MODELING AND EXPERIMENTAL STUDY OF FORBUSH EFFECTS OF GALACTIC COSMIC RAYS

Michael V. Alania M[1,4], Jacek Szabelski[2], Anna Wawrzynczak[3]

1. Institute of Math. And Physics of University of Podlasie, Siedlce, Poland

2. The A. Soltan Institute for Nuclear Studies, 90-905 Lodz, Box 447 3. Institute of Informatics of University of Podlasie, Siedlce, Poland 4. Institute of Geophysics, Georgian Academy of Sciences, Tbilisi, Georgia

ABSTRACT

Temporal changes of the rigidity spectrum of the sporadic and recurrent Forbush effects of galactic cosmic rays (GCR) have been studied using neutron monitors data. An attempt to find a relationship between the rigidity spectrum exponent γ of the Forbush effects ($\delta D/D(R) \propto R^{-\gamma}$, where R is the rigidity of GCR particles) and an exponent ν of the power spectral density (PSD) of the fluctuations of the strength of the interplanetary magnetic field (IMF) (PSD $\propto f^{-\nu}$, where f is the frequency) has been made.

EXPERIMENTAL DATA AND METHOD OF INVESTIGATION.

An attempt to find a relationship between the rigidity spectrum exponent γ of the Forbush effects [1] ($\delta D/D(R) \propto R^{-\gamma}$, where R is the rigidity of GCR particles) and an exponent ν of the PSD of the fluctuations of the strength of the IMF has been made. Data of neutron super monitors and the IMF's B_x, B_y, and B_z components have been used to study peculiarities of two great sporadic Forbush effects (9–23 July 1982 and 9–29 July 2000) and one recurrent Forbush effect of the 1–16 September 1996 (figures 1abc). It is well known that one of the major parameters for the characterizing of the Forbush effects of GCR is the rigidity spectrum of the GCR intensity variations, hereafter called the rigidity spectrum of Forbush effect ($\delta D(R)/D(R) = A\, R^{-\gamma}$, where R is the rigidity of GCR particles and A is the power). The rigidity spectrum of the Forbush effects has been calculated using the data of neutron super monitors and the method presented, e.g. in [2,3]. There was assumed: $\delta D(R)/D(R) = A\, R^{-\gamma}$ for $R \leq R_{max}$. And $\delta D(R)/D(R) = 0$ for $R > R_{max}$. Here R_{max} is the upper limiting rigidity beyond which the Forbush effect of GCR intensity vanishes. Results of calculations of γ based on daily means of data for the sporadic Forbush effects, 9–23 July 1982 (14 stations), 9–29 July 2000 (11 stations) and for the recurrent Forbush effect of 1–16 September 1996 (7 stations) are presented in the figures 1def.

RESULTS, PHYSICAL MODEL AND DISCUSSION.

It is seen from the fig.1de that the rigidity spectrum of the sporadic Forbush effects are soft at the phases of the decreasing of GCR intensity, while that

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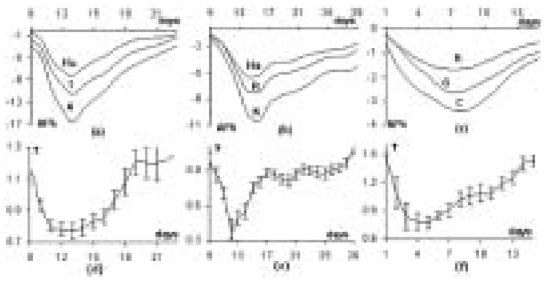

Fig. 1. Temporal changes of the amplitudes of Forbush effects in percents (AF%) and corresponding rigidity spectrum exponent γ for the periods: 9–23 July 1982 (1a and 1d), 9–29 July 2000 (1b and 1e), 1–16 September 1996 (1c and 1f). A-Apatity, C-Calgary, G-Goose Bay, Ha-Halecala, Hu-Huancayo, K-Kiel, R-Rome, T-Tbilisi

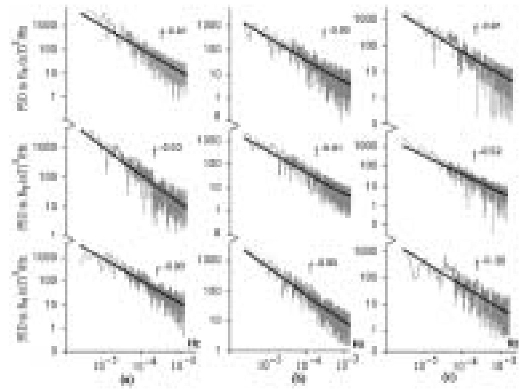

Fig. 2. Power spectral density (PSD) of the B_X, B_Y and B_Z components of the IMF for the periods: 14–27 July 1982 (fig.2a), 15–29 July 2000 (fig. 2b), 2–14 September 1996 (fig.2c)

