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Analysis of solar activity and geomagnetic field influences on the dynamic of relativistic outer radiation belt electrons during 2005-2006

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Abstract

We analyzed the dynamic of relativistic electrons with energies 0.3-0.6 MeV fluxes measured on “Universitetskiy – Tatiana“ micro-satellite during 12 strong and moderate geomagnetic storms in the time period of years 2005-2006. Generally valid proportionality between the value of relativistic electrons with energies 0.3-0.6 MeV maximum position L_{max} and the minimum value of Dst index Dst_{min} ($|Dst_{min}| \sim L_{max}^{-4}$) indicates on the penetration of relativistic electron, manly during magnetic storm periods in Earthward direction. These fluxes good correlated with some indices, which are a measure of geomagnetic field activity level. The correlation coefficients between electron fluxes and Dst, Kp and AE indices were r=0.50, 0.57 and 0.89. The correlation of these fluxes with solar activity was in this time interval much less. The correlation coefficients with solar wind speed v_{sw} were r= 0.12, with F10.7 index r=0.23 and with sunspot number R only r=0.04. The correlation coefficient of electrons fluxes with combited quantity Dst * v_{sw} (r=0.63) is higher in comparison with correlation coefficients of single quantities Dst (r=0.50) and v_{sw} (r=0.12). A good correlation was obtained also between Dst index and product of v_{sw}*B_z (r=0.85), where B_z is southward component of IMF and also between Dst index and B_z (r=-0.58). This testifies the fact about connection between geomagnetic and solar activities and IMF orientation.

INTRODUCTION

It has long time been known, that high-speed solar wind and geomagnetic activity are strongly associated with the appearance of relativistic electrons in outer radiation belt region. More recently Li et al. [1] have shown that the solar wind speed and north-south component of interplanetary magnetic field (IMF) B_z can be used to predict some of the variability of relativistic electrons.

The penetration of electrons in radiation belts region to the Earth dependens on the geomagnetic activity level represented by Dst index. This penetration is significant mainly during geomagnetic storms periods. The analysis of these relativistic electrons during indivitual magnetic storms shows that these electrons can penetrate to the slot region mainly during strong magnetic storms. This dynamic is controled not only by the geomagnetic activity but also by solar activity represented by solar wind speed. Because the geomagnetic activity is strongly associated with solar activity and also with suitable orientation of IMF, there is very difficult especially in geomagnetic storms periods to distiquish the influence of these two factors on the relativistic electrons dynamic. Geomagnetic activity is caused by the energy from the solar wind transform to the magnetosphere during magnetic recconection between IMF and Earth magnetic field. These recconection leads to solar wind plasma injection to the magneto-tail region and later into the night-side magnetosphere and also to forming of ring current. The ring-current fluxes of particles relate to geomagnetic field and during good interplanetary features like southward orientation of IMF the geomagnetic storm can occur.

Zheng et al. [2] studed the long-term relativistic electron behaviour in the inner radiation belt region using 2-6 MeV electron data from SAMPEX satellite during 1992-2004. This analysis shows good correlation between penetration of these electrons in Earth direction with Dst index. The correlation analysis of strong magnetic storms with Dst minimum $Dst_{min} < -130$ nT showed that fluxes of these electrons are better correlated with $Dst_{min}*v_{sw}$ (v_{sw} is the solar wind speed) than with Dst minimum and solar wind speed v_{sw} independently and have a very high anticorrelation with the averaged solar wind density.

Tverskaya et al. [3] proposed the empirical formula between the L position (L_{max}) of the peak intensity of outer radiation belt relativistic electron flux and magnetic storm amplitude Dst_{min} for strong geomagnetic storms (up to 400 nT): $|Dst|_{min} = 2.75 .10^4 / L_{max}{}^4$.

Hari Om Vats reported effect of high speed solar wind on the geomagnetic conditions [8]. He concluded that most of severe geomagnetic storms of 23 solar cycle occurred when z-component of IMF B_z was positive.

Wang et al. [10] reported that geomagnetic storms can occur when magnetic field of the interplanetary feature engulfing the Earth has a strong southward component B_z and a good correlation is obtained between Dst and $v_{sw}*B_z$ product. These results confirmed R.P.Kane [11] , which on the base of magnetic storms data during 1973-2003 period showed the relationship between solar wind speed v_{sw} and Dst had the worse correlation in compare with Dst and $v_{sw}*B_z$ product.

