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Characteristic Features of the 11-Year Cycle in Cosmic Ray Data

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Abstract: Past works suggest the existence of several periodicities in cosmic ray fluxes of both solar and galactic origin. In this paper, neutron monitor data, representing the galactic cosmic ray fluxes and IMP-8 data, mainly representing the solar cosmic ray fluxes, collected from 1974 to 2001, were analyzed by using the wavelet technique to determine medium- and long-term periodicities. We obtained periods of 9.75, 3.76, 2.23 yr for solar cosmic rays and 10.10, 3.00, 1.79 and 1.06/1.15 yr for galactic cosmic rays. These results are compared with the time scales characterizing the quasi periodic variations of the photospheric field and of different phenomena of solar activity.

Introduction

The cosmic ray flux in the heliosphere includes two main components: (i) the Galactic (and extragalactic) Cosmic Rays (GCRs), coming from outside the solar system; (ii) the Solar Cosmic Rays (SCRs), emitted from the Sun in processes such as flares and Coronal Mass Ejections (CMEs). The first component is dominant at energies higher than 1 GeV. The two cosmic ray components are affected by the solar activity in opposite ways. In fact, during periods of high activity, the SCR fluxes tend to increase (because flares and CME are more frequent), while the GCR fluxes tend to decrease (because the interplanetary magnetic field more effectively shields the incoming charged particles). As the solar activity changes on several time scales, the SCR and GCR fluxes should undergo corresponding variations. Previous studies confirmed this expectation, pointing to the existence of periods of about 150 days, 1.3 yr, 1.7 yr and 11 yr for the GCR flux [1, 2, 3, 4] and of a quasi-biennial oscillation for the number of SCR events [5]. However, the reliability of these periods was not often discussed.

Purpose of the present paper is to investigate the possible periodicities of the GCR and SCR fluxes on time scales from a few months to 11 years. Results will be compared with the quasi periodic variations of the photospheric magnetic field and of some different phenomena of solar activity.

Data set and method of analysis

This study, covering the period from 1974 to 2001, is based on the following data:

- Flux of the interplanetary particles in the energy range 0.50 - 0.96 MeV/nucleon, measured by the Charged Particles Measurements Experiment (channel P2) aboard the IMP-8 spacecraft;
- Intensity of particles measured by three neutron monitors (Climax, Rome, Huancayo-Haleakala) with cutoff rigidities of about 3 GV, 6 GV and 14 GV, respectively.

IMP-8 data, available in the form of daily means in the web site http://sd-www.jhuapl.edu/IMP/imp_cpme_data.html, have been averaged over each Bartels rotation. Neutron monitor data, in the form of monthly averages, are available in the web sites http://ulysses.sr.unh.edu/ and http://www.fis.uniroma3.it/~svirco/. IMP-8 data are largely representative of the SCR flux, as the galactic contribution at energies lower than 1 MeV is practically negligible. Neutron monitor

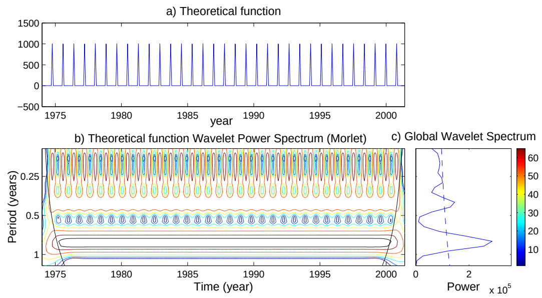

Figure 1: a) Time evolution of the test function. b) The local WPS vs. time. Black contours enclose regions of greater than 95% confidence for a white noise background. The black solid line indicates the cone of influence, where edge effects become important. c) GWPS (solid line) along with the global significance level (dashed curve).

data, on the other hand, well represent the GCR flux, as the ground level enhancements (GLEs) have been removed from the data sets.

Search for periodicities in the above data sets is performed by using the wavelet transform method [6]. This technique offers a significant advantage with respect to the Fourier transformation because it allows to localize in time possible periodicities even those not always present trough the whole interval considered. As a mother function we assume the Morlet which supplies a good resolution in frequency compared to other functions. We compute:

- the Wavelet Power Spectrum (WPS) as a function of time;
- the Global Wavelet Power Spectrum (GWPS) over the whole time interval considered.

The significance of the peaks was evaluated against a white noise background.

The SCR fluxes are subject to abrupt variations from one Bartels rotation to the next, often exceeding one order of magnitude. Such a trend may cause errors in the wavelet analysis. We investigated this issue by applying the wavelet transform to the discontinuous test function F(t) illustrated in Figure 1a, having a period of 0.81 yr. It is seen that in the GWPS (Figure 1c), beside the main peak at

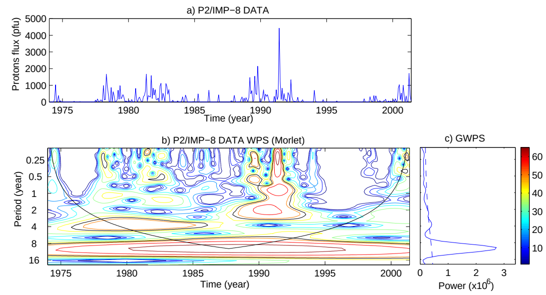

Figure 2: Same as Figure 1 for SCR fluxes.

