Forbush-decreases in 19th solar cycle

A Abunin¹, M Abunina¹, A Belov¹, E Eroshenko¹, V Oleneva¹, V Yanke¹
¹Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation RAS (IZMIRAN), Troitsk, Russia

E-mail: abunin@izmiran.ru

Abstract. The abnormally high solar activity was observed in the late 50’s – the early 60’s of the 20th century, but not many possibilities was available that time of its observation to which we have got in use during the last years. Ground level cosmic ray observations, along with geomagnetic activity, are one of a few kinds of the continuous measurements, allowing to judge on the events of 19th cycle. The IZMIRAN Database in which all Forbush-decreases are collected since July, 1957 has been used for the analysis. To make the statistics of 19th cycle fuller, the catalogue by Lockwood containing rather big Forbush-decreases (>3 %), picked out from the data of one neutron monitor (Mount Washington), was involved. Comparison of the events in cosmic rays with solar and geomagnetic activity has shown that the quantity and intensity of geomagnetic storms in 19th cycle correspond to abnormally high number of the sunspots. However in this cycle there is a certain deficiency of Forbush-effects of the large size. Apparently, deficiency of the big Forbush-decreases during this period means that coronal mass ejections (CMEs/ICMEs) in the 19th cycle distinguished from later CMEs and differently affected of the cosmic ray modulation and geomagnetic activity. Probably, the most powerful CMEs of the 19th cycle had, as a whole, the smaller size, than the greatest emissions of solar plasma in later period.

1. Introduction
The 19th cycle was very unusual, and it greatly differs from other cycles of solar activity. Firstly, in this cycle the highest number of sunspots over the last 250 years was recorded. The sunspot maximum of the cycle 19 almost twice exceeds the maximum of median cycle. Secondly, in the 19th cycle (February, 1956) the greatest ground level enhancement of the solar cosmic rays (GLE) was observed. Since then hundreds proton events and tens GLEs occurred, but all of them are more than an order of magnitude less than the event on 1956. In the third, the highest monthly averaged geomagnetic activity over the last 72 years was observed in September 1957. Moreover, two of three the most active months are from the cycle 19, and one third of all the extreme geomagnetic storms (Kpmax = 9) for the last 7 cycles belong to the 19th cycle. All these features give the possibility to argue that the Sun was particularly active in the 19th cycle, and if we want to know how dangerous can be manifestations of solar activity, we must return to the events in the 19th cycle. Unfortunately, we know much less about the 19th cycle, than on the subsequent cycles of solar activity. In this cycle there were practically no measurements of a solar wind, no observations of x-ray and gamma flares, no data on the coronal mass ejections (CMEs/ICMEs), but continuous ground-based observations of cosmic rays (CRs) by means of the neutron monitors (NMs) were carried out. Ground-based observations are the primary source of information about the solar wind disturbances in the absence of interplanetary measurements and
coronagraphs. In particular, the Forbush-decreases (FDs) are the source of information about the interplanetary disturbances caused by ICMEs and coronal holes.

In this paper we study the FDs of the 19th cycle, compare them with geomagnetic storms and the events of the later cycles, as well as try to get new information on the ICMEs, which in the 19th cycle were not observed, but existed.

2. Data and methods
This work uses two sources of the information about CRs. The first source is a specially created in IZMIRAN database on the interplanetary disturbances and Forbush-decreases (DBFDs) [1, 2] which contains about 6000 events. The CR density and anisotropy for each hour over 50 years (1957–2011) were calculated by Global Survey Method (GSM) by the data of tens «NM64-type» NMs. Results for 10 GV rigidity CRs are combined for the analysis with the solar wind parameters and geomagnetic activity indexes from OMNI database (http://omniweb.gsfc.nasa.gov). The second source is the catalog of the FDs by Lockwood [3] (L-catalog) which is based on data of one station of the CR (Mt. Washington), and contains rather big FDs (>3%). This station operate of the «IGY-type» NM with a resolution interval of 2 hours.

Certainly it is impossible to unite two FD’s catalogs mechanically since these catalogs are different in the detectors used, the types of data, methods of allocation and selection of events, etc. If to compare FDs from two catalogs with each other, we can notice that values of the same events may differ essentially. However, these data are well correlated (figure 1).

![Figure 1. Comparison the events from the L-catalog (AFL) and DBFD (Af)](image1)

![Figure 2. Sunspots and the largest effects for the last five cycles (19-23 cycles)](image2)

The correlation coefficient between the values of FDs from different catalogues (AFL from the L-catalog and AF from the DBFDs) is 0.86. The observed dependence makes it possible to use Lockwood's catalog for estimation the number of FDs of various magnitudes in the first part of the 19th cycle.

3. Analyzed parameters
The DBFDs catalog contains data since 01/07/1957, whereas L-catalog starts from 01/04/1954. In the first part of the 19th cycle (01/04/1954–01/07/1957) L-catalog contains 10 events, in the second part (01/07/1957–31/12/1964) – 60 events. On this basis, we can assume that in the full 19th cycle there were 7/6 times more effects than we counted in the period from July 1957. Thus, the column 19c in Table 1 may be filled. Moreover, the FD in November 1956 (AFL=7.5%) appears to be the biggest of early events in the L-catalog, it corresponds to 8% from the DBFDs (see regression line, figure 1). It is important to note that the increase in number of events shouldn't be extended on the biggest effects (Af>8-10%).
If to arrange in descending order all the effects over the last 55 years, among the first ten will be only one event of the 19th cycle, on the last tenth place. The largest effects of the 19th cycle are much less than the largest FDs from later cycles. Thus, on a background of high solar and geomagnetic activity we found deficiency of big FDs in the 19th cycle.

