The changes of 27-day variations in cosmic rays and geomagnetic activity.

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Abstract

Variations with the period of Sun's rotation have been studied for various interplanetary and near-Earth parameters over 21 - 22 solar cycles. Following parameters were chosen for the analysis: the cosmic ray intensity registered by Deep River neutron monitor, Stanford mean solar magnetic field, geomagnetic activity index K_p, as well as solar wind velocity and the module of the interplanetary magnetic field. It was shown that there are certain crucial points in the course of solar cycle which coincide with drastic changes of the amplitude of the 27-day variations. For simplified cases the expected changes of the amplitude of the 27-day variation of galactic cosmic rays taking into account the decay of the heliolongitudinal asymmetry of diffusion coefficient versus the radial distances have been calculated.

1 Introduction:

Considering the influence of solar activity modulation on the 27-day cosmic ray (CR) variation it was shown that roughly the 27-day variation amplitude has changed similar to the course of the 11-year cycle of solar activity (SA). Yet the detailed analysis of the peculiarities of the 27-day CR variation demonstrates their difference from the 11-year solar cycle time dependence. This difference is reflected in the abrupt changes during the period of high SA, the unusual behavior of the 27-day CR variation coinciding with the inversion of the Sun's global magnetic field (Bazilevskaya et al., 1995, Sabbah et al., 1995, Vernova et al., 1995). This phenomenon seems to have more general character, as it pertains not only to the 27-day CR variation but to a number of other characteristics of the solar activity and heliosphere.

It can be suggested that the solar activity modulation leads to the complex response in CR which is characterized, in case of the 27-day CR variation, by two maxima during a solar cycle and the local minimum between them coinciding with the Sun's global magnetic field inversion. Our aim was to consider long-term data series including different parameters during several solar cycles with the object to elucidate the peculiarities of their behavior at the period of high SA.

2 Experimental Results and Discussion:

To investigate the 27-day variation during solar cycles 21 - 22 the following parameters were chosen: the CR intensity registered by Deep River neutron monitor, Stanford mean solar magnetic field (Sun-as-a-star), geomagnetic activity index K_p, as well as the interplanetary medium parameters (OMNIWEB): solar wind (SW) velocity and the module of the interplanetary magnetic field (IMF). These data were treated with a unified technique, which included the elimination of the 11-year trend and the evaluation of the first harmonics by means of 27-day Fourier analysis. After that the obtained amplitudes were averaged over 13 Bartels rotations with a sliding shift of one rotation. The presented data for the amplitude of the 27-day variation of the solar wind velocity have gaps because of the lack of initial data.

In the present work we are concerned primarily with the decline phase from the maximum to the minimum of SA. In Fig. 1 amplitudes of the 27-day variation of various parameters are presented together with the time dependence of the solar activity. Temporal behaviors of the 27-day variation of the CR intensity and of the K_p

index (Figs. 1a,c) represent the result of modulation with the period of Sun's rotation.

Periodic structure of the near-Earth space may be characterized by the IMF and SW velocity variation amplitudes (Figs. 1d,e), whereas the 27-day variation of the Stanford mean solar magnetic field (Fig. 1b) reflects the global influence of the Sun on the modulation process.

