Bull. Astr. Soc. India (1985) 13, 53–61

On the location of solar active longitudes

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Received 1983 November 27, accepted 1984 December 27

Abstract. The longitudinal distributions of sudden ionospheric disturbances producing active regions with high flare activity and/or with at least one high energy flare particle event (PCA or GLE) have been examined. These active regions appear to cluster at four active longitudes, separated by a longitudinal distance of about 60° and 180°. It is also inferred that these active longitudes drift in position by about 21.55° per year, thus exhibiting almost rigid rotation. Quasi-periodicities of 2.3 to 5.3 yr are also seen in 12 Fourier spectra of time series of high flare activity regions in 30° wide longitude range. These periodicities have been interpreted as due to drifting of four active longitudes having 60° and 120° longitudinal separations.

Key words : longitudinal distribution—active longitudes—the sun

1. Introduction

Several authors have pointed out the existence of 'active Carrington longitudes' on the sun (Warwick 1965; Svestka 1968; Bogart 1982). Recently, Shelke & Pande (1984) through power spectrum analysis of sudden ionospheric disturbance (SID) events from 1978 January to 1982 September have found evidence for the existence on the solar surface of four active logitudes, in two pairs. Active longitudes of a given pair are separated by 180° and a given member of the first pair is located 60° away in longitude from that of the corresponding member of the second pair.

Here an attempt is made to investigate the longitudinal distributions of SID-producing and high flare activity active regions, and to further check the existence of active longitudes, their longitudinal distribution and to investigate the temporal drift of active longitude zones.

2. Observational data

The longitudinal distributions of active regions of high flare activity for the period 1964–1979 and of SID-producing active regions during 1979–81 have been examined.

The locations of SID-producing active regions, taken from Solar-Geophysical Data, are plotted as a function of longitudes in figure 1.

The data on active regions with high flare activity and/or with at least on high energy particle event (Polar cap absorption, PCA or Ground level events, GLE) has been taken from the 'Evolutionary charts of solar activity' (Hedeman *et al.* 1981). From these charts of more than 200 solar rotations, covering the whole cycle 20 and the portion upto the maximum of cycle 21, only the active centres with enhanced flare activity and the regions that produced flares associated with the energetic particle emissions are selected for this study. The longitudinal distributions for each year are shown separately in figure 2.

3. Longitudinal distribution

Warwick (1965) and Svestka (1968) studied the grouping tendency of proton flare regions at certain preferred heliographic longitudes. They pointed out that two active longitudes exist on the solar surface at a longitudinal separation of about 180°. The SID-producing active regions and the active regions with high flare activity also show this tendency of clustering in the preferred longitude ranges on the solar surface (*cf.* figures 1 and 2).

Figure 1 shows that there are five peaks in the histogram designated 1 through 5. To check the reliability of these peaks in the longitudinal distribution, the confidence

