acta physica slovaca vol. 56 No. 2, 103 – 107 April 2006

SOME ASPECTS OF RELATIVISTIC ELECTRON FLUXES DYNAMICS IN THE OUTER RADIATION BELT DURING MAGNETIC STORMS[1]

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Received 6 December 2005, in final form 13 February 2006, accepted 21 February 2006

We investigated relativistic (0.6–1.5 MeV) electron fluxes dynamics in outer radiation belt using MKL device measurements on CORONAS-F satellite within intervals of 22 strong magnetic storms during years 2001–2004. We show that in the time of these magnetic storms the maximum of the electron fluxes shifts earthward in to the slot region.

PACS: 94.30 Hn; 94.30 Lr

1 Introduction

The outer electron radiation belt is populated by relativistic electrons, strongly enhanced following some geomagnetic storms. These $\sim$1 MeV electrons are called "killer electrons", because they represent a serious potential hazard to orbiting satellites, space stations and humans in space. For understanding of the outer radiation belt electrons dynamics it is necessary to investigate the correlation of their fluxes with solar wind and geomagnetic activity parameters. In this paper we investigated relativistic electrons with energies 0.6 – 1.5 MeV, during 22 strong magnetic storms ($Dst < -100$ nT) [2], measured by MKL device (complex SKL) on CORONAS-F satellite during years 2001-2004. The Dst or disturbance storm time index is a measure of geomagnetic activity used to assess the severity of magnetic storms [1]. A short description of SKL complex measuring the energetic particles can be found in [2]. The interval includes also the extremely strong events of October – November 2003 described in detail, e.g., in papers [3] and [4].

2 Analysis of experimental results

For all magnetic storms we analyzed the L profiles of relativistic (0.6 – 1.5 MeV) electrons in the time of CORONAS-F (low altitude $\sim$500 km polar orbiting Russian satellite), crossing the outer radiation belt. At low altitude, the Earth's field is approximately that of a magnetic dipole. Trapped radiation is described by particle fluxes as function of energy and of the geomagnetic co-ordinates L and B. The L is radial distance of the field line from the axis at the geomagnetic

[1]Presented at 15-th Conference of Czech and Slovak Physicist, Košice, Slovakia, September 5–8, 2005
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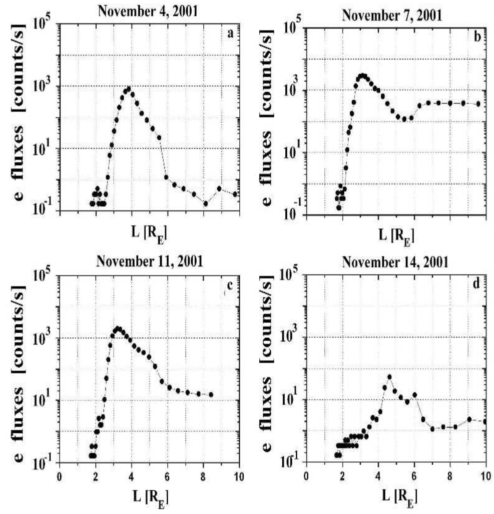

Fig. 1. The radial profiles of relativistic 0.6 – 1.5 MeV electrons fluxes (e fluxes) during the period including the geomagnetic storm on November 5, 2001.

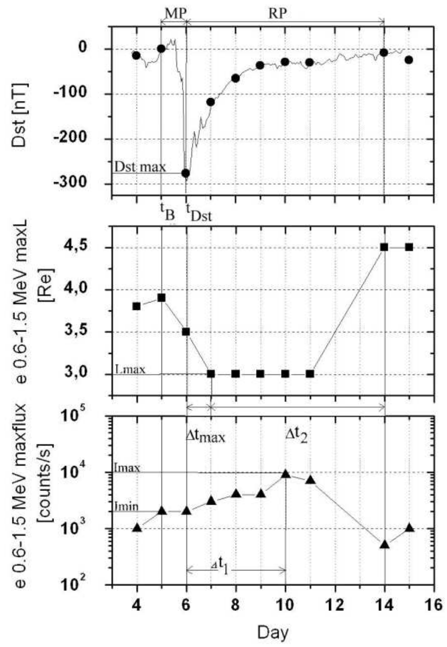

Fig. 2. The example of the typical time behavior of *Dst* index, the position of maximum of 0.6 – 1.5 MeV electron fluxes and maximal fluxes of these electrons around the November 5, 2001 geomagnetic storm (MP – main phase of the storm; RP – recovery phase of the storm).

