The relation between malfunctions of satellites at different orbits and cosmic ray variations

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Abstract

Satellite anomalies (1971–1994) were analyzed in the search for possible influence of different space environment parameters. The database was created by combining malfunction information and various space weather characteristics. It was found, that relation of the satellite malfunctions to the cosmic ray variations is different for various satellite orbits. This was used in the elaboration of the malfunction frequency models.

1. Introduction

Space weather effects and associated satellite anomalies essentially depend on the satellite characteristics, in particular, on the type of orbit [2,5]. In this paper we analyse the relation between satellite malfunctions (for different satellite orbits) and different geo- and heliophysical parameters, with the principal concern to the cosmic ray characteristics near Earth. The satellite malfunction data and different characteristics of space weather were combined into a database. The main contribution of satellite malfunctions was from NGDC satellite anomaly database [7]. Another part of data was from "Kosmos" satellites (circular orbit at 800 km altitude and 74° inclination). The mmajority of 1994 year anomalies were taken from [6]. The satellite characteristics were added from different Internet sources. We have ∼300 satellites and ∼6000 anomalies in our database. All satellites were divided in the groups according to their orbit altitude and inclination. In Fig. 1 each orbit is presented by corresponding mark. Sometimes, one point represents numerous satellites with the very close orbits, as majority (> 100) geostationary satellites and 49 "Kosmos" spacecrafts. We can use any altitudinal boundary within the wide range (1500–15000 km) for altitude separation. Inclination boundary 58° was chosen to separate "shuttles", which are too specific to be analyzed together with the other satellites. As a result, four groups were obtained, with essentially different physical conditions on the orbits: HL (high altitude — low inclination), HH (high altitude — high inclination), LH

pp. 4213–4216

(low altitude — high inclination) and LL (low altitude — low inclination). HL group with all GEO satellites is the most abundant. LL group is too small to be discussed here.

2. Results and Conclusion

Satellite malfunctions are very irregularly distributed along the time. In some days tens malfunctions are recorded on several satellites. One famous period with high frequency of malfunctions was 19–26 October 1989 [2,4], when the magnetic storms, including the severe one on 20–22 October, were registered. However the satellite malfunctions in this period correlate better to 3 huge proton enhancements, observed also as GLE (19–20, 22–23 and 24–25 October). The absolute majority of anomalies were recorded in HH (high altitude — high inclination) group, just at the orbits with maximal effect of solar cosmic rays. Another sample of high frequency satellite malfunctions is presented in [4] (the period of 28 April–6 May, 1991). In these days there was a severe magnetic storm, no proton enhancements but big fluxes of relativistic electrons. The malfunctions were entirely absent in HH group, which played the main role in previous example. Only a few malfunctions were in GEO group and absolute majority of anomalies happened at low altitudes. These two examples illustrate the relation between satellite malfunctions and cosmic ray events, and essential difference between various satellite groups. In fact, there is no correlation between variations of the satellite anomaly frequency at high and low altitudes not only in these examples, but over the whole database.

We compared variations of daily frequency of the satellite anomalies with the different characteristics of solar, interplanetary, geomagnetic and cosmic ray activity. In proton enhancements the frequency of anomalies arises significantly at the high altitudes during two first days, with the greater is proton flux the bigger is an increase of anomaly number (Fig. 2). This effect is especially big in the HH group. The electron flux variations are more important for HL (GEO) and LH groups. Fig. 3 is obtained by the epoch method with a day of every malfunction as 0-day. Mean fluence of the relativistic electrons is maximal in the malfunction day. It is important, that electron fluence arises significantly some days before the malfunction. Such a behavior is characteristic not only for electrons, but for geomagnetic activity and some other indices as well. We used this peculiarity to elaborate models of the satellite malfunction frequency. Fig. 4 shows a difference in cosmic ray effect on malfunctions for different orbits. Proton fluence is much higher in HH group than in other groups. LH group is mainly electron-dependent, and HL group may be considered as mixed one.

