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" SPRING COLLEGE ON GEOMAGNETISM AND AERONOMY "

(2 - 27 March 1987)

" Indices of geomagnetic activity "

" Geophysical indices — past, present and proposed "

" On the computer generation of geomagnetic K-indices from digital data "

" Some features of irregular geomagnetic activity at low latitudes: mean diurnal trends and mean seasonal trends and power spectra.

presented by :

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Indices of Geomagnetic Activity

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The globe gets divided into the following major zones (i) polar cap (ii) auroral zone (iii) sub auroral and mid latitude (iv) Low Latitude (v) Equatorial zone. Geomagnetic field variations following solar-wind magnetosphere interaction and magnetosphere-ionosphere coupling manifest in radically different forms at these regions. In addition there exists day/night dawn/dusk differences in the intensity of variations.

It is very difficult to characterise the entire range of geomagnetic field changes by any single or select few indices of activity. There is, therefore, the necessity of devising suitable indices serving specific needs, defining a chosen parameter.

It should be borne in mind that 'indices' do not replace actual data but only provide a 'summary'. The derivation should take into account the 'physics' the index is expected to represent and should not as far as possible be changed with time. If the index is homogeneous in time, one can perform useful statistical analyses.

Geomagnetism dates back to more than four centuries but geomagnetic indices are available only from 1868.

C - Ci - C9 indices

First steps in 1905 conference of the Commission of Terrestrial Magnetism & Atmospheric Electricity. The simplest index.

C - assigned by each observatory for each day from inspection of magnetograms - 0 - quiet 1 - ordinary and 2 - disturbed.

Ci - Mean of the C values supplied by all cooperating observations at the central Bureau in De Bilt, Netherlands.
More delicate classification 0.0, 0.1 ----- 1.9, 2.0-15 obs. in 1906 reached 100 during IGY and later decreased to about 40. Extended backwards upto 1884.

C9 - In 10 steps from 0 to 9 derived from Ci. Main purpose to graphically display 27-day recurrence tendency. The C9 digits are used in varying size and thickness to present a visual picture of the activity on several consecutive days. With the availability of 99 index, Ci computations were discontinued from 1975.

<u>Disadvantages</u> (i) subjective coding (ii) Non-global representation (too many European ots.) (iii) use of UT day not ideal (iv) combination of effects - auroral zone, ring current.

<u>K-index</u>

Bartels is the main initiator. He suggested clear identification of regular and irregular variations in the records and that the time span for the index definition should be sufficiently less than a day. K - stands for Kennziffer' (character in German language). Introduced in 1938 at Niemegk Observatory.

H and D component examined for every 3 hour UT interval (0-3, 3-6, --- 21-24 of 8 intervals each day). Estimate of the range in the interval after elimination of the change due to regular variations like Sq, L. Largest of the two ranges taken as a basis of the index. The scaling is for a class of ranges. 10 classes are defined with symbols 0 to 9.

As the activity level changes with latitude the class of amplitude should change so that the frequency distribution is same at all latitudes.

Some of the lower limit of ranges for defining K index

	0	1	2	3	4	5	6	7	8	9
Honolulu (21.30)		3	6	12	24	40	70	120	200	300
Tucson (32.3)		4	8	16	30	50	85	140	230	350
Fredriksberg (38.2)		5	10	20	40	70	120	200	330	500
Setka (57.1)		10	20	40	80	140	240	400	660	1000
Godhavn (69.2)		15	30	60	120	200	350	600	1000	1500

The figures in bracket give the geographic latitude of the station. Note that the lower limit for K = 9 is 100 times the upper limit for K = 0.

In principle K-index can be derived for any station. However, elimination of regular daily variation (SR) is more difficult in equatorial zone and polar caps. K-index best suited for subauroral zone between 40 and 55^{o} corrected geomagnetic latitude.

Note that in K scaling there is no reference to any zero level (unlike D_{st} index).

Scaling a class of range substantially reduces uncertainty in elimination of SR. For greater magnitudes SR plays insignificant part.

The K scale choice is such that the frequency distribution of different magnitudes closely reflect the actual magnitude of disturbances i.e. the distribution is asymmetric with rare occurrence of intense storms and corresponding K = 7,8,9.

K-index scaling is "subjective" due to the need of elimination of the correct SR. The observer should have true knowledge of day-to-day variability of SR and seasonal change in SR pattern.

Recent attempts at computer-scaling of "K-indices" are summarised in paper by Hopgood (1986). To quote Mayaud "Is science made for computer or computer for science" can we change the definition of K-indices to scale them with computer? The variability of SR can never be approximated accurately by any machine generated quiet day curve. IAGA meeting at Vancouver, Canada in August 1987 will devote sufficient time to look into this aspect.

Ks and Kp index: To derive a 'planetary' index, we should aim to average K-indices of well distributed and suitably located global station. However 3-hr. intervals near geomagnetic midnight are substantially more disturbed than at local noon. his diurnal variation changes with season (see for e.g. G.K. Rangarajan, RIVISTA, Italiana di Geofisica, IV, 80, 1977). The standardisation process is evolved to overcome this problem. From a given sample of K-indices from participating observations for Kp a frequency distribution of reference is made. Conversion tables for each observation for each season for each 3 UT interval is prepared. giving Ks value in the ranges as below:

0 - 1/6	1/6 - 3/6	3/6 - 5/6	5/6 - 7/6	7/6 - 9/6	
0_o	0_+	1-	1_o	1_+	etc.

Each K-index is converted into Ks index using the tables and averaged to get Kp. Ks and Kp are almost continuous variables between 0.0 and 9.0. Symbols 0_o and 9_o comprise only 1/6 the full interval.

It is to be noted that the conversion tables are weighted greatly in favour of night time which is expected to represent better the effect of irregular variation due to corpuscular radiation.

Stations contributing to Kp-index are listed in Table. Note that there is only one southern hemisphere station and most of the other are in Europe.

a_p and A_p index : K_p has a quasi-loganthmic relation with the range. It, therefore, becomes difficult to compare two days with same $\sum K_p$. For e.g. a_p 1111 1111 and 0000 0008. A linear index directly in terms of the magnitude corresponding to mid-class range was defined with the following conversion table:

K_p	0_o	0_+	1-	1_o	1_+	2-	2_o	2_+	3-	3_o	3_+	4-	4_o	4_+	5-	5_o	5_+
a_p	0	2	3	4	5	6	7	9	12	15	18	22	27	32	39	48	56
K_p	6-	6_o	6_+	7-	7_o	7_+	8-	8_o	3_+	9-	9_o						
a_p	67	80	94	111	132	154	179	207	235	300	400						

Unlike different lower limits for $K = 9$ for individual K-indices the conversion table for a_p from K_p is unique. There is no documented reason for the choice of 400 for the highest value except it corresponds to the first proposed value for Niemegk by the originator of the index.

The average range of the most disturbed component is given by 2 a_p i.e. a_p index is in units of 2 nT.

The average of the 8 a_p values for a day gives the daily equivalent amplitude index Ap .

<u>C_p index :</u> It is similar to C_i index based on a_p values. Ranges from 0.0 to 2.5. Let $\Sigma a_p = u$. Then the following conversion table gives the C_p index:

u	22	34	44	55	66	78	90	104	120	139	164
C_p	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
u	190	228	273	320	379	453	561	729	1119	1399	
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	
u	1699	1999	2399	3199							
	2.1	2.2	2.3	2.4	2.5						

C_p is so defined that the frequency distribution of C_i and C_p are nearly same (based on 10 yr. sample 1940-49). Note that C_9 index can also be represented in terms of C_p index as shown earlier for C_i.

<u>Classification of International Quiet and Disturbed Days</u>

The days of each month are ordered according to three criteria (i) value of ΣK_p (ii) $\Sigma K_p 2$ and (iii) greatest of the 8 K_p values. The average of these orders are taken. The five days with highest mean order number are the most disturbed days and the days with the lowest mean order numbers are the five quietest days in the month. These are called International Quiet and Disturbed Days (IQ and ID).

The major drawback in this scheme is that they will not represent equal disturbance or calm in different months since they depend on the actual percentage of disturbance or quietness within the month. A day is considered as not being really quiet if A_p 6 or if one $K_p \geqslant 3_0$ or 2 $K_p \geqslant 3-$. When $A_p < 20$, the I.D. day is not really disturbed.

<u>a_m, a_n, a_s, K_m, K_n, K_s indices</u>

In view of the nocturnal bias and weightage in favour of northern hemisphere and particularly European zone of the K_p index Mayaud defined these indices representing global (m), northern (n) and southern (s) hemispheres. As with a_p and K_p, they represent equivalent amplitude and quasilogarithmic scales respectively.

A careful choice of groups of observatories in different longitude sectors in each hemisphere close to 50° corrected geomagnetic latitude is made. Present set up has 5 groups in northern and 3 in southern hemisphere. Scheme of conversion from the observed amplitude to equivalent a_n a_s a_m and derived K_n K_s and K_m are shown in the figure.

The scale chosen for deriving K_n, K_s and K_m from equivalent amplitude is also based on the Niemegk scale used for K_p to a_p conversion.

A_a index :

Longest available index has been C_i from 1884. There was suggestion to go back in time but only 3 observations were available. Instead of extending C_i Mayaud suggested using K-indices of just two stations one in each hemisphere at nearly the same geomagnetic latitude and separated by about 12 hours in longitude such a pair is called 'Anti-Podal'. Greenwich and Melbourne constitute such a pair (though the longitude separation is only about 10 hours). Both are close to the ideal subauroral zone location of 50°.

From the K-index of each station, converted to mid-class range we get the average which is denoted as A_a. This index is highly reliable when longer duration averages are considered (24 hr, 48 hr. etc.).

Truly quiet days as derived from a_a index are available in IAGA Bull. No. 33 and 39.

AE, AL, AU and AO indices

These are designed to provide quantitative estimate of geomagnetic activity in the auroral zone due to enhanced ionospheric currents along the auroral oval. These were designed and developed by Davis and Suguira (JGR 71, 785, 1966).

The index is ideally the total range at any instant of time of the deviations from quiet day values of H around auroral oval.

Definition and computation

Digital magnetic data (1 or 2.5 min averages) of H at several chosen locations in the auroral zone well distributed in longitude is the input. A base level, calculated by averaging all the I.Q. days data for a station, is substracted from each instantaneous value. For a given UT, the largest of these departures gives AU and least of them give AL index.

The difference (Au-AL) gives the AE index and the mean value (AU + AL)/2 giving the AO index. It is presumed that AU is indicative of the strength of the eastward electrojet and AL that of the westward electrojet. AE represent the overall activity of the electrojet and AO as a measure of the equivalent zonal current.

The stations should ideally lie just below the instantaneous auroral oveal around local geomagnetic midnight.

The Eastward electrojet strengthens during local afternoon and evening hours and westward jet during local late evening/early morning. The auroral indices are very useful in following development of magnetospheric disturbances especially the substorms, which are significantly local-time dependent..

The AU, AL and AE data can be graphically presented by superposing all the magnetograms of the network (coincident in UT with same ordinate scale) and drawing the upper and lower envelopes of the superposed curves.

In contrast to K-index, AE sampling rate has to be much higher and is therefore basically not a code but data itself.

AE indices have been used in several correlative studies with IMF and solar wind parameters. However the derived index is not really ideal for the following reasons:

(i) Unless the one of the stations is located just below the strongest segment of either electrojets the derived data Au or AL will be under estimated.

(ii) The auroral oval moves dynamically and it is not possible to distinguish between movement away from (toward) a station or weakening (strengthening) of the electrojet.

(iii) The magnetic meridian along which H is recorded is not necessarily normal to the direction of auroral electrojet which are on the average parallel to lines of equal corrected geomagnetic latitude.

(iv) The average latitude of eastward electrojet is a few degrees lower than that of westward electrojet.

(v) The quiet-day base level is derived on a month-to-month basis leading to possible discontinuity.

(vi) By definition Au should not be negative but if equatorial ring current is intense we may have negative Au.

