ON THE NATURE OF FLUX VARIATIONS OF TRAPPED PARTICLES ASSOCIATED WITH SUDDEN COMMENCEMENT AND SUDDEN IMPULSE AT SYNCHRONOUS ORBIT

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***Abstract*:** Morphology and mechanism of the flux variation of energetic particles associated with sudden commencements and sudden impulses are examined on the basis of the observations of high-energy particles measured by the SEM on board the GMS and GOES series, during the period from February 1978 to December 1978. The events are divided into two types morphologically, one is a step-like variation and the other is a pulse-like one. The former shows characteristics of the trapped particles but the latter does not significantly. From the analysis of the former type ones, a weak dependence on ΔH (amplitude of SC or SI) due to betatron acceleration is recognized for the rate of variation of particle flux. The variation of flux is also affected by the level of the flux before the SC or SI, and in some cases the effect surpasses that of acceleration of particles.

1. Introduction

It is known that the flux of the particles trapped by the earth's magnetosphere varies in association with sudden commencement (PAULIKAS and BLAKE, 1970; TOMOMURA *et al.*, 1982; WILKEN *et al.*, 1982).

PAULIKAS and BLAKE (1970), using the data of energetic proton in the energy intervals of 5–21 MeV and 21–70 MeV of the geostationary ATS-1 satellite, suggested that the increase of the flux of the particles is caused by both of the effects of the betatron acceleration and the particles motion across the satellite under the condition of inhomogeneous, spatial distribution of the particles (SUGIURA, 1972).

TOMOMURA *et al.* (1982) analyzed the data of energetic proton and electron of Space Environmental Monitor (SEM) aboard the Japanese Weather Satellite (GMS) including the decrease events of electron, and pointed out that the amplitude of the variations of the particle flux depends only on the amount of the flux in the pre-SC state, that is, the base of the flux before the SC. They proved the result theoretically assuming that the particles obey a power law before and after the SC.

From the point of view of PAULIKAS and BLAKE's (1970) suggestion, we analyzed the combined effect of both of amplitude of SC and SI and the base of flux in order to understand the matter more clearly.

2. Data

We use the particle data of GMS and NOAA synchronous satellites, GOES series as follows; proton (1.2–4.0 MeV) and electron (>2.0 MeV) of GMS (located at −10°S and 140°E) from February to December in 1978 and proton (0.8–4.0 MeV) and electron (>2.0 MeV) of GOES 1 (5°N, 135°W) for February, April and May in 1978, GOES 3 (5°N, 135°W) from September to November in 1978, and GOES 2 (10°N, 75°W) from February to July and from September to December in 1978. The details of the experiments of SEM of GMS and GOES series are shown in KOHNO (1978) and GRUBB (1975), respectively.

The fact that the diurnal variations due to the asymmetry of the magnetosphere are usually seen on magnetically quiet days in these data signifies that the particles in these energy ranges are trapped by the magnetosphere around the vicinities of the satellites, that is about 6.6 R_E from the earth's center.

The method to determine the variation of the flux associated with SC, SI^+ and SI^- is the same as the one employed by TOMOMURA *et al.* (1982).

The number of the events is 74, including 12 SI^- events. They are chosen from 'Report of the Geomagnetic and Geoelectric Observations 1978' published by the Kakioka Magnetic Observatory.

3. Morphology of the Flux Variation

The examples of flux variations associated with SC are shown in Fig. 1. In Fig. 1a, step-like variations are seen for both of proton and electron but patterns are different in Fig. 1b; the proton flux increases in a stepwise fashion, while the electron flux decreases impulsively. In general, each flux varies independently, and so two

