DIFFERENT SPACE WEATHER EFFECTS IN MALFUNCTIONS OF THE HIGH AND LOW ORBITAL SATELLITES

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ABSTRACT

We present preliminary results of the Project of EU INTAS-00810, which is aimed to improve the methods of safeguarding satellites in the Earth magnetosphere from the negative effects of space environment. Malfunction data on “Kosmos” series satellites in the period 1971-1999 are combined in one database together with similar information on other spacecrafts. This database contains, beyond the malfunctions information, various characteristics of space weather: geomagnetic activity indices (Ap, AE and Dst), fluxes and fluences of electrons and protons at different energy, high energy cosmic ray variations and other solar, interplanetary and solar wind data.

A comparative analysis of distribution each of these parameters relatively satellite malfunction was carried out for the total number of malfunctions (about 6000 events), and separately for the high (~5000 events) and low (about 800 events) altitude orbit satellite as well. It was found no relation between low and high altitude satellite malfunctions. The majority of malfunctions of “Kosmos” satellites occurred at the same time with failures on the other low altitude orbit spacecrafts, and they seemed to be related with space weather parameters. Daily number of the satellite malfunctions averaged by epoch method around the SSC and proton event onsets for high (>1000 km) and low (<1000 km) altitude orbits revealed a big difference in a behavior.

The analysis of the total number of satellite malfunctions (about 6000 events) showed well pronounced half-year variation with maxima in spring and autumn. The shape and phase of the half-year wave in the malfunction number looks similar to the seasonal wave in Ap-index of the geomagnetic activity, but the percentage amplitude is bigger. The mean value of spacecraft failed in certain days, is correlated with the geomagnetic and cosmic ray activity indices. This research is partly supported by the grant EU INTAS-00810.

DATA CLEANING AND FORMATION OF DATABASE

Analysis of possible reasons for every case of orbital satellite malfunction was performed. Excluding of malfunctions due to construction errors, errors of operating personnel, low-quality ground spacecraft presetting before launch, low-quality ground service etc. was done. About 50% of the total number of anomalies were identified as not related to man or technological factors. It was supposed that the data free from these malfunctions might be related to space weather and were taken for correlation analysis. We used following parameters for correlation analysis:


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1) parameters of solar activity (sunspot numbers, 2800 MHz (10.7 cm) solar flux F10.7);
2) parameters of geomagnetic activity (Ap, AE and Dst – indices);
3) galactic cosmic ray activity index, determined by NM data;
4) proton (>10 MeV and >60 MeV) and electron (>2 MeV) fluxes;
5) parameters of spacecraft mission reliability: normalized (relative) frequency of anomalies \( R = \frac{M}{N \cdot t} \), where \( M \) - all anomalies registered in an certain time interval, \( t \) - time interval, and \( N \) - number of satellites in operation (this normalized parameter \( R \) defines number of malfunctions \( M \) in one day per one satellite);
6) average statistical satellite lifetime \( T_{av} = \frac{\sum_{i=1}^{n} T_i}{n} \) before the satellite loss.

**MAIN RESULTS**

In Fig. 1 are shown situation with satellite malfunctions and behaviors of some related parameters in October 1989.

During October, 17-25 we have 69 satellite malfunctions as whole, but the only 2 of them were on low altitudes (both on “Kosmos” satellites). In this period we see several proton enhancements, 3 GLEs (19, 22 and 24 October), big Forbush-effects, strong geomagnetic storms, including severe (Kp=8+) storm on 20-21 October.

In Fig. 2 is shown the situation in April-May 1991. It can be seen a majority of satellite malfunctions coincides with period of the strong geomagnetic storm magnetic storm accompanied with a great Forbush decrease according to neutron monitor world-wide network (CR intensity at 10 GV). In this period was also a great FEP enhancement of several order increasing of high-energy electron flux.
Fig. 2. Satellite malfunctions in April-May 1991. Upper panel – cosmic ray activity near the Earth: variations of 10 GV cosmic ray density; solar proton (> 10 MeV and >60 MeV) and electron (> 2 MeV) fluxes. Lower panel – geomagnetic activity: Kp- and Dst-indices. Vertical lines on the upper panel correspond to the malfunction moments. “Kosmos” satellites are marked.

In Fig. 3 are shown daily numbers of satellite malfunctions for high (> 1000 km) altitudes and low (< 1000 km) altitudes.

Fig. 3. Daily numbers of satellite malfunctions for high (> 1000 km) altitudes and low (< 1000 km) altitudes.
In Fig. 4 is shown an important fact, that there are no real relation between low- and high-altitude satellite malfunctions (correlation coefficient smaller than 0.01).

