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ENHANCEMENT OF THE TRAPPED RADIATION ELECTRONS AT 6.6 R_E DURING THE STORM RECOVERY PHASE —RESULTS FROM GMS/SEM OBSERVATION—

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Abstract: We studies the correlation between the increment of relativistic electron flux at the geosynchronous orbit and the interplanetary magnetic field (IMF) properties as well as the magnetic disturbance signature during magnetic storms. Results demonstrates that the large flux enhancement has been made when IMF directed southward during the storm recovery phase.

1. Introduction

It has been demonstrated that relativistic electrons disappear at the geosynchronous orbit, once a major magnetic storm takes place (McILWAIN, 1966). He also demonstrated a good correlation between relativistic electron flux and the magnetic disturbance index (*Dst* index). Some work has been made by accommodating ring current effect (*e.g.* NAGAI *et al.*, 1979) and concluded that the variation of relativistic electrons is due to an adiabatic deceleration as well as an acceleration.

Very recently LI *et al.* (1997a) revealed that the relativistic electron flux decreases not only at the geosynchronous orbit but also around the peak portion ($L=4$) of the outer radiation zone during the storm main phase, based on the SAMPEX and GPS observations. They further demonstrated that relativistic electrons enhanced during the storm recovery phase; occasionally exceeding the pre-storm level.

In the early stage of the exploration, relativistic electrons were considered to originate from the interplanetary medium (SCHOLAR, 1979). FISK (1971) insisted that the shock structures in the solar wind would produce relativistic electrons. TEEGARDEN *et al.* (1974) proposed that relativistic electrons would come from the Jupiter. Recently LI *et al.* (1997b) evaluated the flux level of the energetic electrons in the interplanetary medium and found that they would not account for observed rapid enhancement in the magnetosphere during the storm recovery phase. LI *et al.* (1997b) concluded that some processes are taking place in the magnetosphere, which produce a significant enhancement of the relativistic electrons during the storm recovery phase.

Importance of the relativistic electron study has been recognized recently from the space weather point of view. Much attention has been paid since a large enhancement of relativistic electrons caused a fatal damage in the satellite operation (GUSSENHOVEN *et al.*, 1987). The relativistic electrons will also influence the Earth's environment, making ozone density depletion at around 40 km altitude due to a strong interaction between energetic electrons and ozone spices (THONE, 1977). Hence, a fully understanding of the behavior of relativistic electrons is necessary both from basic research and applied science point of view.

In the present paper, after a brief description of the instrumentation as well as data, we will discuss on the enhancement by paying a particular attention to what is different about storms that produce large relativistic electron enhancements compared to those do not. We will also examine a specific pattern of the magnetic activity that precedes relativistic electron enhancement.

2. Instrumentation

The first Japanese Geostationary Meteorological Satellite (GMS-1) was launched in July 1977, which has been succeeded by GMS-2, GMS-3 and GMS-4. The satellite altitude is about 36000 km, locating at 140° E and at 9.2° S with respect to the geographic longitude and the magnetic latitude, respectively. In order to monitor the space environment, SEM (Space Environment Monitor) has been installed on GMS spacecraft. View of the SEM is perpendicular to the geographic north-south direction. The spin rate of the satellite is about 100 rpm, and the particle accumulation time is one second. Therefore, no spin phase information has been obtained from the SEM observations.

SEM consists of five silicon solid state detectors and moderators. By using these sets we can obtain differential energy fluxes for 7 energy channels (protons), 5 energy channels (alphas) and one energy channel (electrons). We will use the flux of electrons whose energy is greater than 2 MeV. Accumulation time for each channel is 1 s, but the repetition for all channel scan is 16.4 s. Hence, the highest time resolution is 16.4 s.

All the data since the GMS-1 launch are not always valid for the scientific use; data actually contain noises mostly due to the sun light as well as the degradation of the detector. The GMS particle data are available for the following intervals: from 1978 to 1981, from 1984 to 1985, and from 1989 to 1994.