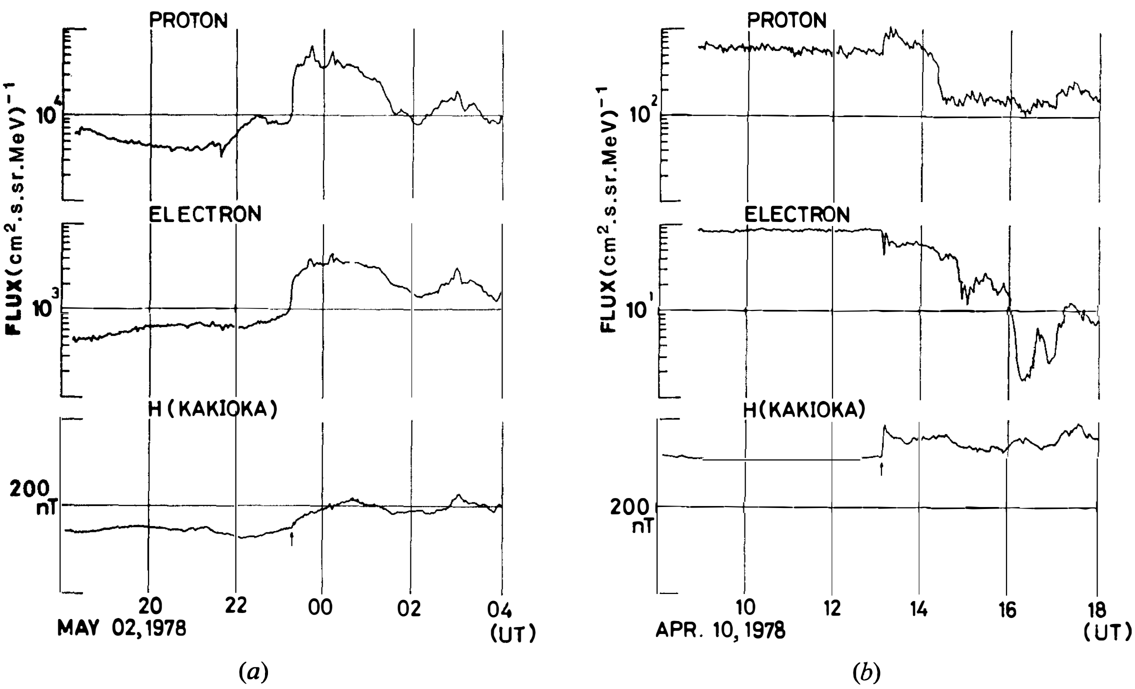

Fig. 1. SC-associated variations of proton (1.2–4.0 MeV) and electron (>2.0 MeV) fluxes observed by GMS. The arrows given in the magnetic records indicate the occurrence times of SC.

fluxes can be treated separately. Hereafter, we call an impulsive variation with a period less than 30 minutes a pulse-like variation, and for other type of variation we call it a step-like one. Thus, the variations of fluxes are classified into four types which are made of the combinations of the shape (step-like or pulse-like) and the direction of the variation (increase or decrease).

Figure 2 is an example of the variations of SC for all the channels. An SC which occurred at 1615 UT at Kakioka and related variations are seen in fluxes of EL, P1, P2, P3 and P4. Local time of the satellite during SC is almost midnight.

