Galactic Cosmic Ray Fluctuations: Long-term Modulation of Power Spectrum

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Abstract

In the present paper we study the time evolution of power spectra of galactic cosmic ray fluctuations during the last three solar cycles (1968-2002) using data of 5-min count rates from two far spaced high-latitude neutron monitors, Tixie Bay (Russia) and Oulu (Finland). We have shown that the power spectrum of cosmic ray fluctuations is a subject of a regular long-term periodic 11-year modulation in phase with solar activity, in accordance with variations of the inertial part of the interplanetary magnetic field turbulence power spectrum. These results present a new kind of modulation of cosmic ray intensities.

1. Introduction

The intensity of cosmic rays (CR) as measured in the vicinity of the Earth undergoes variations in different time scales. The least studied are short-time quasi-periodic variations with periods from minutes to several hours, the so-called CR fluctuations. The magnitude of fluctuations is comparable to the noise level of real data leading to the low signal-to-noise ratio. Accordingly, when studying the CR fluctuations one meets a problem of signal extraction from the high background noise which can be solved by special methods of time series spectral analysis. The power spectrum of CR fluctuations is highly variable, varying both in power and in the frequency depending on the momentary state of the interplanetary magnetic field (IMF) and solar wind. Therefore, such spectra contain a large amount of different kinds of information, and their analysis is not straightforward especially on long-time scales. Accordingly, it is common to introduce various indices of CR fluctuations that characterize the time behaviour of the CR power spectrum [1-3]. Such an approach allows to squeeze the amount of information and study the power spectrum evolution in a given frequency range even on long-time scales. This method was used, e.g., by [4] who studied the monthly index of the spectral power density of CR fluctuation for the years 1980–1990 using 5-min data from the Tixie Bay neutron monitor. They found a significant

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correlation between the solar activity level and the CR fluctuation magnitude suggested that it is related to the corresponding evolution of the spectrum of the solar wind due to solar flare activity. If the modulation effect declared by [4] does exist, it should be present also in other data sets from different cosmic ray stations. The effect is expected to be most significant in high-latitude stations which have lower geomagnetic cutoff rigidities. In the present paper we study the CR fluctuation spectrum using data from two far spaced high-latitude neutron monitors, Tixie Bay and Oulu, for the last three solar cycles.

2. Data and Method

We use 5-min resolution data (corrected for the barometric pressure) of cosmic ray intensity registered by the two far spaced high-latitude neutron monitors, Tixie Bay in North-Eastern Siberia and Oulu in Northern Finland, equipped by the same type of detector (NM–64) but with different number of counters. The data cover the period from 10/01/1980 to 25/06/1990 for Tixie Bay and from 19/01/1968 to 07/07/1975 and from 19/01/1985 to 12/11/2002 for Oulu stations. Therefore, there is a 6.5-year interval where the two data sets overlap allowing for an intercalibration. The total time interval covered by 5-min data from the two stations embraces about 3 solar cycles from 1968 to 2002 but it contains also a 5-year gap 1975–1979. The two NM stations have similar parameters and low rigidity cutoffs defined by the atmospheric cutoff. Narrow asymptotic acceptance cones of the two stations are separated by more than 90° in longitude [5].

First we pre-processed the raw data. From all daily samples we chose only those days where data gaps or apparent errors do not exceed 2 hours in total. Days with ground level enhancements (GLE) were also excluded from further analysis because of their steep increase and high amplitude which would distort the spectral analysis in the short-period domain. Forbush decreases were not excluded since their time profile is equivalent to a low-frequency trend in 5-min data and can be filtered out. Next we calculated daily power spectra of CR fluctuations using the standard Blackman-Tuckey algorithm [6]. Then we calculated 27-day averaged power spectra $P(\nu)$ from the daily spectra, excluding possible longitudinal inhomogeneities in the solar wind and corona. From the obtained power spectra of CR fluctuations we have computed the index of CR fluctuations power in the studied frequency range [2]: $P2 = \int_{\nu_1}^{\nu_2} P(\nu)d\nu$, where $\nu_1 = 1.67 \cdot 10^{-4}$ Hz and $\nu_2 = 1.67 \cdot 10^{-3}$ Hz.

As an index of CR intensity we used 27-day data of Oulu NM count rate, corrected for long-term systematic changes. As a solar activity index we used the 27-day averages of sunspot numbers.