(vii) During quiet conditions, contamination of the indices by regular daily variation possible.

(viii) Large gaps in the longitudinal distribution of the present network. When substorm currents are highly localised, the AE indices may not show them. In other words, low AE does not rule out presence of substorm while large AE is definite indication of substorm.

However, the advantages far outweigh the disadvantages:

(i) It can be derived for any selected interval for any specified sampling rate

(ii) A quantitative index almost directly related to the physical processes producing the observed variations

(iii) Relatively simple to derive, is objective and suitable for computer processing

(iv) Can be used for individual events or on a statistical basis.

(v) By definition Au should not be negative but if equatorial ring current is intense, we may have negative Au

(vi) During quiet conditions, contamination of the indices by regular variation is possible

(vii) Large gaps in the longitudinal distribution of the present network when substorm currents are highly localized, the AE indices may not show them. In other words, low AE does not rule out presence of substorm while large AE is definite indication of substorms.

Dst index

One of the most systematic features of geomagnetic disturbance is the depression below quiet levels m following a storm sudden commencement at low latitudes. This is brought about by the zonal equatorial ring current and Dst index is a measure of the intensity of this zonal current. The axialls symmetric part of the ring current is independent of local time.

The total disturbance field D can be considered as a sum of the symmetric (UT dependent) part and a local time dependent part.

$$D = Dst + Ds$$

If one has a uniform distribution of stations in longitude all approximately located at the same dipole latitude, the average magnetic field values (coincident in UT) will not have any local time component. It is not necessary to have a close network as for AE index. The Dst index can be derived from few low latitude stations. However, if we need continuous data of Dst then base level will have to be critically maintained, unlike K-index where reference level is immaterial.

Derivation of the Index

The station chosen should be at low latitude away from the dip equator and the influence of auroral electrojet currents. Table gives present network used in deriving Dst index. The gap between Hermanus and Kakoka is filled by Alibag in recent times.

In deriving the index, the long term secular variation is eliminated from the data by suitable polynomial fit to annual mean values on quiet days of the observatory data. The quiet-day variation S_R is eliminated computing a statistical Sq for each month.

From a series of monthly Sq for a given year a Fourier series Expansion is computed as

$$\sum_{n=1}^{6} \sum_{m=1}^{6} A_n^m \cos(mT + \alpha_m) \cos(nM + \beta_n)$$

where T is local time and M is the month. The 48 unknowns are derived by least squares fit to the 12 x 24 hourly value data.

From this expression one can now synthesize Sq variation which can then be subtracted from original observed value.

The Dst cannot describe quantitatively the strength of the equatorial ring current. This is due to paucity of station from which it is computed coupled with the tendency of the ring currents to be asymmetric during all but recovery phase of negative storm.

Dst detects all magnetic storms. Within about 2 hour Dst should be able to identify the onset and termination of the main phase of a magnetic storm. It cannot reveal the presence of individual substorms.

Present Dst Computation

The reference level is obtained by expanding the baseline value in a power series in time where coefficient for the term upto quadratic are tetermined by method of least square and annual mean of H for I Q days of each month are used. In this manner secular variation is removed. Sq contribution is now determined for each station as described in the IGY method. However subtraction of Sq is made for each station. Non-cyclic change in Sq is removed by assuming it to be linear from local midnight to local midnight. (During IGY UT was used).

For station j,

$$Dstj = Hobs, j - Sqj - Ho, j$$

where first term on right is the observed data, second is the corresponding quiet day field and third is the secular variation correction.

The Dstj values are then averaged. As Dst magnitude varies with latitude, the values are normalized to obtain the value of the ring current effect at the dipole equator. This is done by multiplying each value by 'Sec θm' where θm is the mean geomagnetic latitude of the stations. The normalised values are called 'Equatorial Dst values'.

Advantages:

The index can be computed almost as a continuous variable, even during quiet conditions.

Provides a good manner to eliminate irregular fluctuation in regular daily variation.

Graph of Dst values enables one to identify significant disturbances.

Disadvantages:

Though it is meant as a measure of equatorial ring current, all UT dependent effects such as magnetospheric compression effect (SSC, Initial phase) and any variation with zonal component will contribute to the index.

The need for maintenance of base level makes it difficult to alter the network of stations even if considered necessary without breaking continuity.

Day-to-day variability in S_R can never be approximated by the fourier Expansion for quiet day variation. However, when disturbance is large S_R contamination is minimized.

By definition Dst should not have positive values. However SR contamination and compressional effects do produce positive Dst.

The ring current is known to be asymmetric and strength of the asymmetry increases with enhanced disturbance. It is difficult to completely eliminate this local time contamination by the few stations chosen for Dst.

The present networks are dominantly in northern hemisphere. Due to the known annual variation in the mean latitude of ring current, an ideal network should have equal representation in N and S hemispheres.

Note : In contrast to AE index, Dst is usually given as hourly values, as the ring current changes are slower in comparison to substorm features.

IMF polarity index (A/T Index)

The weak solar photospheric magnetic field is carried away by the expanding solar corona. The magnetic field lines are frozen into the solar wind plasma and move with it. Near the earth, the observed magnetic field appears to be well organised either being directed away from or toward the Sun along the Archemedian spiral. The average direction remains same for several days and changes abruptly to be constant again for several days. These patterns define the sector structure of the Interplanetary Magnetic Field.

In situ observation of IMF could provide the direction of the IMF Bx and By component (X directed along Earth-Sun line and Y the E-W component in the ecliptic plane). However, there are two disadvantages (i) Spacecraft observations are available only from 1963 (ii) whenever the spacecraft enters the magnetosphere there could be no IMF data.

Svalgaard and Mansurov independently discovered that the diurnal variation of the vertical component of the magnetic field in polar cap responded systematically to the azimuthal (E-W) component of the IMF.

Comparing in situ IMF data and polar cap magnetograms, it was found that when the Earth lies in an 'Away (forward) sector Z perturbation is directed away from (forward) the Earth. It became therefore possible to infer the polarity of IMF from the following thums rule. If Z magnetogram near the invariant pole for a day shows a broad positive (negative) perturbation particularly between local and magnetic noon then the day can be inferred to have an associated Toward (Away) polarity of IMF.

Since magnetograms from polar cap station like Thule, Vastok and Resolutes Bay are available from 1947 onwards, the polarity of IMF could be inferred and indexed as below:

A - when associated with 'Away' sector (By > 0)

Mixed - when no clear signature (By < 0).

Svalgaard (1972) showed that at little lower latitudes, the H component appears to show the polarity effect and used magnercgrams of Godhavni H to derive the polarity backwards from 1926. However, the accuracy was far less.

The success rate of inference is very high but has a significant seasonal dependence. Inference of polarity is more accurate in summer (> 90%).

By choosing two polar cap stations one in each hemisphere the success rate is increased. Presently the Inferred IMF polarity is deriven from Vostok Antarctic station and Thule. The effect is visible at Vostok in the first half of the universal day and at Thule in the second half of the day and is published regularly in PROMPT REPORTS of "Solar Geophysical Data".

Acknowledgement:

These notes have drawn heavily from the monograph "Derivation, Meaning and use of Geomagnetic Indices" by P.N. Mayaud and from article entitled "Auroral electrojet Magnetic Activity Indices (AE) for 1970" by J.H.Allen.

In addition several reviews and papers on the topic have been copiously utilised.

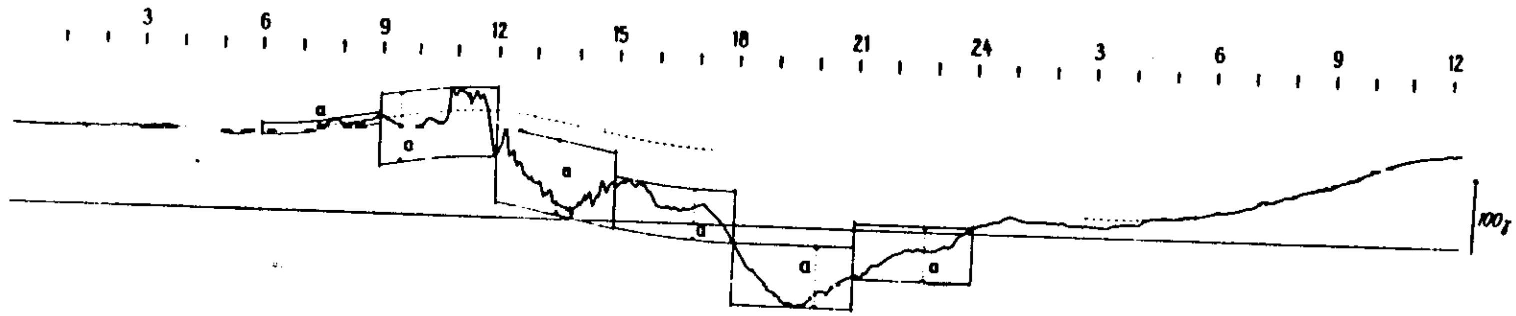


Fig. 9. A record of the *H* component at Guam, a low-latitude station. For some of the 3-h intervals the range *a* corresponding to the definition of the *K* index (i.e., difference between the extreme of the variation within the interval after eliminating the S_R) is indicated [after *Mayaud*, 1967*a*]. Let us note that this figure also illustrates the process of the elimination of the regular variation S_R when scaling the *K* indices. Assuming that the variation S_R from 6 to 18 hours may be estimated to be the dashed line (this estimation is, however, probably very doubtful because it would mean that the intensity of the S_R would be much smaller on that day than on the following day [see *Mayaud*, 1967*a*, pp. 38–59]) one draws within each 3-h interval two lines parallel to this assumed S_R. The upper one passes through the observed maximum, and the lower one through the observed minimum. The distance between these lines corresponds to the range of the irregular variations after subtraction of the assumed variation S_R. Although similar curvilinear rectangles are not drawn during the following day when the assumed S_R is almost identical with the observed curve, it well appears that no elimination of the S_R would give values of *K* almost identical with those obtained during the storm. This clearly illustrates the necessity of the elimination of this regular variation. See the atlas of *K* indices [*Mayaud*, 1967*a*] for the practical way for an observer to scale the *K* indices (in particular, it does not necessitate the drawing of each upper and lower lines within each interval).

The Eleven Observatories of the *Kp* Network

	Geographical Location						
	Latitude	Longitude	Λ	λ	δ	*L*	*l*
(1) Meanook	54°37′	246°40′	61.8°	62.5°	6.2°	1360	1500
(2) Sitka	57°04′	224°40′	60.0°	59.8°	8.4°	1020	1000
(3) Lerwick	60°08′	358°49′	62.5°	58.9°	9.5°	920	1000
(4) Agincourt	43°47′	280°44′	55.1°	57.2°	12.8°	700	600
(Ottawa, 1968)	45°24′	284°27′	56.8°	58.7°	11.3°	790	750
(5) Eskdalemuir	55°19′	356°48′	58.5°	54.3°	13.7°	660	750
(6) Rude-Skov	55°51′	12°27′	55.8°	52.8°	15.2°	600	600
Lovö, 1954	59°21′	17°50′	58.1°	52.9°	12.4°	720	600
(7) Cheltenham	38°44′	283°10′	50.1°	52.1°	17.8°	530	500
(Fredericksburg, 1956)	38°12′	282°38′	49.6°	51.8°	18.4°	520	500
(8) Wingst	53°45′	9°04′	54.5°	50.9°	16.9°	550	500
(9) Witteveen	52°49′	6°40′	54.1°	50.2°	17.5°	540	500
(10) Abinger	51°11′	359°57′	54.0°	45.7°	18.2°	520	500
(Hartland, 1957)	51°00′	355°31′	54.6°	50.0°	17.7°	530	500
(11) Amberley	−43°05′	172°43′	−47.7°	−50.0°	17.7°	530	500
(Eyrewell, 1978)	−43°25′	172°21′	−47.8°	−50.2°	17.3°	540	500
Toolangi, 1970	−37°32′	145°28′	−46.7°	−48.0°	18.5°	510	500
(Canberra, 1979?)	−32°39′	149°30′	−43.8°	−45.2°	24.0°	420	450

A change of site is indicated by listing the new observatory in parentheses. For Rude-Skov and Amberley another observatory was associated from the date given with the original station. It is indicated below the latter. Λ and λ are the dipole and corrected geomagnetic latitudes. *L* is the lower limit for $K = 9$ computed from the angular distance δ to the auroral zone and *l* is the lower limit used for the *K* scalings. All observatories are listed with respect to the λ values.

