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A 120-day oscillation in the solar activity and geophysical phenomena

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Summary. The periodic fluctuation of the Universal Time, with a period of 120 days, is first confirmed. The same fluctuation is identified in the atmospheric angular momentum, the geomagnetic index, the solar activity and the interplanetary magnetic field. The existence of this particular component both in solar and geophysical phenomena, associated with other analysis establishing the excitation of the troposphere by the interplanetary magnetic field conducts to the conclusion that its origin lies in physical processes in the Sun.

Key words: Earth's rotation – atmospheric angular momentum – sunspots – interplanetary magnetic field – geomagnetic field

1. Introduction

From an analysis of the Universal Time data (UT_2) performed by the Soviet Time Service, Belocerkovsky (1963) detected a quasi-harmonic 3-month fluctuation with an amplitude of the order of 2 ms.

Using the observations collected by the Bureau International de l'Heure (BIH), Djurovic (1970, 1974) recomputed the (x, y) coordinates of the pole as well as UT_2 and found a quasi-periodic variation of 122 days with amplitudes of 2 ms in UT_2 and a few milliarcsec (mas) in (x, y). The existence of such a variation has been confirmed and its origin, possibly associated with the atmospheric angular momentum (AAM) and the solar activity, was discussed by Djurovic (1983). This hypothesis is still open because the proofs were probably not sufficiently convincing. For example, a lot of attention has been devoted to the 50-day fluctuation in the Earth rotation (ER) and atmospheric circulation (Madden et al., 1971; Feissel et al., 1980; Langley et al., 1981; Eubanks et al., 1985; Morgan et al., 1985), but the 122-day fluctuation is practically ignored although its amplitude is at least as large as the 50-day one. In the present work, using other methods, we analyse recent data acquired on longer time intervals, with the aim not only to verify the previously obtained results but also to extend the analysis to other series of solar activity and geophysical responses.

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2. Data sets, processing methods, procedure for the data analysis

The data sets are described and referenced in Djurovic et al. (1988); they are composed of the Universal Time ΔUT_1 (1976.0–1985.0), the daily Wolf numbers W (1976.0–1985.0), the daily apparent sunspot areas SA (1976.0–1985.0), the geomagnetic index Aa (1976.0–1983.0), the daily value of the atmospheric angular momentum AAM (1976.0–1985.0), the daily value of the direction of the inferred interplanetary magnetic field IMF (1979.0–1983.0).

All the series were analysed by two spectral analysis methods: the maximum entropy least squares (MELS) and the discrete Fourier transform (DFT); the reasons are given in Djurovic et al. (1988). The smoothing and the one side filtering of the data were performed by the Whittaker-Robinson-Vondrak (WRV) method (Whittaker et al., 1946; Vondrak, 1969).

In several series, as Aa for example, large non-cyclic variations mask the presence of the cyclic ones. The data were then filtered by using the Labrouste narrow band-passing filter $(\mathrm{Sp\,Sq})_L$ (Labrouste et al., 1941).

The detection of the 120-day oscillation in UT_1/UT_2 and AAM by a spectral/periodogram analysis requires first to remove the seasonal components, mainly the semi-annual one, and of course, the drift. If removals are not applied, the 120-day peak can be masked among the subsidiary peaks of the semi-annual component.

The validity of such a method appears in Fig. 1 where four periodograms are presented:

(a) of a theoretical signal composed of 4 sinusoids whose periods and amplitudes, given in Table 1, are close to these assumed in the observational series of ΔUT_1 (Fig. 1a);

(b) of the residual signal, $R(i)$ deduced from the ΔUT_1 series after WRV smoothing with $\varepsilon = 10^{-9}$ (Fig. 1b). The choice of $\varepsilon = 10^{-9}$ allows to eliminate the drift and the annual component. In the same time, it reduces the amplitude of the semi-annual component by a factor $A' = 0.4$.