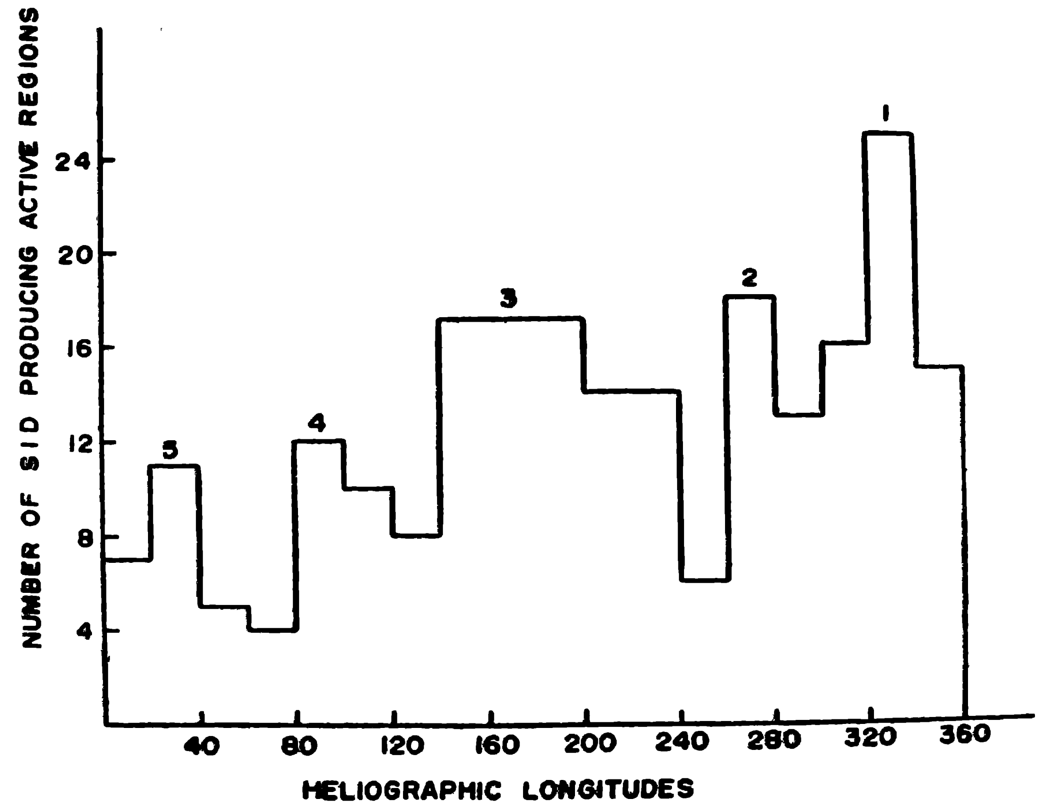

Figure 1. Longitudinal distribution of SID-producing active regions.

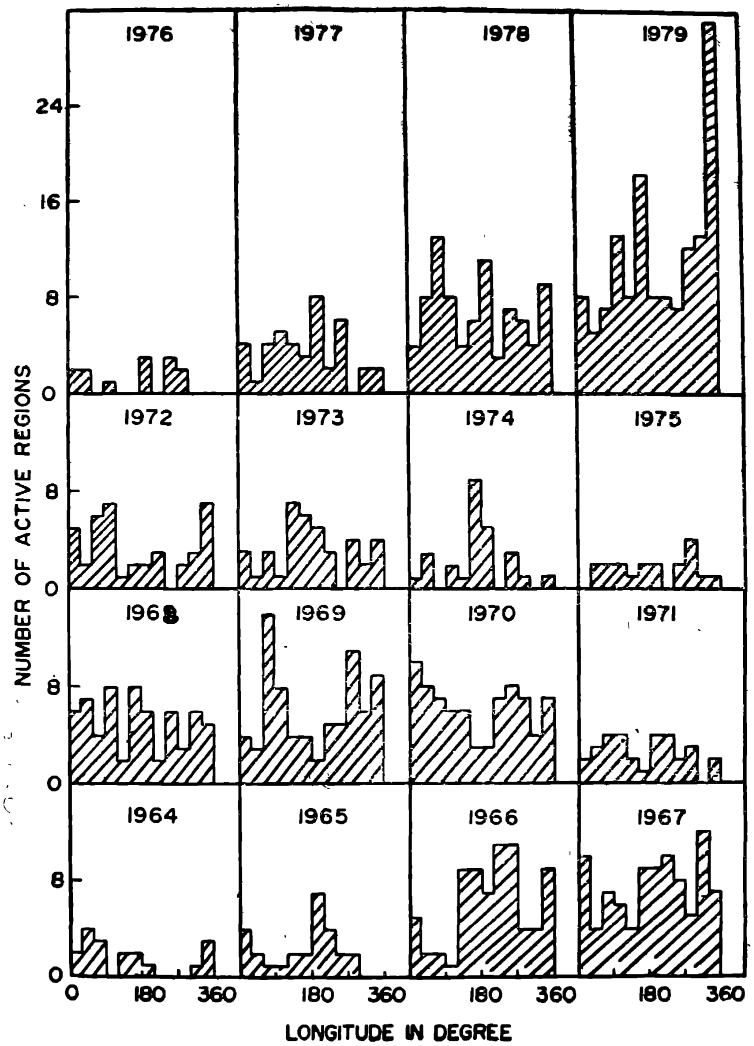

Figure 2. Longitudinal distribution of high flare activity active regions.

