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Cosmic ray variation properties during Forbush effects associated with far western solar sources.

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***Abstract*— By the data from neutron monitor network and relevant measurements of the solar wind parameters a set of Forbush effects have been studied, which occurred on the background of quite or unsettled interplanetary and geomagnetic conditions and are associated with the far western events on the Sun. These Forbush effects may be referred to a special subclass of events, with the characteristics closed to the event in July 2005 and incorporated by the common conditions: absence of a significant disturbance in the Earth vicinity; absence of the strong geomagnetic storm; slow decrease of cosmic ray intensity during the main phase of the Forbush effect. The general features and separate properties in behavior of density and anisotropy of 10 GV cosmic rays for this subclass are investigated and compared with those during the Forbush effects from far eastern sources.**

1. INTRODUCTION

Among Forbush effects (FEs) by the ground methods observable it is possible to distinguish a set of events characterized by relatively quiet interplanetary and geomagnetic conditions (interplanetary magnetic field intensity Bmax <15nT, maximum index of geomagnetic activity Kp<6), by gradual decrease of the cosmic ray (CR) intensity in the main phase of FE and slow recovery phase. Those Forbush effects are rare enough and look as 'anomalous' because of their big amplitude on the background of low IMF intensity. Majority of these anomalous events are related to coronal mass ejections (CMEs) from the eastern part of solar disk [1]. However, analogous effects may be related to the far western events on the Sun, as it was shown on the example of Forbush decrease in July 2005 [2]. Those effects look as 'anomalous among anomalous'. The goal of our work is to search for the other similar events from far western sources and to study distinguishes between FEs caused by the western and eastern solar sources. For this aim the variations of CR density and anisotropy derived from the neutron monitor network data by the global survey method (GSM) [3] have been incorporated for analyses.

2. DATA AND METHODS

Database on the Forbush effects and interplanetary disturbances, created in IZMIRAN, has been used for the mentioned above study. This database includes as parameters of CR density and anisotropy so data on the solar wind, interplanetary magnetic field, solar data and geomagnetic activity indices (SPIDR Data Base, available from http://spidr.ngdc.noaa.gov/spidr/index.jsp, NOAA Space Environment Center Website, available from http://www.sec.noaa.gov/, http://swdcwww.kugi.kyoto-u.ac.jp/dstdir/).

Density and anisotropy for 10 GV CR were derived by the global survey method [3] over the period 1965-2006 by the hourly data from neutron monitor network http://cr0.izmiran.rssi.ru/common/links.htm. The results of these calculations are presented in the Internet [4] (http://cr20.izmiran.rssi.ru/AnisotropyCR/Index.php).

The FEs of >3% magnitude for relatively weakly disturbed interplanetary and geomagnetic conditions (IMF<15 nT, Kp<6), with gradual fall of CR intensity on the main phase of Forbush-effect have been considered. For the beginning only those events were selected which could be directly identified with solar sources. They turned out to be of a small amount: 7 of them were caused by far western (>30^o W) sources on the Sun, 10 FEs were related to the eastern events. It was necessary to understand the distinctive features of such anomalous FEs from western and eastern solar sources. The analysis was based on the study of the CR vector anisotropy behavior and comparing of CR density variations during the FEs. It was found out that equatorial component of CR anisotropy A_{xy} (the projection of the vector of the first harmonic of anisotropy on the Earth equatorial plane) reveals quite different features in dependence on heliolongitude localization of the FE sources. These

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properties have been used for the comparative analyses of those FEs which had insufficient information for a direct identification with the solar sources.

3. RESULTS AND DISCUSSION

For those FEs which can be directly identified with the sources on the Sun, average characteristics of various parameters have been calculated. For 7 western events (mean longitude 43^o) the mean magnitude of FE A_F was obtained as 4.5%, maximum value of the equatorial component of anisotropy Axy =3.5%, maximum solar wind velocity was about 600km/s.

In Fig. 1 the examples of two FEs caused by the far western (of W79 and W52 longitudes) sources are presented. One can see that in both cases on the background of relatively quiescent interplanetary and geomagnetic conditions (Bmax ~10 nT and Kp is 5 and 4 correspondingly) we observe FEs with the amplitude > 4% and appreciate increase of Axy (also, about 4%), herewith the Axy vector takes a direction slightly to the Sun and doesn't change it significantly during the effect. These FEs as well as the others of far western sub group differ from normal western FEs which are usually of less magnitude and short time duration. Among similar anomalous FEs (with large amplitude of CR decrease under quiescent interplanetary and geomagnetic conditions) the group events associated with far eastern solar sources may be defined. It was interesting to compare and contradict the peculiarities of CR variations for these two groups of FEs. Mean parameters of the CR and relevant measurements of solar wind and geomagnetic indexes averaged for 7 western and 10 eastern FEs are entered in Table I. One can see that on the average maximum amplitudes A_F of the FEs caused by far western and eastern sources has no big difference (although the CR density decrease is slightly lower for the eastern events), but equatorial component Axy of CR anisotropy for western events appreciate exceeds those for the eastern group.

