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COSMIC RAY VARIABILITY AT DIFFERENT SCALES: A WAVELET APPROACH.

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Abstract

The scalograms of cosmic ray (CR) time series are constructed from measurements of a muon underground telescope and a neutron monitor, using the Haar functions for wavelet decomposition. This approach provides a simple and useful tool for reviewing the evolution of variability at different scales. Depending on the time averaging of input data, time profiles of contribution of different periodicities to the signal can be obtained.

1 Introduction

Most common methods for the detection of selected periodicities in CR series and for the determination the shape of power spectra is the Fourier transform. This is appropriate for stationary time series, assuming not changing the frequency content in time and providing one integral characteristic over the whole time analysed. The wavelet transform is providing the information both on scale (inverse of the frequency) and on location (time). These methods are used in many geophysical fields of research (see Kumar and Foufoula-Georgiou, 1997).

2 Data and method

The hourly data of two CR time series were used: (i) muon vertical telescope count rates at Misato at a depth 34 hg/cm^2 sensitive to primary particles in rigidity range 143 - 209 GV (Hall et al, 1999, Mori et al, 1976) and (ii) count rates of Deep River neutron monitor (NM) with cutoff 1.07 GV (source data Watanabe, 1998). The gaps were filled by linear interpolation between the border measurements.

The discrete wavelet transform was applied for the 3-hourly averages of both time series (functions f(t)). The computer code was built for the Haar wavelet (Ψ) being one of the simplest of all orthogonal wavelets: $\Psi(t) = 1$ for $0 \le t < 1/2$, $\Psi(t) = -1$ for $1/2 \le t < 1$, and $\Psi(t) = 0$ otherwise. The discrete wavelets $\Psi_{m,n}(t) = 2^{-m/2} . \Psi(2^{-m} .t - n)$ form an orthonormal basis for all m,n. The method is appropriate for $2^{m(max)}$ values. Similarly to the Fourier amplitude coefficients, being of one index, the wavelet expansion coefficients are defined as $D_{m,n} = \int f(t). \Psi_{m,n}(t)\, dt$ with two indices, m and n. The meaning of its absolute value is the contribution of scale 2^m (frequency 2^{-m}) at location n. 2^m to the function f(t), discretized so that $t=1,2,...2^{m(max)}$. For each m and n the values $D_{m,n}$ have been computed. Testing of the correctness of the computing code was done (a) for the data with periodic functions of different periodicities, and (b) for the time series generated as those having the power spectrum density P(f) of type f^{-a} , where a=0, 1, 5/3, and 2 with random distribution of the phases for which the validity of $E(m)=\sum_n D_{m,n}{}^2$, $E(m) \approx 2^{(a-1).m}$ (Yamada and Ohkitani, 1991) was checked.

3 Scalograms

Fig. 1 displays the scalograms obtained by the Haar wavelet method on Misato records (middle panel) and Deep River records (lower panel). The scale on the left side is in days. Data have been added by constants at the end of intervals to have 2^m points. The correct interval is 1975-1994. The darkness is in units $\log|D_{m,n}|$.The time-frequency plane is layered with cells whose minimum area is determined by uncertainty principle: one cannot measure with arbitrarily high resolution in both time and frequency. At large scales (low frequencies) the uncertainty in location (time) is larger and vice versa. In the upper panel of Fig. 1 a solar activity Rz values are displayed. For shorter scales (higher frequencies at which the time profile in Fig.1a is not well pronounced), Fig. 1b and Fig. 1c illustrate their time evolution starting from