interval for the mean μ is estimated using Student's t-distribution (Jenkins & Watts 1968). A 100 $(1 - \alpha)$% confidence interval for mean μ based on the estimates $\bar{x}$ and s obtained from a given sample is

$$\bar{x} \pm t_\nu \left(1 - \frac{\alpha}{2}\right) \frac{s}{\sqrt{n}}.$$

Hence, using the above equation with sample mean $\bar{x} = 12.72$, $s = 5.42$, $n = 18$ and the value t_{17} (0.975) = 2.11 (*cf.* table in Fisher 1938), the 95% confidence interval is found to be (15.41, 10.02). This interval gives 95% confidence that the obtained interval happens to include the true mean μ.

The peaks which are above the upper confidence limit are taken to be significant peaks. Figure 1 shows that only the peaks designated by 1, 2 and 3 are above the upper confidence limit, thus indicating the peaks in the longitudinal distribution of

SID-producing active regions. The remaining two peaks, 4 and 5, are within the confidence limits, and therefore have been neglected. Figure 1 thus reflects that at least three SID-producing active longitudes exist on the sun. The longitudinal separation between the peaks 1 and 2 is 60°, whereas the left-to-right and right-to-left separations between the peaks 1 and 3 are 160° and 200° respectively, which may be approximated to a mean value of about 180°. These longitudinal separations of 60° and 180° are in accordance with our earlier conclusions (Shelke & Pande 1984).

Figure 2 also reveals a tendency of high flare activity regions to cluster in certain preferred longitude ranges. Using Student's *t*-distribution discussed in the preceding paragraph, the upper 95% confidence limits for these 16 histograms are obtained (*cf.* table 1) and the peaks which are above the corresponding upper confidence limit are taken to be significant peaks. The positions of significant peaks thus obtained are plotted in figure 3 as a function of time. Figure 3 shows that more than one active longitude exists and the longitudinal separations among these active longitudes are close to 60° and/or 180° (Shelke & Pande 1984).

Table 1. Upper 95% confidence limits for means μ_s for figure 2

Year	Upper 95% confidence limit	Year	Upper 95% confidence limit
1964	2.54	1972	5.70
1965	3.91	1973	5.48
1966	10.55	1974	4.13
1967	12.53	1975	2.51
1968	8.65	1976	1.89
1969	10.67	1977	5.78
1970	10.41	1978	11.58
1971	4.16	1979	20.09

4. Quasi-periodicity

The number of high flare activity active regions at each longitude strip of 30° wide range are plotted in figure 4 as a function of time. Each peak of figure 4 signifies

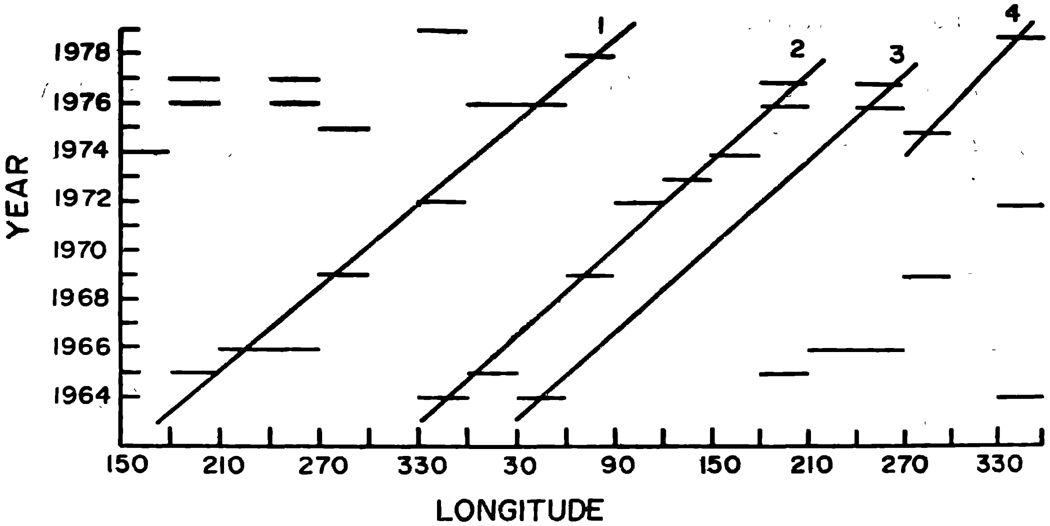

Figure 3. Positions of active longitudes as a function of time. Active longitudes are inferred from figure 2.