Moreover, the direction of equatorial anisotropy indicates significant distinguishes for these two groups of events that is well seen if compare Fig. 1 (for western sources of FEs) and Fig. 2 (vector presentation for two of ten selected eastern events). We can see very sharp changes in a direction of equatorial component of CR anisotropy during the main phase of FEs associated with far eastern sources. Each of anomalous FEs was caused by very powerful CME with far western or eastern localization. For example, the FE in July 78 occurred due to the CMEs from double eastern flares of X3.0 and X2.0 importance (E58 and E38 correspondingly). The June 2000 event was caused by very powerful release with location at E60 helio longitude after flare of M7.6/2B. If the Earth is closer to the straight way of CME propagation the giant FEs and strongly disturbed IMF could be recorded in Earth vicinity. But when a CME passes far to east or west of Earth the Earth enters only a

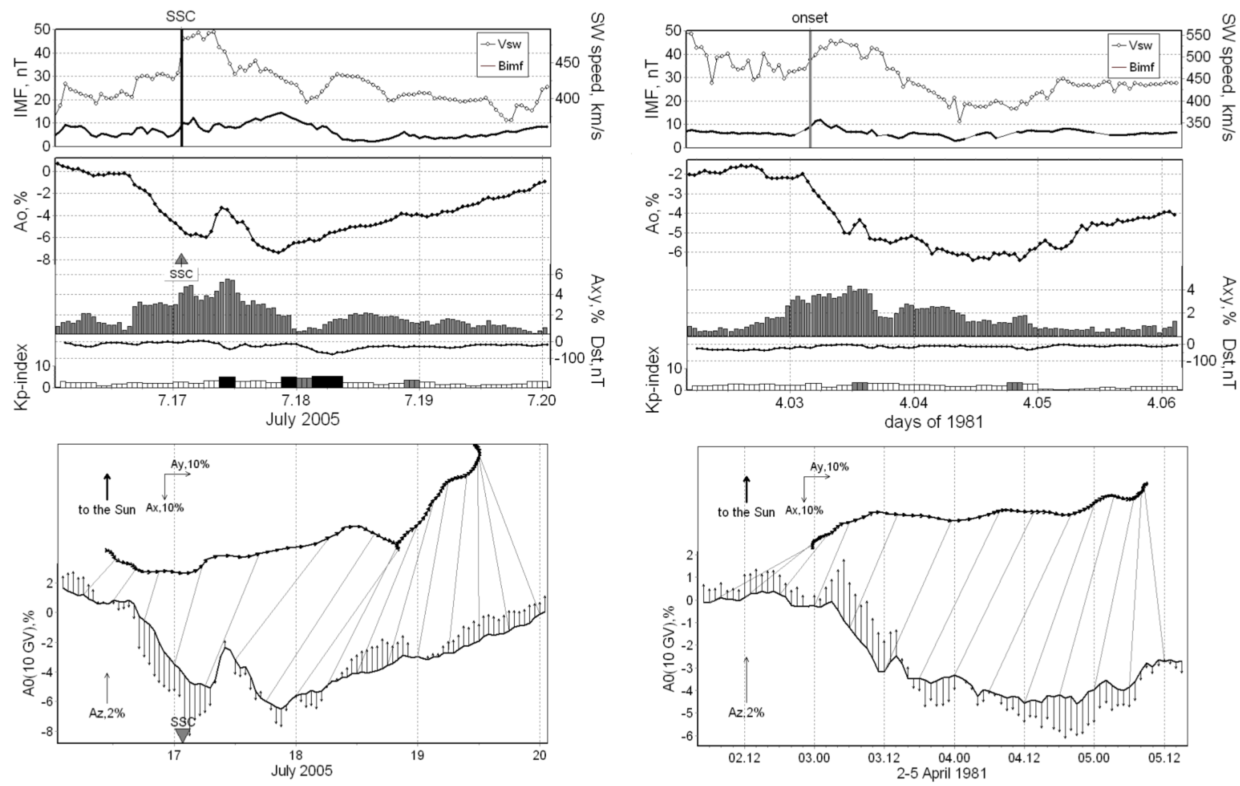

Figure 1. Examples of the FEs in July 2005 and April 1981 caused by the far western solar sources: IMF, solar wind, geomagnetic data (Kp-index and Dst variations), cosmic ray density and anisotropy (A0 and Axy) during the FEs associated with the western power solar ares W79 and W52. In the low panel vector diagram of CR anisotropy (equatorial component Axy) and density (A0) are presented. Vertical vectors mean north-south component of the CR anisotropy. Thin lines connect equal time points in each 6 hours in vector diagram and density curve.

periphery of disturbed area, but due to magnetic connection with CR depleted region behind the shock in the case of strong disturbance it may feel a significant CR decrease. Therefore, the high modulation efficiency of interplanetary disturbances observed in the CR at Earth is most often an evidence of increased power of the IMF disturbance, much greater than it might be concluded from the solar wind measurements near Earth.

