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THE 50-DAY OSCILLATION IN THE EARTH'S ROTATION, ATMOSPHERIC ANGULAR MOMENTUM AND SOLAR ACTIVITY

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SUMMARY: The spectral analyses of Length of Day, Atmospheric Angular Momentum, Wolf numbers and Corona indices series are performed mainly to get additional information about the stability in frequency and amplitude of the Madden-Julian oscillation (MJO). Our study confirms the presence of several spectral concentrations between 40 and 60 days with the predominating ones around 40 and 50 days. In particular the correlations, both in amplitude and phase, between the 50-day oscillation in the Earth rotation, the Atmospheric Angular Momentum, Wolf numbers and Corona indices are investigated. The results obtained support the hypothesis of the solar contribution in short-period fluctuations of the Atmospheric Angular Momentum and the Earth's rotation.

Besides, two possible mechanisms of the solar activity transfer to the tropospheric circulation and the Earth's rotation are described.

1. INTRODUCTION

In recent years the 50-day oscillation has become a topic of particular interest in meteorology, astronomy and precise space geodesy. It was first observed in tropical atmospheric circulation (Madden and Julian, 1971) and later confirmed in the Atmospheric Angular Momentum (AAM) and the Length of Day (LOD) determined by classical astrometry methods. It was pointed out that its period spans from 40 to 60 days with an amplitude of a few tenths of a millisecond of time. In comparison with classical astronomical techniques, the new ones such as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR) and Global Positioning System (GPS), have improved the precision of the Earth rotation measurements by one to two orders of magnitude. Besides, the increased time resolution of the Earth's rotation parameters allows us to study the finer features of the MJO oscillation.

Nowadays it is well established that a close relationship exists between the rotation of the solid Earth and the atmospheric angular momentum from the annual period down to periods of few days. Several studies on LOD variations have been carried out to determine the degree of coherence between LOD and AAM .In an interval of 40 to 60 days, progresses have also been made to understand the origin of LOD variations.

Hide *et al.* (1980) indicated that LOD fluctuations are well correlated with variations observed in the axial component of AAM. Rosen *et al.* (1990) concluded that the coherence between non-tidal LOD and AAM is greater than 0.6 for all periods between 15 and 150 days. Eubanks *et al.* (1985) demonstrated that a broad peak between 40 and 60 days in the spectrum of UT1-TAI does not seem to reflect a true periodic fluctuation; indeed spectral power maxima are observed around 59.5, 55, 51, 48 and 44 days. Dickey *et al.* (1990) found two periods of MJO : 50 days, when the prevailing zonal winds flow in the equatorial zone (between 10^0 S and 10^0 N latitude), and 40 days when the prevailing zonal winds flow outside this latitude.

In the present paper we analyse the 50-day oscillation in LOD, AAM, Wolf number (W) and Corona Index (Ci) with the purpose of getting new information about the MJO origin and its instability in amplitude and frequency.

2. DATA SETS

The following data series from 1976.07.01 to 1992.12.31 are used in the subsequent spectral analysis:

2.1 LOD series of the Bureau International de l'Heure (BIH) and International Earth Rotation Service (IERS).

Since 1972, the observation of the Earth's rotation (UT1-TAI) has been performed both by classical astronomical and modern geodetic space techniques (VLBI, LLR, SLR). For the period 1972 - 1988 the various observations were combined by the BIH to provide time series of one raw value every 5 days. After 1988 only the new techniques (VLBI, SLR, LLR) were adopted by IERS (International Earth Rotation Service). LOD series are obtained from the differences of $UT1^*$-TAI at intervals of 5 days with the expression:

$$LOD^*(t) = -LOD_0 \cdot \frac{(UT1^* - TAI)(t) - (UT1^* - TAI)(t - \Delta t)}{\Delta t}. \quad (1)$$

where Δt is the time interval in seconds between the epochs of the successive estimates of ($UT1^*$-TAI); $UT1^*$ indicates that the observation have already been corrected for annual and semiannual tides as well as for the diurnal nutation; effects of the predictable zonal tides have been removed according to Yoder *et al.* (1981).

2.2 AAM series.

The longest series of AAM was supplied by U.S. National Meteorological Center (NMC); data are available from July 1976. The NMC wind estimates are integrated to 100 mbar and provided twice daily. Data up to 1992 were kindly sent by Dr.Rosen. The angular momentum of the atmosphere around the polar axis relative to an Earth-fixed frame (M) is approximated by the following expression (Rosen and Saltein, 1983):

$$M = \frac{2\pi}{g} a^3 \int \int [u] \cos^2 \phi d\phi dp \quad (2)$$

where a, g, p, ϕ and u are the mean radius of the Earth, gravity acceleration, the air pressure, latitude and eastward component of the wind, respectively. The relation between the variation ΔM of AAM and the angular acceleration of the Earth is represented by :

$$\Delta\omega = -\Delta M / I_{shell} \quad (3)$$

where I_{shell} is the principal (axial) moment of inertia of the Earth's crust and mantle, i.e., the core is excluded. If $\omega = 7.29 \times 10^{-5} s^{-1}$, LOD=86400 s, and Δ M is expressed in units of $kgm^2 s^{-1}$, the LOD variation due to the atmospheric circulation (ΔLOD_{atm}) can be obtained from:

$$\Delta LOD_{atm} = 1.68 \times 10^{-29} \Delta M \quad (4)$$

Using expression (4) a ΔLOD_{atm} can be deduced from the Δ M series.

2.3 W series.

Two daily WOLF numbers series (W) for the period 1956.0-1992.0, analysed in the present work, have been published by the Sunspot Index Data Centre (Koeckelenberg 1986). A series with one value every 5 days has been deduced from the daily series by a spline interpolation.

2.4 Ci series.

It is another solar activity index. The green corona emission at the FeXIV (λ = 5303 nm) line is represented by Ci series (Rybansky, 1979; Rybansky *et al.* 1983, 1988, 1990) computed by using Rybansky's method (1975). Daily Ci data have also been arranged in 5 day intervals.

3. ANALYSIS METHODS

To determine the components of the signals above, regression analysis and cross correlation methods are used. In the frequency domain MJO parameters are computed by the Fast Fourier Transform (FFT) and the autoregressive spectrum (AR).

