The Features of Change of the Drag Perturbations of Artificial Satellite Orbits during Extreme Developments of Solar Activity in years 2003-2004

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In this paper the movement of the artificial satellites of the Earth on low orbits is analyzed which are subject to resistance of a rarefied atmosphere. Temperature and density of terrestrial atmosphere at height of 200-800 km vary over wide range under influence of external conditions. The changes of solar activity are compared to variations of satellite braking (atmospheric drag). In spite of the fact that unequivocal dependence of the atmosphere density behavior from the considered physical factors of solar activity is not present, the attempt is done to find the characteristic periods in these processes. Some periods of fluctuation of an atmosphere density are revealed which can be harmonics of the basic period close to 27 days. Fluctuations of density with the period about 27 days have two close components, which reason is not quite clear. Probably, they are caused by rotation of the Sun and lunar tidal wave in the Earth's atmosphere.

Introduction

The Earth constantly suffers the influence of the Sun. Space weather within the interplanetary space has various influence on the Earth's weather and many other processes on the Earth.

Earth's atmosphere (especially its upper part) is very dynamical system, and it also demonstrates very strong dependence upon the state of the near-Earth's space, and, first of all, upon the solar activity. This is developed in the variation of the temperature and chemical composition, ionization stage and mean density of the atmosphere at a given altitude. Mechanisms of this interactions and perturbation transfer from the upper to inner layers of the Earth's atmosphere are quite complicated and apparently require further investigation.

In this paper we make an attempt to analyze the observable facts concerning the changes in satellites orbits that are caused by changes in the density of the neutral component of the Earth's atmosphere at the appropriate altitudes. From about 9000 catalogued satellites more than 3200 have their perigee orbits lower than 800 km over the Earth's surface, about 2250 of them have this parameter lower than 700 km, thus, their movement is significantly influenced by the interaction with Earth's atmosphere.

The known Earth's atmosphere models Jacchia, CIRA, MSIS etc. more or less adequately take into account the diurnal and seasonal variations of the atmospheric parameters. Nevertheless, nowadays an accuracy of the atmospheric density predictions from the best models is not enough satisfactory, while the relative errors of the mean values reach sometimes from 10-15% to 25-40% at the altitudes from 300 to 800 km. In some periods these errors achieve 70% and more [1, 2]. The posterior analysis of the big ensemble of satellites enables one to calculate empirical corrections to the atmosphere density that minimizes errors of approximation up to 10-15%. Nevertheless, even with this, the mean square errors of estimates for the life-time of low-orbit satellites are at the level of a few percents, while individual estimates have errors of about 30-35%. Such situation requires a further improvement of the dynamical models of the Earth's atmosphere that take into account the solar activity and space weather.

Observations

For our analysis we selected 21 satellites (from them 10 satellites have almost circular orbits, and 11 satellites have orbits with $e > 0.1$) with the perigee value in the region 300-750 km. The list of the satellites of interest and the basic parameters of their orbits are given in Table 1. An initial material used in our analysis was the measured values of the frequency derivation of the satellite orbital motion (i.e. dn/dt, where n is a "mean motion" or number of the satellite revolutions during one day). This value characterizes the rate of the energy loss and decrease of the satellite orbit due to deceleration in atmosphere. It is clear, that at the high altitudes, where atmosphere density is quite low, the movement of the big artificial objects will be decelerated more effectively because of the higher ratio S/m (S is the cross-section, m is the mass of object).

Fig. 1 shows daily averaged changes in ballistic coefficient B, that can characterize the relative changes dn/dt during 16 October 2003 – end of 2004 for some satellites. Fig. 1a demonstrates deceleration curves for two satellites situated at the very extended orbits. In this case satellites are effectively decelerated in that point of their orbits when they are closer to the Earth's surface. Perigee altitudes are about of 200-240 km, atmosphere density at this altitude is rather high and deceleration is efficient. This results in a good correlation of the curves of different satellites. The upper curve shows a seasonal periodicity with period of about 65-75 days. All curves also show more high-frequency modulation. Such a modulation is well seen on the deceleration curves for those satellites that have almost circular orbits (Fig. 1b). In this case satellite is decelerated practically at any part of its orbit and this effect is integrated, thus one can consider the global effect of the satellite interaction with the Earth's atmosphere at a given interval of altitudes.