3. Storm Response of Relativistic Electrons at the Geosynchronous Position

An example of the time variation in the relativistic electrons with energy more than 2 MeV is shown in the top panel of Fig. 1, in which the ordinate is a differential energy flux and the abscissa is a time, covering one week. In the bottom, the *Dst* index is given for the same interval. Flux value was slightly low for most of 2nd and 3rd November. After the sudden commencement of magnetic storm, particle flux peaked for the day. Between 2325 UT on November 3 and 0030 UT on November 4 flux value dropped precipitously. The nearly flat recording on November 4 illustrates particle flux at or below the detectable level. The storm reached its maximum with -120 nT around 12 UT on November 4 and then started to recover. The satellite actually observed a return of the 2 MeV population in the early morning, after a disappearance over 18 hours.

Over the subsequent days flux returned to the present level and then exceeded normal level by more than an order of magnitude. In addition to the large-scale storm variations, this figure shows substorm variations with time-scale of a few hours. The high frequency fluctuations in the profile on November 4–7, and the occasional reduc-

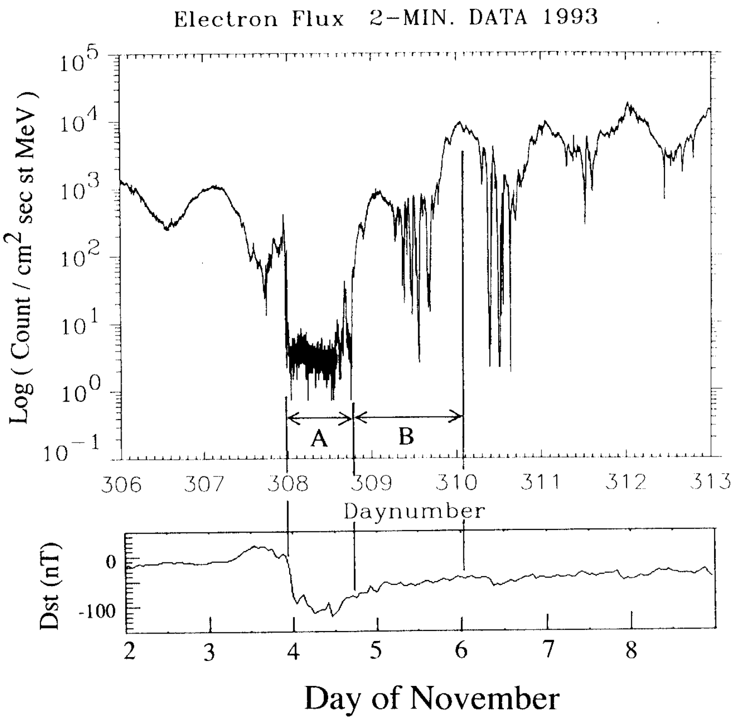

Fig. 1. Time variations in the flux of relativistic electrons with energy greater than 2 MeV (top) and the magnetic disturbance index (Dst index) during November 2–8, 1993.

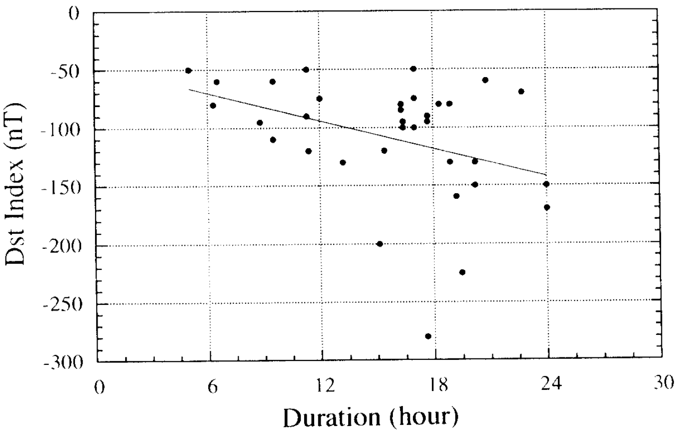

Fig. 2. Distribution of the duration time (A) of the energetic electron disappearance as a function of the storm intensity.

tions in the profile are indicative of substorm-associated perturbations.

