MUTUAL RELATIONS OF THE INTERMEDIATE PERIODICITIES OF THE WOLF SUNSPOT NUMBER

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ABSTRACT

First results of an analysis of the temporal variability of the solar activity represented by the relative Wolf sunspot number in the epoch 1850 – 2002 are presented within range of the intermediate periods from 0.3 up to 4 years. The daily data of the Wolf number has been utilized using the wavelet transform while different ways of estimation of the significance of periods were applied. The performed analysis was focused on a search for possible mutual relations between the appearance of the intermediate periods and their connection to the overall course of the cycle of solar activity. Results have revealed several significant periods but, in general, only of an intermittent character of appearance. Besides some other periods especially that of ∼2-year, ∼1.3-year, ∼0.75-year and 4-year were found to be significant in several instances of time. Comparison of these results allow to conclude that the quasi-biennial period is not related to any particular phase of the solar cycle and that presence of the 4-year period is independent from the quasi-biennial period. Additionally the well-known 155-day period was confirmed with its particular intermittent appearance both in phase and out of phase of the 1.3-year period in difference time intervals. Possible influence of estimation of the background noise for determination of the significance of periods is discussed as well.

1. INTRODUCTION

The temporal behaviour of the Wolf sunspot number characterizes the solar magnetic activity is highly variable at several time scales. The commonly used mathematical methods, used in the past, like e.g. the autocorrelation, the maximum entropy method and the Fourier transform (FT) allow to derive frequency decomposition of the studied data series. Nevertheless these methods do not provide information on the temporal evolution of the contribution of the different periods to the data series. Contrary the wavelet transform (WT) method is suitable for analysis of the time series which could contain non-stationary power.

Both the FT and the WT methods have been applied to the Wolf sunspot number and other data series related to the sunspots or to the different flare indices reporting several significant periods. Recently, relation of the 1.3-year and 156-day periodicities was examined in the sunspot areas and sunspot numbers by Krivova and Solanki (2002) concluding that these two periodicities are probably of a common origin while the 156-day periodicity is the third harmonic of 1.3-year period and both they could be harmonics of the solar activity cycle length. These results have started a search for mutual relations on the particular periodicities found up to now in the data series related to the sunspots by e.g. Lean and Brueckener (1989), Lean (1990), Carbonell and Ballester (1990), Oliver and Ballester (1995), Oliver et al. (1998) and others. Following the well-known N-S asymmetry of the solar activity Temmer et al. (2002b) showed that the asymmetry takes place also in behaviour of the temporal evolution of power around the rotational period of the Sun in the epoch 1975 – 2001. No results in the intermediate periods have been presented so far taking the N-S asymmetry into account as the first catalogue of the hemispheric sunspot numbers was prepared by Temmer et al. (2002a) just recently.

In this work we have focused to the intermediate periods of the Wolf sunspot number in the range of periods between 0.3 and 4 years using the full disk data but within the extended epoch of one and half century. Our aim was to search for possible mutual relations between the intermediate periods themselves and for their connection to the phase of the solar cycle.

2. DATA AND METHOD OF ANALYSIS

The daily data of the Wolf relative sunspot number in the time epoch 1850 – 2002 provided by the Sunspot Index Data Center of Royal Observatory of

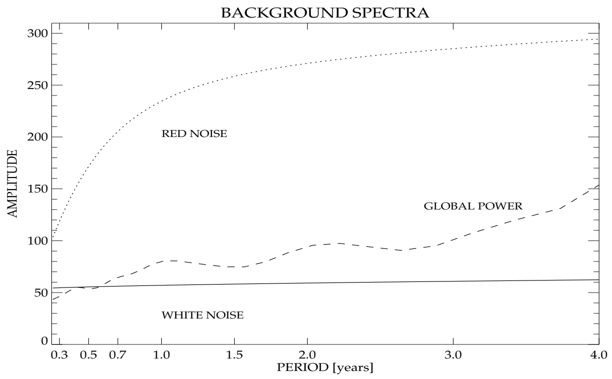

Figure 1. The background spectra of the WT for different ways of estimation of the mean background spectra of the used data series: white noise - solid line, global spectrum - dashed line, and red noise - dotted line. The abscissa corresponds to the period range used in this WT analysis. The range of ordinate is for 10 % larger than the range of the WT power spectra shown in 2D maps of the WT amplitude.