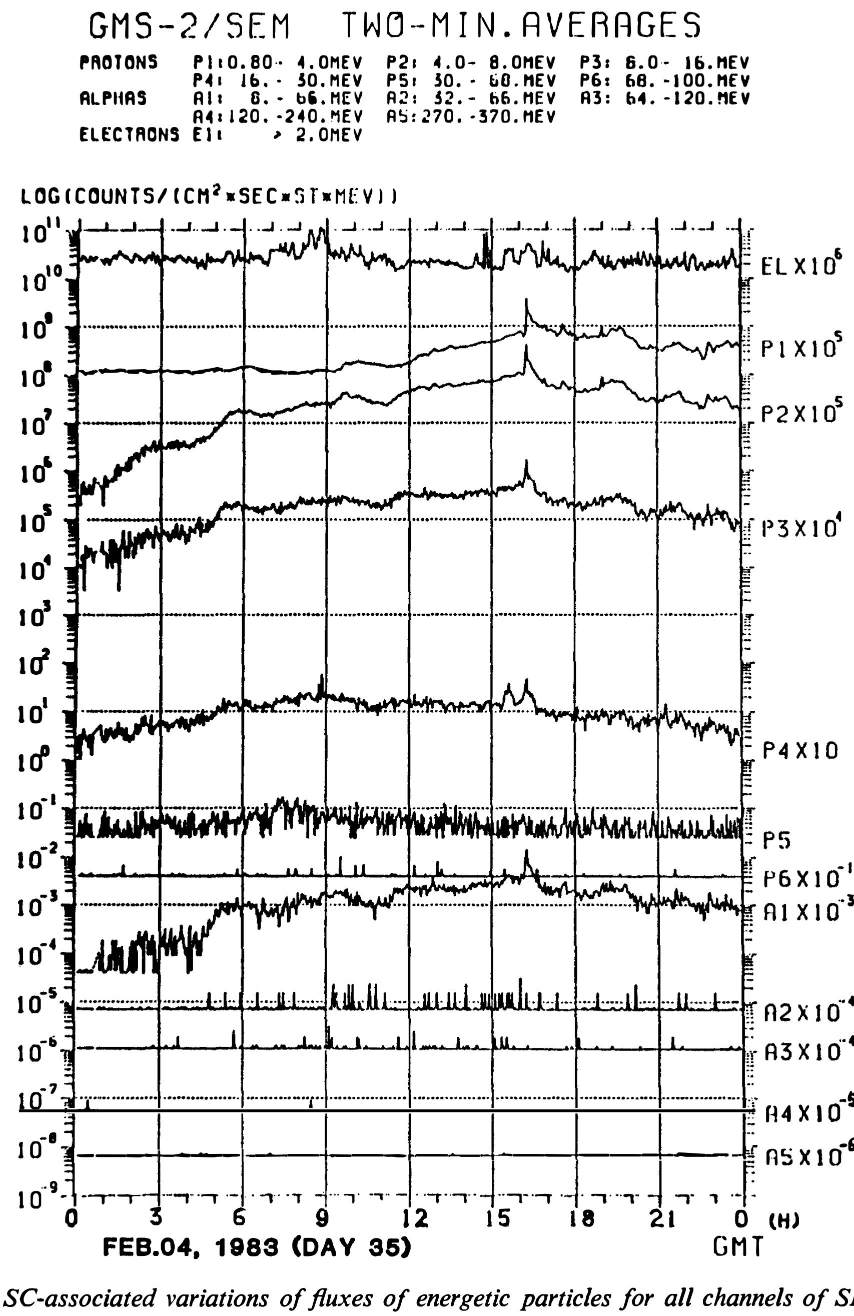

Fig. 2. SC-associated variations of fluxes of energetic particles for all channels of SEM aboard GMS. An SC occurs at 1615 UT at Kakioka.

As energy ranges of P3 and P4 are too high for the trapped particles, the pulse-like increases of them cannot be thought as the variations of the trapped particles but those of the injected particles originated out of the trapping region. Therefore, the pulse-like variation of P1 also cannot be identified to be the trapped particles, even the energy range is for the trapped particle's one.

Local time variations of the occurrence rates of step-like variations and pulse-like

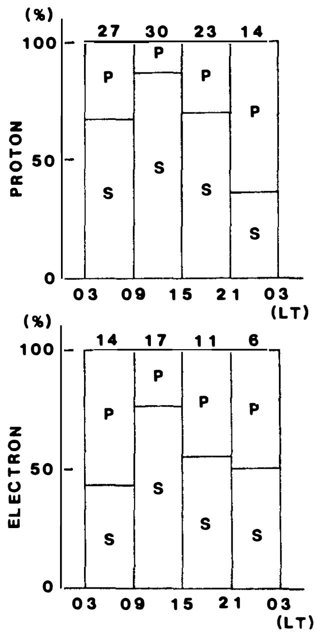

Fig. 3. Local time dependence of occurrence frequency of step-like variations (S) and pulse-like variations (P) for proton and electron. Numbers above the panels are those of total measurements.