A time interval when the relativistic electron flux disappears, for example, as marked A in Fig. 1 is in a range from 6 hours to 24 hours. Figure 2 demonstrates a distribution of the interval A (hours) as a function of the magnitude of the storm, showing some relationship between the storm intensity and the duration interval. According to Yokoyama and Kamide (1997), storm main phase lasts over 12 hours for the case of intense storms. The lack of the data point within 12 hours for intense storms (< -150 nT) is due to the long duration of the main phase for the intense storm. Where do they go? Besides the losses to the atmosphere, a rapid magnetospheric

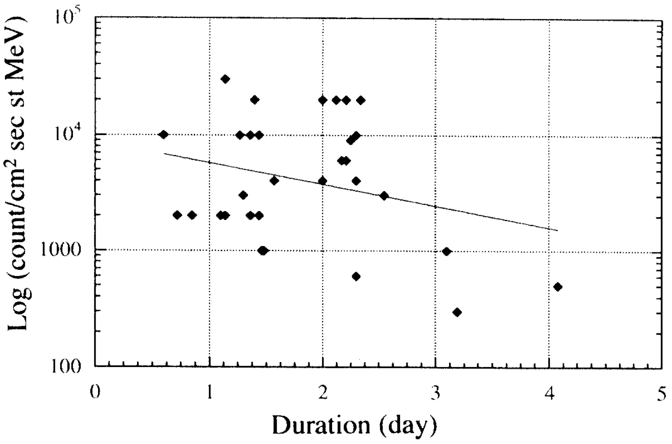

Fig. 3. Distribution of the duration (B) of the energetic electron increase as a function of the peak count.

boundary motion might be responsible for bringing the relativistic particles into the magnetosheath.

Figure 3 demonstrates the distribution of the interval in which the flux is growing, as marked B in Fig. 1. Abscissa is the duration of interval B (days) and ordinate shows a peak flux to which the relativistic electron flux reached at the end of each growing. With some exceptions, most of the duration is in a range from 1 day to 2 days. However, the peak intensity scatters; from 10^2 to 10^4 (count/cm^2 s st MeV).

A question is raised here what is different between storms that produce relativistic high energy electrons and those do not. Is there any particular activity that precedes relativistic electron enhancement? We will discuss this point in the following section.

4. Controlling Parameter for the Relativistic Electron Enhancement

4.1. Long-term variation due to Russel-McPheron effect

Knipp *et al.* (1998), in which T. Obara is one of the co-authors, demonstrates that the relativistic electrons are activated when the IMF polarity is away in the autumnal equinox, and vise versa in the vernal equinox. Li *et al.* (1997a) also found repetitive enhancements of energetic electrons in the late 1993, which were associated with high-speed slar wind streams. Knipp *et al.* (1998) found energetic electron activations (for the >1.8 MeV) for every onset of the primary and secondary high-speed streams (see Fig. 4). It is also noted that the primary stream, which is marked by vertical lines in the Fig. 4, had an away IMF orientation and always activated MeV electrons, although the December (winter) activation was weak. The secondary stream, which was in between primary ones, activated the >6 MeV electrons only when the IMF polarity was away.

Figure 5 demonstrated the relativistic electron flux obtained from GMS/SEM (top panel) and the *Dst* index (bottom panel) for November 1993, when a recurrent structure of the interplanetary magnetic field was seen quite well as mentioned above. Hatched portions in the bottom panel are the intervals of the toward polarity, while the white portions are away polarity. In the case of the storm which started on November 4, a

