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The Energetic Spectrum Changes of Forbush Effects During the Different 11-year Cycles of Solar Activity

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Abstract

We present the statistical properties of Forbush-Decreases (FDs) of Galactic Cosmic Rays (CR) based on data from CR neutron monitor stations obtained during the last three 11-year Solar Activity (SA) cycles. The indexes of rigidity (energetic) spectrum for more than 500 FD events have been determined. The analyses show that the relation between the magnitudes and rigidity spectrum indexes of FDs is linear. In accordance with increases in FD magnitude, the CR variation spectrum becomes softer during all three 11-year SA cycles. However, the character of the relation between these two quantities varies in different cycles of SA. The results have been discussed on the basis of a simple 1D model of the standard cosmic ray transport equation without drifts.

Introduction.

Forbush decreases in Galactic cosmic rays are usually connected with solar flares (Forbush,1938; Morrison,1956; Parker,1963). Further investigations have shown that a defined part of FDs are connected with the passage of active regions through the central solar meridian, with recurrent geomagnetic perturbations or high-speed corotating solar fluxes (McCraken, Rao, \& Bukata, 1966; Balif \& Jones,1969; Shah, Kaul, \& Razdan, 1979). A short time after the introduction of direct measurements, the first assumptions (Morrison, 1956 ; Gold, 1959) about two-step development were confirmed – FDs in cosmic rays consist of two steps caused by the combination of shocks and ejecta (Barnden, 1973). Subsequent studies indicated that small FDs are connected with the disappearance of solar filaments or with corotating high-speed plasma flows (Joselin \& McIntosh ,1981; Ahluwalia, Finci, \& Fikani ,1982; Belov \& Ivanov, 1997; Belov et al., 1991; Nachkebia \& Shatashvili, 1985.). Discussions about the nature of FDs continue. In this respect there is no unified definition of FDs themselves. Here we assume that FDs are CR variations caused by large-scale disturbances of solar wind, lasting 5-15 days, regardless of the reason for decreases. The aim of this work is to establish the relationship between solar wind and energy spectrum parameters of all FD types in three sequential 11-year SA cycles.

Experimental data and method.

On the basis of data from high latitude stations of neutron monitors during 1965 – 1996 more than 500 cases of FDs are identified, the amplitude of which is ≥ 1% according to data from the Kiel station. Solar wind parameters were taken from Solar-Terrestrial Physics CD-ROM NGDC – 05/1 (National Geophysical Data Center, Boulder, Colorado, USA). It is assumed that the rigidity (energy) spectrum of FDs has a power form up to 100GV. The spectrum indexes were determined mainly from data from the neutron monitors of the Kiel and Tokyo stations on the basis of the coupling coefficient (Yasue et al. , 1982). For each FD's case the maximum values of density and solar wind velocity, as well as the modulus of magnetic fields, were determined. Then for each 11-year cycle the FD cases are divided into four groups depending on amplitude (**A**) according to data from the neutron monitor at the Kiel station : $1\% < \mathbf{A} \leq 3\%$; $3\ \% < \mathbf{A} \leq 5\%$; $5\% < \mathbf{A} \leq 7\%$; $\mathbf{A} > 7\%$. For each group, the average values of the following were calculated separately: amplitudes of FDs – **A** ; energy spectra indexes - γ (Fig. 1); the maximum value of interplanetary magnetic field (IMF) modulus – **B**; solar wind velocity – **V** (Fig. 2); as well as plasma density (the latter is not presented here as it varies little).

Discussion of the results.

The analysis of Fig. 1 shows the strong dependence of the energy spectrum index on the FD amplitude in the period of the 20th cycle of solar activity (points). A weaker dependence is observed for the 21st cycle (rectangles). A similar picture was obtained for the 22nd cycle of solar activity (not presented). As, we have no data on solar wind after 1988, we consider in detail only the observations from 1965 – 1986. In all three 11-year cycles of SA considered by us , it can be concluded that with increased FD amplitude the CR variation spectrum becomes soft. The differences in the energy spectrum indexes during the 20th and the 21st cycles of SA, cannot be explained by the change of solar wind parameters presented in Fig. 2, as these parameters differ little from each other. This supports the generally accepted opinion that the energy spectrum index of CR variation is the significant parameter for the description of the integral picture of interplanetary medium disturbances (Alania \& Iskra, 1995). They found a dependence between the energy spectrum index of CR variation and the index of interplanetary magnetic field (IMF) fluctuation power spectrum. One can conclude from our data that with the increase of FD amplitude, the drift of fluctuation in the power spectrum takes place towards the higher frequencies during each of the three 11 – year cycles of solar activity. However, comparing the 21st cycle of SA with the 20th cycle, the drift of fluctuation in the power spectrum in a former is to lower frequencies than occur in the latter.

