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VARIATIONS OF THE ENERGETIC PARTICLES IN THE RADIATION BELTS AFTER THE JULY 22-30, 2004 MAGNETIC STORMS

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Abstract. Temporal intensity variations of relativistic and sub-relativistic electrons and solar protons trapped in the radiation belts after the strong magnetic storms were analyzed using measurements on board of low-altitude satellites SERVIS-1 and CORONAS-F. Variations consist on slow intensity decrease caused by the pitch-angle scattering into the loss cone and fast intensity increases and/or decreases during periods of enhanced magnetic activity. Life time of the energetic particles was estimated for different particle species and energies and radial drift shell position. Working radiation models must take into account that after strong magnetic storms enhanced particle fluxes remain in the radiation belts for months.

1. Introduction

The population of the Earth's radiation belts (RB) became significantly transformed during the strong magnetic storms. Especially effective changes are usually observed in the outer electron and proton radiation belt. During the main phase of the magnetic storm losses are prevailing, while during the recovery phase particle acceleration took place. Necessary references and details of these processes during July 2004 strong magnetic storm are presented in the accompanied paper (Lazutin et al., 2008). It describes significant changes in RB occurred during the magnetic storm or rather a series of three magnetic storms in July 2004. As a result of the acceleration during recovery phase, trapped population of particles both relativistic electrons and protons increases by two order of higher. Present paper is devoted to the processes of radiation belt relaxation after this specific magnetic storm. On the relativistic electron dynamics there are a lot of experimental and theoretical studies (see Friedel et al., 2004 and references therein), but still many uncertainties remain because relaxation is a concurrence of several spatial and energy dependent processes. As for the freshly trapped solar MeV protons, there are several indications that they may remain at the enhanced level from weeks to years (Lorentzen et al., 2002), but we do not know about any special discussion of solar proton decay propertyies.
The study of outer RB relaxation process presented in this paper is based on the measurements of the electron and proton flux variations by low-altitude polar satellites CORONAS-F (C-F) and SERVIS-1 (S-1) at altitudes 500 and 1000 km, accordingly.

2. Experimental data

The radial intensity profiles of electrons measured by C-F and S-1 near the Brazilian magnetic anomaly before the start of July 22-30, 2004 magnetic storm and after the end of the storm recovery phase are presented on the Figure 1. Increasing electron flux (in order of 1-2) accompanied by the shift of the maximum electron intensity closer to the Earth change radial profile, filling the gap between the inner and outer belts. Similar measurements carried out every day near BMA region for the second half of 2004 will be used for detailed analysis.

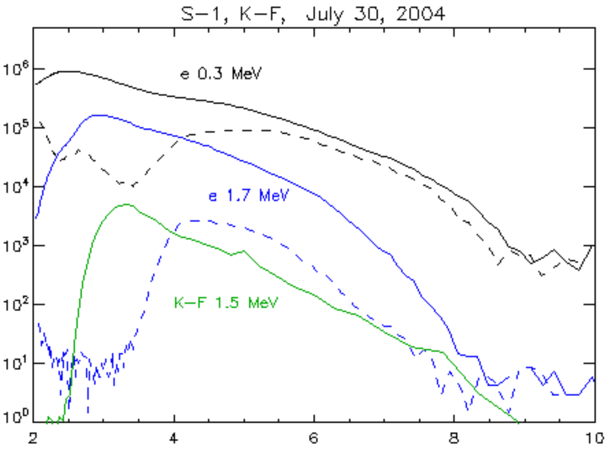

Fig.1 Radial profiles of energetic electrons measured by SERVIS-1 and KORONAS-F satellites before (dotted lines) and at the end of the magnetic storm

Time profiles of electron variations measured by S-1 at L = 2.5, 3 and 4 are shown in Fig.2. In addition to dominating slow process of intensity decay associated with pitch-angle diffusion (PAD) due to interaction with VLF- emission, there were registered short increases of the electron intensity caused by substorms. They are more pronounced in lower energies and at higher L-shells. The fast intensity increases and decreases during a moderate storm on August 30 were observed as well. Below we will consider these variations of electron flux in more details.