equator and B is the magnetic field strength. Analogically, in real geomagnetic field L and B are defined by [5]. For correct comparison we select the orbits when satellite crossed the same line in $L{-}B$ space. Thus comparison is possible only with one day step. Figure 1 displays L profiles of relativistic electrons around the geomagnetic storm on November 5, 2001: before storm onset (a), at the beginning of recovery phase (b), at the end of recovery phase (c) and after the end of this storm (d). This figure illustrates the typical outer radiation belt relativistic electron dynamics. The pre-storm position of electron fluxes maximum was around $L \sim 4\,\mathrm{R_E}$ (Earth's radii). During geomagnetic storm it is shifted to $L \sim 3\,\mathrm{R_E}$ and after storm it returned to the pre-storm position with lower intensity. Time behavior of *Dst* index, the maximum 0.6 – 1.5 MeV electron fluxes position and maximal electrons fluxes around that geomagnetic storm are plotted in the Fig. 2. This storm had $|Dst|_{max}$ = 292 nT and it rank among severe storms with *Dst* between -200 nT and -350 nT. Some parameters, which we studied in all researched geomagnetic storms, are also marked in this figure. They characterize the dynamics and the geometry of relativistic electron population regions in outer radiation belt during individual geomagnetic storms. Mainly there are the beginning time of main phase of magnetic storm t_B, the time of the *Dst* maximum value t_{Dst}, the minimum flux of 0.6 – 1.5 MeV electrons in the time of main phase I_{min} and the maximum flux of these electrons during the recovery phase I_{max}, the time shift of I_{max} position according to the beginning of storm main phase Δt_1, the most earthward position of electron fluxes maximum L_{max}, the time shift between $|Dst|_{max}$ and L_{max} positions Δt_{max} and the time shift between L_{max} position and the end of recovery phase of geomagnetic storm Δt_2. All parameters for studied geomagnetic storms are listed in Tab. 1. That includes the day and the hour (in UT) of storm main phase beginning t_B, the maximum value of *Dst* index during this storm Dst_{max}, the minimal value of relativistic electrons with energies 0.6-1.5 MeV maximum position L_{max} and its calculated value according to the Tverskaya formula [6], class of single storms using Loeve and Prölss, classification (ST-strong, SE-severe and G-great storms) [7], t_{Dst}, Δt_{max}, Δt_2, I_{min}, I_{max} and Δt_1 values and also the maximum fluxes of $>$0.5 MeV and $>$2 MeV electrons measured in the geostationary orbit by GOES-10 satellite in the time of main storm phase. 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 w_p and density n_p measured on ACE satellite and by solar wind speed in the time of main storm phase w_{sw} measured on SOHO satellite.

Most of the magnetic storms are associated with southward orientation of IMF and high speed fluxes of solar wind plasma. All time intervals, in which changes of maximum relativistic electron fluxes position take place, are given by the sum of time intervals Δt_{max} and Δt_2. The resultant time is for individual storms different (from a few days to about two weeks). Longer time intervals respond to geomagnetic storms with two or multi-step character. The fluxes of relativistic electrons with energies 0.6 – 1.5 MeV increase by 1 – 2 orders during the time of main and recovery phase of geomagnetic storm. This follows from I_{max} and I_{min} difference. We can see that maximum value I_{max} reach these electrons usually after some days after beginning of main storm phase.