DATA ANALYSIS

We investigated in this paper the relativistic electrons dynamic using 0.3-0.6 MeV electron data from “Universitetskiy-Tatiana” micro-satellite during 2005-2006. The “Universitetskiy – Tatiana” micro-satellite was launched on January 20, 2005 into a circular orbit with an inclination ~83^o and the initial altitude about 1000 km. In this paper we have used electron data with energies >70 keV, 0.3 - 0.6 MeV, 0.6 – 0.8 MeV and >3.5 MeV for monitoring relativistic electron dynamic. A more detail description of the apparatus measuring the energetic particles can be found in [9].

Investigated time interval was situated to near solar minimum period and this lower solar activity reflected to lower number of geomagnetic storms. We investigated althogether 12 geomagnetic storms from which one storm was severe, seven storms were strong and three moderate magnetic storms. Tables 1a and 1b contain some characteristics of all investigated magnetic storms. Table 1a contains the day and the hour (in UT) of storm main phase beginning t_b, the minimum value of *Dst* index during this storm Dst_{min}, the minimal value of relativistic electrons with energies 0.3-0.6 MeV maximum position L_{max} and its calculated value according to the Tverskaya formula [3], class of single storms using Loeve and Prölss, classification (ST-strong, SE-severe G-great and MO-moderate storms) [6] and the maximum flux of these electrons during the recovery phase I_{max}. These data are completed by parameters of interplanetary magnetic field (IMF) and solar wind plasma during the time of main storm phase. There are the magnetic field module $|B|$, its B_z component magnitude together with the plasma speed v_p and density n_p measured on ACE satellite and Kp and AE indices, sunspot number R and F10.7 solar index (Table 1b).

Table 1a.

Data and time of main phase beginning t_b	Dst_{min} [nT]	L_{max} exp/cal [R_E]	Class of mag. storm	Tatiana 0.3-0.6 MeV I_{max} [counts/s]
4.4.2005/16	-85	3.8/4.2	M	$5.5\ 10^4$
7.5.2005/22	-127	3.1/3.8	ST	$4.0\ 10^4$
15.5.2005/07	-263	2.8/3.2	SE	$1.6\ 10^5$
29.5.2005/23	-138	3.7/3.7	ST	$1.0\ 10^5$
12.6.2995/19	-105	4.0/4.0	ST	$1.5\ 10^5$
23.6.2005/00	-97	3.6/4.1	M	$6.0\ 10^4$
9.7.2005/09	-94	3.7/4.1	M	$4.2\ 10^4$
24.8.2005/10	-216	3.0/3.3	SE	$1.0\ 10^5$
31.8.2005/14	-128	3.3/3.8	ST	$1.1\ 10^5$
11.9.2005/04	-147	3.0/3.7	ST	$1.8\ 10^5$
14.4.2006/02	-111	3.5/4.0	ST	$1.2\ 10^5$
14.12.2006/23	-146	3.4/3.7	ST	$1.2\ 10^5$

Table 1b.

Data of main mag. storm phase	ACE IMF and plasma parameters in t_b				Indices od geomagnetic and solar activity in t_b			
	$\lvert B \rvert$ [nt]	Bz [nT]	v_p [km/s]	n_p [1/cm^3]	Kp	R	AE	F10.7
4.4.2005	12	-10	551	5	50	35	618	88.5
7.5.2005	19	-13	439	25	52	46	707	103.2
15.5.2005	54	-22	962	6	77	39	1057	105.2
29.5.2005	11	5	502	14	73	46	1043	97.5
12.6.2005	14	-17	486	50	60	50	1065	106.3
23.6.2005	17	-17	362	79	57	11	878	80.1
9.7.2005	6	2	308	12	60	42	729	105.2
24.8.2005	43	-36	638	30	73	42	899	100.7
31.8.2005	4	1	508	4	67	29	1162	85.6
11.9.2005	16	-10	1000	8	63	34	1349	111.1
14.4.2006	4	-1	544	3	70	36	1021	79.4
14.12.2006	15	-15	839	6	67	13	1245	84.4

In this paper we investigated not only the dynamic of relativistic electrons during single magnetic storms periods but we tried to find the common characteristic associated with these magnetic storms like their dependence on the rather solar and geomagnetic indices.

