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THE CHANGE INDICES OF SOLAR AND GEOMAGNETIC ACTIVITY AND THEIR INFLUENCE ON THE DINAMICS OF DRAG OF ARTIFICIAL SATELLITE

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ABSTRACT. The time-frequency and multiple regression analysis of the orbital parameter characterizing the drag of satellites on circular and elliptical orbits with different perigees and orbital inclinations in the atmosphere of the Earth was being conducted in 23-24 cycles of solar activity. Among the factors influencing braking dynamics of satellites were taken: W – Wolf numbers; Sp – the total area of sunspot groups of the northern and southern hemispheres of the Sun, F10.7 – the solar radio flux at 10,7 cm; E – electron flux with energies more than 0,6 MeV и 2 MeV; planetary, high latitude and middle latitude geomagnetic index Ap. In the atmospheric drag dynamics of satellites, the following periods were detected: 6–year, 2.1–year, annual, semi-annual, 27–days, 13– and 11–days. Similar periods are identified in indexes of solar and geomagnetic activity. Dependence of the periods of satellites motion on extremes of solar activities and space weather conditions was conducted.

1. Introduction

The state of the upper atmosphere of the Earth depends on solar and geomagnetic activity. Solar and geomagnetic activity affects the atmosphere primarily by increasing its temperature and dencity. Variations in the density of Earth's atmosphere cause changes in altitude satellites. In this work, satellites are used as indicators of the impact of space weather on the upper atmosphere of the Earth [1, 2]. This work is a refinement, expansion and continuation of the work [5].

2. Observational data

For analysis were taken twenty five satellites with different inclinations. Among them: polar, middle–latitude and equatorial satellites. There are fifteen circle orbit and ten elliptic orbit satellites. Table 1 lists: numbers of satellites, periods of observations, inclination of orbits – i, eccentricity – e and the minimum and maximum distance from the surface of the Earth at perigee – r min and r max. Study satellites moved in unmanaged mode and the satellites: 27700, 00063, 00165 – burned in the atmosphere towards the end of the observation period. Observations of these satellites cover the declining phase of solar cycle 23 and the first half of solar cycle 24. It includes the rise phase and beginning of the maximum phase of solar cycle 24.

For the analysis the following indices were taken: W – Wolf numbers; Sp – the total area of sunspot groups of the northern and southern hemispheres of the Sun, F10.7 – the solar radio flux at 10,7 cm; E – electron flux with energies more than 0,6 MeV и 2 MeV; planetary, high latitude and middle latitude geomagnetic index Ap. Data of these indices cover time period from 2005 y. to 2014 y.

Variations of the B–star Drag Term [4] and five indices of solar and geomagnetic activity were studied in this article. Figure 1 shows an example graph of the change of the drag coefficient of the satellites: 27700, 00932 – in the investigated time interval.

Table 1.

Number of satellite	i	e	r min	r max
satellites with circular orbit				
06212 (2005-2012)	98.57°	0.00015	501 km	505 km
25860 (2005-2013)	98.57°	0.0002	647 km	650 km
27700 (2005-2012)	97.7°	0.005	441 km	517 km
01814 (2005-2014)	75.9°	0.00065	675 km	684 km
04139 (2005-2014)	74.03°	0.0006	685 km	692 km
03048 (2005-2014)	74°	0.00073	693 km	702 km
04579 (2005-2014)	73.99°	0.0009	689 km	703 km
04922 (2005-2014)	65.8°	0.0027	490 km	517 km
12054 (2005-2013)	65°	0.007	522 km	546 km
00397 (2005-2014)	58.3°	0.0016	613 km	621 km
00063 (2005-2014)	48.5°	0.0027	465 km	481 km
00165 (2005-2014)	47.9°	0.0013	540 km	549 km
06153 (2005-2014)	35°	0.00077	697 km	708 km
25064 (2005-2013)	34.9°	0.0007	498 km	502 km
23757 (2005-2013)	22.9°	0.0009	487 km	498km
satellites with elliptical orbit				
00932 (2005-2014)	81.3°	0.114	522 km	2307 km
00721 (2005-2014)	78.6°	0.11	592 km	2308 km
00829 (2005-2014)	60.8°	0.3	393 km	6273 km
00746 (2005-2014)	60.8°	0.31	399 km	6409 km
00082 (2005-2014)	38.9°	0.12	631 km	2503 km
00016 (2005-2014)	34.3°	0.2	649 km	4233 km
00005 (2005-2014)	34.2°	0.19	647 km	3841 km
00020 (2005-2014)	33.4°	0.17	505 km	3310 km
00011 (2005-2014)	32.9°	0.15	551 km	2968 km
00963 (2005-2014)	19.75°	0.21	265 km	5680 km

