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Frequency of Forbush effects as an index of solar activity

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During the past ten years a catalog of Forbush effects has been created in IZMIRAN. At present this catalog includes more than 4400 events and covers 37 years with the last four maxima and three minima of the solar activity cycle. The extended data base allows the study of the long term behavior of interplanetary disturbances. For this aim a special index I_F is being introduced, whose factors are the Forbush effect occurrence frequency and the magnitude of the effects. The variation of this index with time as well as of two other cosmic ray indices (the amplitude of the galactic cosmic ray modulation and the cosmic ray activity (CRA) index), are compared with the other indices of solar activity. All three cosmic ray indices are correlated with widely used solar indices (e.g. sunspot number, frequency of the optical and X-ray flares), and with Ap-index of geomagnetic activity. It is shown that the I_F index reflects not only the cyclic structure, but also much finer details of solar activity. It allowed this index to be used together with X-ray index to obtain a new combined index of the burst activity. The long term behavior of solar activity burst occurrence is studied in dependence of the phase of the solar cycle, and attempt of the burst probability forecasting is undertaken.

1. Introduction.

Solar activity is described by a number of indices and they all behave by different way. For example, sunspot number (Fig. 1) reveals well pronounced 11-year cycle, whereas the main feature of the major (>M5) flare number are the series of irregular bursts. What is a solar activity burst? It is a short time enhancement of the solar sunspot number (SSN), of the X-ray and radio fluxes, the appearance of large active regions with complicated magnetic field structure. It is the sharp increase in the number of flares and other sporadic phenomena, as coronal mass ejection (CME), radio bursts and particle enhancements. In particular, during the last solar cycle such bursts were observed in July 2000, March-April 2001, October-November 2003, July and November 2004, January 2005. The most powerful burst turned out to be in October-November 2003 [1,2], a much weaker one was in January 2005, but each burst as a rule is followed by strong changes in the interplanetary magnetic field (IMF) and solar wind characteristics, and by strong geomagnetic activity. At the same time usually the series of Forbush effects associated with the powerful solar flares is observed. It would be important to have any way to predict of such bursts. We need some special index reflecting the nature of the solar activity bursts. Unfortunately, till now there are no measures and no quantitative description of the burst activity. One of the goals of this work is to find a way for the quantitative description of the frequency of these bursts occurrence.

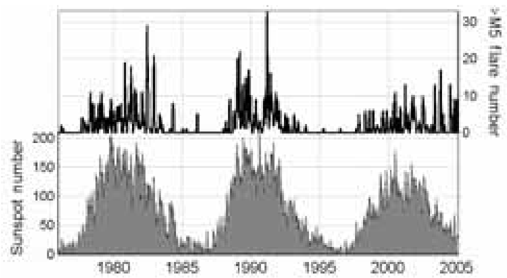

Figure 1. 27 day running averaged sunspot number and number of major (≥M5) flares.

2. Data and Method.

The extended database created in IZMIRAN and including >4400 FEs over the 37 years, allows the study of long term behavior of the interplanetary disturbances. We used daily mean values of different measurements on the Sun, in space and at the ground from 1967 to 2005 – almost 3 full solar cycles [ftp://ftp.ngdc.nasa.gov]. The parameters are sunspot numbers (SSN) - W, X-Ray intensity, optical flare index – I_O [3], Ap-index of geomagnetic activity, variations of 10 GV cosmic ray (CR) density, derived from the neutron monitor network [4], cosmic ray activity (CRA) indices [5,6]. On the basis of these data several new indices were calculated and employed for comparison and further correlation analysis.

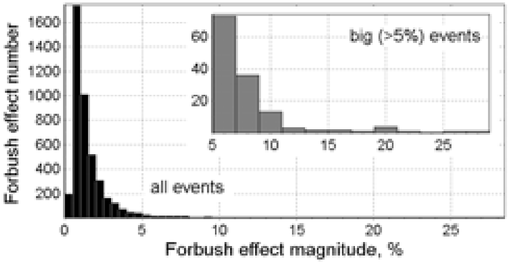

Figure 2. Size distribution of Forbush-effects (1967-2005).

