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# Relation the Forbush effects to the interplanetary and geomagnetic parameters

**A. V. Belov, E. A. Eroshenko, V. A. Oleneva, and V. G. Yanke**

Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation Russian Academy of Sciences (IZMIRAN), 142190 Troitsk, Moscow region, Russia

**Abstract.** Properties of the Forbush effects (FE) and their relation to the sources and different parameters of the interplanetary medium and geospace, are the complex topic till now due to the great variety of FEs origin and manifestation. More definite relations appear to be derived employing the cosmic ray (CR) observations and different related parameters in the space and Earth's environment. To provide the statistical estimations a special database is created, which includes variations of the cosmic ray density and anisotropy, solar wind characteristics, interplanetary magnetic field, solar and geomagnetic data for about 2000 events observed in 1977-1980 and 1986-1997. The preliminary analysis allowed the main characteristics of the FEs and their relation with the solar wind and geomagnetic parameters to be derived and studied. A parameter of the interplanetary disturbance was found which is most closely correlated with the magnitude of the FE. A relation of the FE magnitude to the geomagnetic activity was derived as a dependence of the FE amplitude on the maximal Ap–index throughout the associated magnetic storm.

## 1 Introduction

Research of the Forbush effects (FEs) is carried on more than 60 years, since the beginning of regular cosmic ray observations (Forbush, 1937). Nevertheless, this subject is not only unexhausted but on the contrary, it becomes more and more interesting (Cane, 2000).

The difficulties of the Forbush-effects study are caused at least by two reasons. Firstly, FEs are rather variable in their manifestations, reflecting the various conditions on the Sun and in the interplanetary medium. Secondly, our observations of the FEs are essentially limited. Every FE is a heliospheric phenomena which starts at the Sun and may be over in the outer heliosphere. The spatial scale of some Forbush-effects is of about tens astronomical units (AU), and its time scale may be of up to months. That's why the observations at a single point (at Earth) during several days may give a notion of event far from complete. We see always only a small part of a large scale phenomena. The same Forbush effect may be observed simultaneously, and consequently, in different places separated by several AU, and it may appear in a variety of fashions.

We could understand the main features of FEs only if put through a complex analysis all possible dada on CR observations and relevant data on the Earth environment altogether. Forbush effect is a storm in the cosmic rays. This phenomenon is a result of the storm in interplanetary space, and very often it appears simultaneously with a geomagnetic storm. All these three kind of disturbances in the solar wind, magnetosphere and in cosmic rays – are tightly connected, and it is natural to study them altogether.

The FEs are observed now not only at Earth but onboard the spacecrafts also in the CR of smaller energy. However, these observations have not enough statistical accuracy. In addition, the big difficulties arise with the separating of the modulation and acceleration effects. The ground level CR observations, neutron monitor data first of all, thus remain as the main source of the FE information.

In this work we analyze a large number of the FEs by the ground level observations and discuss a relation these phenomena to the interplanetary and geomagnetic disturbances.

## 2 Data and methods

Forbush effects were studied using the variations of 10 GV CR density and anisotropy obtained from the NM network data by the global survey method. It is in this range of rigidity that our information on the FEs is the most complete and precise; so, the characteristics of 10GV CR suppose to be a basis for statistical analysis and FEs classification. All quantitative estimations presented in this work relate to this rigidity of CR.

*Correspondence to*: A. Belov (abelov@izmiran.troitsk.ru)

We created, and constantly enlarge and update, the special database (Belov et al., 1999a), which combines this CR information with solar, interplanetary and geomagnetic characteristics (OMNI data, Geomag data). At present, data on more than 2000 events are accumulated over the complete 15 years (1977-1980, 1987-1997) and for some other particular periods. Principles of the event selection were described in (Belov et al., 1999a; Belov et al., 2001). We shall not repeat it here. It should be only noted that we tried to select and collect into one base the all, significant enough, disturbances associated both with coronal mass ejection (CME) and with coronal holes. These two different kind of disturbances are often not separable. Solar wind phenomena have a complex origin, because the sporadic and recurrent structures interact and influence each other (Crooker and Cliver, 1994; Gonzales et al., 1996; Ivanov 1997).