The shortcoming of the two methods used lies in the assumption that the signals are stationary and can be represented as the sum of sine or cosine functions. As mentioned above, these assumptions are strictly not valid for MJO, but as it was shown in Djurović *et al.* (1994), the Wavelet Transforms and classical methods give consistent results.

In the interval of 40 to 60 days the oscillation will be analysed both in the time and frequency domains.

Prior to spectral analysis, Vondrak narrow band pre-filter is applied to the four series (Whitaker and Robinson, 1946; Vondrak, 1969, Zheng *et al.* 1986); the coefficient of selectivity E, is chosen to be equal to 0.2310×10^{-3} and 0.5794×10^{-6}, which corresponds to a cut off at 40 days and 60 days, respectively.

4. RESULTS OF THE ANALYSIS

4.1 Analysis of the spectrum between 40 and 60 days of LOD$_{BIH}$, AAM, W, Ci series.

In order to study the time stability of the MJO frequency, both in amplitude and phase, the observation period (1976-1992) was divided into 33 subintervals of 465 days; they were shifted with respect to each other by 180 days. Since LOD_{BIH}, W and Ci showed considerable variations with a period around 27 days, related to the lunar tides and solar rotation, this oscillation is removed by computing the differences:

$$DR(i) = R(i + 27) - R(i)$$

where $R(i)$ are the original data of the three series concerned.

The goal of this computation was to obtain a clearer spectrum in the range 40 to 60 days. The Marple (1980) algorithm process of AR (autoregressive) spectrum and FFT spectrum are widely accepted for various data analysis. First the Marple algorithm of AR is used in the present study for the computation of the spectra for 33 series of LOD_{BIH}, AAM, W, CI.

These spectra are given in Figure 1 (a, b, c, d).

In the time span 1967-1992, there are two predominating dark bands due to oscillations with periods around 35 and 50 days. A conclusion which is also evident from the above results is that periods and amplitudes are changing with time.

It is worth mentionning that the results of Figure 1 are in agreement with the results obtained by Morgan *et al.* (1986), Djurović and Pâquet (1988), Dickey *et al.* (1990), who pointed out the large instability of MJO frequency and amplitude. The results obtained by the Marple algorithm of AR confirm the existence of two prevailing oscillations (at 38 and 53 days) rather than a single one with a continuously variable period.

FFT spectra of the 4 series are given in Fig. 2 (a, b, c, d). In each spectrum the statistically significant peaks around 53 and 38 days are present. Maxima over 60-70 days appear in LOD_{BIH}, AAM, and CI spectra. Bearing in mind the results of Fig. 1 they are probably due to the frequency variation of the prevailing 50-day oscillation. The 53-day peak is larger and more significant than the 38-day one.

To examine whether the perturbation of the 50-day oscillation parameters (period, amplitude, phase) is related to the solar activity, the data were divided in 465-day sub-series shifted by 180 days with respect to each other. The least squares parameters of the best sinusoid were then computed for each sub-series and the period was varied in such a way that the best fitting corresponded to the minimum obtained for the standard deviation. The results are given in Fig. 3 (a, b, c) for the two longest series LOD_{BIH} and W.

In 1985, 1987 and 1988, the peaks of LOD are small and no correlations with sunspot cycles are noticeable. On the other hand, in 1979, 1981 and 1990 large variations are seen in both related series.

From the above results, a link seems to exist between the solar activity and LOD which confirms the hypothesis of Djurović and Pâquet (1988, 1989, 1993, 1995), Djurović *et al.* (1994), about the relation between solar activity and Earth rotation perturbations. Let us remember that Danjon (1960) suggested that there was an increase in LOD when the nucleonic component of solar cosmic rays increased intensity. Challinor (1971) also found hints of a relationship between LOD_{BIH} and cosmic ray activity. He assumed that the circulation of the atmosphere, influenced by solar variation, generates a couple on the solid Earth surface which in turn induces a variation of the Earth's rotation rate.

4.2 Cross correlation.

To examine the statistical dependence between the above mentioned common fluctuations, the cross-correlation between all the series is computed. The cross-correlation coefficients are given in Table 1. As expected the strong correlation between LOD_{BIH} and AAM variations is confirmed. The maximum of the cross-correlation coefficient is for the lag $\tau = 0$.

