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Cosmic Ray Effects Caused by Great Disturbances of the Interplanetary Medium in 1990-1996

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The density variation and 3D anisotropy of 10 GV cosmic ray (CR) for every hour during the 1990-1996 years were inferred from the data of world neutron monitor network (about 40 ground-level stations). The global survey method applied to the neutron monitor data allows to discriminate CR effects even of the small magnitude (<0.5%) with sufficient accuracy. Thus, around 1000 transient effects in CR, caused mainly by CME coming to the Earth, were detected in 1990-1996. It is shown, that a number of small (<2%) effects doesn't decrease along of the solar activity descent, and, despite of the small density variations significant changing of anisotropy can follow these effects. The special interest is in subject of CR variations of the shape of increasing like a reversed, «positive» Forbush-effect.

1 Introduction:

The transient events in cosmic rays, that we propose to consider here, take place on the temporal scale between fluctuations and recurrent variations resulted by the Sun rotation. They are caused often by sporadical phenomena on the Sun, are connected with the expanding disturbances of interplanetary space, and in majority are considered as Forbush-effects (FEs). The time period from 1990 to 1996 contains both extremely disturbed 1991 year, and quiet, typical for solar minimum period starting from 1994. During these seven years a great amount of FEs including very big ones, for example, on March, June and October of 1991 (Belov et al., 1995; 1997a,b), has been observed. However, in this work we devote more attention to small FEs which are more numerous but most often omitted in CR studies. On the base of hourly values of CR density and anisotropy some statistical analysis is carried out. Variations of CR discover a more number CMEs than usually recorded in other measurements (for example, in solar corona observations). Sometimes, when solar wind data have gaps, only CR intensity can provide an information about transient structure. We made it our aim to detect all possible transient effects during considered period. We determine Forbush-effect as of CME action on the background cosmic rays and advisedly say here not about Forbush-decreases (FDs), but about Forbush-effects (FEs). A decrease of CR density is only one feature of the complicated phenomenon. Density decrease, predominated in the majority of FEs, in some cases doesn't reveal itself and gives way to density enhancement. As it is shown in (Belov and Ivanov, 1997; Ivanov, 1998), majority of the small FEs, not connected with solar flares, may be associated with the prominence eruption or resulted by interaction flare and prominence ejecta, two prominence, prominence and sector boundary or coronal hole.

2 Data and Method:

Data from world neutron monitor network (about 40 stations) were processed by the global survey method (Belov et al.,1995). A rigidity spectrum of CR density variation and three components of the first harmonic their anisotropy have been obtained for every hour over the period 1990-1996. Selection of transient effects was carried out on the base of CR (10 GV) density variations which allows to derive reliable even small (around 0.5%) effects. Data of the main characteristics of solar wind near the Earth (velocity, density, plasma temperature, module and components of IMF - OMNI data) were arranged in the complex database joint with CR data and also involved in this process. Time of the shock arriving was determined from sudden commencement of magnetic storms.

3 Results and Discussion:

Transient effects in CR were picked out in the list by the following indications: 1) all events followed

by the shock, even in the cases when there was no obvious effect in CR density; 2) all big enough effects (>1%) independent of conditions in the interplanetary medium; 3) small effects (as a rule, 0.5-1%) if well-defined disturbance of the solar wind occurred in this time. On the whole, about 1000 effects were selected by such a way. This preliminary list needs more detailed comparison of these effects with their possible sources on the Sun and in the solar wind, but we don't expect here principal changes. The studied period spans three years of high activity (1990-1992) and at least two and half quiet years (1994-1996). The behavior of CR density and amplitude of the first harmonic of CR anisotropy was presented in our previous works (Belov et al.,1995, 1997a,b). We can note a gradual transformation of the giant variations in 1991 to their quiet behavior in 1995-96 that gives a chance to trace how a frequency of FEs changes during the solar activity cycle. Average interval between selected events is 2-3 days and is comparable with their typical duration. Of course, such high frequency relates only to FEs of the small magnitude. Almost 2/3 of all effects didn't exceed 1%. Only 365 FEs were >1% and 61 > 3%. As it is shown in (Belov et al.,1997b) a number of great FEs (>2.5%) was maximal in the anomalous 1991, then it dropped with solar activity decrease, and starting from the second half of 1994 the great FEs are absent at all. It is well correlated with solar activity and with long-term CR variations which comprised about 20% on this period. On the contrary, a frequency of small FEs is about constant over these 7 years and remains high enough even on the solar activity minimum. This result confirms the conclusions of (Bothmer and Shwenn, 1996; Ivanov and Kharshiladze, 1998) and well agrees with the high frequency of coronal ejecta, observed by SMM and LASCO. We must conclude that substantial part of coronal transients get the Earth orbit being able to effect on relativistic cosmic rays.

Table 1. Distribution of the number n_f and amplitudes A_f of FEs by the different parameters of solar wind: H_m, V_m and SSC for 1990-1995 years.