Belgium[1] were used for our analysis. These data represent the definitive relative numbers of the sunspots calculated on base of all observations available from different observatories. The start of the selected time epoch was specified to the year 1850 as earlier data suffer from relatively high number of days without independent information.

The continuous wavelet transform was applied as an appropriate tool for analysis of the time series containing non-stationary power for many periods (Daubechies, 1990, Kumar and Foufoula-Georgiou, 1997, Torrence and Compo, 1998). This method is based on searching of a similarity between parts of the data series of a different length localized in time and the scaled wavelet functions of similar basic shape localized in periods. The Morlet wavelet, a plane sine wave with an amplitude windowed in time by a Gaussian function, has been used as the Wolf number data series is very similar to an oscillatory signal (rotational modulation) with a changing amplitude (emergence/decay of active regions). The computing algorithm of Torrence and Compo (1998) was applied to the time series of the 152 year length with the step of 1 day while WT power spectrum was calculated within the period range 0.3 – 4 years with the period resolution changing from 9 to 110 days.

An assumption on existence of the mean wavelet power spectrum was stated in order to estimate significance of the local peaks of the WT power relatively to the global background spectrum what is possible according to results of Percival (1995) and Kestin et al. (1998). Alternatively two other ways of estimation of the background spectrum were calculated. The first way used white noise for determination of the background spectrum and the second way used the red noise background spectrum calculated from the time series. Dependence of all three background spectra on the period is given in Fig.1. The 99 % conficence level was applied to the WT power spectrum for selection of the significance of the local peaks of power.

[1] `http://sidc.oma.be/DATA/dayssn.dat`

3. RESULTS

The WT results are given in the form of the 2D (time-period) map of the WT amplitude where the global spectrum is used for estimation of the 99 % confidence level (Fig.2). According to this confidence level calculated on the base of the two models of the background spectrum (global spectrum and white noise) the following periods were found to be very significant in the particular time localizations: 155-day (∼0.4-year) period in years 1860, 1905, 1930, 1957, 1967, 1978, 1982, 1992 and 2000; ∼0.7-year period in years 1907, 1937, 1980 and 1983; ∼1.3-year period in years 1883, 1917, 1928, 1939, 1957 and 2000; ∼2-year (quasi-biennial) period in years 1873, 1917, 1928, 1939 and 1957; 2.8 year period in year 1990; and ∼4-year period in years 1872, 1917, 1948, 1972 and 2001.

Using the red noise as estimation of the background spectrum of the Wolf number time series no significant peaks of amplitude were found in the WT power both according to the 99 % and also 95 % confidence levels. Application of the red noise is appropriate for short periods (e.g. around the rotation period) as the Wolf numbers were not found independent from each other but correlated with a typical correlation time of about 7 days (Olivier and Ballester, 1995). This is not the case for the intermediate periods as on these scale other process seem to take over and application of the red noise as estimation of the background noise is dimming significance of power what is not in agreement with the visual inspection of some simple parts of the time series (see Fig.3).

Quasi-biennial periodicity was found to appear before as well as after maxima of the solar cycles. Nevertheless there are the time intervals of years 1890 – 1910 (cycles 13 and 14), 1925 – 1940 (cycles 16 and 17) when this periodicity is absent. Therefore it can be concluded that this periodicity is not regularly appearing in these two phases of the solar cycles. Comparing locations of the 2-year and 4-year periodicities we can report that while several time they appear in phase (e.g. years 1880, 1890, 1945) there exist also cases where the 2-year periodicity (1970) was detected without any power of the 4-year period and in opposite the 4-year periodicity was found with no counterpart in the 2-year period (1935, 1965). Two examples of an apparent shift of the 2-year and 4-year periodicity were detected in years 1880-1885 (cycle 12) and 1922-1935 (cycle 16). Moreover the temporal coincidences of the 4-year period with the 1.4-year periodicity were found in years 1885 (cycle 12), 1938 (cycle 17) and 1957 (cycle 19) when at the same time power of the 2-year periodicity is absent or it is only very weak. This suggests that besides the