TABLE I

THE AVERAGED PARAMETERS OF CR VARIATIONS, SOLAR WIND AND GEOMAGNETIC INDEXES FOR FES CAUSED BY FAR EASTERN AND WESTERN SOURCES

Parameter	AF/Bmx> 0.34	Mean values for Eastern group	Mean values for Western group
Forbush-effect magnitude	AF, %	**4.24 ± 0.78**	**4.5 ± 0.57**
Maximal equatorial component of CR anisotropy	Axymax, %	**2.91 ± 0.41**	**4.46 ± 0.51**
Maximal IMF intensity	Bmax, nT	**16.40 ± 1.78**	**15.20 ± 1.38**
Maximal SW speed	Vmax, km/s	**613 ± 46**	**602 ± 24**
Maximal Kp-index	Kpmax	**6.42 ± 0.7**	**5.67 ± 0.49**
Decrement of FD	Dmin	**-1.54 ± 0.30**	**-0.92 ± 0.13**
Minimal Dst-index	Dstmin, nT	**-70 ± 12.6**	**-72.3 ± 11.3**
Time from onset to minimum of FD	Tmin, hrs	**22.43 ± .65**	**30.33 ± .31**

The magnitude of CR anisotropy is defined by CR gradients. In the events from eastern sources it looks as if a disturbance runs over Earth and covers it. The gradients are not so big, the free access of particles from eastern side is difficult and vector of anisotropy A_{xy} sharply changes its direction. In the cases with far western sources the Earth looks catching up with disturbance, the big CR gradient arise on the boundary of its entering of a perturbed region which causes a large anisotropy. A disturbed region is open for penetrating particles from the east that provides gradual recovery of CR intensity and stable direction of anisotropy from east to west during the whole Forbush effect. Such distinguishes and characteristic properties of CR variations during the eastern and western events can help with an identification of sources when there is insufficient information on its localization. One of examples is presented in Fig. 3 where vector diagram of the CR anisotropy and density variations are plotted for the FE on October 1966. This event was not identified with the source, but judging on

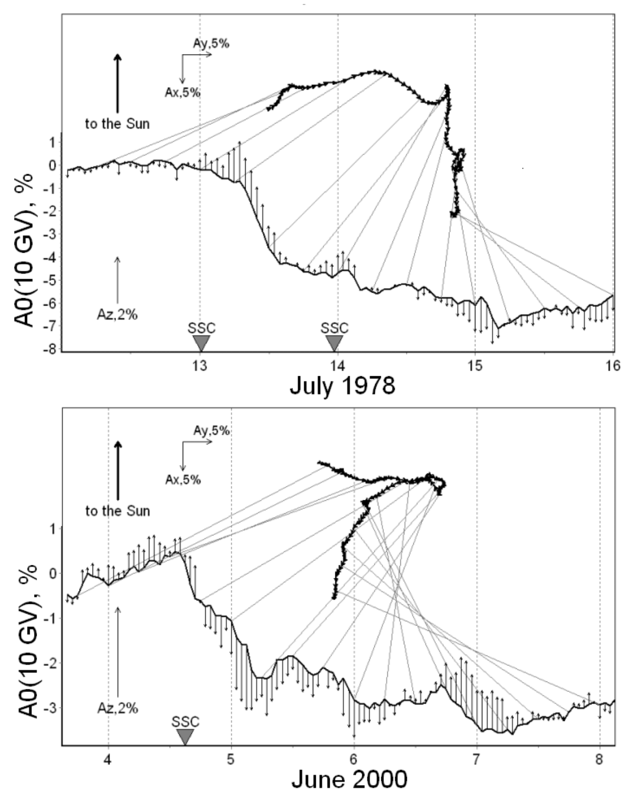

Fig.2. Vector diagram of CR anisotropy Axy and density A0 for two FEs associated with far eastern solar sources: July 1978 (E58 and June 2000 (E60). Vertical vectors mean north-sout component of the CR anisotropy. Thin lines connect equal tim points in each 6 hours in vector diagram and density curve.

the vector anisotropy behavior it should be caused by far western source.