SSC	H_m,nT	V_m,km/s	n_f	A_f
All	All	All	944	1.19±0.04
+	All	All	228	1.94±0.15
-	All	All	716	0.95±0.02
All	<10	All	371	0.81±0.03
All	>15	All	104	2.33±0.19
All	All	<450	272	0.98±0.05
All	All	>600	150	1.65±0.16
+	<10	All	48	1.04±0.12
+	>15	All	56	2.93±0.30
+	All	<450	56	1.10±0.14
+	All	>600	44	3.20±0.45
All	<10	<450	156	0.82±0.04
+	>15	>600	25	3.78±0.54

We found maximal values of solar wind velocity (V_m) and IMF module (H_m) during every detected event where solar wind data existed. All events were divided into groups by the magnitude of these parameters and accordingly to the shock presence (SSC). A number of FEs n_f and their averaged amplitudes A_f for each group are presented in Table 1. A number events caused by the fast (V_m>600 km/s) and slow (V_m<450 km/s) disturbances, followed by SSC, differs a little, but amplitudes and their scatter strongly increase for FEs caused by the fast disturbances that shows their higher efficiency. An average effect in CR in the groups with H_m>15 nT is almost in thrice bigger than in the groups of Hm<10 nT. Large scatter of FE's magnitude shows that IMF magnitude is not so important as its regularity and structure to effect on CR. This is an expected result confirming the conclusions of many researchers (Iucci et al., 1984; Cane, 1993; Cane et al., 1996) who considered relatively big FEs. More important is the connection of A_f with solar wind velocity that reveals in the sets with SSC: in these events groups with high and low velocity differ as well as the groups with strong and weak increase of IMF module. Such a coincidence must not be casual since both IMF module and solar wind velocity are equally important for FE creating. Forbush decrease arises under expanding of the limited solar wind region for which a particle exchange with the outer environment is inhibited. Expansion of this region is tightly connected with V_m and particle exchanging depends on the IMF intensity. It needs to be noticed, however, that big magnitudes of velocity and IMF module are necessary but not sufficient to create a big FE. The amplitude of observed FE is sometimes close to zero even for the fast propagating disturbances, creating a shock and possessive the strong magnetic field.

In Fig.1 several FEs occurred in 1995 and 1996, when solar activity was near minimum, are presented as behavior of 10 GV CR density and anisotropy. There is no significant CR variations (all effects ranged from 0.7% to ~ 2%). but if the real changes are not manifested in density they present in anisotropy, and each effect has own features and definite relation with coming disturbance. It is evident from the joint analysis of CR and solar wind data, that every time turning of the ecliptic component or growing of the N-S anisotropy corresponded to the solar wind disturbance. Thus, on May event (Fig.1) the greatest changes in solar wind occurred on 13.05, when increasing of IMF module and density suggest the solar ejecta passing. In the example for Feb. 1996 increase of plasma density and drop of T started on the end of 15.02 and on 16.02 these changes reached maximal level: V_m fall down to 300 km/s, plasma density increased to ~46, T was very low, IMF changed direction and increased by module. It was followed by the turning of ecliptic and N-S component of CR anisotropy and decreasing on 1.3% in CR density. We suppose this picture reflects the passing of prominence ejecta associated with solar filament disappearance occurred on 12.02 in the centre of solar disk. So, even such small FEs may be used as a tool to study a structure of solar wind disturbance.

