THE VARIATIONS OF THE SOLAR ACTIVITY AND THE LOW RIGIDITY COSMIC RAYS (1969 – 1998)

Anna Antalová[1], Karel Kudela[1], and Ján Rybák[2]

[1]Institute of the Experimental Physics, Slovak Academy of Sciences, Watson str. 47, 04353 Košice, The Slovak Republic
[2]Astronomical Institute, Slovak Academy of Sciences, 05960 Tatranská Lomnica, The Slovak Republic

ABSTRACT

The wavelet power spectra were calculated and compared for the whole solar disk time series: the Mt. Wilson Magnetic Plage Strength Index (MPSI) and the Mt. Wilson Sunspot Index (MWSI) as well as the low rigidity Calgary cosmic rays (CR). The intermediate– and the long–term periodicities are established during a 6-year interval of the respective cycle (2 years before and 4 years after the cycle maximum). The periodicities longer than 100 days are dominant in the post–maximum years. The 260–day period of the MPSI has dual structure, the peaks are in 1979 and in 1981–1982 post–maximum years. We found, that the well known long–term cosmic ray periodicity 1.5 – 1.7 year is present in the low rigidity Calgary cosmic rays, in 1983.5 and in 1991.0 years.

1. INTRODUCTION

In prior papers, the significant variations were found among various solar events (e.g., the long–duration X–ray flares, Antalová, 1994, 1999), the solar wind speed (Richardson et al., 1994), the geophysical data (Mendoza et al., 1999) and the cosmic rays (Valdés–Galicia, Pérez–Enriquez and Otaola, 1996, Kudela et al., 1999). SOHO/MDI and GONG helioseismic data (Komm, Howe and Hill, 2000) reveals very important period around 1.3 year (about 474 days). It is more–less confirmed that the intermediate– and the long–term solar variability periods are related to the solar magnetic flux. In this paper we present the wavelet power spectra (WPS) of the solar and the low rigidity cosmic ray data (from Calgary) for the cycles No. 21 and No.22.

2. THE DATA SETS

Wavelet power spectra have been computed for the following parameters:

(a) Mt. Wilson Magnetic Plage Strength Index (MPSI). For each magnetogram taken at the 150–Foot Solar Tower, the Mt. Wilson Magnetic Plage Strength Index *(MPSI)* value and the Mt. Wilson Sunspot Index *(MWSI)* value are calculated. To determine MPSI the absolute values of the magnetic field strengths is summed for all pixels where the absolute value of the magnetic field strength is between 10 and 100 gauss. This number is then divided by the total number of pixels (regardless of magnetic field strength) in the magnetogram.

(b) Mt. Wilson Sunspot Index (MWSI). The MWSI values are determined in much the same manner as the MPSI, though summation is only done for pixels where the absolute value of the magnetic field strength is greater than 100 gauss. Data are daily means from more then just one measurement (if available). The MPSI and MWSI data were taken from `www.mtwilson.edu/Science/UCLA/`.

(c) CR – the low rigidity Calgary cosmic rays – Calgary latitude 51° 05' N, Calgary longitude 114° 08' W, vertical cutoff 1.09 GV, count rate approximately 2×10^4 per 5–min (Venkatesan et al., 1989).

3. METHOD OF PROCESSING

The common tool of the frequency investigation of the data series - the Fourier Transform (FT) - does not allow the extraction of any temporal information of the data series. Different sines and cosines, into which FT decomposes data series, cannot be localized in time according to the uncertainty principle as these trigonometric functions are calculated for sharp frequencies (Bracewell, 1965). Therefore FT is not appropriate for the study of data series which show significant temporal variability.

The wavelet transform is a suitable tool to analyze time series that contain non-stationary power at many different frequencies (Daubechies, 1990). Its functions - wavelets - are localized in both time and frequency, characterized by non-dimensional time parameter η and frequency ω_0.

As we are dealing with a simple oscillatory data series, the Morlet wavelet - a plane sine wave of amplitude windowed in time by a Gaussian function, has been selected for searching of power in different frequencies over the whole time length of the series.

Describing our data series as x_n with an fixed temporal spacing δt and the data index $n = 0, 1, ..., N$ the Morlet wavelet can be prescribed as the following function $\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0 \eta} e^{-\eta^2/2}$. For this selected wavelet the non-dimensional frequency ω_0 has been set to 6 fixing the length of all wavelets according to their scale s. The continuous wavelet transform of a discrete time series x_n is defined (Torrence and Compo, 1998) as the convolution of data series with a scaled in frequency s and translated in time η wavelet $\psi_0(\eta)$ as

$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \psi^* \left[\frac{(n'-n)\delta t}{s} \right] \quad (1)$$

where the sign ψ^* denotes the complex conjugative of the wavelet ψ. The wavelet transform W_n is so a projection of the data series onto the selected wavelets of different scale s at different time. Varying the scale s and translating along the time index n picture of varying (if existing) amplitude for different scales can be determined over the whole time interval of the data series.