In Fig.4 the variations of CR density and amplitude of the equatorial component of CR anisotropy are presented for a comparative analyses of some FEs from 'eastern' and 'western' subgroups. One can see the obvious superiority of the anisotropy magnitudes in the FEs of western group.

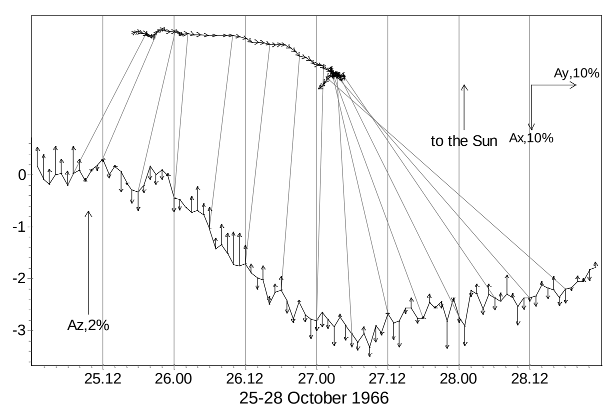

Fig.3.Vector diagram of the equatorial CR anisotropy (Axy) and CR density variations during the FE from unidentified source in October 1966.

4. CONCLUSIONS

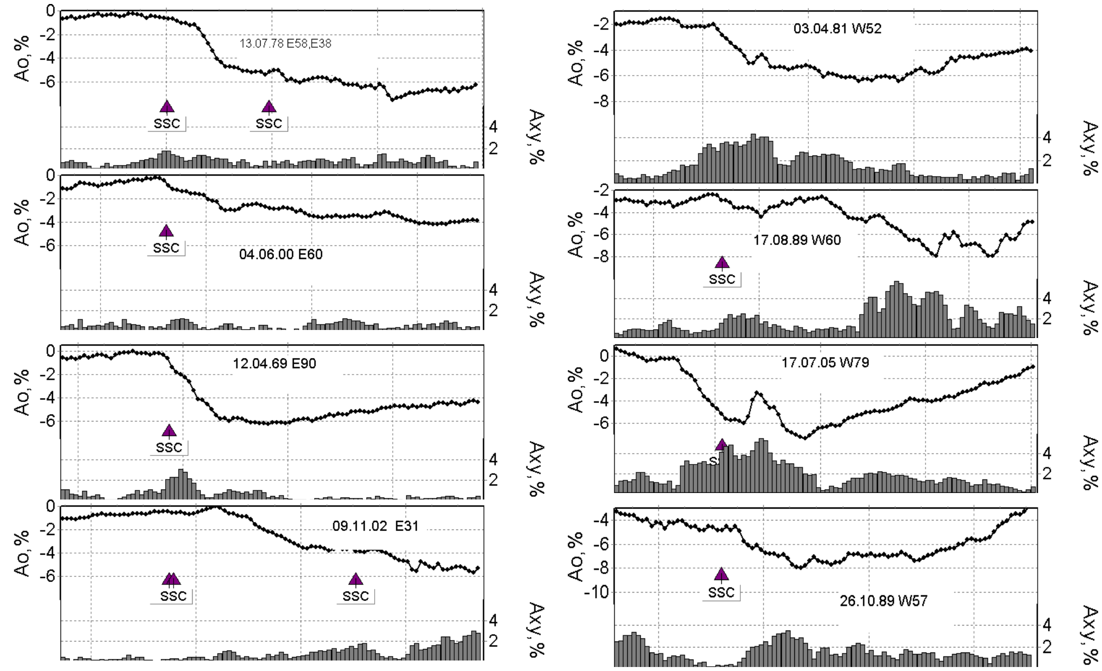

Fig.4. Behavior of the CR density A0 and equatorial component of the CR anisotropy Axy in the FE groups caused by eastern (left side) and western (right side) sources. Digits inside of panels show date of the FE occurring and heliolongitude of identified source.

It was possible to separate small but very definite groups of large FEs which occurred on the background of relatively quiet interplanetary and geomagnetic conditions near Earth, but turned out to be associated with great solar wind disturbances passed apart of Earth.

Those events are preceded by powerful flares on the Sun, which are generally located far from the center of solar disk.

The CMEs and interplanetary disturbances, originated from near the limb longitudes, appear to be of larger size and more complicated structure than it is visible near Earth.

Selected rare events from far western sources strongly differ from typical ‘western’ FEs which are usually not big and short lasted [5]. They also differ from the anomalous eastern FEs by bigger size of CR anisotropy and less variability of its direction.

The anomalous ‘eastern’ FEs have prolonged descent phase with a later minimum but larger magnitude in CR density than western events. They emphasize a sharp change of the anisotropy direction in the minimum of FE

These properties may be used for the diagnostics of inner heliosphere and Space Weather predictions. It may be useful tool when not enough data for accurate identification of a disturbance source.

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