2.1 Slow pitch-angle diffusion, the electrons

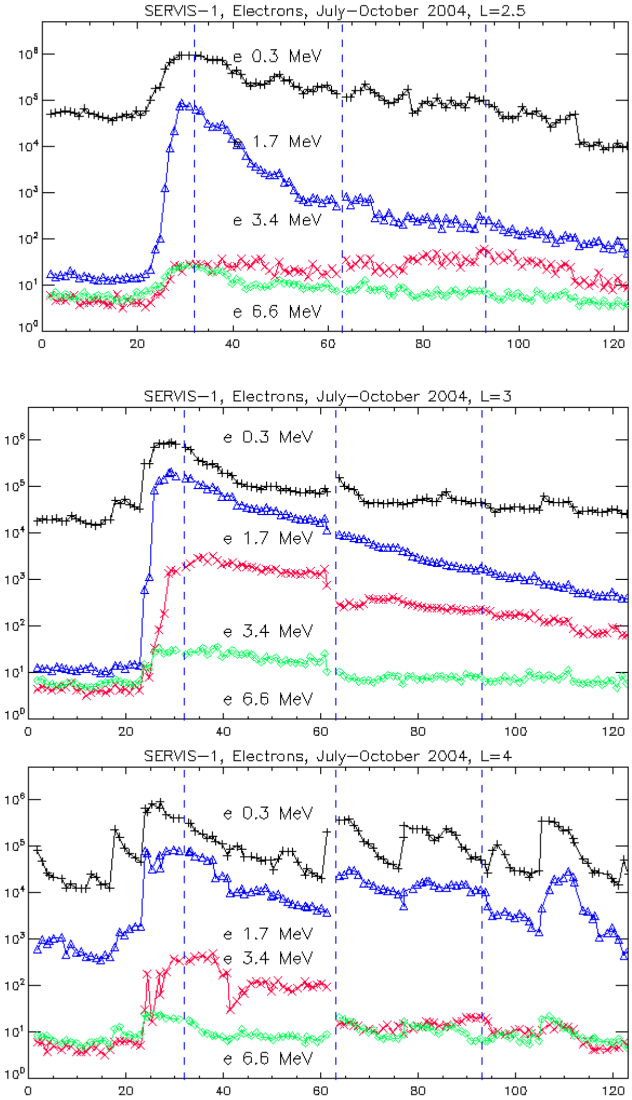

Fig. 2a-c. Energetic electron intensity measured by C-1 over South-Atlantic Anomaly from the July 1 to November 1, 2004 at L=2.5, 3, 4.

Figure 2a shows that the lifetime of electrons at the inner drift shells (L =2.5) for the energies of 0.3 and 1.7 MeV are the same and equals to 20 days. Right after the storm the rapid decline (τ = 5 days) was observed in the channel 1.7 MeV , i.e. the first 30 days particles are effected by fast PAD. In more energetic channels such rapid leakage is not observed. The electron flux in channel 6.6 MeV decreases till the end of the three-month period down to the background level. The flux of electrons in the channel 3.4 MeV remains high and there are intervals when the electron flux does not fall, but increases. At L = 3 (Fig. 2b) the channel 1.7 MeV again stand out against other channels with more rapid intensity decrease with lifetime τ = 15 days in comparing with the electrons with higher energy (3 MeV) τ = 25 days and particles with lower energies (0.3 MeV) τ = 55 days. In channel 6.6 MeV the background intensity level achieved in 40 days. At the outer drift shells (L = 4) the variations associated with magnetic activity are dominant in two low-energy channels (Fig 2c). Rapid increases alternate with rapid decreases (τ ~ 4 days). During the first 29 days of August magnetic activity was relatively quiet but the total particle intensity decrease (τ = 10 days) was faster, than at the deeper L-shells. In channel 6.6 MeV particle flux was weak, but it follows substorm variation simultaneously with the low-energy channels. In 3.4 MeV energy channel such a correlation was not observed. Thus, the lifetime of electrons injected in the radiation belt after magnetic storms in July 2004, depends both on particles energy, and a radial distance. Electrons with the energy 0.3 MeV have a maximum lifetime at L = 3. The particle intensity decrease is faster at L where the gap between the inner and outer belts was situated before the storm, and to the end of the investigated period, the gap between the inner and outer belts restores. High-energy electrons have a higher life time at L = 2.5, comparing with L = 3, but intensity increase was there significantly smaller, therefore the gap remained there during all poststorm period.

