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A short-term periodicity near 155 day in sunspot areas

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Abstract. We present evidence of a nearby 155 days periodicity in the historical record of sunspot areas from 1904 to 1976, rotation by rotation, covering cycles 14 to 20. This suggests that earlier periodicities around 155 days found in other indicators of solar activity during the last three cycles could be connected to this one presented here. Due to the fact that the amount of emerging magnetic flux is directly proportional to sunspot areas, this result also suggests the existence of a periodicity in the emergence of magnetic flux through the solar photosphere. Another peak around 510–540 days, pointed out in solar flares by several authors, is also present in our results, however, is not significant at all, because it remains below the level of the "null continuum".

Key words: sun: sunspots – activity

1. Introduction

During past years, short periodicities in different manifestations of solar activity have been pointed out. Among them, the two more significant and persistent seem to be around 155 and 540 days. The first claim about the existence of a periodicity at 154 days was made by Rieger et al. (1984) in a study of hard solar flares, recorded with the GRS aboard SMM, between February 1980 and September 1983. Later, Ichimoto et al. (1985) investigated the temporal variation of flare activity using data of Hα flares from solar cycles 20 and 21. They found evidence of a 155 days periodicity and suggested that it is connected with the time scale for storage and/or escape of the magnetic field in the solar convection zone, moreover, when the power spectra were calculated for northern and southern hemispheres separately, a peak at 510–540 days was found. Bogart & Bai (1985) studied the occurrence rate of flares, inferred from microwave data, for the interval between February 1980 and September 1983, confirming the existence of a periodicity of about 152 days. By including in the study the data from April 1966, the periodicity is persistent, however, during cycle 20 its significance has been marginal although the phase has remained coherent with that of cycle 21. Bai & Sturrock (1987) studied major flares, observed with the HXRBS aboard SMM, from February 1980 till December 1983, finding that the most prominent peak is around 152 days for the whole disk. The same peak is observed in the power spectra computed for the two hemispheres, taken separately, but not so important. From their study, they conclude that both hemispheres present the periodicity independently, that the phase is coherent between the two hemispheres and that flares within and outside active regions exhibit the periodicity, so, it seems that the periodicity is a global phenomenon. Bai (1987) has, also, investigated the occurrence of major flares (CFI > 5) during cycle 19, finding an important peak at 51 days when the whole disk or the northern hemisphere is considered. Important peaks at 153 and 552 days were found in the southern and northern hemisphere respectively. Akioka et al. (1987) studied the temporal variation of sunspot activity during cycle 21 using: a) The sum of maximum areas of sunspot groups during a disk passage in one solar rotation (TA). b) The total number of sunspot groups observed in one solar rotation (TN). c) The mean area per sunspot group (MA). They performed a maximum entropy power spectra and found peaks around 20 rotations (approximately 17 months) in the TA and MA for both hemispheres. Lean & Brueckner (1989) have analysed the daily values of the sunspot blocking function, 10.7 cm radio flux, sunspot number and plage index for cycles 19, 20, and 21, detecting a periodicity of nearby 155 days in the sunspot blocking function, the 10.7 cm radio flux and sunspot number. The periodicity is present in these signals during each of the three cycles but during cycle 20 is weaker. The periodic behaviour of daily solar flare index during solar cycles 20 and 21 has been analysed by Özgüç & Ataç (1989) finding periodicities at 1408 days and 152 days for the whole disk. For the northern hemisphere the more prominent peak appears at 564 days, while for the southern is at 152 days. When the two cycles are studied individually, the peak at 152 days is very pronounced during cycle 21 while in cycle 20 it is marginal. Finally, in a recent paper, Brueckner & Cook (1990) present evidence about the return of the 155 days periodicity in hard solar flares belonging to solar cycle 22.

The key features of solar activity are sunspots, which are a measure of the amount of magnetic flux emerging through the photosphere. Therefore, a confirmation of the presence of these periodicities in sunspot areas would indicate that they are main features of solar activity, suggesting the existence of periodicities in the emergence of magnetic flux. We have looked for these short periodicities in the historical record of sunspot areas from 1874 till 1976, rotation by rotation, covering solar cycles from 12 to 20. These data have the advantage that we can take into account the whole disk and the two hemispheres in a separate way, in order to ascertain if the periodicities are present in both hemispheres or not.