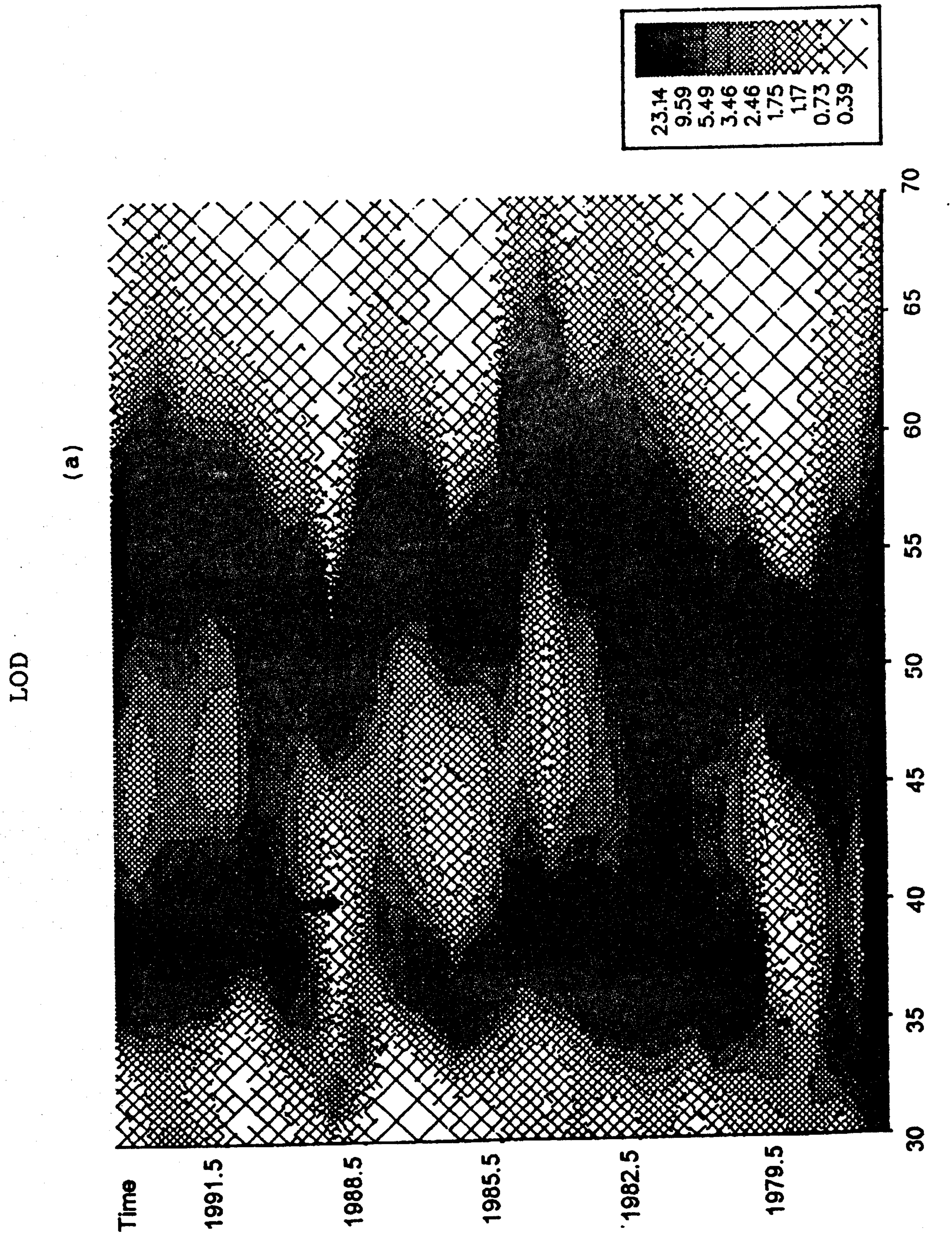

Fig. 1(a). Spectra obtained by the Marple algorithm applied on 33 series of LOD_{BIH}, covering the period 1976 - 1992.

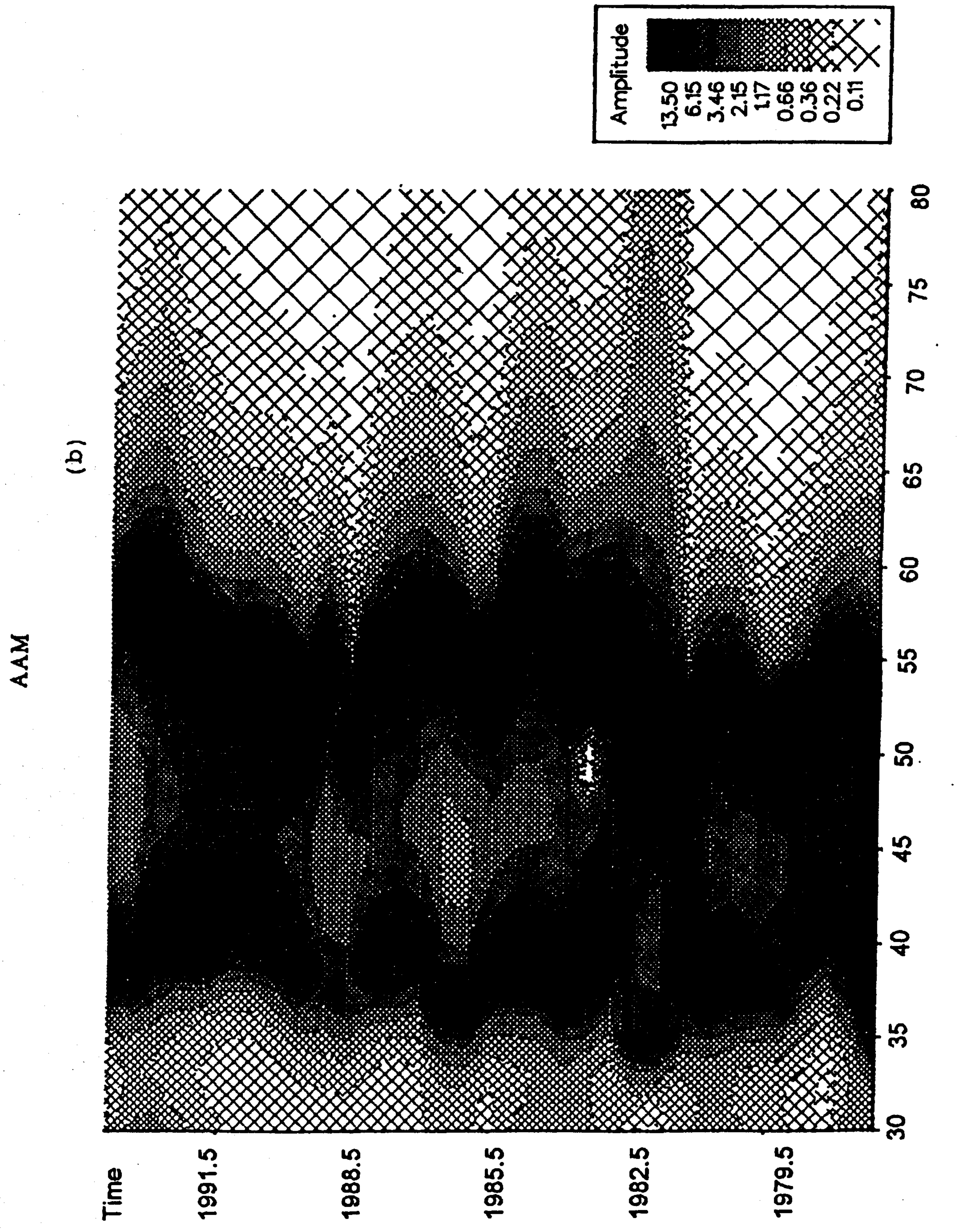

Fig. 1(b). Spectra obtained by the Marple algorthm applied on 33 series of AAM, covering the period 1976 - 1992.