(c) of the differences $DR(i)$ of the theoretical signal values $R(i)$ computed for the lag τ:

$$DR(i) = R(i + \tau) - R(i), \qquad (1)$$

where $\tau = 180$ days (Fig. 1c). As shown later, the semi-annual component is then eliminated, the three others components being amplified by a factor $A' \approx 2$.

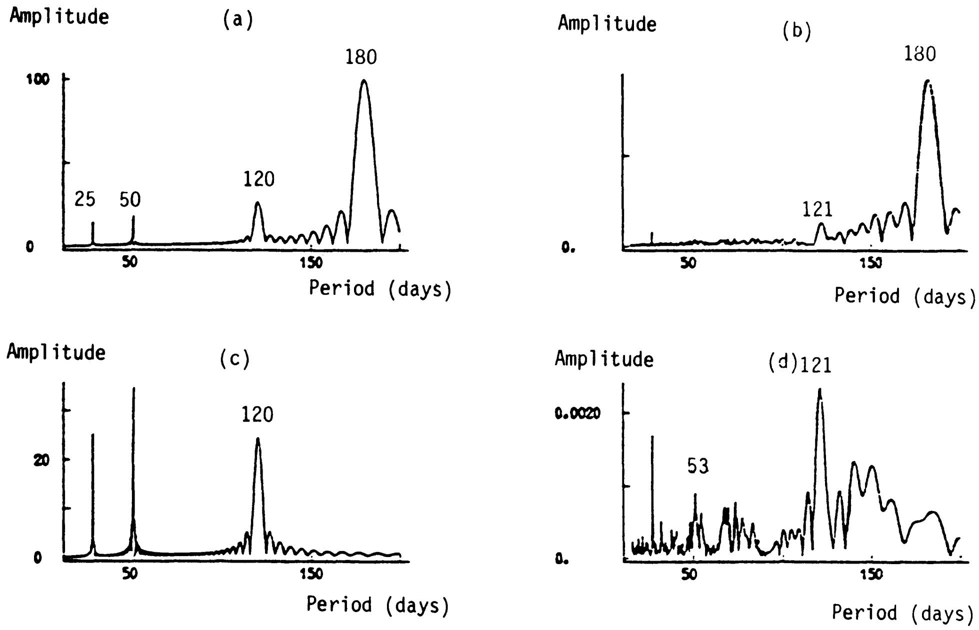

Fig. 1a–d. DFT periodograms of **a** theoretical signal of 4 sinusoids (Table 1), **b** ΔUT_1 filtered by WRV ($\varepsilon = 10^{-9}$), **c** theoretical signal differences with a time lag $\tau = 180$ days, **d** ΔUT_1 differences with a time lag $\tau = 180$ days (units are in $0^{s}.0001$ as in Table 1)

Table 1. Periods (P) and amplitudes (A) of the theoretical signal (units $0^{s}.0001$)

P (days)	A
180	100
120	12
50	18
25	14

(d) of the differences $DR(i)$, also computed with a time lag of 180 days, of the residual $R(i)$ defined in (b) above (Fig. 1d).

Figure 1a indicates that the first subsidiary peak have an amplitude close to the 120-day one; in Fig. 1b, the 120-day peak is nearly masked; if its existence has not been assumed it would have been fairly ignored. Having removed the semi-annual component the 120-day peak is clearly pronounced in Fig. 1c and d. These results allow to understand why the studies of the short-period oscillations of ΔUT_1 and AAM, do not point out the 120-day fluctuation.

The computation of the differences

$$DR(i) = R(i+\tau) - R(i) \tag{2}$$

where $\tau = 180$, leads to modify the amplitudes of the sinusoidal components in $R(i)$ by a factor

$$A' = 2\sin(\pi\tau/P);$$

for the terms of periods $P = 180$, 120, 50 and 27 days, particularly of interest, the corresponding values of A' are respectively 0.0, 2.0, 1.9 and 1.7.