2. Power spectra of sunspot areas time series

The Greenwich Photoheliographic Results from 1874–1976 provides with the mean area of visible sunspots (umbra plus penumbra and pores included) per Carrington rotation, together with the number of days with observations during each rotation. This mean area comes separated by hemispheres, corrected for foreshortening and expressed in millionths of the Sun's visible hemisphere. Then, by multiplying the number of days of observations by the mean area, we can construct three different time series for the total sunspot areas per Carrington rotation, one for the northern hemisphere, another for the southern hemisphere and the last one for the whole disk. In order to preserve the homogeneity of the time series and taking into account that during the years 1874–1903 the number of days with observations during each rotation have been very unequal, we have constructed our time series with the data from 1904 till 1976, solar cycles 14 to 20, since during this period of time the rotations have had a number of observed days equal or greater than 26. These data are shown in Fig. 1 which displays the total area per Carrington rotation from 1904 till 1976. In order to look for the periodicities present in these time series we have performed Blackman-Tukey power spectrum of them (Blackman & Tukey 1958) using as "null" continuum the Markov "red noise" the shape of which depends on the value of lag one correlation coefficient. The procedure to compute these power spectra is as follows (Mitchell et al. 1966): Firstly, for a series of N equally spaced values we compute the serial correlation coefficients for lags 0 to m time units, where $m < N (m \simeq 0.3\,\mathrm{N})$, secondly, the cosine transform of these $m+1$ lag correlation values is computed obtaining $m+1$ "raw" estimates of the power spectrum, thirdly, the "raw" estimates are smoothed by a 3-term weighted moving average with weights equal to 1/4, 1/2 and 1/4 respectively. If the time series contains a Markov-type persistence which means a tendency for the successive values of the series to "remember" their antecedent values then the correlation coefficient for lag τ will approximate to the coefficient r_1 for lag 1 raised to the r^{th} power, if these relationships are found to be approximately satisfied and r_1 differs from zero by a statistically significant amount, then the presence of Markov persistence in the series can be assumed. When r_1 does not differ from zero significantly then the "null" continuum is that of "white noise". The significance of the deviation of prominent peaks from the Markov red noise evaluates the consistency of the spectrum with the continuum. Taking into account that each spectral estimate is distributed as χ^2/ν, being ν the degrees of freedom given by $(2N - m/2)/m$, the ratio of any sample spectral estimate to its local value of the continuum can be compared with the critical percentage – point level of a χ^2/ν distribution for the value of ν, and this comparison establishes the level of statistical significance which we require. In our computations we are using a 99% confidence level for the significance of the peaks. Furthermore, to have a comparison of our results we have performed several FFT which are shown together with the Blackman-Tukey power spectra. Firstly, we compute the power spectra of the total sunspot areas for the northern and southern hemispheres, and for the whole disk. The results are plotted in several figures with the x-axis starting at 20 cycles per 600 rotations in order to avoid the distortion introduced in the figures by the solar cycle peak. In the northern hemisphere (Fig. 2a) significant peaks, above 99% confidence level, at 3.5 and approximately 2 rotations are present. The prominent peak at 5.75 rotations corresponds, approximately, to 153 days, remaining slightly below the 99% confidence level, while the peak around 2 rotations corresponds to 54 days, perhaps the third harmonic of 153 days. A peak around 20 rotations (30 cycles per 600 rotations) can be seen but it is below the level of the red noise, this must be the same peak detected by Akioka et al. (1987) and should be related with the peaks at 564 and 552 days detected by Bai et al. (1987) and Özgüç et al. (1989) in solar flares. In the southern hemisphere (Fig. 3a), the most prominent peak occurs at 5 rotations, approximately 135 days. Other significant peaks in the power spectra of southern hemisphere are at 2.8 rotations and 2.5 rotations (second harmonic of 5 rotations). The peak around 20 rotations is weaker than in the northern hemisphere this being the same behaviour as found in Akioka's results. For the whole disk (Fig. 4a), the most prominent peak remains at 5.75 rotations. Figures 2b, 3b and 4b show power spectra computed via FFT which agree completely with the Blackman-Tukey power spectra, however, it is important to remark that the peak at 20 rotations seems to be more important than the peak at 5.75 rotations in FFT power spectra, while in the other spectra it is found to be not significant at the required level. Secondly, we have removed from the original time series long term trends by means of a first differencing, which helps to identify spurious peaks, and we have computed the power spectra of the resulting time series. Figure 5 shows that the same peaks as before remain significant, the power

