Database capabilities for studying Forbush-effects and interplanetary disturbances

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Abstract. For a comprehensive study of Forbush-effects and their relationship to solar, interplanetary and geomagnetic disturbances, IZMIRAN researchers created (and continuously replenishes) a unique database of transient phenomena in cosmic rays and the interplanetary environment. In it, variations in the density and anisotropy of cosmic rays are combined with solar, interplanetary and geomagnetic parameters. The database includes a large number of different characteristics for about 7500 Forbush-effects, covering more than half a century of observations (1957-2017). In the work presented, some of the features of this tool are demonstrated.

1. Introduction
One of the actual fundamental tasks of solar-terrestrial physics is the advance prediction of space weather parameters and assessment of its influence on various natural, technological and biological systems located both on the Earth or in the near-earth space and at any point of the solar system [1]. The space weather condition is primarily determined by solar activity. The Sun is responsible for creating recurrent (high-speed streams from coronal holes) and sporadic (coronal mass ejections) disturbances of the interplanetary medium. Objects located in near-Earth space are most affected by influence of such disturbances, since the atmosphere is practically absent (or absent at all) and the geomagnetic field is weakened. During such disturbances on space objects, a number of problems can be observed, for example: failure of the spacecraft radio-electronic equipment due to the accumulation of surface and volume charge; single failures in the spacecraft radio electronic equipment due to damage by high-energy particles of solar and galactic origin [2]; violations in the operation of optical, magnetic and other sensors that cause failure in the performance of specified functions; deterioration and loss of communication (at any frequencies); a significant increase in the error of GPS and GLONASS systems; change of ballistic characteristics of orbits due to heating of the upper atmosphere and increase of its density and, as a consequence, loss of altitude and disorientation, unpredictable approach and possibility of collision with other space objects and elements of space debris, possibility of unauthorized uncontrolled descent from orbit; radiation impact on astronauts, etc.

Moreover, in addition to the space segment, space weather also affects earth-based objects, for example: deterioration and loss of communication between ground stations and controlled spacecraft.
of the space complex [3]; defeat of ground infrastructure objects when space debris elements fall to the Earth; appearance of induced currents in long conductors capable of causing accidents in power grids, underwater cables, pipelines and railway automation systems [4]; radiation impact on crews and passengers of flights (especially transpolar flights); failures in communication systems and avionics equipment; deterioration health of the people with cardiovascular diseases, etc.

Thus, it is clear that the impact of space weather on our daily lives cannot be underestimated. It is necessary to be able to predict this impact qualitatively, and then to consider, using earlier gained experience.

In general, forecasting of space weather condition reduces to forecasting solar and geomagnetic activity, as well as the fluxes of various particles (galactic and solar cosmic rays, relativistic electrons of magnetospheric origin, etc.). A prediction model for a given parameter can be constructed using a different approach. For example, it is possible to obtain the result theoretically by solving complex systems of equations describing the solar activity, transfer and transformation of the corresponding disturbances in interplanetary space and the interaction of magnetic inhomogeneities with the Earth's magnetosphere. But this way is very difficult and, often, because of the complexity of the overall picture of interactions, impossible even in the simplest cases.

Another, more simple way is to obtain relations between different parameters describing the space weather based on statistical, comparative or regression analysis. Moreover, the more events will be considered, the more accurately you can determine this connection. Examples of such studies, based on the analysis of a large number of events, will be considered further.

2. Data and methods
An unique database FEID (database of Forbush-effects (FEs) and Interplanetary Disturbances) was created and continuously updated by the IZMIRAN staff for comprehensive study of solar, interplanetary and geomagnetic disturbances [5-7]. It combines variations in the density and anisotropy of galactic cosmic rays with solar, interplanetary, and geomagnetic parameters. Galactic cosmic rays are taken as the basis of this tool. The fluxes of these ultra-energetic particles give us information about the magnetic inhomogeneities that they penetrate. In the database, cosmic rays are represented by the results of a global survey method according to the data of the world neutron monitors network for rigidity of 10 GV. Information on the solar wind is taken from the OMNI database (http://omniweb.gsfc.nasa.gov), geomagnetic activity data is taken from WDC Kyoto (http://wdc.kugi.kyoto-u.ac.jp) and GFZ Potsdam (ftp://ftp.gfz-potsdam.de).