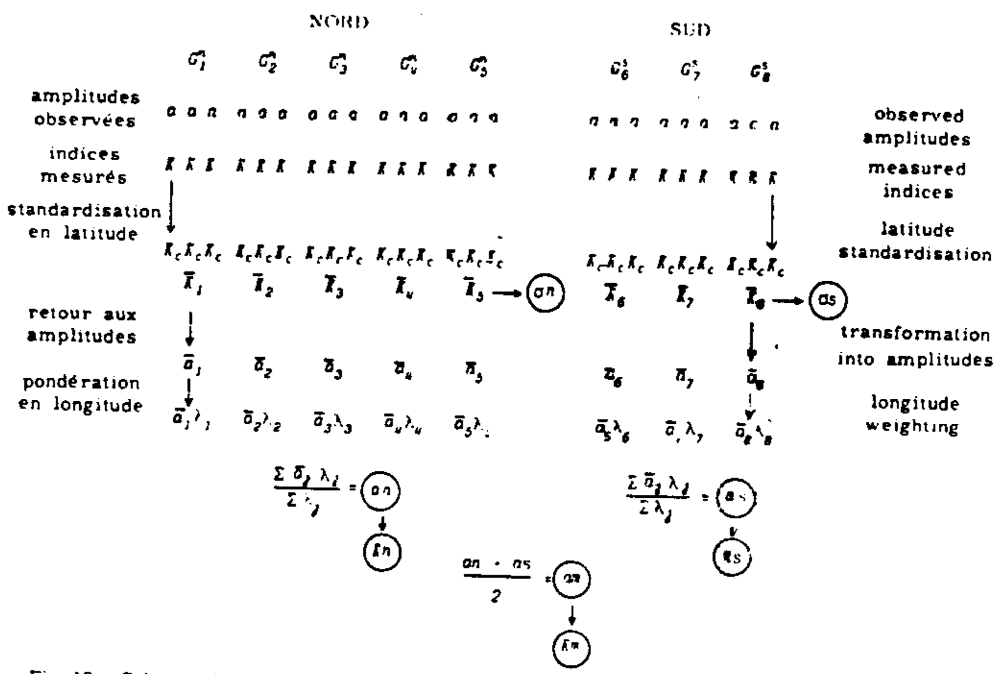


Fig. 19. Scheme of the *am* range index computation. The symbols surrounded by a circle are those which are tabulated in the IAGA yearly bulletins [after *Mayaud*, 1968]. Let us note that, after consultation of the Working Group on Geophysical Indices, the group G_4′ was split up into two groups as of January 1, 1979; see the text p. 65.

Table 1. List of AE(12) stations.

Observatory	Abbreviations		Geographic		Geomagnetic	
	IAGA	WDC-A	Lat. (°N)	Long. (°E)	Lat. (°N)	Long. (°E)
Abisko	ABK	AI	68.36	18.82	66.04	115.08
Dixon Island	DIK	DI	73.55	80.57	63.02	161.57
Cape Chelyuskin	CCS	CC	77.72	104.28	66.26	176.46
Tixie Bay	TIK	TI	71.58	129.00	60.44	191.41
(Cape Wellen)	CWE	UE	66.17	190.17	61.79	237.10
Barrow	BRW	BW	71.30	203.25	68.54	241.15
College	CMO	CO	64.87	212.17	64.63	256.52
Yellowknife	YKC	YEK	62.40	245.60	69.00	292.80
Fort Churchill	FCC	FC	58.80	265.90	68.70	322.77
Great Whale River	GWC	GWR	55.27	282.22	66.58	347.36
Narssarssuaq	NAQ	NAS	61.20	314.16	71.21	36.79
Leirvogur	LRV	LR	64.18	338.30	70.22	71.04

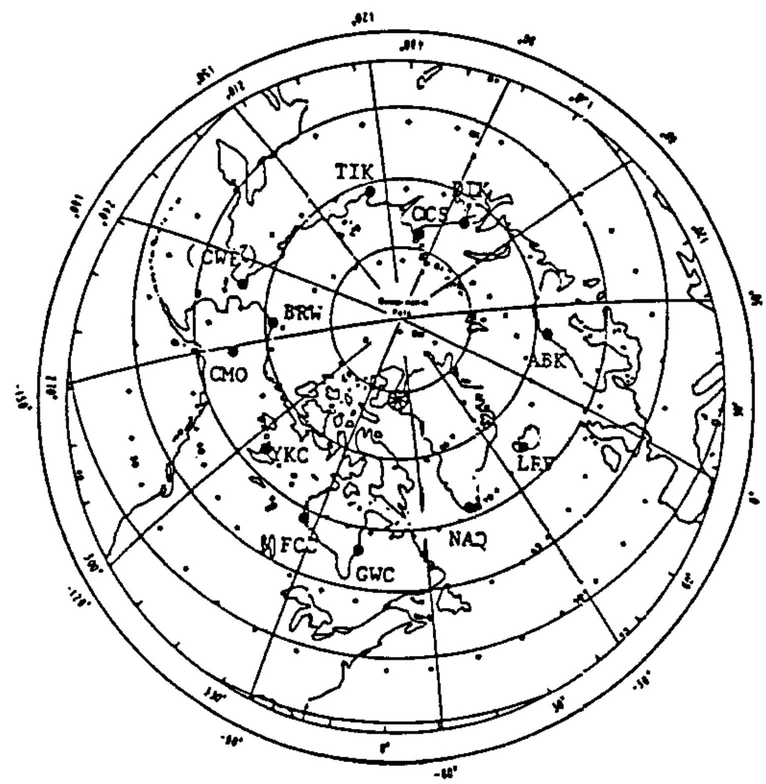
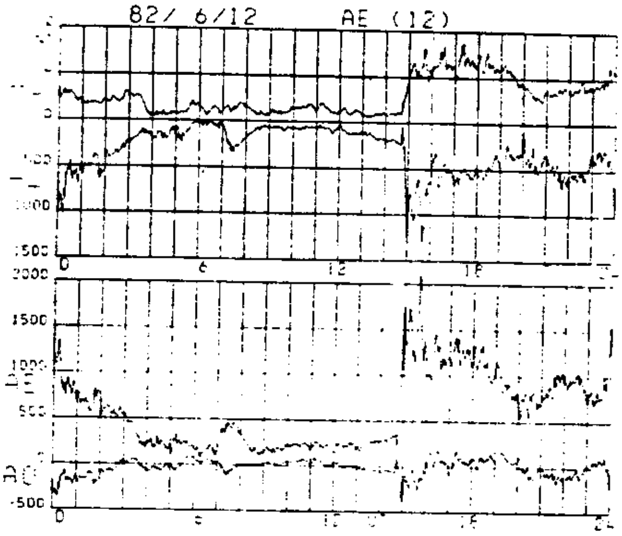


Fig. 1. Distribution of AE(12) stations.

