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Space and Time Correlations of Particle Fluxes after Giant Flares in Radiation Belts Observed by Two Satellites, USERS and SERVIS-1

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Energetic particles trapped in radiation belts were measured by Light Particle Detectors (LPDs) onboard two satellites, USERS and SERVIS-1. LPDs on USERS observed trapped protons with 15 – 130 MeV and electrons with 0.8 – 20 MeV in the inner belt for the period from September, 2002 to February, 2005. LPD on SERVIS-1 has been observing 1.2 – 130 MeV protons and 0.3 – 10 MeV electrons in the inner and outer radiation belt since November, 2003. It is found that the intensities of protons with 1 – 30 MeV and electrons with 0.3 – 2 MeV in the inner radiation belt at $L < 2$ rapidly increased after the flare on 28 October 2003 and then slowly decreased for many months. Furthermore, a new belt is found to be formed in association at $L \sim 2$ with large geomagnetic storms connected with big solar flares.

1. Introduction

The explosive phenomena such as flares and coronal mass ejections over the sun's atmosphere disturb not only magnetosphere but also ionosphere and very high altitude atmosphere around Earth's environment. Energetic particles from the outside of magnetosphere were trapped in the outer radiation belt. However these particles ($<$ 100 MeV) cannot penetrate into deep magnetosphere at $L \lesssim 3$. Albedo neutrons produced by nuclear collisions of galactic cosmic rays with atmospheric nuclei sometimes escape the atmosphere and pass through the geomagnetic field. Some energetic neutrons decay in flight within the field and they become trapped and form the inner radiation belt including South Atlantic Anomaly.

Recent observations reported the formation of a new radiation belt and/or sudden increase of particle intensity just after the solar events. The CRRES mission[1] observed a new radiation belt of electrons at $L \sim 2$ after the March storm in 1991. The SAMPEX mission confirmed the new belt formed at the same period but also another new belt of electrons at $L \sim 2$ after the flare of October 28, 2003 called the Halloween event.[2] Moreover, they reported that proton belts at $L \sim 2$ disappeared for several months after the Halloween event. Thus, it is let to conclude that large SEP events greatly disturb the radiation environment even in deep magnetosphere, but the mechanisms of the dynamic variation and the formation has not been understood.

Two satellites, Unmanned Space Experiment Recovery System (USERS) and Space Environment Reliability Verification Integrated System 1 (SREVIS-1) carring Light Particle Detectors (LPDs) to observe energetic trapped particles in radiation belts, were launched to study the radiation environment in the radiation belts. In the period between late October, 2003 and December, 2004 a few giant flares leading geomagnetic storms were observed. We report the results and discuss the dynamic variation of energetic electrons and ions in the radiation belts during the magnetic storms associated the giant flares.

Table 1. The list of SEP events between late Oct., 2003 and Dec., 2004 summarized by NOAA, SEC. Max proton flux means unit in pfu at > 10 MeV observed by GOES satellite (see [4] for the definition of pfu).

Start (Day/UT)	Max proton flux	class X-ray/Opt	Location	Start (Day/UT)	Max proton flux	class X-ray/Opt	Location
2003				2004			
Oct 26/1825	466	X1/1N	N02W38	Apr 11/1135	35	C9/1F	S14W47
Oct 28/1215 (event 1)	29,500	X17/4B	S16E08	Jul 25/1855 (event 2)	2,086	M1/1F	N08W33
Nov 02/1105	1,570			Sep 13/2105	273	M4/2N	N04E42
Nov 04/2225	353	X28/3B	S19W85	Sep 19/1925	57	M1	N05W58
Nov 21/2355	13	M15/2B	N02W17	Nov 01/0655	63		Backside
Dec 02/1505	86	C7	W limb	Nov 07/1910 (event 3)	495	X2	N09W17

2. Observations

USERS was in operation from September, 2002 to February, 2005 at the altitude of 500 – 600 km with the inclination of 30 deg corresponding to $L \lesssim 2$, and observed trapped protons with 15 – 130 MeV and electrons with 0.8 – 20 MeV in the inner radiation belt. On the other hand, SERVIS-1 has been observing energetic protons and electrons in energy range 1.2 – 130 MeV and 0.3 – 10 MeV, respectively, in radiation belts at the altitude of 1000 km and inclination of 100 deg on solar synchronous orbit since November, 2003. The details of these satellites and the instruments are reported in this proceedings (Hareyama et al.[3]).