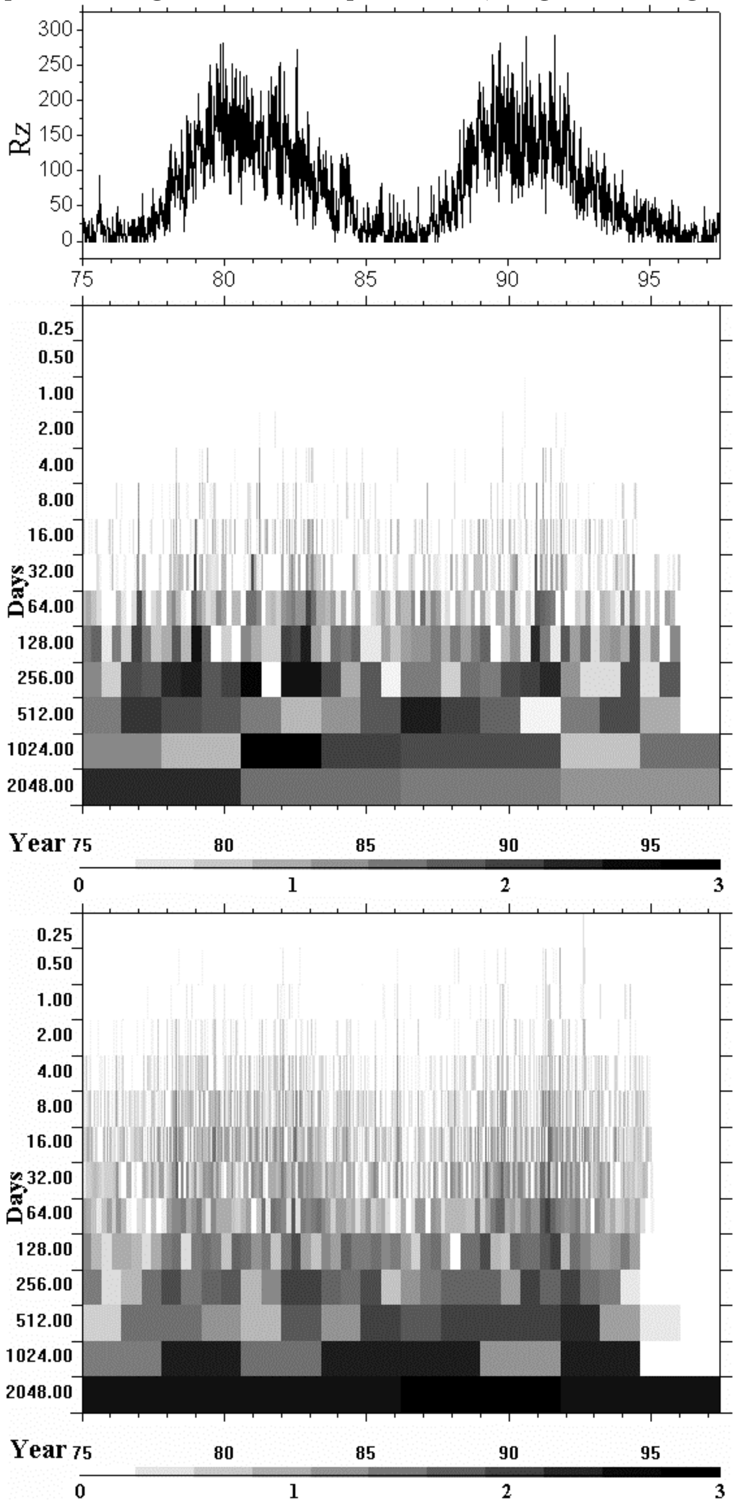

Fig.1 a

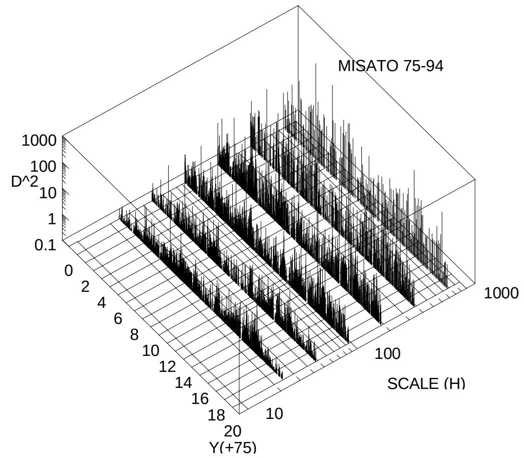

Fig.1 b

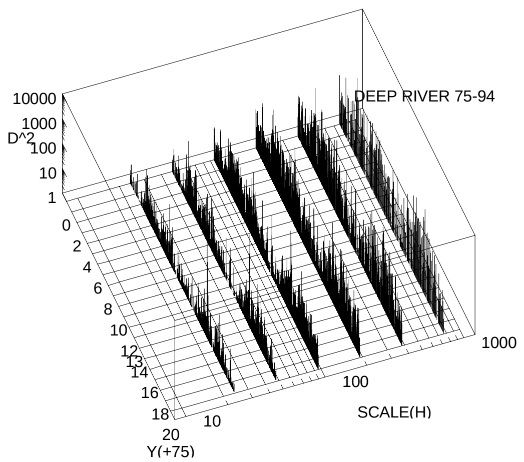

Fig. 1 c

diurnal variation. The scalograms are providing brief inspection of the content of various frequencies: along with many short term peculiarities, two features are seen: (1) the power spectra for higher energies (Misato) are flatter at high scales than those for lower energy CR records (Deep River), and (2) in general in the epochs around solar minima the spectra are steeper than those at solar maxima. While the positive correlation of spectral density at high frequencies (at least at periodicities ≤ 32 days, Fig.1 b,c) is apparent, at large time scales (above 128 days) this dependence is more complicated. This can be connected with transition to long periods at which the effects of MIRs and GMIRs become to be more important. At high frequencies , especially at Misato data (scales 2 - 4 hours, not displayed here) the correlation of density of the signal with the solar activity is missing again. The high frequency cutoff of this dependence can be related to the fact that extent of interplanetary structures (supposed to occur more often during high solar activity), corresponding to 4 h fluctuations during average solar wind velocity, is much smaller than gyroradius of 100 GV proton in IMF and thus CR are not influenced effectively by them, but rather by another effects.

4 Profiles at selected scales

For discrete wavelet transforms the highest sensitivity corresponds to the scale set depending on apriori choice of length of time averaging of the data. By adjusting appropriate averaging, the time evolution of contribution at selected periodicities to the signal can be checked. Averaging by 81 hours, one of the scales, namely m=3, is providing real time scale of 27 days. The profile of this periodicity is seen in Fig. 2. Displayed are $D_{m,n}^2$. The density at this periodicity is relatively small during epochs of solar minima. There is also seen a gap in the 27 day periodicity within the time period of solar maxima (in last solar cycle in the year 1990), discussed in several papers (e.g. Bazilevskaya et al, 1998). Similar depression is seen also in the solar cycle before. Another periodicity, namely 155 days (averaging over 465 hours, m=3) is displayed in Fig. 3. The largest density in both profiles (Misato and Deep River) is observed in late 1981 - late 1982. It should be noted that ~153 days periodicity in IMF strength and solar wind speed at 1 AU was recently reported during the period 1978-1982 (Cane et al, 1998).