2.2 Fast variation, electrons

Energetic electron increases and decreases at high L-shells is well studied by the geostationary satellites, (O.Brien et al., 2003), and our results are in a good agreement with well-known patterns of the electron variations during substorms. During the growth phase particle drift shells are moving eartward with resulting intensity decrease and then returned back with a sharp increase at the beginning of the active phase dipolarisation. Additional acceleration also could take place. The rapid variations during a moderate magnetic storm on August 30, 2004 were more complicated and less predictable. As Figure 3 shows, there is a combination of the effects of dumping and acceleration - the acceleration of electrons with the energy 0.3MeV and the dumping of the electrons with the energy 3.4 MeV observed both at S-1, and at C-F satellites. Electrons in 1.7 MeV channel are slightly decreasing at first but later begin to increase.

Channel 6.6 MeV was not affected by the storm. Particle dumping in 3.4 channel is observed at L > 3 with the maximum 50% decrease at L = 3.5. It can be assumed that the PAD was caused by parasitic resonance with the ion cyclotron (EMIC) waves (Summers and Thorn, 2003), which demand high field aligned speed and therefore affected electrons with the energy not less than several MeV. At the same time intensity of lower-energy electrons is increasing due to the interaction with VLF emission by the same manner as during substorm activity.

2.3 Long-term variations, protons

During the July magnetic storms solar protons with the energies 1-15 MeV were captured on closed drift orbit with an additional acceleration, resulting by the enhanced proton belt after the magnetic storm (Lazutin, 2007,2008).

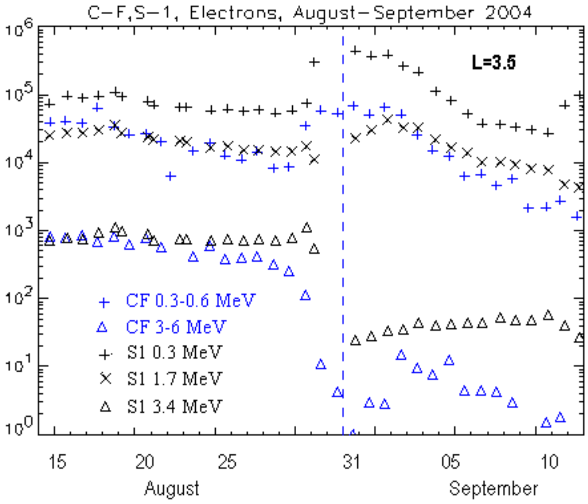

Fig. 3. Fast electron variations during August 30 magnetic storm measured by C-1 and K-F over South-Atlantic Anomaly.

Figure 4 shows proton radial profiles; 1 MeV x maximum at L=3 was 100 times higher after the storm. K-F post-storm profile differs from the C-1 one because it was affected by particle precipitation. Details of the poststorm dynamics of protons SCR will be considered elsewhere, here we will indicate the main features of proton flux variations.

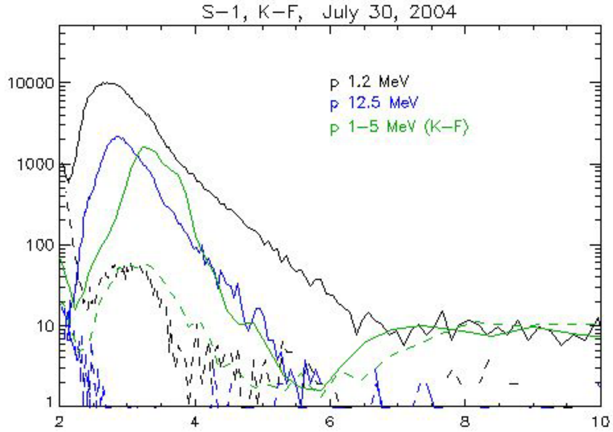

Fig. 4. The same as Fig. 1 for protons.

Figure 5 shows the temporal variations of 1-5 MeV protons measured at the K-F satellite. We should notice that deep gap of counting rates in late August to early October was created by change of telescope spectrometer orientation: when it was normal to the magnetic field line counting rate was at maximum indicating the trapped pitch-angle distribution with a maximum of 90 ° (Muravieva, 2008, these issue). Measurements at the S-1, presented in Figure 5a and 5b, do not show this additional variations, only regular decrease toward the prestorm level.

The following patterns can be noted:

1. For protons two modes: the fast losses and the slow ones are observed.
2. The slow loss of 1 MeV protons at L > 3 are too fast in comparing with the expected rate of losses through the ionization. PAD ought to be proposed as a driving force. However, the decreasing rate is not large enough to reduce the particle flux to the pre-storm level during four months.