The outer radiation belt maximum shifts during the main storm phase with the average velocity 0.56 ± 0.11 $\mathrm{R_E}$/day. After t_{Dst} the shift is slower with the average velocity 0.28 ± 0.06 $\mathrm{R_E}$/day during whole Δt_{max} interval. After the achievement of it's nearest to the Earth position L_{max} the outer radiation belt maximum returns to the pre-storm position with the similar average velocity (0.33 ± 0.10 $\mathrm{R_E}$/day). The maximum shift of outer electron radiation belt position L_{max} is observed after 1 – 3 days from the time t_{Dst} in which the maximum $|Dst|_{max}$ was reached. From Table 1 it appears that L_{max} measured by CORONAS-F satellite for 22 studied geomagnetic storms during period 2001-2004, has a decreasing tendency with increase of $|Dst|_{max}$. The linear correlation between log(L_{max}) and log(*Dst*) is 0.69. The empirical formula $|Dst|_{max} = 2.75 \times 10^4 / L^4_{max}$, proposed by Tverskaya [6] is consistent with the observations.

3 Conclusion

The redistribution of high energy outer electron belt population, as observed on a low altitude polar orbiting satellite during 22 geomagnetic disturbances in the period 2001–2004, revealed complexity of relations between the flux of electrons and the geomagnetic activity level, IMF as well as solar wind plasma characteristics. The most common effect is the inward shift of the *L* shell at which the maximum intensity is observed (L_{max}). After the onset of the storm the average velocity of the radial shift is 0.56 ± 0.11 $\mathrm{R_E}$/day as projected along *B* to the geomagnetic equator. The shift becomes slower by a factor of $\sim$2 after reaching minimum *Dst*. Recovery