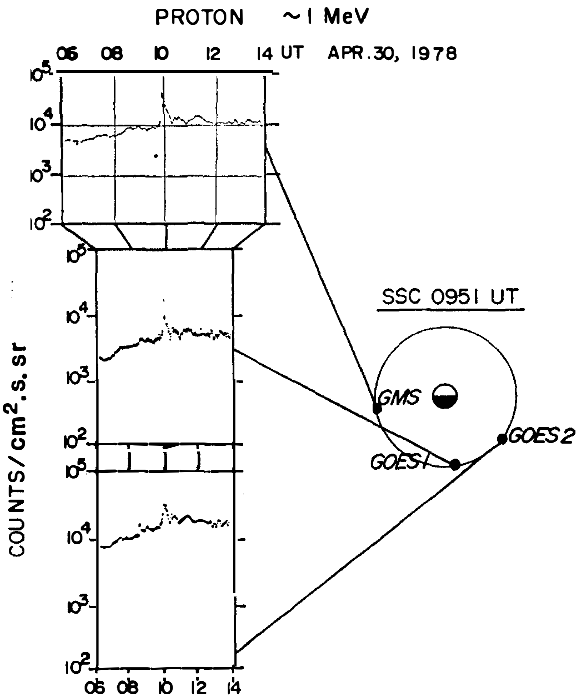

Fig. 4a.

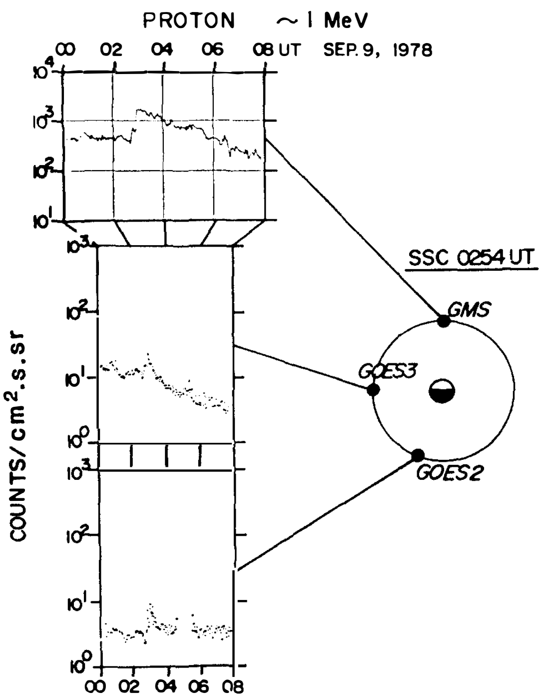

Fig. 4b.

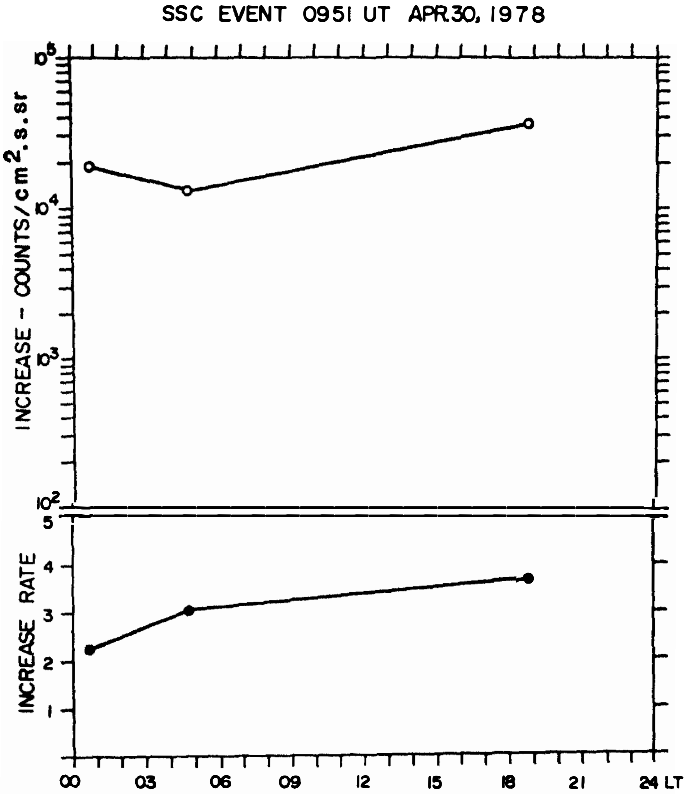

Fig. 4c.