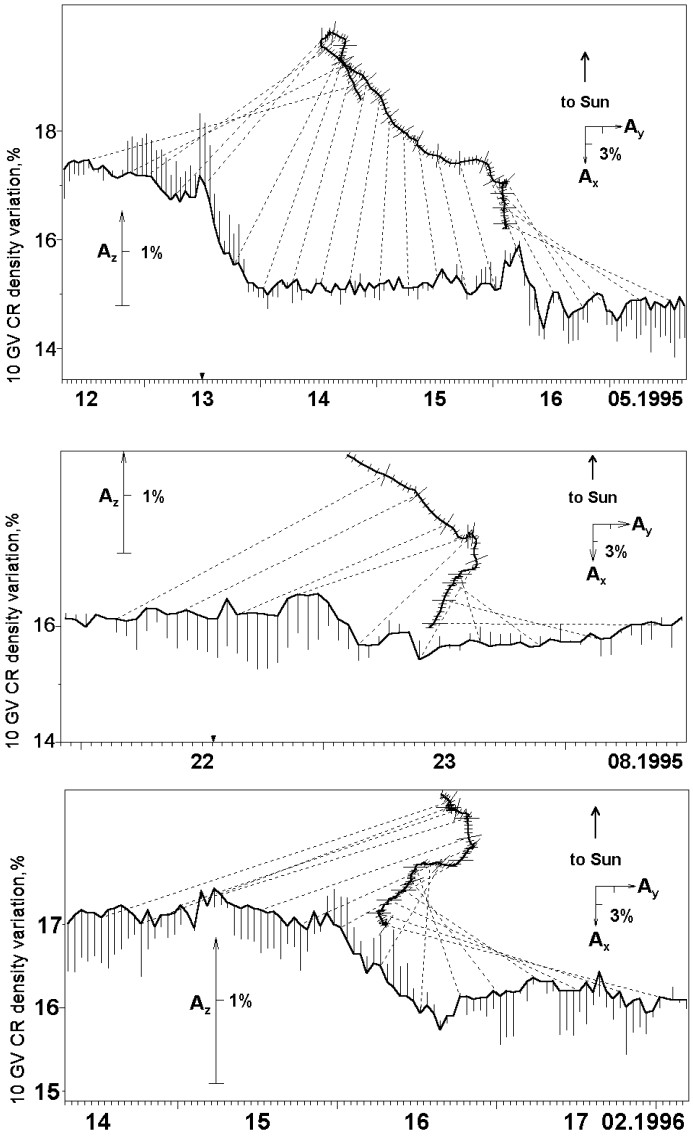

Figure 1: Variations of CR density (low curves), ecliptic anisotropy (upper curves) and N-S anisotropy (vertical lines) on some events near solar activity minimum.

Usually the main part of the Forbush-effect is a decrease of CR density. However it is not always being so. Several examples of anomalous effects, where the IMF strengthening is accompanied not by decreasing, but on the contrary, by increasing of CR density, are shown in Fig. 2. Usually on the same time of short duration but well pronounced increase of plasma density is observed on the background of the solar wind velocity growing. Apparently we are concerned here with interaction of solar wind regions, moving with different speeds, where plasma is compressed joint with the frozen magnetic field. The impression is that cosmic rays take part in this compressing. The discussed phenomenon possible has to be named Forbush-increase. Indeed, the mechanism of its generation shall be similar to that creating the Forbush decrease. It also needs a special region with limited access for charged particles. The main distinction is that this region is not expanded, but compressed. These events are isotropic, that confirms the assumption of quasi-trap for its generation. Of course, «Forbush increases» are seen more rare than decreases. But they are numerous enough and, perhaps, it has to be considered as one of the possible aspect of Forbush-effect as heliospheric phenomenon. It is not improbable that conditions for CR density increasing can arise in some parts and moments of each large scale propagating disturbance. Such conditions can emerge also on interaction of recurrent streams of the solar wind.

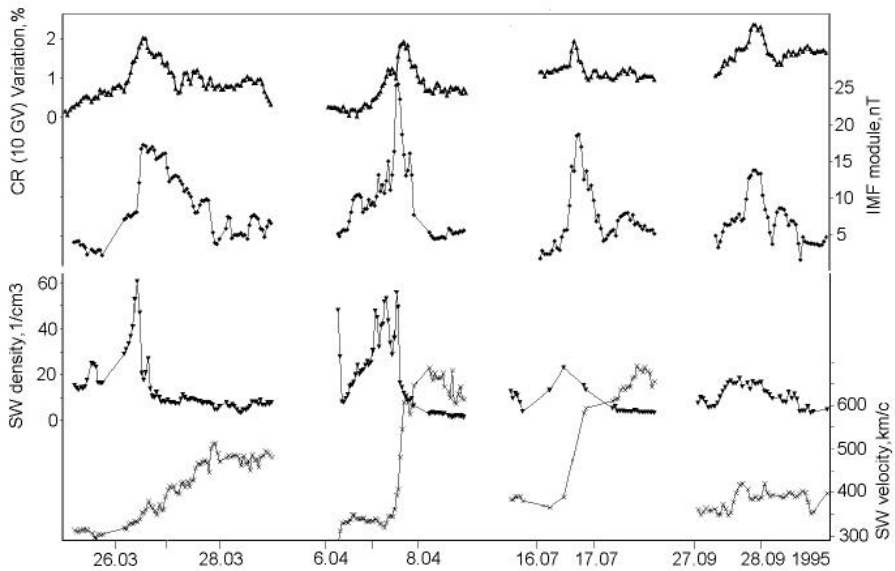

Figure 2: Examples of “positive” transient effects in CR presented joint with solar wind data.

4 Conclusion:

More than 1000 effects in CR associated with passage of disturbed region were detected over the period of 1990-1996 years. Almost 2/3 of the all effects didn't exceed 1%. A number of great FEs (>2.5%) is correlated with solar activity whereas a frequency of the small FEs was near the constant over these 7 years. Substantial part of coronal transients get the Earth orbit being able to act on relativistic cosmic rays.

FEs both of the small and large magnitude reflect a passage of the large-scale disturbances of interplanetary medium. In small FEs changes of CR anisotropy are often more pronounced than density variations.

In some cases transient effects indicate itself not as a decrease, but as an increase of CR intensity well correlated with the strengthening IMF on the background of the solar wind velocity growing. They occur in the regions of the compressed solar wind with limited access for charged particles. They might be named «Forbush increase» since mechanism of its generation looks similar to those creating usual Forbush decrease. It is rather possible that such conditions can arise in some parts of each large-scale solar wind disturbance, propagating with high velocity.

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