**Table 1. Geomagnetic storms and FDs for the last five cycles**

| Solar cycles | 19 | 19c | 20 | 21 | 22 | 23 |
|--------------|----|-----|----|----|----|----|
| All geomagnetic storms | 621 | - | 499 | 588 | 538 | 487 |
| Minor storm (Kp<sub>max</sub>=5) | 317 | - | 294 | 308 | 283 | 272 |
| Moderate storm (Kp<sub>max</sub>=6) | 168 | - | 119 | 173 | 152 | 119 |
| Strong storm (Kp<sub>max</sub>=7) | 72 | - | 49 | 73 | 72 | 60 |
| Severe storm (Kp<sub>max</sub>=8, 9-) | 57 | - | 34 | 32 | 30 | 33 |
| Extreme storm (Kp<sub>max</sub>=9) | 7 | - | 3 | 3 | 1 | 3 |
| FDs (>1%) | 435* | 508 | 631 | 593 | 586 | 635 |
| FDs (>3%) | 71* | 83 | 102 | 94 | 123 | 110 |
| FDs (>5%) | 35* | 41 | 23 | 35 | 38 | 50 |
| FDs (>10%) | 10 | 10 | 2 | 7 | 7 | |
| FDs (>15%) | 1 | 1 | 1 | 2 | 6 | 1 |

Table 1 and figure 2 show that the 19th cycle differs from other cycles both by a quantity of sunspots and the number of extreme geomagnetic storms (19th = 7 storms, other cycles ≤ 3 storms). Similarly, the severe storms (19th = 57, other cycles ≤ 34). One would have expected a large number of big and giant FDs, but this is not confirmed. The quantity of FDs in the 19th cycle with magnitude A<sub>F</sub>&gt;5% is almost the same as in 21 or 22 cycles, and clearly lower than in 23 cycle (figure 3). In the case where the magnitude of the FD &gt;10% there is a slight dominance of the 19th cycle. And finally, the 19th cycle almost haven’t giant events (>15%).

**Table 2. The biggest FDs observed in the 19th cycle.**

| Date         | A<sub>F</sub> | Kp<sub>max</sub> | Dst<sub>min</sub> |
|--------------|---------------|-----------------|-----------------|
| 1957.08.29   | 11.6          | 6.7             | -75             |
| 1957.10.21   | 11.8          | 6.7             | -60             |
| 1959.05.11   | 14.6          | 8.3             | -88             |
| 1959.07.11   | 10.1          | 6.7             | -36             |
| 1959.07.15   | 14.8          | 9.0             | -429            |
| 1959.07.17   | 14.4          | 8.7             | -183            |
| 1960.03.30   | 11.0          | 8.7             | -327            |
| 1960.05.08   | 10.1          | 8.3             | -129            |
| 1960.11.12   | 16.1          | 9.0             | -339            |
| 1961.07.13   | 11.8          | 8.3             | -77             |

**Figure 3.** Number of &gt;5 % FDs and geomagnetic storms with Kp≥8 versus maximum SSN in 19-23 cycles

Table 2 shows the upper part of big FDs of the 19th cycle. Event 12/11/1960 is the biggest (A<sub>F</sub>=16.1%) of the 19th cycle, but its profile was distorted by two GLEs. And a series of three big FDs occurred in July 1959 what is often described in different papers (e.g., [4]). As an example of the 19th cycle, figure 4 shows the event in March-April 1960. The magnitude of this FD is A<sub>F</sub>=11%. The events have been observed with high frequency in the 19th cycle. For example, five shocks came to Earth during the short time (one week) as it seen in figure 4.
Figure 4. March 30 - April 10, 1960: The behavior of the density and anisotropy of cosmic rays (top), and Dst & Kp indexes of geomagnetic activity (bottom).

Note that all big FDs were accompanied by geomagnetic storms (at least of the $K_{p\text{max}} \geq 7$). Moreover, all these storms occurred in the second part of the 19th cycle (after 01/07/1957) which is completely presented in DBFDs catalog.

4. Conclusion
The methodical reasons and the features arising in interplanetary space may affect the characteristics of the FDs. But this influence is not of that kind which could explain deficiency of big effects in the period of high solar and geomagnetic activity. It means that the ICMEs of the 19th cycle and of the later cycles are distinguished by someway, and this difference is very essential for the modulation of cosmic rays. Besides, these differences influence the CR modulation and geomagnetic activity by different way. The main characteristics of the ICME, affected the level of geomagnetic activity, are the solar wind velocity and the magnitude of $B_z$ component of the interplanetary magnetic field (IMF). A large number of severe ($K_{p\text{max}} = 8,9$) and extreme ($K_{p\text{max}} = 9$) storms clearly shows that in the 19th cycle a lot of ICMEs with high speed and strong magnetic field were generated. These characteristics also influence the magnitude of the FD. But the magnitude of the FD also depends on the size of the disturbance. The larger the size of the ICME, the greater should be Forbush-decrease. On the other hand, the strength of the magnetic storm is independent on the size of the ICME. These considerations force us to suggest that the size of CMEs (of the most powerful ones) in the 19th cycle was, in general, less than the size of coronal ejections in the later cycles.

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