We investigated the dependences between electron fluxes and Dst index not only in the time of sigle magnetic storms but also in periods before and after these storms. It is evident that the dependence between L_{max} and Dst_{min} proposed by Tverskaya is valid for very strong geomagnetic one step storms. On the other hand it is evident too that the validity of the proportion between these quantities in the form $|Dst_{min}| = A.\ L_{max}^{-4}$ (A is constant which is for very strong geomagnetic storms equal 27500) is far wider and is probably valid also in the time of geomagnetic quieter intervals.

Figure 1 shows this dependence for all 12 geomagnetic storms in 2005-2006 time interval according to Universitetskiy-Tatiana data. The solid line shows values according to the empirical formula proposed by Tverskaya [3] and dotted line is the linear fit of our data. We can see that our fit has the same inclination like this obtained from Tverskaya empirical formula only it is moved to lower values of with constant A = 17500. Obara et al. reported in [4] the dependence of the peak location of the outer radiation belt L and Dst index value, in total 46 magnetic storms with Dst from -50 nT to ~ -300 nT based on Akebono satellite observations. The constant A has (according our account) for this storms value about 20000. In paper [5] were analyzed data from 31 strong magnetic storms with Dst <-100 nT based on CORONAS-F measurements of relativistic electrons during 2001-2005 time interval. The obtained dependence between L_{max} and Dst_{min} was also $|Dst_{min}| = 17500.\ L_{max}^{-4}$. We can see that the strongest magnetic storms fulfill better the empirical formula, proposed by Tverskaya.

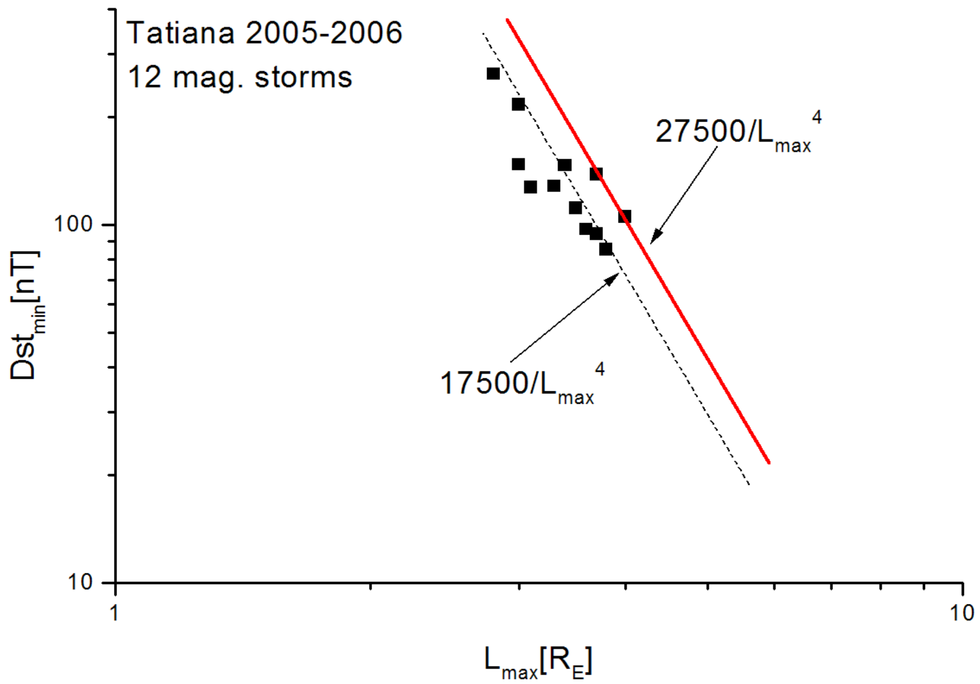

Figure 1

Figure 2 shows the L_{max} and Dst index dependences for two single geomagnetic storms periods during Jun 12 and 23 , 2005 magnetic storms (a) and during August 31 and September 19, 2005 magnetic storms (b). We can see that all points lie under theoretical line, except these which are measured during the main storm phase of single storms (these are signposted by arrows). These points lie very close to the theoretically proposed value. Values of the constant A in dependences $|Dst_{min}| = A.\ L_{max}^{-4}$ for single geomagnetic storms are in Table 2.