Tab. 1. Parameters of 22 studied geomagnetic storms

Data and time of main phase beginning t_B	Dst_{max} [nT]	L_{max} exp/cal [R_E]	CLASS	t_{Dst} [day/hour]	Δt_{max} [in days]	Δt_2 [in days]	CORONAS F 0.6-1.5 MeV electron fluxes			GOES-10 electron fluxes		ACE IMF and plasma parameters				SOHO solar wind
							I_{max} [counts/s]	I_{min} [counts/s]	Δt_1 [in days]	E_e>0.5 MeV [/cm^2.s.sr]	E_e>2 MeV [/cm^2.s.sr]	$\vert B \vert$ [nT]	B_z [nT]	w_p [km/s]	n_p [1/cm^3]	w_{sw} [km/s]
25.09.2001/02	-166	3.1/3.6	ST	03.10./15	3	9	3.10^{4}	4.10^{3}	4	4.10^{5}	10^{4}	45	-30	550	10	750
21.10.2001/19	-187	3.7/3.5	ST	22.10./22	2	9	3.10^{3}	2.10^{2}	7	10^{4}	10^{1}	30	-20	600	10	700
28.10.2001/05	-157	3.2/3.6	ST	28.10./12	2	4	10^{4}	10^{3}	7	5.10^{4}	10^{1}	20	-20	450	10	500
05.11.2001/21	-292	3.0/3.1	SE	06.11./07	1	10	10^{4}	2.10^{3}	5	10^{4}	10^{3}	80	-80	-	-	>750
24.11.2001/18	-221	2.6/3.3	SE	24.11./17	5	1	5.10^{4}	10^{4}	3	4.10^{4}	10^{2}	60	-40	850	2	>750
11.05.2002/13	-110	3.7/4.0	ST	11.05./20	2	5	10^{4}	2.10^{3}	2	10^{3}	2.10^{2}	20	-20	400	7	500
23.05.2002/13	-109	3.8/4.0	ST	23.05./18	1	2	10^{4}	10^{3}	2	3.10^{3}	10^{3}	60	-40	800	1	750
04.09.2002/01	-109	3.8/4.0	ST	04.09./06	1	3	2.10^{4}	10^{3}	1	10^{3}	10^{1}	20	-20	500	10	-
07.09.2002/16	-181	3.0/3.5	ST	08.09./01	3	5	2.10^{4}	10^{4}	2	10^{5}	3.10^{2}	25	-25	450	20	580
01.10.2002/05	-176	3.5/3.6	ST	01.10./17	1	2	10^{4}	10^{2}	6	5.10^{3}	3.10^{2}	20	-15	400	20	500
29.05.2003/20	-131	2.8/3.8	ST	30.05./03	2	6	3.10^{4}	2.10^{4}	2	5.10^{4}	5.10^{3}	35	-20	700	20	>750
18.06.2003/03	-145	3.0/3.7	ST	18.06./10	2	2	4.10^{4}	10^{4}	1	10^{5}	10^{3}	20	-15	600	15	580
18.08.2003/16	-168	3.0/3.6	ST	18.08./02	0.5	13	3.10^{4}	10^{2}	0	2.10^{5}	10^{3}	25	-20	460	5	460
28.10.2003/17	-363	3.0/3.0	G	30.10./01	1	-	5.10^{3}	2.10^{3}	1	2.10^{4}	10^{3}	60	-60	>1500	-	>750
30.10.2003/19	-401	2.5/2.9	G	30.10./23	1	9	2.10^{4}	5.10^{3}	-	5.10^{5}	10^{2}	40	-20	>1500	-	>750
20.11.2003/04	-472	2.8/2.8	G	20.11./20	1	4	10^{4}	2.10^{3}	4	10^{5}	10^{2}	50	-50	600	20	750
22.01.2004/06	-149	3.5/3.7	ST	22.01./14	2	5	3.10^{4}	8.10^{3}	3	10^{5}	10^{3}	30	-20	650	10	700
03.04.2004/16	-112	3.5/4.0	ST	04.04./01	1	5	10^{4}	10^{3}	3	10^{4}	10^{2}	10	-5	500	30	500
22.07.2004/20	-182	2.8/3.5	ST	27.07./14	2	7	2.10^{4}	10^{2}	2	10^{5}	10^{1}	20	-5	600	5	400
30.08.2104/02	-125	3.6/3.9	ST	30.08./22	3	9	10^{4}	10^{3}	2	10^{4}	10^{2}	12	-12	420	-	400
07.11.2004/22	-384	2.9/2.9	G	08.11./04	2	-	4.10^{4}	10^{3}	1	10^{4}	10^{3}	40	-40	700	10	>750
09.11.2004/12	-296	2.8/3.1	SE	10.11./11	3	4	10^{4}	10^{3}	6	3.10^{5}	2.10^{3}	40	-20	750	5	>750

of L_{max} to its pre-storm position takes various time intervals and depends on appearance of a subsequent disturbance. Among 22 cases the best correspondence between the observed minimum value of L_{max} and the extreme value of *Dst* according to [6] is observed for the events with large value of IMF module ($|B| > 40$ nT), negative B_z as a dominant component of *B* and high solar wind plasma speed. The study of longer time intervals both during disturbed and quiet time periods to understand the relative importance of solar, interplanetary and geomagnetic activity on the dynamics of outer electron belt as observed at low altitudes is in progress.

Acknowledgement: The authors thank all the providers of ACE, GOES, SOHO and geomagnetic data. This work was supported by the Grant agency APVT; project APVT-20-25902 (K.Kudela) and by the VEGA Grant agency; project 4064 (M.Slivka).

References

[1] M. Suguira: *Annals of the International Geophysical Year* **37** (1964) 945

[2] S.N. Kuznetsov et al.: *Adv. Space Res.* **30** (2002) 1857

[3] Yu.I.Yermolaev et al.: *Geomagn. Aeron.* **45** (2005) 20

[4] I.S. Veselovsky et al.: *Cosmic Res.* **42** (2004) 435

[5] C.E. McIlwain: *J. Geophys. Res.* **66** (1961) 3681

[6] L.V. Tverskaya: *Adv. Space Res.* **18** (1996) 135

[7] C.A. Loeve, G.W. Prölss: *J. Geophys. Res.* **102** (1997) 213