One can note some sharp increase of the deceleration synchronous for all satellites that could be connected with some external impact on the Earth's atmosphere, and subsequently on the satellite motion. Nevertheless, the degree of such interaction differs for different satellites. Comparison with data on the solar activity shows that perturbation of the satellite motion coincides with an increased solar activity. Especially such a correlation was clearly developed in October-November 2003 and at the end of 2004. In these periods deceleration for all the satellites became maximal [3]. Thus, there is a close correlation between the level of the solar activity, heating degree and thermal "expansion" of the Earth's atmosphere. However, the coefficient of correlation between values of satellite braking and measured physical characteristics in near-Earth space shows the absence of unequivocal dependence (Table 1).

TABLE 1

List of the satellites, their orbital parameters and correlation coefficients of satellite drag with the factors of solar activity

NORAD catalog number	*i*, incli-nation, deg	*e*, eccen-tricity of its orbit	Height, Perigee - apogee, km	Correlation with Radio Flux 10.7cm	Correlation with Wolf Number	Correla-tion with X-ray	Correlation with Proton E >1 MeV	Correlation with Proton E >10 MeV	Correlation with Middle-Latitude Ap-index	Correlation with Planetary Ap-index
27551	97.2	0.0	378 - 513	0.6	-	-	-	-	-	-
27700	97.3	0.0	456 - 543	0.6	-	0.51	0.57	0.64	0.52	-
25860	97.8	0.0	652 - 654	0.58	-	0.52	0.57	0.64	0.61	0.54
13552	82.5	0.0	544 - 562	0.62	-	0.54	0.56	0.59	0.51	-
11332	81.2	0.0	422 - 450	0.56	-	-	0.5	0.57	0.5	0.51
12054	65.0	0.0	464 - 602	0.62	-	-	-	0.55	0.54	-
25544	51.6	0.0	368 - 376	0.52	-	-	-	0.53	-	-
25064	35.0	0.0	505 - 511	0.62	-	0.56	0.6	0.7	0.5	-
21694	31.3	0.0	402 - 414	-	-	-	-	0.5	-	-
23757	23.0	0.0	495 - 506	0.69	0.55	0.65	0.54	0.61	-	-
19822	75.1	0.3	267 - 5974	-	-	-	-	-	0.53	0.55
23191	70.0	0.1	353 - 1900	0.53	0.51	-	-	0.5	-	-
00829	60.8	0.3	409 - 6280	-	-	-	-	0.53	-	-
22277	34.9	0.27	241 - 5007	0.51	-	-	-	-	-	-
22781	34.6	0.24	212 - 4230	-	-	-	-	-	-	-
20299	34.1	0.26	195 - 4607	-	-	-	-	-	-	-
12908	26.3	0.16	224 - 2666	-	-	-	-	-	-	-
22788	26.9	0.35	243 - 7500	-	-	-	-	-	-	-
12069	26.1	0.2	244 - 3500	-	-	-	-	-	-	-
12497	24.0	0.4	300 - 8990	-	-	-	-	0.56	-	-
12445	23.6	0.44	328 - 10800	0.65	0.5	0.57	0.58	0.57	-	-

Analysis of frequency spectra

To analyze such a correlation we considered frequency spectrum of the satellite deceleration curves and then compared it with frequency spectra for different parameters that characterize the solar activity. Fig. 2 shows frequency spectra (periodograms) of the satellite deceleration for those satellites that are situated at the high-elliptic orbits with low perigee (Fig. 2a) and at low circular orbits (Fig. 2b). X-axis is a frequency in day-1, the corresponding period values (in days) are given in the upper part of the figure. Y-axis gives the relative power density of a given frequency in the spectrum. The most expressed peak in the middle region is presented for all the satellites at P_1 ≈ 27d. Another clear peak is situated around P_3 = 8.9d, it is also seen for all satellites. For the circular orbits the peak at P_5 = 5.3d is clearly seen. One can assume that these peaks belong to the third and fifth harmonics of the fundamental period P = 26.66 days.

This period is really presented in the deceleration curves of satellites as one of the components around peak P_1 = 27d. Second component corresponds to P = 29.6d that is very close to synodic period of the Moon P_{Syn} = 29.53d.