We analyzed data set observed by LPDs on USERS and SERVIS-1 between late October, 2003 and December, 2004. Table 1 shows the list of solar proton events summarized by NOAA, SEC in this period.[4] There are three giant flares to be remarked in this period. The flare of October 28, 2003 with class X17 (as cited event 1) is known as one of the most famous SEP events, as so called "Halloween" event, which disturbed not only radiation environment as mentioned above, but also caused many troubles on satellites. As soon as after this event, other giant flare happened in November 4 with class X23. However, we don't divide here these two events. The flare of July 25, 2004 (event 2) has large proton flux observed by GOES, though the flare class is not so large (M1). The flare of November 7, 2004 with X2 (event 3) was reported enough disturbing magnetosphere to be observed aurora in mid latitude area , for instance, Hokkaido in Japan. This report focuses the correlation between these large SEP events and trapped particles observed by LPD on USERS and SERVIS-1.

3. Results

The data set obtained by LPD facing the anti-solar direction onboard USERS were preliminary analyzed for the period between June, 2003 and December, 2004. The time profile of intensities for protons and electrons are shown in Fig. 1. The periodic variation of intensities for protons and electrons can been seen with its period of about 45 days . This might be explained by a long duration while the satellite was in the orbit passing through the SAA region. USERS came back to the same point in geographic coordinate every 40 and several days. This effect was responsible for the periodic variation of their intensities. Three arrows from No. 1 to 3 in this figure indicate event 1, 2 and 3 corresponding to the days of remarkable giant flares. It can been seen from Fig. 1 that both fluxes in lower energy region increased by a factor of about 5 for protons with 16 – 44 MeV and for electrons with 0.8 – 3.8 MeV after the event 1, but not seen such a variation in higher energy region. Then these high intensities were retained for several months. Whereas, at the events 2 and 3, such appearances

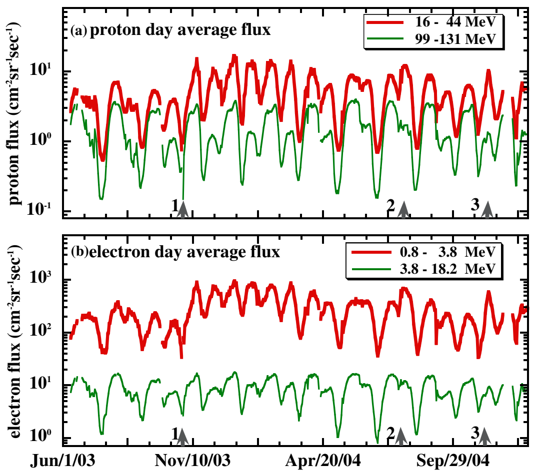

Figure 1. The time profile of the fluxes for (a) proton and (b) electron between Jun.,2003 and Dec., 2004. The arrows from 1 to 3 correspond to event 1, 2 and 3 as SEP events in Table 1, respectively.

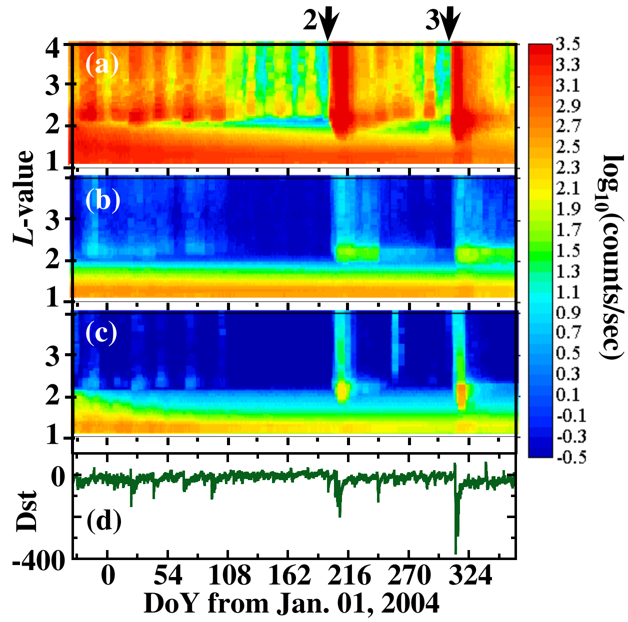

Figure 2. Daily average of particles count rate against L and time between December 2003 and December 2004 observed by LPD on SERVIS-1. (a) 1 – 2 MeV electrons, (b) 2 – 3 MeV electrons, (c) 12 – 20 MeV proton, (d) Dst index

as event 1 were not seen clearly. It is generally impossible for such charged particles with energies less than a few ten MeV to penetrate from outer region to the region at $L < 3$.