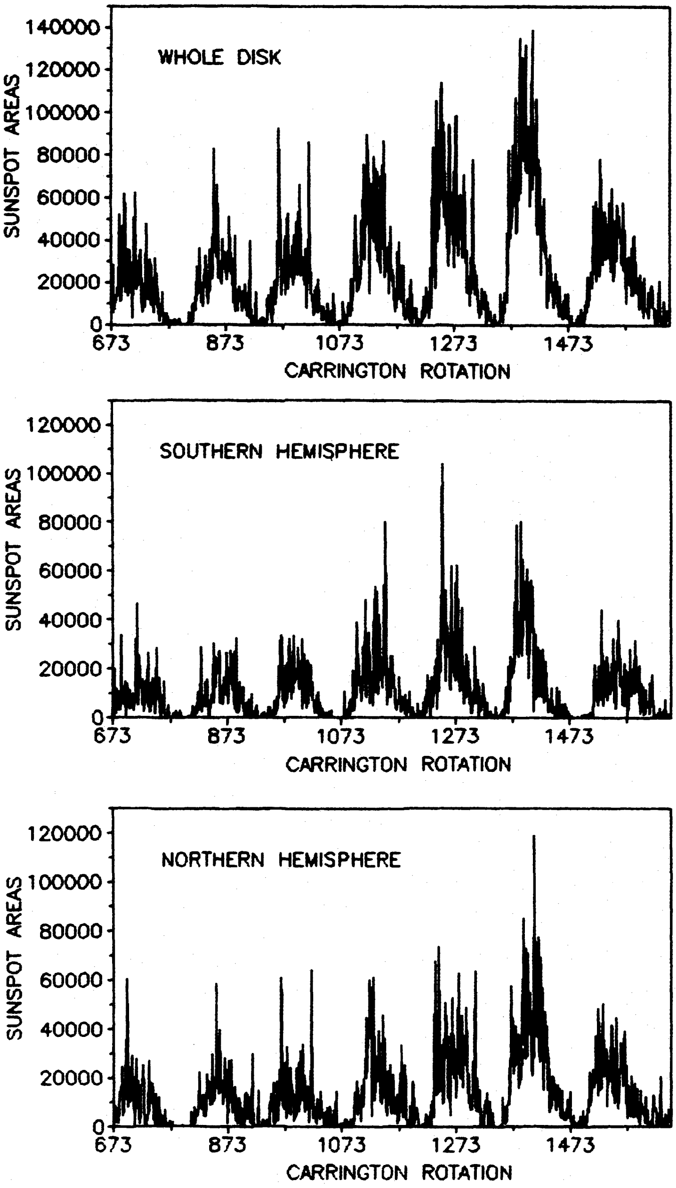

Fig. 1. Sunspot areas per Carrington rotation (1904–1976)

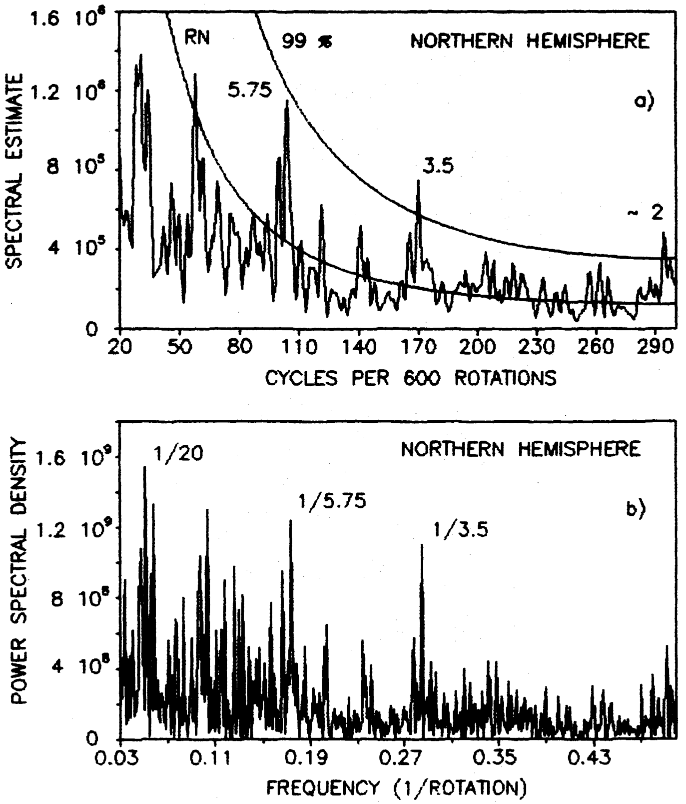

Fig. 2. **a** Blackman-Tukey power spectra of sunspot areas. **b** FFT power spectra of sunspot areas