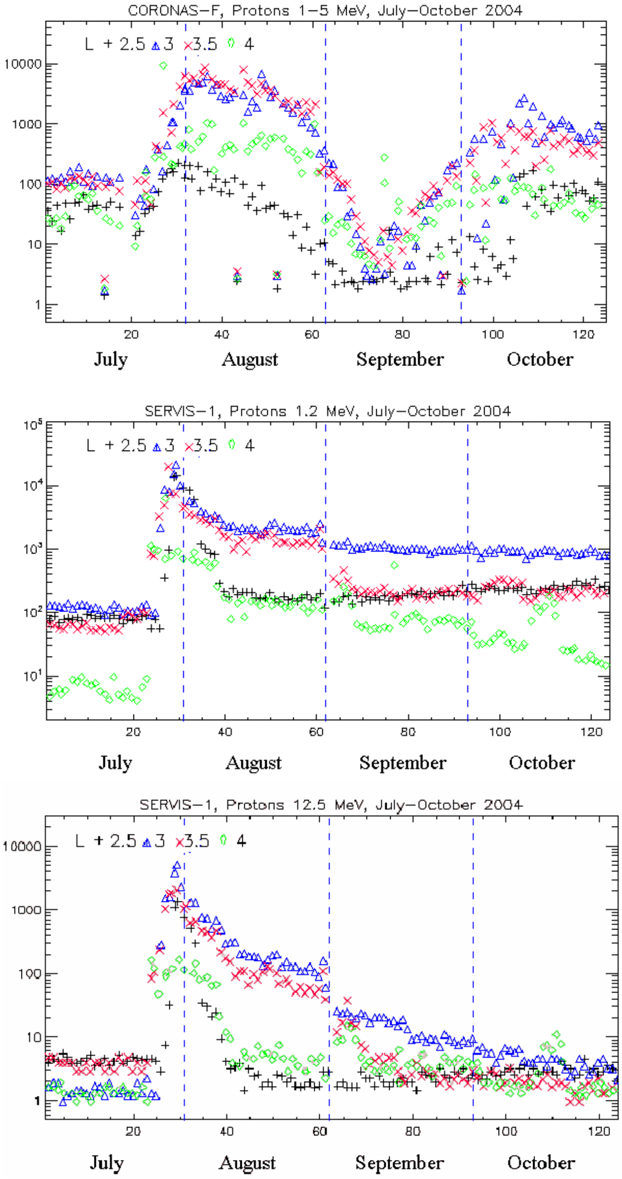

Fig 5 a-c. Trapped solar proton intensity variations at several L-shells.

The slow decrease rate depends on magnetic activity. For example, during the last 20 days of August the proton intensity was constant. During the same interval the Earth’s magnetosphere was quieter than on other periods.

3. Dumping of protons with the energy > 1 MeV at high L-shall are faster and lead to the return to background level toward the end of revised period or sooner.
4. Fast losses are observed immediately when maximum intensity was reached at the end f the July storm and during a moderate magnetic storm on August 30. In the first case we see a rapid decreasing

at all L-shells and for all energy channels while in the second case, during a storm on August 30 only narrow drift shell region around L = 3.5 is involved. On outer L-shells the opposite effect (intensity increase) has been observed. One can see the similarity with simultaneous relativistic electron variations.

3. Discussion and conclusions

Presented analysis of temporal energetic electron variations after severe storms in July 2004 shows that perturbed electron belt returns to the its background intensity and position (which were observed before the storm) slowly - during several months. This process of belt restoration is faster at higher L, where to the end of October it returned to the background intensity level for all energetic channels. This L - dependence confirms the suggestion that the particle intensity decrease was caused by the pitch-angle diffusion of electrons into the loss cone by VLF-waves, which power has the maximum in auroral magnetosphere.

The rapid variations superimposed on a slow decrease are especially intense in the auroral zone, which indicates the relationship of these variations with substorm activity. During the moderate magnetic storm, exceptionally intense decrease of 3.4 MeV electron was observed, which can be explained by parasitic resonances with ion cyclotron waves (EMIC). This mechanism is achievable only at the energies more than several MeV. Initiation of ion cyclotron emission during this period is experimentally confirmed by the rapid decrease of 1-5 MeV protons observed by both satellites – C-F and S-1.

The trapped protons fluxes also slowly decrease due to pitch-angle diffusion with superimposed fast variations during substorms and magnetic storms 20.08.04. The trapped solar protons remain in the magnetosphere at the enhanced level for a long time, more than 4 months. So that SCR input in low-energy part of radiation belt is essential.

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