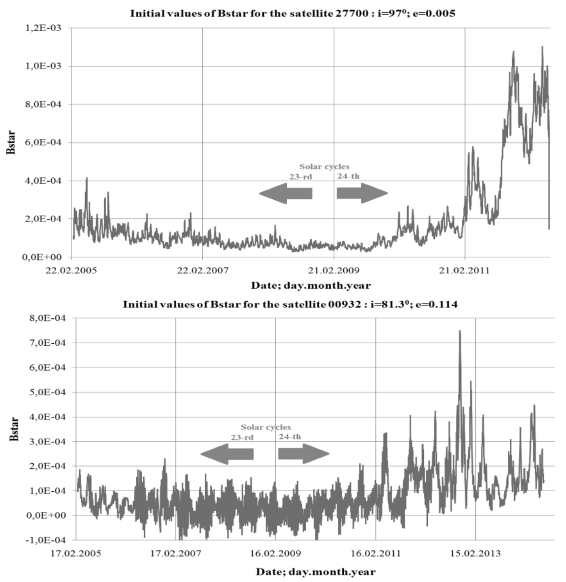

Figure 1: Initial values for polar satellites 27700 (circular orbit) and 00932 (elliptical orbit).

3. Methods of data processing

Packages of the statistical analysis were used for our estimations, which are: Origin Pro 8.1, STATISTICA 8 и PSELab.

For primary processing of data was used software package – Origin Pro 8.1. With it performed data interpolation by B–spline method and subtracted the trend (polynomial 3–rd order and using of frequency filtering). The primary processing of indices of solar and geomagnetic activity data wasn't used. These indexes are daily. After this package used statistical analysis software package STATISTICA 8. With this package were constructed periodograms for all satellites and indices of solar and geomagnetic activity. At the last stage was used the PSELab package for construction of the spectrograms. PSELab allows to carry out the spectral and spectral–time analysis of data.

For quantitatively characteristics of the mutual influence of the selected indices on the B–star Drag Term was used multiple correlation analysis in software package STATISTICA 8.

4. Results

Fig. 2 shows initial values for one of the indices of solar activity – the solar radio flux at wavelength 10,7 cm. Periodograms was built based on these initial values. This index is an indicator of ultraviolet radiation from the sun. It affects the change in the temperature and density of the upper atmosphere of the Earth.

The results of primary processing of B–star Drag Term are given in [5].

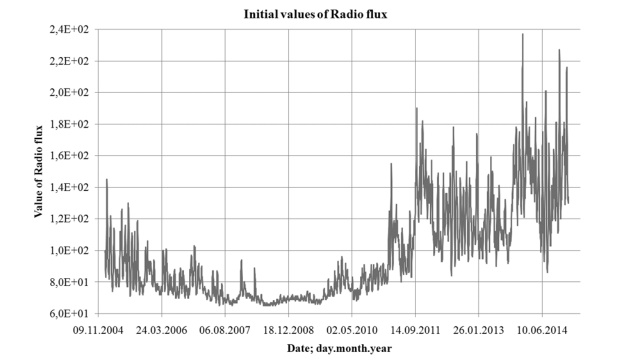

Figure 2: Initial values for index of solar activity the solar radio flux at wavelength 10,7 cm.