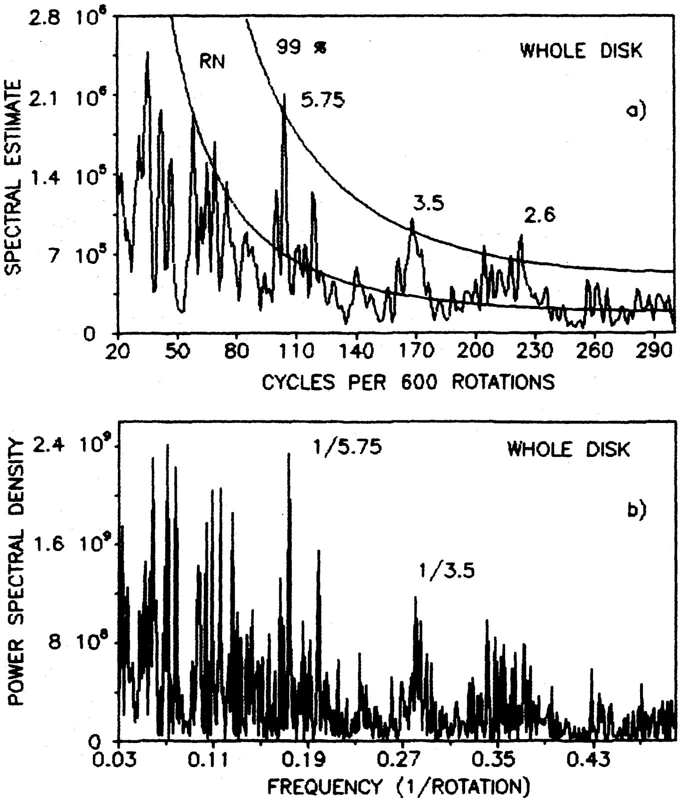

Fig. 4. **a** Blackman-Tukey power spectra of sunspot areas. **b** FFT power spectra of sunspot areas

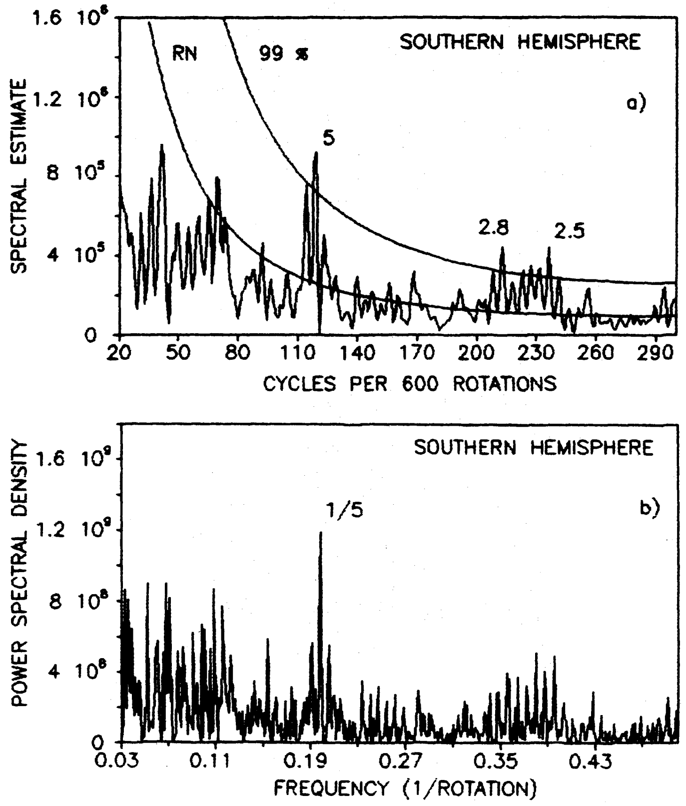

Fig. 3. **a** Blackman-Tukey power spectra of sunspot areas. **b** FFT power spectra of sunspot areas