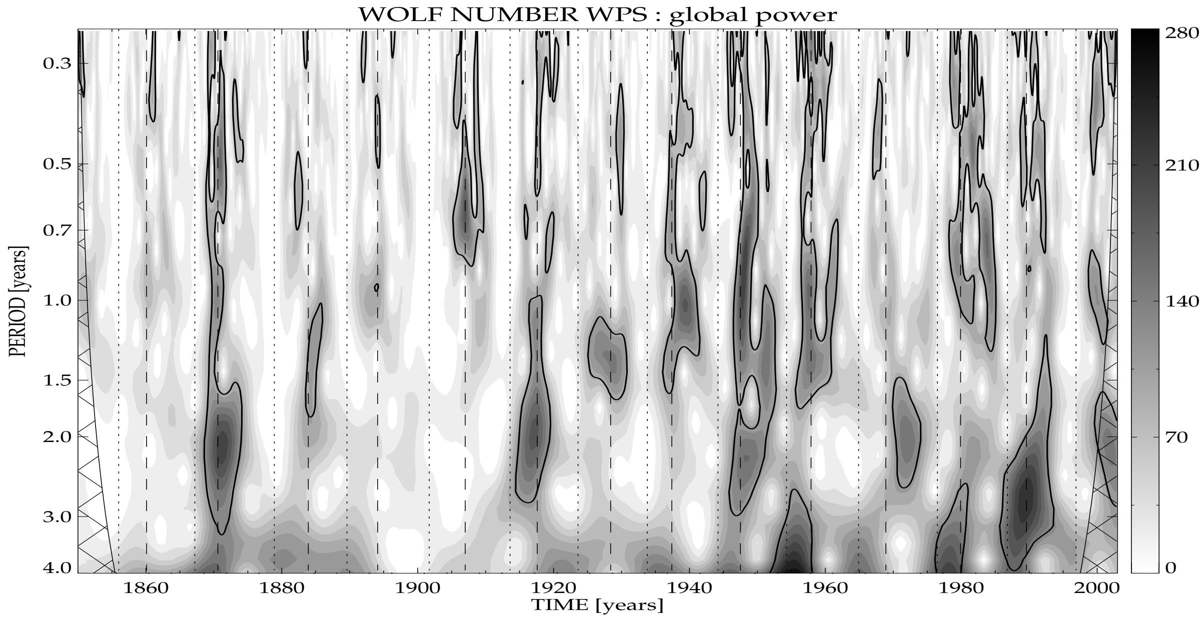

Figure 2. The 2D map of the WT power spectrum amplitude of the Wolf sunspot number in the epoch 1850 – 2002 and within the period range 0.3 – 4 years. The full solid line shows the 99 % confidence level derived according the global spectrum used as a background spectrum. Dashed and dotted vertical lines depict solar activity maxima and minima respectively. The cone of influence are marked by the crossed-hatched regions.

temporal coincidence of periodicities with the ratio of the periods 1:2 (2 and 4 years) also another ratio 1:3 (1.3-1.4 and 4 years) exists. It should be noted here that the WT does not produce harmonics of the signal stored in the data series and therefore we can rule out that these coincidences appear due to the intrinsic property of the used mathematical tool.

Relation of appearance of the periodicities detected in the WT power spectra to the strength of the solar cycles was also examined. The 4-year period was detected both in weak solar cycles (cycle 12) and in strong cycles (cycles 17,19,21). On the other hand the 2-year periodicity was found in strong cycles 11,15,18,20 and 22 but it is absent in the strongest cycle 19. Nearly 1.3-year periodicity was significant in weak cycles (12,16) but also in strong cycles (17,19,22). Similarly the nearly 0.4-year period was present during weak (16) and strong (11,15,21) cycles as well as during the strongest cycle 19. Therefore no clear relation between the periodicities and the strength of solar cycles can be reported.

4. DISCUSSION

Checking correctness of our interpretation of the WT power spectra it is helpful to analyse few simple samples of the whole data series. The first example (Fig.3) shows part of the time series (years 1970-1974) where a visual inspection of data clearly confirms the periodicity of a 2-year wave obtained with help of the WT. Contrary the second example gives another part of the series which contains several 'jumps' in the temporal behaviour of the Wolf number (years 1868-1872). In case of such data the WT provides the enhanced peaks of power but simultaneously for a broader range of periods, part of which are in fact false. Such WT results obtained in the calculated WT 2D power spectra were not taken into account (e.g. years 1870, 1947) although some of these periods could be real.