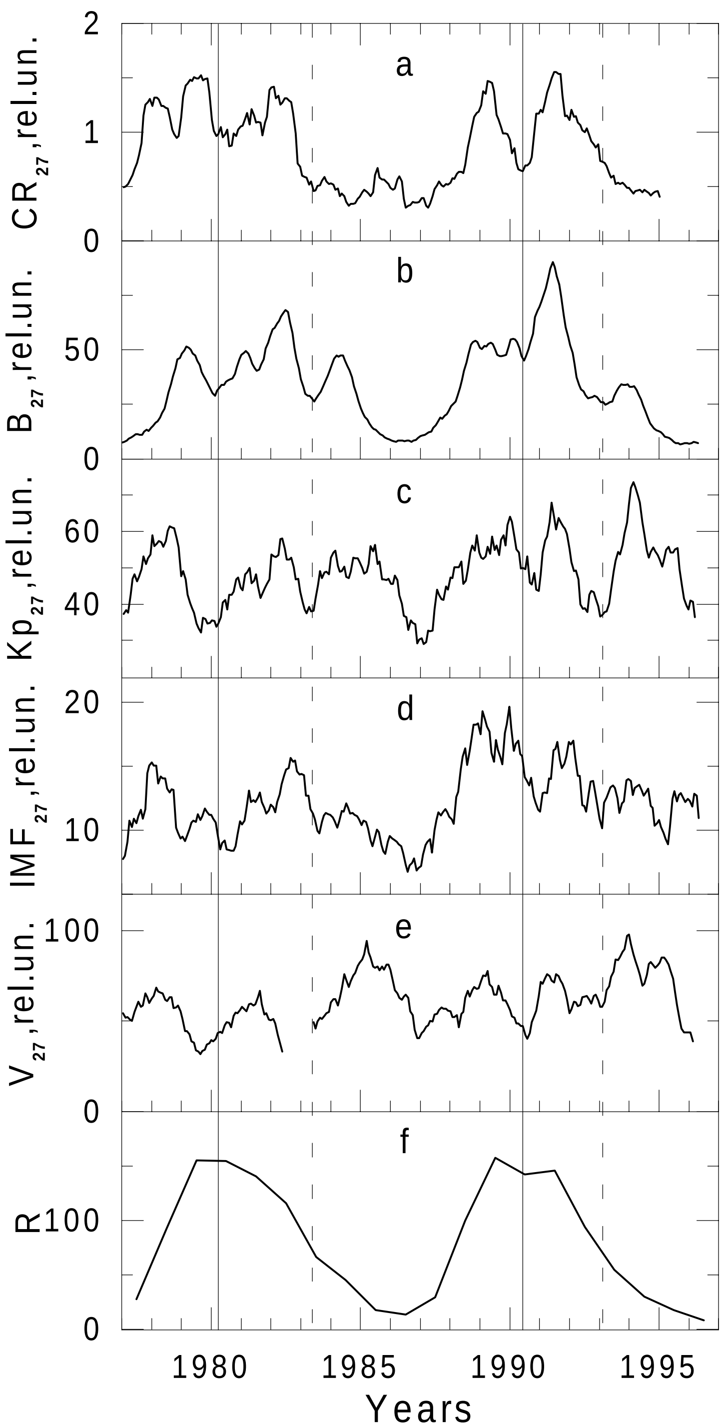

Fig. 1. Amplitude of the 27-day variation (relative units): a) Deep River neutron monitor; b) Stanford magnetic field; c) geomagnetic Kp index; d) interplanetary magnetic field; e) solar wind velocity. Sunspot number - f). Vertical lines denote crucial points of the solar cycle (see text).

It can be seen, that among the five parameters only the 27-day variations of CR and Stanford data follow the time dependence of the solar cycle (Figs. 1a,b). However, even for these parameters significant deviations from the solar cycle time dependence are observed. These deviations manifest themselves in the sharp drop of the amplitude of variation in the year of the inversion of the Sun's global magnetic field and in the sharp increase of the amplitude in the year next to the inversion of the Sun's global magnetic field. It should be emphasized that, as a rule, the 2nd maximum has a larger value than the 1st one coinciding with the solar activity maximum, which fact is especially clear presented in Stanford data (Fig. 1b). The amplitudes of the 27-day variations of K_p index, interplanetary magnetic field and solar wind velocity have more complex structure, so that it is rather difficult to see the reflection of the 11-year solar cycle in their behavior (see Figs. 1c,d,e). This complexity of the structure is connected first of all with the sharp increases and decreases in the amplitudes of the 27-day variations on decline phase of SA. Nevertheless, there is, apparently, a very close connection between the changes of these amplitudes and the 11-year solar cycle. The point is that those years, which correspond to neither very large nor very small values of the amplitude, are presented in each cycle, moreover, the intervals between the respective extreme points are approximately equal to 11 years.