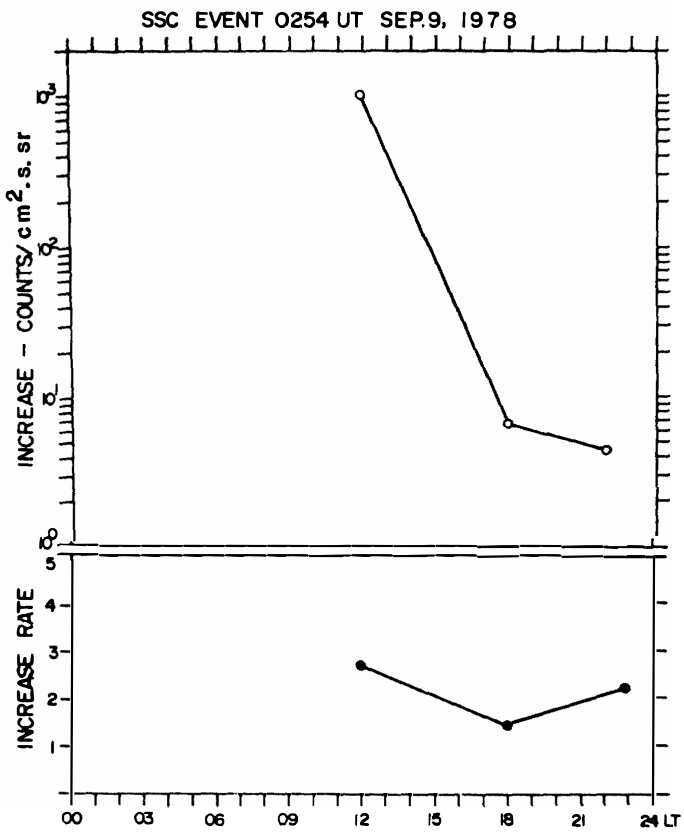

Fig. 4d.

Fig. 4. Multi-satellites observations of the variations of proton flux associated with SC; 4a and 4b show the locations of the satellites and the plots of the records, 4c and 4d the amplitudes and the rates of the flux variations. Figures 4c and 4d correspond to 4a and 4b, respectively.

ones for increasing events are shown in Fig. 3. The numbers above the panels are those of total measurements. The occurrence rates of the step-like variations take maxima at noon and minima at night for both particles. This tendency may be due to the noon-night asymmetry of the trapping region in the magnetosphere.

Figure 4 shows the examples of simultaneous observations of flux variations of proton by three satellites. Figures 4a and 4b are the positions of the satellites and the plots of the records, and 4c and 4d are the amplitudes and the rates of the variations of the fluxes; 4c and 4d correspond to 4a and 4b, respectively.

When all satellites are in the night side (Fig. 4a), the variations are all pulse-like ones, but the patterns are different when only one of them (GMS) is in the day side. A step-like variation is seen for the flux in the day side and pulse-like ones are apparent in the night side. The amplitude of the step-like variation is much larger than those of pulse-like ones in Fig. 4d. Meanwhile, local time variation is not clear among the pulse-like ones as can be seen in Fig. 4c. Step-like variations are, therefore, distinguished from the pulse-like ones physically. Besides, step-like variation of the flux means that the particles remained to be trapped after the SC.

Hence, it can be said that step-like variations are due to the trapped particles in the magnetosphere. As the pulse-like ones are uncertain whether they are the variations of the trapped particles or not, we exclude them from the present analysis.