In order to compare directly the WT at each scale s the wavelet functions were normalized to have unit energy at each scale. As the wavelet Morlet function ψ_0 and its wavelet transform $W_n(s)$ are complex the wavelet power spectrum $|W_n(s)|^2$ was calculated to visualize the time–frequency behaviour of the data series amplitudes.

A convenient set of scales has been selected following the formula $s_j = s_0 2^{j \cdot \delta j}$ for $j = 0, 1, ..., J$ where s_0 is the smallest computed scale and J specifies the largest one. Parameter δj specifies the scale resolution. For broader period range (16 – 2048 days) these parameters has been set as $s_0 = 16$ and $J = 336$, for the narrower one (18 – 38 days) parameter s_0 has been changed 2. For both ranges the scale resolution δj was fixed to 48 scales per octave.

The WT computational algorithm of Torrence and Compo (1998) has been used in this study. As it is based intrinsicly on the FT of the data sets of the finite length the data sets had to be padded with zeroes in order to bring the total length of the data sets N to the next higher power of 2. This padding with zeroes decreases the amplitudes of the wavelet power spectrum $|W_n(s)|^2$ as still more and more zeroes entered the temporary data set increasing the scale s of the transform. Therefore the coin of incidence was introduced here as the e-folding time of the wavelet power autocorrelation at each scale. Within the wavelet power spectrum $|W_n(s)|^2$ areas covered by this coin of incidence (indicated in our plot by cross-hatched regions) the amplitudes has been reduced in their magnitude.

In order to setup the significance levels of the derived wavelet power spectrum the null hypothesis has been formulated according to Torrence and Compo (1998) assuming that the time series has a mean power spectrum, given by normalized FT power spectrum of the red noise univariate lag–1 autoregressive process. If a wavelet power spectrum is well above the background mean power spectrum (global spectrum), then it can be assumed to be real with a certain confidence level. The 95 % confidence level, used in this study, implies that 5 % of the wavelet power should be above this level for each scale. In this study the global wavelet spectrum $\overline{W}^2(s) = 1/N \sum_{n=0}^{N-1} |W_n(s)|^2$ has been used as an estimate of the background mean power spectrum against which the significance of the local WPS features has been tested according to findings of Percival (1995) and Kestin et al. (1998). In Table 1 we give the global power spectra periods of our data series.

4. RESULTS AND DISCUSSION

Our investigated period is still very short to be able to draw general conclusions about the time–frequency behaviour of the long–term solar periodicities during solar cycles. Nevertheless, the following conclusions can be drawn on periods given in Table 1.

- The time – period WPS show the significant statistical differences of the MPSI and the MWSI data comparing to the low rigidity Calgary cosmic rays, in studied years. We found the large differences between WPS of the increasing and the declining parts of the last two cycles. We present quantitative evidence that in the maximum epoch of the last two solar cycles, there is no continual duration of the long–term periodicities, but there are multi-frequency dual peaks of the solar cycle maxima. Time location of WPS impulses coincide with pre– and post– maximum years (Gnevyshev gap, Storini and Pase, 1995; Bazilevskaya et al., 1998, Rybák, Antalová and Storini, 2000).

- The 21–st solar cycle characteristics: The 21–st solar cycle is unique in the density of the occurrence of 150–day periodicity in all solar parameters. The 154–day periodicity (Rieger et al., 1985) was expected in the solar and the heliospheric (Cane, Richardson and von Rosenvinge, 1998) data and really such period is present (together with other larger periods) in the XBG (in late 1980, 1982.7), the SXR–flare indices (in late 1980, 1982.7, see Rybák, Antalová and Storini, 2000), in the MPSI and the MWSI (there is significant multi–period peak with periods greater than 128–days, mainly in post–maximum years). In the CR, the 154–day period is present in 1981.4, 1982.7, 1986.1, 1990.0, and 1991.6 years.

- What concerns of the quasi-biennial period, which is generally but erroneously believed that is better expressed in the even than in the odd cycles, we obtain following result. The occurrence of the quasi–biennial period is remarkable high during the 21–st cycle in the MPSI (877–days, 2.4–year) and the MWSI (around 900 days, 2.5 year) data. The quasi–biennial period, in the occurrence of the LDE flares is not related to the 21–st cycle (as the MPSI and MWSI), but to the 22-nd solar cycle maximum (see Table 1, LDE –2.3 year, IMP–2.2 year). This is very important difference between the 21–st and the 22–nd cycles.