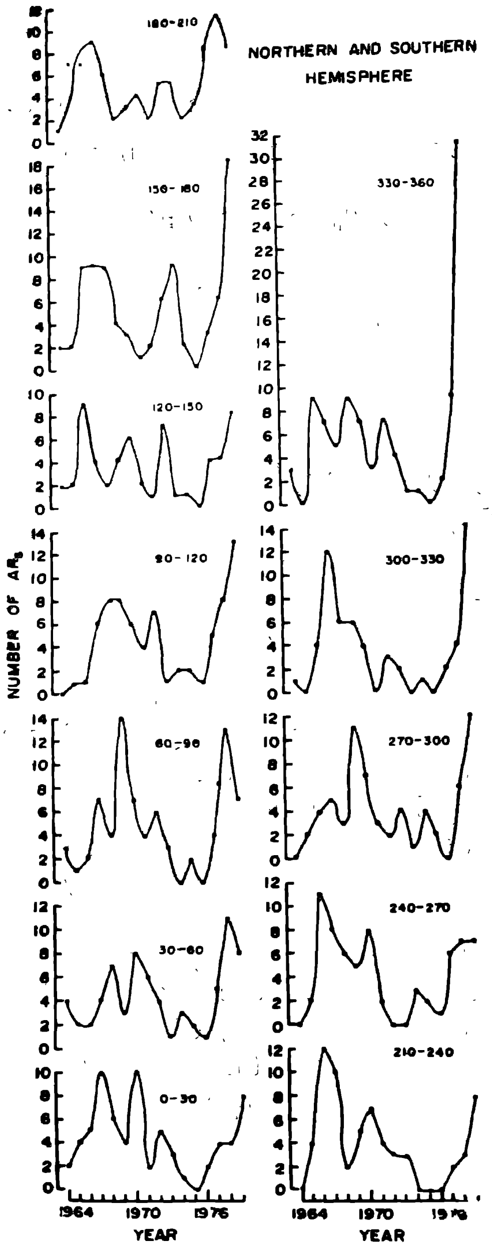

Figure 4. The number of high flare-activity active regions for each longitude strip of 30°-wide range as a function of time.

a cluster of such active regions on the solar surface which we shall call active longitude. An examination of figure 4 shows that every 30°-wide longitude strip becomes an active longitude approximately periodically and these plots have quasi-periodicities of 2 to 7 years, in which periodicities of 2 to 4 years are most frequent.

The quasi-periodicities have also been brought out by obtaining Fourier spectrum for each plot of figure 4. The mean square value of signal S_r, or the average power dissipated by signal S_r, can be decomposed into contributions arising from each harmonic. The mean square value or average power of the signal is

$$R_0^2 + 2 \sum_{m=1}^{n-1} R_m^2 + R_n^2,$$

which is a special case of Parseval's theorem (Jenkins & Watts 1968). For the zeroth and n-th harmonic the contribution is R_m^2 but for the m-th harmonic the average power is $2R_m^2$. Here, R_m may be written as

$$R_m = \sqrt{A_m^2 + B_m^2},$$

where

$$A_m = \frac{1}{N} \sum_{r=-n}^{n-1} S_r \cos \frac{2\pi mr}{N}$$

and $$B_m = \frac{1}{N} \sum_{r=-n}^{n-1} S_r \sin \frac{2\pi mr}{N},$$

from $m = 0, 1, ..., n$. Here N (number of data points) is even and equal to $2n$ so that r may run through the integers $-n, ..., 0, 1, ..., n-1$.