## 3 Results and Discussion

### 3.1 Time dependence

The mean time interval between picked out events is about 3 days and comparable with their typical duration at Earth. Of course, such a high frequency is a characteristic only of the small magnitude FEs. The majority effects didn't exceed 1% by the magnitude, and only 1 from 12 events was of >=3%. Forbush effects, especially the biggest ones, are very no uniformly distributed along the time. Let us consider the 11-year period 1987-1997 (Fig. 1) when we have continuous data. It involves the complete 22-nd solar cycle including 4 years of the high activity (1989-1992) with 1989 and 1991 years of anomalously high activity, and 4-5 quiet years also (1987, 1994-1996 and long part of 1997). It allows the change of the FE frequency to be followed within the solar cycle. The frequency of relatively small FEs (1-2%) varied only slightly during these 11 years and proves to be high enough even in the solar activity minimum. The same regards also to the less effects (<1%). On the contrary, a number of big Forbush effects (>2.5%) varies very strongly. It increased rapidly within the 1987-1988, and was of maximal amount in the anomalously active 1989 and 1991.

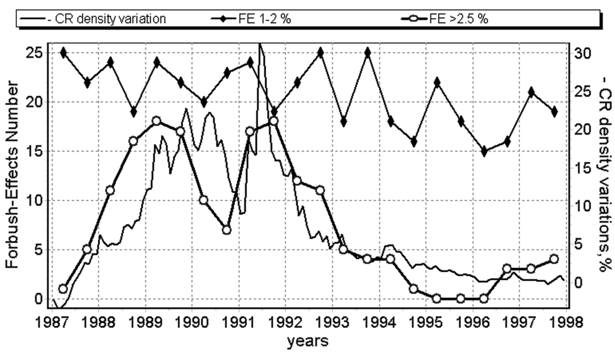


**Fig. 1.** Half year data on the number of big and small FEs observed through the 22nd solar cycle. Solid line indicates the CR of 10 GV density variation (Belov et al., 1999b) plotted opposite in sign.

Starting from 1992 with the solar activity decrease, Forbush-effect number reduced gradually and they were absent at all in the period from the second half of 1994 to the second part of 1996. A number of big FEs is well correlated with solar activity, especially with its most powerful manifestations, such as large X-ray flares or proton enhancements. The same is also revealed in such a peculiarity as "Gnevyshev's gap" (Feminella and Storini, 1997). We see that a number of large FEs was nearly in twice lower in 1990 than those in 1989 and 1991. The similarity in the changes of the big FEs frequency and long term variance of the CR modulation is evident (Fig.1). It indicates the great CMEs, creating the big FEs, seems to be related to the global heliospheric modulation of CR.

### 3.2 Relation to interplanetary disturbances

It is clear, that magnitude of FE ($A_{FE}$) can not uniquely be derived from the local SW parameters only. This parameter should be depended on the dimension of solar wind disturbances, on the features of their construction and the progressing, on the characteristics of these disturbances in the wide heliospheric region. Nevertheless it is desirable to infer maximal information from the solar wind local measurements. It would be very useful to obtain a generalized characteristic of the interplanetary disturbance which would be the best related to the FE. A relation of the FE magnitude ($A_{FE}$) with intensity of the interplanetary magnetic field (IMF) within the solar wind disturbances, is well known (Barnden et al., 1973; Iucci et al., 1979; Burlaga et. al., 1984; Cane 1993). The FEs are also correlated with solar wind velocity (Belov and Ivanov, 1997a, 1997b; Belov et al., 1997). What is still better, a correlation of $A_{FE}$ with the upper limit of magnetic rigidity $R_u$, up to which the given disturbance has influence on charge particles (Dorman, 1963, Belov and Ivanov, 1997a, 1997b). Unfortunately, the estimation of $R_u$ is difficult and possible only with continuous SW observations.

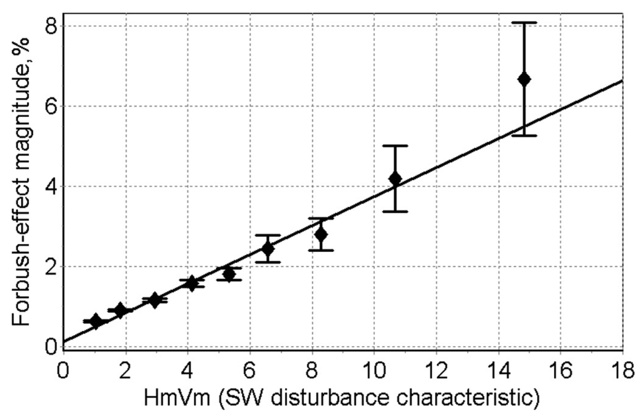


**Fig. 2.** Dependence of FE magnitude on product of maximum for a given disturbance IMF intensity ($H_m$) and SW velocity ($V_m$). Points with their standard errors derived as the averaged data within the equal intervals of $H_mV_m$ changing. The line shows the linear regression best fitted to measurements.