Geographic latitude is indicated by the concentric circles of solid lines. Geomagnetic latitude is indicated by the numbered concentric circles formed by + signs. Geographic longitude is given by the outer circle of numerical values with meridians shown as solid lines every 30°. Geomagnetic longitude is given by the inner circle of numbers and the border of hash-marks at 10° intervals.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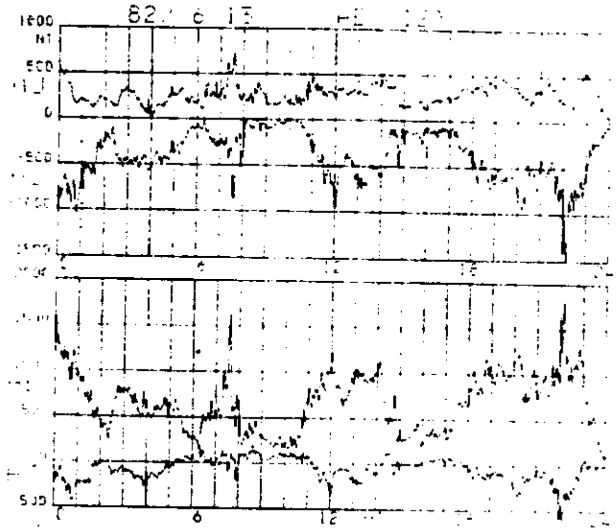
-1500
0 6 12 18 24
2000
1500
AE
500
AO
-500
0 6 12 18 24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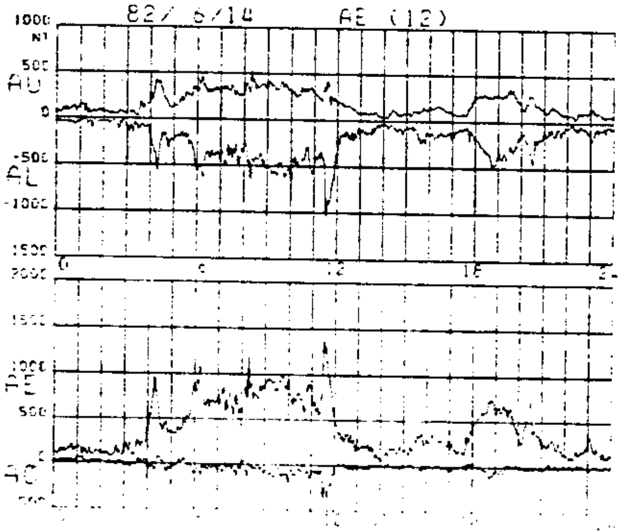
82/ 6/14 AE (12)
1000
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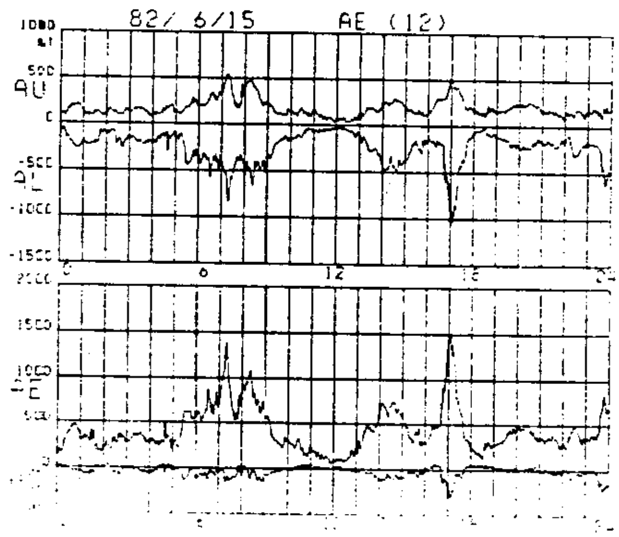
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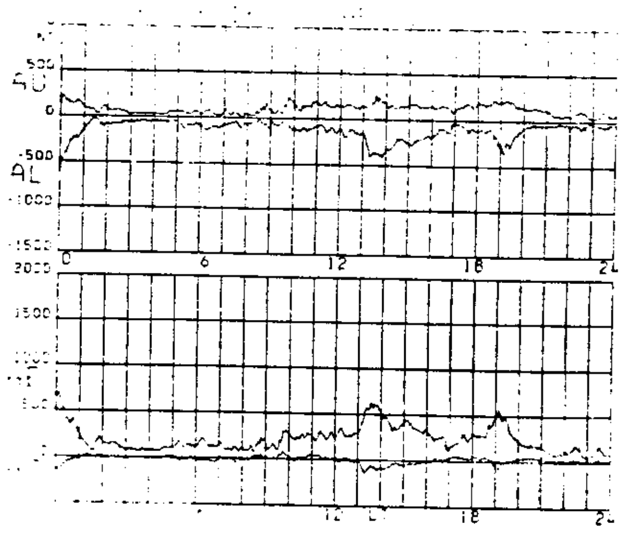
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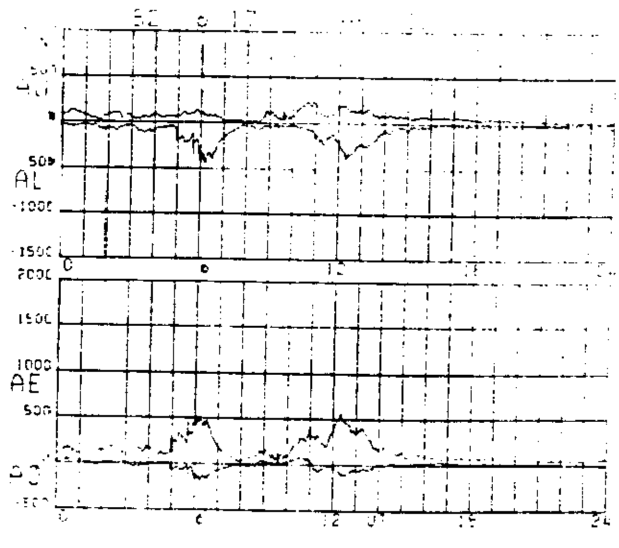
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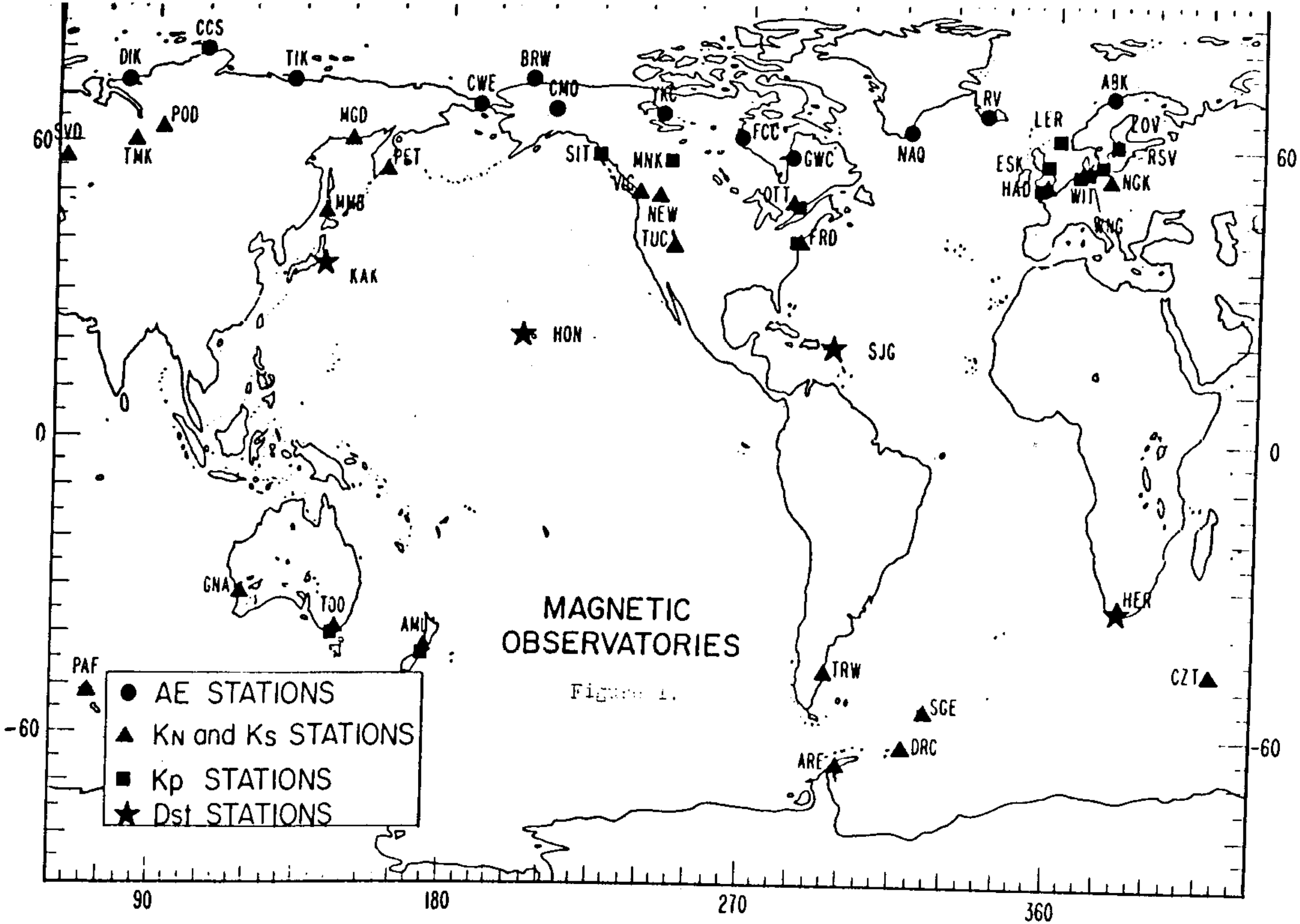
MAGNETIC
OBSERVATORIES
AE STATIONS
KN and KS STATIONS
Kp STATIONS
Dst STATIONS
DIK
CCS
TIK
CWE
BRW
CMO
YKC
FCC
GWC
NAQ
RV
ABK
LER
ZOV
RSV
ESK
HAD
WIT
NGK
VIC
NEW
TUC
OTT
FRD
SIT
MNK
SVD
TMK
POD
MGD
PET
MMB
KAK
HON
SJG
GNA
TOO
AMU
PAF
TRW
SGE
DRC
ARE
HER
CZT
60
0
-60
90
180
270
360

Figure 1.

TABLE 35. Dipole Coordinates, Cosine of the Latitude Λ, Distance Δ Between Two Consecutive Stations, and UT Hour *h* Corresponding to 1800 in Local Dipole Time

	Dipole Coordinates				
	Φ	Λ	cos Λ	Δ (long), h	*h*
HO	266.4°	21.0°N	0.93		4.9
				6.5	
SJ	3.2°	29.9°N	0.87		22.4
				5.1	
HR	80.3°	33.3°S	0.84		17.3
				8.4	
KA	206.0°	26.0°N	0.90		8.9
				4.0	
HO	266.4°	21.0°N	0.93		4.9

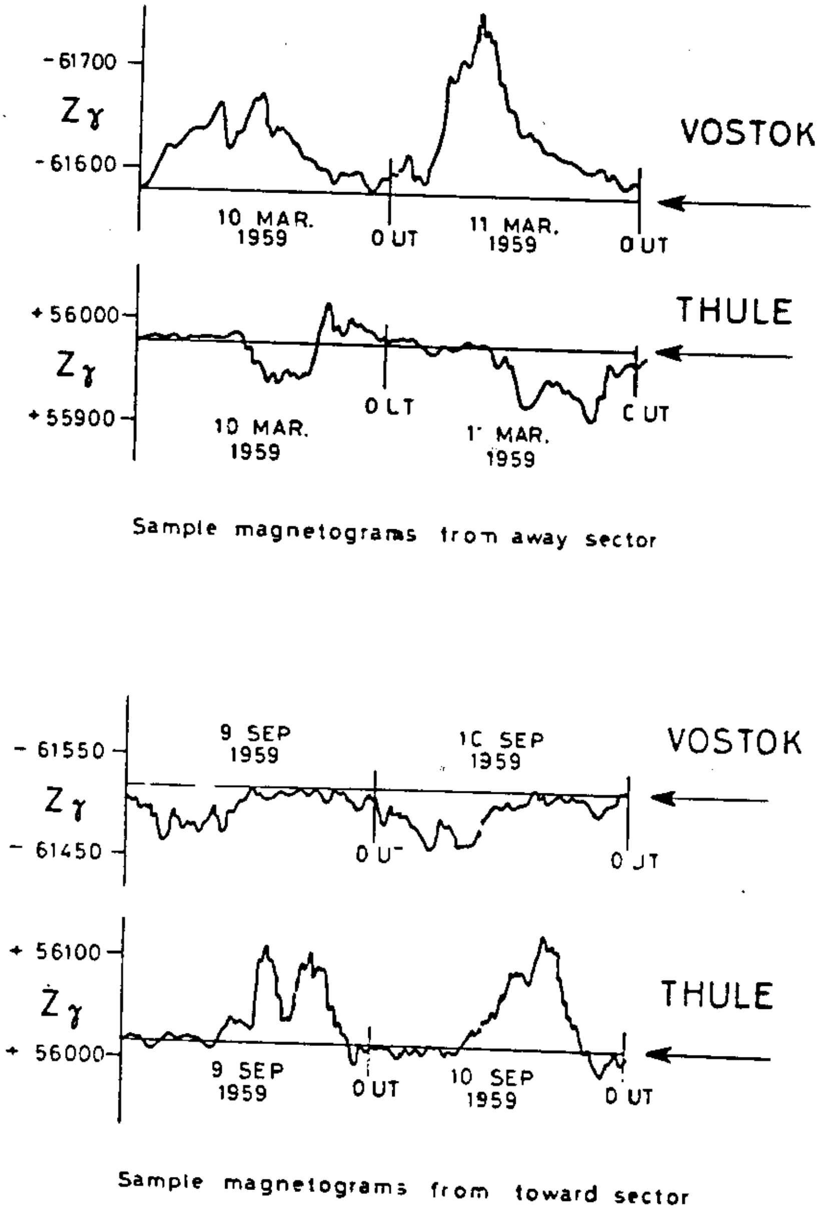

Fig. 2. Sample *Z* magnetograms from (a) away sector and (b) toward sector showing typical daily variations of the polar geomagnetic field observed at Vostok (34.9S) and Thule (86.2N). The arrows point to the quiet undisturbed level. (After Svalgaard, 1972).

GEOPHYSICAL INDICES -- PAST, PRESENT AND PROPOSED

by

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The tables in the following pages are an attempt to list geophysical indices with their sources and availability. These indices serve different purposes. Undoubtedly, the list is not comprehensive. Only indices have been given that are or could be prepared on a continuing basis. Another restriction in their selection was that the publication source should be reasonably available. The IAGA Working Group V-6 on Geophysical Indices requested their publication in the IAGA News.

