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Forbush Decreases observed at the level of 25 m.w.e. in the underground detector in Lodz

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Abstract. The muon telescope in the underground laboratory in Lodz, Poland, has started registration of cosmic ray muon flux ($E > 5$ Gev) in September 2000. 3 Forbush Decreases in 2000: on September 17th, October 26th and November 28th, and a series of Forbush effects in March–April 2001 have been observed.
The Lodz underground muon telescope has not yet high accuracy. However, the muon flux data together with neutron monitor data provide opportunity to study features of temporal changes of energy spectra and to estimate upper energy limit of Galactic Cosmic Rays modulated in FDs.

1 Introduction

Energy spectrum of galactic cosmic ray variations gives an information not only about the energy dependence of the modulation (Alania et al., 1991), but allows us to study a character of diffusion of galactic cosmic ray particles in interplanetary space (Alania and Iskra, 1995; Alania et al., 1997). Namely, temporal changes of the power energy spectrum index of the isotropic intensity variations (e.g. based on the annual average data analyses) is strongly connected with the rearrangements of the structure of the interplanetary magnetic field fluctuations from minima to maxima epochs of the 11–year solar cycle.

The same can be noted for Forbush decreases of galactic cosmic rays, especially dealing with the period of cosmic ray intensity recover of Forbush decreases. For lots of recurrent Forbush effects with the gradually decreases and recoveries of intensity the temporal changes of the power energy spectrum index (based on the daily average data) describes the changes of the structure of the interplanetary magnetic field fluctuations from day to day (directly responsible for the character of diffusion of galactic cosmic ray particles) in the vicinity of the region where the Forbush effect is formed.

It is obvious that for such kind of investigations it is extremely necessary to have a data of cosmic rays for large energy range. From this point of view recently constructed underground muon telescope in Lodz (Poland) among the other usefulness has much valuable significance to extend our understanding about the electro-magnetic processes taking place in the interplanetary space, in the Earth's atmosphere and magnetosphere during the short period events, as are Forbush effects of galactic cosmic rays generally accompanied by geomagnetic storms.

From September of 2000 by muon telescope of cosmic ray station in Lodz have been registered a few Forbush decreases with different profiles and amplitudes. It is extremely important (in spite of still poor statistics of data) to show that Forbush effects registered by the muon telescopes are recognizable and reliable on the one hand and then data of muon telescopes can be used with neutron monitors data for the investigation of the energy spectrum of Forbush effects, on the other. Here we restrict ourselves to the calculation of energy spectrum for the minimum point of intensity of Forbush effects.

2 Energy spectrum of Forbush effects

Energy spectrum of the observed Forbush effects of galactic cosmic ray intensity can be calculated using the data of the world network of neutron monitors and the Lodz's undergrounda muon telescope.

The power type rigidity spectrum of Forbush effects is represented in the following way (Alania et al., 1991):

$$\begin{aligned} \delta D(R)/D(R) &= BR^{-\gamma} \quad R \leq R_{max} && (1)\\ &= 0 \quad\quad\;\; R > R_{max} && (2) \end{aligned}$$

Here R is the rigidity of galactic cosmic ray particles, R_{max} – the upper limiting rigidity beyond which the Forbush effect vanishes, and γ is the power of the rigidity spectrum of galactic cosmic ray Forbush effect.
A change of the amplitude of Forbush effect $\delta J/J$ (secondary

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neutron component of galactic cosmic rays) at any point of observation with the geomagnetic cutoff rigidity R_0 and the atmospheric depth h is defined in the following way:

$$\delta J/J = \int_{R_0}^{\infty} \delta D(R)/D(R) \cdot W(R,h)dR \qquad (3)$$

where $W(R,h)$ is the coupling coefficient of cosmic rays. Coupling coefficients for neutron and muon intensities of galactic cosmic rays in the suitable form for calculation of energy spectrum have been presented by Yasue et al. (1982); Fujimoto et al. (1984).

For the definition of the rigidity spectrum parameters of Forbush effect (for the recently observed Forbush effects we have not collected enough data, yet) a method of the ratio of two cosmic ray stations data have been used. Namely, we used different pairs of neutron monitors: Apatity (Vashenyuk et al., 2001), Climax and Haleacala (Simpson et al., 2001), and recently (in 2000) constructed Lodz muon telescope's data for the period of March–April of 2001. The ratio of the amplitudes $(\delta J/J)_i$ and $(\delta J/J)_k$ of Forbush effects for two, i and k stations has the form:

$$\frac{(\delta J/J)_i}{(\delta J/J)_k} = \frac{\int_{R_1}^{\infty} \delta D(R)/D(R) \cdot W_1(R,h)dR}{\int_{R_2}^{\infty} \delta D(R)/D(R) \cdot W_2(R,h)dR} \qquad (4)$$

where $W_1(R,h)$ and $W_2(R,h)$ are the corresponding coupling coefficients at different depth h_1 and h_2 of the Earth's atmosphere. For the power energy spectrum of (1) then we obtain:

$$E(\gamma) = \frac{\int_{R_1}^{\infty} R^{-\gamma} \cdot W_1(R,h)dR}{\int_{R_2}^{\infty} R^{-\gamma} \cdot W_2(R,h)dR} \qquad (5)$$

It is clear that $E(\gamma)$ is a function of γ, i.e. that the certain magnitude of γ corresponds to to the definite value of $E(\gamma)$.