Belov et al. (2001) offered the characteristic of interplanetary disturbance more simple calculated. It is a product of maximal interplanetary magnetic field intensity and maximal solar wind velocity for an associated disturbance $H_m V_m = \frac{H_m}{5\ \mathrm{nT}} \frac{V_m}{400\ \mathrm{km/c}}$. This term is arbitrarily considered as a characteristic of modulating ability of the solar wind disturbance.

In our database the values $H_m$ and $V_m$ are derived for the all events when the solar wind measurements are available (OMNIdata). Fig. 2, where data on 1062 events are combined, clearly demonstrates a relation $A_{FE}$ with a product $H_m V_m$. All data were divided into equal intervals of 1.2 in $H_m V_m$ values. The last interval includes the most powerful disturbances with $H_m V_m > 12$. Values averaged in this manner have a strong correlation (the correlation coefficient is 0.99). Correlation was significantly less separately for $H_m$ and much less for $V_m$ . We performed the same analysis only for the events associated with interplanetary shocks (as proxy for shocks we used Sudden Storm Commencements - SSC). In this case the number of events decreased by a factor of 4, but the level of correlation and regression dependence was changed slightly. Because an influence of recurrent structures on the set of events with SSC should be small, we conclude that the close relation of the FE magnitude with $H_m V_m$ parameter exists both for the effects caused by the solar ejecta and associated with coronal holes.

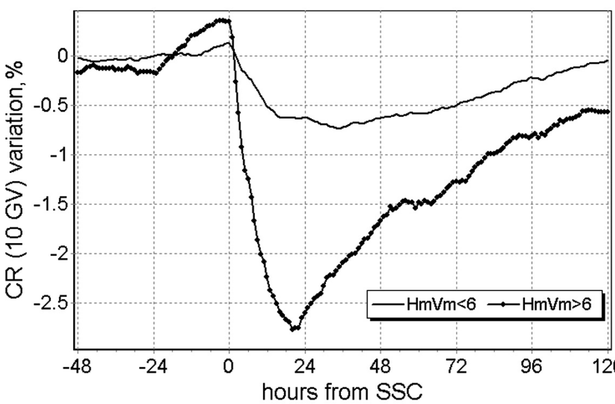


**Fig. 3.** Averaged time profiles of the FEs associated with the powerful ($H_m V_m$>6) and relatively weak ($H_m V_m$<6) disturbances in the solar wind

We divided arbitrarily all solar wind disturbances on the powerful and weak ones taking as a boundary $H_m V_m$=6, and found an averaged profile of the FE in each group by the epoch method (Fig. 3). To derive the onset more precisely, the events only with SSC have been chosen. In the group of weak disturbances the 206 FEs were included, and 56 events - into "powerful" group. Big difference between two these groups is indicated in Fig.3, and the analysis of events from these groups confirms this. The mean magnitude of FEs from the "weak" group was 1.6±0.1 %, whereas within the "powerful" group it was 4.2±0.4 %. Effects from the first group are usually followed by the weak magnetic storm (Kp-index not higher than 5). The strong magnetic storm (Kp-index on average reaches 7-) is characteristic for the events from second group. An interesting feature of the averaged FE profile for "powerful" group is a preincrease before the onset (with mean value ~1%), which lasts about the whole day. The preincrease is also notable in the "weak" group, but it is much less and shorter there.

3.3 Relation to geomagnetic activity.

The common interplanetary disturbances caused both FEs and geomagnetic storms. The common, as well as essentially different features, appear in the response of magnetosphere and CR variations to the interplanetary disturbances. Both the geomagnetic activity and CR modulation increase as the IMF intensity and solar wind velocity rise. However, of the solar wind density augmentation effects the magnetosphere, doesn't impact on the CR. A sign of the IMF $B_z$ component has a key importance for the magnetic storm evolving, but it is of secondary importance for the CR variations and does not effect the CR density. The main difference is, that FE is conditioned by the extended heliospheric region, whereas geomagnetic activity depends on the local situation near Earth.