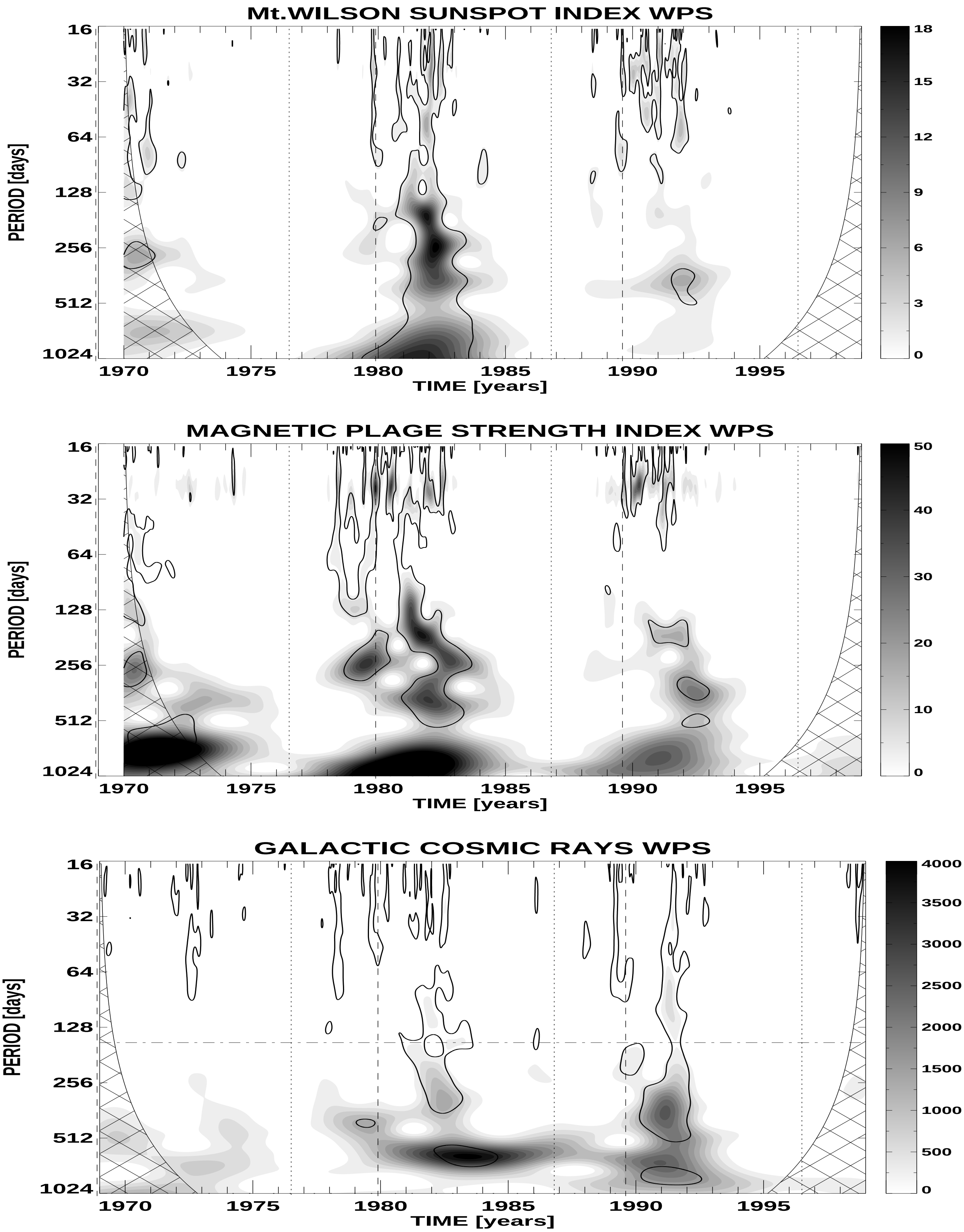

Figure 1. The wavelet power spectrum (WPS) of the Mt. Wilson Magnetic Plage index, the Mt. Wilson Sunspot index and the Calgary Cosmic Ray data series. The time spacing parameter of the series is 1 day, the scale resolution is 48 scales per octave. The thick solid curve stem for the 95% confidence level of the spectrum. The coin of incidence is marked by the cross-hatched regions. The solar activity cycle maxima and minima are signed by dashed and dotted vertical lines respectively according to the Wolf's sunspot index. 150–day period is marked by the point–dashed horizontal line (in bottom panel).

Table 1. The synodic recurrence, the intermediate–term and the long–term periods obtained from wavelet global power spectrum analysis. In the head–line are given expected periods, from Wolff's g–beats (Wolff, 1974). LT (1)– stay for the long–term periods lower than 1000–days, LT (2)– for the long–term periods greater than 1000–days.