In the following tables these abbreviations have been used:

AFCRL	Air Force Cambridge Research Laboratories (now Air Force Geophysics Laboratory), Hanscom AFB, MA 01731, U.S.A.
IAGA #12 or #32	IAGA Bulletins
IAU QB	International Astronomical Union Quarterly Bulletin on Solar Activity
JATP	Journal of Atmospheric and Terrestrial Physics
JGR	Journal of Geophysical Research
NASA/GSFC	NASA Goddard Space Flight Center
NGSDC	National Geophysical and Solar-Terrestrial Data Center, NOAA
NRC	National Research Council, Ottawa, Canada
TERR. MAG.	Terrestrial Magnetism and Atmospheric Electricity
WDC	World Data Center

PAST GEOPHYSICAL INDICES

Index	Purpose	Time Resolution	Years Available	Time Delay from Observatory to Index	Based upon	Sponsor or Source	Published
S.I.	Use in solar-weather/climate studies	Daily	1874-1964		Greenwich faculae and sunspots	Baur	"Climate, Present, Past & Future" by H.H. Lamb
C	Gives geomagnetic character of day at individual observatory	Daily	1884-1975	Next day	Appearance of magnetogram at observatory	IAGA	IAGA #12 or #32 SGD JGR
Ci	Gives international mean of geomagnetic character of day	Daily	1884-1975	Second month following	Mean of daily C-indices	IAGA	IAGA #12 and #32 SGD JGR
K	Measures intensity of equatorial electrojet	Monthly	1922-1939		Huancayo daily range of Sq in H-component	Bartels	Terr. Mag. 1946, 51, 187
u	Measures ring current at equatorial geomagnetic observatories	Monthly	1872-1949		Mean value of H for one day subtracted from value of preceding day without regard to sign	Bartels	"Handbook of Geophysics", 1965, p. 11-46
u_1	Measures ring current at equatorial stations with compensation for severe storms	Monthly	1872-1930		Same as u	Bartels	"Chapman & Bartels" (first edition)
HR_H, ZR_Z	Experimental measure of geomagnetic activity that would hopefully be proportional to energy of the disturbance	Daily	1930-1939		Daily absolute ranges (R_H, R_Z) and average values (H, Z) of H and Z components at selected stations, Sq not removed	Crichton Mitchell (Chapman & Bartels, Vol. 1, p. 361)	IATME "Caractère magnètique numérique des jours", Tomes 1-10, De Bilt
ΔHi	Measures geomagnetic activity	Daily	1933-1944		Differences of consecutive hourly values of H in γ/hr, Huancayo	AFCRL (Chernosky)	"Handbook of Geophysics", 1965, p. 11-55

PRESENT GEOPHYSICAL INDICES

Index	Purpose	Time Resolution	Years Available	Time Delay from Observatory to Index	Based upon	Sponsor or Source	Published Currently	Time Delay from Observation to Publications
Rz	Measures level of solar activity	1. Daily 2. Monthly 3. Yearly	Since 1610	1. Same day 2. Fifth of month following 3. Within month of end of year	Zurich sunspot observations	Waldmeier, Zurich, Switzerland	SGD JGR IAU QB	1 month 4 months > 1 year
S or S_A (10 cm or 2800 MHz solar flux)	Measures level of solar activity	1. Daily 2. Monthly	Since 1947	1. Same day 2. Tenth of month following	Solar radio emissions, adjusted to 1AU or unadjusted, from Algonquin Observatory, Canada	NRC Ottawa, Canada (Covington)	SGD JGR IAU QB	1 month 4 months > 1 year
R'_A	Measures level of solar activity	Daily	Since July 1957	Tenth of month following	American Association of Variable Star Observers sunspot observations	NGSDC, NOAA Boulder, CO	SGD	1 month
Inferred Interplanetary Magnetic Field (Sector Crossings)	Delineates sector structure of solar wind-polarity away from or toward the Sun	Half daily	Since 1957	Tenth of month following	Vostok and Thule Magnetograms	USSR Arctic and Antarctic Research Institute (Mansurov) and Danish Meteorological Institute (L.Svalgaard)	SGD JGR	1 month 4 months
Mean solar magnetic field	Gives weighted average of the net magnetic field on the visible disk of the Sun	Daily	Since May 16,1975	Tenth of month following	Sun-as-a-star integrated light measurements at Stanford Solar Observatory	Stanford University (Wilcox)	SGD	1 month
Calcium Plage index, CAII	Measures solar disk activity	Daily	Since Jan 1,1958	Tenth of second month following	Area and intensity of calcium plages	NGSDC, NOAA	SGD	2 months
Solar flare index	Measures solar disk activity	Daily	Since Sep 1969	Six months following	Hα solar flares, based on area and hours of patrol	NGSDC, NOAA	SGD	6 months
Region solar flare index	Measures solar region activity	One per solar region	Since Sep 1970	Seven months following	All Hα solar flares reported in a given region	NGSDC, NOAA	SGD	7 months
Ip	Gives ionospheric index for polar cap blackout	Daily	Since 1969	Seven months following	f_{min} data Resolute Bay	NGSDC, NOAA	SGD	7 months
Ia	Gives ionospheric index for auroral blackout	Daily	Since 1968	Seven months following	f_{min} data from Kiruna and Fort Churchill	NGSDC, NOAA	SGD	7 months
B	Measures interplanetary magnetic field from F hourly mean freq. of pulsations in millihertz	Hourly (for 6-12 UT)	Since 1970	About 1 year after observation	Borok micropulsations $B=0.7 + 0.15F + .16Kp$	Borok, USSR Academy of Science	USSR Cosmic Data	About 1 year

Index	Purpose	Resolution	Available	from Observatory to Index	Based upon	Sponsor or Source	Published Currently	Observation to Publications
Vorticity Area Index VAI	Used in solar-weather studies	Twice daily	Since 1946	About 6 months following	National Meteorological Center 500 mb grids - northern hemisphere > 20°N	U. of Colorado (W.O.Roberts)	Solar-Terrestrial Physics and Meteorology: A Working Document No. 2 SCOSTEP	—
AE	Measures geomagnetic substorms	2.5 min, or hourly, or 1 min since 1976	Since 1957	About 2 years	Northern auroral zone magnetograms, (Leirvogur, Narssarssuaq, Great Whale River, Fort Churchill, College, Barrow, Cape Wellen, Tixie Bay, Cape Chelyuskin, Dixon Island, Abisko, Sodankyla)	WDC-A for Solar-Terrestrial Physics (J.H.Allen)	IAG Reports IAGA #32 (provisional values) (Early years-NASA/GSFC)	About 2 years
Dst	Measures geomagnetic ring current	Hourly	Since 1957	Second month following	Magnetograms from Hermanus, Honolulu, San Juan and Kakioka	NASA/GSFC (M.Sugiura)	NASA/GSFC SGD IAGA	— 2 months About 1 year
K	Measures 3-hr geomagnetic variation at individual observatory, regular daily variations eliminated	3-hourly	Since 1932	End of month	Magnetograms at almost all geomagnetic observatories	IAGA	Until 1975 in IAGA #32 Available at WDC	—
Kp	Used as 3-hr planetary index of solar wind particles	3-hourly	Since 1932	Two weeks after end of month	Magnetograms from Meanook, Sitka, Lerwick, Eskdalemuir, Lovö, Rude Skov, Wingst, Witteveen, Hartland, Agincourt, Fredericksburg, Amberley	Göttingen (M.Siebert)	SGD JGR IAGA #32	2 months 4 months About 1 year
Kn	Measures northern hemisphere geomagnetic activity	3-hourly	Since 1959	Month following	Magnetograms from Magadan, Petropavlovsk, Memambetsu, Sverdlovsk, Tunguska, Niemegk, Witteveen, Hartland, Ottawa, Fredericksburg, Victoria, Newport, Tucson	Institut de Physique du Globe, France (Mayaud)	SGD JGR IAGA #32 (#39)	2 months 4 months About 1 year
Ks	Measures southern hemisphere geomagnetic activity	3-hourly	Since 1959	Month following	Magnetograms from Amberley, Toolangi, Gnangara, Kerguelen, Hermanus, Port Alfred, Argentine Island, South Georgia, Trelew	Institut de Physique du Globe, France	SGD JGR IAGA #32 (#39)	2 months 4 months About 1 year

PRESENT GEOPHYSICAL INDICES

Index	Purpose	Time Resolution	Years Available	Time Delay from Observatory to Index	Based upon	Sponsor or Source	Published Currently	Time Delay from Observation to Publications
Km	Measures geomagnetic activity	3-hourly	Since 1959	Second month following	Averaging Kn and Ks	Institut de Physique du Globe, France (Mayaud)	SGD JGR IAGA #32	2 months 4 months About 1 year
Q	Measures high latitude geomagnetic activity	15-min	Since 1957	?	Magnetograms from Sodankya currently, 27 observatories have prepared	Individual observatories	See IAGA Bull. 32f, p. 50, for availability at WDC	—
a_k	Measures individual station geomagnetic activity	3-hourly	Since 1932	Month following	Magnetograms of observatory	IAGA	Available at WDC	—
Ak	Measures individual station geomagnetic activity	Daily	Since 1932	Month following	Based on 8 daily a_k at observatory	IAGA	Available at WDC	—
aa	Measures worldwide geomagnetic activity	Daily	Since 1868	Month following	Magnetograms from antipodal stations Toolangi and Hartland	Institut de Physique du Globe (Mayaud)	SGD JGR IAGA #32	2 months 4 months About 1 year
ap	Measures worldwide geomagnetic activity	3-hourly	Since 1932	Second month following	Kp	IAGA	IAGA #32	About 1 year
Ap	Measures worldwide geomagnetic activity	Daily	Since 1932	Second month following	8 daily ak	IAGA	SGD JGR IAGA #32	2 months 4 months About 1 year
an, An	Measures northern hemisphere geomagnetic activity	3-hr, daily	Since 1959	Second month following	Kn	Institut de Physique du Globe (Mayaud)	IAGA #32 (#39)	About 1 year
as, As	Measures southern hemisphere geomagnetic activity	3-hr, daily	Since 1959	Second month following	Ks	Institut de Physique du Globe (Mayaud)	IAGA #32 (#39)	About 1 year
am, Am, Am2	Measures worldwide geomagnetic activity	3-hr, daily, 48 hr mean centered on day	Since 1959	Second month after observation	Km	Institut de Physique du Globe (Mayaud)	IAGA #32 (#39)	About 1 year
Cp	Measures worldwide geomagnetic activity	Daily	Since 1932	Month following	Based on Kp	Göttingen (Siebert)	SGD JGR IAGA #32	2 months 4 months About 1 year

Index	Purpose	Time Resolution	Years Available	Time Delay from Observatory to Index	Based upon	Sponsor or Source	Published Currently	Time Delay from Observation to Publications
C9	Measures worldwide geomagnetic activity	Daily	Since 1932	Month following	Cp	Göttingen (Seibert)	SGD	About 1 year
R	Measures high-latitude geomagnetic variations	Hourly	Varies, mostly since IGY	At least a year	Hourly range cf H-component from magnetograms in sources: 1. Canadian yearbooks 2. Thule and Godhavn 3. 12 Arcic and Antarctic stations, USSR	1. Canada 2. Denmark 3. USSR	See IAGA #32, p.51, for availability	USSR in "Auroral Phenomena", Polar Geophys. Inst. (since 1970)

Footnotes

1. International quiet days (10 per month) and disturbed days (5 per month) are selected by Institut für Geophysik, Göttingen (Prof. M. Siebert), and published in SGD, JGR, and IAGA No. 32.

2. Data on rapid variations, ssc, sfe, very unusual events are provided by Observatorio del Ebro, Spain (Dr. A. Romaña), published in SGD, JGR, and IAGA No. 32.

3. Data on a number of selected special intervals with diagrams of indices, ssc and other storm-data from individual observatories, common-scale magnetograms, provisional AE-indices at 2.5 min. intervals are published annually in IAGA Bulletin No. 32.