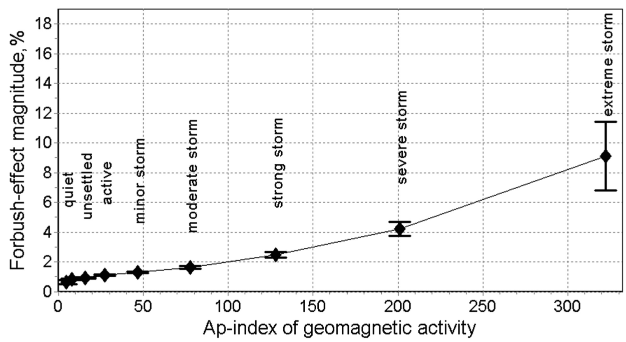


**Fig. 4.** Dependence of the Forbush effect mean magnitude on the maximal Apm-index of an associated geomagnetic activity.

From linear regression analysis, performed to the 2059 events, we derived a correlation coefficient 0.54 between the FE magnitude ($A_{FE}$) and maximal Ap-index, and it was -0.47 only, for $A_{FE}$ and Dst-index correlation. Along of this, the averaged values reflected the geomagnetic and cosmic ray activity are close correlated (Fig.4). To obtain the results plotted in Fig.4 all the events were grouped by the maximal Kp-index ($Kp_m$). Thus, in one group all events of $Kp_m$=5-, 5, 5+ were included (i.e. all minor magnetic storms). Another group consisted of the moderate storms ($Kp_m$ from 6- to 6+), and so on. A derived correlation between $A_{FE}$ and Ap-index is more close to the linear one than a dependence of $A_{FE}$ on $Kp_m$ (Belov et al., 2001). We can see from Fig. 4 that very small FEs (of $A_E$ ≤1%) are associated to the quiet and unsettled geomagnetic background. Even during the minor magnetic storms ($Kp_m$=5) the averaged FE is of <1.5%. And typical magnitude of the FE becomes bigger (4% and higher) only during the severe magnetic storms ($Kp_m \geq 8$). Despite of a good agreement between the averaged values a ratio of the geomagnetic and cosmic ray activity may be rather different in separate cases. The solar wind disturbance, which is able to create a magnetic storm, must necessarily effects the cosmic rays. Forbush effect thus corresponds to each magnetic storm. However, this effect is sometimes too small or even hardly revealed in the CR density variations at the Earth observations. The opposite situation, when FE occurs without magnetic storm, is more often phenomena (a little more than 50% in our data base). Though, a contribution of such events reduces quickly as the magnitude of FE increases (it is <30% for the $A_{FE}$>2% and <20% for the $A_{FE}$>3%). Forbush effects of >5% magnitude are almost not encountered without magnetic storm, and, in these seldom cases the geomagnetic activity is always enhanced.

## 4 Conclusion

The storms in the solar wind, in the Earth's magnetosphere and in the cosmic rays are closely related. We are able to find the quantitative connections between the averaged characteristics of the interplanetary, geomagnetic and cosmic ray activity and use it in the diagnostic of the solar activity manifestation.

An essential deflection of the observed FE magnitude from the averaged dependence in Fig. 2 is the evidence of the anomalous situation. The interplanetary disturbance suppose to be of unusual dimension, or, alternatively, to be unusually positioned with respect to the Earth in this case. Such additional information in combination with the other data is able to help us to identify a disturbance with its solar sources and to predict its further progressing. A correlation between the FE magnitude and $H_m V_m$ product may be used to estimate the solar wind characteristics if their measurements have not been carried out.

Distortion of the FE magnitude and Ap-index correlation (Fig. 4) informs us most often about contribution of the IMF $B_z$-component. Interrelation of cosmic ray and geomagnetic activity appears to be reasonable used for the FEs classification. The classification of magnetic storms indicated in Fig. 4 is universally accepted (NOAA Space Weather Scales). The FEs gradation has probably to be adapted to the magnetic storms gradation, for the similarly named phenomena would be observed with the approximately equal frequency both in the magnetic and CR activity. We came to conclusion after the analyzing a frequency of FEs and magnetic storms over the 15-years period, that FEs of the 2-3% magnitude (in 10 GV CR density variations) correspond to the moderate magnetic storms. Thus we can name >2% effect as major Forbush effects, but FEs of <=2% magnitude – as minor FEs. Analogously, a number FEs of 3-5% magnitude correspond to a frequency of the strong magnetic storm, ànd FEs > 5% are observed as seldom as the severe magnetic storms.