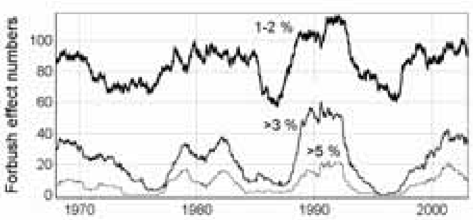

Figure 3. 729 day running sum for number of Forbush effects with different magnitude.

Forbush effects are a permanent part of CR variations, but they do not occur homogeneously during the cycle [7]. The magnitude of FEs ranges within 0-28% (Fig. 2), and more than half of them are less than 1%. Only ~3% of the whole amount of FEs (140 events) have a magnitude more than 5 %. The number of 1-2% FEs doesn't show significant variability along the solar cycle. Relatively small FEs are observed in any period (Fig.3), whereas the events of >3%, and especially >5% magnitude are practically absent near the solar minimum. More clearly a correlation of the FE number and solar activity is revealed in the behavior of FEs with >5% magnitude. The Forbush effect index was introduced as a daily sum of the FE magnitudes - $I_F = \sum A_F$, where magnitude A_F is the maximum variation of 10 GV particle density during each event. CRA index was calculated by the method described in [5]. The flare optical index is available from [3] for 1976-2003. Special index was introduced for X-ray flares, as the sum of maximum fluxes of all flares in one day: $I_X = \sum_{Jx>=C1} J_x / 10^{-6} Wm^{-2}$. The flares of A and B classes were not taken into account because they are often below the X-ray background. The flares of C1 class give 1 to I_X, and a X10 flare - 100. A running averaging was applied to the initial daily data. Finally, for each of observations the special burst index R was derived. In particular, for the X-ray data it looks as $R_X = \sqrt{\frac{I_{X27}}{I_{X729}} \frac{I_{X27}}{I_{Xmean}}}$, where X27 means 27-day smoothing, X729 - smoothing for ~27 rotations (27x27=729 days ≈ 2 years) and it used as a current reference period; X_{mean} is a long time averaging (1976-

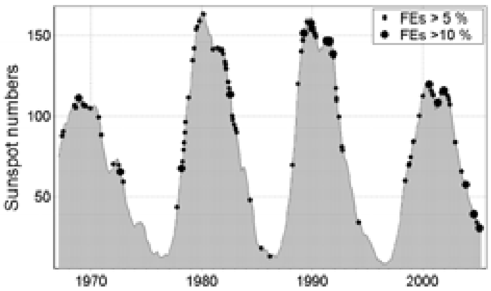

Figure 4. The largest Forbush effects with sunspot numbers as background.

2003 for all data). By the same way the burst indices were calculated for other parameters: R_W (for SSN), RA (CR modulation), R_R (for CRA), R_G (for Ap), R_O (optical flares). The criterion for the burst indication was arbitrary accepted as R>1.

3. Results and discussion.

Fig.4 presents the sunspot number and the largest FEs throughout 1967-2005. Distribution of large FEs is irregular: one can see the periods completely without FEs and some clusters of FEs of large magnitude especially around the solar activity maximum, reflecting distribution the solar activity bursts. As a rule, during the such clusters appearance (March-April 2001, October-November 2003 and etc) series of FEs and series of magnetic storms occurred within a short one–two weeks- period. We observe several clusters of large FEs in the 23-rd cycle during the bursts of activity in the late descending phase, and this is specific feature of the current cycle. This information argues the FE behavior to be appropriate to use in the burst index calculation.