Monthly Bulletins

1. International Service of Geomagnetic Indices, De Bilt
   - Daily aa-indices
   - International quiet and disturbed days
   - Preliminary report on rapid magnetic variations (ssc, sfe, very unusual events)
   - Provisional hourly Dst
2. International Service of Geomagnetic Indices, Göttingen
   - International quiet and disturbed days
   - Three-hourly Kp
   - Daily Ap and Cp
   - Preliminary ssc
   - "Musical Notes" 27-day rotation Kp chart
   - R9 and C9 - 27-day rotation chart
3. Institut de Physique du Globe de Paris
   - Three hourly Km, Kn, Ks, am, an, as
   - Daily Am, An, As

PROPOSED GEOPHYSICAL INDICES

Index	Purpose	Time Resolution	Years Available	Time Delay from Observatory to Index	Based upon	Sponsor or Source	Published
Contour map Geomagnetic Activity	Measures geomagnetic storminess with time, of longitudinal extent and intensity of the auroral electrojets to study polar magnetic disturbances	Hourly	Samples 1957 and 1965	As soon as data available at WDC	ΔH, ΔD and ΔZ from selected magnetograms	IZMIRAN (A.N.Zaitsev) and Royal Institute of Technology Sweden (R.Boström)	Report 70-34 Electron and Plasma Physics, Royal Institute of Technology Sweden, Nov 1970
ΣKc3	Indicator of solar wind	Daily	Feb 1962-Jun 1964	?	20 min double maximum amplitudes of pc3 in γ (> 0.28) from 19^h to 4^h LT on Onagawa induction magnetograms--summed for 42 intervals of UT day	Tohoku Univ. Japan (T.Saito)	Report of Ionosphere and Space Research in Japan 1964, XVIII, 260
AA	Auroral activity	Each image--every 102 min	Jul 1973-Jun 1975	2 months following	DMSP Auroral imagery rated: X-no judgment N-no aurora Q-quiet M-moderate A-active	AFGL (Carvillano)	AFCRL-TR-75-0556
P1-P12	Measures solar wind	Daily	Since 1966	Available free of charge upon request to Verö	Nagycenk Observatory pulsation indices -occurrences in the 12 frequency bands	Geodetical and Geophys. Res. Inst., Sopron, Hungary (J.Verö)	JATP 1975, 37, 561
Auroral Index	Measures auroral activity on scale: 1-no aurora to 9=strong aurora all night, for optical observations of aurora unaffected by scattered moonlight	Daily	?	?	Optical spectrograph at zenith at College, AK	Geophysical Institute, College, AK	JGR 1977, 82, 2842
Interplanetary P9	Uses $F_{kinetic} = \frac{1}{2} m_p N V^3$ (erg $cm^{-2} s^{-1}$) for solar wind estimate	Daily	Jun 1965-June 1968	?	Degree of activity of the interplanetary plasma near Earth for measurements of solar wind on Vela 3, Explorers 33, 34, 35 and HEOS-1	Geophysical Institute of Slovak Acad. Sciences (S.Pinter) Lab. per il plasmo nello spazio, Frascati (G.Moreno)	Acta Geodaetica Geophysica et Montanistica, Acad Sci Hung. 1976, 11, 321

PROPOSED GEOPHYSICAL INDICES

Index	Purpose	Time Resolution	Years Available	Time Delay from Observatory to Index	Based upon	Sponsor or Source	Published
EUV_x or EUV_{y-z} (x=wavelength in nm and y-z wavelength range from y to z in nm)	Absolute solar energy fluxes used as solar index in place of sunspot number or 10 cm solar flux-units of $10^{-6} Wm^{-2}$ (10^{-3} erg $cm^{-2}sec^{-1}$)	Daily	1973	?	Measurements from Aeros satellites, used EUV_{103-80} and EUV_{80-15}	Institut für Physikalische Weltraumforschung der Fraunhofer Gesellschaft (G. Schmidtke)	Geophys. Res. Letters 1976, 3, 573
EUV flux	Measures true long-term variations of solar EUV flux	Daily	1974- (Oct 1978)	?	Measurements for Satellite AE-C in lines FeX, BeI, Ly-β	AFGL (Hinteregger)	COSPAR Space Res., Vol. 17, 1976; Geophys. Res. Letters 1977, 4, 231
178 kHz radiation	Measures auroral kilometric radiation associated with auroral and magnetic disturbances	10 min	Aug 31 to Dec 3, 1971; Dec 1, 1972 to Mar 31, 1973	Near real-time	Satellite low frequency radio measurements from IMP6 (power flux in $Wm^{-2}Hz^{-1}$)	Univ. of Iowa (G.R. Voots and D.A. Gurnett) Geophys. Inst. Alaska (S.I. Akasofu)	JGR 1977, 82, 2259

J. Geomag. Geoelectr., 38, 861-871, 1986

On the Computer Generation of Geomagnetic *K*-Indices from Digital Data

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Since the advent of digitally recording magnetic variometers and the ready accessibility of computers, there has been a search for a technique to produce *K*-indices of geomagnetic activity by machine.

The principal difficulty in the determination of *K*-indices is the estimation of the regular solar diurnal variation (*SR*) for each day, which is used as a reference from which the *K*-Variations are scaled. A number of methods for the machine estimation of the daily *SR* are reviewed. These fall into two categories: (i) by use of neighbouring quiet days, or (ii) filtering out the high frequency harmonics. Of the techniques proposed to date, those which are data adaptive are considered preferable.

A data adaptive method which divides a magnetogram trace into high and low frequency harmonics is presented. It is found that there is no particular frequency below which can be considered all the *SR* variations and above which are all the *K*-variations.

The latitude dependence of the tolerace to differences between estimation of the *SR* by machine and that manually is also discussed.

1. Introduction

The *K*-index to classify the range of geomagnetic activity was proposed in 1939 by BARTELS *et al.* and was soon adopted internationally to become the most widely used of all geomagnetic indices. The index is derived from the largest range over each 3-hour U.T. interval, of the variations in *H* and *D* after removal of the regular variations. According to MAYAUD (1967): "the purpose of the *K*-index is to measure the effects of the solar corpuscular radiation on the terrestrial magnetic field, as distinct from the effects of the wave radiation and post-perturbation". Although the *K*-index is now recognized as poorly suited for this purpose, it still serves as a convenient indicator of geomagnetic activity.

The principal difficulty in the determination of *K*-indices is identification of the non-*K* variations, in particular the regular solar diurnal variation or *SR*, and much has been written on the subject e.g. BARTELS (1957), MAYAUD (1967), MAYAUD (1980). Many claims have been made that the manual scaling of *K*-indices introduces a component of subjectivity and that there is much to be said in favour of producing a *K*-index or a quasi-*K*-index by computer using an agreed upon algorithm. Since the

introduction and proliferation of digitally recording magnetic variometers and the ready accessibility of fast digital computers to most geomagnetic observatories, the trend towards machine produced indices has grown.

There are two schools of thought on the viability of scaling a geomagnetic '*K*-index' by computer. (The term in apostrophes is used to denote a machine produced index). The traditional view insists that the *K*-index, by definition, is scaled by hand by an experienced observer, thereby virtually eliminating subjectivity and resulting in as little as 5% variability between experienced observers (MENVIELLE, 1981). Although MAYAUD (1980) conceded that scaling *K*-indices by computer may eventually become possible, MENVIELLE (1981) states that any such attempt must follow the very same rules applied in hand scaling (to avoid a discontinuity in the *K*-index series).

The difficulty in producing machine '*K*-indices', as with the hand-scaling method, is the separation of the *K*-variations from the *SR*-variations. When hand-scaling is performed by an experienced observer, he draws upon his knowledge of the form of the quiet variations as well as the day to day and seasonal variability which can occur therein, at a station where he has had many years of experience. For a machine to yield an identical result it must apply the same rules to identify the *SR* as would the observer. The problem then is how to program into a machine the equivalent of the observer's experience!

Those who favour machine scaled '*K*-indices' would argue on the grounds of time savings, the elimination of the need for an experienced observer and the consistency and objectivity of such methods. Although conceding that machine methods to date have not followed the very same rules as for hand-scaling, it has been argued that this in itself is unimportant since the resulting consistency with hand-scaling is on a par with the consistency between two observers performing hand-scaling. Some would further argue that the machine produced '*K*-indices' be given another name to distinguish them from their hand-scaled predecessor. LUNDBACK (1984) has gone so far as to propose an alternative to the *K*-index called *aK*, which, although conforming to the *K*-index to some extent, does not attempt to remove the *SR* variation at all. Such a notion is abhorred by the traditionalists, drawing the response: "is science made for computers or computers for science?" (MAYAUD, 1980). But the notion is not without its merits. As well as eliminating the requirement of having to identify the *SR* variations exactly (it is debatable whether this can be achieved by any means) a definition could be proposed which is not only simple to perform and therefore easy to standardize, but the resulting index could be made to have a precise meaning, unlike the *K*-index which is a rather nebulous parameter in physical terms. (see MAYAUD, 1980)

2. Techniques for Computer Scaling

Over the past 25 years there have been a number of techniques suggested for the machine production of '*K*-indices'. In 1960 ALLDREDGE put forward the method of applying a running mean to estimate the *SR* variations, which was then subtracted from the original data to leave the '*K*-variations'. MAYAUD (1980) raised the possibility of this method eliminating, at least to some extent, some of the longer period *K*-variations.

Another technique of approximating the *SR* variations was suggested by VAN WIJK and NAGTEGAAL (1977), involving the selection of 7 nearby quiet days which were smoothed by eliminating all harmonics with periods less than 6 hours and comparing each in turn with the day to be scaled. The smoothed quiet day which most closely matched, was deemed to be the *SR* for the day, and the '*K*-indices' scaled from that reference. The difficulty with this method as pointed out by MAYAUD (1980) is the limited number of quiet days from which the appropriate *SR* is selected. The probability of having an entirely appropriate *SR* in the nearby quiet days is small. This may be contrasted with the knowledge of the experienced observer who has an appreciation of the day to day variability and limits of the *SR* variations.

RANGARAJAN and MURTY (1980) described a method of scaling *K*-indices claimed to eliminate all subjectivity which is inherent in hand-scaling. Their technique used the 'Method of Orthogonal Natural Components' to identify the mean diurnal variations from a set of selected quiet days in a month. From an harmonic analysis of this mean diurnal variation the first six harmonics were used to synthesize the average *Sq*, the deviations from which were regarded as *K*-variations and scaled accordingly. This method was criticised by MENVIELLE (1981) who noted that subjectivity existed in the choice of quiet days and condemned the method as a failure. He further stated the method was not consistent with the definition of the *K*-index, having reverted to "iron-curve" method as coined by BARTELS (1957).

A comparison of various techniques for deriving "quasi-*K*-indices" by computer by RIDDICK and STUART (1984) concluded that it does not seem possible to derive an algorithm to accomodate the *Sq* variations at all latitudes. A comparison was made between hand scaled and machine generated *K*-indices from both analogue La Cour magnetographs and digitally produced magnetograms. Various automatic methods were used including: a simple min-max technique where no attempt is made to remove the diurnal variations; approximation of the diurnal variation by a straight line; and estimation of the diurnal variation from a selection of quiet days during the month by taking either their mean or the first 4 harmonics of the mean. The extent of agreement between hand-scaled analogue magnetograms and hand-scaled digital magnetograms was found to be 80%–90%. This would serve to demonstrate that care must be taken when dealing at all with discrete digital data, as pointed out by LOOMER *et al.* (1984). However these authors concluded that, at least for Ottawa, digital data recorded at 30 seconds or shorter intervals are adequate for the derivation of *K*-indices by hand.

Of the methods of producing *K*-indices by computer investigated by RIDDICK and STUART (1984), the method of harmonically synthesizing the diurnal variations from quiet days was only marginally better than the direct min-max method, when compared to hand scaling the same record. All their methods yielded an agreement around 75% compared to hand scaling.

3. Discussion of Methods

The methods of estimating the *SR* which have been proposed to date (with the exception of approximating it with a least-squares straight line) fall into two categories:

1) Use of a selection of neighbouring quiet days to give a mean *SR*;
2) Filtering out the high frequency variations (4–6 hour periods);

Or a combination of both methods.

Although the various methods proposed for machine scaling are all only moderately successful, achieving about the same degree of agreement with hand-scaling of the same magnetogram traces of 70%, 80%, the methods utilizing neighbouring quiet days seem, in principle, the less satisfactory; bringing with them vestiges of the "iron curve" method. Nor can these methods take into account the full range of variability that the form of the *SR* may take. Furthermore, the element of subjectivity which ideally should be eliminated by machine scaling, is introduced via the selection of quiet days for use in the analysis.

On the other hand, the technique of filtering the data on the particular day to be scaled and retaining the first 4–6 harmonics to estimate the *SR*, while not 'gaining experience' from nearby quiet days, is not misled by them either. Neither is there any element of subjectivity in the method. With the filtering or harmonic analysis method, it does not matter what form the *SR* variations may take, nor whether they are anomalous, nor whether nearby quiet days have a similar form (or even if there are any nearby quiet days!). The method does implicity assume that the frequency spectra of the *SR* and *K*-variations do not overlap. Methods which do not rely on a limited selection of nearby quiet days with which to estimate the *SR*, seem to have more potential to eliminate subjectivity in machine scaling.