One of the points, wherein a sharp drop of the amplitude is observed for all data under consideration, is the inversion of the Sun's global magnetic field (the 1st drop, denoted by a vertical solid line in Fig. 1), the second point is located three years after the inversion (the 2nd drop, a dotted line in Fig. 1). The next drop of the amplitude coincides with the minimum of SA observed for all data and cycles. This drop has the largest value for almost all data. A characteristic feature, which is observed near the minimum of SA, should be noted. One year before the minimum of SA the amplitudes of the 27-day variations of K_p index and solar wind velocity reach very high values and have a sharp drop towards the year of the minimum (Figs. 1c,e). This peculiarity for K_p index was already discussed in (Bumba & Hejna, 1990).

Thus, while considering decline phase of SA it is characterized by sharp drops of the amplitude of the 27-day variations at the points, which are located in the strictly fixed positions with reference to the solar cycle: the 1st drop occurs at the period of the inversion of the Sun's global magnetic field (1980, 1990), and the 2nd drop occurs approximately 3 years after the inversion (1983, 1993). These drops are followed by sharp increases of the amplitude, which provide for peaks also located in strictly fixed positions of the solar cycle. Thus, peaks of the amplitude of the 27-day variation appear in the years following the 1st drop (the years of the 2nd maximum: 1982, 1991) and the 2nd drop (the years of the 3rd maximum: 1984 - 1985, 1994).

In the work (Svestka, 1995) it was concluded that the relative sunspot number R is not the best characteristic of the solar cycle activity: in this work the years were considered, which are noted for the most outstanding periods of activity outbursts during the decline phase of solar cycles; these years coincide with the years of the 2nd and the 3rd maximums mentioned above. Apparently, the parameters under consideration are influenced not only by SA level, but by a more fine structure of the solar cycle. Two drops considered in the present paper, apparently, differ from each other in their origin. The 2nd drop presented mainly in K_p index, solar wind velocity and interplanetary magnetic field is connected most likely with the processes taking place in close proximity to the Earth. At the same time, the 1st drop coinciding with the inversion of the Sun's global magnetic field is present also in the 27-day CR variation, which may be interpreted as evidence of large heliospheric regions being involved in the CR modulation process.

3 Theoretical Model and Conclusion:

The 27-day CR modulation takes place not only in the vicinity of the ecliptic plane and of the Earth's orbit but also far away from these regions. So, the longitudinal asymmetry of the electromagnetic conditions in the nearer part of the outer heliosphere plays an important role in the behavior of the 27-day CR variation in the vicinity of the Earth's orbit (Alania, Shatashvili & Dorman, 1968). Therefore, in order to have the significant amplitude of the 27-day CR variation in the vicinity of the Earth's orbit the heliolongitudinal asymmetries of the SW velocity and of the IMF strength should exist up to the region of the outer heliosphere, i.e. far away from the Earth's orbit. However, during the middle of maximum solar activity epochs there are lots of reasons to destroy the regularities in the asymmetries of the solar wind velocity and of the IMF strength far away from the Earth's orbit. In this connection, merged interaction regions (MIRs) and global merged interaction regions (GMIRs) must play a crucial role in the outer heliosphere as the general destructive phenomena (Burlaga, McDonald & Ness, 1993, Potgieter & Le Roux, 1994).

The 27-day variations of CR can be described using the transport equation (Parker, 1965)

$$\partial N/\partial t=\nabla_i(K_{ij}\nabla_j N)-\nabla_i(u_i N)+R/3(\partial N/\partial R)(\nabla_i u_i) \quad (1)$$

where N, R and K_{ij} are density, rigidity and diffusion tensor of GCR particles, respectively. u_i is solar wind velocity and t- time. Eq (1) in spherical coordinate system r, θ, ϕ, can be written:

$$\partial n/\partial t=A_1\partial^2 n/\partial r^2+A_2\partial^2 n/\partial\theta^2+A_3\partial^2 n/\partial\phi^2+A_4\partial^2 n/\partial r\partial\phi+A_5\partial n/\partial r+A_6\partial n/\partial\theta+A_7\partial n/\partial\phi+A_8\partial n/\partial R \quad (2)$$

where A_1, A_2, . . , A_9, are, the function of r, θ, ϕ, R and time t; n is equal to the N/N_0, where N_0 is density in the interstellar medium and is accepted as $N_0 \propto R^{-4.5}$ for the rigidities to which neutron monitors are sensitive. In general, the amplitude of CR 27-day variation is time-dependent, but in order to show a dependence of CR 27-day variation amplitude at the Earth orbit only on the radial decay of the asymmetry of the electromagnetic processes in interplanetary space the addend $\partial n/\partial t$ in Eq(2) can be neglected (quasi statinary case). There is another opportunity to simplify Eq(2). Namely, as the dip of the amplitude of CR