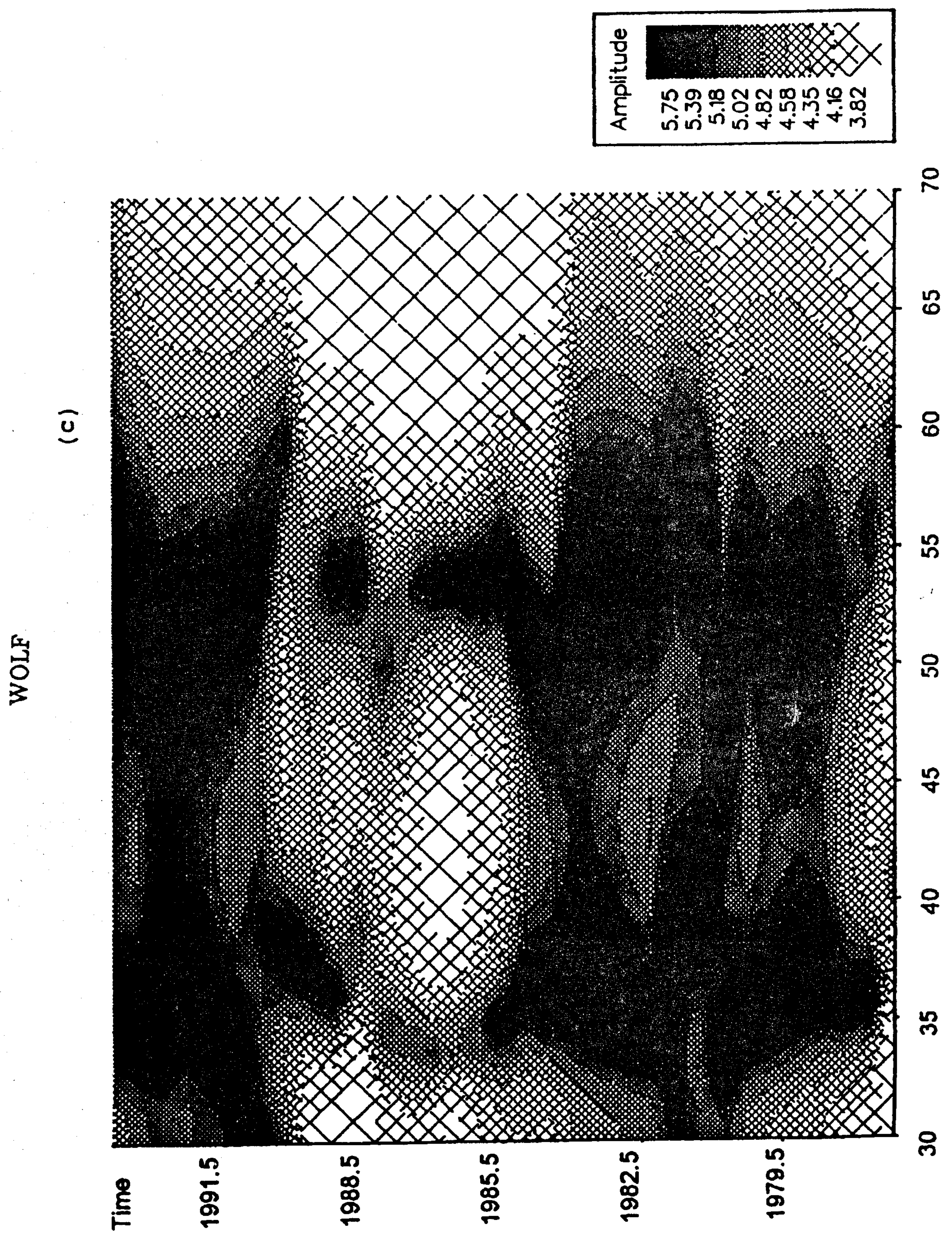

Fig. 1(c). Spectra obtained by the Marple algorithm applied on 33 series of Wolf numbers (W), covering the period 1976 - 1992.