has been redistributed because first differencing filters out long periods and amplifies short periods. Thirdly, to be sure that a periodicity suggested by a strong peak is not produced by aliasing, we remove from the original time series sine curves (Ferraz-Mello 1981; Delache & Scherrer 1983) with the period of interest; first, we have removed a sine curve with a period of 140 rotations (corresponding to the eleven years peak), and after a sine curve with a period of 5.75 rotations, then, we perform, again, the power spectra. The left-hand side of Fig. 6 shows the power spectra computed after the subtraction of a sine curve with a period of 140 rotations, the peak at 5.75 rotations has not been affected. The right-hand side displays the power spectra computed after the subtraction of the two sine curves, the second one with a period of 5.75 rotations. In this case the power at 5.75 rotations has decreased in a significant way which means that the peak is not due to aliasing. Moreover, we have computed a power spectra of umbral areas for the same period of time, the result, shown in Fig. 7, indicates that the peak at 5.75 rotations is even more significant than in the case of the total areas.

3. Conclusions

Our aim has been to look for the existence of the short periodicities around 155 and 540 days in one of the key features of solar activity, sunspot areas. The results show that during cycles 14–20 a significant peak around 155 days is present in the power spectra of sunspot areas when we consider the whole disk or the northern hemisphere, while in the southern hemisphere is not significant at all. However, a significant peak at 2.8 rotations, probably