4. Results and Discussion

Dependence of the flux variation on the amplitude of SC is quite complex because the variation is primarily controlled by the base (TOMOMURA *et al.*, 1982). We must take the rate of variation of the flux, *i.e.*, the flux variations normalized by the base, in order to discuss the dependence on the amplitude of sudden variation of magnetic field. The distribution of the rates of variations of fluxes *vs.* the departure of the horizontal component of geomagnetism (ΔH) at Kakioka is shown in Fig. 5. The minus values of (ΔH) are for SI^-s. Circles are for GMS's data and triangles are for GOES series' ones. Closed figures are for the events whose bases exceed 10^3 and open ones for lower than it. The value of 1 for the rate of variation means that there is no variation of the flux at SC or SI.

Positive correlation is seen in the result of proton but the linearity is not good. The rates of the variations are not large for large values of ΔH. There may be an upper limit for the rate of variation.

The behavior of electron is complex. The flux sometimes decreases for positive ΔH, especially for large ones but increases for most cases when the base is large.

The fact that the flux does not vary or decreases besides increasing for positive ΔH means that the flux variation is influenced not only by the effect of betatron acceleration (increasing effect) but also by the decreasing effect due to the particle motion across the satellite under the condition that the particles decrease radially. Both effects are in proportion to ΔH (FILLIUS and MCILWAIN, 1967) and the latter is most obvious near the trapping region where the radial decrease of the density of the particles is steep.

From these points of view, the fact that proton flux increases in most cases is ex-

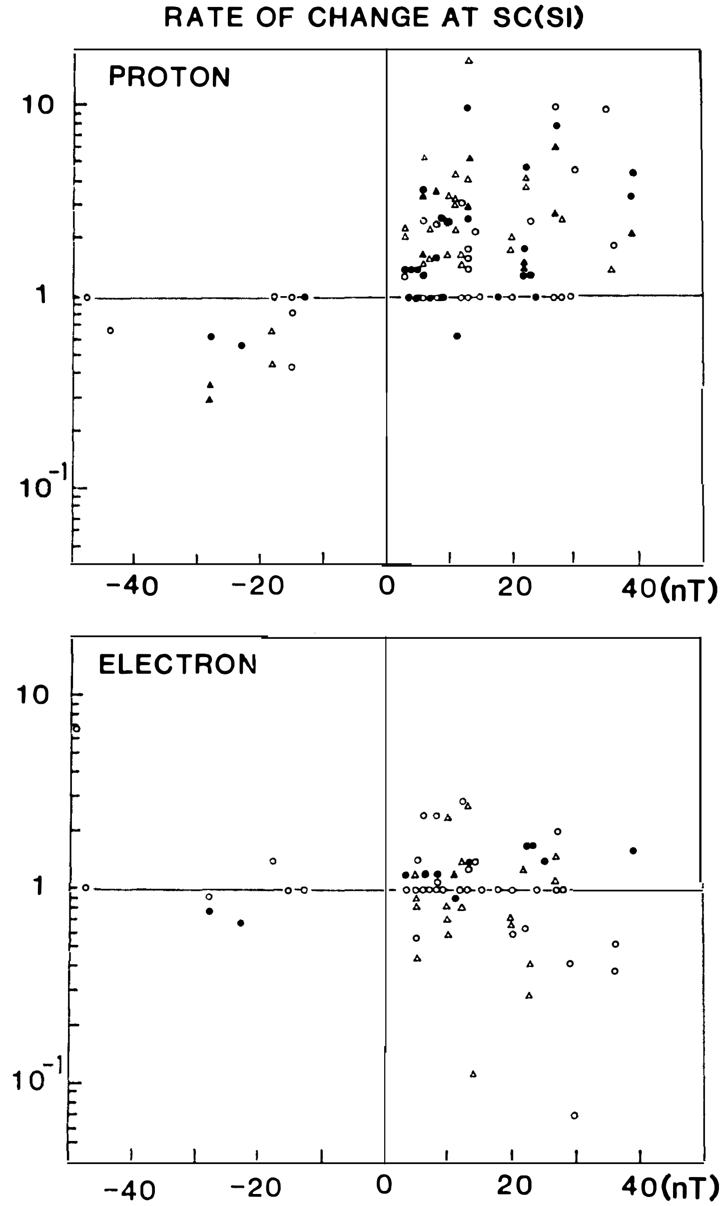

Fig. 5. The dependence of the rate of variation of flux on ΔH. Circles are for GMS's data and triangles for GOES series' ones. Closed ones are for the events whose bases exceed 10^8 and open ones for lower than it.

plained that the effect of the acceleration surpasses that of particle motion as well as for electron flux of large bases.