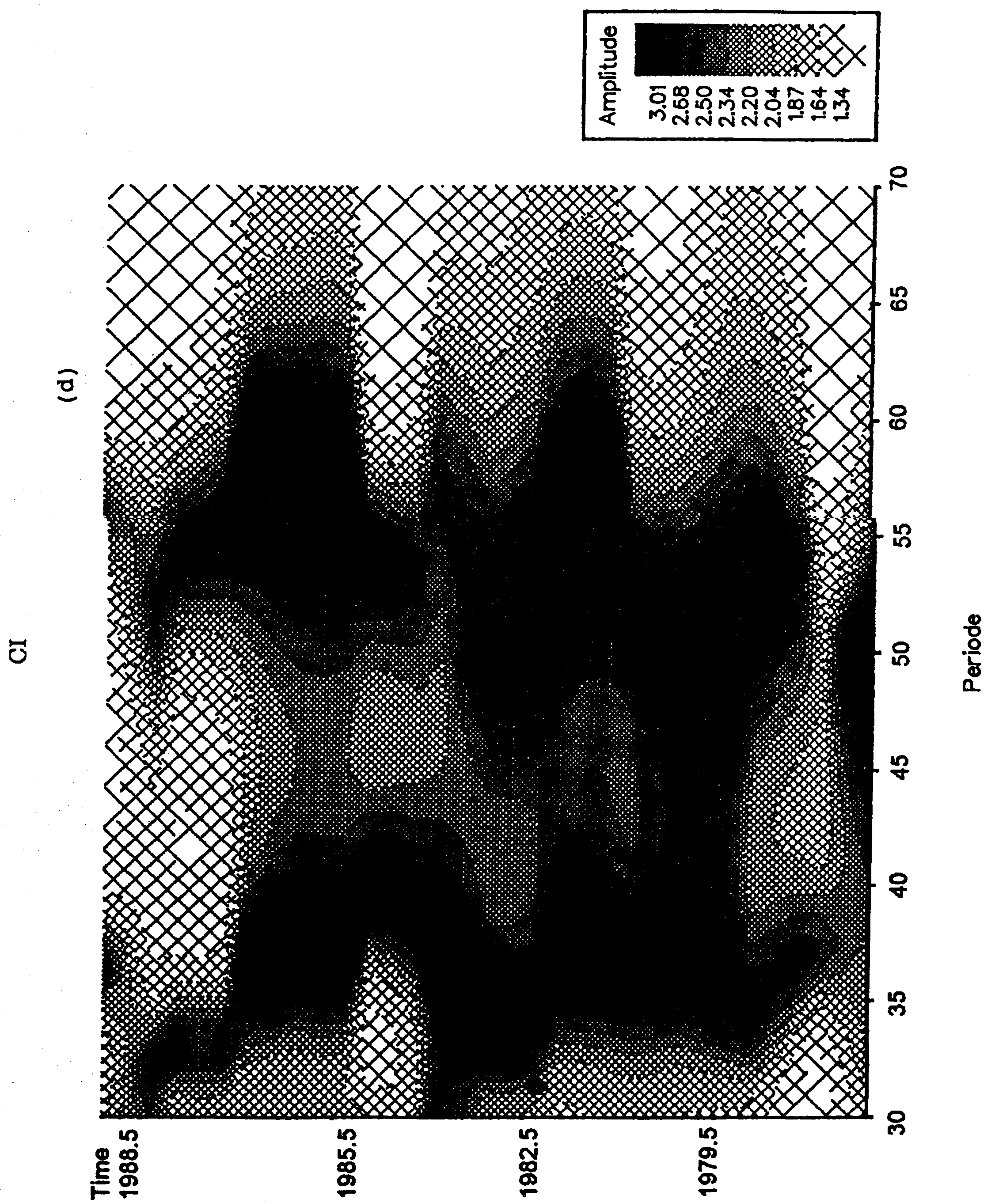

Fig. 1(d). Spectra obtained by the Marple algorithm applied on 33 series of green corona emission (CI), covering the period 1976 - 1992.

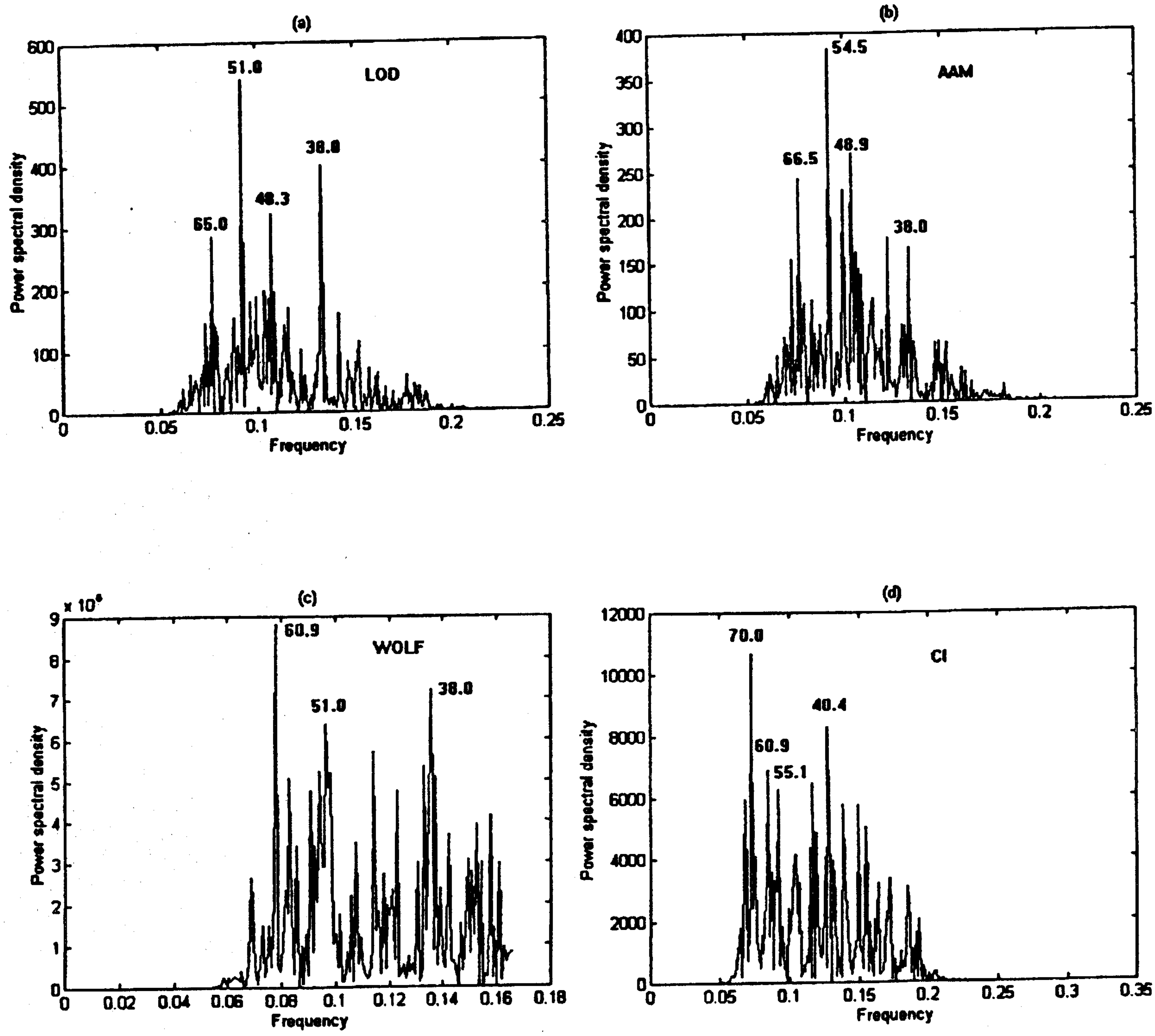

Fig. 2(a, b, c, d). FFT spectra of LOD_{BIH}, Wolf numbers (W), Atmospheric Angular Momentum (AAM) and green corona emission (CI).