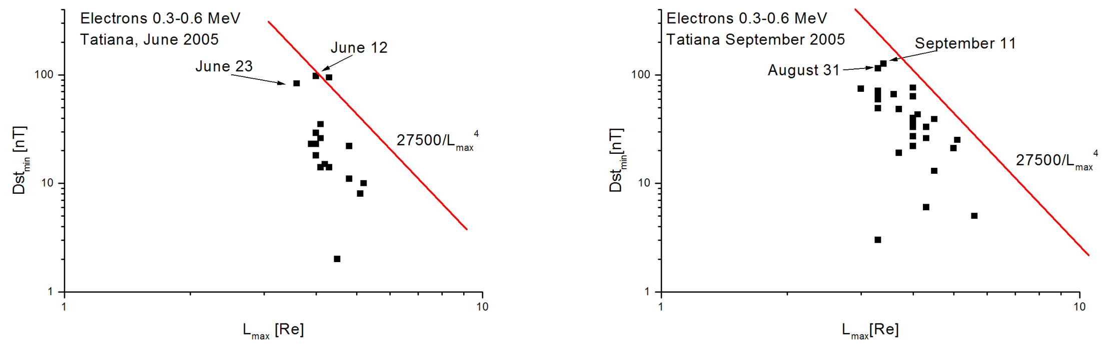

Figure 2

Table 2. Values of constant A in dependences $|Dst_{min}| = A.\ L_{max}^{-4}$ for single geomagnetic storms.

Magnetic storm	A [$nT.R_E^4$]	Magnetic storm	A [$nT.R_E^4$]
4.4.2005	4900	9.7.2005	11200
7.5.2005	6200	24.8.2005	4300
15.5.2005	6200	31.8.2005	8000
29.5.2005	5000	11.9.2005	8000
12.6.2005	5600	14.4.2006	6200
23.6.2005	5600	14.12.2006	1200

Iles et al. [7] published the dependence between L_{max} and Dst for relativistic electrons with energies ~ 1 MeV measured on STRV-1a and STRV-1b satellites during 46 above all moderate magnetic storms. It is interesting that in this case the most of point are situated over the Tverskaya's theoretical values. This can be caused may be by the fact that in this case the Dst values weren't values in the time of L_{max} but minimum values during single magnetic storms. The constant A is in this case ~ 37000.

The penetration of relativistic electrons during strong magnetic storm period are demonstrated on Figure 3. The L-t diagram of 3-hour averaged relativistic electron fluxes with energies 0.3-0.6 MeV for the period of May 2005 completed by Dst behaviour is on this figure. We can see the trip of relativistic electron fluxes in Earth direction during three magnetic storms on May 7, 15 and 29 on this figure.