The situation seems to be reverse for small bases of electron. These results show that the satellites are located near the trapping boundary of electron but distant from that of proton, and that the base of flux is important to discuss the matter systematically.

Figure 6 shows the dependence of the variations of proton fluxes on the base and ΔH; 6a and 6b are for observations in the night side and the day side, respectively. Note that we use only GMS's data here. Open circles are for increase, closed ones

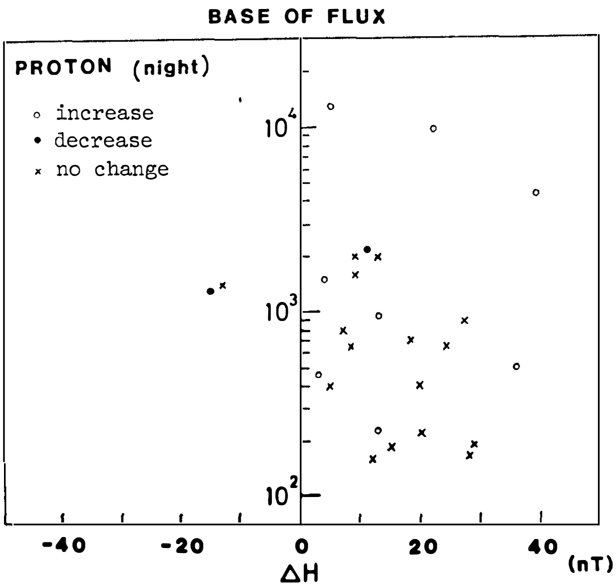

Fig. 6a.

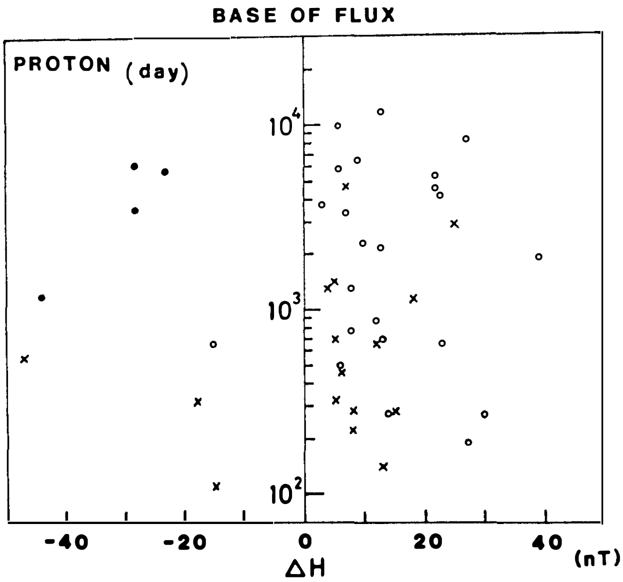

Fig. 6b.

Fig. 6. The dependence of the direction of the variation of proton flux on ΔH and the base. Open circles are for increase, closed ones for decrease and crosses for no variation events, respectively.

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In the night side, the variations are not apparent up to large, positive values of ΔH for small bases. In the day side, the occurrence rate of the event of no variation is larger for small bases than for large bases.

Flux increases even for small, positive values of ΔH in both sides when the bases are large. As to the negative values of ΔH, decrease events are seen for the large bases in the day side. This means that the variation of the proton flux is antisymmetric with respect to zero value of ΔH and indicates the validity of the mechanism of betatron acceleration.

