearly eliminated, the semiannual variation in *K*-indices as a function of local time should exhibit only the features associated with disturbance as is observed here. The results, shown in Table I, are in close conformity with the results and suggestions above.

Power Spectra of K-*indices.*

To ascertain the nature of periodic oscillations of *K*-indices and the changes with solar activity we have computed power spectra for the three classes as outlined below:

Each 3-hour *K*-index was converted into its equivalent amplitude using the standard table for conversion of K_p to A_p. The mean daily A_k for each year was then spectrally analyzed using Maximum Entropy Method. This is a radically different method and is a relatively novel technique of spectral estimation. Basically, this approach generates a filter based only on the information contained within the available data sample which serves to « whiten » the input data, so that the spectrum of the input data is proportional to the reciprocal of the power response of the filter. In recent years, application of MEM to geophysics has been eminently successful. While there is no defined criterion for the number of prediction error coefficients (PECs), an upper limit of half the data lenght has been recommended by ULRYCH & BISHOP (1975). The Akaike criterion for choosing the number of PECs, recommended by them, fails to be helpful when data contain strong periodic oscillations. Few trials with different PECs revealed that about 30% of the data string provided adequate resolution without introducing many spurious peaks. Hence, for each sample covering one year, 100 PECs were computed and spectral estimates were obtained adopting a bandwidth of (1/1080) cpd (cycles per day). Amplitudes were computed by multiplying the power with the bandwidth and taking the square root (LACOSS, 1971). Amplitude spectra for the different years representing a particular class were then suitably stacked to obtain the mean spectra representative of three phases, low, declining and maximum, of solar activity. The spectra are depicted in Fig. 2. Significant periodicities are indicated in the figure. Significant results emerging from a close examination of the spectra can be summarised as below:

1) A peak corresponding to the semiannual variation is seen for all the three categories (due to less

resolution in the low frequency part the period appears shifted from the expected 183 days); it is most well-defined during minimum phase.

2) Peaks corresponding to the solar synodic rotation period appears as a doublet during high solar activity conditions, is well resolved during declining phase and is sharp and spike-like during minimum activity.

3) The period of oscillation changes from about 31.8 days to 27.0 days from high to low solar activity. This conforms to the known migration of the active centres of the Sun from higher to lower heliographic latitudes with decreasing solar activity.

4) A significant oscillation with period corresponding to 13.7 days is detected in all the three spectra. Even as the period near 27 days varies with changing solar activity, the consistency of the peak at 13.7 days leads to the conclusion of equidistant spacing of active centres on the Sun.

5) While the spectra for declining and minimum phases have significant peaks corresponding only to semiannual oscillation, 27, 13.7 and 9.0 days, the stacked spectrum during high solar activity appears very ragged and depicts many peaks. These features were shown to exist in spectra of individual years' data earlier by Yacob & Rangarajan (1969), who used Blackman-Tukey approach.