This procedure has been applied because the choice of $\varepsilon = 10^{-9}$ in WRV filtering practically unaffects the 120-day term amplitude, with the disadvantage that the semi-annual one is not sufficiently damped. A choice of larger ε (10^{-8}, 10^{-7}, for example) could better eliminate the semi-annual component but would reduce the 120-day one.

For eliminating the drift and the seasonal components least squares procedure is often applied. However, taking into account the fact that these components are perturbed (Djurovic, 1979) their analytical representation is not satisfactory. Consequently, their elimination is less efficient. Although the semi-annual component in series other than the UT_1 and AAM ones is weaker (Aa) or nonexistent (Wolf, SA), the same procedure has been applied on all data sets with the aim to make easier comparisons of the results. In the present work the results concerning the 27- and 50-days terms will not be discussed, since this has already been done elsewhere (Djurovic et al., 1988).

3. Results of the data analysis

The cyclic composition of the differences $DR(i)$ is presented under the form of amplitude periodograms DFT in Fig. 2. Besides the tidal peak M_m in ΔUT_1 and AAM, the 24 to 30 days peaks in W, SA, Aa, IMF, due to the Sun rotation, and those between 40 to 70 days in all series, it must be noted in all series except Aa, the presence of a clearly pronounced peak around 120 days. The curve IMF in Fig. 2 represents the periodogram of the function $S(j)$ defined as the polarity inferences of the interplanetary magnetic field (Djurovic et al., 1988). In the case of the Aa periodogram the last result is not conclusive; for this reason the differences $DR(i)$ are filtered by the Labrouste narrow band-passing filter $(Sp\,Sq)_L$ (Labrouste et al., 1941) and the periodogram of the output signals recomputed are presented in Fig. 3. They confirm the existence of the 120-day peak, in all series. For IMF, the periodogram can not be computed since the original series only covered 4 years, the application of the Labrouste filter conducting to lose too much data at both end of the series.

For each series the DFT 120-day component amplitude and period are given in Table 2 where A and A_L respectively represent the amplitudes with and without Labrouste filtering process.

It is well known that the Labrouste filter generates pseudo-peaks at the periods of amplification and odd sub-harmonics. In our case at 120, 40, 24 ... days. However, from many numerical