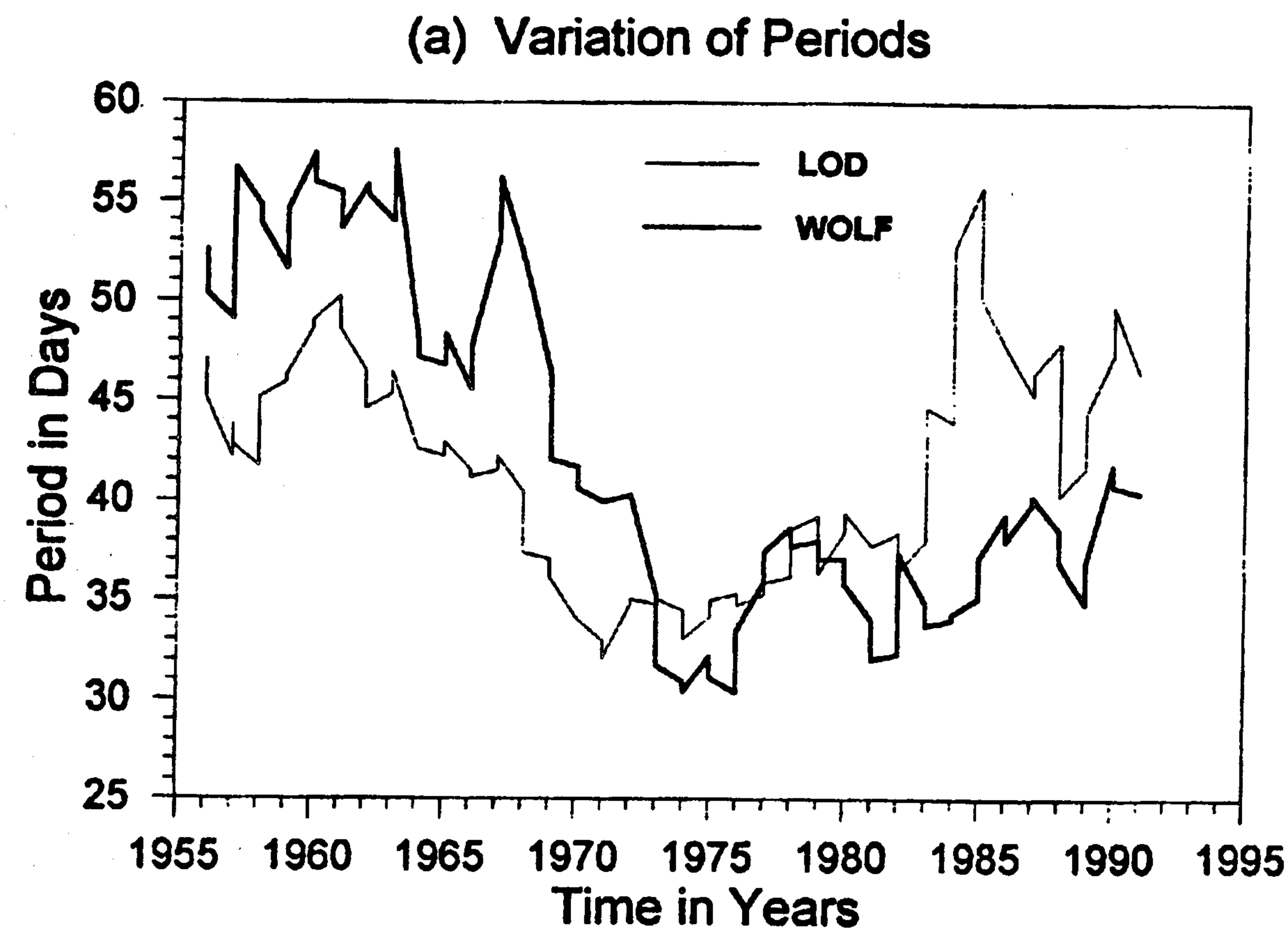

Fig. 3(a). Time variation of period of LOD and W series composed of 465 days, first data of each series are separated by 180 days.