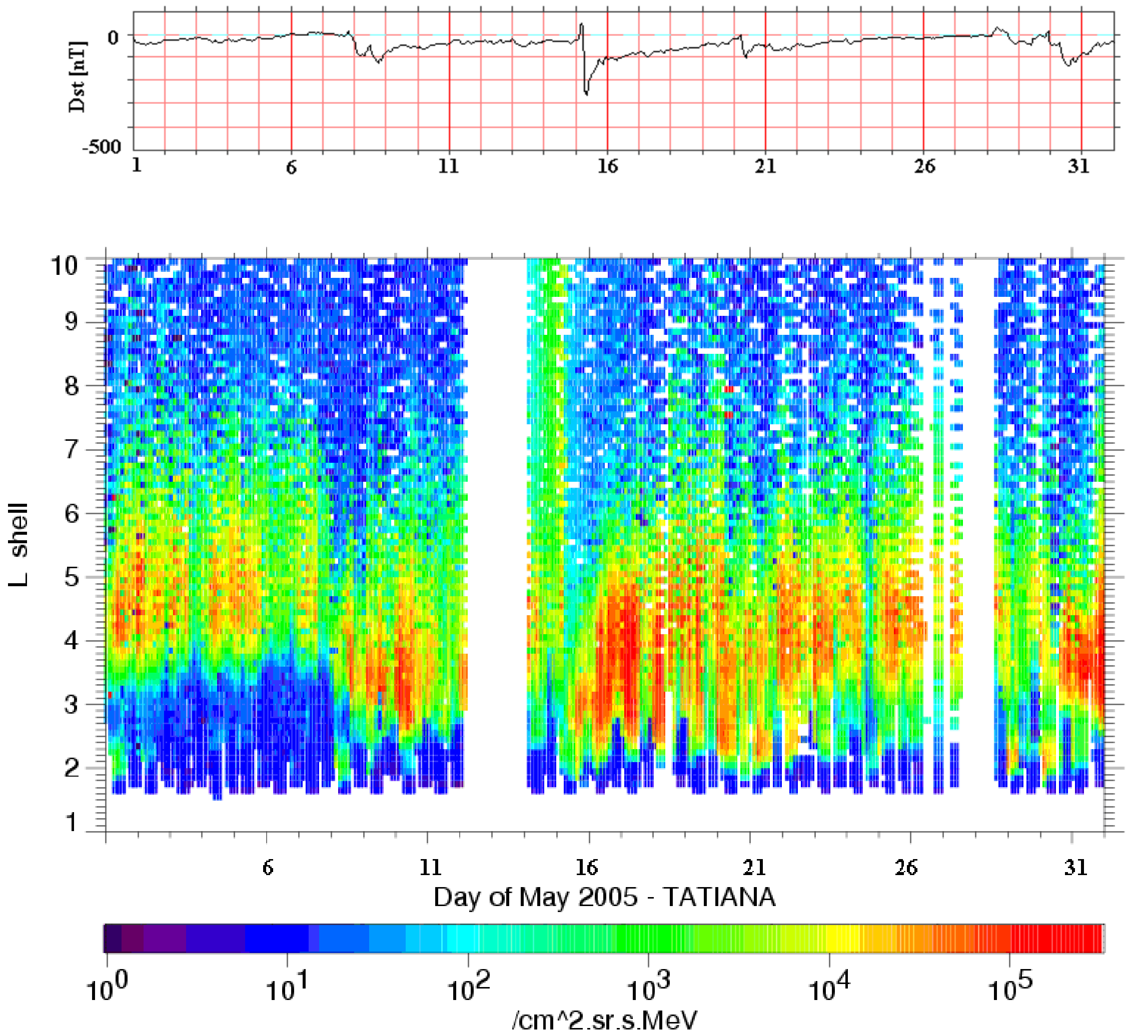

Figure 3

Radiation belt electron fluxes depend both of geomagnetic and solar activity level. Table 3 contains the correlation coefficients of peak electron fluxes with energies 0.3-0.6 MeV measured during 12 magnetic storms in researched period with Dst, K_p , AE indices, which characterized geomagnetic activity and also correlation coefficients with solar wind speed v_{sw}, F10.7 index and sunspot number R, characterized solar activity level. During this period is the correlation between electron fluxes and geomagnetic activity higher in compare with solar activity. But both these influences play some role in electron dynamic, which change from one eventh to another.

Table 3 Correlation coefficients of rather parameters of geomagnetic and solar activity versus peak electron with energy 0.3-0.6 MeV fluxes I_{max} .

Parameter	Correlation coefficient **r**
Dst	0.50
Kp	0.57
AE	0.89
v_{sw}	0.12
F 10.7	0.23
R	0.04

Figure 4 shows the dependences between relativistic electron with energy 0.3-0.6 MeV fluxes I_{max} and (a) Dst index, (b) solar wind speed v_{sw} and also with (c) v_{sw}*Dst product. The best correlation between electron fluxes and v_{sw}*Dst product (r=0.63) referees to the influence of both activities (geomagnetic and solar) on relativistic electron dynamic. These results correspond to results of Zheng et al. [2], only the correlation of electron fluxes with solar wind density was a little smaller according our data. These dependences only confirm the fact about importance of both geomagnetic and solar influences on the relativistic electron dynamic.

The orientation of IMF play also very important role in relativistic radiation belt electron dynamic. G.Vichare el al. [8] present study analyses nine strong geomagnetic storms with Dst <-175 nT. This study confirms the crucial role of southward IMF in controlling the magnitude of the magnetic storm. The dependence between deviation of Dst versus the magnitude of maximum south IMF is linear which indicates that the strength of the magnetic storm is directly proportional to the strength of southward IMF.