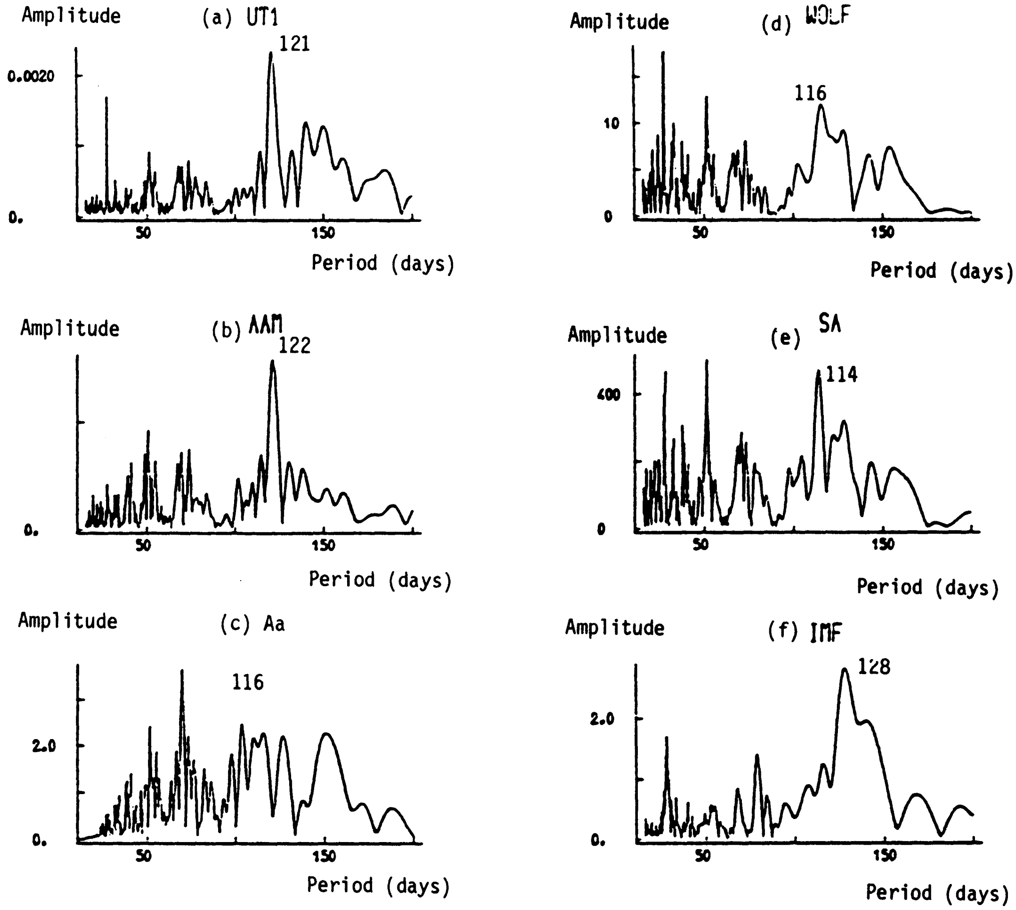

Fig. 2. DFT periodograms of the $DR(i)$ differences with a time lag $\tau = 180$ days of solar activity data (Wolf, SA, IMF) and geophysical data (ΔUT_1, AAM, Aa); the units are given in the last columns of Table 3