The importance of the precision to which the *SR* must be identified is inversely proportional to magnetic activity (MAYAUD, 1980). If a machine method is to work well, on a very quiet day it must be able to identify virtually all the variations as *SR*. To this end any proposed algorithm for the machine production of *K*-indices must obey the (hand-scaling) rules at least as well as an experienced observer scaling by hand, and therefore estimate the *SR* from only the data of the day being scaled.

4. Application of an Harmonic Analysis Method

In view of the considered superior features of data adaptive computer scaling techniques described in the previous section, an harmonic analysis method has been applied to both magnetically quiet and disturbed conditions at the new digital magnetic observatory at Charters Towers, Australia (CTA): geographic co-ordinates 20° 05'.3 S, 146° 15'.2 E. The procedure to produce '*K*-indices' for a day was to:

1) Make the data up to 2048 values by adding 304 values to the beginning and end of the day's data (1440 minutes) from the previous and next days' data respectively.

2) Fill any gaps in the data by interpolation using a cubic polynomial.
3) Detrend the data by removal of the least-squares straight line of best fit and aper the data by the application of a split cosine bell affecting 15% of the data at each nd.

4) Apply a radix-2 FFT algorithm to the data, set to zero those harmonics with eriods greater than the desired cut-off (of the order of 300 minutes), and then erform an inverse FFT.

5) The resulting high passed data are divided into 3-hour U.T. intervals and the inge of the variations within each interval compared with the appropriate quasi-garithmic scale and an index allotted.

6) The '*K*-index' is the larger of the individual *H* and *D* indices.

Figure 1 shows the power spectra of the *H* and *D* components on a magnetically uiet day. Clearly there is little power in any harmonic with period less than 293 inutes in either spectrum. This period may thus serve as convenient cut-off, above d including which may be defined as the *SR* variation spectrum. Figure 2 shows the agnetogram of the same day decomposed into '*SR*' and '*K*' variations using the ove criterion. Of course the estimated *SR* very closely approaches the total riations although the fit is not as close in some places as perhaps an 'experienced server' would choose.

The spectra of a disturbed day are shown in Fig. 3. Inspection of the ignetogram filtered at 293 minutes (Fig. 4) clearly indicates that the *SR* estimated longer resembles the *SR* on a quiet day nor that which would be estimated by an perienced' observer. Removal of the long period harmonics clearly distorts the variations and so leads to incorrect 'K-indices'.

The method has also been applied to a wide selection of days using values of the -off period ranging from 180 minutes to 400 minutes. The results were similar to se cited above.

Clearly it is not satisfactory to simply apply a sharp filter to a magnetogram trace to expect all the *SR* to be contained in harmonics with periods longer than some off value and all the *K*-variations to be contained in the shorter period harmonics ch remain. The foregoing examples are sufficient to demonstrate that the *SR* and ariations may have overlapping spectra. It is therefore obvious that the method ribed is too simplistic to be applied to any magnetogram and expect to derive ndices' which always agree with true, hand-scaled *K*-indices.

Being at a low latitude, the lower limit for a *K*-index of 9 at Charters Towers is Indeed, at 300 nT no station has one lower. It follows that at this station any epancy between a machine identification of the *SR* and that determined ually will result in the greatest possible discrepancy between respective *K*-indices. e U.K. stations which RIDDICK and STUART (1984) used to test their algorithms, 9 low limits range between 500–1000 nT, giving a tolerance of around 2–3 times at Charters Towers. Inspection of the mean quiet day horizontal intensity etogram traces presented for the U.K. stations show that no 3-hour *K*-index g interval has a range of more than about 40 nT which is similar for the quiet viour at Charters Towers. It follows that the ratio of the range of the *SR* in any 3

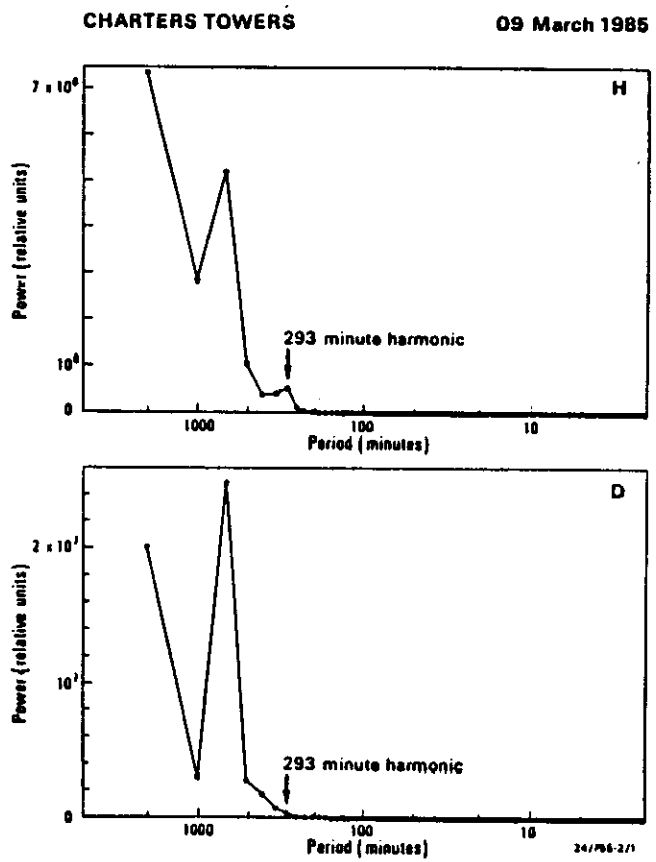

Fig. 1. Power spectra for *H* and *D* on a magnetically quiet day, 09 March 1985 at Charters Towers.

hour interval to the *K*9 low limit is relatively small for the U.K. stations. It is therefore not surprising that at the U.K. stations the simple maximum-minimum method taking no account of the *SR* yielded results only marginally worse than the harmonic method.

5. Discussion

The limitation in even the manual scaling of *K*-indices is the impossibility of identification of the *SR* at all times, especially during magnetically disturbed periods. Although the larger *K*-indices are more tolerant of improper *SR* identification, when

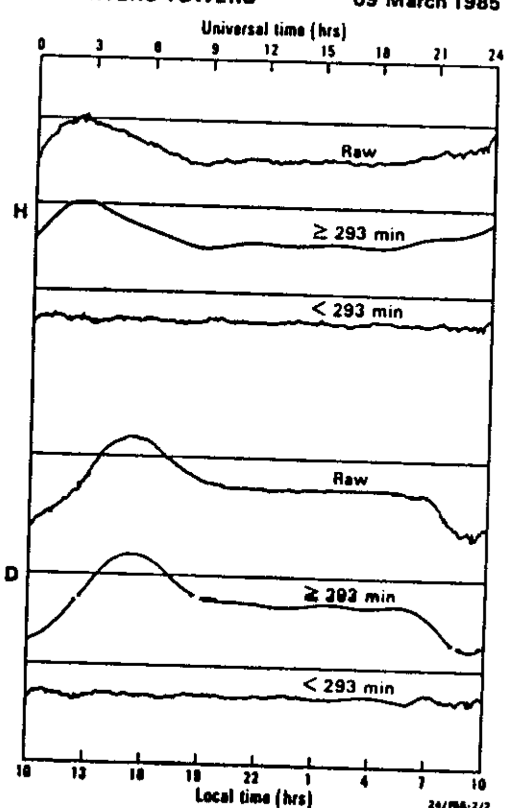

Fig. 2. Magnetogram for H and D on 09 March 1985 shown both raw and filtered at 293 minutes.

the rule "interpretation ... should always be the simplest and least speculative" (MAYAUD, 1976) is applied, i.e. no interpretation at all in which case the *SR* is implicitly assumed to be zero, the resulting *K*-indices will frequently be erroneous. This limitation was noted by Mayaud, who recognised that the *SR* must be present every day even though it could not always be identified.

That the *SR* is present every day regardless of magnetic disturbance has recently been highlighted by HIBBERD (1981). By choosing pairs of stations having similar longitudes but on opposite sides of the latitude of the path of the *Sq* focus, Hibberd was able to identify a composite *Sq* variation, which was found to be more regular and uniform than the H variations at either station. The analyses of Hibberd gives some justification once again to the "iron curve" method of gaining *K*-indices. Without

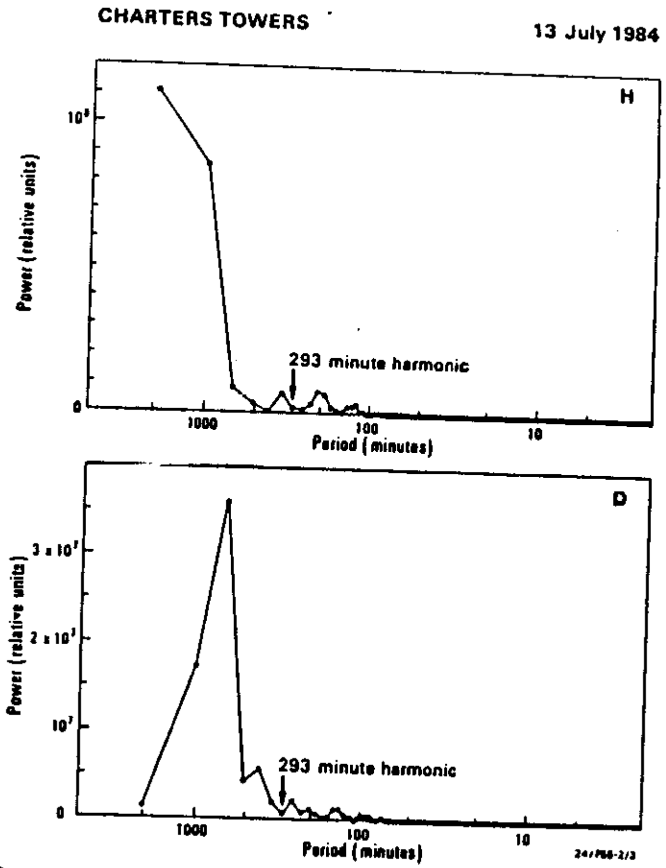

Fig. 3. Power spectra for H and D on a magnetically active day, 13 July 1985 at Charters Towers.

condoning the technique for all days, it is suggested that it may be useful on days when the *SR* cannot be estimated in any other way!

In view of the problems encountered with the manual identification of the *SR* it is not surprising that hitherto it has not been achieved by machine methods.

Consider the harmonic method described in Section 4 when applied to magnetically quiet conditions. Although the form of the magnetogram trace can almost entirely be represented by the long period harmonics as seen in Fig. 1, the existence of virtually flat regions on the magnetogram traces during the night and the sharp variations, particularly in declination, during the day-time, necessitate the inclusion of shorter period harmonics to faithfully represent the *SR*. Almost

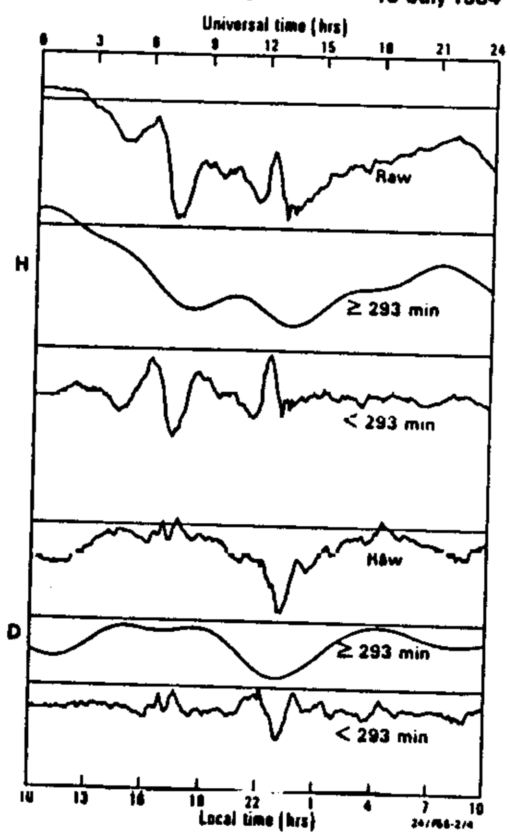

Fig. 4. Magnetogram for H and D on 13 July 1985 shown both raw and filtered at 293 minutes.

ariably the result is over-estimation of most of the resulting 'K-indices' throughout day.