are hard (with some peculiarities) in the minima and the beginning phase of the recovery period of GCR intensity. These kind of changes of the rigidity spectrum of the Forbush effects of GCR are connected with the specific changes of the structure of the vicinity of the interplanetary space where sporadic Forbush effects of GCR have been occurred. Namely, at the beginning of the GCR intensity decrease the disturbances in the interplanetary space are in the phase of developing and are undergoing to the spatial extension. The velocity of the disturbances is large and intensive convection of relatively low energy particles of GCR takes place. Owing to the both above mentioned reasons low energy particles of GCR are preferentially modulated and γ is large (γ = 1.2–1.3), i.e. rigidity spectrum is soft. Then the sizes of the disturbances increases (the vicinities of the shock waves and magnetic clouds are extended) and due to the interaction of these relatively high velocity disturbances with the background solar wind there could be created new irregularities with the larger sizes [4]. Due to the both above mentioned reasons there should be preferentially modulated relatively higher energy particles of GCR than before. These must be resulted to the hard rigidity spectrum of the Forbush effects of GCR, which was really observed (γ = 0.6–0.8) by the experimental data of neutron monitors. The above mentioned explanation is dealing with the case of GCR modulation when a diffusion-convection is valid in general. This kind of scene takes place for many cases of the Forbush effects of the sporadic type when the disturbances occupies a large size of the inner heliosphere. However, that is not by no means always so. There are observed a lots of the sporadic Forbush effects of GCR with the peculiar manners of behavior directly connected with geometrical factor and concrete structure of the shock waves, magnetic clouds and intensity of the coronal mass ejecta (CME) [5–6]. In fig.1f are presented the temporal changes of γ for the recurrent Forbush effect which has been occurred in the September of 1996 (fig. 1c). It is seen from the figure 1f that at the beginning of the gradually decrease of the GCR intensity the rigidity spectrum is soft (γ =1.4–1.5), in the period of the minimum and near minimum intensity of GCR there is tendency of hardening of the rigidity spectrum (γ = 0.8–0.9); during the gradually recovering period of the intensity of GCR the rigidity spectrum progressively more becomes again the soft one (γ =1.2–1.3). During this recurrent Forbush decrease the dynamical processes in the interplanetary space are generally established. Particularly, in cases like above mentioned the Earth slowly entrances to the corotating region of the disturbances and low energy GCR are intensively modulated. It leads to the soft rigidity spectrum of GCR. Then the Earth continuous its voyage to the deep of the extended disturbances where GCR particles with relatively higher energies are modulated and the rigidity spectrum of Forbush effect is hardening. Then the Earth slowly leaves this region of the disturbances and the contribution of the modulated high energy particles of GCR is gradually getting less; it again leads to the soft rigidity spectrum of Forbush effect. For the diffusion-convection approximation an exponent γ of the rigidity spectrum of the isotropic intensity variations of GCR (11-year variation) is determined by the parameter α showing the dependence of the diffusion coefficient χ on the rigidity R of galactic cosmic rays ($\chi \propto R^{\alpha}$) [7]. The same can be predicted when in the course of the Forbush effect a diffusion-convection approximation is valid. In this case the rigidity spectrum of the Forbush effect of GCR can be used as a source of the information about the disturbed vicinity of the interplanetary medium. Bearing in mind that during the Forbush effect there is not enough experimental data of the IMF's irregularities for the reliable spectral analyses, data of GCR intensity becomes very much valuable and an unique one. Indeed, as it was mentioned above, the parameter α depends on the IMF's structure [8,9] and changes over the range from zero to 2, ($0 \leq \alpha \leq 2$). The minimum value of α ($\alpha = 0$) can be ascribed to the type of the scattering that occurs when the Larmor radius ρ of GCR particles is slightly less or comparable with the effective size L of the IMF's irregularities ($\rho \leq$ L) and the scattering angle φ is large. This is the case when a scattering free path λ and, correspondingly, the diffusion coefficient χ of cosmic ray particles does not depend on the particle's rigidity R ($\chi \neq$ R). The maximum value of α ($\alpha = 2$) can be ascribed to the scattering of cosmic ray particles on the IMF's irregularities when the Larmor radius ρ of the GCR particles of the given energy is larger than that the effective size L of the magnetic irregularities of the IMF ($L \ll \rho$). In this case the scattering angle φ of GCR particles on the individual irregularities is small, i.e. $\varphi \leq 5^\circ$ –10° and the scattering free path λ and the diffusion coefficient χ strongly depend on the particle's rigidity R, ($\chi \propto \lambda \propto R^2$). It was found that the rigidity spectrum exponent γ of the GCR isotropic intensity variations is strongly related with parameter α, ($\gamma \propto \alpha$) [7]. The parameter α characterises the nature of the structure of the IMF's irregularities (turbulence) being responsible for the GCR particle's scattering [8,9]. As far γ is related to the parameter α, there must be an explicit relationship between the parameter γ and the parameters characterizing the structure of the irregularities of the IMF ($\alpha = 2 - \nu$ [8,9]). Then in the case of the existence of the direct relationship between γ and α one can write, $\gamma \propto 2 - \nu$. In figures 2abc are presented power spectral densities (PSD) of the B_X, B_y and B_Z components of the IMF's strength fluctuations for the periods of: 14–27 July 1982 (fig.2a), 15–29 July 2000 (fig. 2b) and 2–14 September 1996 (fig.2c). Fortunately, for the considered Forbush decreases there were possibilities to have more or less good enough statistics: 12–14 days duration (5-minute data of the IMF obtained from [10]). These periods were selected as a time duration when γ in the scope of accuracy can be considered approximately constant for each Forbush effect. Supposing an expected relationship between γ and ν as $\gamma \approx 2 - \nu$, it is easy to recognize a satisfied connection between the γ and ν for all three cases of the Forbush effects.

CONCLUSION

1. Temporal changes of the rigidity spectrum exponent γ can be considered as one of the important indexes for the determination of the large scale structure of the IMF's irregularities during the Forbush effects of GCR.

2. The nature of the temporal changes of the rigidity spectrum exponent γ of the sporadic and recurrent Forbush effects of GCR are completely different. In the course of a lot of cases of the sporadic Forbush effects there are observed a significant hardening of the rigidity spectrum in the minima and near minima phases of sporadic Forbush effects remaining almost constant or slightly softening during the recovery phase of GCR intensity.

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