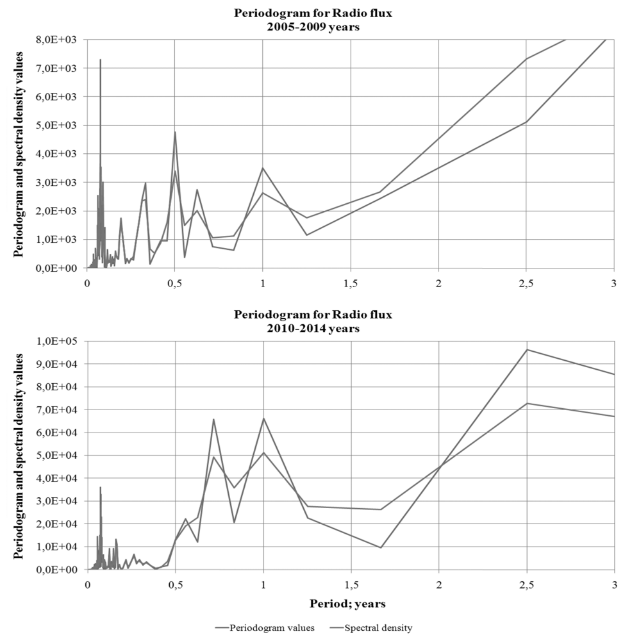

Figure 3: Periodogramm of initial values for radio flux at wavelength 10,7 cm.

4.1. Dividing the data into two intervals of observations

The study period of satellites and solar and geomagnetic indexes includes phase of declining of 23–rd solar cycle, phase of rise of 24–th solar cycle. State of solar and geomagnetic activity during these periods differ significantly.

That's why observations data were divided into two periods: 2005–2009 y. and 2010–2014 y. In STATISTICA 8, using Fourier analysis, we constructed periodograms for these intervals for B–star Drag Term and five indices of solar and geomagnetic activity. An example of periodograms is shown in Figure 3.

In the resulting periodograms, for indexes of solar and geomagnetic activity, for period 2005 – 2009 y. we obtained the periods:

1. For Wolf numbers: in years (for 2005 – 2009 y. does't exist); in months (6; 3,3; 1,7; 1,2); days (28,5; 25; 21,2; 17,1; 13,4; 11,1; 8,9).

2. For the total area of sunspot groups: in years (for 2005 – 2009 y. does't exist); in months (6; 3,8; 2,4; 1,6; 1,1); days (27,7; 23; 17,2; 13,5).
3. For the solar radio flux at 10,7 cm: in years (1); in months (7,5; 6; 4; 2,3; 1,1); days (27,7; 22,8).
4. For the electron flux with energies >0.6 MeV: in years (for 2005 – 2009 y. does't exist); in months (10; 7,5; 6; 3,8; 3,2; 2,5; 1); days (26,5; 13,4; 9; 6,7; 5,4).
5. For the electron flux with energies >2 MeV: in years (2,5); in months (7,5; 6; 5; 3,8; 3,2; 1,9; 1,5; 1,3; 1); days (26,5; 20,5; 16,2; 13,9; 9; 6,8; 4,5).
6. For the planetary geomagnetic index Ap: in years (1,3); in months (7,5; 3,8; 1,9; 1,4); days (26,9; 13,5; 9; 6,7; 5,4).

In the resulting periodograms, for indexes of solar and geomagnetic activity, for period 2010 – 2014 y. we obtained the periods:

1. For Wolf numbers: in years (2,5); in months (6,7; 1,9; 1,5); days (26,1; 23,7; 21; 17,2; 16; 15,2; 13,6; 9,6).
2. For the total area of sunspot groups: in years (2,7); in months (9,1; 6,4; 3; 1,9; 1,5; 1,1); days (28,1; 27; 25,9; 24,1; 20,4; 18,6; 15,3; 13,9; 6,9).
3. For the solar radio flux at 10,7 cm: in years (2,5; 1); in months (8,6; 3,2; 1,9; 1,8; 1,5); days (26,1; 20,3).
4. For the electron flux with energies >0.6 MeV: in years (1,7); in months (7,5; 5,5; 3,7; 2,2; 1,1); days (28,1; 14,5; 12,8; 9,2; 6,7).
5. For the electron flux with energies >2 MeV: in years (1); in months (7,5; 5,5; 3,8; 2,5; 1,5; 1,2); days (28,1; 24,3; 26,1; 20,5; 17,4; 14,5; 12,8; 8,9; 7,1; 6,7).
6. For the planetary geomagnetic index Ap: in years (1); in months (5,5; 3,8; 1,9; 1,5; 1); days (28,5; 16,8; 13,3; 9; 6,6; 5,4; 4,5).