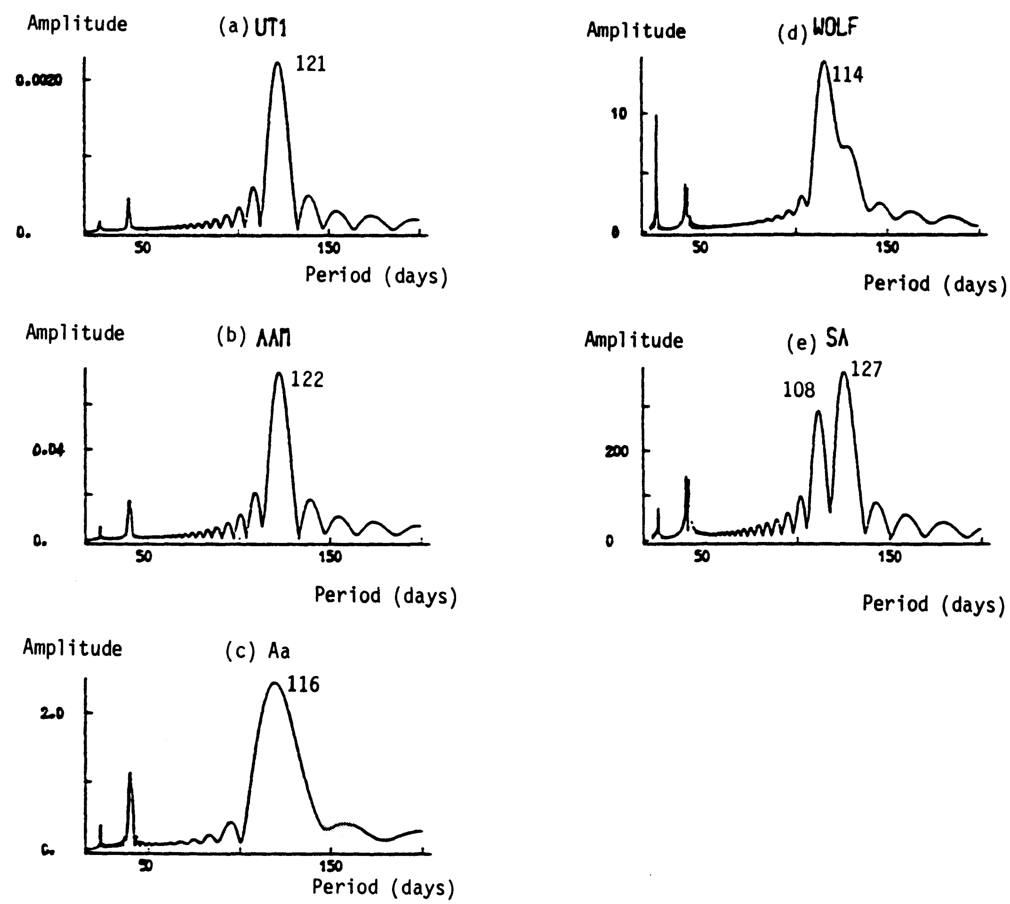

Fig. 3. DFT periodograms of the $DR(i)$ differences after Labrouste filtering $(Sp\,Sq)_L$ of solar activity data (Wolf, SA) and geophysical data (ΔUT_1, AAM, Aa); the units are given in the last columns of Table 3

Table 2. Amplitudes (A, A_L) and periods P of the 120-day components of the $R(i)$ computed by DFT, taking into account the amplification factor $A' = 2$

Series	P (days)	A	A_L	Units
ΔUT_1	121.2	1.2 ± 0.5	1.2	10^{-3} s
AAM	121.6	396 ± 12	400	10^{26} kg m^2 s^{-1}
W	115.6	6 ± 0.5	7	–
SA	114.0	237 ± 17	195	10^{-6} Sun disk
Aa	116.0	1.2 ± 0.1	1.2	μT
IMF	128.0	1.4 ± 0.1	–	–

Table 3. Amplitudes A_p of the pseudo-peaks at 120 days generated by the Labrouste filter

Series	σ	$2A_L$	A_p	Units
ΔUT_1	2.8	2.4	0.4	10^{-3} s
AAM	650	800	97	10^{26} kg m^2 s^{-1}
W	30	14	2	–
SA	960	390	145	10^{-6} Sun disk
Aa	1.5	2.5	0.2	μT

experiments with series of random numbers (gaussian distribution) of similar length, same sampling and standard deviation (σ) as the observational data, we have found that the mean amplitude of the pseudo-peaks is in average of the order of 0.15σ and practically does not exceed 0.30σ. The st. dev. (σ) and the amplitudes ($2A_L$) of the $DR(i)$ as well as the amplitudes (A_p) of the corresponding pseudo-peaks are given in Table 3. From the results of Table 3 it follows that the 120-day peaks of Fig. 3, are not generated by the Labrouste filter processing. It must also be remarked that the peaks at 40 and 24 days are higher than the corresponding pseudo-peaks. This is not surprising due to the presence of the 50-day, the synodic and the tidal oscillations. On the other hand, for the 120-day component, we observe in Fig. 3 that the sharpness of the peaks corresponding to ΔUT_1 and AAM is similar to that one of the theoretical signal (Fig. 1) while for the other series it is larger (Wolf, Aa) or even double (Sa). To test the hypothesis of a double peak the MELS method, well recognized for its high resolution, has been applied to all original series after the semi-annual and lower frequency components elimination by the WRV filtering with $\varepsilon = 10^{-7}$. Moreover, having in mind that the relative random fluctuations in Aa series are greater than in the other series analysed here, after the filtering of the Aa data with $\varepsilon = 10^{-7}$, the residuals were smoothed with WRV method and $\varepsilon = 10^{-4}$. The last results, presented in Fig. 4, confirm the existence in all series of the 120-day oscillation and prove that it corresponds to a single peak.