The Fourier decomposition of mean square value (Fourier spectrum) thus obtained for each 30° wide longitude strip data is displayed in figure 5 by plotting the average power at the harmonic versus the frequency of the harmonic. These 12 Fourier spectra (*cf.* figure 5) show that the peaks have a wide range of periodicities ranging from 2.3 to 8 yr. However, the peaks with periodicities of 2.3 through 5.3 yr are most frequent. Quite a wide range of these most frequent quasi-periodicities may be interpreted as due to passing of four drifting active longitudes of 60° and 180° longitudinal separations through a 30°-wide longitude strip which in turn becomes an active longitude around quasi-periods of 2.3–5.3 yr.

5. Drift of active longitudes

Active regions at active longitudes tend to drift in time. Svestka (1968) points out that it is a real effect. New active regions form in complexes of activity with slightly shifted positions and this shift is about 70° over 10 solar rotations (Svestka 1968). Our study also reveals that the active longitudes themselves drift in position which is well illustrated in figures 3 and 6.

The significant peaks of figure 4 after applying upper 95% confidence limits (*cf.* table 2) are plotted in figure 6. Each horizontal bar of figures 3 and 6 implies an active longitude zone. The regression lines fitted through least squares assuming a linear trend in figures 3 and 6 are the 'propagation lines' of the active longitudes. The mean slopes of the propagation lines in figures 3 and 6 are about 16.6° and 21.5° in longitude per year (mean value is 19.08° per year) respectively. These

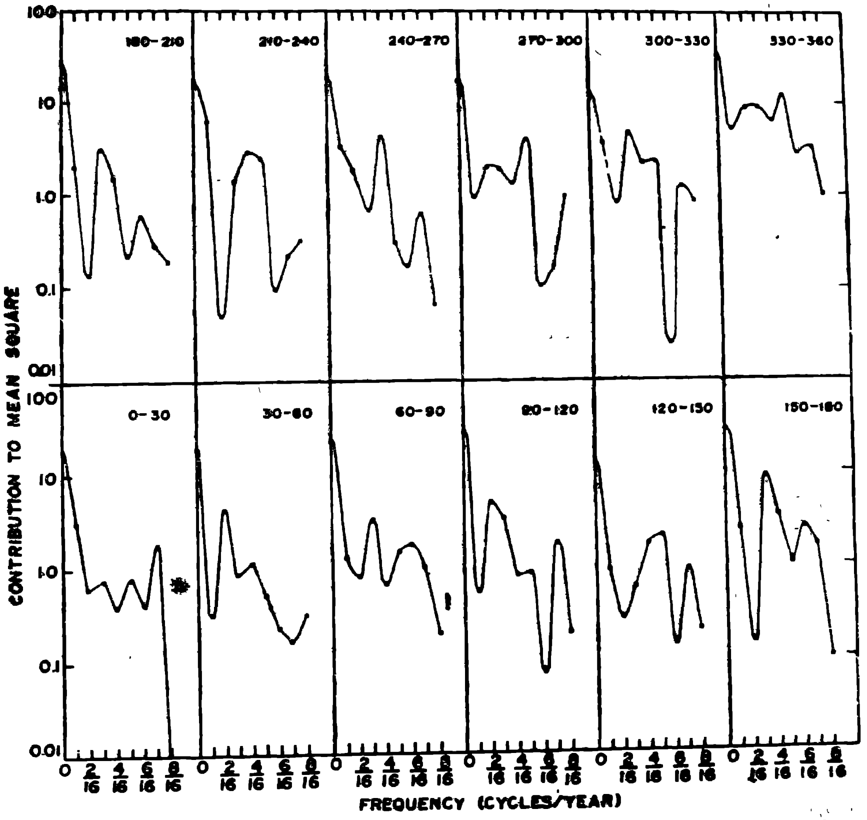

Figure 5. Fourier spectra of high flare activity regions for longitude strips 30° wide.