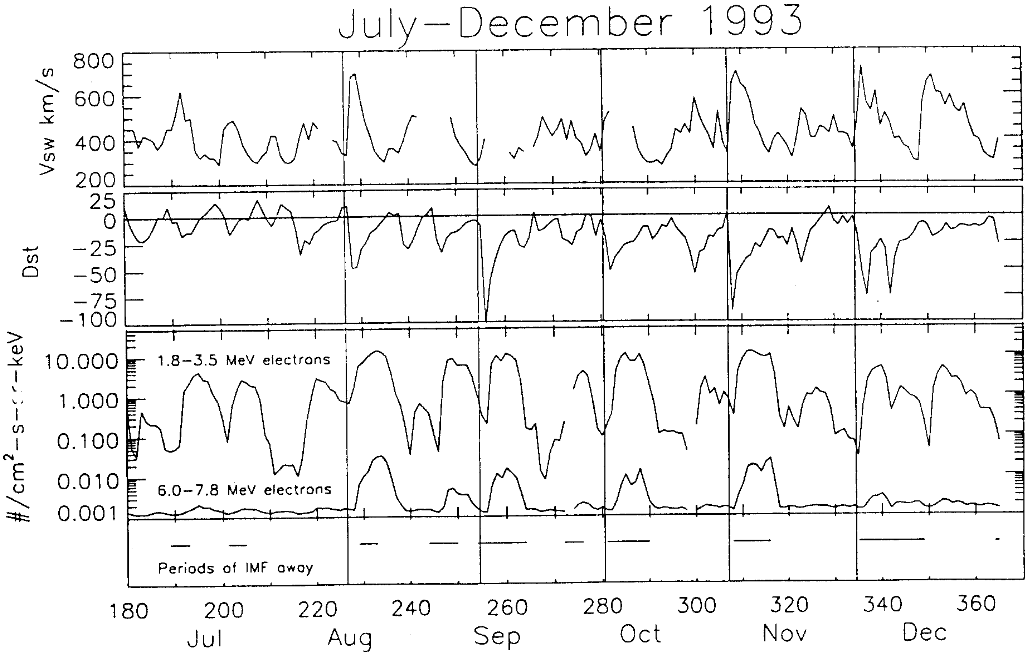

Fig. 4. Summary plot of daily averaged solar wind velocity, Dst index, differential flux of 1.8–3.5 MeV electrons and 6.0–7.8 MeV electrons at L = 6.6 and indication of IMF "away" sector in the last half period of 1993 (after KNIPP *et al., 1998).*

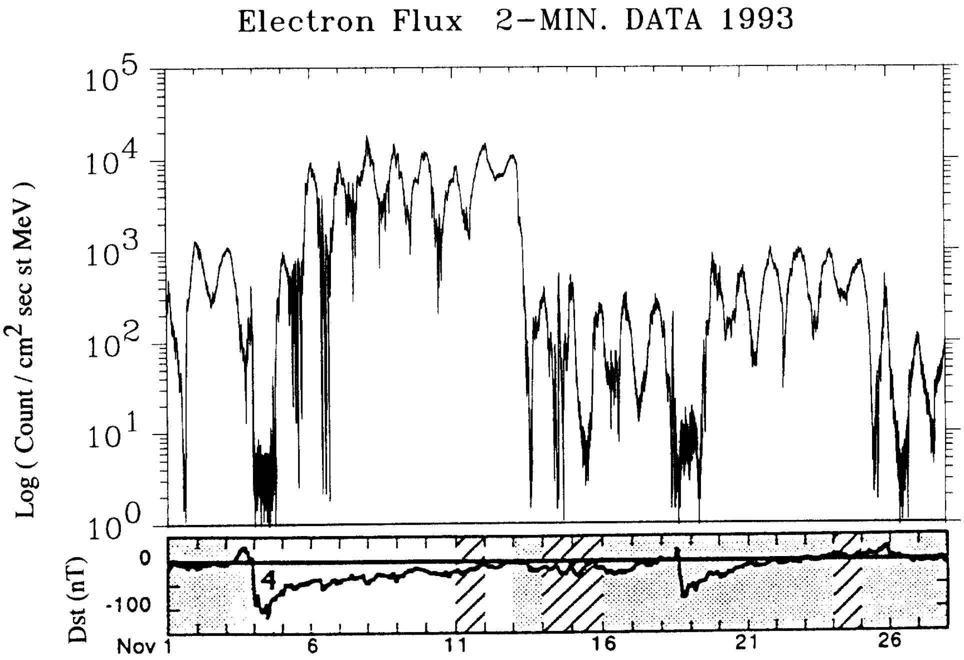

Fig. 5. Time variations in the relativistic electron flux and the Dst index.

large enhancement of the relativistic electrons was made, while in the storm on November 18, the energetic electron flux did not increase so much.

Both in Figs. 4 and 5, we can also identify sharp decreases of the flux, for instance on November 13, being accompanied by the slight *Dst* decrease. There was a substorm activity on November 13, which also caused an abrupt decrease of the relativistic electron fluxes at the geosynchronous orbit. This reduction is due to an intense induced electric field, causing a sudden shifting of relativistic populations toward the Earth, although such an interpretaion is still open.

Returning to the IMF polarity, it would be possible to say that an activation of relativistic electrons requires prolonged IMF away condition, favorable for enhancing the coupling between the solar wind and the magnetosphere. In Autumn, passage of away polarity enhances "merging" owing to the Russell-McPheron effect.