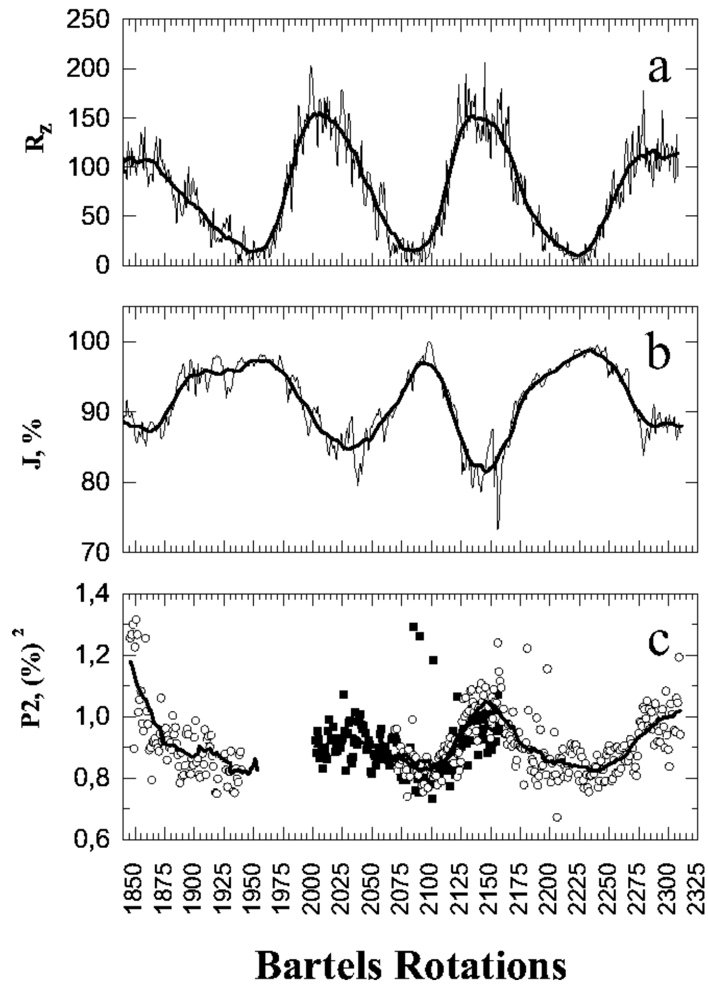

Fig. 1. 27-day averaged time profiles of the sunspot activity R_z (panel a), CR intensity J measured by Oulu NM (b) and CR fluctuation index $P2$ for Oulu (open symbols) and Tixie Bay (solid symbols) (c). Thick lines depict long-term smoothing.

3. Results and Discussion

Fig. 1. shows the sunspot activity R_z, CR intensity J as measured by Oulu NM as well as the index of CR fluctuations $P2$ computed for both Oulu and Tixie Bay stations for the studied time period. One can see that the $P2$ index time profile is in phase with sunspot activity and in antiphase with CR intensity. The cross-correlation coefficient between $P2$ and R_z is $\rho(0) = 0.67$ for zero time shift between the series with the maximum correlation being $\rho(10) = 0.71$ for $P2$ delayed by 10 Bartels rotations (270 days) with respect to R_z. The probability of a random origin of this correlation is less than 0.01. The maximum of CR fluctuation index $P2$ corresponds to early descending phase of solar activity when a maximum of flare and coronal activities occurs. The coefficient of cross-

correlation between the $P2$ index and the CR intensity recorded by Oulu NM is $\rho(0) = -0.78$. Therefore, the maximum of CR fluctuation magnitude corresponds to the minimum of CR intensity. Meanwhile the cross-correlation coefficient between J and R_z reaches the maximum of $\rho(5) = -0.9$ for 5 Bartels rotations time shift, in accordance with the average delay between CR and solar activity [7]. A similar solar cycle dependence is observed also for small-scale ($10^{10} - 10^{12}$ cm) turbulence of the solar wind. This is in accordance with recent results by [8] who demonstrated that significant (more than 2 orders of magnitude) regular changes take place in the inertial part of the IMF turbulence spectrum, in the same frequency range, during the 11-year solar cycle. This can be due to MHD-waves (Alfvén or magnetosonic) generated by an intensive flux of low energy ($0.01 - 10$ MeV) particles related to solar flares or coronal mass ejections (see [4,8], and references therein). Thus, the results obtained here present a new CR phenomenon, regular high-frequency modulation of the galactic CR modulation spectrum, which was first mentioned by [4]. This modulation of the CR fluctuations is persistent during the last three solar cyles being in phase (with few months delay) with solar activity and in anti-phase with the CR intensity. The modulation of the CR fluctuation spectrum is interpreted to be related to the corresponding modulation of the inertial range of IMF fluctuation spectrum in the course of solar cycle [8].

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