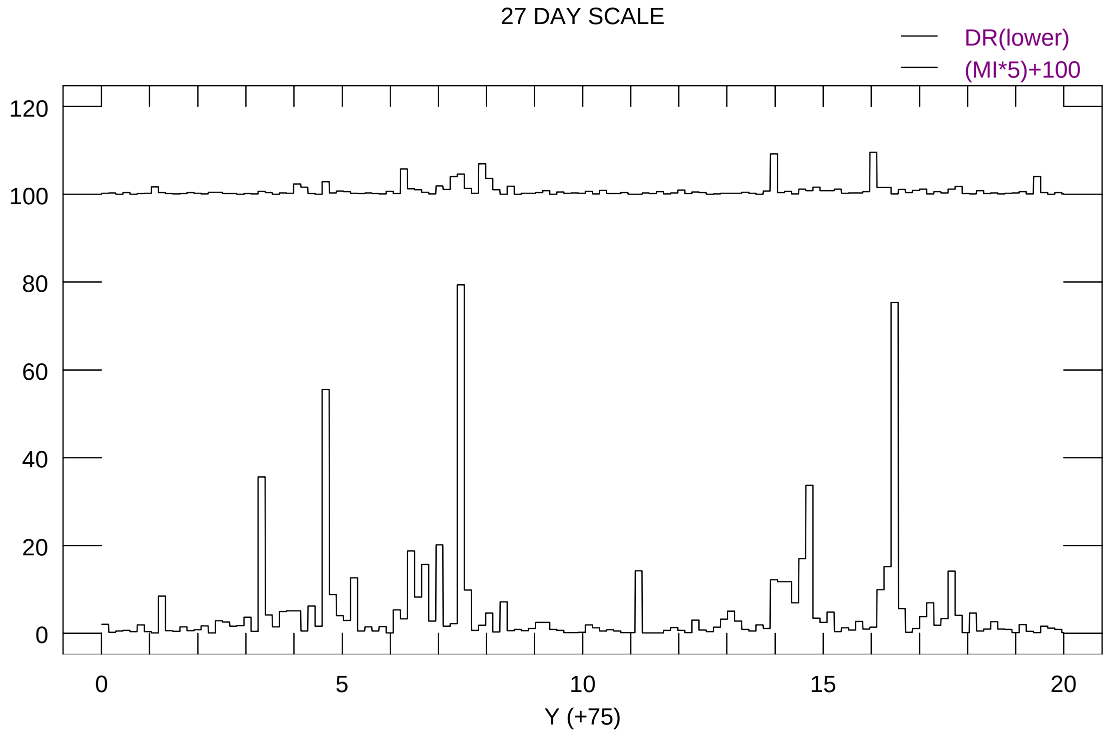

Fig. 2

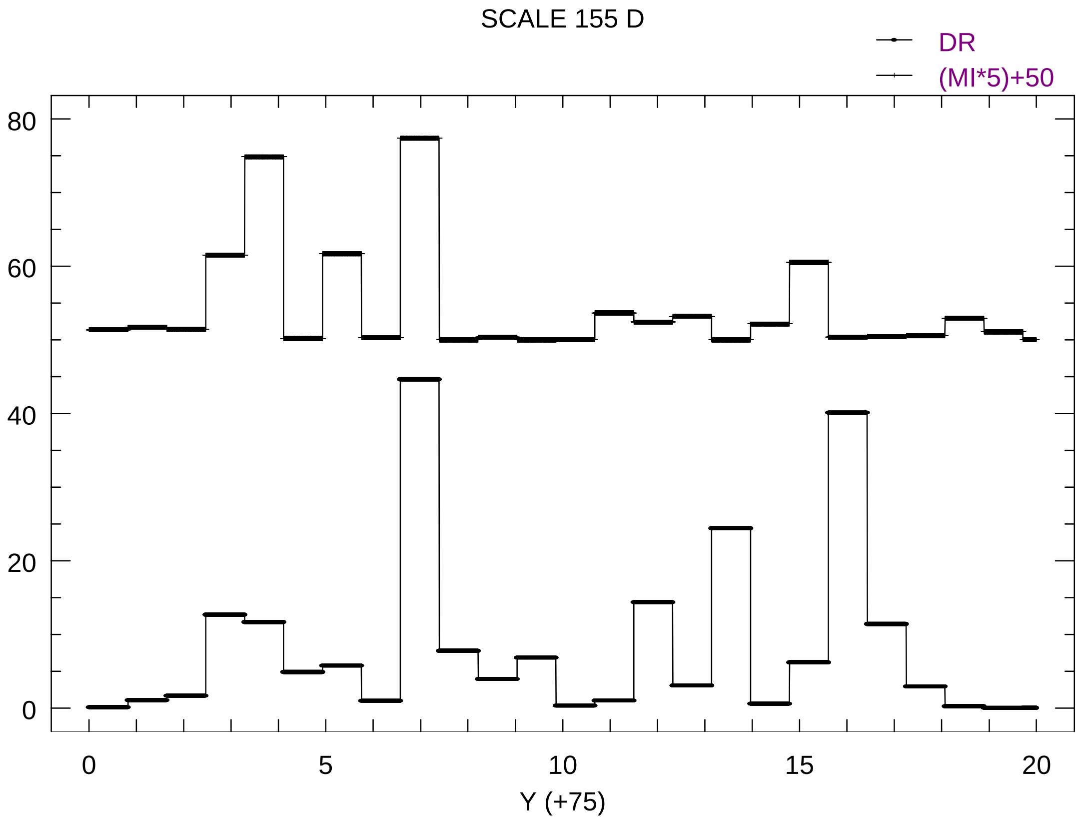

Fig. 3

5 Summary

The scalograms constructed here with using of simple Haar functions for wavelet transform can provide a survey of the contribution of various scales (periodicities) to the cosmic ray count rate series and may be useful for checking the time evolution of selected periodicities. The advantage is no apriori assumption on time stationarity is needed.

Acknowledgements. Support of Slovak grant agency VEGA, 5137 and that of Shinshu University, Matsumoto, Japan is acknowledged.

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