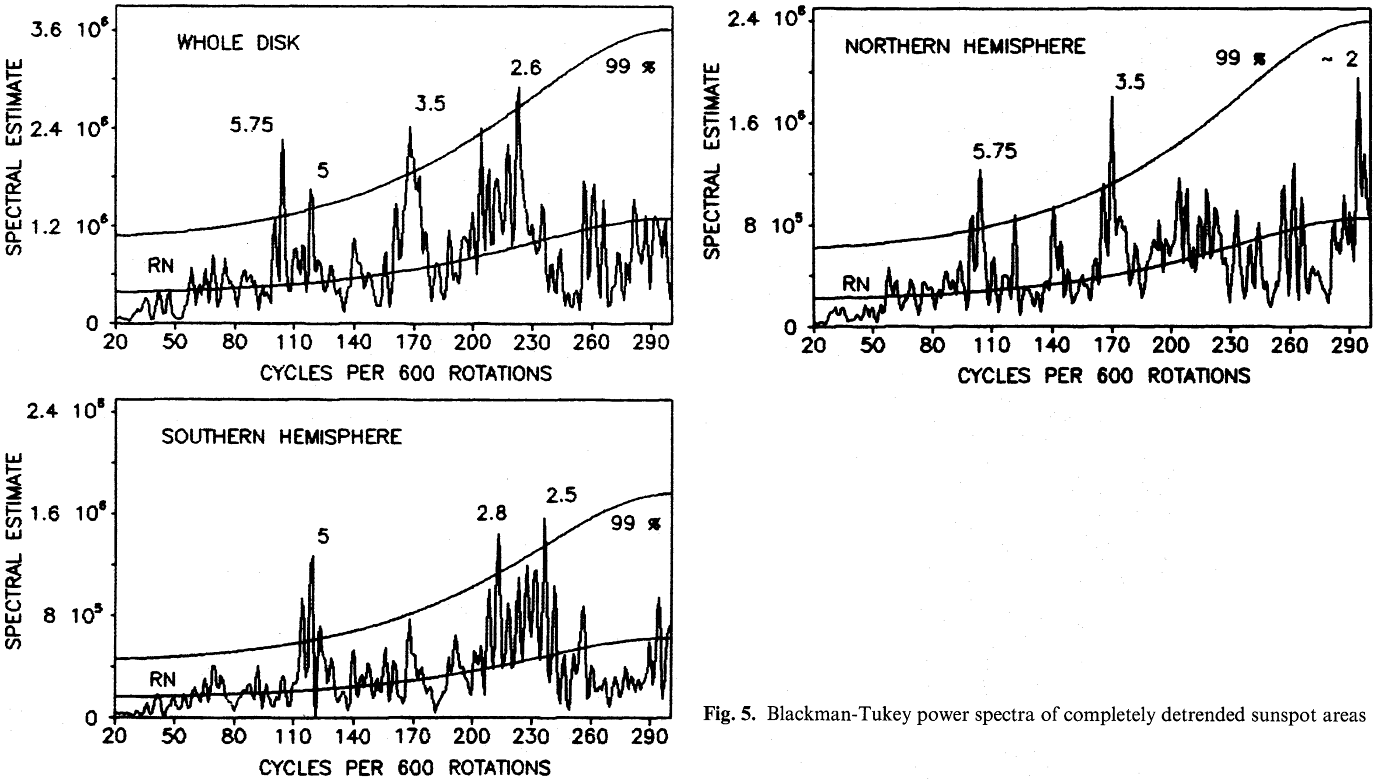

Fig. 5. Blackman-Tukey power spectra of completely detrended sunspot areas

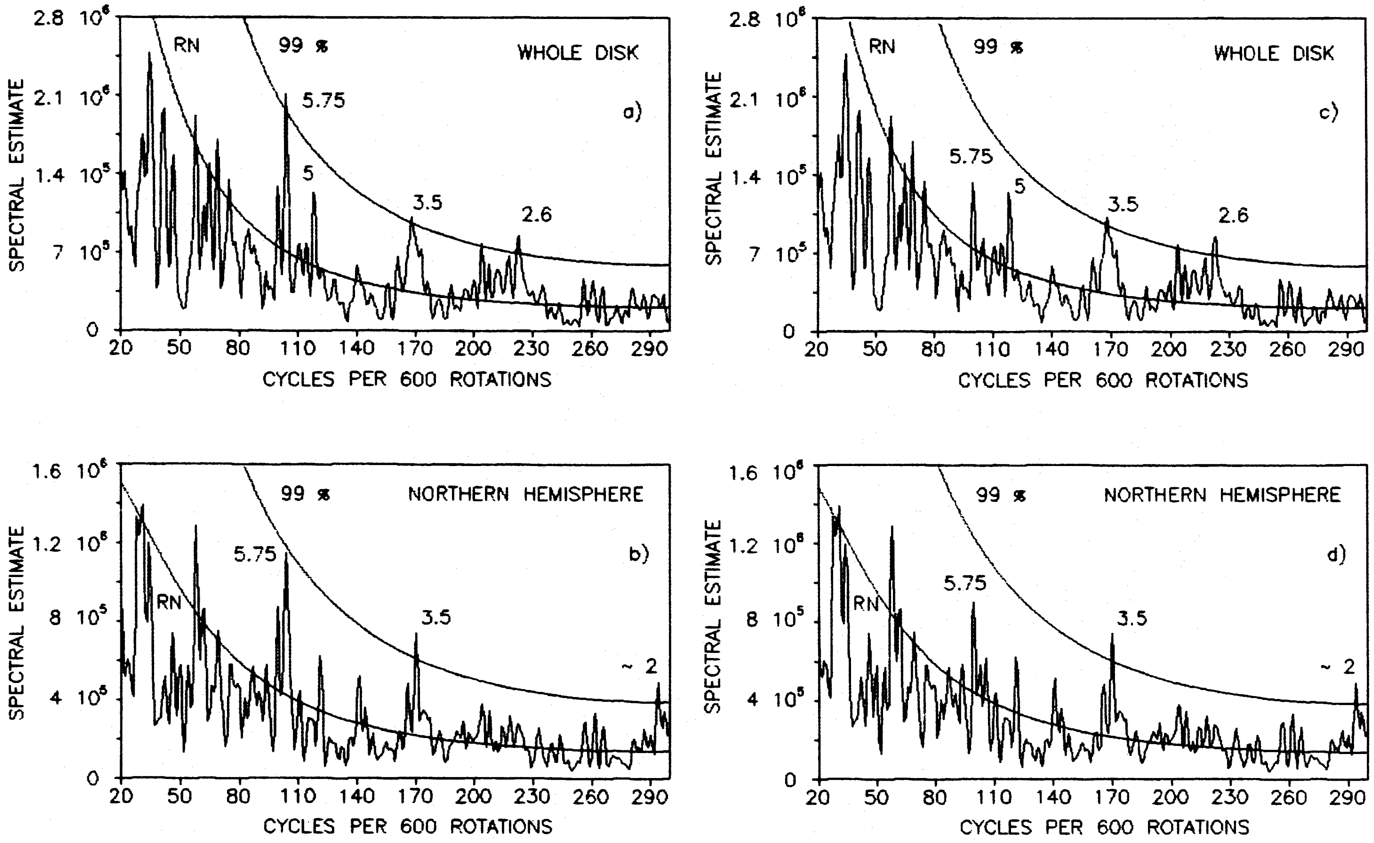

Fig. 6a–d. a, b Blackman-Tukey power spectra of sunspot areas after subtraction of a sine curve with a period of 140 rotations. **c, d** After subtraction of two sine curves with periods of 140 and 5.75 rotations