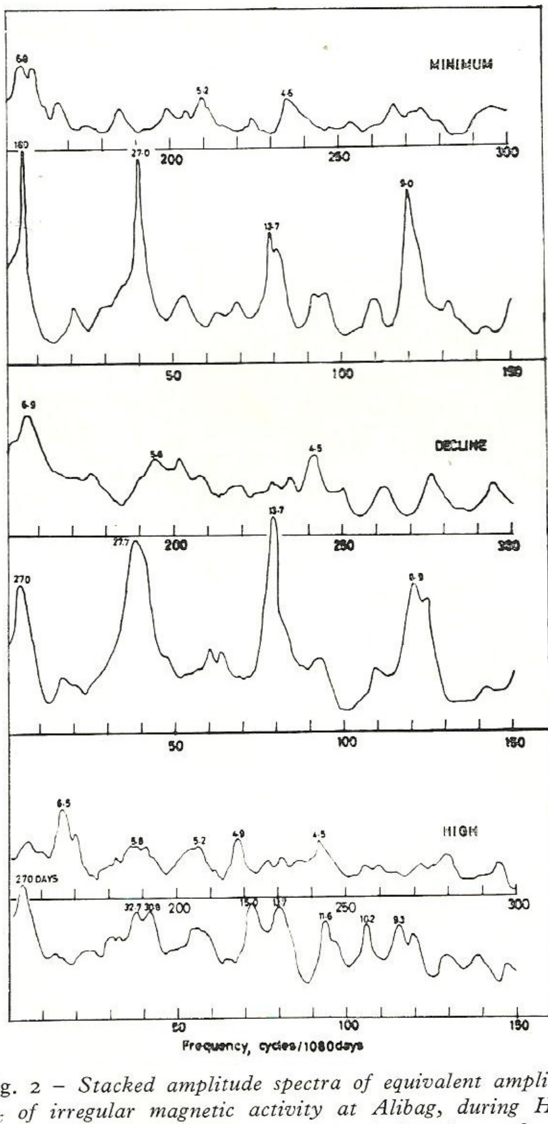

Fig. 2 – *Stacked amplitude spectra of equivalent amplitude* A_k *of irregular magnetic activity at Alibag, during High, Declining and Minimum phases of the solar cycle.*

6) Among the spectral peaks with periods less than 9 days, the one near 7 days appears consistently in all the three. This is probably associated with the geophysical effect of the basic four sector structure of the interplanetary field, as suggested by Abdel-Wahab & Goned (1974). If this period is considered as the third harmonic of the basic synodic rotation signal, the change from 7 days during low solar activity to about 6.5 days during high activity would indicate that the heliographic latitude of the solar source of IMF observed near Earth changes with solar activity. This is in agreement with Wilcox & Colburn (1969) who, from autocorrelation analysis of IMF direction for three years, suggested that the solar source may have been at a higher heliographic latitude near the start of a solar cycle and then declined as the cycle progressed.

Acknowledgement.

The author expresses his grateful thanks to Prof. B. N. Bhargava, Director, Indian Institute of Geomagnetism and to Dr. D. R. K. Rao for careful scrutiny of the manuscript and several useful suggestions.

REFERENCES

B. R. Arora & G. K. Rangarajan (1974): J. Geomag. Geoelectr. 26, 467. — S. Abdel-Wahab & A. Goned (1974): Planet. Space Sci. 22, 537. — B. N. Bhargava (1972): *a*) Planet. Space Sci., 20, 423. — B. N. Bhargava (1972): *b*) Ind. J. Radio Space Phys., 1, 9. — B. N. Bhargava (1972): *c*) Ann. Géophys., 28, 357. — B. N. Bhargava, D. R. K. Rao & B. R. Arora (1973): Planet. Space Sci., 21, 1251. — R. T. Lacoss (1971): Geophysics, 36, 661. — T. J. Ulrych & T. N. Bishop (1975): Rev. Geophys. Space Phys., 13, 183. — J. M. Wilcox & D. S. Colburn (1969): J. Geophys. Res., 74, 2388. — A. Yacob & G. K. Rangarajan (1969): Ind. J. Met. Geophys., 20, 135.

Summary — Study of seasonal variation in *K*-indices as a function of local time indicates that the amplitudes of annual and semiannual components are largest during local night hours. Phases of the annual component between day and night hours are in opposition while the phase of the semiannual component is constant throughout the day. With increasing solar activity a phase shift to the latter part of the equinoctial months in noticed. Results regarding amplitude variation of the annual and semiannual components in irregular geomagnetic activity are in good agreement with those derived from horizontal intensity observations by other researchers. Stacked power spectra for three phases of solar cycle show that the period (in days) of the recurrent disturbance decreases from high to low solar activity. The recurrence is best defined during the minimum of the solar cycle. Equidistant spacing in longitude of active centres is evidenced by consistency of the spectral line at 13.7 days. Periodic oscillation associated with four-sector pattern of the IMF can be inferred from the corresponding periodicity of about 7 days.