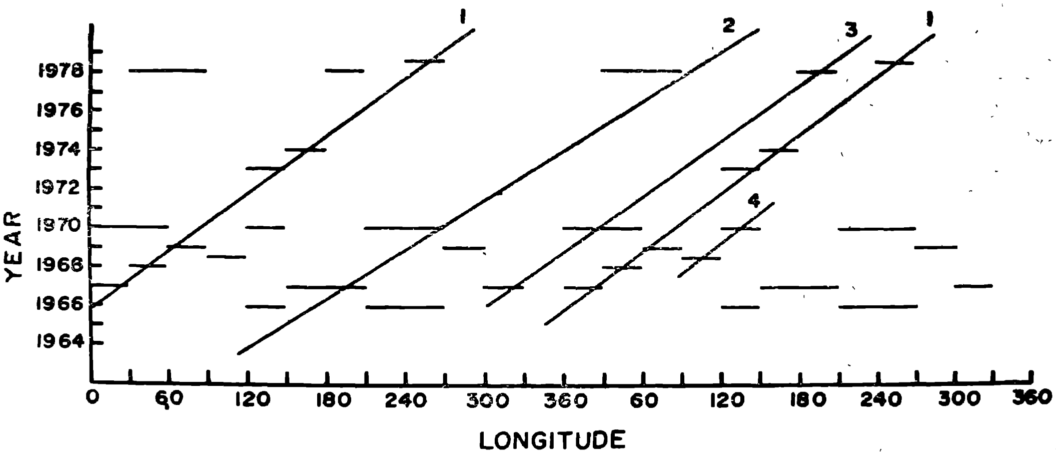

Figure 6. Longitudinal distribution of active longitudes as a function of time. Active longitudes are inferred from figure 4.

figures also reveal that active longitude regions drift westward and therefore the rotation period of active longitude is close to 27.18 days (mean value obtained from the above two drift rates). This rotation period exhibits almost rigid rotation of active longitudes.

Table 2. Upper 95% confidence limits for mean μ_s for figure 4

Longitude range	Upper 95% confidence limit	Longitude range	Upper 95% confidence limit
0–30	6.99	180–210	8.19
30–60	7.06	210–240	6.62
60–90	8.02	240–270	6.99
90–120	7.51	270–300	6.83
120–150	5.75	300–330	6.49
150–180	8.91	330–360	11.10

Table 3. Quasi-periodicities from drift rates

Longitudinal separations (deg.)	Period, yr, for drift rate		
	$16.6° \mathrm{yr}^{-1}$	$21.55° \mathrm{yr}^{-1}$	$19.08° \mathrm{yr}^{-1}$
60	3.61	2.78	3.14
120	7.22	5.56	6.28
180	10.83	8.3	9.43

Figures 3 and 6 show that there are at least four propagation lines at longitudinal separations close to 60° and/or 180° (or 120°) among them. If such a pattern of four active longitudes drift westward then each 30°-wide longitude strip would get activated as per the quasi-periodicities showed in table 3.

6. Conclusions

This investigation shows that there are at least three active longitudes in case of SID-producing active regions and four active longitudes in case of high flare activity regions, located at longitudinal separations of about 60° and 180° in both the cases. Further, it is shown that active longitude regions themselves drift westward at a rate of about 21.55° in longitude per year, thus demonstrating an almost rigid rotation of active longitude. These drifting four active longitudes with longitudinal separation of 60° and 120° would activate each 30°-wide longitude range as per quasi-periodicities of 2.78 and 5.56 yr respectively. The quasi-periodicities of 2.3 to 5.3 yr are also seen in the Fourier spectra of the time series of high flare activity active regions in 30° wide longitude strips.

The existence of relatively long-lived longitude zones of enhanced solar activity may result from the fluctuations in the rate of sunspot eruptions in the pre-existing p- and f-magnetic regions (Leighton 1969). The p- and f-magnetic regions represent regions of specially high and specially low rates of sunspot eruptions. The areas of p-polarity will enhance the rate of new sunspot formation while areas of f-polarity will supress it. A few areas might then persistently possess enhanced fields of p-polarities on the solar disc, and thereby the persistence of preferred longitudes of eruption might arise. The presence of four such long-lived unipolar magnetic regions of p-polarity would lead to the existenee of four active longitudes as inferred by Shelke & Pande (1984).

Acknowledgement

The authors are thankful to Dr M. C. Pande for many valuable suggestions.

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