Temporal changes of the neutron and muon intensities of galactic cosmic rays (data of the Climax and Haleacala Neutron monitors and the muon telescope in Lodz, respectively) are presented in Figure 1 for the period of 25 November – 2 December, 2001. In the figure on the abscissa axis are days and on the ordinate axis relative intensity for above mentioned stations. Data of all stations for 26 November 2000 are taken as the 100% level. One can see that in Lodz cosmic ray station data of the muon telescope shows the existence of the Forbush effect according to the energy dependence of galactic cosmic ray Forbush effect's amplitude.

In the Figure 2, there are presented the changes of profiles of intensities of galactic cosmic rays for the above mentioned cosmic ray stations for the period of 5–10 April 2001. As in

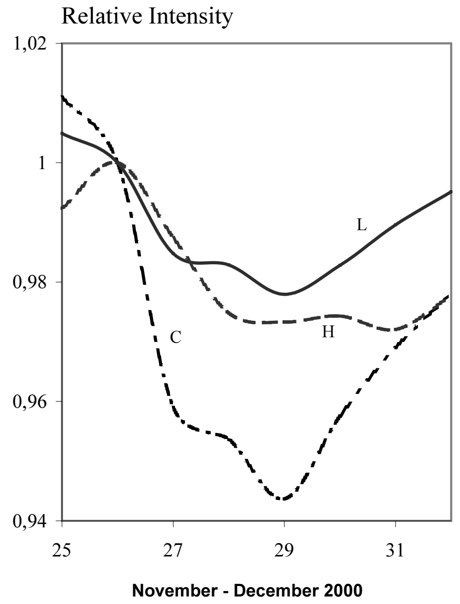

Fig. 1. Temporal changes of the neutron and muon intensities of galactic cosmic rays for the period of 25 November – 2 December, 2001: C – data of the Climax Neutron monitor, H – data of the Haleacala Neutron monitor, L – data of the Lodz muon telescope.

the first case (Fig. 1) the Forbush effect is registered by Lodz muon telescope.

In the Figure 3, there are presented data of the above mentioned stationsfor the period of 26–29 April 2001, when the data of Lodz muon telescope does not show any Forbush effect, while the Climax and Haleacala stations registered a quite significant Forbush effect.

Calculation of the energy spectrum has been performed for Forbush effect of November–December 2000 and the series of Forbush effects in March–April 2001, when the observed amplitude of the Forbush effects were recognizable at the Lodz cosmic ray station. For different pairs of stations for the periods of 18–22 March, 7–9 and 11-12 April 2001, the value of γ changes between $-1.3 \pm 0.5 \leq \gamma \leq -0.5 \pm 0.5$. It is clear that the accuracy is not good enough for the conclusion of the characters of the different Forbush effects. Nevertheless, it is possible to underline single-valued that muon telescope of the Lodz station (in spite of a little statistics) reliably has registered Forbush effects of galactic cosmic rays and gives possibility to extend our imagination about Forbush effects in higher energy range.

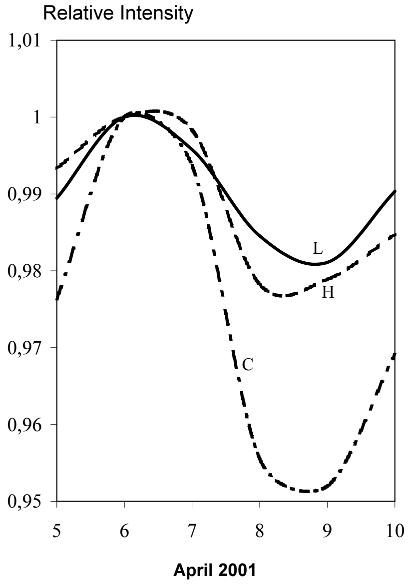

Fig. 2. Temporal changes of the neutron and muon intensities of galactic cosmic rays for the period of 5 – 10 April, 2001. Lines as in the Fig. 1.

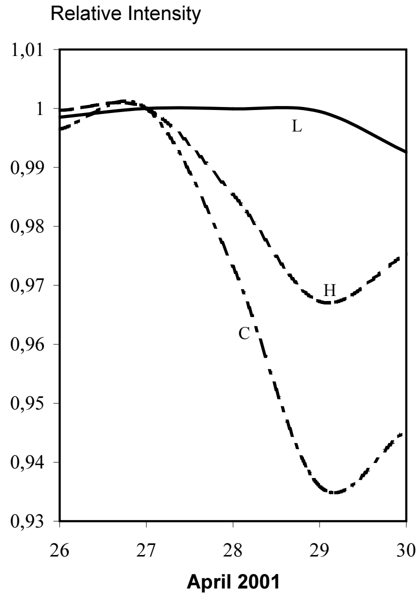

Fig. 3. Temporal changes of the neutron and muon intensities of galactic cosmic rays for the period of 26 – 29 April, 2001. Lines as in the Fig. 1.

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