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Comparing the 11-yr and 22-yr cycles in cosmic ray modulation

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The monthly averages of the nucleonic intensity registered by Climax, Huancayo/Haleakala, and Rome until the end of 2004 are used to investigate the characteristic features of the 11-yr and 22-yr cycles. Main results from the wavelet transform technique suggest (i) the power of the 11-yr cycle is different from one cycle to next (with the power envelope showing a modulation from 1960 to 1990), while the phase is practically the same for the three data series; (ii) the power of the ~ 22-yr cycle for Climax maximizes after (before) the power for Huancayo/Haleakala during the positive (negative) heliomagnetic semicycle.

1. Introduction

Time variabilities in Cosmic Ray (CR) records were analyzed by different research teams to look for the contribution of significant periods (e.g., [1] among others). In particular, the method of the continuous wavelet transform (WT) was recently used, it being convenient for the time-frequency decomposition of the data series containing non-stationary processes [2]. In principle the WT works by using arbitrary scales and almost arbitrary wavelets. Nevertheless, the wavelet choice is the most important task because the wavelet type can influence the time and frequency resolution of the obtained results.
For example, it is expected that:

- the Morlet (a plane sine wave with an amplitude windowed in time by a Gaussian function) wavelet gives a high frequency resolution with a less good time localization;
- the **D**erivative **O**f **G**aussian (DOG) wavelet provides a poor frequency resolution but a good time localization.

The monthly CR data from three neutron monitors are here analyzed by means of the WT method (up to a period of 512 months) to investigate the 11-yr and 22-yr CR variabilities. Both the described mother wavelets (Morlet and DOG) are used.

2. Data Used and Results

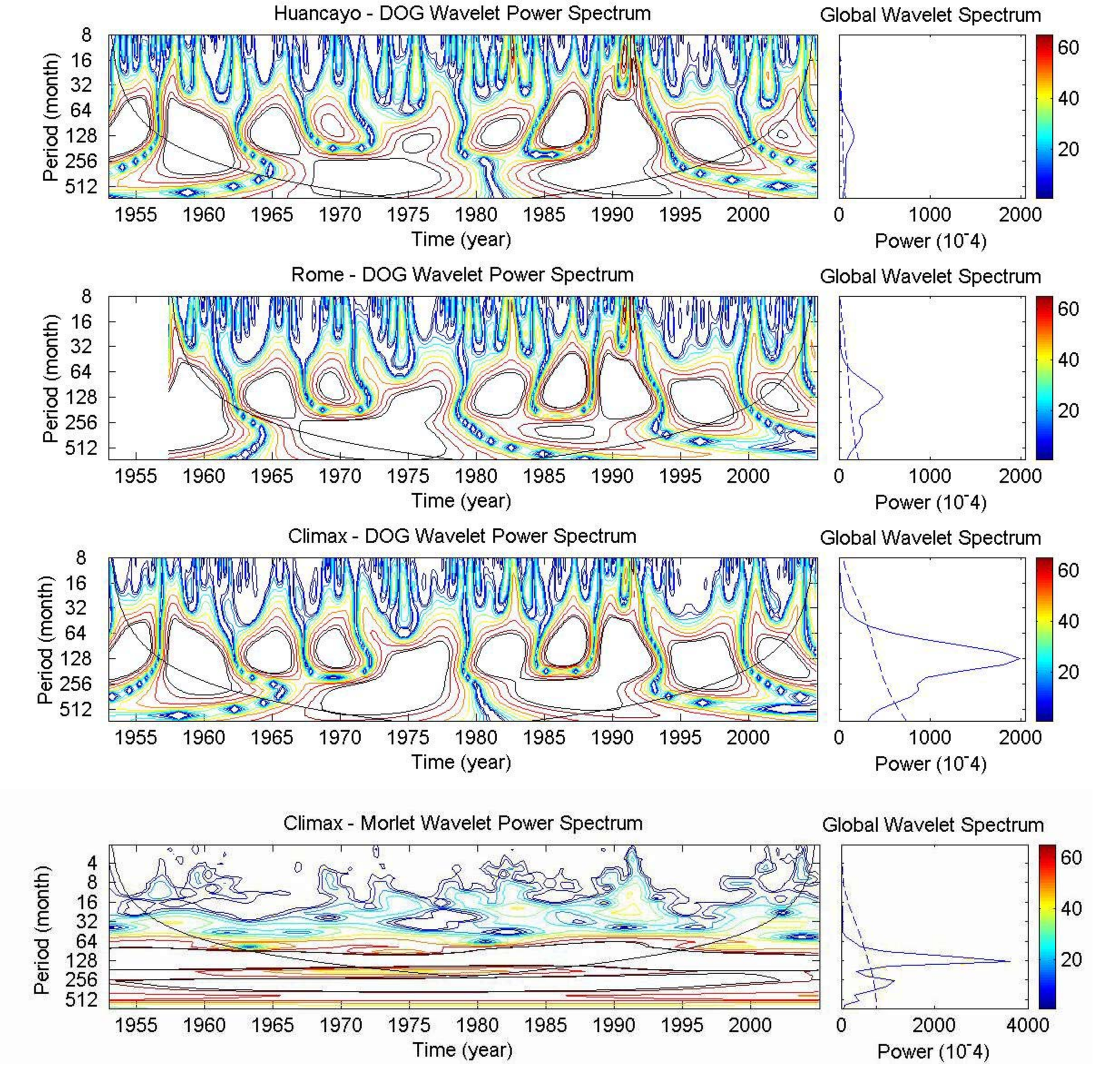
The monthly pressure-corrected values from the following neutron monitors are considered:

(i) Climax (CLI, USA - Colorado: N39.37° - E253.82°, height: 3400 m a.s.l.; cutoff ~ 3 GV; January 1953 - December 2004; see http://ulyses.sr.unh.edu/);

(ii) SVIRCO (RM, Italy - Rome; the used data set contains data from UNILaSapienza location [N41.86° - E12.47°, height: 60 m a.s.l.] and its virtual counting rate after May 1997 to ensure data continuity, being at that time the detector moved to UNIRomaTre; cutoff ~ 6 GV; July 1957 - December 2004; see http://www.fis.uniroma3.it/svirco/);

(iii) Huancayo/Haleakala (HH, Peru: S12.03° - E284.67°, height: 3400 m a.s.l. & Hawaii: N20.72° - E203.73°, height: 3030 m; cutoff ~13 GV; January 1953 - December 1991 for Huancayo & January 1992 - December 2004 for Haleakala; see http://ulyses.sr.unh.edu/).

The Wavelet Power Spectrum (WPS) and the Global Wavelet Spectrum (GWS) for the considered series are reported in Figure 1. The upper panels contain results from the use of the DOG (m=2, Mexican hat), while the lower one from the Morlet mother wavelet ($\omega_o = 6$) on CLI data.


Huancayo - DOG Wavelet Power Spectrum

Rome - DOG Wavelet Power Spectrum

Climax - DOG Wavelet Power Spectrum

Climax - Morlet Wavelet Power Spectrum

Global Wavelet Spectrum

Figure 1. WPS (left) and GWS (right; with the red noise background as a dashed curve) of CLI, RM and HH data by using DOG (upper panels) and Morlet (lower panel; only for CLI) mother wavelets. Black contours correspond to the 95% confidence level. WPS are meaningless outside the thick curve which represents the cone of influence.

The GWS shows for the three data sets a first significant periodicity at 11.02 yr (Morlet) and 10.6 yr (DOG); the second significant periodicity occurs at 22.04 yr, 26.21 yr, 26.21 yr (Morlet, but outside the cone of influence) and 25 yr, 28 yr, 28 yr (DOG) for CLI, RM and HH, respectively. The WPSs illustrate the difference in the time and frequency resolution.