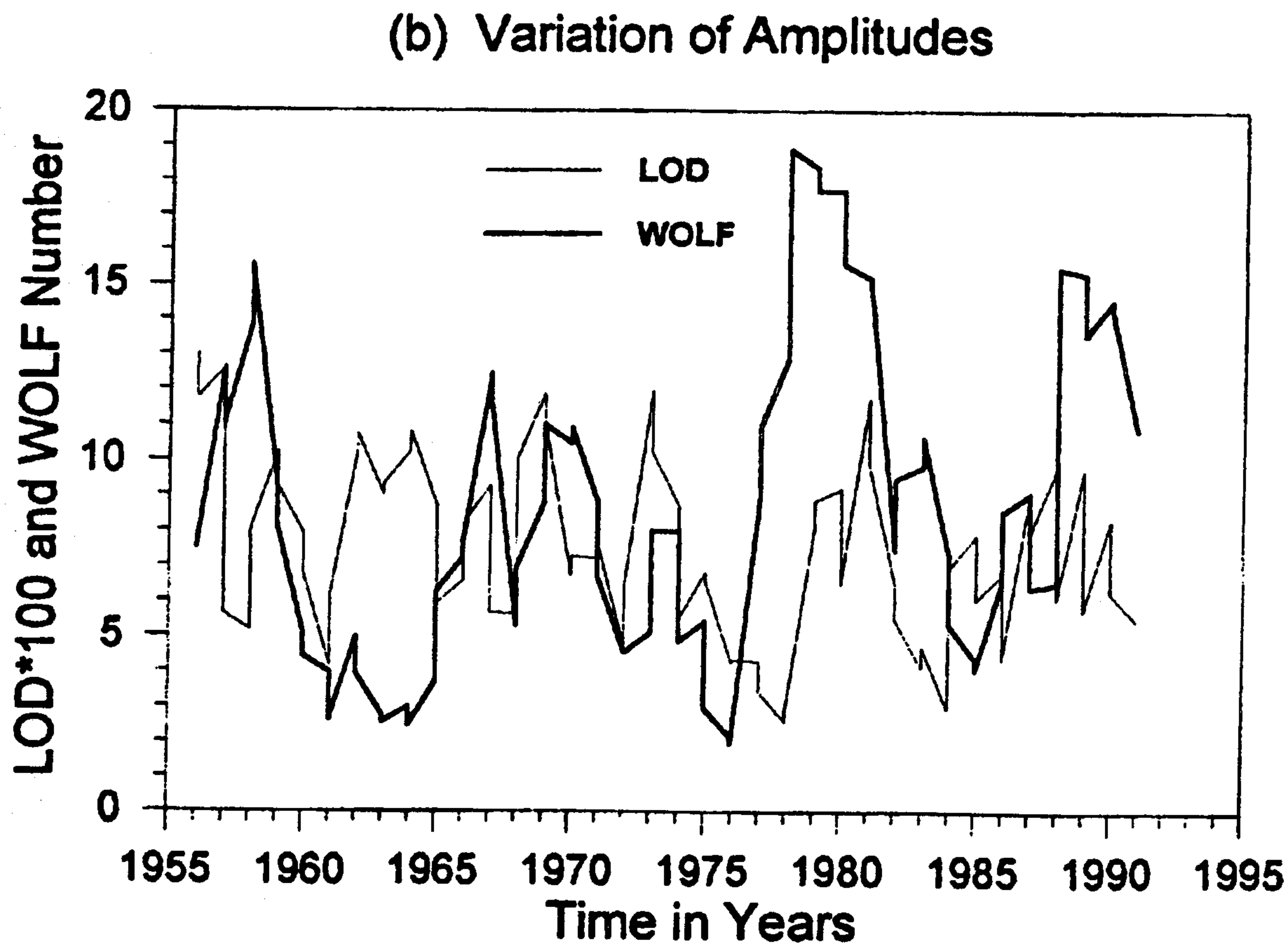

Fig. 3(b). Time variation of amplitude of LOD and W series composed of 465 days, first data of each series are separated by 180 days.

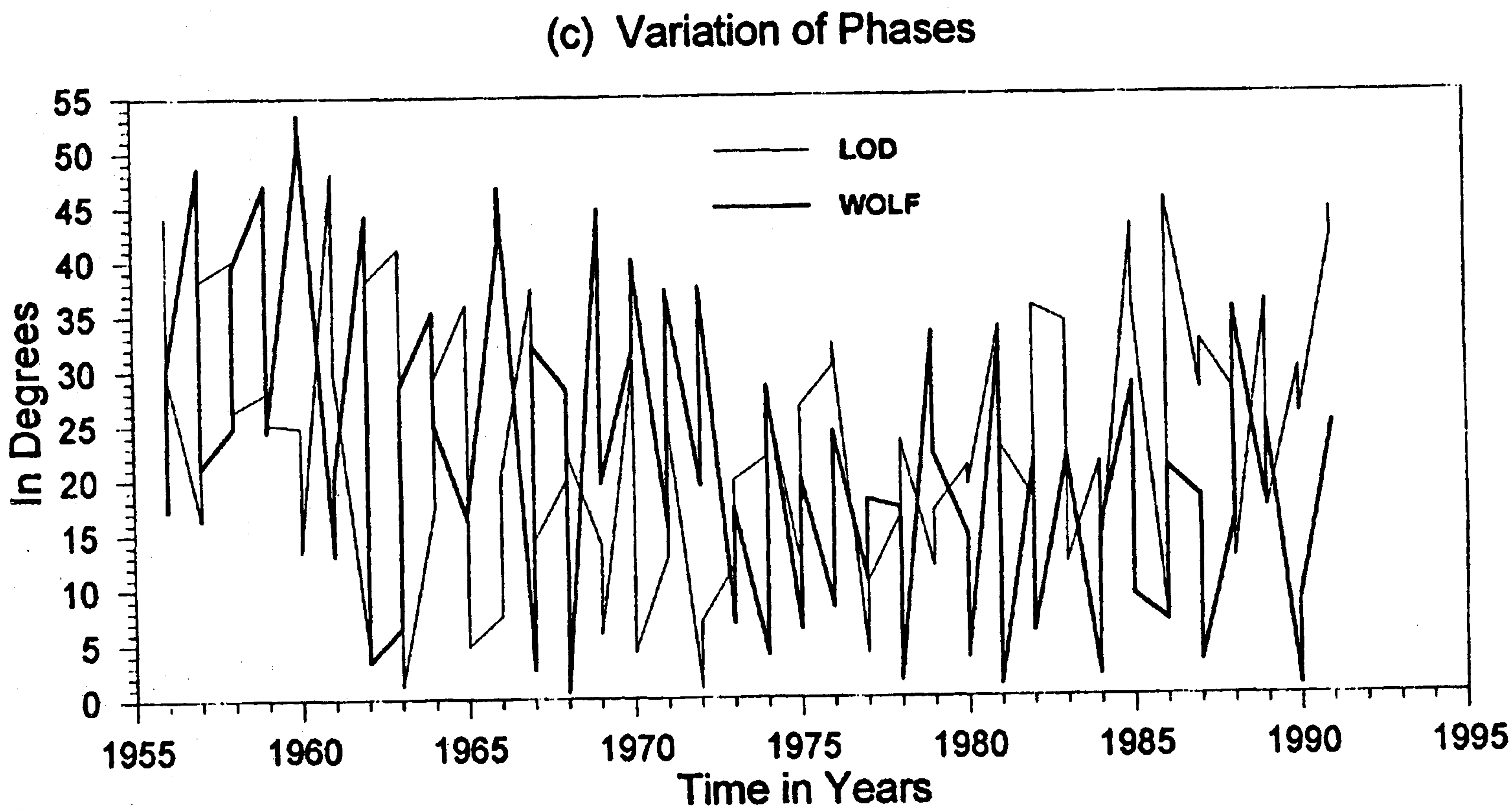

Fig. 3(c). Time variation of phase of LOD and W series composed of 465 days, first data of each series are separated by 180 days.

Table 1. Maximum value and phase lag τ (in days) of the cross correlation function

series	r	τ	N	$Pb.$
LOD_{BIH}/AAM	0.83	0	1206	0.99
LOD_{BIH}/W	−0.17	11	1181	0.99
LOD_{BIH}/Ci	−0.18	10	840	0.99
AAM/W	0.15	−37	1181	0.99
AAM/Ci	−0.20	29	840	0.99
W/Ci	0.17	0	840	0.99

In the above Table N is the number of data pairs, Pb - the probability minimum for the statistical significance of r.

Therefore, the atmosphere is the main source of the short-period variations in LOD_{BIH}. The correlation coefficients for the other series combinations are small but statistically significant.

5. DISCUSSION

From the results obtained in this work one can confirm the large instability of the MJO period with two concentrations of the power spectra: around 40 and 50 days, approximately. The concentration at 60-70 days is not sufficiently argumented.