4.2. Comparison with the IMF Bz component

Dependence on the IMF sector polarity will give us a clue to discuss some possible parameters which enhance or activate relativistic electron fluxes. In Autumn, IMF away polarity makes a negative component of the IMF with respect to the GMS coordinate system. We have examined the GMS data in the Spring 1994, and found that the relativistic electrons were activated during the toward polarity. Since dependence on the IMF polarity becomes evident, we examined the IMF *Bz* values.

In Fig. 6, we plot an IMF *Bz* value averaged for interval B (*cf.* Fig. 1) together with a peak level of the relativistic electrons. Even though a number of data is quite small, we

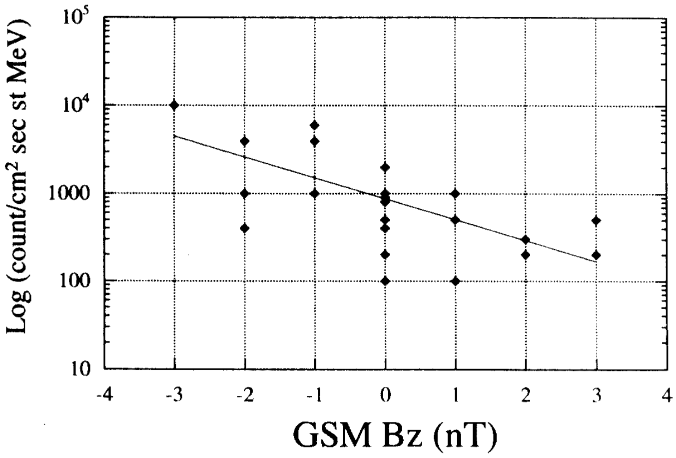

Fig. 6. Scatter plot of the peak count and the averaged IMF Bz for interval B.

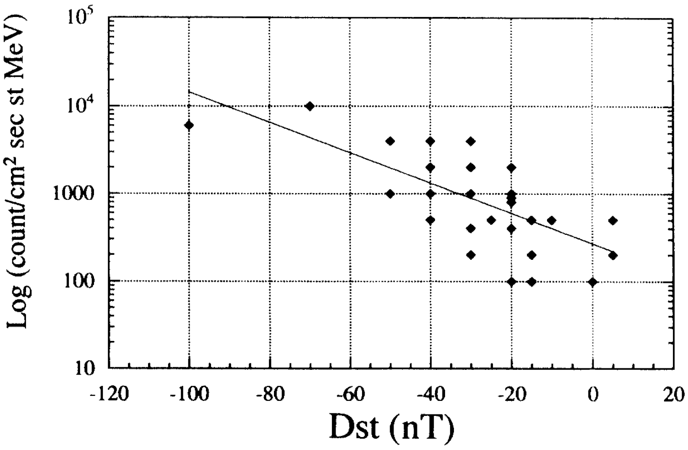

Fig. 7. Scatter plot of the peak count and the averaged Dst value for interval B.

can see a significant tendency that southward IMF polarity activates the relativistic electrons, and the flux of energetic electrons is reduced when the IMF directed to the north.

It is also interesting to see that the *Dst* value did not tend to recover rapidly for the case of November 4 storm, while in the case of November 18 storm the *Dst* value recovered rather quickly. By using the relativistic electron data together with the *Dst* index, we have performed some statistics. In Fig. 7, we plot a peak count as a function of the *Dst* averaged for interval B. From this figure, we notice that negatively large *Dst* value produced a large enhancement of the relativistic electrons, which seems consistent with the results shown in Fig. 6.

5. Summary and Discussion

We pave performed a comparison between the GMS/SEM observations and the IMF as well as the *Dst* index. Results demonstrate that the southward IMF component activates the enhancement of energetic electrons during storm recovery phase.

The present observations suggest that some acceleration processes are taking place in the inner magnetosphere which produce sufficient relativistic electrons with a magnetically active condition. A candidate of the sources is from the plasma sheet, being convected into the inner magnetosphere by an enhanced convection. The source electrons with a few tens of keV are needed in the plasma sheet location ($L=10$) to get a sufficient energy by the conservation of 1st and 2nd invariants in approaching to the outer radiation zone ($L=3$–4). We are, therefore, thinking that the energetic electrons originate as the high energetic tail of the electrons, being injected by the enhanced convection, and that the ring current populations are more energized due to an enhanced manetic activity during the storm recovery phase.

We need more comprehensive analyses by means of simultaneous satellite observations at different portions and different techniques as well as model considerations.

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