IP(days)	27.0–	53–	83–	155–	270–	323–	LT (1)–	LT (2)–
MPSI	27.5				268	396–1.1y	877–2.4y	
MWSI	26.4	53		164	263	414–1.2y		
XBG	28.0		83	155	301		568–1.5y	1333–3.7y
LDE	31.5	48	80	146	223	770–2.1y	850–2.3y	1412–3.9y
IMP	38.2		83	157	268		810–2.2y	
CR						400–1.1y	647–1.7y	

- The expected the 1.7 year (647–days) period of the cosmic rays (Valdés–Galicia, Pérez–Enríquez and Otaola, 1996) is found in the 21–st cycle: the 1983.5 peak in CR and in XBG; the 1982.5 peak in the LDE flares. In the 22–nd cycle, the CR–peak is present in 1991; but its dominant periods are 400– and 800–days.

- We found the occurrence of the 1.1 – 1.5 year periodicity in the following data: in the MPSI (period 396–days, 1.1–year), the MWSI (414 days, 1.2 year), XBG (568–days, 1.5 year) and in the low rigidity Calgary CR (in 1991, the period is 1.1 year).

- Synodic recurrence. As is well known, the synodic recurrence of the cosmic rays is indicator of quasi–stable heliospheric conditions (Vernova et al., 1995) and reflects the repetition of *the all 27–day CR profile* as ' time unit '. We found the synodic recurrence of CRs mainly in 1978, 1979, 1982 and also in 1986, 1989, 1991 and in 1998.

ACKNOWLEDGMENTS

This contribution was carried out within the scope of the Slovak VEGA Grant 2/7229/20 and 2/5137/20. A. Antalová thanks the warm hospitality of the Instituto de Astrofisíca de Canarias during the 1–st SOLSPA Euroconference and expresses her gratitude to European Union for financial support.

The computations were performed using the modified wavelet software, original of which was provided by C. Torrence and G. Compo (Program in Atmospheric and Oceanic Sciences, University of Colorado, Boulder, U.S.A.) available at URL: `paos.colorado.edu/research/wavelets/`.

This study includes data from the synoptic program at the 150-Foot Solar Tower of the Mt. Wilson Observatory. The Mt. Wilson 150-Foot Solar Tower is operated by UCLA, with funding from NASA, ONR and NSF, under agreement with the Mt. Wilson Institute.

REFERENCES

Antalová, A., 1994, Adv. Space Res. 14, 721

Antalová, A. 1999, Proc. of the 9–th European Meeting on Solar Physics, ESA SP–448, 743

Bazilevskaya, G.A., Krainev, M.B., Makhmutov, V.S., Sladkova, A.I, Storini, M. and Flückiger, E., 1998, in Proc. 16–th ECRS, Alcala, Spain, 83

Bracewell, R.N., 1965, *The Fourier Transform and Its Application*, McGraw-Hill, New York

Cane, H.V., Richardson, I.G. and von Rosenvinge, T.T., 1998, Geophys. Research Letters 25, 4437

Daubechies, I., 1990, *IEEE Transactions on Information Theory* 36, 961

Komm, R., Howe, R. and Hill, F., 2000, in these Proceed.

Kudela, K., Yasue, S., Munakata, K. and Bobik, P., 1999, 26–th ICRC, Vol. 7, 163

Kumar, P. and Foufoula-Georgiou, E., 1997, Reviews of Geophysics 35, 385

Mendoza, B., Lara, A., Maravilla, D. and Valdés–Galicia, J.F., 1999, Solar Phys. 185, 405

Percival, D.P., 1995, Biometrika 82, 619

Richardson, J.D., Paularena, H.I., Belcher, J.W. and Lazarus, A. J., 1994, Geophys. Res. Letters 21, 1559

Rieger, E., Share, G.H., Forrest, D.J., Kanbach, G., Reppin, G., Chupp , E.L., 1985, Nature, **312**, 623

Rybák, J., Antalová, A. and Storini, M., 2000, in these Proceedings

Solar Geophysical Data, 1969 – 1976, Parts I and II; 1994, No. 602, part II

Storini, M. and Pase, S., 1995, *STEP GBRSC News* 5, Special issue, 255

Torrence, C. and Compo, G.P., 1998, *Bulletin of the American Meteorological Society* 79, 61

Valdés–Galicia, J.F., Pérez–Enríquez, R. and Otaola, J.A., 1996, Solar Phys. 167, 409

Venkatesan, D., Mathews, T., Graumann, H. and Sharman, P., 1989, *Calgary Cosmic Ray Intensity Records–Super Neutron Monitor*, The Calgary University

Vernova, E.S., Tyasto, M.I., Baranov, D.G. and Grigorian, M.S. 1995, in the 24–th ICRC, Roma, Vol. 4, 564

Wolff, C.L., 1974, Astrophys. J. 193, 721