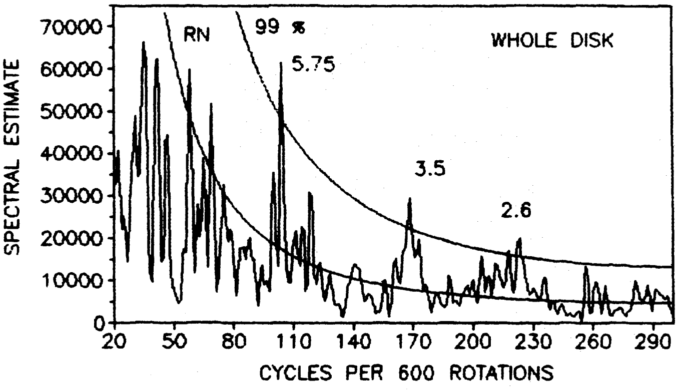

Fig. 7. Blackman-Tukey power spectra of umbral areas

corresponding to the second harmonic of 5.75 rotations, is present in the power spectra of sunspot areas belonging to the southern hemisphere. The peak at 20 rotations is present in the Blackman-Tukey power spectra, exactly at the same position as in the power spectra computed via FFT, for the whole disk and northern hemisphere but it is not significant at all because it remains below the "red noise" level, so, further work is needed in order to assess if this peak is a real periodicity. On the other hand, there is observational evidence which suggests that many Hα flares seem to occur when new flux emerges, within pre-existing magnetic regions, and reconnects with the old flux (Martin et al. 1984). Theoretical models have been set up to explain how the emergence of new flux through the photosphere could give rise to small flares and, even, to trigger large flares (Priest 1986). It follows that the presence of this short periodicity in the most characteristic feature of solar activity, which is a measure of the emerging flux, could point out the existence of a periodicity in the emergence of magnetic flux, which could produce the similar one found in solar flares. This result together with the fact that sunspot areas have presented a clear North-South asymmetry (Vizoso & Ballester 1990) during most of the period considered here, allow us to conclude that the emergence of magnetic flux is asymmetric, between hemispheres, and present, as well as the well-known periodicity of eleven years, short-term periodicities. Furthermore, these results indicate the need to perform a complete analysis of the historical daily record of sunspot areas in order to: a) confirm definitively the existence of the periodicity near 155 days, b) determine with accuracy, thanks to a higher resolution, its exact position in the power spectrum, and c) study its behaviour during the different cycles. On the other hand, the other short periodicities found to be significant in our power spectra also deserves further study in order to confirm their existence and significance.

References

Akioka, M., Kubota, J., Suzuki, M., Ichimoto, K., Tohmura, I. 1987, Solar Phys. 112, 313
Bai, T., Sturrock, P.A. 1987, Nature 327, 601
Blackman, R.B., Tukey, J.W. 1958, The Measurement of Power Spectra, Dover, New York
Bogart, R.S., Bai, T. 1985, ApJ 299, L51
Brueckner, G.E., Cook, J.W. 1990, ApJ 350, L21
Delache, P., Scherrer, P.H. 1983, Nature 306, 651
Ferraz-Mello, S. 1981, AJ 86, 619
Ichimoto, K., Kubota, J., Suzuki, M., Tohmura, I., Kurokawa, H. 1985, Nature 316, 422
Lean, J.L., Brueckner, G.E. 1989, ApJ 337, 568
Martin, S.F., Bentley, R.D., Schadee, A., Antalova, A., Kucera, A., Dezso, L., Gesztelyi, L., Harvey, K.L., Jones, H., Livi, S.H.B., Wang, J. 1984, Adv. Space Res. 4, 61
Mitchell, J.M., Dzerdzeevskii, B., Flohn, H., Hofmeyr, W.L., Lamb, H.H., Rao, K.N., Wallen, C.C. 1966, Climatic Change, WMO Publ. No. 195, Geneva
Özgüç, A., Ataç, T. 1989, Solar Phys. 123, 357
Priest, E.R. 1986, Adv. Space Res. 6, 73
Rieger, E., Share, G.H., Forrest, D.J., Kanbach, G., Reppin, C., Chupp, E.L. 1984, Nature 312, 623
Vizoso, G., Ballester, J.L. 1990, A & A 229, 540