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## References

Barnden, L.R., The Large-Scale Magnetic Field Configuration Associated with Forbush Decreases, *Proc. 13th Internat. Cosmic Ray Conf.*, **2**, 1277-1281, 1973.

Barouch, E., and L. F. Burlaga, Causes of Forbush Decreases and Other Cosmic Ray Variations, *J. Geophys. Res*., **80**, 449, 1975.

Belov, A.V., and K. G. Ivanov. Forbush-effects in 1978. 1. The role of suddenly disappearing filaments *Geomagnetism and Aeronomy*, **37,** 3, 32, 1997a.

Belov, A.V. and K. G. Ivanov, Forbush-effects in 1977-1979, *Proc. 25th Intern. Cosmic Ray Conf.*, **1**, 421, 1997b.

Belov, A.V., E. A. Eroshenko, and V.G.Yanke, Modulation effects in 1991-1994 years, in: Correlated Phenomena at the Sun, in the Helosphere and in Geospace, ESA (Noordwijk), 463-468, 1997.

Belov A.V., E. A. Eroshenko, and V. G. Yanke, Cosmic Ray Effects Caused by Great Disturbances of the Interplanetary Medium in 1990-1996, *Proc. 26th Int. Cosmic Ray Conf.*, **6**, 431-434, 1999a.

Belov, A.V., R. T. Gushchina, and V. G. Yanke, Long term cosmic ray variations and their relation with solar activity parameters, Proc. 26-th ICRC. Salt Lake City, 7, 175-178, 1999b.

Burlaga L. F., McDonald F.B., N.F.Ness, R. Schwenn, Lazarus A.J., and F. Mariani, Interplanetary flow systems associated with cosmic ray modulation in 1977-1980, *J. Geophys. Res.*, **89**, 6579, 1984.

Cane H.V., Cosmic Ray Decreases and Magnetic Clouds, *J.Geophys.Res*., **98**, A3, 3509-3512, 1993.

Cane H.V., CMEs and Forbush Decreases, in: *ISSI Space Science Series*, **10**, "Cosmic Rays and Earth", 41-62, 2000.

Cane H.V., Richardson J.G., and T.T. von Rosenvinge, Cosmic Ray Decreases and Particle Acceleration in 1978-1982 and the Associated Solar Wind Structure, *J. Geophys. Res.*,**98**, A8,13,295-13,302, 1993.

Crooker, N.U., and Cliver E.W., Postmodern view of M-regions, *J. Geophys. Res*., **99**, 23383, 1994.

Dorman L.I., Cosmic Ray Variation and Space Research,. Ì.: ÀN USSR, 1027 ñ. 1963.

Feminella, F. and Storini M., Large-scale dynamical phenomena during solar activity cycles, Astronomy and Astrophysics, 322, 311-319, 1997

Forbush, S.E., On the Effects in the Cosmic-Ray Intensity Observed During Magnetic Storms, *Phys. Rev*., **51**, 1108, 1937.

Gonzalez, W. D., Tsurutani, B. T., McIntosh, P. S., Clúa de Gonzalez A. L., Coronal hole-active region-current sheet (CHARCS) association with intense interplanetary and geomagnetic activity, *Geophysical Research Letters*, **23**, 19, 23.2577G, 1996.

Iucci N., Parisi M., Storini M., and Villoresi G., High Speed Solar Wind Streams and Galactic Cosmic Ray Modulation, *Nuovo cimento Soc. Ital.Fis. C,* **2**, 421, 1979.

Ivanov K.G., Solar Sources of the Interplanetary Plasma Streams on the Earth's orbit, *Geomagnetism and Aeronomy*, **36**, 2, 19-27, 1996.

OMNI Data:, http://nssdc.gsfc.nasa.gov/omniweb/ow.html.

Geomag Data:, ftp://ftp.ngdc.noaa.gov/STP/