The analysis of Fig. 2 shows a strong dependence of FD amplitude on the maximum value of the IMF modulus – **B** and solar wind velocity – **V**. The obtained result can be explained on the basis of the standard 1D equation of CR propagation without drifts (Wibberenz et al., 1997). In this model FD amplitude **A**

$$\mathbf{A = - V\,L\,(\,1/\,K - 1/\,K_0\,)} \qquad (1)$$

where **V** is the solar wind velocity, **L** is the size of perturbed region, **K** and $\mathbf{K_0}$ are the diffusion coefficients in disturbed and undisturbed regions, respectively. Assuming that

$$\mathbf{K/K_0 = B_0/B} \qquad (2)$$

where **B** and $\mathbf{B_0}$ are the average values of IMF in disturbed and undisturbed regions of the solar wind, respectively, we obtain:

$$\mathbf{A_1/A_2 = (\,V_1\,L_1/\,V_2\,L_2\,)\,(\,B_1 - B_0)/(\,B_2 - B_0\,)} \qquad (3)$$

where indices 1 and 2 correspond to different FD cases. According to the experimental data (Fig. 2) we can assume that $\mathbf{A_1 \approx 2\%}$ (minimum value of the average amplitude**),** $\mathbf{A_2 \approx 10\%}$ (maximum value of the average amplitude), $\mathbf{V_1 \approx 600\ km/s}$, $\mathbf{V_2 \approx 800\ km/s}$, $\mathbf{B_1 \approx 15\ nTl}$, $\mathbf{B_2 \approx 30\ nTl}$, $\mathbf{B_0 \approx 5\ nTl}$. these values allows us to estimate $\mathbf{L_2/L_1 \approx 1.5}$ relation, which is assumed to be quite satisfactory.

It should be noted that dependence between FD amplitudes and solar wind parameters was often discussed (Iucci et al., 1984; Barouch \& Burlaga, 1975 ; Cane, 1993; Belov \& Ivanov, 1997a). Our results are in agreement with the above mentioned studies. We show that such a connection is possible not only for large FDs, but also for small ones, and not only for a single phase of SA, but for a quite long interval of time: 1965 – 1986. Finally, the analysis of these problems, together with the dependence of the energy spectrum index on the FDs amplitude, is very interesting and it deserves further investigation.

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References

Ahluwalia, H.S., Finci, A.G., \& Fikani, M.M. 1982 ,Proc. 17th ICRC, Paris, v.10, p.210.

Alania, M.V., \& Iskra, K. 1995, Adv. Space Res. v.16, No 9, p.241.

Balif, J.R., \& Jones, D.E. 1969, J. Geophys. Res., v.74, p.3499.
Barouch, E., \& Burlaga, L.F. 1975, J. Geophys. Res., v.80, p.449.
Barnden, L.R. 1973, Proc. 13th ICRC, Denver, v.2, p.1277.
Belov, A.V., Ivanov,K.G., \& Shatashvili ,L.Kh.1991,Geomagnetizm I Aeronomia, 31, No 1, p.345.
Belov, A.V., \& Ivanov, K.G. 1997, Proc. 25th ICRC, Durban-South Africa, v.1, p.421.
Belov, A.V., \& Ivanov, K.G. 1997a, Geomagnetizm I Aeronomia, 37, No 3, p.32.
Cane, H.V. 1993, J. Geophys. Res., v.98, A3, p.3509.
Iucci, N. et al., 1984, Nuovo Cimento C., v.7, p.467.
Forbush, S.E. 1938, Prys. Rev., 54, p.975.
Gold, T. 1959, J. Geophys. Res., 64, No 11, p.1665.
Joselin, J.A., \& McIntosh, P.S. 1981, J. Geophys. Res., v.86, p.4555.
McCraken, K.G., Rao, U.R., \& Bukata, R.P. 1966, Phys. Rev. Lett., 17, p.928.
Morrison, P. 1956, Phys. Rev.,V. 101, p. 1397.
Nachkebia, N.A., Shatashvili, L.Kh. 1985, Geomagnetism i Aeronomiya, 25, No 2, p. 189.
Parker, E.N. 1963, Interplanetari Dynamical Processes. New York –London, p. 362.
Shah, G.N., Kaul, C.L., \& Razdan, H. 1979, Proc. 16th ICRC, Kyoto, Japan, v.3, p.423.
Wibberenz, G., Cane, H.V., \& Richardson, I.G. 1997, Proc. 25th ICRC, Durban–South Africa, v.1,p. 397.
Yasue, S. et al., 1982, Coupling Coefficients of Cosmic Ray Daily Variations for Neutron Monitor Stations. Nagoya, Japan, p. 84,85,184,185.