The special burst indices R calculated for the different parameters characterizing the solar activity are presented in Fig. 5. We can notice very similar behavior of the R_W, R_O, and R_A indices but the strong 11-year variation masks the burst activity. The R_F and R_X indices turn out to be more preferable, showing also similar behavior, and at the same time, a more clear variability according to the burst periods. We calculated the burst time fraction F_B for each index as the ratio of the accumulated burst time duration to the whole time of observation. It was accounted, that a number of indices regards to the Sun (R_W, R_O, R_X) and other part is connected with the solar activity manifestation in the interplanetary space and at Earth, that should cause a delay of one indices relatively to others. The burst time fractions and matrix of the correlation coefficients calculated over the 1977-2002 are entered in

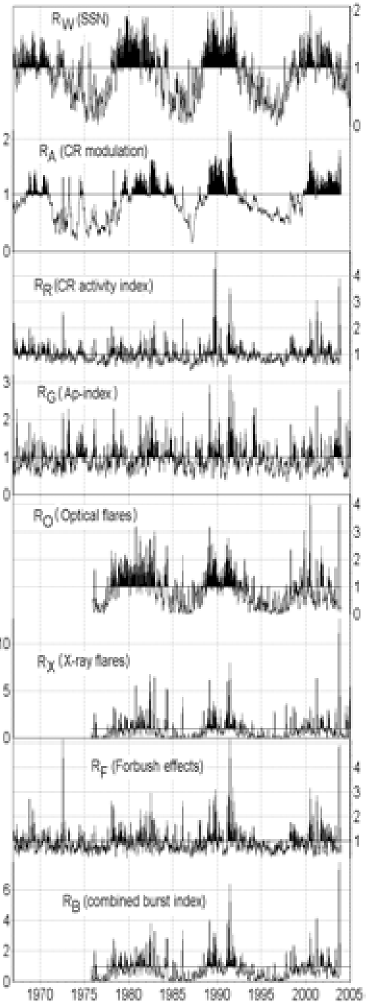

Figure 5. Different burst indices.

Table 1. The fraction of burst days for different burst indices and maximal correlation coefficients between them.

Index	F_B, %	R_W	R_O	R_X	R_G	R_R	R_A	R_F
R_W	48.9	1(0)	0.80(0)	0.56(0)	0.21(4)	0.37(5)	0.66(11)	0.45(0)
R_O	41.7	0.80(0)	1(0)	0.78(0)	0.37(3)	0.47(4)	0.61(10)	0.58(2)
R_X	32.0	0.56(0)	0.78(0)	1(0)	0.44(3)	0.56(4)	0.55(11)	0.65(2)
R_G	39.3	0.21(-4)	0.37(-3)	0.44(-3)	1(0)	0.48(0)	0.45(5)	0.65(0)
R_R	37.2	0.37(-5)	0.47(-4)	0.56(4)	0.48(0)	1(0)	0.47(6)	0.81(0)
R_A	45.1	0.66(-11)	0.61(-10)	0.55(-11)	0.45(-5)	0.47(-6)	1(0)	0.55(-7)
R_F	36.7	0.45(0)	0.58(-2)	0.65(-2)	0.65(0)	0.81(0)	0.55(7)	1(0)

The indices R_X (characterizing the processes at the Sun) and R_F (related to the response in the near Earth space) reveal a relatively tight correlation and show a lower F_B as compared with the other indices, therefore they have been chosen to construct the combined burst index $R_B = \sqrt{R_X R_F}$ over the period from 1977 to 2003, and it is plotted in Fig. 5 on the last panel. The behavior of R_B reflects well bursts of the solar activity. Analysis of the burst activity relation to the sunspot cycle phases allows the prognosis of such bursts for a future time. In Fig.6 a probability of the burst occurrence at every day is presented for the past cycles and plotted for the next years.

4. Conclusion

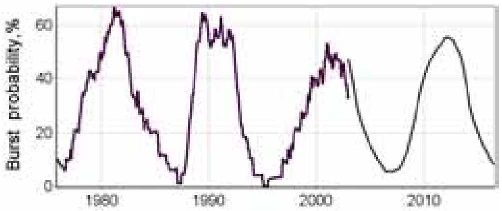

Figure 6. Probability of the solar activity burst observed throughout the three last cycles and predicted for the next cycle.

The analysis of long time behavior of different parameters of the solar activity allowed the index of X-ray together with FE frequency, characterized geo-efficiency of the burst activity, to be chosen for construction of the burst activity combined index R_B. A study of R_B changes gave a possibility to calculate probability of the burst occurrence throughout the many years of observations and allowed a prognosis of this probability for the next solar cycle.

5. Acknowledgement.

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