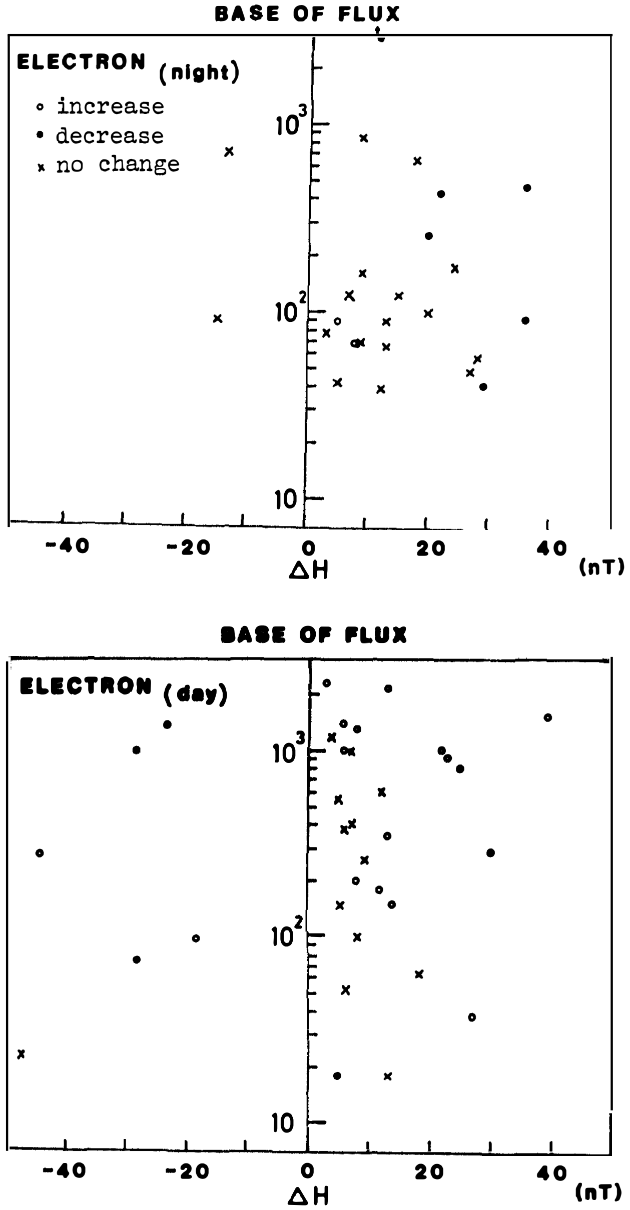

Fig. 7a.

Fig. 7b.

Fig. 7. Same as Fig. 6 for electron flux.

Figure 7 is for electron flux showing the dependence on the base and ΔH; 7a and 7b are the same as in Fig. 6. The distribution of events of no variation and occurrences of increase events in the day side are almost the same as those of proton. Differences are seen in the night side and for minus values of ΔH in the day side. Flux decreases when ΔH is large even for large bases in the night side. This means that electron density decreases rapidly with increasing altitude in the night side, and that the satellite is in the vicinity of the trapping boundary of electron. The latter difference is the occurrence of increase events for minus values of ΔH. This also means that the satellite comes inside the trapping region of electron after the SI^-.

With all these results, the following situation is deduced; density gradient of trapped particles is small where the density is large and the effect of acceleration is detected mainly there, while both of the effects of acceleration and particle motion are balanced where the density is small or the situation is reversed in the vicinity of the trapping region.

5. Summary

The flux variations associated with sudden variations of the magnetosphere by SC and SI are classified into four types. Among them pulse-like variations are not identified as the events due to trapped particles. In the day side, step-like variations showing the feature of trapped particles are roughly proportional to ΔH including minus values (SI^-) but are largely affected by the base. In the night side, the events of no variation are dominant. This is qualitatively understood for considering the fact that the flux of particles is usually smallest in the night no magnetically quiet days (NAGAI *et al.*, 1979; TOMOMURA *et al.*, 1982), that is, the satellites come nearer to the trapping boundary in the night side than in the day side.

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