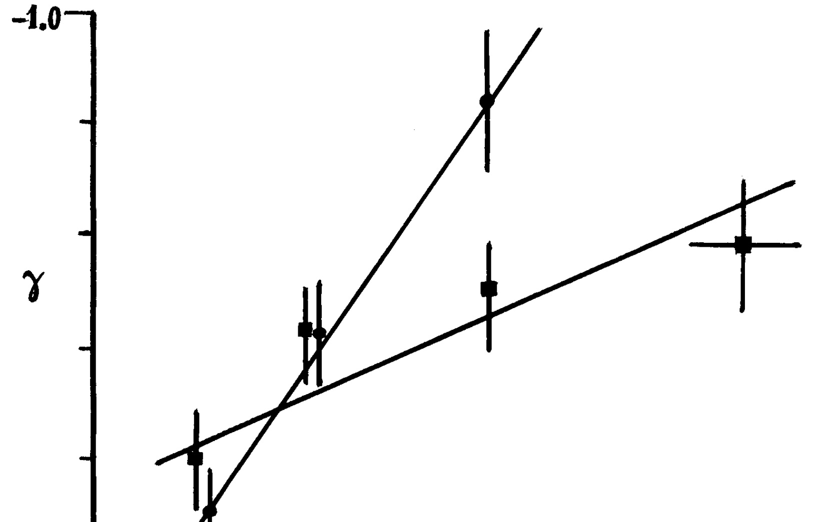

Fig.1 Dependence of energy spectrum index γ on FD amplitude **A** in the period of the 20th (points) and the 21st cycles (rectangles) of 11-year solar activity.

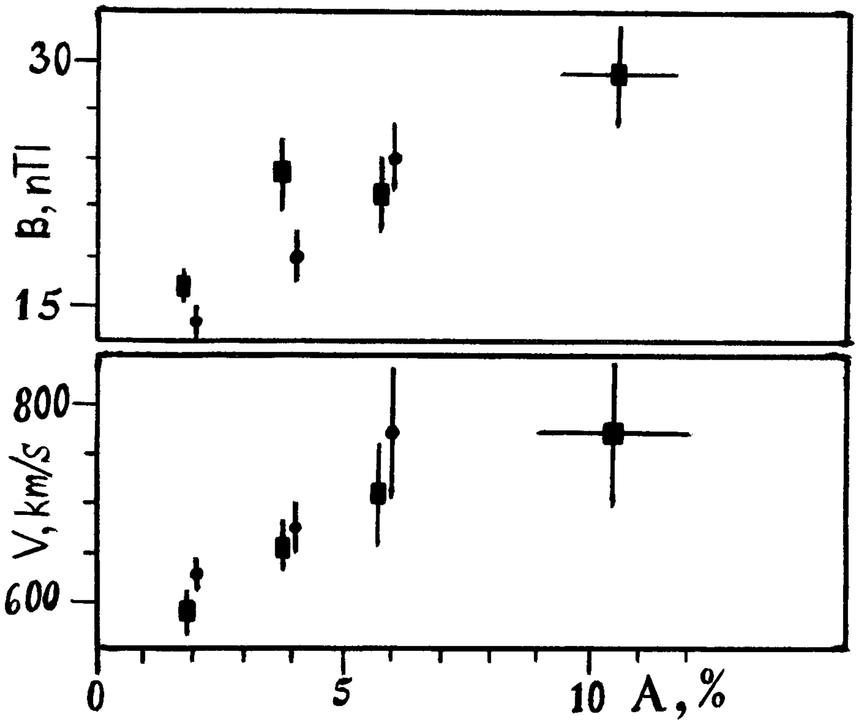

Fig. 2 Dependence of FD amplitude – **A** on the maximum value of IMF modulus – **B** and solar wind velocity – **V** in the period of the 20th (points) and 21st cycles (rectangles) of 11-year solar activity.