**Fig. 4.** Daily numbers of low satellite malfunctions versus the same for high altitudes

Let us consider in more details data on soviet Kosmos satellites. These satellites were 49 single-type low Earth (LEO) orbit satellites with orbit inclination of 74°, circular orbit at about 800 km. During 1971-1997 were registered 459 cases of anomalous performance. During the studied period at least two of Kosmos satellites were present simultaneously in the magnetosphere. On the average, about 9 anomalies that may be related to space weather were observed in each satellite, though for certain satellites this number was much bigger. Kosmos data were 7% of the total data in our data-base, but In the low-altitude subset, Kosmos anomalies came to 25%. Moreover, majority of days with low-altitude anomalies were provided by Kosmos data. In Fig. 5 is shown the long-term variation of the relative frequency of anomalies (per day and per one satellite) in Kosmos satellites during more than two solar cycles.

The dependence of Kosmos anomalies relative frequency from the level of geomagnetic activity (index AE) is shown in Fig. 6. It can be seen that with increasing of geomagnetic activity the frequency of Kosmos anomalies increases in many times (from smaller than 0.01 up to 0.3 anomalies per day and per one satellite).

**Fig. 6.** The dependence of Kosmos anomalies frequency from the level of AE index geomagnetic activity.

The influence of geomagnetic storms with sudden commencements on low-altitude satellites and high-altitude satellites are shown in Fig. 7 and Fig. 8, respectively. Fig. 7 and 8 show the...
big difference in response of high-altitude and low-altitude satellite malfunctions to geomagnetic activity. These plots are obtained by epoch method with sudden storm commencement (SSC) as the zero-day.

**Fig. 7.** The low-altitude satellite malfunction frequency (malfunctions per day per satellite) averaged by the epoch method relative to SSC days. 0 – day of sudden storm commencement. Magnetic storms with maximal Ap ≥ 50 nT were selected.

**Fig. 8.** The same as in Fig. 7, but for high-altitude satellite malfunction frequency.

Our data show that malfunctions of high-altitude as well as low-altitude satellites are not independently, but their distribution in time show that mainly they occurred by groups with length of few days (see Fig. 9).

**Fig. 9.** The mean distribution of the satellite malfunctions (events) relative to day of each malfunction for low (<1000 km) and high (>1000 km) altitudes separately.

The Fig. 9 demonstrates the clusterization of malfunctions. It means that the satellites malfunctions occur often by series. It is true as for high altitudes so for low altitudes, but the clusterization is more pronounced for low altitude malfunctions, on low altitudes the series are more abundant and more prolonged. The connection with Cosmic Ray Activity (CRA) index (Belov et al., 1999) is shown in Fig. 10 for high-altitude satellites (for low-altitude satellites...
in the frame of statistical errors we did not find any connection with CRA). From Fig. 10 can be seen an important feature: the increasing about 6 times of malfunction frequency occurred about one day after CRA increasing.

**Fig. 10.** The connection of malfunctions frequency for high-altitude satellites with Cosmic Ray Activity (CRA) index.

**CONCLUSIONS**

Database, comprising the orbit anomalies of Soviet/Russian satellites ("Kosmos" series) together with other spacecraft malfunctions and related space weather parameters (solar activity indices W, F10.7, geomagnetic activity indices Ap, AE, Dst, cosmic ray activity indices and proton and electron fluxes), is developed.

Daily number of anomalies of low altitude (<1000 km) satellites does not show correlation with the anomalies of high-altitude spacecraft.

The "Kosmos" data were “cleaned” from malfunctions identified as ones due to construction errors, errors of operating personnel, low-quality ground spacecraft presetting before launch, low-quality ground service etc. These anomalies come to about 50% of the total number of anomalies.

"Kosmos" malfunctions occurred with different time delay (up to 4-5 days) after the space weather disturbance.

"Kosmos” reliability decrease with increase of solar and geomagnetic activity. Relative number of malfunctions increase in solar maximum and decrease in solar minimum. Average satellite lifetime show a tendency to increase during solar activity minimum.

"Kosmos” anomalies depend on space weather: number of satellite anomalies, normalized per day and per one satellite, increase with the increase of all considered solar and geomagnetic activity indices.

The increasing about 6 times of high-altitude satellite malfunction frequency about one day after Cosmic Ray Activity (CRA) index increasing can be used for forecasting.

In the near future we intend to improve the database substantially. We plan:
1. To enlarge the database with including new satellite anomalies (in the first turn from Soviet/Russian satellites);
2. To include the additional space weather parameters (electron fluxes etc);
3. To advance the software with developing new subroutine for new kind of plots and statistical analysis;
4. To investigate the relations of the satellite malfunction frequency to the different geo- and heliophysical characteristics;
5. To distinguish groups of satellite anomalies with specific response to the space weather manifestations;
6. To construct the multi-parameter models for relation of space weather state to the satellite malfunction probability for low altitude and high altitude satellites separately.

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**REFERENCES**


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