T = $0.79^{+0.04}_{-0.03}$ yr, two more peaks are present at T_1 = 1/2 T and T_2 = 1/3 T. Both of these fictitious peaks are apparently above the global significance level. In the case of our data set, one expects the appearance in the GWPS of peaks corresponding to subharmonics of the Schwabe period (about 11 yr). We overcame this difficulty by using suitable pass band filters bracketing the frequencies of interest. In fact, it turns out that a peak in the GWPS can be considered reliable, with a high degree of confidence, if the ratio of its amplitude to that of any other peak, occurring at frequencies lower than that being tested, results always greater than 1 after the filtering procedure has been performed.

Periodicities in the SCR fluxes

Panel a) of Figure 2 illustrates the time history of the SCR fluxes observed by IMP-8 during the considered time period. One notes the large fluctuations of the data, mentioned in the previous section, and a long term modulation, which is in phase with the sunspot cycle. The WPS and the GWPS are shown in panel b) and c) of Figure 2, respectively. In the GWPS two peaks are above the global significance level: one occurs at $9.75^{+0.44}_{-0.40}$ yr and the other at 3.76 $^{+0.17}_{-0.16}$ yr. In the WPS, the 3.76 yr period is present from 1976 to 1986. In addition, a period of $2.23^{+0.10}_{-0.08}$ yr is detected from 1988 to 1994 and one of 0.86 yr in several time intervals. The last period, however, was discarded because, when a pass band filter was applied, the criterion of reliability discussed in the previous section was not satisfied.

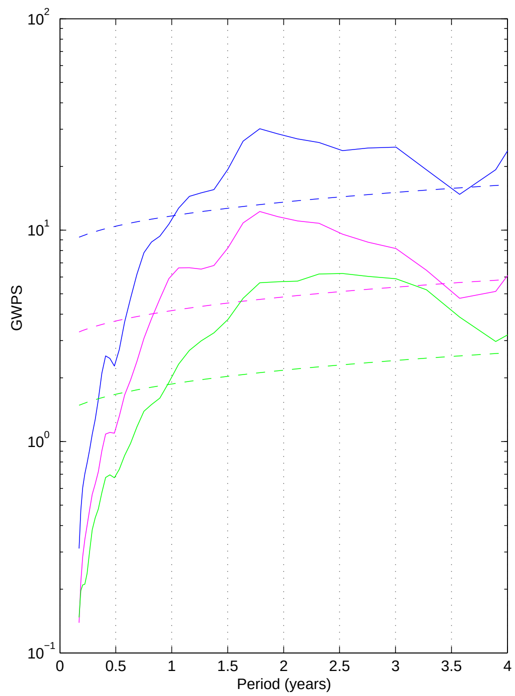

Figure 3: Comparison of the GWPS for Climax (blue line), Rome (magenta line) and Huancayo (green line).

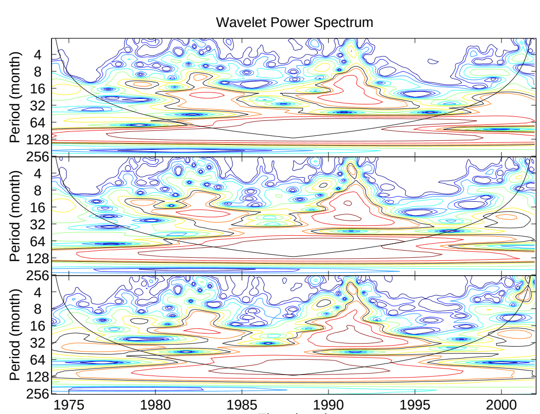

Figure 4: Same as Panel b) of Figure 1 for neutron monitor data after the filtering procedure: Climax (top), Rome (middle), Huancayo-Haleakala (bottom).

Periodicities in the GCR fluxes

The wavelet analysis indicates that the basic periodicity in the neutron monitor data, taken at all the three observatories, is $10.10^{+0.46}_{-0.42}$ yr. In order to better reveal shorter periods, we applied to each data set a filter in the 0-4 yr band. Figure 3 compares the GWPS of data recorded at the three neutron monitors whereas Figure 4 gives the corresponding WPS. The significant variations occur on the following time scales: i) a quasi-annual periodicity ($1.15^{+0.17}_{-0.16}$ yr at Climax, $1.06^{+0.04}_{-0.04}$ yr at Rome) during the maximum phases of both the cycles 21 and 22; ii) a $1.79^{+0.08}_{-0.07}$ yr period, mostly apparent during the maximum and decreasing phases of both the cycles; iii) a $3.00^{+0.14}_{-0.13}$ yr period, most clearly observed from the maximum of cycle 21 to the one of cycle 22. In addition, the Huancayo-Haleakala data show also a peak at a period of $\sim$ 2.5 yr around the cycle 22 maximum.

