The connection between high-speed streams from coronal holes and cosmic ray intensity

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Abstract: The effect of high-speed solar wind streams from low-latitude coronal holes on cosmic ray intensity is studied. The database on Forbush effects created at IZMIRAN, with cosmic ray density and anisotropy calculated by the Global Survey Method (GSM) on the basis of Neutron Monitor network data has been used. From the analysis of events it was found that the highest correlation of the FE magnitude was found with the magnetic parameters (IMF intensity and critical CR rigidity), but not with solar wind speed. As a rule, Forbush effects caused by coronal hole streams were small but prolonged.

Keywords: cosmic ray, coronal hole, Forbush effect.

1 Introduction

It is reasonable to divide the Forbush-effects (FEs) into the groups by their solar sources: sporadic and recurrent [1], where the first group is being connected with disturbances of the interplanetary medium caused by ejection of the solar coronal mass (ICMEs), while the events in latter group are usually caused by streams of high-speed solar wind from the low-latitude coronal holes (CHs) [2]. During the minimum solar activity the big CMEs are rare, so the observable FEs are mainly caused by CHs. The goal of present investigation is studying of influence of the high-speed solar wind streams (HSSs) from low-latitude CHs on the cosmic rays (CRs). First of all, for this purpose one needs to select a sufficient amount of CH-caused events surely free from substantial influence of the coronal mass ejections (CMEs).

2 Data and methods

In our study we use the database of FEs which has been created in IZMIRAN. Using the global survey method (GSM) [3,4] for calculation of the CR density variations and anisotropy vectors we operated the whole bulk of experimental material through the 2007 year. The CR parameters were supplemented by the information on the interplanetary medium taken from the OMNI database (http://omniweb.gsfc.nasa.gov/ow.html), and by the data of geomagnetic activity (ftp://ftp.gfz-potsdam.de/pub/home/obs/kp-ap/sdc). The CR parameters were calculated for particle of rigidity 10 GV which is close to the effective rigidity of the particles being registered by neutron monitor world wide network.

One of advantages of the 2007 year for our study is a possibility to observe the high-speed streams from CHs without CME. The background velocity of solar wind during this year was usually so low that the streams of medium-speed (and sometimes also below than that) were noticeable resulting in an interaction with the low-speed solar wind and in additional modulation of the CR. Also, this year falls on a long period...
of large number of CHs which has started at the end of 2002. The numerous (nearly 50) and diverse CHs were the main source of interplanetary perturbations in 2007, while the CME-caused disturbances were a minority, and the CMEs connected with a big solar flares were nearly absent. The events caused by solar filaments were met a little more frequently, but not so often as from CH. Hence, this year was favorable for selection and observation of the pure FE events caused by CHs.

An additional advantage of the 2007 year is its good representation in the CH database (http://www.solen.info/solar).

3 Analysis of the events

As an example of the disturbance caused by HSS from the low-latitude CH the event on 11-15 March, 2007 is presented in figure 1. During this event the peak velocity Vsw of solar wind was 698 km/s (maximum over all our subset) but the highest value of the IMF intensity and FE magnitude were modest and typical for 2007 - 11.1 nT and 1%.

In this FE we see two minima of CR density. The first one was reached relatively quickly in the period of the enhanced IMF, the second one - much later. In this event, we see that the direction of the vector of the equatorial component of CR anisotropy (Axy) changes before Forbush decrease.

The mean characteristics averaged by all the events in 2007 caused by coronal holes, are shown in figure

Fig. 2: Behavior of the mean characteristics by all the FDs in 2007 caused by coronal holes: IMF intensity and solar wind velocity (upper panel); 10 GV cosmic ray density (A0) and equatorial component of the CR anisotropy (middle panel); Kp and Dst-indexes of geomagnetic activity (lower panel). All parameters are averaged by epoch method, where zero day is the day of the FD onset.

Fig. 3: Average characteristics of FEs in 2007 caused by coronal holes (48 events), and events for all years, created by CME (349 events). X axis - time from FE onset, Y axis - magnitude of CR modulation.
The prolonged CR decrease with a late minimum is rather characteristic for the events in 2007. The maximum speed of HSS from CH, averaged for 48 events, was 567 km/s, and the maximum IMF intensity was 11.6 ± 0.5 nT. Kp-index of geomagnetic activity was 4.08 ± 0.13, equatorial component Axy of the vector CR anisotropy varies very slightly.

For a comparison with CH group events, the average characteristics of all events from our database including CME, separated each from other by not less than 48 hours, are plotted in figure 3.

Comparison shows that high-speed streams of a solar wind from coronal holes created small (on the average, 1.03 ± 0.06%) slowly developing FE. In the CME caused events maximum of the IMF intensity (tHmax), maximum of a solar wind speed (tvmax) and minimum of CR density are located by the compact group in the range of several hours, whereas in the CH associated events maximum of solar wind speed and CR density minimum are delayed essentially relatively to maximum of IMF intensity (tHmax).

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A tight enough relation between FE magnitude and solar wind velocity and especially Hmax (maximum of IMF intensity) exists not only for the big FEs [5, 6, 7], but for the small ones, not only for the flares but for the filament events also. We tried to find correlation for the CH events. Figures 4 and 5 show dependence of the FE magnitude on the maximum speed of solar wind and on maximum IMF intensity.

The maximum speed in considered CH events varied between 354 and 698 km/s, i.e. the FE in cosmic ray intensity during the 2007 occurred even at a very low wind velocity.

It follows from these plots and other calculations (not presented here) that the connection of the FE magnitude for cosmic ray rigidity R = 10 GV with the solar wind velocity (correlation coefficient c = 0.38, see figure 4) is much weaker than that with the maximum IMF intensity (c = 0.74). One can suppose that the solar wind velocity itself has not a decisive influence upon modulation of CR.

The most tight correlation of the FE amplitude (c = 0.86, see figure 6) was found with the critical CR rigidity [8], which is determined by a thickness of magnetic shield arising in the region of interaction of the wind streams having different velocities.

We can calculate some critical rigidity (R_CR) (formula [1] up to which all charged CR particles with velocities normal to the regular IMF component must be reflected. This value of R_CR may be used as a measure of modulation ability of the studied disturbance. A dependence of the FE magnitude on R_CR is shown in figure 6.

$$R_{CR} = C \int_{t_{ons}}^{t_{min}} V(t)(H - H_0)dt$$

where V is SW velocity, B_0 is intensity of undisturbed IMF (in this work B_0 ≈ 7nT), C – normalizing coefficient chosen by such a way for R_CR to be measured in GV. Integration is carried from the onset (t_ons) to minimum (t_min) of FE decrease.
5 Conclusions

Forbush effects caused by coronal hole streams in 2007 were small but prolonged.

The highest correlation of the FE magnitude was found with the magnetic parameters (IMF intensity and critical CR rigidity), but not with solar wind speed. It is possible to assume that properties of recurrent FEs in 2007 are typical for effects from coronal holes, but this statement needs a confirmation.

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References