4.2. Subtract of the trend component

To identify short–components, trend components were removed. In order to eliminate the influence of the trend components was subtracted the 3–rd order polynomial. In the next step was conducted frequency filtering of periodicities more than three and one years.

4.3. Calculation of the spectrograms for data with subtracted trend

To identify the time of existence of periodic components used program PSELab [3]. As a result of this calculations trend periods were found (periods that do not retain their values).

For elliptic orbit satellites: from 10,2 to (=>) 9,7 days; 12=>13 days; 2,6=>1,3 month;

and for the circle orbit satellites: from 4,6=>3,7 days; 6,4=>7,2 days; 13=>11,4 days; 23=>13 days; 28 days =>1,1 month; 29,2 days =>1,2 month.

Spectrograms for the indices of solar and geomagnetic activity showed that the identified periods are present on all the studied time interval. Spectrograms for the total area of sunspot groups show periods from 5,4 to 20 days. These periods more clearly visible in the decline phase of 23–rd solar cycle.

4.4. Building of multiple correlation models

One of the final stages of data processing is to build models of multiple correlation between the B–star Drag Term and indices of solar and geomagnetic activity. Building of this models consists in finding the regression and beta coefficients of model and to find multiple correlation coefficients. Models should not contain parameters that correlates with each other. Also these models must include the total number of factors influencing the studied parameter [6].

The highest correlation coefficients (between B-star and indices of solar and geomagnetic) greater than 0.7, as expected from the literature, between the B-star and radio flux at 10.7 cm, Wolf numbers and the total area of sunspot groups.

Fig. 4 and 5 show correlation between B-star and the solar radio flux at wavelength 10,7 cm for «circle» orbit and «elliptic» orbit satellites respectively.

Correlation coefficients between indices: W, Sp and F10.7 is more than 0.87. Therefore, we can't use these indexes together in the model. Thus we have built three models which we called (depending on the main influencing index): model F 10.7, model W and model Sp. The examples of models (for example model F 10.7) are shown in Table 2 and Table 3 for circle orbit and elliptic orbit satellites respectively.

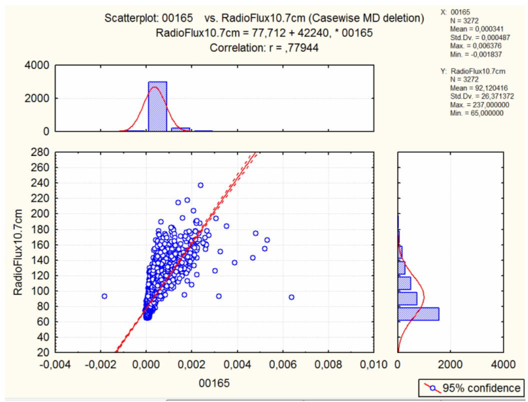

Figure 4: Graph of correlation between B-star and radio flow at a wavelength of 10.7 cm.

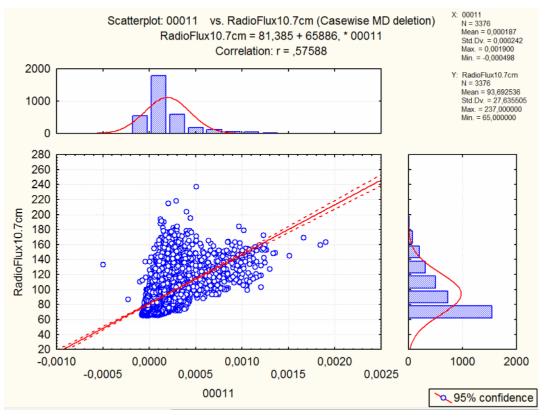

Figure 5: Graph of correlation between B-star and radio flow at a wavelength of 10.7 cm.

Table 2.