We checked a relation between different space weather parameters (> 30 in total) and their combinations and satellite anomalies at different orbits in 1987–1994. We used the parameters for anomaly day and for several preceding

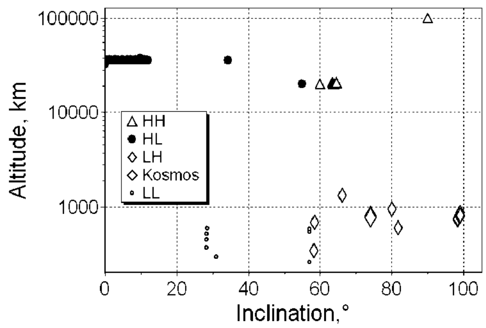

Fig. 1. Altitude-inclination distribution of the satellite orbits.

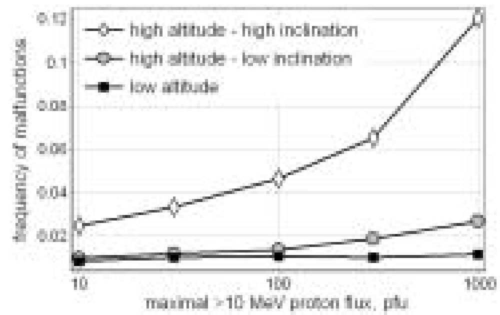

Fig. 2. Mean anomaly frequency in 2 first days of proton enhancement at different orbits in dependence on maximal >10 MeV proton flux.

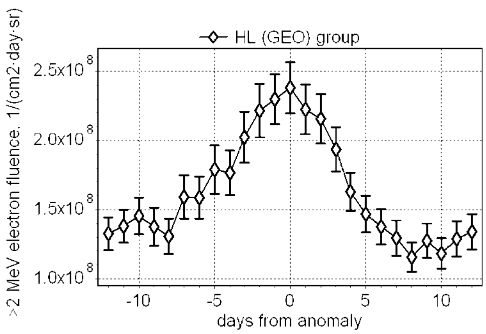

Fig. 3. Electron fluence in 1987–94 obtained by the epoch method. 0-day is the satellite anomaly day.

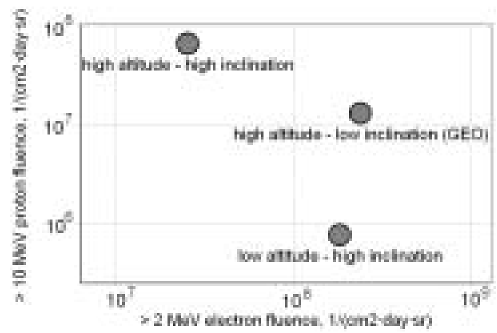

Fig. 4. Mean proton and electron fluencies in the anomaly day (1987–1994).

days and simple linear regression (with power law dependence for the proton and electron indices). Some peculiarities of models, simulated frequency of the satellite malfunctions by means of 5–8 different indices, are presented in Table. Index sequence and letter size in the names reflect the contribution of this index to the model.

Table 1. Models of the satellite malfunction frequency.

Group	HL	HH	LH
Parameters of model	**e2** p100, p60d sf, Ap, Vsw Bz, da10	p60d, p100 Eak SSN365, Bznsum	**e2** CRA AE, sf, Ap Bz, Vsw

Explanations to the Table: e2 and p100 — > 2 MeV electron and > 100 MeV proton fluencies (GOES); p60d — daily flux of > 60 MeV protons (IMP8); Ap and AE — indices of geomagnetic activity, Eak — estimation of energy incoming to the magnetosphere supposed by Akasofu [1]; Vsw — solar wind velocity; Bz — daily mean Bz-component of IMF, Bznsum — sum of negative values Bz-component; SSN365 — yearly running averaged sunspot number; CRA and da10 — cosmic ray activity indices [3], obtained from neutron monitor network data. Seasonal factor sf (semi-annual variation with maxima close to equinoxes) was used as one of the independent parameters.

The models describe the relation of the satellite malfunction frequency to the space weather parameters in rather complex way and they differ significantly for different satellite groups. They combine the geomagnetic activity indices, solar wind and some other parameters. However, cosmic rays give the main contribution in all groups. The characteristics of the obtained models allow them to be used for the satellite malfunction forecasting.

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3. References

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