The origin of the MJO is still not known. So, Ghil and Childress (1987), Dickey *et al.* (1990) proposed that the instability of non-zonal westerly flow, generated by a viscous couple between the jetstream and Earth topography is the main mechanism in extratropical regions.

Kosek (1987) suggested a possibility that the global thermospheric circulation, which is caused by the solar wind as well as by the solar ultraviolet and extreme ultraviolet radiations through upper atmospheric ionization, can transfer heat to stratospheric and tropospheric gases. It would be responsible for the perturbations of the Atmospheric Angular Momentum, which induce changes in the Earth rotation.

Djurović and Pâquet (1988) gave an up-to-date discussion taking solar activity as a possible origin of LOD_{atm} and LOD_{BIH} periodic variations.

To follow the time variations of the 50-day oscillation, period and amplitude are estimated for 465-day subseries, shifted by 180 days. The variations in LOD_{BIH} and W series are correlated; the correlation coefficient for amplitude variations of the 50-day oscillation in LOD and W series is -0.31 ($n = 93$); the maximum occurred during the odd cycle of solar activity, in particular, the extrema are well pronounced during 1957-58 and 1980-81. It is shown that LOD becomes shorter when the sunspot number increases, which means the solar activity accelerates the rotation of the Earth with a 50-day oscillation. A maximum in the correlation coefficient between amplitudes occurred at solar even cycles, in 1968-69 and 1990-91. The correlation is also significant between the periodic variations of AAM and W. The minimum of a 50-day fluctuation occurred in 1975-76. Therefore, according to these results the 50-day oscillation in AAM is caused by solar activity and, of course, reproduced in the Earth's rotation.

A theory which could be widely accepted as an explanation of the solar activity-atmospheric circulation-Earth's rotation relations does not exist yet. However, one possible explanation how solar activity acts on the Earth's rotation is described below.

A variation of cosmic-ray intensity changes ionization and a decrease in cosmic-ray intensity following sunspot activity was observed by Forbush (1954). This phenomenon could be explained if the Earth is enveloped by a plasma cloud ejected from the Sun as a consequence of sunspot activity; the surrounding magnetic field prevents the cosmic rays from reaching our planet (Morrison,1956). Meanwhile, magnetospheric activity driven by high-speed streams of solar wind results in a geomagnetic storm which starts with a compression of the magnetosphere during the course of a storm, with enhanced ring current intensity. The ionospheric current region will move towards the equator and greatly broaden. From the satellite OGO-3 observation data (Frank *et al.* 1970) it is shown that during the main phase of the storm, the proton flux of ring currents is enhanced by 7 times or even more. However, the geomagnetic storm also produces a variation of the atmospheric electrical conductivity. Due to both ionization and conductivity of the atmosphere which control currents and electric field intensity, this variation generates a sudden formation of cirrus clouds and variation of cirrus clouds covering areas. Therefore, it leads to the variation of the Earth's albedo. In this case, it has an impact on the tropospheric circulation and produces an abrupt change of the Vorticity Area Index (VAI) (Wilcox *et al.* 1976). In this respect it is worth pointing out that the existence of the 50-day component in cirrus cloud observations is accepted (Liou, 1973). Moreover, Klett (1981) reviewed the electrical processes in clouds, and recognized in fact that there is a good correlation between storm and solar event.

Danjon (1960) and Cribbin *et al.* (1973) examined the relation between large solar storms and LOD variations. They recognized that the LOD increases when the nucleonic component of solar cosmic rays increased.

A decrease in cosmic-ray intensity following an increase in sunspot activity was observed by Forbush (1954). So, these results are in agreement with the previous discussion.

One other explanation of the above correlative evidence is that the ozone response to solar ultraviolet variation is accompanied by a temperature response in the upper stratosphere. So, from Nimbus 7 solar backscattered ultraviolet (SBUV) (Hood *et al.* 1991), solar 205 nm flux measurement in the 1-3 mbar pressure range yields significant coherence at periods near 27 and 13 days during 1980-81 maximum solar activity.

Since the Earth's atmosphere is a complicated system with its own internal variations and responses driven by solar heating, atmospheric electrical and ionization states induced by cosmic-ray intensity and geomagnetic storms, today we are still far from undestanding the whole set of processes between the Sun and the Earth's troposphere.

6. CONCLUSIONS

On the basis of the above results, the following conclusions about the 50-day oscillation could be proposed:

1. The existence of 40 to 60-day oscillation in LOD, AAM, W and Ci is probably real: that is confirmed by two methods of spectral analysis.
2. The amplitude and the period of MJO are variable in time. The strongest circulation occured at the periods of 38 and 53 days.
3. The correlations between LOD, AAM, W and Ci are statistically significant. These correlations are stronger during the stronger solar activities.
4. The maximum amplitude of the 50-day oscillation in Wolf number are observed when the variations of LOD were decreasing. This relation is better pronounced in odd-numbered cycles than in even-numbered ones. So, it might be connected with the Hale-Nicholson cycle.

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ПЕДЕСЕТОДНЕВНА ОСЦИЛАЦИЈА У ЗЕМЉИНОЈ РОТАЦИЈИ, АТМОСФЕРСКОМ МОМЕНТУ КОЛИЧИНЕ КРЕТАЊА И СУНЧЕВОЈ АКТИВНОСТИ

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Оригинални научни рад

Ради изучавања стабилности фреквенције и амплитуде Madden-Julian-ове осцилације (MJO) анализирани су спектри дужине дана (LOD), атмосферског момента количине кретања (AAM), Wolf-овог броја (W) и индекса Сунчеве короне (Ci). Овом анализом је потврђено постојање неколико спектралних концентрација између 40 и 60 дана, са доминантним концентрацијама на 40 и 50 дана.

Посебна пажња посвећена је корелацијама између промена амплитуде и фазе MJO у LOD, AAM, W и Ci. Резултати овога рада подржавају хипотезу о утицају Сунчеве активности на атмосферску циркулацију и Земљину ротацију.

Поред горњих резултата, описана су и два механизма за трансфер Сунчевог зрачења на тропосферску циркулацију и Земљину ротацију.