This is in contrast to the success achieved by the similar technique applied to the K. data by RIDDICK and STUART (1984). As well as being more tolerant to errors in identification of the SR, as shown earlier, the form of the SR at the U.K. stations shown to be quite smoothly varying and so more faithfully represented by long iod harmonics alone, in contrast to the SR form at Charters Towers.

Under magnetically disturbed conditions it is clear from Fig. 4. That K-iations can have long period components which overlap with the dominant monics in the spectrum of the SR under quiet conditions.

6. Conclusion

For a computer derivation of K-indices to work, without re-definition of the K-index, we must return more closely to the rules (MAYAUD, 1967) applied when manual scaling is performed by the 'experienced observer'. The question to be addressed is: how can a computer be given "experience" so as to identify the SR like the human eye? Although the filtering method goes some way towards this by recognising certain periods, there is not enough experience built in. No attention is given to amplitude or phase of the periods selected as the SR and so it is possible to come up with estimations of the SR which would never be obtained by hand scaling.

It is seen that the simple harmonic analysis method is inadequate to identify the SR sufficiently well during both magnetically quiet and disturbed conditions at Charters Towers. This is in contrast to the results of other workers at higher latitudes. This is sufficient to indicate the method is in general not suitable to use in the machine production of K-indices.

On the basis that even the traditional rules for the manual scaling of K-indices do not always adequately identify the SR, the production of a sophisticated algorithm to imitate these rules may not be well justified. We may well be better served by a quasi-K-index or an index which does not require the identification of the SR. It would seem the present time is appropriate for the introduction of such a machine produced index. This might be based on the range or variance, possibly of only certain spectral components or harmonics, within the same 3-hour intervals as the K-indices. Any new index should be simple to produce and ideally have a clear physical meaning. Harmonic analysis techniques achieve these goals as well as eliminating subjectivity.

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

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

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

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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:

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

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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.

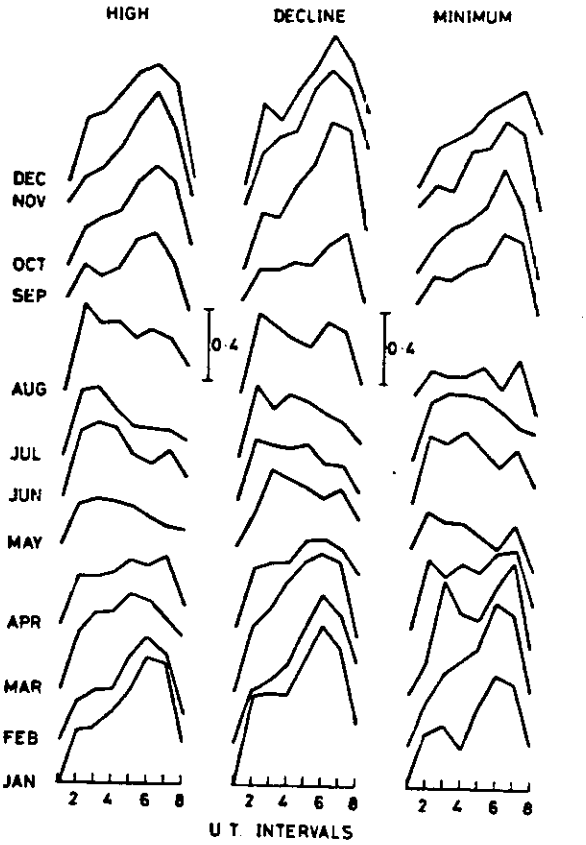

Fig. 1 – *Mean diurnal variation of irregular geomagnetic activity for each month during High, Declining and Minimum phases of solar cycle.*

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:

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

where K_n, K_m indicate the K-index for the *nth* and *mth* 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 Tromsø (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	25	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

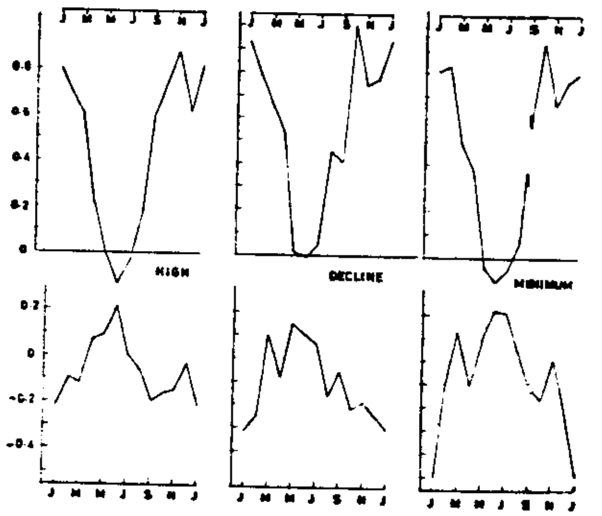

Fig. 2 – *Mean annual variation of J-effect (bottom) and N-effect (top) at Alibag during High, Declining and Minimum phases of solar cycle.*

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

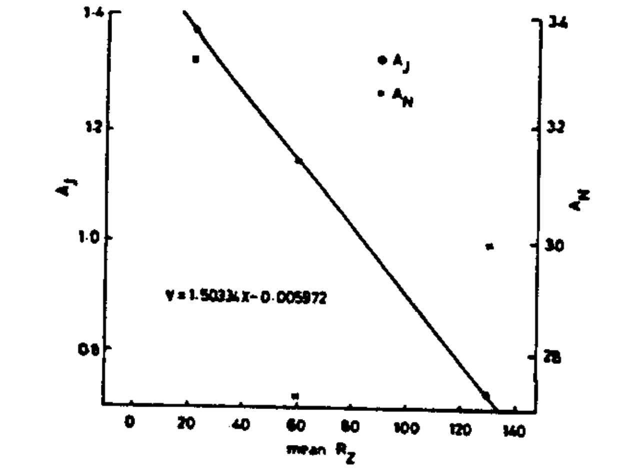

Fig. 3 – *Relation of the amplitudes of J- and N-effects with relative sunspot number,* R_z*. The equation of straight line of best fit given in the figure pertains to* (R_z, A_J).

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° at 0430 UT in June and at 1630 UT in December. At equinoxes it attains 90° 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*.

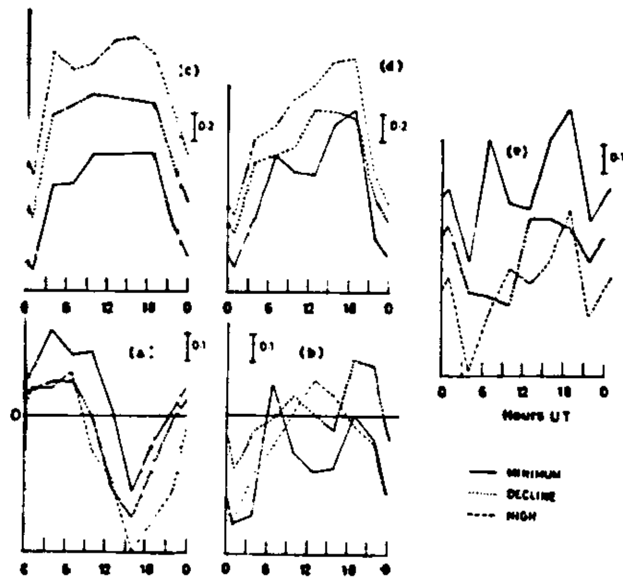

Fig. 4 – *Universal Time component of geomagnetic activity at Alibag:* a) *« June-December » curve;* b) *« March-September » curve;* c) *« June + December » curve;* d) *« March + September » curve;* e) *« March + September » minus « June + December » curve.*

(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. *4a*, 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. *4b* 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. *4c*, 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. *4d* 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.

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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.

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

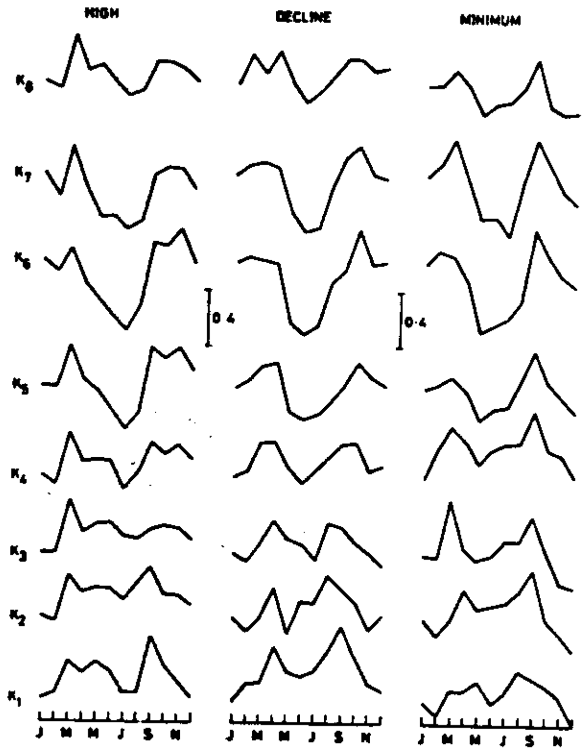

Fig. 1 – *Mean seasonal trends in average magnitude of* K*-index for each 3 hour UT interval during High, Declining and Minimum phases of solar cycle.*

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 night-time component vanished. BHARGAVA *et al.* (1973) concluded that in low latitudes the day-time compo-

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Table I: *Results of harmonic analysis of mean seasonal trends for each UT interval for three phases of solar activity.* (Amplitudes in 10^{-2} 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.

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.

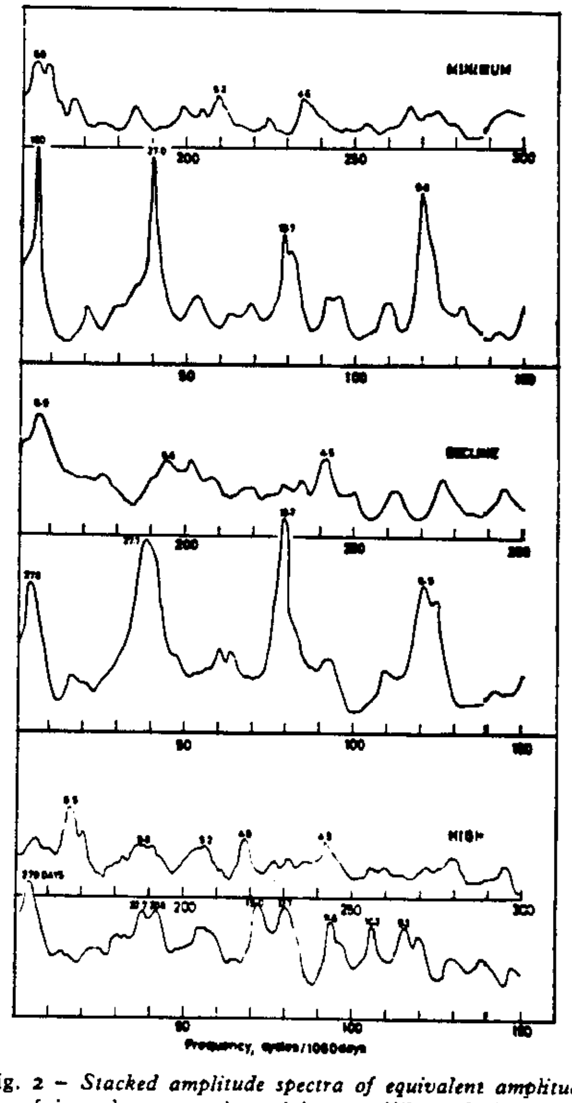

Fig. 2 - *Stacked amplitude spectra of equivalent amplitude* A_k *of irregular magnetic activity at Alibag, during High, Declining and Minimum phases of the solar cycle.*

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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.