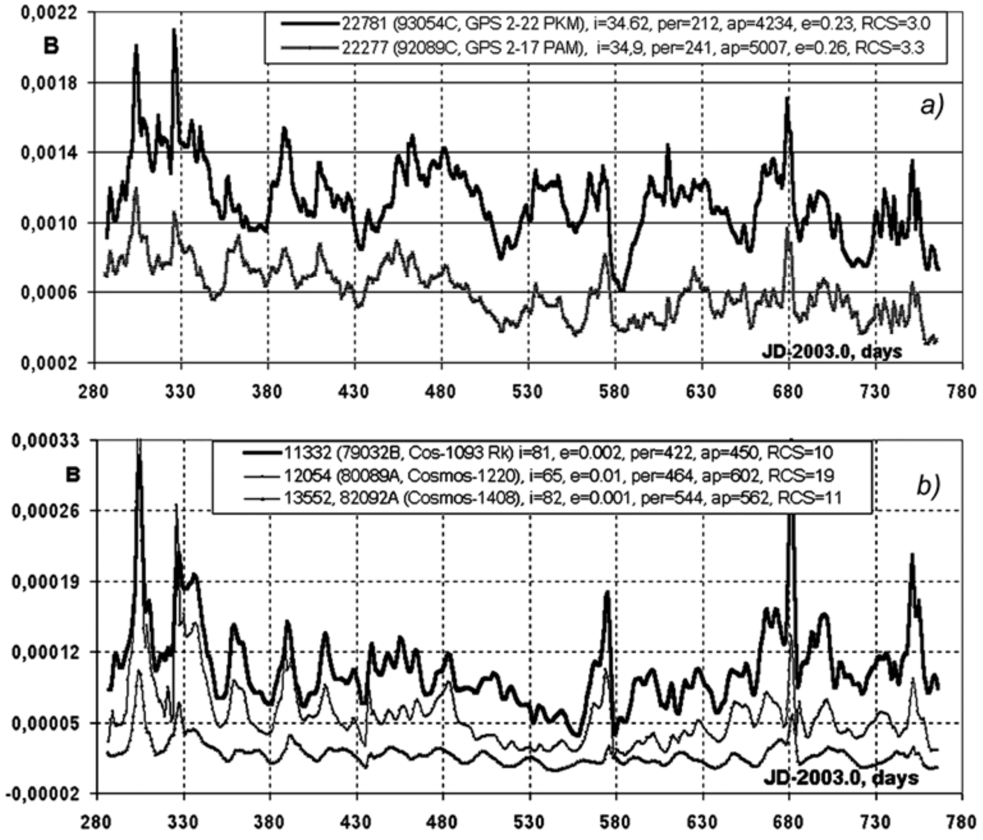

Fig.1. Change of drag coefficients of the Earth's satellites moving on high-elliptic orbits (a) and on circular orbits (b).

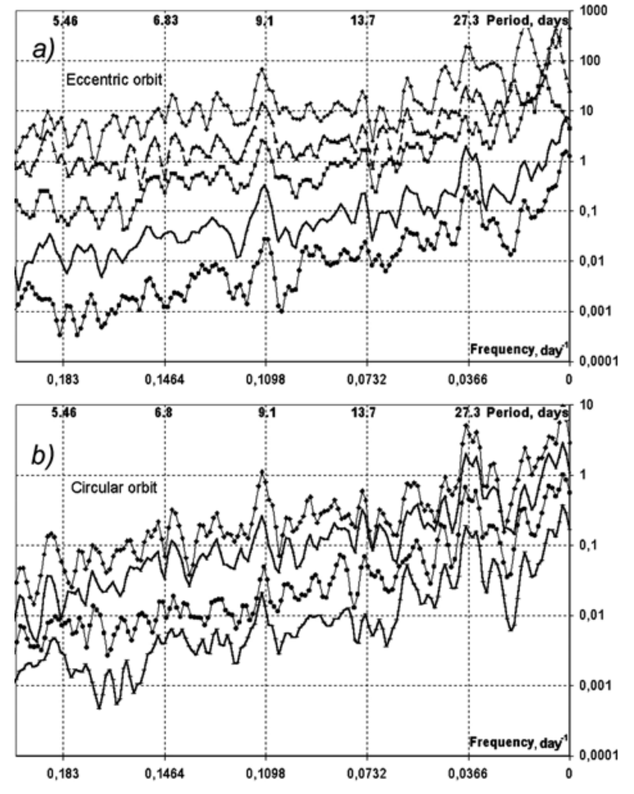

Fig.2. Frequency spectra of variations of the satellites drag in terrestrial atmosphere.