The data set obtained by LPD on SERVIS-1 were analyzed for the period from December 1, 2003 to December 31, 2004. The daily average of counting rate against L-value and time is shown in Fig.2 and also Dst data are shown in the lowest panel. The horizontal axis indicates the day of year from January 1, 2004 and the vertical one is L-value based on IGRF-10 model. The color scale is logarithmic counting rate per second. The arrows in this figure indicate SEP events as in Fig.1.

The intensity of electrons with (a) 1 – 2 MeV and (b) 2 – 3 MeV in $L = 1 - 2$ has decreased for many months since December, 2003. Unfortunately, LPD onboard SERVIS-1 did not observed the event 1 because of its launching just the day after the event 1 happened. However, USERS observed proton and electron intensities which drastically increased just after the event 1 as shown Fig.1. The slow decrease in the intensity observed by SERVIS-1in the region $L < 2$ is contributed from the event 1 as expected from the result obtained by USERS. The similar situation was seen in the day of the event 3, though the scale of variation is smaller than that for the event 1. Furthermore the SEP events, 2 and 3, may have produced a new belt of electrons at $L \sim 2$. Particularly for electrons with 2 – 3 MeV in Fig.2(b), the new belt had been retained long for several months. The similar phenomena were reported by CRRES[1] and SAMPEX[2] as mentioned in the previous section, though their observation periods and energy range have been different from this work. The result of protons with 12 – 20 MeV is also shown in Fig.2(c). The variation of proton intensity is similar to that of electrons. However, in case for higher energy protons, there is no such response as described above. Particles from normal SEP events can not break into low L region over the slot region around $L \sim 3$. However, the event 2 and the event 3 broke into the region around $L \sim 2$ and built a high intensity spot there. By comparing Dst index as shown in

Fig.2(d), the phenomena appeared clearer as Dst is smaller, particularly in the case of the event 3 with powerful Dst dropping -400 nT.

4. Discussion

This work clearly introduces two following phenomena:

1. When giant flares such as the event 2 and 3 disturb the magnetosphere and strongly make Dst decrease, the intensities of protons and electrons produce a transient belt around $L \sim 2$.
2. In the case of super storms with Dst down to -400 nT as the event 1 and 3, both intensities increase in the lowest L region at $L \sim 2$ and decay in a long period for more than several months.

Figure 3 is the zoom-up results of the Fig.2(b), (c) and (d) in the period including the event 3. The SEP event 3 occurred on the day of 311/19:10 UT, while the intensity increase delays about 2 days after the event 3 corresponding to Dst strong decrease. This result may indicate that one of the origin of energetic particles in the inner belt is caused by particle acceleration to a few – a few ten MeV and/or particle precipitation to a lower region by induced electric field produced by geomagnetic storm with strong Dst. The observation data for more giant flares must be collected to confirm this idea.

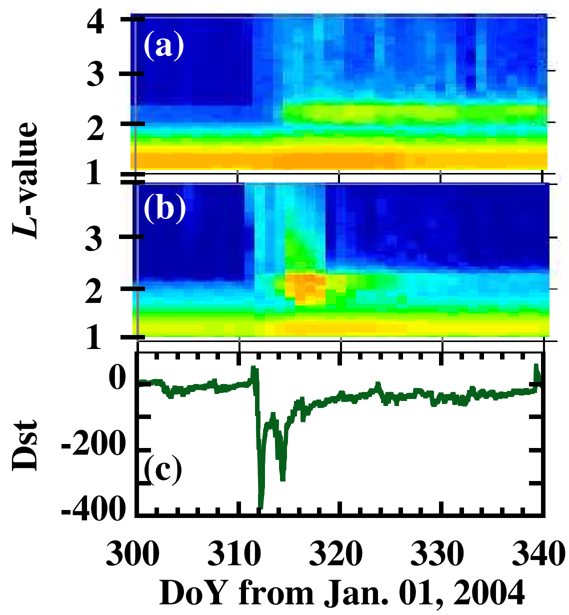

Figure 3. Daily average of particles count rate against L and time between DoY of 300 and 340 including large SEP event (event 3) observed by LPD on SERVIS-1. (a) 2 – 3 MeV electrons, (b) 12 – 20 MeV proton, (c) Dst index

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[3] M. Hareyama, *et al*, see SH3-6 in this proccedings
[4] “http://sec.noaa.gov/Data/index.html”, prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center (SEC)