Currently, FEID includes about 7500 events covering more than half a century of observations (1957-2017). Each event is described by more than one hundred parameters. It is safe to say that this is the largest and most complete database of interplanetary disturbances in the world.

Based on the database described above, a directory with similar information was developed and posted to the Internet (http://spaceweather.izmiran.ru/rus/dbs.html). In the scientific community you can find a lot of publications and dissertations, which are based on information about interplanetary disturbances, taken from this database.

3. Examples of use of information from FEID
The described database of transient phenomena in cosmic rays and interplanetary medium is not only a storage bank for information on interplanetary disturbances, but also a convenient tool for its processing, allowing to perform various types of analysis of these data (statistical, comparative, regression, etc.), giving the requested information in numerical and graphical forms. Several examples of using the database are given below.

3.1. Study of Forbush-effects with a sudden and gradual onset.
Isolated events (3455 events participated in the analysis) were divided into two groups in paper [8]: $S$ – events that were accompanied by the arrival of the shock wave to the Earth (with SSC), and $NS$ – events that were not accompanied by SSC (noSSC). The analysis revealed that these groups differ
from each other not only quantitatively, but also qualitatively (figure 1 a-c), for example, in the structure of the disturbances. And more powerful events, on average, were in the S-group.

The obtained results show that different mechanisms of cosmic ray modulation predominate in the selected groups. The events of the S–group are largely due to coronal mass ejections, while a significant part of the events of the NS-group are due to high-speed streams from coronal holes.

Figure 1. Distributions of FEs magnitude in groups with SSC and without SSC (a); a schematic representation of the average FEs in the groups S and NS (b); the dependence of the FEs magnitude on the Ap (c).

3.2. Relationship between Forbush-effect parameters and the heliolongitude of solar sources

Forbush-effects from the FE ID database confidently identified with the corresponding solar source were analyzed (334 events) in [9]. All events were divided into five sectors.

Figure 2. Dependence of the FE magnitude and geomagnetic activity (Ap) on the solar source longitude (□ and ◊ – observable results; o – calculated with accounting of the full number of events) (a); behaviour of the cosmic ray density and vector (daily) anisotropy during FEs caused by: a eastern source (b), the source from the region of central heliolongitude (c), the source from the western group (d).
It was shown that solar sources with different heliolongitudes have different effectiveness of creating Forbush-effects and geomagnetic storms (figure 2a). In addition, it was found that, the behavior of the anisotropy of galactic cosmic rays is significantly different, depending on the longitude of the solar source (figure 2b-d). Thus, having information only about galactic cosmic rays and being able to decipher it correctly, it is possible to determine a set of parameters of interplanetary disturbances.

4. Conclusion
Analysis of a large number of events allows us to obtain statistical relationships between different parameters characterizing the state of space weather. This makes it possible to estimate with a certain degree of probability the effect of space weather on space and ground-based objects. The database of transient phenomena in cosmic rays and the interplanetary medium created by IZMIRAN stuff is not the only development of this group of scientists. There are a number of databases that cover a large time interval and contain many parameters: geomagnetic disturbances (1868-2018, 103 parameter), solar activity (1975-2018, 64 parameters), cosmic ray variations (1957-2018, 45 parameters), coronal mass ejections (1996-2018, 25 parameters), coronal holes, etc.

Using these databases, statistical regularities have been obtained, that form the basis for the developed models for the realization of short, medium and long-term forecasts for each of the space weather directions. Continuous updating of information and timely recalculation of dependencies between parameters makes it possible to always keep databases and models up-to-date. And the result of such analysis is used in the daily work of the IZMIRAN Space Weather Prediction Center to provide its customers with the necessary information for 20 years (since 1998).

Acknowledgments
The work was performed using the instruments of UNU "SCL Network". The work was partially supported by RFBR grant № 17-02-00508 and RSF №15-12-20001. We are also grateful to all the staff of the cosmic ray station network http://cr0.izmiran.ru/ThankYou.

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