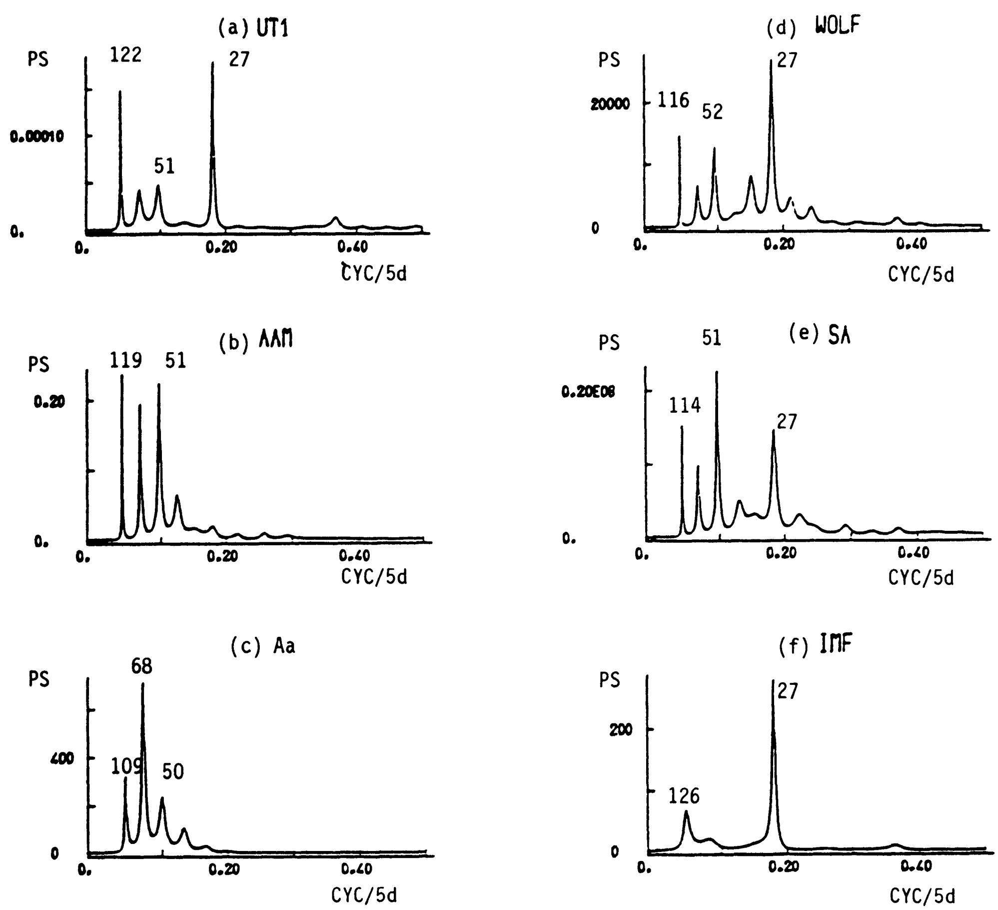

Fig. 4. Power spectra of the $DR(i)$ differences with a time lag $\tau = 180$ days and WRV filtering ($\varepsilon = 10^{-7}$) of solar activity data (Wolf, SA, IMF) and geophysical data (ΔUT_1, AAM, Aa)

The results presented above authorize to conclude that the 120-day oscillation exists. They also indicate that it originates in the solar activity process as already recognized for the 50-day fluctuation (Djurovic et al., 1988). Keeping in mind that the amplitude of the analysed oscillation is small, the random fluctuations of the phases are so large that their comparison does not conduct to any deterministic conclusion. This was also discussed in Djurovic et al. (1988).

4. Conclusions

A 120-day oscillation exists in the Earth's rotation, the atmospheric zonal circulation, the geomagnetic field and the solar activity. These results are complementary with those obtained by Wilcox et al. (1974, 1976) who demonstrated the dependence of the Vorticity Atmospheric Index (VAI) from the IMF sectorial structure. It must be also useful to remind that the detection of the 120-day oscillation in ΔUT_1 and AAM needs the preliminary elimination of the seasonal components and the drift.

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