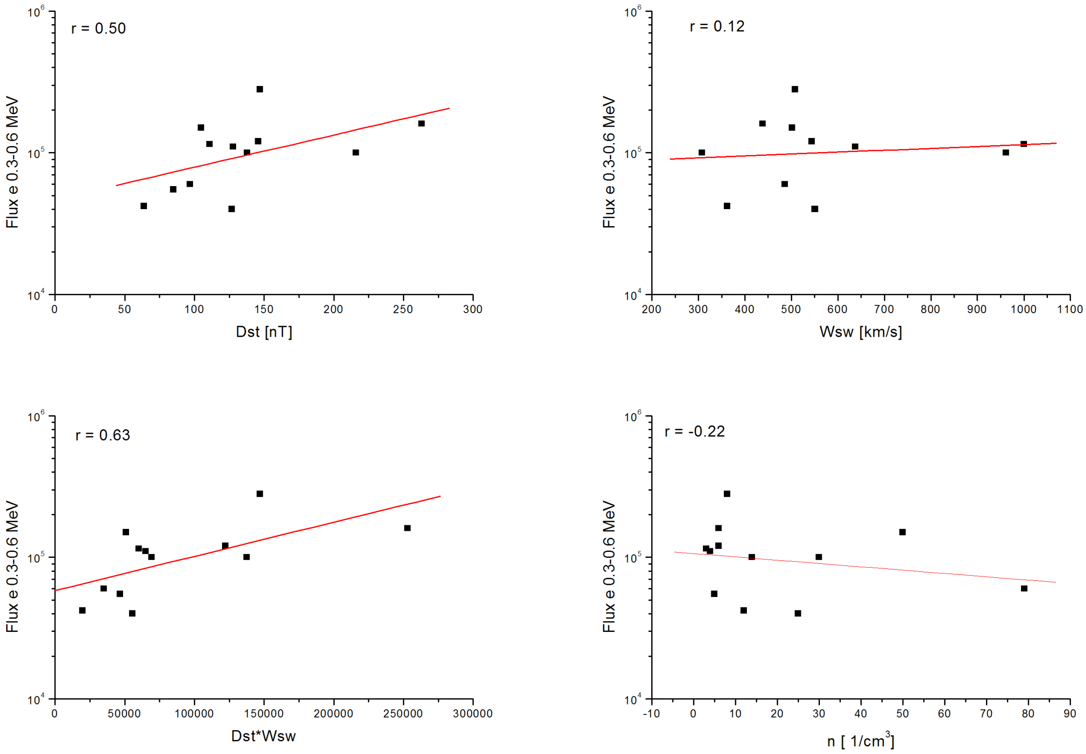

Figure 4 a,b,c,d

Figure 5 shows the dependences between Dst index and v_{sw}*B_z product and with only B_z for all investigated geomagnetic storms. The high correlation between these two quantities and Dst index with high correlation coefficients r= 0.85 resp. r=0.58 testify the fact about connection between geomagnetic and solar activities and IMF orientation.

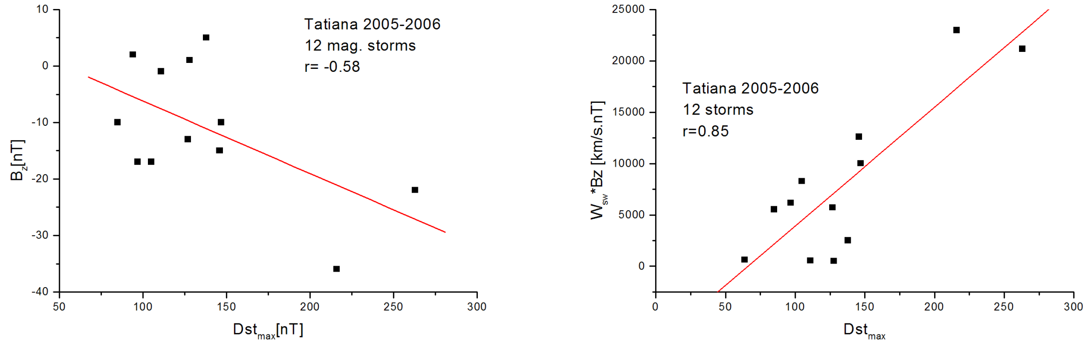

Figure 5

During strong magnetic storms we observed except shifts of relativistic electron flux maximum from the position L_B before magnetic storm to the position L_{max} also values of relative shifts of this maximum during sigle magnetic storm periods $\Delta L = L_B - L_{max}$. This correlated with L_{max} , Dst, v_{sw} and B_z . We can observe this correlation on Figure 6 abcd.