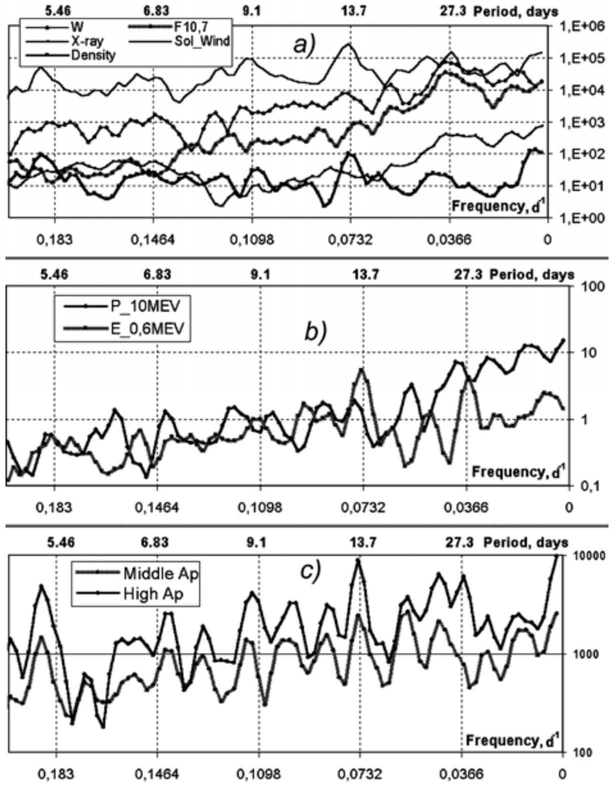

Fig.3. Frequency spectra of variations of the physical factors which is caused by solar activity.

Fig. 3 presents the frequency spectra of the parameter change that characterize the solar activity – Wolf numbers, solar radio-emission flux at 10.7 cm, X-ray flux, velocity and density of the solar wind (Fig. 3a), the flux of protons with E > 10 MeV and electrons with E > 0.6 MeV (Fig. 3b), and change of the low- and high-altitude geomagnetic indexes Ap (Fig. 3c). It should be noted that these parameters do not show a clearly expressed periodicity near to P = 27d. Only in the spectrum of electron flux such a frequency is well localized, although the peak at 13.5d is more powerful. This period is also presented in the plots of velocity and density of the solar wind, as well as in spectrum of the high-latitude geomagnetic index. Wolf numbers, radio-emission at 10.7 cm and X-ray flux show only loose periodicity with P ≈ 27d. Velocity of the solar wind correlates quite well with high-altitude Ap index with well expressed periodicity of 5.3d.

Thus, there is a complex picture of an interaction between the external factors connected with solar activity and condition of magnetosphere and upper Earth's atmosphere. To derive the reliable values of the periodic components in the spectra of the solar activity parameters it is necessary to organize the long-term observations. Nevertheless, total change of the solar activity level by a factor of ten makes it difficult to perform a frequency analysis using the long time intervals.

The comparison of frequency spectra of the same satellites drag in 2004 and 2005 shows, that the basic details of a spectrum are kept, and we shall note on stability of the period P3 = 9 days, even in that time when the period P = 27 days is expressed poorly. The reason it is not clear, as it seems, that the external disturbance with the period 9 days is absent.

Conclusions and future work

Summarizing, all observed short-term increases of the satellite deceleration are caused by the solar activity. The moments of these increases correlate with various parameters of the solar and geomagnetic activity. An analysis of the data on deceleration observed for the low-orbit satellites show the presence of periodical components. Some of them, for instance, P = 17.2d and P = 14.8d correlate with the solar radio-emission flux modulation at10.7 cm, and therefore with the short-wave emission of the Sun. For some periods, e.g. P = 13.3d, 8.9d and 5.3d there is a correlation with density and velocity of the solar wind.

An analysis of the satellite deceleration is an effective method of the global probing of the Earth's atmosphere neutral component density at the altitudes 200-800 km, especially during extreme periods of the solar and geomagnetic activity. This is very important for elaboration of the dynamic model of the Earth's atmosphere that will take into account an influence from the Sun and space weather.

REFERENCES

[1] B.R.Bowman, "The Semiannual Thermospheric Density Variation from 1970 to 2002 between 200-1100 km", in: Proceedings of the Sixth US/Russian Space Surveillance Workshop (August 22-26, 2005), P. Kenneth Seidelmann (Ed.), St.Petersburg, VVM Co Ltd., 2005. http://lfvn.astronomer.ru/report/0000015/ssw_4_1/index.htm

[2] A.I.Nazarenko, V.S.Yurasov, "Atmospheric Density Correction Using Real Orbital Data", Report at the 17th International Symposium on Space Flight Dynamics, Moscow, June 2003.

[3] V.N.Ishkov, "The Sun and geomagnetic conditions in 2004", Odessa astronomical calendar, Odessa, 2005, pp. 176-188.