27-day variation is observed in 1990 (when the Sun's global magnetic field reversal had taken place), the drift effect can be neglected. To solve the Eq(2) the next assumptions are done. The ratio of perpendicular $K_\perp$ and parallel $K_{||}$ diffusion coefficients is assumed to be equal to 0.2 and the parallel diffusion coefficient $K_{||}$ is represented by the following expression, $K_{||}=K_0 K(r) K(\phi,\theta) K(R)$; here K_0 is equal to 10^{22} $cm^2 s^{-1}$ for the energy of 1 GeV; K(r) = (1 + r) and K(R) = R (in units of GV); In order to avoid an intersection of the magnetic field lines in space we assumed the heliolongitudinal asymmetry only of the diffusion coefficient as $K(\phi,\theta) = 1+0.3 \sin\phi\ K(\theta)\times\exp[-r/s]$. This is equivalent to the heliolongitudinal asymmetry of the magnitude (which changes two times during the Sun's rotation,) of the regular interplanetary magnetic field; the existence of the heliolatitudinal asymmetry of the diffusion coefficient in the range of the heliolatitudes $30^0 \le \theta \le 150^0$ ($\pm 60^0$ with respect to the solar equatorial plane) is assumed as, $K(\theta) = \sin\theta$, and for heliolatitudes in the range of $0^0 \le \theta < 30^0$ and $150^0 < \theta \le 180^0$ as, $K(\theta) = 0$; The expression exp[-r/s] shows a decay of the heliolongitudinal asymmetry of diffusion coefficient versus the radial distance. The radius of the modulation region is taken as 80 astronomical units (AU) and solar wind velocity U equals 4×10^7 cm/s. Eq (2) was solved numerically using the Crank-Nikolson implicit method for three cases; the first one (a), when s = 80 AU (i.e. helongitudinal asymmetry takes place almost up to the end of modulation region), the second one (b), when s = 20 AU, and the third one (c), when s = 10 AU. Thus, the expression of the Parallel diffusion coefficient $K_{||}$ is as, $K_{||} = 10^{22} (1+r) (1+0.3 \sin\phi\ K(\theta)\times\exp[-r/s])R$.

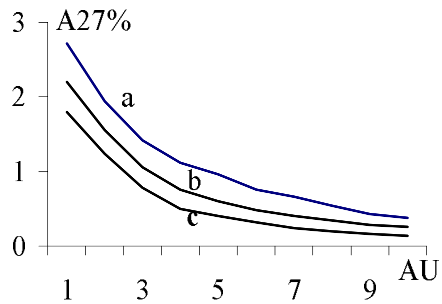

Fig.2.(See text)

The expected radial changes of the amplitude of CR 27-day variation corresponding to above mentioned three cases are plotted on the figure 2. It is clear that the 27-day amplitude of CR diminishes versus radial distances for all cases but it is less when the decay of the heliolongitudinal asymmetry takes place nearer to the Sun (c).The decay of the heliolongitudinal asymmetry of the diffusion coefficient can be ascribed, e.g. to the destructive effect of MIR or GMIR in the interplanetary space. So, the destruction in the asymmetry of the IMF strength in the heliosphere could be the partial cause of the dip in the amplitude of the 27-day CR variation during the maxima epochs of solar activity, particularly, in 1990. Thus, MIR or GMIR should play the certain role in diminishing of the 27-day amplitude of CR, particularly, at the Earth orbit. Nevertheless, theirs destructive effect in decay of the heliolongitudinal asymmetry of the diffusion coefficient could not explain completely the dip of the 27-day amplitude of CR in 1990. It seems that in the course of Sun's polar magnetic field reversal a part of the Sun's energy is spending for this reversal process and there is necessary some new idea how it must be happened. It is obvious that the problem of the CR 27-day variation significant dip in the course of solar activity maxima epochs needs further Investigation.

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