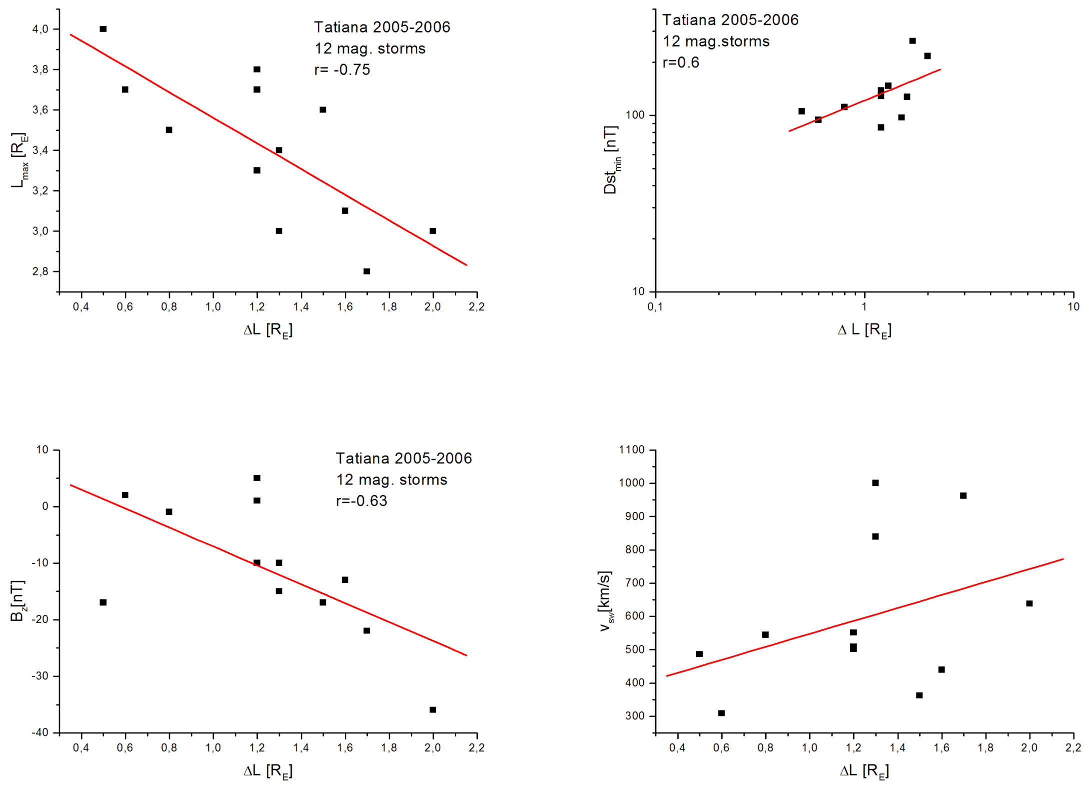

Figure 6 a,b,c,d

We can see that the shift of outer radiation electron fluxes with energies 0.3-0.6 MeV ΔL good correlated with L_{max} and also with Dst, v_{sw} and B_z parameters.

CONCLUSIONS

Generally valid proportionality between L_{max} and Dst_{min} ($|Dst_{min}| \sim L_{max}^{-4}$) indicates on the penetration of relativistic electron, manly during magnetic storm periods in Earthward direction due to radial diffusion or storm time enhanced by wave-particle interactions. This dependence indicates also the importance of "ring current" for dynamic of relativistic outer radiation belt electrons.

The better correlation between relativistic electron with energy 0.3-0.6 MeV I_{max} fluxes and v_{sw}*Dst product in comparison with single quantities Dst a v_{sw} indicates that we can not separate the influence geomagnetic and solar activities on the electron dynamic each others.

The dependence of geomagnetic activity on solar activity and IMF orientation is due to over results clear, but also during analyzed in this paper geomagnetic storms period were the orientation of IMF not already negative.

The high correlation between Dst index and v_{sw}*B_z product and with only B_z these two quantities and Dst index (r= 0.85 resp. r=0.58) testifies the fact about connection between geomagnetic and solar activities and IMF orientation.

Relative shifts of this maximum during sigle magnetic storm $\Delta L = L_B - L_{max}$ period have a good corellation with L_{max} , Dst, v_{sw} and B_z parameters of geomagnetic field, solar activity and IMF level.

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