Discussion and conclusions

The main period revealed in both the SCR and GCR fluxes, over the entire time interval examined, is about 10 yr; more precisely $9.75^{+0.44}_{-0.40}$ yr for SCRs and $10.10^{+0.46}_{-0.42}$ yr for GCRs, coinciding with the Schwabe period. The duration of cycles 21 and 22 was respectively 9.70 yr and 10.25 yr.

The other periods are probably related to the main modes of variability of the photospheric magnetic field at low and middle latitudes. In fact, the toroidal and poloidal components vary on characteristic time scales of $\sim$ 2 yr (quasi-biennial oscillation, QBO) and of $\sim$ 3 yr respectively [7]. Note that QBOs, revealed mainly during solar maxima, were also found in several phenomena of activity (e.g. [8, 9, 10, 11]).

The QBO of the toroidal field should be identified with the 2.23 yr period, present in the SCR flux around the solar maximum of cycle 22 (1988-1993) and with the 1.79 yr in the GCR flux in the epochs of high or decreasing solar activity.

As one may have expected, the 3 yr periodicity of the poloidal solar field closely matches the variations of GCRs that are strongly influenced by the large scale evolution of the interplanetary field. Consistently with this interpretation, this periodicity is observed in the GCRs during the maximum and declining phases of the solar cycles, when open fields lines on the solar surface are mainly present at middle and low latitudes. On the other hand, the 3.76 yr period, present in the SCR flux during the cycle 21, could arise from the interaction of both the QBO and $\sim$ 3 yr oscillation of the photospheric field. The solar origin of this periodicity is confirmed by the quasi periodic variation, on similar time scales, of several activity phenomena: the sunspot number ($3.45^{+0.16}_{-0.14}$) and the intensity of the coronal green line ($3.61^{+0.32}_{-0.30}$) as found by reference [7], the sunspot group number [12] and the N-S distribution of flares [13, 14].

Concerning the quasi annual periodicity we recall that the solar rotation rate has been found to vary on a similar time scale at the base of the convective region [15]. It is conceivable that this variation reflects on photospheric fields and hence in a corresponding GCR modulation.

In conclusion, our analysis shows that the SCR emission and the GCR propagation through the heliosphere are modulated on the same time scales ($\sim$ 2 and $\sim$ 3 yr) of the quasi periodic variations found in the photospheric magnetic field and in different phenomena of solar activity.

Acknowledgements

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References

[1] K. Kudela, J. Rybák, A. Antalová, M. Storini, Time evolution of low-frequency periodicities in cosmic ray intensity, Solar Phys. 205 (2002) 165.

[2] J. F. Valdés-Galicia, R. Perez-Enriquez, J. A. Otaola, The cosmic ray 1.68-year variation: a clue to understand the nature of the solar cycle?, Solar Phys. 167 (1996) 409.

[3] J. F. Valdés-Galicia, V. M. Velasco, B. Mendoza, Mid term cosmic ray quasi periodicities and solar magnetic activity manifestations, in: 29^{th} International Cosmic Ray Conference, Vol. 2, 2005, p. 211.

[4] K. Mursula, Simultaneous occurrence of mid-term periodicities in solar wind speed, geomagnetic activity and cosmic rays, in: 26^{th} International Cosmic Ray Conference, Vol. 7, 1999, p. 123.

[5] G. A. Bazilevskaya, V. S. Makhmutov, A. I. Sladkova, Gnevyshev gap effects in solar energetic particle activity, Adv. Space Res. 38 (2006) 484.

[6] C. Torrence, G. P. Compo, A practical guide to wavelet analysis, Bull. Am. Meteor. Soc. 79 (1998) 61.

[7] M. Laurenza, Variability of the large scale solar and interplanetary magnetic fields, PhD Thesis, Universitá La Sapienza , Roma, 2006.

[8] J. O. Stenflo, M. Güdel, Evolution of solar magnetic fields - Modal structure, Astron. Astrophys. 191 (1988) 137.

[9] S. J. O., Global wave patterns in the Suns magnetic field, Astrophys. Space. Sci. 144 (1988) 321.

[10] E. E. Benevolenskaya, A model of the double magnetic cycle of the Sun, Astrophys. Journ. 509 (1998) L49.

[11] M. Laurenza, M. Storini, Solar QBO and particle emission, Mem. SAIt. Suppl., in press.

[12] K. P. Rao, Short periodicities in solar activity, Solar Phys. 29 (1973) 47.

[13] G. Vizoso, J. L. Ballester, Periodicities in the north-south asymmetry of solar activity, Solar Phys. 119 (1989) 411.

[14] B. Joshi, A. Joshi, The north-south asymmetry of soft X-ray flare index during solar cycles 21, 22 and 23, Solar Phys. 219 (2004) 343.

[15] R. Howe, J. Christensen-Dalsgaard, F. Hill, R. W. Komm, R. M. Larsen, J. Schou, M. J. Thompson, J. Toomre, Dynamic Variations at the Base of the Solar Convection Zone, Science 287 (2000) 2456.