Number of satellite	Model F10,7						
	R	RadioFlux10.7cm	E>0,6 MeV	E>2 MeV	Ap Middle Latitude	Ap High Latitude	Ap Planetary
		Beta					
06212 i=98.57°	0,87	0,863265	-0,059673	0,083503		-0,021088	
25860 i=97.7°	0,83	0,823517	-0,032059	0,029299		-0,070153	
27700 i=97°	0,86	0,840233	-0,093921	0,109538		-0,018819	
01814 i=75.9°	0,83	0,832595	-0,006108	0,018648		-0,044460	
04139 i=74.03°	0,81	0,813082	-0,009609	0,022791		-0,047087	
03048 i=74°	0,83	0,834077	-0,010642	0,035625		-0,034309	
04579 i=73.99°	0,83	0,835709	0,002717	0,010322		-0,042718	
04922 i=65.8°	0,86	0,868181	-0,003077	0,032240	-0,042336		
12054 i=65°	0,8	0,803983	-0,001342	0,035297	-0,032477		
00397 i=58.3°	0,85	0,853947	-0,008261	0,038848	-0,047085		
00063 i=48.5°	0,85	0,842893	-0,025441	0,040645	-0,013985		
00165 i=47.9°	0,78	0,783882	-0,009629	0,015843	-0,039318		
06153 i=35°	0,74	0,754956	0,013817	-0,008446	-0,053864		
25064 i=34.9°	0,88	0,879330	-0,005374	0,056744	-0,019261		
23757 i=22.9°	0,85	0,854784	-0,008745	0,052372			-0,052543

Table 3.

Number of satellite	Model F10,7						
	R	RadioFlux10.7cm	E>0,6 MeV	E>2 MeV	Ap Middle Latitude	Ap High Latitude	Ap Planetary
		Beta					
00932 i=81.3^{0}	0,6	0,603455	-0,013660	0,067882		-0,025280	
00721 i=78.6^{0}	0,65	0,654942	0,026145	-0,012962		-0,028445	
00746 i=60.8^{0}	0,23	0,213755	-0,030896	0,030685	0,016173		
00829 i=60.8^{0}	0,44	0,435915	0,011477	0,018019	0,034176		
00082 i=38.9^{0}	0,52	0,297911	-0,460390	0,306179	-0,069210		
00016 i=34.3^{0}	0,25	0,158849	-0,190783	0,130887	-0,001614		
00005 i=34.2^{0}	0,25	0,179848	-0,168847	0,110631	-0,047277		
00020 i=33.4^{0}	0,72	0,735799	0,016697	-0,018490	-0,092955		
00011 i=32.9^{0}	0,59	0,531823	-0,139970	0,163480	0,074136		
00963 i=19.75^{0}	0,03	0,025194	-0,015062	0,015949			0,002930

5. Conclusions

As a result of the calculation using the programs: OriginPro 8.1, STATISTICA 8 and PSELab have been found:

1) Using Fourier analysis identifies periodic components and their presence in the studied time interval.
2) For circle orbit satellites: in the models which include F 10.7 multiple correlation coefficient greater than 0.8, mostly for all satellite. The models which include W have the same picture as in the models of F 10.7, only the multiple correlation coefficient for the Wolf numbers slightly more than 0.7. But multiple correlation coefficient of models which includes Sp little more than 0.6, but in the last two models, the value of the beta coefficient for electrons fluxes increased significantly compared to previous models
3) For elliptic orbit satellites: in the models which include F 10.7 multiple correlation coefficient is slightly more than 0.6, for satellites with NORAD numbers: 00011, 00020, 00721, 00932. For other satellites multiple correlation coefficient is just above 0.2. The main contribution is making two parameters: the radio flux at a wavelength of 10.7 cm, and the electron fluxes with energies >0.6 MeV. In models which include W and Sp is the same picture as in the models which include F 10.7 only except that increases of contribution from electron fluxes with energies >0.6 MeV and the planetary geomagnetic index Ap.

Detected periods with trend probably related to the long dynamics of influence of solar and geomagnetic activity and tidal phenomena on the upper atmosphere of the Earth.

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