3. Discussion

As DOG wavelet captures in the WPS both positive and negative oscillations as separate peaks, the 11-yr period appears with a maximum in the power both at the maximum and minimum phases. Figure 2 (left panel) reports the DOG Power/Red noise for CLI, RM and HH. It is seen that: - the power of the 11-yr cycle is different from one cycle to next; - the power/noise envelope shows a modulation from 1960 to 1990, which seems to begin again in the following years; - the power/noise phase is practically the same for the three data series; - the peak amplitude for the three measurement sites are not related in a constant way, as one could expect from the different median energies of the involved particles. Moreover, all these features suggest a role for the latitudinal distribution of solar activity in time. In a recent paper Laurenza and Storini analyzed, with the FFT and WT techniques, the green corona (GC) data for the period 1943-2001 (made available by Dr. J. Sýkora courtesy) to look for the latitudinal dependence of the 11-yr and 22-yr cycles [3]. Their Figure 1 shows that the GC 11-yr cycle is present at all the heliographic latitudes but its significance can drastically reduce when going from the equator to the pole. Furthermore, this reduction depends on the hemispheric activity and the considered sunspot cycle. Their Figure 2 (showing the power to noise ratio of the GC 11-yr cycle vs. the heliographic latitude and time) illustrates such features. In particular, it results for sunspot cycle 20 that the GC 11-yr cycle has an intense power to noise ratio only at latitudes within +/- 40°. Our Figure 2 demonstrates for the corresponding CR DOG peaks that the Power/noise signal is indeed low, even if it increases with the CR gyro-radius decrease (note that the HH signal is not significant).

Figure 2 shows in its right panel the DOG WPS/red noise for the ~ 22-yr signal of CLI and HH data inside the cone of influence. It is seen that the wave is longer for HH than CLI data, as reported in Section 2. Taking into account the heliomagnetic cycle evolution (made up by two semicycles with opposite magnetic field polarities and extending from the maximum phase of one sunspot cycle to the next [4]), we notice that the HH signal maximizes before the CLI signal when the solar N-pole is positive and after when the N-pole is negative (see the arrows in Figure 2). The drift theory (see [5] and references therein) forecasts an easier CR access in the heliosphere through: (i) the heliomagnetic polar lines when the N-pole is positive and (ii) the heliomagnetic current sheet when its is negative. In this context, the latitudinal distribution of solar activity centers should have a relevant role on the ~ 22-yr CR modulation only in the (i) case. Nevertheless, we found in both cases a shift in the maximum power of the semicycle (even if with opposite sign), being the bigger one when the N-pole is negative. Unfortunately, available data do not allow to investigate the CR modulation for several heliomagnetic cycles but, if confirmed our findings, they should furnish some constraints to the current CR theories.

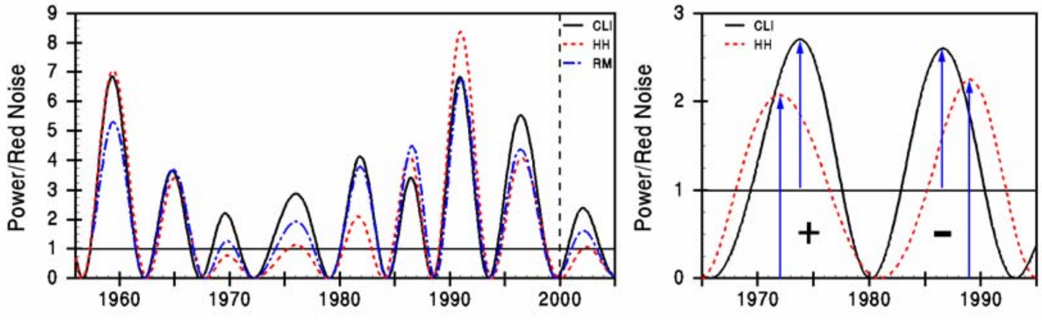


Figure 2. DOG WPS/red noise for the ~ 11-yr (left) and ~ 22-yr (right) waves in CR data. In the left panel the vertical dashed line separates data after 2000 because it is outside of the influence cone. Arrows in the right panel show the peak shift during positive and negative heliomagnetic semicycles for CLI and HH (see the text for details).

4. Conclusions

The wavelet technique, originally applied in geophysics, is nowadays largely used for the numerical analysis of multidimensional discrete signal series [6]. The CR time series on monthly basis contain smoother variations, that can be analyzed with the Morlet or mexican hat wavelets. We used both mother wavelets on Climax, Rome and Huancayo/Haleakala data and we found that the use of the WT on data series with different median CR energies adds information to our knowledge on the ~ 11-yr and ~ 22-yr CR modulation.

Particularly interesting is the result that the ~ 22-yr signal of Climax goes to ~ 26-yr cycle for Rome and Huancayo/Haleakala. A similar long period exists also in the GC data but only at high latitudes [3].

A more extensive work on the topic will be published elsewhere [7].

5. Acknowledgements

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