The results derived from the full disk Wolf number data series can suffer (at least in some time intervals) from significant effects caused by omitting of the N-S asymmetry of the solar activity as it was shown for the rotational period by Temmer et al. (2002b). Therefore possible influence of N-S asymmetry should be studied for the intermediate periods in future.

Our results on periodicities 0.35-0.5 year are in general in agreement with the results derived by Ballester and Oliver (1999) in the sunspot number and with the results of Oliver et al. (1998) and Carbonell and Ballester (1990) in the sunspot areas. Moreover our results confirm finding of Krivova and Solanki (2002) that the 155-day periodicity is significant also in the most recent solar cycles.

Comparing appearance of the ∼0.4-year and 1.3-year periodicities it can noticed that although there exist an example of their simultaneous presence in time (1939-1940) there are also other instances of time when their appearance is out of phase. For example the 2-year periodicity in years 1922 – 1923 and

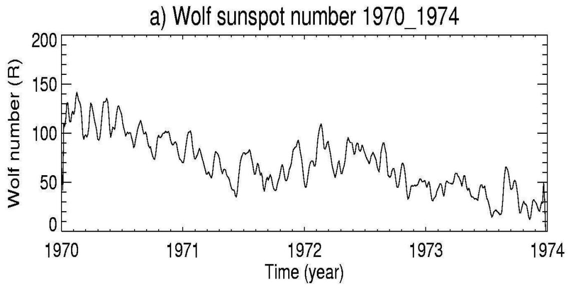

Figure 3. Example of the behaviour of the Wolf sunspot number (smoothed by a 7-day running mean average) in the time interval 1970 – 1974. Besides the rotational period also a wave of a 2-year period can be seen visually. The wavelet transform has derived also another significant peak at 0.25-year period localized in the middle of the selected interval.

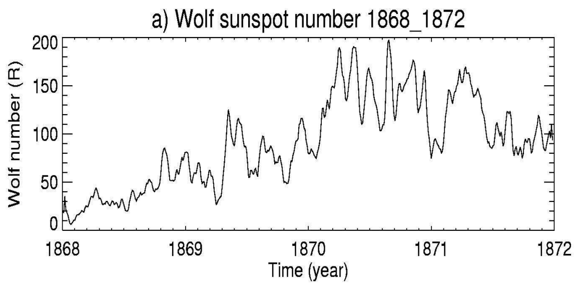

Figure 4. Example of the behaviour of the Wolf sunspot number (smoothed by a 7-day running mean average) in the time interval 1868 – 1872 where sharp 'jumps' are found. In particular in the year 1870 several periodicities within a broader range were detected by the WT algorithm: from 0.25 up to 3.3 years for the global background and several separated peaks near 4.0, 2.0, 1.0 and 0.45 years for the white noise background. These periodicities were not taken into account.

the ∼0.4-year one in 1924 – the first one before and during maximum and the second one 2 years after maximum of cycle 16 or, in opposite, the ∼0.4-year periodicity in year 1967 leading for 3 years the 2-year periodicity powered in years 1971-1973 – the first one a year before the maximum and the second one on the ascending phase of the cycle 20. Recently Krivova and Solanki (2002) concluded that these two periodicities are probably of a common origin while the 156-day periodicity could the third harmonic of 1.3-year period and both they could be probably harmonics of the solar activity cycle length. Our results show that their appearance in phase in not a common rule.

5. CONCLUSIONS

The wavelet transform analysis of the Wolf sunspot number in the range of the intermediate periods within the epoch 1850 – 2002 has shown very intermittent character of the solar activity displaying power at 0.4, 0.7, 2 and 4 years periodicities. Results suggest that the 2-year periodicity is not related to any particular phase of the solar cycle and that it does not appear in all cycles. The 4-year period is not regularly appearing in phase with the 2-year periodicity (period ratio 1:2) and sometimes the 4-year periodicity displays together with the 1.3-year period (period ration 1:3). Therefore in can be concluded that the 4-year periodicity is not related in particular only to 2-year one. The 155-day periodicity is confirmed with several isolated temporal locations both in phase and out of phase of the 1.3-year period in difference time intervals.

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